BIOLOGICAL INVASIONS

Issues in Biodiversity Conservation and Management

Proceedings of the National Conference -
3rd to 4th December, 2022,
Thiruvananthapuram

Kerala State Biodiversity Board

Kailasam, T.C. 24/3219, No. 43, Belhaven Gardens,
Kowdiar P.O., Thiruvananthapuram – 695 003
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No.53/Press/CMO/24

12 January, 2024.

MESSAGE

Over the past few decades, invasive alien species have seriously threatened the environment, local biodiversity and human health. Biological invasions also affect agriculture, forestry, and fisheries-the main livelihood sectors of people. The rapid spread of invasive species has been recognised as a major threat to biodiversity in Kerala.

The Kerala State Biodiversity Board took a commendable step to address this issue by organising a national conference with the participation of more than 100 eminent scientists from across the country, in 2022. The proceeding of the conference is being brought out titled 'Biological Invasions: Issues in Biodiversity Conservation and Management'.

It is a compilation of the research papers presented during the conference with a focus on forest ecosystem, marine and freshwater ecosystems, and agro-ecosystems. I hope that it will help to formulate action plans for the management of invasive organisms both at the state and local levels.

My best wishes.

Pinarayi Vijayan

The Chairman
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Preface

Invasive alien species are recognised as one of the five major drivers of biodiversity loss globally, others being land and sea-use change, direct exploitation of organisms, climate change, and pollution. It has been reported that many alien plants introduced through global trade and exchange of seeds and planting materials are negatively affecting agriculture and forestry. Similarly, the presence of invasive plants and fishes in water bodies is posing massive threat to our unique inland fish stocks and other natural aquatic species.

As the name suggests, 'invasive' species can displace native species and dominate them through invasion. Consequently, biological invasion accelerates biodiversity loss at the local, national, and global levels. The "Convention on Biological Diversity" stipulates that the invasion of alien species that threaten the survival of species, habitats, and ecosystems shall be prevented and controlled as early as possible. All the countries including India who signed the treaty are bound to comply with it. Meanwhile, the Kunming-Montreal Global Biodiversity Framework (GBF) was adopted during the 15th meeting of the Conference of the Parties (COP 15) held in 2022. This historic Framework sets out an ambitious pathway for biodiversity, and it has 23 actionable targets for 2030, including a target on invasive alien species (TARGET 6: Reduce the introduction of invasive alien species by 50% and minimize their impact).

A policy on invasive species at the state level is essential to prevent and control the invasion of terrestrial and aquatic alien species in Kerala. A two-day National Conference, organized by the Kerala State Biodiversity Board on the theme "Biodiversity: Trends, Threats and Management" from 2 to 3 Dec. 2022, was the first step towards this goal. This Conference stressed on three relevant areas—agriculture and managed systems, forest ecosystems, and marine and freshwater ecosystems. The present docuemnt, "Biological Invasions: Issues in Biodiversity Conservation and Management" is the proceedings of the Conference with 48 selected papers, consisting of invited and contributory, presented by various eminent scientists and researchers. I hope that the papers included will be useful for an assessment of the status of invasive species in Kerala.

We are extremely grateful to the Hon'ble Chief Minister of Kerala, Sri. Pinarayi Vijayan for inaugurating the Conference and for the elegant message included in this publication. Dr. V. Venu, Additional Chief Secretary, Department of Environment, Govt. of Kerala presided over the function, and we acknowledge the constant encouragement provided by him. Dr. Shiroma Sathyapala, expert from FAO, Rome delivered the keynote address and Dr. A.K. Singh former Director ICAR-DCFR and Emeritus Scientist ICAR-National Bureau of Fish Genetic Resources, Lucknow delivered the plenary talk. I also acknowledge the initiative and enthusiasm of the former Member Secretary, Dr. A.V. Santhoshkumar and all the staff members of KSBB in successfully conducting the Conference. The help from Dr. Preetha, N., Senior Research Officer and Ms. Hanna Thomas, NBA Intern in editing and proof reading the book is acknowledged. I am also grateful to all the Board members for their active involvement and cooperation. Thanks are also due to various eminent scientists from different parts of India for their contributions and active participation.

Dr. C. George Thomas
Chairman, KSBB

Invasion in Agriculture and Managed System

PLANT INVASIONS: A THREAT TO AGRO-ECOSYSTEMS

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Abstract

Problems from invasive alien species are on the rise because of several reasons leading to ecological, economic, and social impacts. Anthropogenic factors are the major reason for this serious threat. Rapid loss of biodiversity and crop loss in terms of both quantity and quality can negatively influence the ecosystem resilience and can have serious implications in agriculture. The success of invasive plants depends on factors like prolific seed production, efficient dispersal mechanisms, higher germination rate, rapid growth rate, rampant vegetative spread with special organs such as offsets, root suckers, or bulbs, and wide adaptability and tolerance to changing environments and higher competitive ability. Invasive weeds like lantana and Siam weed have allelopathic effect on agricultural crops making them more competitive. The absence of natural enemies in the new environment also provides favourable conditions for invasive species. Although technological options are available for managing invasive aliens, most often, economically and environmentally viable practical methods are limited. Biological control measures suffer from many drawbacks, and they are successful only in a few weeds and specific situations. Many studies have already been done on the utilization of weed biomass produced from invasive weeds. However, its large-scale adoption is still limited. A multipronged approach, which integrates biological, ecological and social dimensions, can help in preventing further loss of biodiversity and sustaining the productivity of arable lands for the benefit of future generations.

Introduction

Invasive species are a threat to the environment, acting as a key driver of biodiversity loss besides disturbing ecosystem functions. Biological invasions have the potential to significantly affect species composition and alter species interactions within the invaded community and even can have an adverse impact on the economy by affecting income-generating activities, especially in agriculture and allied sectors.

Prameela, P., Antony, S., Thomas, C.G., and Krishna, V.R. 2023. Plant invasions: A threat to agro-ecosystems. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.1-23.

As defined by the Invasive Species Definition Clarification and Guidance Policy Frame Work, approved by the Invasive Species Advisory Committee of USDA in 2006, “invasive species are those that are not native to the ecosystem under consideration and that cause or are likely to cause economic or environmental harm or harm to human, animal, or plant health” (USDA, 2006). Note that plant and animal species that have been domesticated, introduced, or cultivated by humans, which are under their control are not invasive species. Furthermore, it is made clear that for a non-native to be deemed invasive, its detrimental consequences must outweigh its favorable virtues. Additionally, a non-native species in one area may not be regarded as invasive in another area. The status of a plant as an invasive species is greatly influenced by human values. Even if they have some positive impacts, invasive non-native species are deemed harmful to human health, the environment, or both.

Human intervention is the major factor behind species introductions and movements of species, which began in the post Columbian times by European colonists. Plants were introduced in vast scale to colonial regions and back, largely by European concerns such as the East India Company, for agricultural and ornamental purposes (Heywood, 1989). Botanical Gardens played a key role in this by acting as ‘ports’ where new species could be propagated for wider distribution (Heywood, 1989; Hulme, 2011). International trade is the primary source of introduction of alien plants on a global scale still now. In particular, agriculture is a major introduction pathway, either accidental or purposive. The United Nations Convention on Biological Diversity held in 1992 as a part of the ‘Earth Summit’, concluded that the biological invasion of alien species is the second worst threat to biodiversity, after habitat loss. According to Pimentel *et al.* (2001), the adverse effects of invasion can be broadly categorized into five major areas, 1) agriculture and plantation forestry, 2) active biota, 3) ecosystems, 4) natural communities and human and livestock health, and 5) industrial processes. In this paper, plant invasions are discussed with special reference to agriculture in Kerala, including a brief history of introduction and research findings.

From an agricultural point of view, ‘plant invasion’ is synonymous to ‘weed invasion'. Weed invasion can be considered as a process of successful establishment of a plant in an arable land posing serious threat to agricultural activities causing serious economic loss, by competing with crops or by interfering with cultural practices. Out of the 1599 alien plant species recorded in India, 225 species are invasive (Khuroo *et al*., 2012). In India, annual losses in crop production due to weed invasion were estimated to be 37.8 billion US dollar according to 1950-1981 estimates (Pimentel, 2002).

What makes a plant an invasive weed?

A weed is often defined as a plant where it is not desired to grow. In crop production, a weed is an undesirable, injurious, and troublesome plant, which interferes with cultivated crops and affects human affairs. To define invasive alien weeds, one must be familiar with three terms, noxious, invasive, and alien. *Noxious weeds* are plant species that tend to be injurious to public health, crops, livestock, or other properties. *Invasive weeds* are plant species that have the potential to spread rapidly and become noxious. A species moved by human activities beyond the limits of its native geographic range into an area in which it does not naturally occur is called an *alien species*. When we say *invasive alien species*, we mean an introduced species to a specific location, which has a tendency to spread and cause damage to crops, biodiversity, economy, public health, or the environment. Plants that overcome geographical barriers are known as alien plants, and major disturbances that promote the establishment of alien plants in a new habitat are agriculture, forest fire, and biome shift (Early *et al*., 2016).

For a new plant to establish itself successfully and to become a weed in a disturbed area, it has to overcome several barriers as noted below (USDA, 2006).

1. *Large-scale geographical barriers*: These can be geographical boundaries like mountains, sea or any physical obstacles for the movement of seeds or any reproductive plant parts.
2. *Survival barriers*: These include germination and survival barriers such as moisture availability, physico-chemical properties of soil, nutrient availability, and competition ability.
3. *Establishment barriers*: These are the barriers to establish itself successfully to form a population that is self-sustaining and does not need re-introduction to maintain a population base such that it continues to survive and thrive in its new environment. Once the non-native plant survives this barrier, its population is considered established.
4. *Dispersal and spread barriers*: Not only the species has to overcome the establishment barriers but also ensure its succession by seed dispersal and progeny production. Additionally, the rate of spread must be relatively fast. However, this movement or spread alone does not necessarily make the non-native plant an invasive weed.
5. *Harm and impact*: A plant is considered as an invasive weed, if it causes negative environmental, economic, or human health effects, which outweigh any beneficial effects. For example, *Mikania micarantha* is a source of nectar for bees. Nevertheless, the displacement of native and other desirable plant species caused by this weed leads to biodiversity loss. Further, it is reported that nectar and pollen availability from this plant is indirectly affecting the pollination and seed set in native plants. As the negative effects greatly overshadow the positive effects, it is considered an invasive species.

The success of invasive plants depends on factors like prolific seed production, efficient dispersal mechanisms, higher germination rate, rapid growth rate, rampant vegetative spread with special organs such as offsets (*Eichhornia crassipes*), turions (*Hydrilla verticillata*), root suckers or bulbs, wide adaptability and tolerance to changing environments and higher competitive ability. Invasive weeds like lantana and siam weed have allelopathic effect on agricultural crops making them more competitive (Sahid and Sugau, 1993). The absence of natural enemies in the new environment also provides favorable conditions for invasive species.

Often, invasive species are grouped as driver species, passenger species, and back seat drivers (Barua and Deka, 2016). Weeds that can establish themselves easily in undisturbed habitats and bear the capacity to alter the community structure within a short period of time in an irreversible direction can be termed as driver species. *Mikania micrantha* is an example for a driver species. Weeds that are abundant in disturbed areas where population of a primary floral community is in a declining phase can be classified as passenger species (Didham *et al*., 2005), for example, lantana and Siam weed. The third type, back seat drivers can establish in disturbed areas but they further deteriorate the native community over a period of time

(Bauer, 2012). Carrot grass (*Parthenium hysterophorus)* is a back seat driver, invading cropped areas, which in its pure stand eliminates majority of resident plant populations.

A brief history of weed invasions in India

Major plant introductions to India can be traced back to the establishment of a Botanical Garden by East India Company during 1786 at Culcutta. The spread of invasive alien weeds like *Mikania micrantha*, *Lantana camara,* and *Chromolaena odorata* in India are examples of such introductions (Table 1). However weeds like *Parthenium hysterophorus* was accidentally introduced along with the wheat import in 1950s.

Table 1. Invasion pathway of some agriculturally important alien weeds

Plant	Country of origin	Pathway of invasion
Parthenium hysterophorus	Central and South America	Import of wheat from Australia
Lantana camara		Introduced as ornamental
Mikania micrantha		Brought for camouflaging army during World War II
Eichhornia crassipes		Introduced as ornamental
Salvinia molesta		Accidental/ornamental

In Kerala, maritime trade also paved way for the introduction of many invasive weeds. In addition to terrestrial invasive plants, aquatic invasive plants are also posing great challenges, especially to water resources of Kerala. It is believed that floods occurred in August, 2018, hastened invasive weed growth by the transport of propagules through water thus encroaching new areas. Some weeds like water hyacinth and Kariba weed, which were earlier noticed mainly in the backwaters of Kuttanad, have now spread to several low-lying paddy fields. Some weeds like *Hydrilla*, *Vallisneria*, and *Utricularia*, introduced as aquarium plants are now attaining the status of major weeds in rice fields. Many invasive plants continue to be adored by people who may not be aware of their weedy nature. For example, Singapore daisy (*Sphagneticola trilobata*), a problematic invasive weed, is still being used as an ornamental plant due to its attractive bright yellow flowers. Several species are exploited by people for various purposes, but eventually develop invasive traits and harm other plants. For example, the leguminous cover crop, *Mucuna bracteata* used in rubber plantations to manage soil erosion has attained the status of a noxious weed, spreading fast and inhibiting the growth of native plants and trees.

Major invasive weeds of Kerala

Out of the 225 invasive plant species reported from India, 11 species are included in the list of the 100 worst invasive species categorized by the International Union for Conservation of Nature (Lowe *et al*., 2000). These 11 species are *Acacia mearnsii, Arundo donax, Chromolaena odorata, Clindemia hirta, Imperata cylindrica, Lantana camara, Leucaena latisiliqua, Mikania micrantha, Opuntia stricta*, *Ulex europaeus* and *Sphagneticola trilobata*.

According to Abraham *et al*. (2009), *Lantana camara*, *Mimosa pudica, Chromolaena odorata*, *Mimosa invisa, Merremia vitifolia,* and *Mikania micrantha* are the major terrestrial invasive alien weeds in humid tropics of the country. They listed *Eichhornia crassipes, Salvinia molesta*, *Limnocharis flava*, *Ipomoea carnea*, and *Alternanthera philoxeroides* as major aquatic alien weeds. The names of 51 major invasive weeds in Kerala selected by us based on various studies and observations are listed in Table 2 (Listing has been done alphabetically based on the most popular scientific name of the plant).

Table 2. Major invasive weeds in Kerala

Sl. No	Common name	Scientific name	Origin
1	Greater club rush	*Actinoscirpus grossus*	S.E. Asia
2	Alligator weed	*Alternanthera philoxeroides*	Tropical America
3	Calico plant	*Alternanthera betzickiana*	Tropical America
4	Purple joy weed	*Alternanthera brasiliana*	Central and S. America
5	Goat weed	*Ageratum conyzoides*	Tropical America
6	Floss flower	*Ageratum houstonianum*	Central America
7	Prickly amaranth	*Amaranthus spinosus*	Central and S. America
8	Coral vine	*Antigonon leptopus*	Mexico
9	Red cabomba	*Cabomba furcata*	South America
10	Heart of jesus	*Caladium bicolor*	South America
11	Calopo	*Calapagonium mucunoides*	Tropical Asia
12	Siam weed	*Chromolaena odorata*	Tropical America
13	Koster's curse	*Clindemia hirta*	South America
14	Dodder plant	*Cuscuta* spp.	North America
15	Cat's claw	*Dolichandra unguis-cati*	South America
16	Water hyacinth	*Eichhornia crassipes* *(Pontederia crassipes)*	South America
17	Crofton weed	*Eupatorium adenophorum*	Central America
18	Mexican fire plant	*Euphorbia heterophylla*	Central America
19	Water thyme	*Hydrilla verticillata*	Asia and North Australia
20	Cogon grass	*Imperata cylindrica*	Asia/ Africa
21	Water spinach	*Ipomoea aquatica*	China
22	Railway creeper	*Ipomoea cairica*	Tropical Africa to Asia
23	Bush morning glory	*Ipomoea carnea*	Tropical America
24	Common lantana	*Lantana camara*	Tropical America
25	Yellow velvetleaf	*Limnocharis flava*	South America
26	Peruvian primrose bush	*Ludwigia peruviana*	South America
27	Chocolate weed	*Melochia corchorifolia*	Tropical America
28	Pignut	*Mesosphaerum suaveolens* *(Hyptis suaveolens)*	South America
29	Grape vine weed	*Merremia vitifolia*	Indo-Malasia and China
30	Mile-a-minute weed	*Mikania micrantha*	Central and S. America
31	Giant sensitive plant	*Mimosa diplotrich var. diplotricha*	South America
32	Sensitive plant	*Mimosa pudica*	South America
33	Mucuna	*Mucuna bracteata*	Asia
34	Jamaican cherry	*Muntingia calabura*	South America
35	Guppy grass	*Najas guadalupensis*	North and S. America
36	Carrot grass	*Parthenium hysterophorus*	Tropical America
37	Stinking passion flower	*Passiflora foetida*	North America
38	Deenanath grass	*Pennisetum pedicellatum* *(Cenchrus pedicellatus)*	Africa and Asia
39	Mission grass	*Pennisetum polystachyon* *(Cenchrus polystachios)*	Tropical Africa

40	Tropical duckweed	*Pistia stratiotes*	South America
41	Bracken fern	*Pteridium aquilinum*	Tropical America
42	Rangoon creeper	*Quisqualis indica*	Tropical Africa and S. E. Asia
43	Itch grass	*Rottboellia cochinchinensis*	Tropical Africa and Asia
44	Interrupted cup scale grass	*Sacciolepis interrupta*	Tropical Africa and Asia
45	Water fern	*Salvinia molesta*	South America
46	American cassia	*Senna spectabilis*	Tropical America
47	Singapore daisy	*Sphagneticola trilobata*	Central America
48	Synedrella	*Synedrella nodiflora*	West Indies
49	Mexican sunflower	*Tithonia diversifolia*	Mexico to Central America
50	Bladderworts	*Utricularia* spp.	America
51	Eel grass	*Vallisneria spiralis*	S. Europe, N. Africa, and S.W.Asia

The menace of weeds normally increases in the Kharif season due to monsoon rains. In this season, annual invasive weeds like *Ageratum conyzoides, Alternanthera bettzickiana, Mimosa invisa, Hyptis suaveolens, Synedrella nodiflora, Merremia vitifolia, Mikania micrantha,* and *Rottboellia cochinchinensis* dominate both cropped and non-cropped areas. By the end of the season, their density decrease and dry off. Weeds like *Pennisetum pedicellatum* and *Pennisetum polystachyon* are the major weeds during the Rabi season. Some major Kharif weeds are also noticed in this period, for example, *Ageratum conyzoides, Alternanthera bettzickiana,* and *Synedrella nodiflora.* During the summer, perennial weeds like *Chromolaena odorata* and *Clerodendrum infortunatum* survive and predominate the weed flora (NIWSP, 2011).

Management of invasive weeds

Prevention is the most important measure for managing invasive weeds, and it requires utmost attention, as prevention is always better than cure. Proper surveillance, monitoring, strict quarantine laws, and treatment of imported goods that might include invasive species in the entry points are the preventive measures that should be taken care of immediately to avoid future introductions. International organizations like International Union for Conservation of Nature and Natural Resources (IUCN) and Convention on Biological Diversity (CBD) are concerned with the prevention and management of this problem. At a global level, IUCN through a group of specialists, the Invasive Species Specialist Group (ISSG), elaborated a list of the invasive species and established a set of rules for the prevention of biodiversity loss caused by invasive species.

Management practices can be targeted in two different ways, for those that have already been established and those, which have the potential to become invasive. The potential invasive weeds can be managed through environment impact assessment, collecting information regarding pathways of invasion to prevent further spread, strict post quarantine measures to eradicate the potential invasive weeds, and conducting awareness programmes to public.

Once a plant is introduced and become invasive, manual, mechanical, cultural, biological, or chemical control measures can be adopted, but in an integrated manner as no single method has been found effective for a long term and sustainable management. Understanding the weed ecology and biology can help in devising proper management practices. Manual collection and removal is largely followed in managing weeds in fragile ecosystems. Manual hand pulling or mechanical weeding is possible only if the extent of spread is less. Mechanical methods include mowing, slashing and digging with various implements. After the removal of plants, they should be properly burnt or buried. Cultural control includes mulching, cover cropping, crop rotation or frequent soil disturbances, and stale seedbed.

Biological control has classical, augmentative, and conservative approaches. Classical biological control includes searching for the efficient natural enemies (insects, mites, and pathogens) from the native range of the weed, its introduction, multiplication, and finally release, to reestablish the equilibrium between pests and natural enemies (Table 3).

Table 3. Classical biological control agents introduced to manage weeds in India

Weed	**Biological control agent**
Parthenium hysterophorus	*Zygogramma bicolorata*, *Smicronyx lutulentus*, and *Epiblema strenuana*
Eichhornia crassipes	*Neochetina eichhorniae*, *N. bruchi*, and *Orthogalumna terebrantis*
Salvinia molesta	*Cyrtobagous salviniae*, *Phoma glomerata*, and *Nigrospora sphaerica*
Opuntia spp.	*Dactylopius tomentosus*
Lantana camara	*Ophiomyia lantanae*, *Orthezia insignis*, *Diastema tigris*, *Salbia (Syngamia) haemorrhoidalis*, *Uroplata girardi*, *Teleonemia scrupulosa*, *Octotoma scabripennis*, and *Epinotia lantanae*
Alternanthera philoxeroides	*Agasicles hygrophila*
Eupatorium adenophorum	*Procecidochares utilis*
Chromolaena odorata	*Pareuchaetes pseudoinsulata*, *Apion brunneonigrum Cecidochares connexa*
Mikania micrantha	*Puccinia spegazzinii*
Submerged aquatic weeds (eg: *Hydrilla*, *Vallisneria*)	*Ctenopharyngodon idella, Puntius javanicus, Pulchellus pulchellus, Tilapia mossambica, T. melano pleura, and Oophorinum gourami*

Source : Kumar, 2015

Although classical biological control is highly effective and environment friendly, it is time-consuming and useful in non-cropped situations only. Sometimes, natural enemies may not establish well as that of the native place or may give only partial control of weeds. Singh (2004) reported that 56 per cent control was noticed in aquatic weeds and 24 per cent in terrestrial weeds by classical biological control in India. Efforts to increase the population of natural enemies either by propagation and release or by environmental manipulation and conservation are followed in augmentative and conservative approaches. About 30 exotic biological control agents have been introduced to control invasive weeds in India (Kumar, 2015). Of these 30, 6 bio-agents could not be released to the field. Among these, 7 well-established bioagents gave excellent control, 4 gave significant control, and 9 gave partial control (Kumar, 2015).

Bioherbicides consisting of phytopathogenic microorganisms or phytotoxins derived from microorganisms can be used to control weeds. This method makes use of plant pathogens that are cultured to produce significant amounts of infectious material. However, this approach has only limited application because of many practical hurdles.

Table 4. Popular bioherbicides

Microorganism	**Trade name**	**Targeted weed**
Phytophthora palmivora	Devine	*Morrenia odorata*
Colletotrichum gloeosporioides f.sp. *Aeschynomene*	Collego	*Aeschynomene virginica*
Colletotrichum gloeosporioides f.sp.*malvae*	Bio Mal	*Malva pusilla*
Puccinia canalicuta	Dr. bioSedge	*Cyperus esculentus*

Chemical weed management is one of the efficient ways to control weeds. Suitable herbicides can be chosen, and it can be applied at proper time depending upon the weed. Nevertheless, continuous use of herbicides may result in herbicide resistance. Therefore, herbicide rotation is mandatory. Possible chances of pollution of aquatic water bodies and the environment should also be monitored.

Research on invasive weed management in Kerala

Some of the major invasive species, which caused severe impacts in terrestrial and aquatic ecosystem, along with the works undertaken in Kerala for managing them are detailed below. In Kerala, salvinia, water hyacinth, and Siam weed are the first noticed and studied invasive alien weeds. In Kerala, serious attempts to control invasive alien weeds started after the establishment of two centres at Vellanikkara, Thrissur, one under the All India Coordinated Research Project on Crops Pests and Weeds in 1977 and another under the All India Coordinated Research Project on Weed Control in 1985.

Aquatic weeds

Salvinia molesta

Salvinia (*Salvinia molesta*), also called Kariba weed or locally as African payal, is ranked the second most noxious weed in the aquatic system. In Kerala, this troublesome aquatic fern is widespread in the water bodies including deep-water paddy fields. It was first reported in the 1950s at Veli Lake, Thiruvananthapuram, and attained the status of noxious weed in the wetland rice ecosystems of Kerala in 1964 itself (Cook and Gut, 1971). In rice, during preparatory cultivation time, this weed can be controlled to some extent. However, recently salvinia is reported as a problem in paddy fields from few districts of the state, where it interferes with cultural operations and reduce the rice yield by competing for available nutrients.

In the 1970s itself, Kerala Agricultural University developed a salvinia harvesting machine, with conventional pump sets as the prime mover (Samuel and Jacob, 1977;

Sankaranarayanan *et al*., 1985; Hajilal, 1987). A high capacity check device built into the machine sucks, fluidizes, and pumps out the weed material to the desired height or location. A 10 horsepower machine achieved a harvesting rate of 16 tonnes/h for continuous operation. M/s Kelachandra Precision Engineers, Kottayam, Kerala also developed a weed harvester, with a steel barge fitted with conveyor belts, driven by a marine diesel engine of sufficient capacity for operating the hydraulic system. Navigation is through propellers or paddle wheels. The harvester consists of 3 conveyor belts. The first one to collect the weeds onto the barge, another one for storage and the third one for discharge onto land or to a transport barge.The harvester can remove 40-80 tonnes of weeds per day in an hour (Jayan and Sathyanathan, 2012).

Biological control of salvinia was started with the establishment of Kerala Agricultural University in 1972 (Joy, 1978). Earlier works were conducted with Chinese grass carp (*Ctenopharyngodon idella*), snails, plant pathogens (*Pythium* sp), insects (*Nymphula responsalis, Rhopalosiphum nymphaea, Dysmicoccus* sp., and *Bagous* sp.). All these attempts were not effective (Joy *et al*., 2000). Later, three exotic biological control agents, aquatic grasshopper (*Paulinia acuminate),* pyralid borer (*Samea multiplicalis)* and a weevil, (*Cyrtobagous salviniae)*, were tried in Thrissur, Kottayam, and Alappuzha districts (Joy *et al*., 1985). Among these, salvinia weevil was highly successful for controlling kariba weed, which found a place in the Package of Practices Recommendations- Crops (KAU, 2016). In a particular area, 50 to 100 weevils have to be released and in cases, weevil collection is not possible, one kilogram of infested salvinia can be used as a inoculums. Larvae tunnel the rhizomes, whereas, adults feed on unopened leaf buds and tender leaves. Under field conditions, complete weed destruction was observed after five to ten months of release depending on the area of release. The weevil took more than a year to cover 30 metres in an undisturbed canal at Kumarakom, while, it spread to a distance of three kilometers in six months at Athirampuzha. This is attributed to quick dispersal of the weevil in tidal waves and air currents experienced in navigation canals (Joy *et al*., 2000).

Eichhornia crassipes

Water hyacinth (*Eichhornia crassipes;* Syn*: Pontederia crassipes)*, also called lilac devil or Kulavazha locally, is one of the world's most troublesome aquatic weeds, native to South America, was introduced to India in 1896 (Biswas and Calder, 1954). Its occurrence was first reported from many parts of Kerala, and it has affected agriculture, fishing, and livelihoods in the state. It is a free-floating perennial plant, producing daughter plants primarily from offsets or stolons. Leaves are waxy green and waterproof. Inflated bulbous spongy structures are present in petioles, which help to float in water and form a mat by spreading to larger areas. This causes problems in irrigation and navigation. This weed prevents sunlight and oxygen from reaching the water column and submerged plants. It drastically diminishes biological diversity in aquatic habitats. Massive invasion of this weed to paddy fields caused a serious threat to paddy cultivation in the Kuttanad region of Kerala. In addition, this forms a breeding place for mosquitoes, which are vectors for many diseases. An example of this is the high occurrence of elephantiasis in Cherthala and Alapuzha (Kerala), where the plant is flourishing well compared to other locations in the state (Haq and Sumangala, 2003).

Studies to manage water hyacinth biologically were initiated with the introduction of *Neochetina eichhorniae*, a weevil from USA in 1982. Field release of weevils started in 1983 in Alappuzha, Kottayam, Thiruvananthapuram, Ernakulam, and Thrissur districts. The insect preferred the young unopened leaves and gave significant control. *N. bruchi* was introduced in 1983 and field trials were started in 1984. However, the species failed to establish in Kerala, probably because of the preference of cooler climate by the weevil. In 1990, Oribatid mites, *Orthogalumna terebrantis* were field released to control water hyacinth. However the field level success was not promising, in spite of its widespread establishment (Joy *et al*., 2000).

Bio herbicidal potential of fungal pathogens of water hyacinth was studied at the Department of plant pathology, College of Agriculture, Vellayani, and *Colletotrichum gleosporioides*, *Fusarium pallidoroseum,* and *Fusarium equiseti* were identified as pathogens capable of infecting water hyacinth. However, *Colletotrichum gleosporioides* was pathogenic to amaranth, bhindi, chilli, and mango; *Fusarium equiseti* to amaranth; and *Fusarium pallidoroseum* to napier grass. With the narrow host range and high intensity of infection on water hyacinth, *Fusarium pallidoroseum, Fusarium equiseti* and their metabolites can be effectively used in controlling water hyacinth. Coir pith, rice bran, and guinea grass straw powder was found to be good substrates for mass multiplication of pathogens (Naseema and Balakrishnana, 2001).Using *Fusarium pallidoroseum* as the bio-agent, 50 per cent infection of the weeds could be observed, and it is found promising as a biocontrol agent (Praveen and Naseema, 2004).

Efforts to manage water hyacinth by its utilization for various purposes were also reported from Kerala. Good quality feed material can be prepared from water hyacinth as silage. Indulekha *et al*. (2019) reported that the quality and palatability of water hyacinth silage prepared with wilted water hyacinth and cassava powder (10%), wilted water hyacinth along with rice straw (10%) and cassava powder (10%), and wilted water hyacinth along with guinea grass (10%) and cassava powder (10%) had good fodder quality. Water hyacinth can also be used for the preparation of compost by various composting techniques such as Bangalore composting, Indore composting, phospho composting, and vermin composting. Out of the various methods, the lowest C: N ratio (11.58) and maximum porosity (61.18%) were recorded with vermin compost. Nitrogen content at three months after composting was also found higher in vermin compost (Indulekha, 2018). Indulekha and Thomas (2018) evaluated water hyacinth for its mulch value as a part of management strategies. Water hyacinth performed equally well with that of other mulching materials—jack fruit leaves and coconut leaves in turmeric. These mulch materials substantially reduced weed density, weed dry weight, and turmeric-weed competition for different growth factors.

Prabhu (2016) discussed various methods to change the perceived negative economic impacts of aquatic weeds such as water hyacinth into positive income generating enterprises. He mentioned several alternative approaches such as making of furniture, handicrafts, paper, packing material, mulching, composting, biogas production, organic manure, animal feed, and bio-active compounds. Water hyacinth is used for making handicrafts by a few groups in Kerala, and thereby generating employment for women groups.

Pistia stratiotes

Water lettuce (*Pistia stratiotes* L.*;* Family: Araceae) is a perennial free-floating aquatic macrophyte which is stemless, stoloniferous and has fibrous roots. It is one among the world's worst weeds and is widely distributed in tropical and sub-tropical waters. It was listed as invasive species in the Global Invasive Species Database due to its adverse effects on biodiversity and the environment, where its mats clog waterways, block the air–water interface, reduce oxygen levels in the water, and ultimately lead to degradation of water quality.In a study conducted to identify the invasive alien plant species in the flood affected areas of Alappuzha District, it was observed that *P. stratiotes* has invaded the wetlands of all the 17 villages and was categorized as high risk species (Beevy and Kamarudheen kunju,2019).

Actinoscirpus grossus (Syn: *Scirpus grossus*)

Actinoscirpus grossus, commonly called 'greater club rush' or 'bulrush' (local name, *Pottapullu*) is a robust plant with sharp triangular stem, widespread and troublesome, spreading by stolons, which is capable of colonizing rice crops and wetlands fast. It is native to Southeast Asia. This perennial weed grows to a height of 2 m. It occurs in swampy and inundated places, pools, ditches, and marshes. It is reported from Alappuzha, Kottayam, Kozhikkode, Trivandrum and Ernakulam districts of the state. The weed has high tolerance to a wide range of field conditions and ecological flexibility. It can accumulate heavy metals with its huge biomass (> 30 t ha^{-1}), thus reducing heavy metal from contaminated soil. Thus it has a potential for phytostabilisation of heavy metals (Gayathri, 2017).

For managing the wed, a demonstration trail was conducted by Kerala Agricultural University in an area of 26 acres in Thekkumkulangara padasekharam, Vellankallur block of Thrissur district. The area was cleared off the weeds and paddy seeds were sown. A post emergence sprays of 2, 4-D at 1 kg/ha was sprayed 18-20 DAS to control the regrowth of weeds from stubbles. This was a very effective method of management resulting in good growth of rice seedlings (AICRP, 2010). However, later in the succeeding seasons, the fields were kept fallow and the weed covered the entire area. Still, it has a complete coverage in the fallow land as per the recent diagnostic field visits of AICRP team. This indicates that leaving the land uncultivated for a long time provides open niches for the further spread of the weed.

Cabomba furcata

Cabomba furcata is also known as pink forked fanwort. The first authentic report of spotting *Cabomba aquatica* in India was in 1977 from Cochin (Alekutty and Inamdar, 1978). Over a period of five decades, it has conquered the streams and inland waters in different parts of the state, particularly, Ernakulam, Alappuzha, Pathanamthitta, Thrissur, and recently in Kozhikkode (AICRP, 2020). It is a native of South America. Cabomba was probably introduced as an aquarium plant, which later escaped to natural habitat. As per surveys, the most serious concern is that visitors coming to this area are taking the stem cuttings for using it as an ornamental aquarium plant. It was also observed that, clearing of riparian vegetation favoured the growth of this aquatic weed due to heliophytic nature of the plant.

Ipomoea **spp.**

Ipomoea carnea and *Ipomoea aquatica* are two alien species seen in aquatic habitats. *Ipomoea carnea* is commonly known as ‘Shoe flower’ or ‘Gramaphone plant’. It is usually noticed in low lands, shallow ponds, and ditches where water stagnation occurs for some part of the year. It is widely observed in the rice growing tracts of Kerala.

Ipomoea aquatica is also a semi-aquatic vine, creeping on muddy streams and ponds. When it reaches water surface, it forms a dense floating mats, which is an ideal breeding environment for mosquitoes and also shading out native aquatic flora. Canals used for flood control and drainage are heavily obstructed by tangled vegetation (GISD, 2006).

Limnoharis flava

Limnoharis flava (water cabbage) is another alien invasive weed of aquatic system. It can also destroy the native aquatic flora and fauna by its quick spread. In a study to utilize water cabbage as compost, it along with water hyacinth, coir pith, and farm wastes were used as substrates. *Trichoderma reesei* and *Pleurotus sajor-caju* and commercial enzyme cocktail as composting inoculums. Among different combinations, water cabbage + composting inoculum produced the best compost in terms of their chemical composition followed by water hyacinth + composting inoculum (Anushma and Aparna, 2016). Jayapal *et al*. (2021) reported that *Limnocharis flava* can be profitably converted into vermicompost for commercial use.

Wetland rice ecosystem

Weeds pose recurrent threat to productivity of rice, which is the major food crop cultivated in the state. Abraham and Thomas (2002) reported 38 weed species in Kole lands of Thrissur , of which 22 were widely distributed. *E crusgalli* and *E stagnina* were important grass weeds in Kole. Other dominant ones based on frequency and average density were *Fimbystylis miliaceae, Cyperus iria*, and *Cyperus diffomis*. In general the predominant weed flora were similar to that in Kuttanad, Alappuzha (Abraham *et al*, 1993), which have almost similar physiochemical characteristics as that of Kole lands

Currently, weedy rice (*Oryza sativa* var. spontanea), locally termed 'Varinellu' in Malayalam is a major weed of rice tracts of Kerala and is a difficult to manage weed as herbicidal measures are not effective due to close genetic similarity to cultivated rice. In some cases, the alarming rate of infestation is forcing the farmers to even abandon rice cultivation. Weedy rice is a superior competitor to rice cultivars due to its early vigour, greater tillering and plant height. Yield losses largely depend on season, method of establishment, growth rate and density of weeds, as well as the rice cultivar. Weedy rice at 35 percent infestation can cause about 60 percent yield loss, and under serious infestation, yield loss of 74 percent is reported in direct seed rice. Dwarf short varieties are usually more susceptible to weedy rice competition than tall types. (AICRP-WM, 2021)

Sacciolepis interrupta, locally called 'Pollakkala', is a troublesome invasive alien weed found abundantly in semi-dry rice fields of Kerala. The problem of *S. interrupta* assumes significance as many farmers resort to dry seeding mainly because of the uncertainty of the receipt of rains in time and to avoid the hassles of transplanting. Renu *et al.* (2000), from field trials observed that adoption of stale seedbed technique reduced the competition from all the weeds including *S. interrupta*. Stale seedbed with paraquat showed reduced weed incidence than stale seedbed with hoeing. Pre-emergence application of oxyfluorfen 0.15 kg ha $^{-1}$ was efficient in reducing cupscale grass problem.

Leptochloa chinensis or Chinese sprangle top is another graminaceous weed in rice which was earlier confined to alkaline soils of Kerala and later spread to other rice tracts through contaminated seeds. It is reported that the continuous use of broad spectrum herbicide bispyribac sodium resulted in emergence of this weed as a problematic one. The same case was earlier reported from Srilanka. However, the graminicides cyhalofop butyl as well as fenoxaprop are effective in controlling this weed and are an example for the importance of herbicide rotation in weed management (AICRP, 2012).

Upland ecosystems

Chromolaena odorata

Siam weed (*Chromolaena odorata*), is locally known as 'Communist Pacha', as it quickly expanded throughout the state, just like Communism did in the 1950s. It is also known as 'Christmas weed' as it flowers in December. The plant is native to the America, introduced to Kerala during 1940s from Assam and Sri Lanka, which took over the barren lands of Kerala, after which many native species like the medicinal plant *Sida cordifolia* started disappearing (GOI, 2022b). *Chromolaena odorata* is a very serious weed in plantation crops such as coconut, rubber, cashew, and pepper as well as uncultivated areas. However, its population showed a declining trend in recent past.

In Siam weed, earlier biological control attempts were tried with native insects. However wide host range of these insects limited the scope for use in biocontrol. Therefore, exotic insects, *Apion brunneonigrum* and *Pareuchaetes pseudoinsulata* were introduced. Among these, *Apion brunneonigrum* couldn't establish in the fieldand performance of *Pareuchaetes pseudoinsulata* was unsatisfactory (Joy *et al*., 1985).

Mikania micrantha

Mile-a-minute vine (*Mikania micrantha*) also called bitter vine, climbing hemp vine, or American rope, is locally known as 'American vally' or 'Dritharashtra pacha' indicating its smothering effect on other plants. This plant can grow luxuriantly even in nutrient poor soil. The creeping and climbing nature of the weed makes cultural operations and harvesting difficult. In Kerala, it was first reported from rubber plantations of Kottayam in 1968 (Sajeev *et al*., 2012). It has some effects on the food chain as well. Numerous animals, including the spotted deer, which is prevalent in Kerala's Tholpetty and Muthanga regions, experience food shortages because of the extinction of the natural plant species it inhabits due to dominance of this weed (GOI, 2022a). A single plant produced 45812 seeds (Abraham and Abraham, 2005) and seed easily disperses in wind. It also reproduces through vegetatively by stem cuttings. Sankaran and Sreenivasan (2001) reported that in the last 20 years, mikania has become serious threat to large forest plantations in Kerala. The thin canopy of young plantations and frequent cultural operations increased the infestations.

Abraham (1999) studied the biology, control, allelopathic effect and utilization of Mikania, and observed the suppressive effect of mikania on crop growth in pineapple, banana, rubber, coconut, cocoa and teak plants. Among the various test crops (rice, cowpea and rubber), allelopathic effect was observed on rubber seedlings. Mikania was found to be an alternate host for certain insect pests, aphids, tea mosquito bugs, thrips, and some pathogens. Sundried or composted mikania can be used as an ideal organic manure, with nutrient contents of around 2 per cent nitrogen, 0.4 per cent phosphorus, and 3 per cent potassium, and almost 100 per cent decomposition within one year. The pre-emergence herbicides, diuron at 1.5 kg/ha and oxyflourfen at 0.2 kg/ha were effective in preventing germination and establishment of *Mikania micrantha*. Post emergent application of 2,4 -D, glyphosate, and glufosinate ammonium were also effective.

Sphagneticola trilobata

Sphagneticola trilobata, also known as ‘Singapore daisy’, is a spreading, mat-forming perennial herb, which strikes root from every node. The plant has already become a threat to agricultural and forest biodiversity with its extensive spreading habit, and the plant is in the IUCN(International Union for Conservation of Nature) list of 100 worst invasive species (Lowe *et al*., 2000). The dense mats of Singapore daisy can be a threat to other plants because they shade and cover native plant species, and can even prevent the regeneration of other species from the soil seed bank (Macanawai, 2013).

Studies conducted in Kerala to manage Singapore daisy has brought out some promising findings (KAU, 2018). Singapore daisy spreads rapidly through stem bits, and therefore, very difficult to manage it through regular control measures. Herbicides such as glyphosate or 2,4-D, generally recommended for the post emergence control of common vegetation, are not effective. Metsulfuron methyl (Algrip) at 7.5 g/ha or 10g/ ha is the most effective herbicide for the control of Singapore daisy, which prevents regrowth as well. Removing the top 5cm of soil and sowing cowpea was the most effective non-chemical way of managing Singapore daisy. Digging and removing stubbles occasionally is the other alternative. In another trial, (metsulfuron-methyl + chlorimuron-ethyl) at 10.0 g/ha or 12.0 g/ha and metsulfuron-methyl alone at 10.0 g/ha were found very effective for controlling Singapore daisy (AICRP, 2021).

Parthenium hysterophorus

Parthenium hysterophorus, also called carrot grass or congress grass, introduced accidentally, is another example of invasiveness in almost all states of the country. It is believed that Parthenium was introduced into India as contaminants in PL 480 wheat imported from the USA and remained unreported until 1956 (Patel, 2011). Presently, it has spread to almost all Indian states causing severe yield reduction in major crops, and Karnataka government has declared it as noxious weed in 1975 as per Agricultural Pests and Diseases Act, 1968. Carrot grass grows very rapidly in cropped as well as non-cropped areas. The pollen is known to inhibit fruit set in many cultivated crops. This also causes allergic reactions in human and animals. From an experiment in Kerala to control the weed in non-cropped areas, Abraham *et al*. (1991) reported that application of sodium chloride as 15% spray, 2,4-D at 1.5 kg/ha, glyphosate at 0.8 kg/ha, glyphosate at 0.6 kg/ha + 1% ammonium sulphate, and combined application of glyphosate at 0.8 kg/ha + 2,4-D at 1.0 kg/ha were effective for its control.

Mimosa diplotricha

Giant mimosa *(Mimosa diplotricha* var. *inermis),* introduced as a cover crop for coffee plantations, vigorously encroaches on indigenous plants and grows into dense, tangled thickets that can reach a height of 3 m, preventing regeneration, reproduction, and growth of native species. Both spiny and spineless forms are found in Kerala and first reported from Kottayam district in 1964. The species is widespread in non-forested areas, and there is a very high chance that it will invade forests (Sanjeev *et al*., 2012).

Another species, *Mimosa pudica*, is also a troublesome weed in tropical crops with widespread occurrence in the state. All the plant parts of both *Mimosa* species are toxic to livestock, if ingested, due to the mimosine content in the plant. However, ensiling could reduce the mimosine content. Ensiling can be done with less than 50 per cent admixture of giant mimosa with fodder grass (Jayasree, 2005). In a study to observe the toxic effects of mimosine on the weight of rabbits and their internal organs, giant mimosa and Hybrid Napier mixed in different proportions ranging from 50 to 90 per cent ensiled for 60 days and feeding trials recorded rapid weight reduction, alopecia, and sluggishness. The proportion of pastures with giant mimosa up to 50 percent was safe for feeding after cutting and ensiling (Jayasree *et al*., 2007).

Jayasree and Abraham (2008) reported that giant mimosa could be effectively controlled by applying glyphosate at 0.6 kg/ha during active vegetative stage. 2,4-D was ineffective for the weed even at higher concentrations (5 kg/ha). Giant mimosa can be effectively used as a green manure with 90 per cent decomposition in three months and an efficient nitrogen fixing cover crop. The green material of the weed can also be used as a good substrate for vermin composting along with banana pseudostem in 1:1 proportion and *Eisenia foetida* as composting agent (Jayasree, 2005).

***Alternanthera* spp**

Alternanthera bettzickiana and *A. brasiliana* are low growing plants capable of spreading quickly in open areas and uncultivated lands. Surveys conducted in 2020 and 2021 in the uplands/ garden lands of central zone of Kerala showed dominance of *Alternanthera bettzickiana* both in uncultivated and cultivated areas. Density and growth of *A. bettzickiana* have significant positive correlation with organic carbon and nitrogen content of soil (Alex and Menon, 2022a). In 2008-11, it was reported as a major weed in the non-cropped areas of central districts of Kerala only (NIWSP, 2011 Strong stimulation to germination was observed in light condition and under higher temperatures (30-34°C), whereas lower temperature of 22 and 26°C and darkness caused inhibition of germination. Seed longevity studies revealed that germination of *A. bettzickiana* seeds increased up to five months age and thereafter exhibited a decline, and seeds beyond the age of nine months showed no germination. Studies showed short persistence of *A. bettzickiana* seeds in soil, irrespective of depth of burial (Alex, 2022). Allelopathy provided no significant contribution to the dominance of *A. bettzickiana* (Alex and Menon, 2022b). Sankaran *et al*. (2012) attributed its dominance to the dense coverage of the canopy. Vermi composting of *A. bettzickiana* biomass along with banana pseudostem at various proportions (8:1, 4:1, 2:1, 1:1 and weed alone) showed enhanced nitrogen, phosphorus and potassium content, but reduced organic carbon content and C:N ratio in the compost.

Alternanthera philoxeroides, commonly known as 'alligator weed' is a stoloniferous herb found in both aquatic and terrestrial habitat. The plant is capable of destroying the aquatic environment by forming a blanket over the water surface thereby impeding penetration of light and gaseous exchange. As *Alternanthera philoxeroides* had sprouting pieces in normal aerobic composting for 45 days, it has to be composted for a longer time of more than 90 days or anaerobic composting has to be opted (AICRP, 2010).

Lantana camara

Lantana camara, introduced in India in 1809 in the Calcutta botanical garden for its bright flowers and ornamental value, poses serious threat to native flora and wildlife. The plant was first reported from Malabar area in 1872. Native plant species lose vigour and productivity due to lantana's allelopathic effects. The plant has included in top 100 invasive species of the world by Global Invasive Species Database (GISD, 2022). Plant produces small berries, which are eaten and spread by birds, developing into dense thorny shrubs. The weed is serious problem in coffee, oil palm, coconut plantations etc, as well as in non-cropped areas.

Melochia corchorifolia

Melochia corchorifolia, also known as 'Chocolate weed', a common weed in both upland and lowland rice during *kharif* season. According to a state-wide survey, 2011, *Melochia corchorifolia*, which was only present in small patches ten years ago, was found to have expanded to many regions and was now a problematic weed in rice and sesame (NIWSP, 2011). This weed has probably reached rice fields of Kerala through use of pulse seeds from North Indian states sown as third crop in rice fallows. For post emergent control of melochia, herbicide carfentrazone ethyl 0.02 kg a.i per ha applied 15-18 days after sowing rice is very effective (AICRP, 2015).

Merremia vitifolia

Merremia vitifolia, grape leaf wood rose, locally called 'Velipadal' is a perennial climber, which is frequently found in forest edges and fences. It has the power to fully smother native vegetation, blocking the sunlight from reaching the native species beneath. Particularly when the plant is a few years old and the stem is thick, it spreads quickly, reproduces vegetatively, and is very challenging to remove manually.

Rottboellia cochinchinensis

Rottboellia cochinchinensis is a tropical grass weed commonly known as itch grass and in Malayalam 'Muriyanpullu'. The plant is native to the Old World Tropics, and probably originated from present Vietnam (CABI, 2014). It is an annual erect, profusely tillering grass with prop roots near the base of the plant. Stem and leaves are highly pubescent that can irritate the skin. This grass is a facultative sciophyte. It was not recorded in the surveys conducted during 2008-2011 in te premises of FCI godowns of Kerala. However, in recent surveys of AICRP on Weed Management (2020-22), this weed has been observed in the same premises of the earlier survey, which confirms the spread through seeds and grains.

***Cuscuta* spp.**

Cuscuta spp. commonly known as dodder('Moodilathali' in Malayalam) is an invasive, obnoxious, complete stem parasite, which attach itself to leaf and stem of wide range of host plants. Currently infestation of this parasitic weed is reported in different crops like pulses, chilli, amaranth, ornamentals, brinjal and tomato in Kerala and this spread might have occurred due to the floods 2018(AICRP, 2022). Another source is through trade of ornamental plants from other states. They can even transmit tomato leaf curl virus from infected plants to healthy plants (Prasad *et al*., 2016).

Mucuna bracteata

Mucuna bracteata, locally known as 'Thottapayar', introduced as a cover crop in rubber plantations has now escaped from plantations and occupied road sides, forest boundaries, and non-cultivated and cultivated areas. Unless the growth is managed by periodic cutting, it is a major threat to plantations also. Sruthi *et al.* (2014) developed a vermicomposting technique for *Mucuna bracteata* with the native earthworm species, *Perionyx ceylanensis.* Mucuna was first subjected to pre-compost with cattle dung in a ratio of 6:1 for 15 days. The partially decomposed product was fed into vermireactors and operated for 15 days.

In a study to transform the weed biomass to carbon rich humic substance, a mixture of weeds, *Chromolaena odorata*, *Macaranga peltata*, *Lantana camera*, and *Mikania micranta* were used in 3:2:1:1 proportion with various activators such as urea, cow dung, microbial consortium (*Bacillus subtilis*), and *jeevamrutham*, an organic manure used by farmers as part of zero budget farming. Among the different activators used, farm derived organic formulation was the most effective to convert the weed biomass to carbon rich humic substance within a period of 70–75 days. The final product was also rich in essential nutrients and microorganisms (Sujatha *et al*., 2021).

In the recent years, new weeds such as *Hydrilla, Vallisneria, Utricularia, Najas, Rhyncospora corymbosa, Cyperus javanicus* and *Cyperus digitatus* are invading wet land rice ecosystems, *Clerodendrum indicum, C. infortunatum, Syngonium podophyllum,* and *Pyrossia piloselloides* from tree crops were also reported. A new weed, Common Cocklebur (*Xanthium strumarium),* belonging to Asteraceae family was recently found to invade large tracts of 'Chimminey dam catchment area' in Thrissur, replacing the native vegetation and has attained the status of a troublesome weed in the forest ecosystem. These are potential invasive plants in the process of establishment and spread. Even though, these are not major weeds affecting cultivation, in future, it can be a serious threat to cultivation, if they are not properly managed.

Conclusion

Weed invasions are increasing at an alarming rate year after year leading to ecological, economic and social impacts. Annthropogenic factors are the major reason for this serious threat. The rapid loss of biodiversity can negatively impact the ecosystem resilience and can have serious implications on production sector. Declining agricultural productivity and profitability is directly affecting the farming community, ultimately forcing them to stay away from agriculture and shifting to some other income generating activities, keeping the land fallow, which enhances the chances of weed invasion. Although technological options are available for weed management, most often, economically and environmentally viable practical methods are limited, especially with respect to aquatic systems. Biological control measures suffer many draw backs and are successful only in a few weeds and specific situations. Although many studies have already been done on the utilization of weed biomass produced from invasive weeds, its large scale adoption is limited.

The perception of all stakeholders including farmers, local people and those indirectly benefited from the ecosystem services are important in successful implementation of management and eradication programmes. In addition, the silent role played by many invasive species like water hyacinth in phytoremediation of polluted water bodies cannot be ignored. Hence measures to prevent point and non-point pollution also should be strictly implemented through community awareness and participation. Unscientific land use, urbanization, filling of wetlands, prevention of natural flow of runoff water leading to water stagnation and pollution are favouring the process of colonization and establishment of many alien species. A proper land use plan, which integrates ecological and social dimensions can help in preventing further loss of biodiversity and sustaining the productivity of arable lands for the benefit of future generations.

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QUARANTINE METHODS TO PREVENT INVASIVE SPECIES MOVEMENT IN KERALA

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Introduction

Alien species are those species while crossing over their natural distribution area get introduced into new habitats (Saxena, 1991). When in a new location, these species almost always gets freed from its natural enemies that checked its population in the native areas and thus get an opportunity to explode its population size, if other abiotic factors are in favourable condition (Keane & Crawley 2002). Those alien species which have increased its spread outside their normal distribution range in the new locale by displacing the native local biota are called 'Alien Invasive Species' (Torchin et al. 2002; Mitchell & Power 2003). Nowadays, biological invasion has emerged as a global environmental issue and needs a systematic scientific research to properly address it. Due to its enormity and complexity, it concerns across countries, international organizations and agencies by affecting their economic interests with a multitude of activities from local to global scales.

In the Indian context, its complex topography with diversified climate and vegetation made it one of the favourite venues for alien species invasion. India being one of the fastest-growing economies contributed an export and import of $330.07 and $462.9 billion, respectively in 2014 and as many as 190(export) and 140 (import) countries are involved. This excessive trade among nations has made India an opportunistic target for the entry of the alien species. It has been predicted that owing to the high adaptability of alien invasive species to new environments, their threat is going to increase in the context of global climate change and associated changes in local habitats.

Kerala with its year-long maritime history has paved way for introduction of a large number of invasive species. There is an array of species which have established in India as well as in Kerala and are spreading fast. They imposed huge amount of costs in terms of ecological destruction, economic damage and detrimental social effects including animal and human health. Keeping these in view, the present paper is formulated to discuss in brief about the different aspects of invasive alien species such as their characteristics (including criteria to identify whether a species is invasive or not), steps in invasion, pathways to introduction, factors affecting invasion, impacts on biodiversity, current status, control and management strategies with emphasis on plant quarantine measures.

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Characteristics of an invasive alien species

The characteristic features of invasive alien species are presented in Fig. 1. Both the life history traits and the environment in which invasive species is introduced are playing important role in their invasiveness, because it is evidenced from the fact that all new species introductions could not become invasive. However, if these species become invasive in that new environment it could have profound effects on different fields such as industry, agriculture and conservation lands within the new location where they become established (Paini et al., 2016).

Fig. 1 Characteristic features of invasive alien species (IAS)

Different aspects of invasive alien species management with their stages of invasion are presented in Fig. 2.

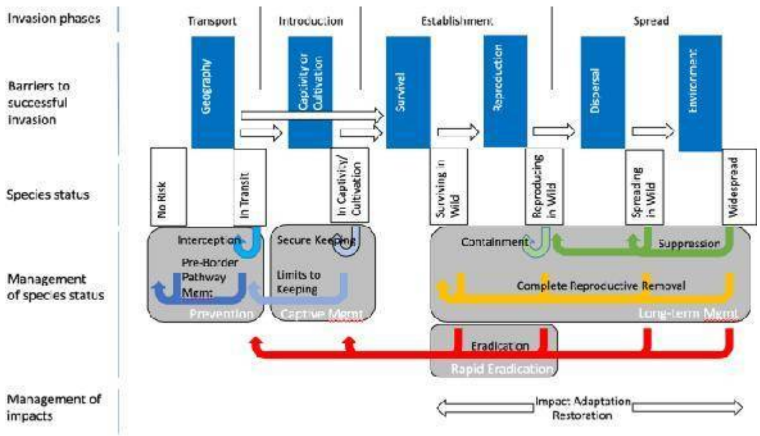

Fig. 2 Different aspects of invasive alien species management with stages of invasion (*Source*: Kocovsky *et al.*, 2018)

Pathways of introductions

Pathways of introductions are the predicted routes that helps to invasive species in transit to new habitat/ environments. The most common pathways include the sea, land and air. There have been several examples of entry of various species through these pathways into India and abroad. These are the major pathways by which live plants, animals and biological materials cross bio-geographical barriers that would usually block their way (Shine, 2005). In particular, international trade in agricultural and horticultural goods plays a potentially important role in distributing plants and animals beyond the borders of their indigenous habitats. The rise of introductions of invasive species beyond their natural range of environments has been attributed to increased trade, transport, travel and tourism associated with globalization of trade in line with agreements related to WTO. Analysing these possible pathways for invasive species, a working group of the National Invasive Species Council (NISC) and the Aquatic Nuisance Species (ANS) Task Force in the USA differentiated three major pathway categories: (i) transportation related pathways; (ii) living industry pathways; and (iii) miscellaneous pathways (NISC, 2006).

Impacts on biodiversity & society

The Convention on Biological Diversity (CBD) identified “Invasive Alien Species” as a major factor in the loss of biodiversity based on their capacity to out-compete or prey on native species and subsequently cause a degradation of the biodiversity in the area of their introduction. The risks and damages caused by these IAS species can be massive, especially for fragile island ecosystems (CBD, 2010). Though invasive species poses major threat to natural resource management (Diwakar, 2003), India has no reliable empirical data on invasive flora (Khuroo et al., 2012) and the impact of them on community structure and ecosystem processes is also poorly understood (Mandal, 2011). Invasive species may cause economic damages through yield losses or control costs and may also adversely affect animal and/or human health (e.g. zoonoses or plants with allergenic properties) (CBD, 2010). These IAS species frequently monopolize the environment and cause health hazards, reduce crop yields, increase labour costs and prevent the re-establishment of native species such as fodder grasses, shrubs and forest trees after land disturbance. In north-eastern India and the Western Ghats, IAS plants, including *Chromolaena odorata*, *Lantana camara* and *Mikania micrantha* infest extensive tracts of agricultural and forest land, displacing native flora and animals and even human activities (Ramakrishnan, 2001). Interference with water flow and availability following invasion by waterweeds such as water hyacinth (*Eichhornia crassipes*) has led to decline in wetlands and associated wildlife. Parthenium weed (*Parthenium hysterophorus*) dominates the vegetation in town and city wastelands and is a potential allergen threatening human health.

Current status

India has harboured a total of 171 invasive species represented in ecosystem such as aquatic, terrestrial, agricultural and Island as 32.7, 30.4, 27.5 and 8.2%, respectively. It includes 47 invasive species of agriculturally important, out of which 23 are insects [6]. In another study, 225 species (14%) of alien plant species in India are invasive, with another 134 (8%) having the potential to become invasive in near future (Khuroo et al., 2012).In case of Kerala State of India, a qualitative appraisal of the invasive alien species was reported by Sankaran et al., (2012) as “Handbook on Invasive plants of Kerala” which dealt about 82 species of terrestrial and semi-aquatic plants species required most urgent attention in terms to control and management of them. Further, they classified the probable impact risk due to each of these species into high risk (21), medium risk (22), low risk (13) and insignificant (26). During exploration trips made by ICAR-NBPGR Regional Station, Thrissur across Kerala state over the years noticed the presence of 24 out of 82 invasive alien species reported in 2012 and they could pose a major threat to existing biodiversity of state. The list of weeds invaded into Kerala and are at high risk level is presented in Table 1. In another study, Sajeev et al., (2012) identified 38 alien invasive species on forests of Kerala and classified them as high risk (10), medium risk (12), low risk (10) and insignificant (6) on basis of field surveys and using a risk assessment protocol.

Table 1: The list of invasive plant species in Kerala with high-risk category

No	Common name	Local name	Scientific name	Country of origin	Regions in Kerala
1	Black wattle	*Karuva*	*Acacia mearnsii*	South East Australia	Idukki
2	Calopo	*ManjaPayar*	*Calopogonium mucunoides*	Tropical Asia	Alapuzha, Idukki, Kollam, Kozhikode, Kasaragod, Malapuram, Pathanamthitta, Thiruvananthapuram, Thrissur
3	Siam weed	*Assam Pacha, Communist pacha*	*Chromolaena odorata*	Tropical America	Throughout Kerala
4	Knob weed	*Nil*	*Hyptis capitata*	Central America	Alapuzha, Ernakulam, Idukki,Kollam, Kozhikode, Malapuram, Thiruvananthapuram, Thrissur
5	Bush Morning glory	*Neyvelikatta*	*Ipomoea carnea*	Tropical America	Ernakulam, Malapuram, Thiruvananthapuram, Thrissur
6	Lantana	*Arippu.Kongini, poochedi, Unnichedi*	*Lantana camara*	Central and South America	Throughout Kerala
7	Mile-minute weed	*American vally, dhritharashtra pacha, Mayakkuvally*	*Mikania micrantha*	North, Central and South America	Throughout Kerala
8	Giant sensitive plant	*Anathottawadi*	*Mimosa diplotricha*	Tropical America	Throughout Kerala
9	Congress grass	*Congress pacha*	*Parthenium hysterophorus*	North and South America	Idukki, Kollam, Kasaragod, Wayanad, Thiruvananthapuram, Thrissur, Palakkad
10	Mission grass	*Kothappullu*	*Pennisetum polystrachyon*	Tropical Africa	All district in the state except Kasargod and Pathanamthitta
11	Velvet mesquite	*Varuni*	*Prosopis juliflora*	North, South Central and America	Idukki, Palakkad
12	Tropical Kudzu	*Thottapayar*	*Pueraria phaseoloides*	Tropical Asia	All district in the state except Wayanad

13	Prickly sesban	*Kedangu,Killannu*	*Sesbania bispinosa*	Asia and Africa	Ernakulam, Kannur, Pathanamthitta, Palakkad and Thrissur
14	Singapore daisy	*Veriappacha*	*Sphagneticola trilobata*	Tropical America	Throughout Kerala

Management of invasive species

The process of management of invasive species includes management at three different levels of invasion of pest: a) When the pest has not been introduced; b) When the species is introduced but is not spread to nearby areas and c) When the introduced insect has established itself.

a) *When the pest/species has not been introduced*: Preventive measures are taken to avoid the entry of the invasive pest, viz. pest risk analysis (PRA), quarantine and monitoring. This is the best way in managing the invasive species;

Prevention is always better than cure and is also a most economical and safest way to manage invasive species. Hence, strict quarantine is the best solution for the management of invasive species, that is, a thorough investigation of all kinds of imported goods and products in order to hamper the introduction of dangerous species by means of early detection and their rapid response than trying to control at widespread infestation (Fig. 3). There is a total of 71 plant quarantine stations across major and minor ports (34 seaports, 12 airports, 14 land frontiers and 11 foreign post offices) in India which deals exclusively on restricting the import of any foreign contaminants.

Plant quarantine refers to the holding of plants in isolation until they are believed to be healthy. Now, broader meaning of the plant quarantine covers all aspects of the regulation of the movement of living plants, living plant parts/plant products between politically defined territories or ecologically distinct parts of them. Intermediate quarantine and post entry quarantine are used respectively to denote the detention of plants in isolation for inspection during or after arrival at their final destination. Most of the quarantine pests could be classified as invasive alien species according to the interim guiding principles of the CBD (2001), as they are alien to a specified area/ region, and threaten the ecosystems, habitats, or species in that area/ region. As a result of global trade, invasive species are often introduced into new environments where they become established and cause harm to human health, agriculture, and the environment. Prevention of new introductions is a high priority for addressing the harm caused by invasive species, but unfortunately efforts to prevent new introductions do not address the economic harm that is presently manifested where invasive species have already become established.

Importance of plant quarantine is ascertained as: To prevent the introduction & spread of exotic pests that are destructive to the country by regulating the import of plants/plant products through adequate policy and statutory measures; To support India's agricultural exports through credible export certification; To facilitate safe global trade in agriculture by assisting producers, exporters & importers and by providing a technically comprehensive & credible Phyto-sanitary Certification.

The Indian government has framed certain legislative measures to cope with the invasive species. Plant Quarantine Regulatory Measures (PQRM) in India operate on the basis of 1) 'The Destructive Insects & Pests Act, 1914' promulgated to prevent introduction and spread of destructive pests affecting crops (Rules promulgated for regulating import of live insects in1941; of fungi in 1943; and of cotton in 1972); 2) New Seed Policy, 1988, formulated in 1988 to provide access to best available seeds and planting material to Indian farmers, domestic & imported; 3) 'The Plants, Fruits & Seeds (Regulation of Import into India) Order, 1989', notified for prohibiting and regulating the import into India of plants/ plant materials and the like, based on post-entry Quarantine checks and 4) The new Plant Quarantine Order'2003 (84 amendments till date, the last being S.O.2390 (E) dated 20th July, 2020) to replace the PFS Order 1989.

The Plant Quarantine Order 2003 includes new import policies with required statutory measures which aim to restrict the import of infested plants or plant products. The order advocates a prior PRA to estimate the phytosanitary measures required to protect plant resources against the invasive pest. In India, there are general and specific conditions for the import of plants (including bulbs, tubers, rhizomes, corms, cuttings, buddings, grafts, layers, suckers, roots and flowers) and plant materials (including plant products such as ginned cotton, unmanufactured tobacco etc.). General conditions are: 1. Import permits are essential; 2. All plants should be accompanied by Phytosanitary certificate from the country of origin; 3. All plants on arrival at port, shall be inspected and if necessary fumigated, disinfested or disinfected by Plant Protection Adviser to the Government of India or any other officer authorized by him on his behalf; 4. Plants and seeds which require post-entry quarantine inspection shall be grown in post-entry quarantine facilities approved by the Plant Protection Adviser to the Government of India; 5. Import of hay or straw or any material of plant origin used for packing is prohibited; 6. Import of soil, earth, compost, sand, plant debris along with plants, fruits and seeds is prohibited.

There are number of plant quarantine methods which are used separately or collectively to prevent or retard the introduction and establishment of exotic pests and pathogens. For this purpose, the following Plant quarantine facilities are used: 1) An integrated information management system; 2) An integrated pest risk analysis system and a national pest risk analysis unit for conducting an integrated pest surveillance; 3) An integrated phytosanitary border control system; 4) A national phytosanitary database and 5) A national management centre for phytosanitary certification to continuously review the national standards for export phytosanitary certification.

Components of plant quarantine activities include:

1. *Complete embargoes* - It involves absolute prohibition or exclusion of specified plants and plant products from a country infected or infested with highly destructive pests or diseases that could be transmitted by the plant or plant products under consideration and against which no effective plant quarantine treatment can be applied or is not available for application;
2. *Partial embargoes* - It applies when a pest or disease of quarantine importance to an importing country is known to occur only in well-defined area of the exporting country and

an effectively operating internal plant quarantine service exists that is able to contain the pest or disease within this area;

3. *Inspection and treatment at point of origin* - It involves the inspection and treatment of a given commodity when it originates from a country where pest/disease of quarantine importance to importing country is known to occur;
4. Inspection and certification at point of origin - It involves pre-shipment inspection by the importing country in cooperation with exporting country and certification in accordance with quarantine requirements of importing country;
5. *Inspection at the point of entry* - It involves inspection of plant material immediately upon arrival at the prescribed port of entry and if necessary subject to treatment before the same related and
6. *Utilization of post-entry plant quarantine facilities* - It involves growing of introduced plant propagating material under isolated or confined conditions.

b) ***When the species is introduced but not spread to nearby areas***: Post quarantine measures are taken in such cases such as rejection of the consignment from which the pest has introduced and eradication by means of fumigation of the consignment lot;

Eradication of invasive species is often impractical once they have become established (Britton et al., 2011). In some cases, it is possible to contain invasive species at the site where the initial introduction occurred and eradicate the population before it has the opportunity to spread beyond the limits of the area where eradication measures are effective (Steck et al., 2019). In other cases, eradication is not considered an option and management plans are instead implemented as a means of preventing further spread. Most control efforts primarily focus on limiting the harm associated with the invasive species to an acceptable level. In many cases this may involve integrated pest management (IPM), an approach which utilizes multiple pest management tools in the hopes of obtaining a synergistic control effect (Kogan, 1998). Although the result of such an approach can be expensive and sometimes inefficient, there are few options to effectively limit the harm associated with invasive species. If eradication is not possible, the invasive species may be subject to control and management efforts.

c) ***When the introduced insect has established itself***: Various curative measures such as cultural, biological and chemical means of management are adopted.

Cultural control**:** It includes manipulation of habits to increase mortality of invasive species or reduce its rate of damage (selection of pest-resistant crops, winter cover crops, changing planting dates). Cultural measures are aimed at changing human behavior to address the issue of spreading invasive species -- using opportunities to educate people about practices to increase awareness to prevent the spread of invasives (signage, public awareness campaigns). Cultural practices also include mulching, soil solarization with plastic film, thermal weed control (e.g., flaming, hot water, and steam), prescribed burning, water manipulation, and prescribed grazing with domesticated herbivores (e.g., cattle, sheep, goats, and horses).

Mechanical control techniques: It include mowing, hoeing, tilling, girdling, chopping, and constructing barriers using tools or machines. Mechanical treatments complement herbicide (chemical) control and sometimes increase efficiency.

Physical or manual control: It involves physical activities (i.e. harvesting) such as hand-pulling, digging, flooding, mulching, manual destruction or removal of nests, egg masses, larva or other life stages; generally includes the destruction of invasive species by hand.

Biological control: It is the intentional manipulation of natural enemies by humans for the purpose of controlling pests reducing the population using prey targeting the invasive species. Natural enemies used in classical biological control of weeds include different organisms, such as insects, mites, nematodes, and pathogens. Sometimes the biological control comes with a consequence which should be pre-analysed before the introduction of the bioagent. For example, *Zygogrammabicolorata* was introduced in India to manage *Parthenium hysterophorus* which ended up as a pest of sunflower. There must be prior research to prevent such introduction of natural agents which may have a negative impact.

Chemical control: It includes the use of pesticides, herbicides, fungicides, and insecticides. Although chemical use can be very effective, they can be dangerous to other species or to the ecosystem in general.

CBD and Invasive Alien Species

The Convention on Biological Diversity (CBD) and its members recognize that there is an urgent need to address the impact of invasive alien species. The CBD lays down global priorities, guidelines, collects information and helps to coordinate international action on invasive alien species. The CBD has adopted guidance on prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species.

IUCN and Invasive Alien Species

To address the Invasive Alien Species (IAS), IUCN follows these three steps:

1. **Assess**

- The IUCN's Invasive Species Specialist Group (ISSG) under the auspices of the Species Survival Commission (SSC) aim to reduce threats to ecosystems and their native species by increasing awareness of ways to prevent, control or eradicate IAS.
- IUCN has developed two knowledge platforms:
- The Global Invasive Species Database (GISD);
- The Global Register of Introduced and Invasive Species (GRIIS)
- IUCN is working on new platforms to track and reduce the spread of invasive species:
- Island Biodiversity and Invasive Species Database;
- IAS Pathways Management Resource;
- Classifying the environmental impact of different IAS

2. **Plan**

- IUCN, will work along with the ISSG to provide technical and scientific advice towards achieving Aichi Target 9.
- In order to manage and assess the risk of Invasive alien species, the ISSG provide technical and scientific advice to national and regional agencies when developing policy and strategies.

3. **Act**

- IUCN develop capacity for combating IAS on the ground. The InvaZiles Project for example, works with organisations in the Western Indian Ocean to develop capacity and networks for preventing and managing IAS.
- The most effective way to stop the negative impacts of IAS is through prevention of spread by regulating the trade or movement of a species.

Early detection, monitoring and eradication can stop the species spreading.

Suggestions for the control of invasive alien species

- Strengthening domestic quarantine measures to contain the spread of invasive species to neighbouring areas.
- Developing a national database on invasive alien species reported in India.
- Developing appropriate early warning and awareness systems in response to new sightings of invasive alien species.
- Providing priority funding to basic research on managing invasive species.

- Prevention of new introductions at a local level is the prime most activity to control the invasive alien species followed by eradication of early invasions;
- Surveillance campaigns on important pathways of introduction to prevent or minimize their risks;
- Monitoring should be continual, and articulated across several activities; Extensive monitoring of vast areas of possible invasions;
- Intensive monitoring of vulnerable sites for invasion (loading stations, nurseries, import–export material checking points);
- Use of sentinel plants;
- Early warnings assisted by both conventional and innovative molecular diagnostic tools; and
- Involving volunteers in early detection.

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INVASIVE ALIEN INSECT SPECIES IN INDIA

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Invasive alien species (IAS) are species that have been introduced outside of their natural range and have a negative impact on biodiversity. IAS disrupt native flora and fauna, most importantly threatening the livelihood of humans and countries' well-being. India is the 4th largest economy in the world and agriculture is the backbone. Invasive insects cause significant damage to crops, resulting in financial loss to farmers and leads to inflation due to loss in trade. The International Union for Conservation of Nature (IUCN) describes IAS as one of the top causes of biodiversity loss and the second most common cause of species extinctions. The study reveals that the introduction of new invasive species has steadily increased over the past 200 years, with more than a third of all first introductions occurring between 1970 and 2014, especially, invasive insects in India. It also points out that, with the exception of mammals and fishes, more new species invasions are expected shortly across all groups of species. Agriculture and fisheries are particularly vulnerable to the effects of invasive insect species, threatening food security and livelihoods. The recent livelihood threats like fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) introduced to Sub-Saharan Africa in 2016, most likely from the United States, is rapidly spreading across the continent, causing yield losses of more than 40 per cent for small holder maize farmers in small countries.

How did they get here?

The packaging, crop contamination, transport containers, and ship cargo are held to contribute unwittingly introducing IAS into the ecosystem. The number of species being introduced into new locations is growing as a result of the expansion in global trade, the movement of people and goods, the opening of new trade routes, and improved transportation. One of the most lucrative industries is thought to be the trade in logs. Although it generates a significant amount of foreign exchange, it also has the side effect of introducing Invasive Alien Species. The logs are responsible for the introduction of insect species as they are breeding grounds for numerous insects and viruses due to their extended time of untreated storage in godowns. Additionally, logs' importation also spreads the resident alien species. The living industry refers to the trading of living things, such as horticulture, agriculture,

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aquaculture/aquariums, the pet trade, and live seafood. These live things could very well accompany their respective pests as they are exported. For instance, it has been anticipated that Apple woolly aphids may infiltrate India through the importation of apple rootstock from England. Different food items and seeds have been imported into India from other nations. An admixture of pollutants in the food lot is harmful to the importing country in the past when there was a lenient legal restriction for the importation of food goods. For example, *Parthenium hysterophorus* was imported from the US together with food grains as part of the US PL 480 scheme (a food assistance programme run by the US government for India). Some invasive alien insects are excellent flyers at 100km/per night, there is a rumour that fall armyworms have travelled from Africa continent to India. In India, domestic transportation has been improved, and the networks of highways, airports, and ports have all been improved. This has made it easier for introduced insects to spread throughout the nation, usually by accidentally travelling with people.

Process of Invasion

The invasive species must first move from its current habitat or arrange to be moved to settle in a new area outside of its normal range. Passive transport is the movement of invasive alien insect species caused by vectors. Humans or human consignments are currently the most prevalent vectors. Invasive species are frequently transported passively, which makes them challenging to control. It is challenging to find the cryptic early stages of the insect that might be brought in by tourists, even after rigorous quarantine examinations. For example, a single gravid female insect can likewise cause havoc in the newly introduced environment because it is a prolific producer and lacks a natural opponent. Insects occasionally possess a built-in ability for long-distance migration. Therefore, they migrate away from that location once the favourable conditions change. In India, *Spodoptera frugiperda*, a recent invasive insect pest, known as the fall armyworm are excellent flyers that can travel approximately 100 kilometres in a few hours and are believed to have escaped from Africa to the Indian subcontinent, though the exact way the invasive insect arrived is still unknown. Another illustration is the North American native Monarch butterfly, *Danaus plexippus* (Nymphalidae), which was discovered migrating to Australia in the early nineteenth century.

Establishment

Even while brief colonisation is fairly common, an insect cannot be considered invasive unless it has successfully established itself in the new environment, which is only achievable once the invaded insect overcomes the environmental obstacles. The establishment of an invasive species is based on the quantity of propagule introduced, as opposed to local colonisation. It is thought that perturbations made in the receiving environment help to encourage the establishment. IAS are frequently adapted to disturbance and are so predisposed to colonisation in such ecosystems, while native species are poorly suited to the number, severity, or timing of human-mediated disturbances. Due to increasing resource availability and decreasing biotic resistance, insects are more vulnerable to invasiveness. Global warming has modified the resource availability and habitat suitability, thereby deteriorating the biological regime of the native insects, hence favouring the establishment of alien insects.

Spread

Spreading is the process where the species initially established in an area spread to other areas. Spreading is guided by environmental factors such as weather conditions, microclimate and habitat quality. The success rate of the spread is highly dependent on the habitat permeability of the habitat to which the insect spread. The invasive alien insects spread very easily due to local transportation, mechanization, lack of awareness among the farmers and lack of regular monitoring by quarantine officials.

Characteristics of an invasive species

The invasive alien insects are very resilient, adaptable to new environments very easily, reproduce quickly with high fecundity, and can attack numerous hosts. They are voracious feeders, have high dispersal abilities, and benefit from mutualist interaction.

Current status of invasive insects in India

There are 195 invasive species introduced to India, including 54 terrestrial plants, 56 aquatic organisms, 47 organisms having agricultural importance, and 14 organisms of an island ecosystem. On the other hand, 24 insect pests wreak havoc in India. The chronological order of invasive insects in India is given in Table 1.

Massive economic costs incurred due to biological invasions

One of the main causes of the current biodiversity crisis is biological invasions. The extent of economic effects of invasive is one underappreciated side effect. For expanding economies like India—the world's fastest-growing economy—knowledge gaps on the economic losses caused by Invasive Alien Species (IAS) are widespread. Bang *et al*. (2022) compiled information on the financial costs of IAS in India to highlight and close this gap. The IAS costs are distributed in terms of space, the environment, sectors, taxonomies, time, and introduction paths. The IAS costs change according to socioeconomic indices. The IAS has cost the Indian economy between US$ 127.3 billion and US$ 182.6 billion (about 8.3 trillion to 11.9 trillion in Indian Rupees) between 1960 and 2020, and these expenses have risen over time. These information gaps are more evident in India than anywhere else in the world, despite the enormous recorded costs, as the majority of them were not attributed to specific places, settings, sectors, cost categories, and causal IAS. When costs were specifically assigned, invasive alien insects in semi-aquatic habitats caused the highest costs in West, South, and North India. These costs were primarily borne by the public and social welfare sector and were linked to damages and losses rather than management costs. Some of the invasive alien insects with the incurred cost are given in Table 2.

Table 1. Chronology of invasive insects reported in India

S. No	Common Name	Scientific name	Origin	Entry to India	Hosts	Highlights	Reference
1.	Woolly aphid	*Eriosoma lanigerum* (Comstock) (Hemiptera: Diaspididae)	China	1889, Kashmir	Apple, Pear	The average production loss per tree was 2.4 kg (13 apples), which translates to a gross loss per hectare of $465.18.	Thakur and Dogra, 1980 and Brown *et al.* 1995
2.	San Jose scale	*Quadraspidiotus perniciosus* (Hausmann) (Hemiptera: Aphididae)	China	1911, Coonoor/ Tamil Nadu	*Populus* spp.; *Betula*s pp.; *Celtis* spp.; *Fagu s* spp.; *Morus* spp., *Salix* spp.; *Aesculus* s pp.; *Alnus* spp.;	This pest can destroy entire trees shortly after being introduced to a new area. The trees age more quickly and lose their vigour.	Fotedar, 1941
3.	Diamondback moth	*Plutella xylostella* Linnaeus (Lepidoptera: Plutellidae)	Italy	1914	Cruciferous vegetables	The control costs for *P. xylostella* in China are estimated at US$100/ha for each crop for the peak periods of April/May and September/October. If no sprays were applied, the crop losses of the summer crop of cabbage there were 99% in 1992 and 80% in 1994, compared with the plots treated with insecticides.	Fletcher, 1914 and www.cabi.org
4.	Lantana bug	*Teleonemia scrupulosa* Stal (Hemiptera: Tingidae)	Sri Lanka/West indies	1915	*Lantana*, coffee, *Jacaranda*, *Citrus*, sweet potato, gumwood, brinjal, rose	-	Muniappan and Viraktamath, 1985
5.	Cottony cushion scale	*Icerya purchase* Maskell (Hemiptera: Margarodidae)	Australia	1921, Tamil Nadu	*Acacia decurrens*, *Acacia dealbata*, and also a wide range of forest trees and agriculture are affected by this insect	The pest attacks a wide range of plants, including some of the endemic flora, and could endanger the native flora and the fauna dependent on it.	Rao, 1951

6.	Potato tuber moth	*Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae)	Italy	1937, East Bengal (Now in Bangladesh)	Potato, Tobacco, tomato, brinjal, beet and stored potato	The range of damage is from 3.3% in deep-planted tubers to 16% in shallow-planted tubers. It is also a significant post-harvest pest on potatoes in the same regions.	Singh, 2004
7.	Pine woolly aphid	*Pineus pini* (Macquart) (Hemiptera; Adelgidae)	Western and Central Europe	1970, Nilgiris, Tamil Nadu	*Pinus* spp. *Pinus patula*	*Pineus boerneri* infestation reduces productivity and results in up to a 50% loss of growth increment and up to 20% tree death by causing premature needle shedding and shortening of infected needles.	McAvoy *et al*. 2007
8.	Subabul psyllid	*Heteropsylla Cubana* Crawford (Hemiptera: Psyllidae)	Central America	1988, Tamil Nadu & Bangalore	*Leucaena* sp.	Leucaena was first cultivated in 1972, and it is grown on 10,000 acres of land in Karnataka State alone. Only six months after *H. Cubana* arrived in India, Leucaena cultivation decreased drastically throughout the entire region.	Veeresh, 1990
9.	Coffee berry borer	*Hypothenemus hamperi* Ferrari (Coleoptera: Curculionidae)	Northeast Africa	1990, Gudalur, Tamil Nadu	Arabica and robusta types of coffee	Crop losses caused by this pest can be severe, ranging from 50-100% of berries attacked if no control measures are applied	Kumar *et al*. 1990
10.	Serpentine leaf miner	*Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae)	USA	1990, Hyderabad, Telangana	Polyphagous pest	There is no significant impact of serpentine leaf miners on the yield.	Viraktamath *et al.* 1993
11.	Spiralling whitefly	*Aleurodicus disperses* Russell (Hemiptera: Aleyrodidae)	Caribbean region, Central America	1993, Kerala	Wide range of plants (481 hosts)	The pest could lower crop yield, and crop value (including increasing crop production costs) and trigger the loss of markets.	Palaniswami *et al.* 1995
12.	Coconut eriophyid mite	*Aceria guerreronis* Keifer (Arachnida: Eriophyidae)	Mexico	1997, Ernakulam, Kerala	Coconut	The accurate crop loss due to this pest ranges from 7.5% and 30% to 60%	Sathiamma *et al.* 1998 Julia and Mariau, 1979

13.	Silver leaf whitefly	*Bemisia argentifolii* Gennadius (Hemiptera: Aleyrodidae)	-	1999	Tomato, Squash, Poinsettia, Cucumber, Eggplants, Okra, Beans, and Cotton	Polyphagous pest	Singh, 2004
14.	Blue gum chalcid	*Leptocybe invasa* Fisher & La Salle (Hymenoptera: Eulophidae)	Australia	2001, Karnataka/ Tamil Nadu	Eucalyptus	-	Jacob *et al.* 2007
15.	Erythrina gall wasp	*Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae)	Tanzania ,East Africa	2006, Kerala	*Erythrina* sp., black pepper vanilla	-	Faizal *et al.* 2006
16.	Cotton mealybug	*Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae)	USA	2005, Gujarat	Cotton, brinjal, okra, tomato, sesame, sunflower, rose	In India 2008, the cotton crop severely destructed by this pest and yield losses up to 50-60%	Tanwar *et al.* 2005 Nagarare *et al.* 2009
17.	Papaya mealybug	*Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae)	Central America	2007, Coimbatore, Tamil Nadu	Mulberry, tapioca, *Jatropha*, cotton and several fruits, flowers and plantation crops	This papaya mealybug, severely impacted the low marginal farmers and resulted in 100% losses	Tanwar *et al.* 2010
18.	South American tomato leaf miner	*Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae)	South America	2014, Pune, Maharashtra	Tomato, potato, pepper, brinjal	The pin hole sized holes on the fruit reduces the market value of the crop and unable to detect the pest. The pest causes 100% yield losses without control measures	Shashank *et al.* 2015
19	Invasive thrips	*Thrips parvispinus* (Karny) (Thysanoptera: Thripidae)	Thailand	2015, Karnataka	Chilli, fruit crops and vegetables	In recent years, it became a big problem in chilli and mango cultivation	Tyagi *et al*. 2015; NPPO 2019
20.	Rugose spiralling whitefly	*Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae)	Central America	2016, Tamil Nadu	Coconut, guava, banana, mango, drumstick, jackfruit	It can cause38% - 50% nut yield loss	Srinivasan *et al.*2016

21.	Fall armyworm	*Spodoptera frugiperd* (JE Smith) (Lepidoptera: Noctuidae)	America to Africa, Africa to India	2018, Karnataka	Polyphagous pest	FAW cause 21-53% loss in annual maize production It attacks 353 plant species belonging to 76 families	Sharanabasappa 2018 Montezano *et al.* 2018 Suby*et al.* 2020
22.	Woolly whitefly	*Aleurothrixus floccosus* (Maskell) (Hemiptera: Aleyrodidae)	Neotropical	2019, Kerala	Guava, Citrus species	The woolly whitefly becoming serious threat to fruit and plantation crops. This whitefly species dominates the remaining species	Sundararaj *et al*. 2020
23.	Neotropical whitefly	*Aleurotrachelus atratus* Hempel (Hemiptera: Aleyrodidae)	Neotropical	2019, Mandya/ Bangalore	*Cocos nucifera* and *Dypsis lutescens*	Distributed widely in the tropics and subtropics and colonize more than 110 plant species	Selvaraj *et al.* 2019
24.	Cassava mealybug (CMB)	*Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae)	Africa	2020, Kerala	Cassava	CMB damages 50-60% of cassava and reduction in crop acreage from 9300ha to less than 2000ha in Tamil Nadu due to the severity of CMB	Joshi *et al.* 2020 Sampathkumar *et al.* 2021 Farmers training cum awareness program- SPAC, Erode_0.pdf (nbair.res.in)

Table 2. Invasive insect species with reported costs in India, geographical origin, introduction pathways, reasons for introduction and year of the first record

Invasive insect species	US$ billion	Pathway	Reason	First record in India
Paracoccus marginatus	0.14	Contaminant	Trade; Live plant material	2008
Spodoptera frugiperda	0.04	Contaminant	Tourism/Trade	2018
Hypothenemus hampei	3.81 E−03	Contaminant	Trade; Plant material	1990
Aleurodicus rugioperculatus	0.13 E−06	Contaminant	Trade; Live plant material	2016

Management of invasive insects

For the management of Invasive alien insects, a number of laws have been enacted by the Indian government. The Destructive Insects and Pests Act (DIPA) of 1914 was the first law made specifically to prohibit the arrival of invasive species into India. These statutes underwent periodic modifications as time went on and the plant quarantine order 2003 now addresses India's main plant quarantine concerns. New import regulations and needed statutory measures are part of the plant quarantine order 2003, which aims to prevent the import of infected plants or plant products. The directive encourages an earlier Pest Risk Analysis (PRA) to determine the phytosanitary safeguards needed to guard plant resources against the invasive pest.

Three main degrees of pest invasion are managed during the management of invasive insects

When a pest is not yet present: Pest Risk Analysis (PRA), quarantine, and monitoring are preventative methods attempted to stop the spread of the invasive insect. This method of handling invasive species is the best.

When a species is first introduced, but it does not spread to surrounding areas: Post-quarantine actions are conducted, such as rejecting the consignment from which the pest was imported and eradicating it by fumigating the consignment lot.

Presently in India monitoring includes 71 plant quarantine stations, spread out among large and minor ports (including 11 foreign post offices, 14 land frontiers, 12 airports, and 34 seaport offices) these are dedicated to limiting the import of any external contaminants Early discovery of invasive insects is one of the key management strategies. However, the precise identification of the insect is the issue (at the species level) and taxonomical knowledge of insects is a restriction in India.

After the newly introduced bug has become established: Different treatments, including cultural, biological, and chemical methods of management are used.

Strict quarantine is the best solution for the management of invasive insects that is a thorough investigation of all kinds of imported goods and products to hamper the introduction of dangerous species. After the breaching of this barrier, the next prompt control measure is pesticides - pesticides are quick acting and are very efficient in reducing invasive insects. Due to the absence of their natural opponent and an endless supply of food, invasive insects reproduce rapidly in new environments. The use of natural enemies (predators and parasitoids) from their native environments in timely introductions (classical biological control), mass releases of native or exotic natural enemies, and habitat management are all examples of biological control, an age-old method for reducing the population of introduced pests to non-harmful levels. Once the natural enemy is established, biological control is sufficient to curb the worrisome invasiveness because it has lasting effects and is also reasonably cost-effective. Before the introduction of the bio agent, it is sometimes necessary to examine the consequence of the bio agent in a new environment.

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EXOTIC PESTS AND PREPAREDNESS FOR POTENTIAL INVASIVE ALIEN SPECIES ON COCONUT

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Abstract

Coconut (*Cocos nucifera*) eulogised as "Tree of Life" is the mainstay of agrarian economy in Kerala. However, coconut has witnessed extensive bio-invasion by trans boundary pests that has upset its production and result in biodiversity loss. Increased trade, travel and tourism could be few of the modes of pest introduction into the country. Incursions by the non-native coconut eriophyid mite, *Aceria guerreronis* Keifer (Eriophyidae: Acarina) during 1988 resulted in significant crop loss including setbacks to coir industry. Non-chemical pest management solutions including botanicals and nutrients have subdued infestation by eriophyid mite significantly. Invasion by four exotic whiteflies during 2016-2022 *viz.*, rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin, Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchi, non-native nesting whitefly, *Paralyerodes minei* Iaccarino and palm whitefly, *Aleurotrachelus atratus* Hempel (Aleyrodidae: Hemiptera) in to Kerala changed the pest scenario and the emergence of sucking pest complex on coconut. In a span of 4-6 years, non-native whiteflies have invaded coconut all over the country including Lakshadweep and Bay Islandson most other crops as well. Climate extremes and transport of planting materials without proper phytosanitary certificate within the country attributed to inadvertent introduction and area-wide distribution of invasive pests. Morphological identification of these exotic whiteflies using the puparium and adults as well as molecular characterization using cytochrome oxidase sub-unit-1 gene has been established with decoding of evolutionary significance. Pesticide holiday approach and conservation biological control using the aphelinid parasitoid, *Encarsia guadeloupae* Viggiani, predators such as *Apertochrysa* sp. (Chrysopidae: Neuroptera), *Jauravia pallidula* Motschulsky (Coccinellidae: Coleoptera), *Cybocephalus* sp. (Cybocephalidae: Coleoptera) in synergy with sooty mould scavenger beetle, *Leiochrinus nilgirianus* Kaszab (Tenebrionidae : Coleoptera) have reduced the invasive potential of exotic whiteflies. Heterogenous landscapes with crop pluralism in coconut garden induced stimulo-deterrence by disorientation of exotic whiteflies and de-risking farming community by realising sustainable farm income. Competitive displacement of native arecanut whitefly, *Aleurocanthus arecae* David & Manjunatha (Aleyrodidae:

Josephrajkumar, A., Merin Babu, Regi, J. T, Anes, K.M., Jilu V. S., and Hegde,V., 2023. Exotic pests and preparedness for potential invasive alien species on coconut. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.46-56

Hemiptera) and intense regulation of *A. rugioperculatus* by nesting whiteflies could be documented. Indiscriminate use of insecticides invariably affects the natural defenders and pollinators in coconut auguring agro-ecosystem based principles in restricting invasive pests. Occurrence of leaf beetle, *Wallacea jarawa* Prathapan and Shameem (Chrysomelidae: Coleoptera) from Andaman and Nicobar Islands warrants strict domestic quarantine in transport of planting materials of coconut. Some potential invasive pests *viz.,* Coconut leaf beetle, *Bronstispalongissima* Gestro (Chrysomelidae: Coleoptera) and false coconut scale *Aspidiotus rigidus* Reyne (Diaspididae: Hemiptera) ravaging South-East Asian coconut are at our doorsteps for possible entry at any time. Implementing strict quarantine protocols, systematic surveillance surveys and timely awareness campaign are the best options to combat such incursion in future. Regulatory measures could effectively restrict biological invasions into the country for which an inclusive approach on biosecurity measures including emergency preparedness module is the need of the hour.

Keywords: Bioinvasions, Biosecurity, Non-native pests, Emergency preparedness, Bio-control

Introduction

Coconut (*Cocos nucifera* L.) is the backbone of agrarian economy of Kerala, the “land of coconuts”. In the recent past, due to expansive trade, travel and tourism there had been incursions by a wide array of non-native trans boundary pests, causing biosecurity risks and coconut is no exception to such pestilence. Exotic pests cause biodiversity decline and impacts economic livelihood of mankind. Furthermore, invasions by invasive alien species (IAS) imbalance native ecosystems and are likely to breed profusely in the absence of natural enemies in the new environment and cause upsets in biodiversity by out-competing native species (Josephrajkumar *et al*., 2016).Changes occurring in cropping patterns, adoption of modern agro-techniques, climate change and indiscriminate use of chemicals leading to diminishing defenders and pollinators add to the biotic imbalance and consequent emergence of new pest problems (Paini *et al*., 2016).Invasive alien insects alone, due to their impacts on agriculture and forestry, cost at least US$70 billion/year globally. Agriculture and fisheries are particularly vulnerable to the impacts of IAS, placing food security at risk and jeopardising livelihoods (IUCN, 2018). The timeline of IAS on coconut, the potential invasive pests waiting at the country’s borders and the possible incursion management strategies to suppress the biosecurity risks on coconut is reported. The paper also highlights on conservation biological control in the bio-suppression of non-native whitefly complex, displacement of native whitefly, *Aleurocanthus arecae* David and Manjunatha in coconut system as well as the natural occurrence of the sooty mould scavenger beetle, *Leiochrinus nilgirianus* Kaszab (Tenebrionidae: Coleoptera) during monsoon phase in bio-cleansing sooty mould encrustations on palms infested by whiteflies.

Methodology

Systematic surveillance was undertaken at regular and periodic intervals to monitor and document different pestilence on coconut at all strategic points of entry and characterise the possible IAS by critical observations on the damage symptoms. Insect samples were also routinely taken to the laboratory for precise identification and comparison with the existing literature on the possible entry of transboundary pests. Puparium of whiteflies and their adults intercepted during these investigations were characterised as outlined by Martin *et al*. (2000). Characteristic puparium and adult features were documented using stereomicroscope LEICA EZ4W and were further confirmed by Nikon Eclipse Ni trinocular research microscope for diagnostic features on vasiform orifice. Other pests were also diagnosed by the characteristic morphological features. In support of the morphological identity, molecular characterization using mitochondrial cytochrome oxidase subunit 1 (*COI*) was also attempted on the adult whiteflies as described by Josephrajkumar *et al*. (2020).

Results and Discussion

The first invasive insect known to India was the San Jose scale, *Diaspidiotus perniciosus* (Comstock) (Hemiptera: Diaspididae) probably introduced from China during 1879 into Jammu and Kashmir invading the temperate crops including apple, plum, pear, peach *etc*. Subsequently *D. perniciosus* was effectively bio-suppressed by the natural enemy population of *Aphytis* sp., *Encarsia perniciosi,* and the ladybird predator, *Coccinella infernalis* in the region though its invasive potential was well felt during the initial phase of introduction (Fotedar, 1941).

In Kerala, however, the first report of the exotic pest *viz.*, spiralling whitefly (*Aleurodicus dispersus* Russell) (Hemiptera: Aleyrodidae) was on cassava during 1993(Palaniswami*et al*., 1993). *A. dispersus* was also recorded on coconut in 1996 causing very limited damage in Kerala (Prathapan *et al*., 1996). Despite insecticides recommended for the management of this exotic whitefly on flower and vegetable crops, it proved ineffective and by and large the pest remained unchecked. However, after the fortuitous introduction of *Encarsia guadeloupae* Viggiani (Hymenoptera: Aphelinidae) from Minicoy, Lakshadweep Island into the main land, *A. dispersus* was successfully subdued in India (Ramani *et al*., 2002). Soon afterwards, Faizal *et al*. (2006) reported the exotic gall wasp, *Quadrasticus erythrinae* Kim (Hymenoptera: Eulophidae) on *Erythrina variegata* from Kerala which was expected to collapse the black pepper standards,but fortunately failed to establish aggressively due the co-introduction of natural enemy complex which reduced its invasive potential. Very recently, cassava mealy bug, *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae)was also reported on tapioca from Thrissur, Kerala (Sunil Joshi *et al*., 2020) which has never caused severe setbacks in Kerala, however, the nation has introduced the exotic parasitoid, *Anagyrus lopezi*(De Santis) (Hymenoptera: Encyrtidae) through ICAR-National Bureau of Agricultural Insect Resources, Bengaluru which was successfully re-isolated from the cassava gardens in Tamil Nadu after its introductory release (Poorani *et al*., 2022).

Timeline of coconut exotic pests

The spiralling whitefly, *A. dispersus* was reported as the first invasive whitefly on coconut in 1996 with mild damage on leaflets (Prathapan, 1996). Sathiamma *et al*. (1998) reported the most severe nut feeding coconut eriophyid mite, *Aceria guerreronis* Keifer (Acarina: Eriophyidae) from Ernakulam, Kerala which caused economic impact and affected the fibre quality significantly. During 2010, the Asian grey weevil, *Myllocerus undatus* Marshall (Curculionidae: Coleoptera), native of Sri Lanka was reported as a minor pest on coconut in root (wilt) disease endemic region (Kayamkulam, Kerala) [Josephrajkumar *et al*., 2011]. During 2016-2019, four exotic whiteflies (Hemiptera: Aleyrodidae) were reported on coconut in the country *viz.*, rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin in 2016 from Changanasseri, Kerala (Shanaset al., 2016; Chandrika Mohan *et al*., 2017), Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchiin 2018 from Kayamkulam, Kerala (Josephrajkumaret *al*., 2019a), non-native nesting whitefly, *Paraleyrodes minei* Iaccarino in 2018 from Kayamkulam, Kerala (Chandrika Mohan *et al*., 2019b) and the palm whitefly, *Aleurotrachelus atratus* (Hempel) in 2019 from Mandya, Karnataka (Selvaraj *et al*., 2019) and later from Kannur, Kerala in 2022 (Jilu *et al*., 2022). Timeline of coconut exotic pests is pictorially represented in Fig 1.

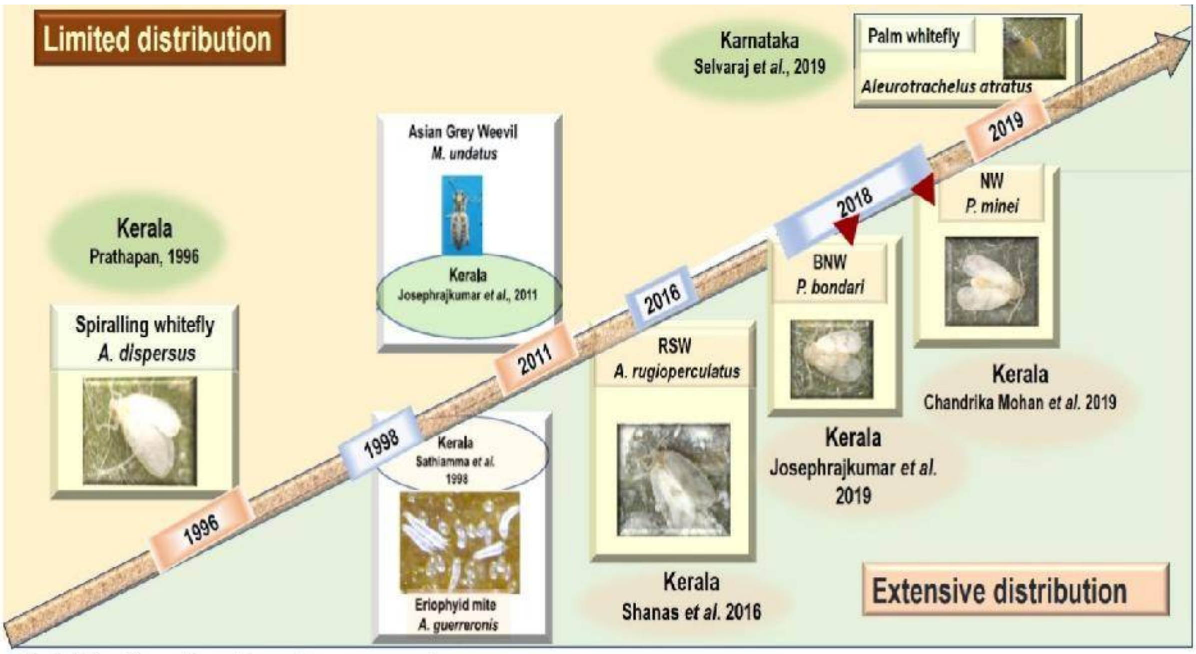

Fig 1. Timeline of exotic pests on coconut

Coconut eriophyid mite

Coconut eriophyid mite, *A. guerreronis* Keifer damage was invariably recorded from all coconut gardens in the surveyed locations. The occurrence ranged from 22%-44% mostly with mild to moderate damage scale. Re-occurrence of the acaropathogenic fungus, *Hirsutella thompsonii* was observed from the dead mites on infested nuts at Kayamkulam, Kerala and was re-isolated during 2022. Natural incidence of predatory phytoseiid mites belonging to *Neoseiulus baraki* Athias-Henriot subdued the pest incidence quite considerably. Conservation of the natural enemies and need based intervention by neem based botanical formulation as well as soil-test based nutrition improved the palm health status and reduced the mite incidence significantly (Nair *et al.*, 2005). Though the pest incidence has been reported from Ernakulam, Kerala in 1998 (Sathiamma *et al*., 1998), the damage potential of the pest has reduced in subsequent years.

Exotic whiteflies

Whitefly identity is very important because different whitefly species co-occur on the same niche leading to confusion in their identification even for experts. Whiteflies are identified by the puparium features in general and the male genitalia characteristics are used in the identification of nesting whiteflies.

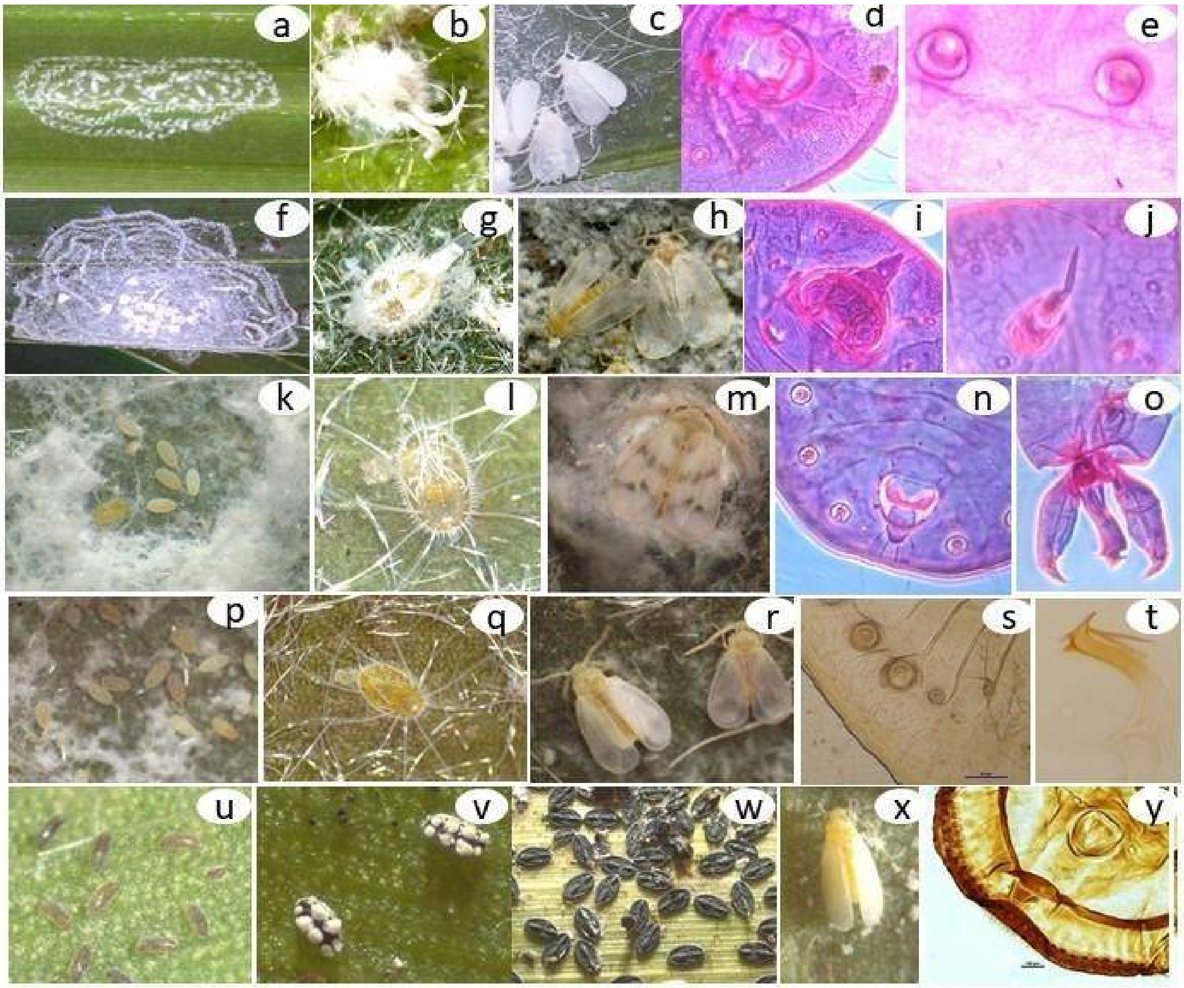

Fig. 2: Exotic whiteflies - *Aleurodicus dispersus* Russell a) colony b) puparia c) adults d) lingula e) compound pore ***Aleurodicus rugioperculatus* Martin** f) colony g) puparia h) adults i) lingula j) compound pore ***Paraleyrodes bondari* Peracchi** k) eggs l) puparia m) adult n) lingula o) male genitalia ***Paraleyrodes minei* Iaccarino** p) eggs q) puparia r) adults s) compound pore t) male genitalia ***Aleurotrachelus atratus* Hempel** u) eggs v) nymphs w) puparia x) adult y) lingula

Morphological identification is also supported by molecular characterization using the cytochrome c oxidase subunit-1 gene (*COI*). Features of the immature stages are also documented and characterized for the five exotic whiteflies reported on coconut (Josephrajkumar*et al*., 2020). Operculum is smooth, compound pore with conical process and lingula tongue-like for *A. dispersus*, whereas operculum is rugose, compound pore dagger-shaped and lingula is acute and triangular for *A. rugioperculatus* (Shanas *et al*., 2016; Josephrajkumar *et al*., 2020). While the puparium and compound pores are mostly identical for nesting whiteflies, the male genitalia have an anterior horn with a pair of lip-like structure at the posterior end for *P. bondari* and the male genitalia is cock-head like for *P. minei* (Josephrajkumar *et al*., 2019a; Chandrika Mohan *et al*., 2019b). Puparium is black, lingula round and submarginal fold interrupted at vasiform orifice for *A. atratus* (Josephrajkumar *et al*., 2020). Life stages, puparium and adult identification features of exotic whiteflies are presented in Fig 2. Establishment of these exotic whiteflies have competitively replaced the native arecanut whitefly, *Aleurocanthus arecae* David & Manjunatha.

Molecular characterization of adult whiteflies using *COI* gene revealed three distinct clades for *Aleurodicus*, *Paraleyrodes* and *Aleurotrachelus* genera. The aleurodicinae genera

(*Aleurodicus*, *Paraleyrodes*) are closely linked than the aleyrodinae genus, *Aleurotrachelus* which is phylogenetically too far. In addition, correct identification would lead to effective management of exotic whiteflies including identification of natural enemies (Josephrajkumar *et al*., 2020).

Defenders and bio-suppression

High maximum temperature favoured whitefly outbreak, whereas high humidity and precipitation subdued whitefly population. The aphelinid parasitoids*viz.*, *Encarsia guadeloupae* and *Encarsia dispersa* are found to be very effective in the bio-suppression of exotic whiteflies *A. dispersus* and *A. rugioperculatus*. Parasitism ranged from 5% to >80% under favourable weather conditions. Unfavourable weather conditions and parasitism by aphelinid parasitoids reduced the invasive potential of *A. rugioperculatus* which was currently brought down to <10% in many parts of the state from as high as 60% to 80% during 2016-2017. The organic policy promulgated by the state had favoured the successful survival of these defenders. The chrysopid predator, *Apertochrysa*sp., the cybocephalid predator, *Cybocephalus* sp. and the coccinellid predators, *Jauravia pallidula*, *Scymnus* sp. also reduced the aggressiveness of exotic whiteflies in the state (Chandrika Mohan *et al*., 2017; Josephrajkumar *et al*., 2019b; Josephrajkumar *et al*., 2022c). As part of the National task force team, pesticide holiday approach was advocated for the management of exotic whiteflies and no insecticide is recommended due to the predominance of natural defenders in the system. Furthermore, entomopathogenic fungus, *Aschersonia* sp. was also isolated from severely infested coconut gardens.

Bio-cleansing of sooty mould deposits

One of the key production constraints of whitefly infestation is the interruption of functional photosynthesis due to the deposit of sooty mould on the palm leaflets. ICAR-CPCRI has discovered a sooty mould scavenger beetle, *Leiochrinus nilgirianus* Kaszab (Tenebrionidae: Coleoptera) which would feed away the sooty mould on the palm leaflets and revitalize the palms during monsoon phase (Josephrajkumar *et al*., 2018). Emergence of these sooty mould scavenger beetles during monsoon period was recorded during 2017-2022. This action of bio-cleansing on palm leaflets to dispense off the sooty mould deposits is one of the ecosystem services of insects in coconut system and reported for the first time (Josephrajkumar *et al*., 2022c).

Crop-habitat diversification for pest regression

Heterogenous landscaping with coconut (Kalpa Sankara hybrid) and intercrops including fruit trees, spices, banana, flower crops *etc* as well as honey bees, fish system and bird perches produced diverse volatile cues and reduced pest attack on coconut by 2-3 folds. The coconut yield from ecological engineering garden was found to be 161 nuts per palm per year for a period of six years which provided a sustained income. Such a crop pluralistic climate-smart garden is highly preferable for its de-risking effect than the mono-cropped coconut plantation auguring sustainable developmental goal (Josephrajkumar *et al*., 2022b; Josephrajkumar *et al*., 2022c).

Conservation Biological Control

Conservation biological controls using the natural defenders as well as the *in-situ* preservation of the sooty mould scavenger beetles have effectively subdued the invasive potential of exotic whiteflies infesting palms. Through this conservation tactics, natural defenders, scavenger beetles and the pollinators are conserved in the coconut system which enhanced ecosystem vitality and delivered economic benefits to the tune of 1760 crore rupees (Josephrajkumar *et al*.,2019b; Josephrajkumar *et al*., 2022c). Natural enemies of exotic whiteflies, sooty mould scavenger beetle and crop habitat diversification model are presented in Fig 3.

Fig. 3: Conservation biological control of exotic whiteflies infesting coconut a) *Apertochrysa* sp. b) *Cybocephalus sp.* c) *Jauravia pallidula* d) *Scymnus nubilis* e) *Encarsia guadeloupae* f) *Aschersonia* sp. g) *Menochilus sexmaculatus* h) *Leiochrinus nilgirianus* i) crop pluralistic approach

Potential invasive pests on coconut

The coconut leaf beetle, *Brontispa longissima* Gestro (Chrysomelidae: Coleoptera), the false coconut scale, *Aspidiotus rigidus* Reyne (Diaspididae: Hemiptera) and the Red ring nematode, *Bursaphelenchus cocophilus*(Cobb) Baujard are potential invasive pests that are looming large in the country's doorstep (Rajan *et al*.,2012; Josephrajkumar *et al*., 2022a). These potential IAS have the ability to destroy the production potential of coconut in no time and impacts the economic livelihood of the nation. Efforts are to be made strenuously to avoid entry of these pests in to the country. During 1920's strict quarantine regulation under DIP Act 1914 effectively curtailed the movement of coconut leaflets across the state and halted the spread of black headed caterpillar, *Opisina arenosella* Walker (Lepidoptera: Oecophoridae). As a follow up, parasite breeding station was set up at different locations in Kerala with a functional boat laboratory for parasitoid rearing and releases in 1929 itself, indicating a classic success story on biological control suppressing black headed caterpillar.

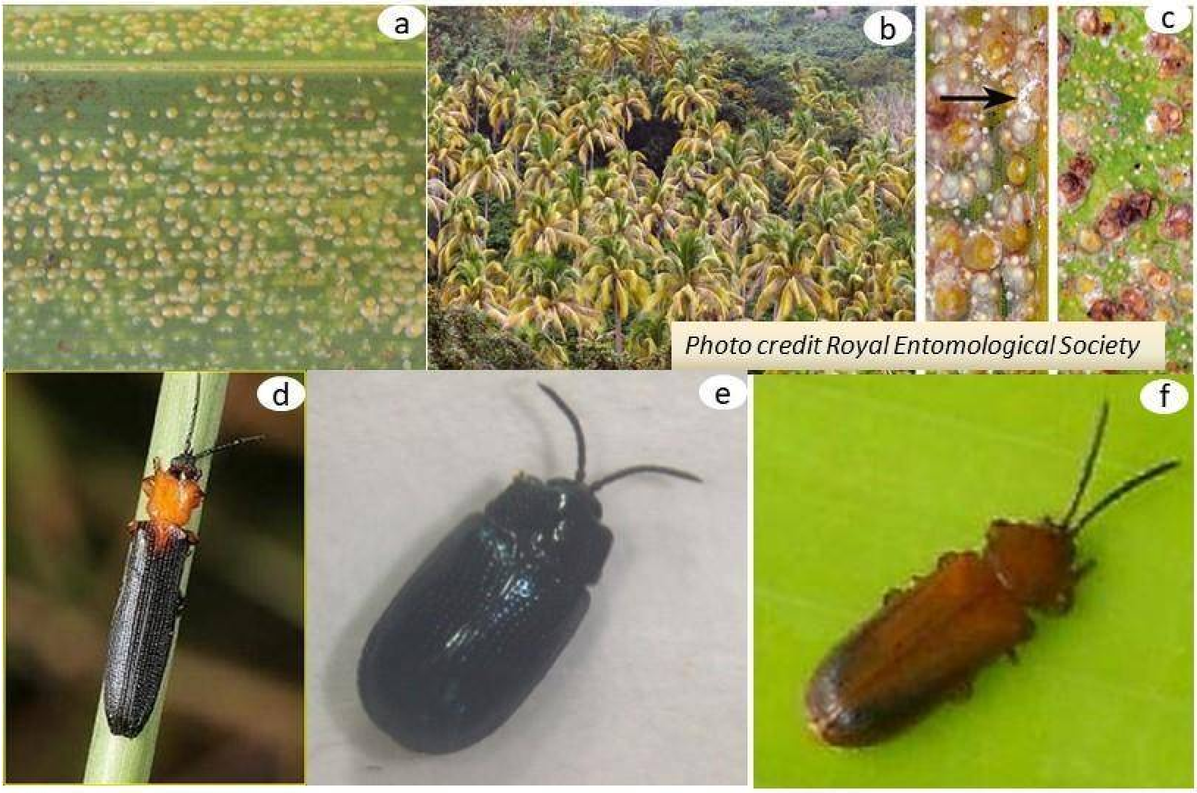

Fig. 4: Scale insects a) *Aspidiotus destructor* b) *A. rigidus* damage symptom c) scales d) *Brontispa longissima* e) *Callispa keram* f) *Wallacea jarawa*

The country has already witnessed a mild incidence of chrysomelid coconut leaf beetles, *Callispa keram* Shameem and Prathapanand *Wallacea jarawa* Prathapan and Shameem on coconut from Alappuzha, Kerala and Port Blair (Andaman and Nicobar Island), respectively. *Callispa keram* was reported on adult palms whereas *W. jarawa* was observed on older nursery seedlings. These pests are under check due to the possible natural enemies. Domestic quarantine needs to be further strengthened to avoid entry of *W. jarawa* from Andamans into the mainland as well as root (wilt) disease from Kerala to other parts of the country (Thomas *et al*., 2015; Josephrajkumar *et al*., 2022a). Similarly, *Aspidiotus destructor* (Diaspididae: Hemiptera), a close relative of *A. rigidus* has been reported from different parts of the state is subdued by the conservation biological control of the aphelinid parasitoid, *Aphytis* sp. and by the coccinellid predators *Chilocorus nigritus* Fab., *Sasajiscymnus dwipakalpa* Ghorpade and *Pharoscymnus horni* Weise quite successfully (Chandrika Mohan *et al*., 2019a). The potential invasive alien species waiting at the doorstep and other native coconut leaf beetles are presented in Fig 4.

Invasive pests and horticultural nurseries

Most of the exotic pests are introduced in to the country through contaminated planting materials of exotic varieties reaching horticultural nurseries without proper phytosanitary certification. The rugose spiralling whitefly reached Kadiyam nursery at Andhra Pradesh in 2017 itself. In general, most of the horticultural nurseries import exotic plants through inappropriate means laced with exotic pests. The quarantine station at Kochi is not empowered to examine invasive alien species of planting materials as well. Due to excessive demand of exotic fruit plants in Kerala many are imported through illegal trade without proper phytosanitary certificate for which stringent measures are to be undertaken. Very recently, we have come across invasive nematode infesting guava through contaminated planting medium. The state of Kerala is also known to harbour eight exotic whiteflies on coconut, guava (*Aleurothrixus floccosus* Maskell), chillies (*Aleurotrachelus trachoides* Back) and on a green leaf manure *Gliricidia sepium*(*Tetraluerodes acaciae* Quaintance) in a very short period (Josephrajkumar *et al*., 2020; Sundararaj *et al*., 2020; Josephrajkumar *et al*., 2022d).

Incursion management strategies (Josephrajkumar *et al*., 2022a)

a) Strengthening quarantine

- ✓ Enforcement of strict domestic quarantine and insistence of phytosanitary certificate
- ✓ Fumigation of vehicles in trans-boundary strategic sites
- ✓ Nursery act to be enacted in all states and licensing of horticultural nurseries to be made mandatory. Stringent penalty to be enforced for those who operate nurseries without proper certification and license.
- ✓ Monitor coconut and other horticultural nurseries and inspect planting materials for the presence of exotic pests and destruction if intercepted.
- ✓ Baggage check for ornamental plants, palms and commercial flowers at air ports and sea ports

b) Surveillance surveys

- ✓ Enforce direct surveillance surveys in sensitive zones including other host plants. This activity can be clubbed with Pest & Disease scouting work done at different blocks all over the country under the aegis of Agricultural Technology Management Agency (ATMA).
- ✓ Movement of seeds, planting materials (even soil and potting mixture materials) from seaports, airports, railway stations (near international boundary) and check posts near international boundaries should be done employing "Bharat Bio security App" so that the point of origin and point of destination of the consignment can be tracked.
- ✓ Critically examine plants for transboundary pests
- ✓ Formation of Incursion Management Team with scientists from all discipline
- ✓ State Referral Laboratory on Plant Health Inspection Services
- ✓ Development of emergency preparedness module for potential invasive pests

c) Awareness campaign

- ✓ Organizing nation-wide seminars, workshops and sensitization campaigns
- ✓ Bio security, Bio safety and related topics to be made mandatory topic for school and college students
- ✓ Capacity building on mass production of bio-control agents
- ✓ Intensive bio-control programme in endemic regions
- ✓ Display posters in lounges of airports and seaports
- ✓ Mass media programme in *Prasar Bharati, Doordarshan* (News Clippings)

Conclusion

Bio security risks are looming large in the state for which enforcing strict quarantine measures is the need of the hour. Regular capacity building initiatives are to be undertaken to empower all stakeholders about the exotic pests and other potential invasive pests at the country's doorstep. An emergency preparedness module to tackle invasive pests are to be evolved. Conservation biological control was found to be effective in the management of exotic whiteflies infesting palms. A state referral laboratory on plant health inspection services should be introduced for timely diagnosis and crop advisory services to the coconut community. It is the need of the hour to develop a National Bio security Policy.

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WEEDS AND WEED MANAGEMENT IN KERALA: RECENT TRENDS - A REVIEW

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Weeds pose serious threats to agricultural production and agrobiodiversity as they are hardy, climate resilient and ubiquitous across the world. Total economic loss caused due to weeds, in 10 major crops of India, was estimated to be about USD 11 billion (Gharde *et al*., 2018). Despite the development of weed management technologies from time to time, they continue to be a major problem and weed related problems have been mounting due to the threats posed by alien invasion, climate change, globalization, herbicide resistance development in weeds and commercialization of herbicide-tolerant crops.

Kerala, bestowed with wide variability in climate in different regions has rich diversity of weed flora in crops indifferent parts of the state. Moreover, weed problems are very severe in majority of crops because of intermittent rains and hot humid conditions in the state causing substantial yield loss (Table 1). The regular disturbance and high fertility of cropped fields favour species with extreme ruderal strategies characterized by high specific leaf area, early flowering and long flowering duration. The alien intruders had also interfered with the growth and production of food and commercial crops of Kerala and also exercised adverse effects on the biodiversity of native species.

Important weed species, weed shift and their management in Kerala

The major weed flora associated with different crops varied with crops (Table 2) and agro ecological situation. Traditionally, ploughing and hand weeding were adopted, which were then replaced with mechanised agriculture. Labour scarcity had led to the era of chemical weed management using herbicides. The first trial on testing the efficiency of herbicides in Kerala was conducted by Nair *et al.*(1974) with achlor and propanil to control the weeds in direct seeded rice at the then Rice Research Station (now Regional Agricultural Research Station), Pattambi. They concluded that these herbicides can be safely used in rice fields and it is economical to use herbicides over hand weeding. Later Nair *et al.* (1978) evaluated new

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pre-emergence herbicides for the control of weeds in flooded rice at RARS, Pattambi. The study identified 2, 4-D isopropyl ester (IPE) as the best one over unweeded control and was on par with all herbicidal treatments.

Weed shifts also occur due to changes in agricultural practices over the years. Due to continuous use of the herbicide 2, 4-D, broad leaved weeds were controlled efficiently, but it led to the dominance of grass weeds. 2, 4-D also led to the dominance of *Marsilia quadrifolia* which was later controlled using Almix (metsulfuron methyl 10%+ chlorimuron ethyl 10% WP). 2, 4-D induced grass dominance was brought under control using propanil. But it was not much effective and led to the dominance of grass weeds such as *Echinochloa* sp. The use of cyhalofop butyl (Clincher) brought about appreciable control of grasses. A study was conducted by Abraham *et al.* (1999) to evaluate the bioefficacy of cyhalofop butyl to control *Echinochloa* spp. in direct seeded rice of Kole lands of Kerala. The study revealed that all doses of cyhalofop butyl 10 EC (45, 60, 75, 90 and 120 g ha^{-1}) controlled *Echinochloa*. Effectively with significantly higher yield with no phytotoxicity to the crop even with the highest dose tested in the experiment.

The introduction of bispyribac sodium in 2005-06 for the control of grasses, broadleaved weeds and sedges gained popularity among farmers for broad spectrum weed control in rice. However, continuous use of the herbicide by the rice farmers resulted in the dominance of Redsprangletop (*Leptochoa chinensis);* heavy infestation of this weed has been reported from the major rice tracts of Kerala, *viz*., Kuttanad, *Kole* and Palakkad. Jacob (2014) reported that *Leptochoa chinensis* emerged as one of the problematic weeds in rice due to shift in weed flora in the paddy fields of Kerala. Sekhar (2021) reported that the application of fenoxoprop-p-ethyl @ 0.06 kg ha^{-1} recorded least population count of *L. chinensis* weed at all stages of crop and it was on par with HW (Hand weeding) twice at 20 and 45 DAS.

Several herbicidal mixtures were tested and employed for efficient weed control. Post emergence application of penoxsulam + cyhalofop butyl @ 135 and 150 g ha^{-1} recorded efficient weed control for all types of weeds in wet seeded rice (Abraham and Menon, 2015). Another premix herbicide mixture in granular form in green triangle with pre-emergence application *viz*., benzsulfuron methyl + pretilachlor @ 60 + 600 g ha^{-1}applied on the day of sowing recorded efficient weed control during initial stages in semidry rice (Arya and Ameena, 2016).

A serious threat to rice cultivation in the form of weedy rice (*Oryza sativa* f. *spontanea*) appeared first in Palakkad district during 2007-08 and many farmers were forced to abandon rice cultivation. Heavy infestation of weedy rice in rice fields of Kerala caused a yield reduction of 30 to 60 per cent with a severity of infestation ranging from 3 to 10 mature plants per m^2 (Abraham *et al*., 2012). At present, weedy rice has infested large rice growing areas across major rice tracts of Kerala *viz*., Palakkad, Kuttanad and Kole lands with its diverse morphotypes. Absence of selective herbicide, close morphological similarity, higher competitive ability and seed shattering has further worsened the problem.

The research programme undertaken at Rice Research Station, Moncompu, Kerala Agricultural University, for the post-emergence management of weedy rice by direct contact application (DCA) of broad-spectrum non-selective herbicides using specially designed novel hand held weed wiper device could selectively dry the panicles of weedy rice at 60-65 DAS, taking advantage of the height difference of 15-20 cm between weedy rice and cultivated rice. The novel 'Weed wiper device' (WWD) could thus prevent the build-up of soil seed bank in weedy rice infested areas, its further spread and invasion (Jose *et al*., 2020).

Table 1. Yield loss due to weeds in major crops of Kerala

Crops	Direct seeded rice(%)	Rainfed lowland rice (%)	Wet direct seeded rice (%)	Semi dry rice (%)	Cowpea (%)	Cassava (%)	Brinjal (%)	Chilly (%)
Extent of yield loss	52.3-55.6	59.7	56.7-63.1	52.2	70	45-75	49-51	93.6
Reference	Arya (2018)	Reddy and Ameena (2021)	Sekhar *et al.*, (2020 a)	Arya and Ameena (2016)	Sinchana *et al.* (2022)	Suja *et al.* (2020)	Syriac and Geetha (2007)	Fasna *et al.* (2021)

Table 2. Dominant weed flora in major crops of Kerala

Rice (Kuttanad)	**Rice (Kole lands)**	**Rice (Pokkali)**	**Direct seeded low land rice**
Kharif- *Echinochloa stagnina, E colona, Salvinia molesta, Fimbristylis miliacea, Monochoria vaginalis, Sacciolepis interrupta, Isachne miliacea* Punja- *Monochoria vaginalis, Marsilia quadrifoliata*	*Grasses* *Echinochloa stagnina, E crusgalli, Fimbristylis miliacea, Monochoria vaginalis, Sacciolepis interrupta, Isachne miliacea, Cyperus iria, C.difformis, Marsilia quadrifoliata, Salvinia molesta*	*Grasses: Diplachne fusca , E crusgalli, Fimbrisrylis miliacea,* *Eleocharis dulcis, Cyperus difformis, Eichhomia crassipes, Monochoria vaginalis,Sphenoclea zeylanica,*and *Sphaeranthus africanus*	Grasses: *Echinochloa colona, Echinochloa stagnina,* *Oryza sativa* f.*spontanea* (weedy rice) and *Leptochloa chinensis.* Sedges: *Cyperus iria* and *Fimbristylis miliacea* Broad leaf weeds: *Ludwigia perennis, Monochoria vaginalis, Sphenoclea zeylanica* and *Limnocharis flava*
Abraham *et al*. (1990)	Abraham and Thomas	Vidya *et al*. (2004)	Reddy and Ameena

	(2002)		(2021)
Direct seeded rice	**Wet seeded rice**	**Upland rice**	**Pulses in summer fallows**
Grasses: *Echinochloa crusgalli, Echinochloa stagnina* and *Leptochloa chinensis* Sedges: *Fimbristylis miliacea, Cyperus iria* and *Cyperus difformis* Dicot: *Ludwigia parviflora* Sedges: *Fimbristylis miliacea, Cyperus iria* and *Cyperus difformis*	Grasses: *Leptochloa chinensis, Echinochloa colona,* and *Isachne miliacea*. Broad-leaf weeds *Sphenocleaa zeylanica, Bergia capensis, Monochoria vaginalis, Limnocharis flava, Ludwigia perennis, Alternnathera philoxeroides* and *Lindernia parviflora.* Sedges: *Cyperus iria, Cyperus difformis, Fimbristylis miliacea.*	Grasses: *Dactyloctenium aegyptium, Setaria barbata, Eleusine indica, Digitaria ciliaris* Sedges: *Cyperus rotundus* Broad leaf weeds: *Alternanthera sessilis, Phyllanthus niruri, Mimosa pudica*	Sedge: *Cyperus rotundus* and broad-leaf weeds: *Boerhavia diffusa*
Jacob *et al*. (2014)	Sekhar *et al*. (2020 a)	Ravikiran *et al.* (2019)	Adarsh and John (2021)
Cowpea	**Okra**	**Cassava**	**Elephant foot yam**
Grasses: *Setaria barbata, Digitaria sanguinalis* Broad leaf weeds: *Alternanthera sessilis, Phyllanthus niruri, Synedrella nodiflora* Sedges: *Cyperus rotundus*	Grasses: *Setaria barbata, Digitaria sanguinalis* *Synedrella nodiflora, Phyllanthus niruri, Boerhavia diffusa, Mimosa pudica, Tridax procumbens*.	Grasses: *Dactyloctenium aegyptium, Digitaria sanguinalis, Cynodon dactylon , Echinochloa crusgalli,* Sedges: *Cyperus rotundus*. Broad leaf weeds: *Borreria hispida, Celosia argentia, Ageratum conyzoides , Commelina benghalensis, Cleome viscosa, Mimosa pudica, Phyllanthus niruri*	Grasses: *Digitaria ciliaris, Panicum maximum* and *Cynodon dactylon* Sedges: *Kyllinga monocephala* Broad leaf weeds: *Borreria hispida, Alternanthera bettzickiana, Commelina benghalensis* and *Cleome viscosa*
Sinchana *et al.* (2022)	Chacko *et al.* (2021)	Nedunchezhiyan *et al.*	Sekhar *et al.* (2017)

		(2017)	
Ginger	**Pine apple**	**Groundnut**	**Rubber plantations**
Monocots: *Kyllinga monocephala, Mollugo pentaphylla, Cyperus rotundus*. *Spermacoce latifolia Mimosa pudica Ageratum conyzoides, Oldenlandia auricularia, Cleome rutidosperma*, *Oxalis corniculata* and *Ludwigia hyssopifolia*	*Mikania micrantha, Chromolaena odorata, Merremia umbellata, Mimosa pudica, Alternanthera bettzickiana, Cyclea peltata, Cleome burmanii, Centrosema pubescens,* and *Ichinocarpus frutescens*	Grasses: *Cynodon dactylon* and *Eleusine indica.* Sedges: *Cyperus rotundus*	*Chromolaena odorata*, *Axonopus compressus, Clerodendron infortunatum*, *Borreria hispida*, *Mimosa pudica, Cyathula prostrata*, *Justicia simplex* and *Ischaemum indicum*
Thankamani *et al.* (2016)	Girija and Menon (2019)	Sarin *et al.* (2021)	Abraham and Abraham (2000)
Coconut	**Cocoa**	**Cardamom**	**Black pepper**
Axonopus compressus, Mimosa pudica, Synedrella nodiflora, Ageratum conyzoides, Ischaemum rugosum, Borreria hispida, Chromolaena odorata, *Ischaemum indicum*, *Desmodium triflorum, Hyptis suaveolens* and *Alternanthera philoxeroides*	*Borreria hispida, Mollugo pentaphylla, Amaranthus viridis* and *Ludwigia perennis.*	*Bidens pilosa, Ageratum conyzoides, Crassocephalum crepoides, Drymaria cordata, Paspalum conjugatum, Synedrella nudiflora* and *Elusine indica*	*Ageratum conyzoides, Peperomia pellucida, Spermacoce latifolia, Mimosa diplotricha.* Monocots*: Cynodon dactylon, Commelina diffusa, Kyllinga monocephala Rottob, Pteris quadriuarita*
Ramya *et al*. (2009)	Shylaja (2001)	Sudheesh (1996)	Sajini (2010)

Table 4. Weeds of economic significance in specific crops of Kerala

Sl No	Rice	Dominant weed	Yield loss (%)	Reference
1	Direct and wet seeded rice & Transplanted rice	Weedy rice	30 to 60	Abraham and Jose (2015)
2	Wet seeded rice	*Isachne miliacea*	61.8 to 62.9	Renjan (2018)
3	Wet seeded rice	*Leptochloa chinensis*	56.7 to 33.1	Sekhar (2021)

Weed Management in major crops of Kerala

Hand-weeding and mechanical control were commonly used to achieve acceptable weed control from the beginning.Hand weeding, though effective, is now fetching less attention and more difficult owing to increased labour paucity, mounting wages and its dependence on weather conditions. Moreover, the morphological similarity of weeds especially grass weeds with cultivated rice makes hand weeding incomplete and ineffective. Since the discovery of 2, 4-D for broad-leaf weed control in rice and non-crop situation, farmers relied on herbicides for weed management in rice fields. Herbicides provided superior weed control and were found more labour efficient than hand/manual or mechanical methods of weed management and ensured a high B: C ratio. The most economical weed management practices identified for major crops are given in Table 5.

Changes in management practices resulted in major shift of weedy flora in many instances. Within the group of weedy plants, agricultural intensification filtered out species adapted to intermediate levels of soil fertility characterized by a relatively large seed, later flowering and short stature. Even human intervention and contamination can cause weed shift as in the case of a study in Sasthamkotta Lake by Thomas *et al*. (2009) where fish excreta and detergents from households changed the pH of water and promoted the rampant growth of submersed aquatic weeds like *Hydrilla verticillata* and floating weed *Salvinia molesta.*

Table 5. Most economical weed management methods for managing weeds in major crops of Kerala

Sl no.	Crop	Weed	Economical weed management methods	Reference
1	Transplanted rice	All weeds	Pre-emergence application of anilofos+ 2,4-D ethyl ester (0.40+0.53 kg ha^{-1}) at six days after transplanting supplemented with 2,4-D Na salt (1.0 kg ai ha^{-1}) at 20 days after transplanting (DAT)	Jacob and Syriac (2005)
2	Semi dry rice	All weeds	Pre-emergence application of either benzsulfuron methyl + pretilachlor @ 60 + 600 g ha^{-1} or pyrazosulfuron ethyl @ 25 g ha^{-1} on the day after sowing followed by post emergence application of azimsulfuron @ 30 g ha^{-1} at 25 DAS	Arya and Ameena (2016)
3	Semi dry rice	*Sacciolepis interrupta*	Pretilachlor + bensulfuron-methyl 0.6 + 0.06 kg/ha 5 DAS followed by (*fb)*cyhalofop-butyl + penoxsulam 0.15 kg/ha 15 to 20 DAS *fb* one hand weeding	Sreelakshmi and Menon (2020)
4	Wet seeded rice	All weeds	Bensulfuron-methyl + pretilachlor 60 + 600 g/ha at 3 DAS or penoxsulam +	Reddy and Ameena

			cyhalofop-butyl 150 g/ha at 20 DAS both fbHW at 40 DAS	(2021)
5	Upland rice	All weeds	Stale seedbed method with penoxsulamat 25 g ha^{-1} at 10-15 DAS *fb* HW at 35-40 DAS	Ravikiran *et al.* (2019)
6	Wetland rice	*Scirpus grossus* L	Application of glyphosate @ 0.5 kg ha^{-1} + 2, 4 – D @ 1.0 kg ha^{-1} at the reproductive stage was found to be the best, giving complete weed kill with no further regrowth	Karthikeyan (2017)
7	Groundnut	All weeds	Application of imazethapyr @ 70 g ha^{-1} at 20 DAS	Sarin *et al.* (2021)
8	Cowpea	All weeds	Stale seedbed or normal seedbed + dried banana leaf mulching @ 10 t ha^{-1} *fb*quizalofop-p-ethyl@ 50 g ha^{-1} at 25 DAS	Sinchana *et al.* (2022)
9	Green gram	All weeds	Imazethapyr + imazamox80 g ha^{-1} at0-3 DASfb hand weeding at 25 DAS or diclosulam fb hand weeding at 25 DAS	Gopakumar and Menon (2022)
10	Cassava	All weeds	Pre-emergence (PE) herbicide, oxyfluorfen at 0.2 kg ai ha^{-1}	Suja *et al.*(2020)
11	Elephant foot yam	All weeds	Mulching with black polythene/ Pre emergence application of oxyfluorfen 0.2 kg ha^{-1} + manual weeding at 75 days after planting (DAP)/ post emergence application of glyphosate 0.8 kg ha^{-1} + manual weeding at 75 DAP	Sekhar *et al.* (2017)
12	Bajra napier hybrid	All weeds	Oxadiargyl @ 90 g ha^{-1} on 3-5 DAP *fb* hand weeding on 25-30 DAP	Swathy and Thomas (2020)
13	Ginger	All weeds	Paddy straw 6 t ha^{-1} along with green leaf mulch 7.5 t ha^{-1} at 45 and 90 DAP and application of dried coconut leaves at the time of planting 5.4 t ha^{-1}	Thankamani *et al.* (2016)

Stale seed bed method (SSB)

Renu (1999) reported that SSB with oxyfluorfen @ 0.15 kg ha^{-1} had effectively controlled Polla (*Sacciolepis interrupta*) in semi dry rice. According to Renu *et al*. (2000) SSB with one or two weed flushes destroyed before the main crop being planted and the final seed bed withheld from planting is the most effective method for managing mimicry weed i.e., *Sacciolepis interrupta* in Kerala under semi dry rice conditions.

Sheela *et al.* (2007) assessed different weed management practices and conveyed that SSB was effective in suppressing weeds thereby improving the yield of Bhindi crop. Sindhu *et al.*

(2010a) evaluated different seed bed manipulative techniques and non-chemical methods of weed control in wet seeded rice during *Rabi* season in Kole lands of Thrissur district, Kerala. They inferred that SSB+ pre-emergence herbicide along with hand weeding or simultaneous adoption of green manuring would provide better weed control and improve grain yield.

Sindhu *et al.* (2010b) concluded that adopting SSB for 14 days significantly reduced the weed dry weight and increased B:C ratio in dry seeded rice. They further concluded that integrating SSB with simultaneous growing of cowpea is an effective way for weed management in dry seeded rice. Preparation of stale seed bed method by ploughing the land at 25-30 days interval before sowing in between two germinations of rice, helped in germination of most of the weed seeds. Comparatively wet ploughing was more efficient over dry ploughing to control weedy rice (Jose *et al.,* 2012a)

Soil solarization

Sheela *et al*. (1991) found that soil solarization using black polythene sheets for 45 days and then for 30 days resulted in suppressing weeds effectively except for purple nutsedge. They also found that soil solarization combined with application of herbicide can control weeds considerably as well.

Sainudheen and Abraham (2001) evaluated the effect of soil solarization using transparent sheet for perennial weed control. Results showed that soil solarization for 2-6 weeks during summer increased the temperature of about 8-10°C in upper layers, destroyed all weed seeds and helped in reducing weed growth for next season, but it was found ineffective to control perennial weeds.

Syriac and Geetha (2007) reported that soil solarization carried out for one month recorded higher fruit yield (18.92 and 18.12 t ha^{-1}, respectively) in both the years *i.e*., 1998-99 and 1999-2000. It was comparable with alachlor @ 2.0 and 2.5 kg ha^{-1}, pendimethalin @ 2.0 kg ha^{-1} and oxadiazonen @ 0.5 and 0.75 kg ha^{-1}.

A study conducted at KAU revealed that soil solarization using polythene of 100 microns transparent sheets for 30-45 days in summer led to nearly 90 per cent of weedy rice control. This practice is helpful to produce seedlings free from weedy rice during nursery stages (Jose *et al.*,2012a)

Mulching

According to Sainudheen (2000), among weed management practices, mulching with black polythene is the most efficient weed control practice in okra.Bin *et al.* (2018) revealed that among different mulches evaluated, polythene sheet (black) recorded higher weed control efficiency (WCE) of about 95.21 per cent and higher yield (15.6 t ha^{-1}). It was followed by paper mulch (94.21%) and mango leaves (90.77%) in Okra. Further, silver-black polythene mulch was noted to be the best for weed control in cabbage (Akshata *et al.,* 2018). Fasna *et al.* (2021) concluded that polythene mulch and straw mulch recorded reduction in weed dry matter and increased yield of chilli. These were considered as the best non-chemical methods of weed control and are economical.

Intercropping

Resmy (2003) evaluated different weed management practices with green manure intercropping in semi dry rice. They concluded that cowpea was superior over others and helped in suppressing weeds effectively. Intercropping reduced weed population of about 42.8- 56.8 per cent up to 60 DAS.

Dual cropping of cowpea and incorporation of cowpea using 2,4-D at 45 DAS helped in reducing weeds under semi-dry rice along with 25 per cent N supplementation and increased yield (Anitha *et al*., 2009).

Weed cloth

Weed cloth covering ground surface acts as mulch thereby preventing the growth of weeds providing physical barrier, decreased light penetration and altering the soil temperature. Suja *et al.* (2020) reported that the use of weed cloth suppressed weeds to the extent of nearly 35 percent with increased yield of about 15 per cent over hand weeding and chemical weed control methods in cassava.

Weed wiper

Weed wiper is a new architype standardised by Kerala Agricultural University (KAU). It showed better weed control efficiency (WCE) by drying panicles of weedy rice at 60-65 DAS when used with broad spectrum herbicides *i.e.,* glyphosate, and glufosinate ammonium at the concentrations of 15-20 per cent of the formulated product by direct contact application. It was based on the advantage of height difference *i.e.,* 15-20cm difference occurring between weedy rice and cultivated rice (Jose, 2015).

Wheel hoe weeding

Chacko *et al.* (2021) reported that among the weed management practices adopted, wheel hoe weeding at 15, 30 and 45 DAS, recorded lowest the weed biomass and was concluded as the best weed management option which promotes the availability and uptake of nutrients by crop and decreasing the nutrient uptake by weeds thereby improving the yield of okra.

Biological weed control

Biological control of weed is the intentional manipulation of natural enemies by humans for controlling harmful weeds. Introducing a natural enemy (e.g. water hyacinth weevil, Neochetina spp. for *Eichhornia*; *Lantanophaga pussilidactyla* insect for *Lantana camara,* Z*ygogramma bicolorata* insect and *Cassia uniflora* plant species for *Parthenium hysterophorus*) for the eradication of invasive species is a focus of interest for biological conservationists. However biological control may not be evenly effective over all areas infested by the invasive species. *Cyrtobagous salviniae* dispersed quickly and devoured the weed within two years of its first release, clearing over 1,000 square km of water bodies (Joy et al., 1986). Praveena and Naseema (2004) identified *Myrothecium advena* and *Fusarium pallidoroseum*. as promising biocontrol agents of water hyacinth as they caused more than 50 per cent infection of the weed.

Nymphs and adults of *Aphis fabae* and *A. spiraecola* fed on tender leaves and shoots of *Chromolaena odorata* cause severe leaf crinkling (Lyla et al.,1995). Re-occurrence of *Pareuchaetes pseudoinsulata* larvae was reported in Thiruvananthapuram which feeds voraciously on auxiliary and terminal buds of *Chromolaena odorata*. It has to be further investigated for its further spread for this weed control (Arjun et al., 2016).

Chemical weed management

Yadav (2006) evaluated bio-efficacy and residue effect of pyazosulfuron ethyl, in transplanted rice. Application of pyazosulfuron ethyl @ 20, 25 and 30 g ha^{-1} at 10 DAT were found effective in controlling all the grasses, sedges and broad - leaf weeds. With respect to net returns and B:C ratio, application of pyazosulfuron ethyl @ 20 g. ha^{-1} at 10 DAT was efficient and economical in rice lowlands.Spray of tank mixture of glyphosate @ 1.0 kg ha^{-1}+ 2,4-D @ 2.0 kg ha^{-1} after giving an initial mowing was effective in controlling greater club rush weed (*Scirpus grossus* L.) and was found sustainable enough to bring the infested land into cultivable form (Sreethu, 2011).

Application of oxyfluorfen 0.2-0.3 kg ha^{-1} during the initial stage successfully controlled weedy rice dry weight of about 84 per cent, when applied 3 days before sowing on 2cm standing water (Jose *et al.* 2012b). Ilangovan *et al*. (2012) evaluated the efficacy of herbicide mixtures under rice-rice cropping system. Results showed that sequential application of herbicides was effective with respect to weed control. Among various herbicide combinations, bensulfuron-methyl+ pretilachlor (pre-plant application) applied in combination with glyphosate (pre-planting) was effective followed by glyphosate (pre-planting)+ butachlor (post planting).

Prameela *et al.* (2014) reported that the best herbicide treatment with low weed dry matter production in wet seeded rice was fenoxaprop - p- ethyl or cyhalofop-butyl with follow up spray of Almix. Bispyribac sodium registered the highest weed control efficiency next to hand weeding which was comparable to application of cyhalofop - utyl/fenoxaprop – p - ethyl/metamifop with follow up spray of Almix.

Karthikeyan (2017) evaluated different chemical treatments to manage greater club rush (*Scirpus grossus* L.), invasive weed species in rice wetland ecosystems. They stated that the application of tank mixture of glyphosate @ 0.5 kg ha^{-1}+ 2,4-D sodium salt @ 1.0 kg ha^{-1}at the reproductive stage helped in effective control of this weed thereby recovering the paddy fields. Arya (2018) concluded that application of flucetosulfuron @ 20, 25 and 30 g ha^{-1} in wet seeded rice at 10-12 DAS recorded significantly higher weed control efficiency controlling all sedges, grasses and broad-leaved weeds with higher yield and net returns.

Kumar *et al.* (2019) stated that pre-emergence application of pendimethalin in elephant foot yam was very effective in suppressing weeds associated with increased corm yield and net income. Tembotrion followed by propaquizafop - two sprays [new generation herbicide combination] and treatment having weed free control were the other better treatment. Prameela *et al.* (2011) stated that diuron @ 2 kg ha^{-1} recorded better weed control with 86 per cent savings over manual weeding in sole tapioca crop. However, in tapioca intercropped with green gram, diuron can not be recommended due to the mortality outcome on green gram.

Application of ready mix of either bensulfuron-methyl + pretilachlor 60 +600 g/ha at 3 DAS or penoxsulam + cyhalofop-butyl 150 g/ha at 20 DAS both fbHW at 40 DAS was observed as the most effective weed management strategy in wet-seeded lowland rainfed rice (Reddy and Ameena, 2021a)

Interaction of favourable soil condition and management practices resulted in dominance of *L. chinensis* in wet seeding. Among herbicidal treatments, application of fenoxofop-p-ethyl @ 0.06 kg $ha^{-1}$was to have least population count of *L. chinensis* at all stages of crop and it was found on par with HW (Hand weeding) twice at 20 and 45 DAS along with bispyribac sodium @ 0.025+ fenoxofop-p-ethyl @ 0.06 kg ha^{-1} in wet seeded rice (Sekhar *et al*., 2020 a).

New generation herbicides

During the last 20 years, a generation of low application rate herbicides called 'New-generation herbicides' or low dose high efficiency herbicides has been developed that act by inhibiting the action of key plant enzymes, resulting in arrested growth and eventual plant death. They are applied at lower doses with less environmental persistence and exceedingly low toxicity to non-target organisms, and therefore gained popularity among farmers. Low dose high efficacy herbicide functions by inhibiting the action of key plant enzymes. Major groups include sulfonylurea, sulfonamide, imadazolinone etc, applied either pre or post emergence to crops at rates ranging from 30-60 gm a.i/ha low closes than many traditional herbicides. Recommended dose of widely used traditional rice herbicides like butachlor, pendimethalin, 2,4-D etc. ranges from 1 to 2 kg a.i/ha. New generation herbicides are more effective, applied at lower rates and have low mammalian toxicity and reduce the risk of environmental pollution. Application rates have been reduced from 1.8 – 3 kg/ha to just 20-25 g/ha. They showed high herbicidal potency at very low rates making them environmentally safe. (Table 6.)

Yadav (2006) evaluated bio-efficacy and residue effect of pyazosulfuron ethyl, a new herbicide in transplanted rice. Application of pyazosulfuron ethyl @ 20, 25 and 30 g ha^{-1} at 10 DAT was effective in controlling all the grasses, sedges and broad -leaved weeds. Whereas, with respect to net returns and B:C ratio, treatment with the application of pyazosulfuron ethyl @ 20 g ha^{-1} at 10 DAT was efficient and of economic significance in rice lowlands.

Kunnathadi *et al.* (2014) found that post emergence application of cyhalofop-butyl @ 1 kg ha^{-1} followed by metsulfuron-methyl 10%+ chlorimuron-ethyl 10% recorded higher net income and B:C ratio when applied at 20 days after transplanting in rice under SRI method. It was on par with hand weeding and conoweeding followed by post emergence herbicides. In transplanted rice, the lowest weed dry matter production and weed control efficiency, and highest grain yield were recorded by triafamone combined with ethoxy sulfuron, and bispyribac-sodium combined with premix of (chlorimuron-ethyl + metsulfuron-methyl) (Menon *et al*., 2016).

Raj (2016) reported that the application of penoxsulam+ cyhalofop butyl @ 135, 130 and 125 g ha^{-1} was effective in controlling weeds at all stages of crop with lower total weed dry weight in direct seeded puddled rice conditions. Sekhar *et al*., (2020 b) reported that a combination of stale seedbed followed by glyphosate plus oxyfluorfen at 15-20 days after land preparation followed by either bispyribac sodium plus fenoxaprop-p-ethyl, bispyribac sodium plus cyhalofop butyl orpenoxsulam plus cyhalofop butyl could be a viable option in managing a broad spectrum of weeds especially in areas with high soil weed seed bank. The study also signifies the importance of herbicide combinations for managing complex weed flora and enhanced the weed control efficiency in DSR to reduce the development of herbicide resistance and weed shift.

Table 6. New generation herbicides based on target weed flora

Grass herbicides				
Chemical Name	**Trade Name**	**Dose**	**Time of application**	**Colour code**
Cyhalofop butyl 10 EC	Clincher	80 g ha^{-1}	15 DAS	Green
Fenoxaprop-p-ethy7.5 EC	Rice star, Whip super	56 g ha^{-1}	15 DAS	Blue
Metamifop	Critel	100 g ha^{-1}	15-20 DAS	
Quizalofop-ethyl	-	37.5 g ha^{-1}	15-20 DAS	Blue
Haloxyfop R Methyl 10.5% w/w EC	Gallant	108-135 g ha^{-1}	20 DAS	Green
Sedges and broad-leaf weeds				
Chorimuron ethyl + metsulfuron methyl	Almix	4 g ha^{-1}	20-25 DAS	Blue
Carfentrazoneethyl	Affinity	20-25 g ha^{-1}	20-25 DAS	Green
Ethoxysulfurom	Sunrice	12.5-18 g ha^{-1}	20-25 DAS	Blue
Diclosulam	Strongarm	12.5 g ha^{-1}	0-3 DAS	Green
Halosulfuron methyl	Sempra	67.5 g ha^{-1}	3-4 leaf stage of weed	Green
Pyrazosulfuron ethyl	Saathi	20 g ha^{-1}	3-6 DAS	Blue
Broad spectrum herbicides				
Bispyribac sodium 10 % SC	Nominee gold, Tarak, Adora	25 -30 g ha^{-1}	15- 18 DAS	Blue

Penoxsulam 24 SC	Granite	22.5- 25g ha^{-1}	15-18 DAS	Green
Imazethapyr, Imamox	Pursuit	30 g ha^{-1}	10 DAS	Green
Flucetosulfuron	-	15-30 g ha^{-1}	10-12 DAS	-
Herbicide mixtures				
Bensulfuron methyl 0.6%+Pretilachlor 6% GR	Londax power	60 + 600 gm	0-6 DAS	Green
Metsulfuronmethyl 10% + Chlorimuron ethyl 10% WP	Almix	4 g ha^{-1}	15-20 DAS	Blue
Penoxsulam+ cyhalofop butyl	Vivaya	135 g ha^{-1}	15-20 DAS	Blue

Table 7. Herbicides banned in Kerala (GOMS No.123/2011/Agri.Dated12.5.2011)

Common name	Colour Code	Substitute	Colour code	Dose
Paraquat	Yellow	Glufosinate ammonium/ Glyphosate	Blue	500g /ha 0.8 kg /ha
Thiobencarb	Blue	Butachlor 50 % EC	Blue	1.25 kg /ha
		Pretilachlor 50% EC	Green	1.5 kg /ha
Anilophos	Yellow	Butachlor 50 % EC	Blue	1.25 kg /ha
		Pretilachlor 50% EC	Green	1.5 kg /ha
*Glyphosate under restricted use				

Integrated weed management

Rajan (2000) standardised an integrated weed management practice for rice-based cropping system taking rice-rice-sesame cropping system in Onattukara tract. Among different treatments, during the first season, pre-emergence application of pendimethalin alone or integrating it with hand weeding or post-emergence application of 2,4-D was effective in controlling weeds. Nair (2001) evaluated integrated weed management methods in upland rice. Application of pendimethalin @ 1.5 kg ha^{-1} + one hand weeding recorded high yield and net income followed by butachlor application @ 1.25 kg ha^{-1}.

As reported by Ameena (2003) stale seed bed method with polythene mulching or pre-emergence and post-emergence application of glypho sate was effective in controlling under cropped area. Nishan (2012) stated that 2,4-D was effective in controlling water cabbage in rice wetlands. Among the new generation herbicides, almix (metsulfuron methyl+ chlorimuron methyl @ 6 g ha^{-1}) and BS (bispyribac sodium @ 30 g ha^{-1}) were equally effective in controlling water cabbage (*Limnocharis flava* L.) in wetland rice.

Thomas *et al*. (2012a) investigated different integrated weed management methods in aerobic rice. The study concluded that the application of PE (pre-emergence) herbicide pendimethalin

@ 1.0 kg ha^{-1} followed by bispyibac sodium or 2,4-D sodium salt @ 20 DAS integrated with hand weeding @ 40 DAS was effective in controlling weeds in aerobic rice in central Kerala. The study conducted by Thomas *et al.* (2012b) in dry direct seeded rice in Kerala concluded that pretilachlor 50 EC application @ 0.75 kg ha-^{1} at 4-6 days after effective rainfall followed by HW (hand weeding) at 20 DAS or the application of metamifop 10 EC @ 1.0 kg ha^{-1} at 2-3 leaf stage of grasses were suitable weed management approaches.

Reshma *et al.* (2015) reported that application of oxyfluorfen as pre-emergence @ 0.15 kg ai ha^{-1} and hand weeding once at 20 days after sowing recorded higher WCE of about 89.43 per cent with higher yield of 3500 kg ha^{-1} and net returns (Rs. 31967 ha^{-1}), in rice thus considering economical over hand weeding. Renjan (2018) evaluated the management of blood grass (*Isachne miliacea* Roth) in rice wetlands. Among the various management practices, integrated management of intensive tillage (three ploughings followed by puddling), deep water ponding (more than 7.5 cm till panicle initiation and thereafter saturation) and at 3-5 leaf stage of weed with the application of azimsulfuron @ 35g ha^{-1} showed efficient management of blood grass.

The ready mix herbicides bensul furonmethyl + pretilachlor (at 3DAS) and penoxsulam+ cyhalofop butyl (at 20DAS) each fb HW at 40DAS provided a minimal weed presence at the critical period and resulted in superior grain yields (5461and 5355 kg ha^{-1}, respectively), dry matter production (13.17 and 13t ha^{-1}, respectively,) crop NPK uptake and weed NPK removal in direct seeded rain fed lowland rice (Ameena and Reddy, 2021b).

Weed management strategies in commercial crops

Pineapple

In Kerala, pineapple is grown mainly as an intercrop in rubber and coconut, and also as pure crop in garden land and in converted paddy fields. Planting of pineapple is done throughout the year, except in the days of heavy monsoon. Planting is done in trenches of about 90 cm width and 15-30 cm depth, aligned at a distance of 165 cm from centre to centre (KAU, 2016). The bare spaces between trenches and the high rainfall, which is a characteristic of the state promote the abundant growth of weeds. Black plastic mulching is a worldwide practice in pineapple cultivation for weed control. In the absence of mulching, pre-emergence herbicides are sprayed in the areas between trenches with subsequent growth managed by spraying post-emergence herbicides.

According to Girija and Menon (2019), the highest representation of weeds was observed from the family Asteraceae (10), followed by Poaceae (8) and Fabaceae (5). Frequency generally refers to the degree of uniformity of occurrence or dispersion of a species in an area and represents the number of sampling units in which that particular species occurred. In pineapple, highest frequency values were obtained for *Mikania micrantha* (63), *Chromolaena odorata* (60), *Merremia umbellata* (53.3), *Mimosa pudica* (50), *Alternanthera bettzickiana* (50), *Cyclea peltata* (46.6), *Centrosema pubescens* (43.3), *Cleome burmanii* (46.6), *Commelina diffusa* (43.3), and *Ichinocarpus frutescens* (43.3). Out of these ten weed species, five were climbers and the others were fast growing invasive species commonly found on disturbed soils. The higher frequency values reflect the greater uniformity and spread of these species and climbers were thus, a major problem in pineapple cultivation. Seasonal influence on weed diversity in the pineapple fields was observed with broad leaf weeds dominating from June-July to December and grasses from August to December. The population of climbers was almost uniform throughout the growing period.

Ginger

Pillai *et al*. (2015) studied variations in the weed flora in ginger in the four districts in Kerala where ginger is the major crop. In the plains (Thrissur and Palakkad) the major weed species were *Cyperus difformis, Cyperus haspan, Alternanthera betzickiana, Scoparia dulcis, Ageratum conyzoides, Mollugo pentaphylla* and *Ludwigia parviflora*. whereas in the high ranges *Spilanthes radicans, Ageratum conyzoides, Crassocephalum crepidioides, Scoparia dulcis, Erigeron Canadensis* were dominant. *Ageratum conyzoides, Scoparia dulcis, Ludwigia parviflora, Cyperus iria, Mimosa pudica* and *Eragrostis japonica* were the common weed species observed both in plains and high ranges. This indicated their adaptation to the micro climatic conditions in ginger crop. Usually high ranges (Idukki and Wayanad districts) have forest soil rich in organic matter and suitable for weed growth. At the same time, variation in weed species was observed between the plains and the high range ecosystems of Kerala due to the variability in climatic conditions mainly temperature. The results indicated that the growth and distribution of weed flora largely depend on the climatic conditions of the region.

Black pepper

Black pepper being widely spaced crop and grown in high rainfall tropical humid climate offers great scope for weeds to emerge and compete with crop at different magnitude (Parthasarathy and Kandiannan, 2009). *Ageratum conyzoides, Cynodon dactylon*. and *Spermacoce latifolia* were the most frequently occurring weeds in blackpepper crop having average frequencies of 62, 62and 52 per cent, respectively (Sajini *et al*., 2012).

Herbicide use and residues

The continuous use of herbicides leads to the problem of soil persistency which possesses far reaching environmental consequences. The longer persistence of herbicides poses a hazard to subsequent land use and is undesirable. The persistent quantity of herbicide present in soil in its original or closely related phytotoxic form after its operational function is referred as herbicide residue. Ameena (1999) reported non residual effect of glyphosate on germination and growth of successive crops. Yadav (2006) emphasized the safety of the herbicide pyrazosulfuron ethyl to soil environment and to the produce as the herbicides at all doses tested have dissipated before the harvest of crop and concluded that pyrazosulfuron ethyl did not leave any harmful level of its residues in the post experiment soil.

The effect of the herbicide flucetosulfuron 25 g ha^{-1} on soil enzymes viz., dehydrogenise, acid phosphatase, and urease and organic carbon content of soil under wet seeded system of rice cultivation was tested. Significant and positive correlation was noticed between dehydrogenase enzyme and organic carbon content of the soil. Acid phosphatase enzyme activity was found to be non-significant at 15 and 30 days after herbicide application, during both the seasons. It was also observed that herbicide application could increase the urease enzyme activity irrespective of dose and time of application, in both the seasons. Overall, the results revealed that none of the major enzymes were harmfully influenced by the sulfonyl urea herbicide, flucetosulfuron at the tested doses and time of application (Arya *et al*. 2018).

A long-term herbicide trial in rice- rice system showed that continuous application of butachlor/pretilachlor in rice for 13 years from 2001 to 2014 in a lateritic soil did not result in build-up of residues in soil, grain and straw. Farmyard manure application significantly improved the bioefficacy of herbicides. Increasing organic matter content increased the rate of adsorption of herbicides as well as degradation by soil micro flora. However, research results indicated that indiscriminate use of 2,4-D in lowland paddy fields in Kuttanad region (lying below the sea level) resulted in the persistence of residues in water bodies. Long-term application of herbicides had no significant negative effect on the basic soil properties, viz. pH, organic C and available nutrients (Durgadevi *et al*., 2019).

The effect of pre and post emergence herbicides on microbial biomass carbon and dehydrogenase activity in soils was studied by Amritha and Devi (2017). Results indicated that the herbicides had negative effect on microbial biomass carbon. Dehydrogenase activity also showed a decline due to the application of herbicides, but to a lesser magnitude than microbial biomass carbon. The adverse effect was pronounced only at 15 days after application of herbicides and followed the order viz., pendimethalin >bispyribac-sodium > oxyfluorfen > cyhalo fop-butyl. The adverse effects were of lower magnitude in the soils of high organic matter content.

Future outlook in developments in weed science

The weed science research is getting diversified with increased research activities in areas such as allelopathy, bio control, weed ecology, weeds utilization, crops cultivars with combined (stacked) herbicide tolerant traits, genome sequencing to understand weed populations; use of unmanned aerial vehicles (UAVs), imaging sensors-based tools and geospatial information technology, harvest weed seed control (HWSC) and integrated weed management (IWM). Revolutions in machine learning and automation have led to use global positioning system (GPS) to distinguish weeds from crops and deliver spot herbicide application. These technologies open multiple possibilities for efficient weed management, whether through chemical or mechanical mechanisms

Conclusion

The impact of weed management tactics on crop yield must be evaluated case by case for economic benefits to farmers. A system approach with emphasis on weed seed bank is critical in developing a strategy for management of annual weeds. A good understanding of biology and ecology of few major weeds in the system will further strengthen the efforts. Such an approach based on ecological principles and system concept in mind will ensure management of weeds on a sustainable basis. It is important to frame multi-tactic approach involving relevant preventive and cultural methods with little reliance on herbicides to help the small holder farmers.

The overall objective of the approach would be to: (i) reduce recruitment of weed seedlings from the soil seed bank,(ii) alter crop–weed competitive relations to the benefit of the crop and (iii) ensure gradual reduction of the size of the weed seed bank. Potential higher income with any new technologies would be an incentive for farmers. Farmers must be educated for implementing new and sustainable technologies. Weed science research must aim at developing integrated weed management systems that give farmers more flexibility and options which use both chemical and nonchemical practices in order to offer a more robust sustainable weed management system.

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CERTAIN OBSERVATIONS ON THE SPREAD OF THE INVASIVE SLUG *LAEVICAULIS ALTE* IN KERALA

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Abstract

Laevicaulis alte also known as the Tropical Leather leaf is a slug native to Africa. It has spread to many countries. It has been reported from many parts of India and is expanding its range stealthily. Field studies have been conducted in the early morning hours to record the terrestrial gastropod diversity in various ecosystems of Central Kerala from 2019 -2021. Data from direct field surveys and citizen science surveys through pictorial google forms shows the presence of *Laevicaulis alte* in all the 14 districts of Kerala. Studies in the forest ecosystem have also recorded the slug but only from the disturbed forest areas. In one recorded instance in Piravom municipality in Ernakulam, the slugs were observed to be comparatively bigger in size and turned pestiferous in nature. The morphometrics of the slugs of the area was also recorded for further study. Usually the slug spreads by ornamental plant trade. In some places where slugs have turned pestiferous, they pose a threat to vegetable crops. *Laevicaulis alte* has already established its population in many countries like USA and has attained the invasive pest status. Hence, it is necessary to monitor the slug population and its distribution.

Keywords: slug, gastropod, invasive malaco fauna, Tropical leather leaf, African slug

Introduction

Laevicaulis alte is a terrestrial slug which belongs to Class Gastropoda under Phylum Mollusca (Brodie and Barker, 2012).Gastropods include organisms like snail, slug and semi-slug. They perform a wide variety of ecologically important roles like nutrient cycling, detritivory, calcium reserves, pollination, seed dispersal and so on (Cyril and Joseph, 2023). Globally, the terrestrial gastropod fauna has many infamous invasive species like *Achatina fulica*, *Euglandina rosea* etc. which have wreaked havoc by spreading fatal diseases, destroying crops, causing aesthetic nuisance and affecting the native malaco fauna (Brodie and Barker, 2011).

Originally a native of Africa, *Laevicaulis alte* has expanded its range to Asia, Australia and most Pacific islands. The species have spread to new regions through horticultural trade(Ali and Robinson, 2022). They are phytophagus and feed on many ornamental plants and vegetables. Hence, they are also known as garden slug (Brodie and Barker, 2012).

Cyril,A.E. and Joseph,G.K. 2023. Certain observations on the spread of the invasive slug *Laevicaulis alte* in Kerala. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp .79-82,

Laevicaulis alte has many adaptations that helps it to thrive well in the tropical region. They possess good ability to camouflage against the soil and leaf litter layer. They have a leathery dorsal side and a narrow foot which help minimize the waterloss. At rest they shrink to a near oval shape to reduce the exposed area (Brodie and Barker, 2012).

Laevicaulis alte is an invasive pestiferous slug which can pose serious threat to many crops. They also affect the native species negatively (Ali and Robinson, 2022). The slug is infamous as a carrier of the Rat Lungworm which causes Human Eosinophilic Meningitis (Mahajan et al.,1992). Hence, it is important to study the ecology and population dynamics of such invasive species for effective management and control of these species.

Materials and methods

The study was conducted in different ecosystems of selected districts in Kerala namely Kottayam, Ernakulam, Idukki and Pathanamthitta. The study was conducted for three years from 2019 to 2021 during the pre-monsoon, monsoon and post-monsoon seasons. Random sampling was employed during early morning hours in quadrats of 1*1 sq. mtr. Opportunistic observations were also made whenever possible to study the ecology and biology of the slug. Citizen science survey was done by circulating a pictorial google form through peer groups, social media and mailing lists. Citizen science surveys were done during two years. It covered various aspects like local malaco fauna, local pest status, crops affected, natural predators of slug and the mitigation measures adopted. Five morphometric parameters viz., length, width, live weight, circumference and width of foot were studied. Measurements were taken using a twine and scale. Mean values were calculated using MS Excel.

Results and discussion

I. Observations on the Ecology of *Laevicaulis alte*

The slug was mostly observed in moist and shady habitats especially under leaf litter and damp soil. They are very active during the late evening and early morning time. The egg masses were recorded in the late monsoon period. The translucent eggs are seen in clusters. They are found in moist soil. Special faecal pellets with high soil content are also observed on top of this egg mass. This helps them to maintain humidity and prevent the eggs from drying off.

They feed on leaves of plants. They were observed to feed on leaves of tomato, cucumber, cabbage and brinjal during the study. The natural predators of the slug as observed during the study include duck, crow pheasant and glowworm larvae.

The slime is transparent and less viscous at normal state and it becomes thick whitish and sticky substance when the slug is disturbed. Similar observations were made by (Bhavare and Magare, 2017). The faecal matter appears as slender thread like substance. The colour of the faecal matter varies depending on the diet.

II. Distribution of *Laevicaulis alte*

From the systematic field surveys, opportunistic visits and citizen science surveys, it was found that *Laevicaulis alte* is found in all fourteen districts of Kerala.

Table 1: Presence of *Laevicaulis alte* in various ecosystems in Kerala

Sl No	Ecosystem	Presence of *Laevicaulis alte*
1	Agroecosystem	Yes
2	Wetlands	Yes
3	Disturbed Forest	Yes
4	Undisturbed Forest	No
5	Sholas	No

Laevicaulis alte was recorded in wetlands, agroecosystems and in some disturbed forest patches. It was found absent in the sholas and undisturbed forest areas. *Laevicaulis alte* was recorded from monoculture plantations as well as mixed crop agroecosystems. They were also recorded from uncultivated fallow lands. All *Laevicaulis alte* recorded during the study was observed from under leaf litter or moist hiding places like fallen logs.

Normally, the slug population has caused only minimal damages to the crops in our state. But in one instance from Piravom, Ernakulam, the slug population has become a nuisance in the agroecosystems and households near the Piravom river after the flood. The slugs increased in number and had comparatively bigger size. They mostly affected vegetable crops.

Table 2: Summary of morphometric analysis of *Laevicaulis alte* from Piravom region

Morphometric Parameter	Measurement			
	Minimum	Maximum	Mean	SD
Length (cm)	3.2	10.7	5.5	±2.0
Width (cm)	1.1	2.4	1.7	±0.5
Circumference (cm)	6.1	12.8	10	±2.7
Width of foot (cm)	0.4	1	0.7	±0.2
Live weight (g)	1.1	14.3	5.7	±3.2

Although the mean length of population is approximately equal to that reported from Odisha, standard deviation values show great variation in the slug population from Piravom region(Das and Parida, 2015).The mean live weight of the slug population is 5.7 ± 3.2g which is higher than that obtained in the previous studies (Das and Parida, 2015). Both these indicate that the slug population in the region attain higher growth which may be due to the ambient conditions like moisture, lush vegetation and moderate leaf litter layer near the riverine areas that facilitates their survival.

Conclusion

Laevicaulis alte has expanded its range all over Kerala through trade and ornamental routes. Though the slug population normally causes only minimal damages to the crops, in isolated instances, they have caused serious damages to vegetable crops. The slug was also recorded from disturbed areas of forest ecosystems which is indicative of the forest degradation due to anthropogenic interferences. A constant monitoring of the slug population using morphometric studies is advisable to know their status and effects on the society. If not controlled at early stages, the situation may run out of hand as in case of the Giant African Snail.

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A CHECKLIST OF INVASIVE PLANTS OF THREE MAJOR WETLANDS OF KODUMON GRAMAPANCHAYATH, PATHANAMTHITTA DIST.

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Abstract

An exploratory survey conducted on three major wetlands of Kodumon Gramapanchayth of Pathanamthitta district reveals the presence of 24 species of invasive alien plants. Among which *Mikania micrantha, Mimosa diplotricha, Salvinia molesta* and *Sphagneticola trilobata* shows serious levels of invasion and needs further attention.

Keywords: Invasive Alien Species, Wetland, Pathanamthitta, Invasive plants, *Mikania, Mimosa, Sphagneticola trilobata.*

Introduction

Biological invasion is considered to be the second biggest threat to natural ecosystems after habitat loss (CBD, 1994). Invasive Alien Plant Species (IAPS) refers to any plant species that are not native to that ecosystem which may have been accidentally or deliberately introduced to the ecosystem (Enserink, 1999; Van der Putten 2007), without any predator pressure to keep their populations in check they thrive and become invasive by displacing native plant species. The impacts of IAPS include displacement of native plant species, change of soil chemical profile and rewarding pollinators better than the native species thereby reducing the reproductive success of local species (Nilsson & Grelsson, 1995).

Invasive species can change the function of an ecosystem. Invasive species are closely related with rare native species and have the potential to hybridize with the native species. Harmful effect of hybridization has led to a decline and even extinction of native species (Kumar et al., 2009). Trivedi (2009) well illustrated the diagnostic features of invasive exotic which includes their ability to reproduce both asexually and sexually, fast growth rate, rapid reproduction, high dispersal ability, tolerance of a range of environmental conditions, and the ability to live off of a wide range of food types.

Alex, A. P. and Thomas, V. P. 2023. A checklist of invasive plants of three major wetlands of Kodumon Gramapanchayath, Pathanamthitta dist. In:, Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp. 83-87.

Methodology

The study was conducted on IAPS of Edathitta, Manjippuzha and Moozhikkal wetlands of Kodumon Gramapanchayath, Pathanamthitta district, Kerala (9°12'N 76°46'E). The surveys were conducted during the months of September - November 2022. The study site covers 147 acres comprising paddy fields and uncultivated fields, along with a small water body that exists year-round and a small stream that runs through the middle of the wetland. The study area has an elevation below 50 m from sea level and lies within 10 km of the Konni reserve forest. The site was divided into square cells measuring 30.5 x

30.5m and the flora was surveyed. The IAPS were identified using the 'Handbook on Invasive Plants of Kerala' (KSBB, 2012) and with the help of subject experts. The abundance of IAPS was estimated visually and recorded. A detailed checklist of Invasive plants was prepared with scientific name, family, habit and country of origin.

Results & Discussion

Taxonomy: The study on IAPS of the area has revealed that the area is composed of 24 species of IAPS belonging to 21 genera and 11 families (Table 1). Among Dicotyledons, Polypetalae is represented by two families (18.18%), five genera and seven species; Gamopetalae represented by three families (27.27 %), nine genera and nine species and Monochlamydeae represented by one family (9.09 %), two genera and three species. Monocotyledons represented by three families (27.27 %), three genera and three species. Pteridophytes (18.18 %) are represented by two genera and two species.

Habit: Among the IAPS, 37.5 % represented by herbs, 16.66 % represented by shrubs,

12.5% represented by floating herbs, 8.33% represented by creepers, 12.5 % represented by climbers and 12.5 % represented by sub-shrubs.

Contribution of Geographical Area: The contribution of Tropical America is 54.16%, Tropical Asia 8.33 %, Tropical Africa is 12.5 %, Central America is 25 %. The American continents have contributed majority of the IAPS of the study area.

Out of the IAPS recorded, *Mikania micrantha, Mimosa diplotricha, Salvinia molesta* and *Sphagneticola trilobata* showed the most invasive nature and possess a threat to the ecosystem.

Conclusion

The farmers engage in yearly weeding practices which keep the IAPS under control, but they go unchecked in uncultivated fields and can pose a serious threat to endemic flora and fauna if no proper measures are taken. This study was limited to only 3 small wetlands of Pathanamthitta district. The level of biological invasions has yet to be studied in the remaining habitats of the district. This study has not shown any significant monocot invasions, the extent of invasion by monocot members is to be re-evaluated.

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Fig 1: Location of Pathanamthitta dist.

Fig 2: Location of Kodumon Gramapanchayat.

Table 1: Checklist of Invasive Alien Plant Species.

Sl No:	Phylum	Class	Sub	Series	Family	Species	Habit	Country / Region of
1	Pteridophytes				Salviniaceae	*Salvinia molesta*	Aquatic Herb	Brazil
2					Dennstaedtiaceae	*Pteridium aquilinum*	Herb	Tropical America
3	Angiosperms	Dicots	Polypetalae	Disciflorae	Fabaceae	*Calopogonium mucunoides*	Creeping	Tropical Asia
4						*Centrosema*	Climbing	America
5						*Mimosa diplotricha var. diplotricha*	Sub shrub	Tropical America
6						*Mimosa pudica*	Herb	South America
7						*Senna alata*	Shrub	Tropical America
8						*Senna occidentalis*	Shrub	South America
9					Melastomataceae	*Clidemia hirta*	Shrub	Tropical Central and South
10			Gamopetalae	Inferae	Asteraceae	*Ageratum conyzoides*	Herb	Central America and Caribbean
11						*Cosmos sulphureus*	Herb	North America and
12						*Chromolaena*	Shrub	Tropical America
13						*Mikania micrantha*	Climbing	North, Central and South
14						*Sphagneticola*	Creeping	Tropical America
15						*Synedrella nodiflora*	Herb	West Indies
16						*Tridax procumbens*	Herb	Tropical America
17				Bicarpellat	Convolvulaceae	*Ipomoea cairica*	Climbing	Tropical Africa and
18					Lamiaceae	*Hyptis capitata*	Subshrub	Central America
19			Monochlamydea	Curvembryae	Amaranthaceae	*Alternanthera bettzickiana*	Herb	Tropical America
20						*Alternanthera brasiliana*	Subshrub	Mexico to Brazil
21						*Amaranthus spinosus*	Herb	South and Central
22					Alismataceae	*Limnocharis flava*	Aquatic Herb	America

23		**Monocots**		**Apo**	Araceae	*Pistia stratiotes*	Aquatic Herb	Africa
24				**Glumac**	Poaceae	*Pennisetum*	Herb	Tropical Africa

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TAXONOMIC DOCUMENTATION OF INVASIVE ALIEN ANGIOSPERMS IN PATHANAMTHITTA MUNICIPAL AREA

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Abstract:

Taxonomic documentation of the Invasive Alien Angiosperms (IAA) in Pathanamthitta Municipality revealed that the area harbours 48 species of IAA composed of 49 species of IAA belonging to 39 genera and 21 families. Among Dicotyledons, Polypetalae is represented by 7 families (33.3 %), 9 genera and 12 species; Gamopetalae is represented by 8 families (38.09%), 20 genera and 26 species and Monochlamydeae is represented by 5 families (21.00%), 8 genera and 9 species. Monocotyledons are represented by 1 family (4.7 %), 2 genera and 2 species. Asteraceae is the most dominant family in the study area. Most of the invasive alien plants in Pathanamthitta municipality are indigenous to the American continents.

Keywords: Taxonomic documentation, Invasive, Alien Angiosperms, Pathanamthitta, Municipality

Introduction

An invasive alien species is a plant or animal those are not native to a specific location, and has the tendency to spread which is believed to cause damage to the environment and the human health. Invasive alien plants leads to loss of biodiversity including species extinction, and changes in hydrology and ecosystem function (Pandey *et al*., 2009). These biological invasions of plants are believed to be the 2nd largest cause of current biodiversity loss, after habitat destruction (Vitousek, *et al.,* 1997). Most alien plant species that are known to be invasive in India were 1st introduced in to the country as ornamentals. They decline the yield of agricultural crops, forests, decrease the water availability and also contribute to the spread of disease (Srivasthava & Srivasthava, 2009).Biological invasions are intentionally or unintentionally introduced species in to a new area or alter ecosystem in ways that promote invasions. Global factors both primary and secondary that supports the introduction and spread of alien invasive species. Trivedi (2009) well illustrated the diagnostic features of

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invasive exotic which includes their ability to reproduce both asexually and sexually, fast growth rate, rapid reproduction, high dispersal ability to live off a wide range of food type.

Materials and Methods

The present study is based on the repeated collection of available specimens of invasive alien angiosperms from 32 wards of Pathanamthitta Municipality area in its reproductive and vegetative stages. The specimens of appropriate size with relevant plants were collected from the field and sealed in polythene covers after treating with formaldehyde. Herbaria were prepared following wet method. The dried specimens were mounted on the herbarium sheet and labelled properly, after including all the relevant information. The specimens were deposited in the herbarium of Catholicate College, Pathanamthitta. The specimens were identified with available literature. After identification, worked out each material and drawn in Gate way tracing paper using Micro tip pen (ROTRING). Illustration consists of habit, flower, sepal, petal, stamens, gynoecium, ovary c.s., seed and fruit.

The materials collected were brought to laboratory for the detailed study of microscopic characters. Observations were made using a dissecting microscope. Invasive alien plants were identified using Kumar *et al.* (2009), Chatterjee *et al.* (2009), Singh and Singh (2009), Srivastava and Srivastava (2009), Sajeev *et a.,*.(2012), Sasidharan (2012) and Surendra *et al.* (2013).The present work is based on the survey and the taxonomic studies on invasive alien angiosperms of Pathanamthitta Municipality and the consultation of herbarium specimens deposited at CATH and KFRI. The specimens were identified using Floras, Monographs, publication, *etc.* The identity of the taxon was confirmed with materials deposited at CATH and KFRI.

Citations of all taxa published were obtained from IPNI. The databases of the International Plant Name Index (IPNI). (http:www.ipni.org) was utilized. Author names were given following *Author of plant name index* by Brummitt and Powell (1992). Acronyms of herbarium (Thiers, 2011).The risk status if the species were tentatively identified and grouped based on Sajeev*et al*., 2012.

Results and Discussion

A preliminary taxonomic investigation on the Invasive Alien Angiosperms (IAA) of Pathanamthitta Municipality has revealed that the area is composed of 49 species of IAA belonging to 39 genera and 21 families (Table 1). Among Dicotyledons, Polypetalae are represented by 7 families (33.3 %), 9 genera and 12 species; Gamopetalae are represented by 8 families (38.09%), 20 genera and 26 species and Monochlamydeae are represented by 5 families (21.00%), 8 genera and 9 species. Monocotyledons are represented by 1 family (4.7 %), 2 genera and 2 species.

Table 1. Representing families

Families	Number of Genera	Number of Species
ACANTHACEAE	1	1
AMARANTHACEAE	3	4
ASTERACEAE	11	12
CAESALPINACEAE	1	2
CAPPARIDACEAE	1	2
CONVOLVULACEAE	2	6
EUPHORBIACEAE	1	2
LAMIACEAE	1	2
MALVACEAE	1	1
MELASTOMACEAE	1	1
MIMOSACEAE	1	2
PAPILIONACEAE	3	3
PASSIFLORACEAE	1	1
PHYTOLACEAE	1	1
PIPERACEAE	1	1
POACEAE	2	2
PONTEDERIACEAE	1	1
RUBIACEAE	1	1
SOLANACEAE	1	1
SCROPHULARIACEAE	1	1
VERBENACEAE	2	2

Taxonomic distribution of alien flora: In the alien flora of the Pathanamthitta Municipality, Asteraceae are the most dominant family with 11 genera and 12 species (Table 2). It may be due to their prolific seed production and ability to spread fast. Asteraceae are the dominant invasive family and contributed most of the exotic weed species in our country (Reddy, 2008). Singh *et al.* (2010) also recorded the dominance of Asteraceae in invasive alien flora of Uttar Pradesh. Rao and Murugan (2006) also recorded that Asteraceae are the dominating family in alien flora of India. Amaranthaceae are the second largest family represent by 3 genera and 4 species. Due to the suitable conditions, they grow abundantly. Fabaceae are the third largest family represented by 3 genera and 3 species, and having the potential of Nitrogen fixing capacity which would be helpful to them in colonizing the empty niches. Due to the nitrogen-fixing bacteria associated with these taxa, these species improves the soil fertility. Other families *viz.* Convolvulaceae are represented by 2 genera and 6 species, Verbenaceae are represented by 2 genera and 2 family Euphorbiaceae are represented 2genera and 2 species, Poaceae are represented by 2 genera and 2 species.

Table 2. Relative dominance of families of invasive alien angiosperms in the study area

Family	Number of Genera	Number of Species
ASTERACEAE	11	12
AMARANTHACEAE	3	4
PAPILIONACEAE	3	3
CONVOLVULACEAE	2	6
EUPHORBIACEAE	2	2
POACEAE	2	2
VERBENACEAE	2	2

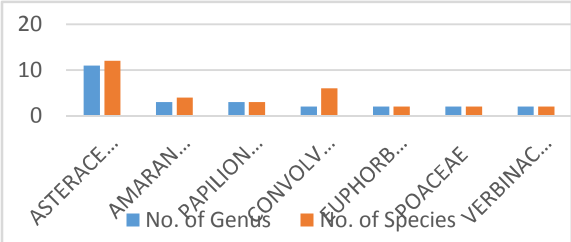

Figure 1: Relative dominance of families of IAA

Habit-wise Distribution: Among the Invasive Alien Angiosperms, 53.06% is represented by herbs, 28.57% by shrubs 2.04% by floating herbs, 12.2% by climbers, 4.08% by sub-shrubs. Habit-wise analysis shows herbaceous species share 151 species of Invasive alien species in India (Reddy, 2008). The herbs having greater vegetative and tolerance to harsh conditions could results in the dominance (Surendra *et al*., 2013).

Contribution of Different Geographical Regions: Contribution of different geographical regions in terms of nativity is shown in Figure 2 (Table 3). The contribution of Tropical America is 48.98%, South America is 16.32%, Central America is 10.20%, North America is 2.04%, Africa is 6.12%, Australia is 2.04%, West Indies is 4.08%, Asia is 8.16%, and Pan-tropical is 2.08%. The American continent contributed majority of the Invasive Alien plants in Pathanamthitta Municipality.

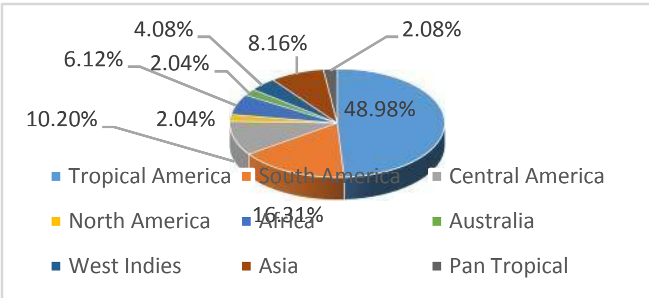

Figure 2: Contribution of different geographical region

Potential Uses of Alien flora: A search in the literature indicated that several of these species have potential uses for different purposes (Figure 3.) This can be important for management of these alien floras in sustainable way. The analysis of uses of Invasive Angiosperm of Pathanamthitta Municipality indicates (in the Figure 3. 8) 77% of IAA are medicinal, 4.08% are edible, 6.1% are cover crops, 4.08% are fodder, 6.12% are ornamental, and 40.85%are unknown.

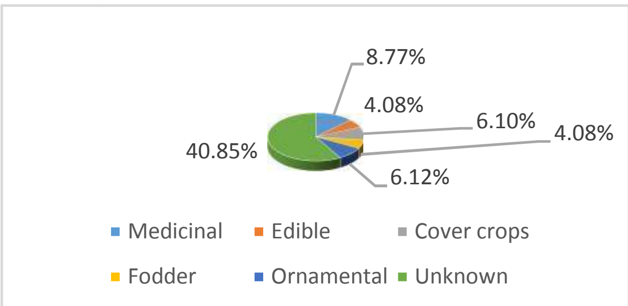

Figure 3: Potential uses of alien flora

Possible mode of Introduction of Alien flora: Based on literature, only 11 (22.91 %) seems to have been introduced deliberately and the rest of them unintentionally through trade exchanges including grain import (Surendra, *et al.*, 2013). The mode of introduction of plants is represented in the Figure 4. In this study 6.12% of plants are introduced as ornamentals, 6.1% as cover crop, 1.85% as food and 40.85% as unintentional.

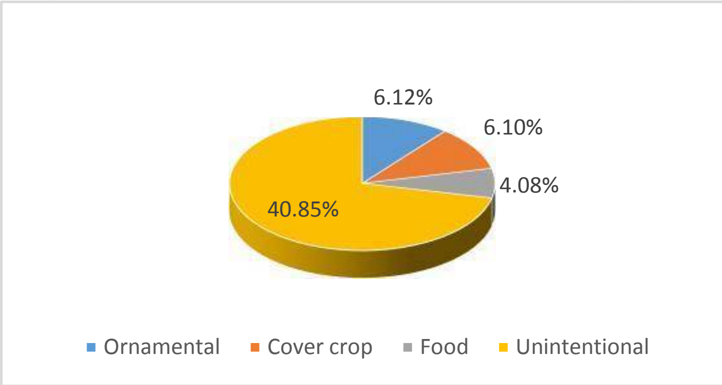

Figure 4: Possible mode of introduction of alien flora

Risk analysis

The IAA of Pathanamthitta Municipality has been tentatively grouped into 4 classes based on their nature, specificity and risk *viz.* High risk, Medium risk, Low risk and Insignificant following Sajeev *et al*. (2012).

Table 3. Alien invasive species in Pathanamthitta municipality & their risk classes

SPECIES	FAMILY	HABIT	RANK	NATIVE	USES	PURPOSE OF INTRODUCTION
Ageratum conyzoides	Asteraceae	Herb	Low	Trop. America	Medicinal	Ornamental
Ageratum haustonium	Amaranthaceae	Herb	Low	Trop. America	_	_
Alternanthera bettzikiana	Amaranthaceae	Herb	High	Tropical America		
Alternanthera brasiliana	Amaranthaceae	Herbs	Insignificant	Central & South America	Ornamental	Ornamental
Amaranthus spinosus	Amaranthaceae	Herb	Low	Trop. America	Medicinal	_
Blumea lacera	Asteraceae	Herbs	Low	Tropical America	_	_
Calopogonium mucunoides	Papilionaceae	Herb	Low	Trop. America West Indies	Cover crop	
Centrosema molle	Papilionaceae	Climber	Medium	Central America	Cover crop	Cover crop
Chromolaena odorata	Asteraceae	Shrub	High	Trop. America	_	_
Cleome burmannii	Capparidaceae	Herb	Low	Indo-Malesia	_	
Cleome viscose	Capparidaceae	Herb	Medium	Trop. America	Medicinal, Edible	Ornamental
Clidemia hirta	Melastomaceae	Shrubs	Medium	Tropical America	_	_
Crassocephalum crepidioides	Asteraceae	Herbs	Low	Tropical America	_	_
Cuscuta refloxa	Convolvulaceae	Climbers	Medium	Mediterranian	_	_
Dactyloctenium aegyptium	Poaceae	Herb	Low	South America	Medicinal	
Datura innoxia	Solanaceae	Shrub	Low	Trop. America	_	Ornamental
Eclipta prostrata	Asteraceae	Herb	Insignificant	Trop. America	_	_
Eichhornia crassipes	Pontederiaceae	Floating	High	Trop. America	_	Ornamental

		herb				
Euphorbia hirta	Euphorbiaceae	Herb	Low	Trop. America	Medicinal	
Gomphrena celosioides	Amaranthaceae	Herb	Medium	South America	_	
Hibiscus hispidissmus	Malvaceae	Shrubs	Medium	Asia	_	_
Hyptis capitata	Lamiaceae	Shrub	Medium	Central America	_	_
Hyptis suaveolens	Lamiaceae	Sub shrub	Medium	Trop. America	Medicinal	_
Ipomoea cairica	Convolvulaceae	Climber	Medium	Africa & Asia	_	_
Ipomoea carnea	Convolvulaceae	Shrub	Medium	Trop. America	Medicinal	_
Ipomoea hederifolia	Convolvulaceae	Climbers	Low	Trop. America	*Ornamental*	_
Ipomoea purpueria	Convolvulaceae	Climbers	Low	Trop. America	_	_
Lantana camara	Verbenaceae	Shrub	High	Central America	Medicinal	Ornamental
Merremia vitifolia	Convolvulaceae	Climber	High	Asia	Medicinal	_
Mikania micrantha	Asteraceae	Climber	High	South America	Cover crop, Fodder	Cover crop
Mimosa diplotricha	Mimosaceae	Sub shrub	High	South America	Cover crop, Fodder	Cover crop
Mimosa diplotricha	Mimosaceae	Sub shrub	High	South America	Cover crop, Fodder	Cover crop
Mitracarpus hirtus	Rubiaceae	Herb	Low	Trop. America & Trop. Africa	_	
Parthenium hysterophorus	Asteraceae	Herb	High	North America	Medicinal	
Passiflora foetida	Passifloraceae	Climber	High	South America	Medicinal, Edible	
Pennisetum polystachyon	Poceae	Herb	Medium	Paleo-Tropical	_	
Peperomia pellucida	Piperaceae	Herb	Insignificant	South America	_	_
Pueraria phsilioides	Ppilionaceae	Herbs	High			
Ricinus communis	Euphorbiaceae	Shrub	Medium	Trop. Africa	Bio-fuel	
Rivina humilis	Phytolaceae	Shrubs	Low	Trop. America	_	-
Ruellia tuberosa	Acanthaceae	Herb	Low	Trop. America	Medicinal	_
Scoparia dulcis	Euphorbiaceae	Herb	Low	Trop. America	_	-
Senna alata	Caesalpiniaceae	Shrub	Low	South America	Medicinal	Ornamental
Senna occidentalis	Caesalpiniaceae	Shrub	Low	South America	Medicinal	_
Spilanthess radicans	Asteraceae	Herbs	Low	Trop. America	Medicinal	_
Stachyterpheta jamaicensis	Verbinaceae	Shrubs	Insignificant	Trop. America	_	_
Synedrella nodiflora	Asteraceae	Herb	Low	West Indies	_	
Tridax procumbens	Asteraceae	Herb	Low	Central America	Medicinal	
Wedelia trilobata	Asteraceae	Herb	Low	West Australia	Ornamental	

Studies are also needed to understand their introduction pathway and status and to quantify the severity of invasion in different habitat. Global Invasive Species Program (GISP) proposes three major management options– prevention, early detection and eradication (Syrett *et al*., 2000).

Invasive alien species are increasingly seen as a threat not only to biodiversity and ecosystem services, but also to economic development and human well-being. They reduce yield of agricultural crops, forest and fisheries, decrease water availability, cause costly land degradation, block transport routes and contribute to the spread of disease. They also reduce effectiveness of development investment by chocking irrigation canals, fouling industrial pipelines and impeding hydroelectric facilities (Pandey *et.al,* 2009).

Invasive species are tolerant against environmental extremes and possess greater flexibility for survival in wide range of condition with high water, light and nutrient use efficiencies.

Some of the invasive species also exhibit fire resistance besides better competitive ability and allelopathy (Dey, 2009).

Although an invasive species is often defined as an introduced species that has spread widely and causes harm, some species native to a particular area can, under the influence of natural events such as long term rainfall changes or human modifications to the habitat, increase in numbers and become invasive (Kumar *et.al*, 2009).

Prevention is the most cost efficient and effective method against invasive alien species. Halting the establishment of potentially invasive species in the first place is the first line of defense. Government conduct customs checks, inspect shipment, conduct risk assessments and set quarantine regulations to try to limit the entry of invasive species. However, global inspection and risk analysis capacity is usually not sufficient (Kumar *et.al*, 2009). Exotic invasion is often associated with declines in local plant diversity (Richardson *et al*., 1989). To verify this quantitatively in Pathanamthitta municipality area, further study on correlation between native species richness and abundance of alien flora should be carried out.

Conclusion

This present work is an attempt to document the Invasive Alien Angiosperms (IAA) of Pathanamthitta Municipality area and to prepare a brief account on the taxa with a key for identification. The listed invasive exotic species will serve as basic information for future research towards the conservation of endemic and natural vegetation of this area. In Pathanamthitta Municipality area, 49 species of IAA are distributed in 39 genera under 21 families. From the study it is noticed that terrestrial plants are dominant than aquatic forms. Out of the 48 species of IAA in the Pathanamthitta Municipality 11 falls under high risk category, 12 pose medium risk category, 21 pose low risk category and 5 are insignificant category. Majority of the species are native to Tropical America (48.98%). The present study also suggests some of the control measures to check the spread and development of IAA of Pathanamthitta Municipality area.

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A STUDY ON THE DISTRIBUTION OF INVASIVE PLANT SPECIES ALONG AN URBAN-RURAL GRADIENT, MALAPPURAM, KERALA

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Abstract

An invasive species is a plant, fungus or animal that is not native or non-indigenous and can displace native habitat, disrupt nutrients and cause changes in an ecosystem. According to the convention for biological diversity, invasive species are the second most threat to biodiversity. Generally, they are introduced as a consequence of anthropogenic activities. Invasive alien plants have caused extensive economic and ecological damage by homogenizing the flora of native ecosystems. Roads play a key role in spreading invasive species as it serves as prime habitats and corridors for invasive plant species. Thus it can gradually affect and can contribute significantly to the spread and establishment of weeds along urban to rural areas. Urban ecology deal with the interactions between organisms and human-dominated environment and linear intrusions enhance the spread of invasive species. According to the study of global invasive species, data reported 242 invasive species. Of these 173 plant species were recorded from India. Species such as *Lantana Camara* L., *Euphorbia Heterophylla* L., *Parthenium Hysterophorus* L., and *Mikania Micrantha* are widely established in various parts of India. Hence, it is very essential to study the extent of the proliferation of invasive species in urban areas. The current study aims to know the status of invasive species along the roadside areas of the Tirur to Parappanangadi region. The survey was conducted on the Tirur to Parappanangadi road which connects Tirur and Kozhikode. A total of thirty 30mx3m rectangular plots were randomly selected along the road. The number and area occupied by invasive and native plant species encountered within these plots were recorded and identified with the help of the "Handbook on invasive plants of Kerala" published by Kerala Forest Research Institute. This study delivers detailed information on the density and diversity of invasive alien species and co-occurring species along an urban-to-rural gradient.

Keywords: Invasive plants, Urban ecology, Diversity, Abundance

Introduction

Anthropological disturbance alters both structure and function of biodiversity (Blair 2004). Such disturbances reduce species abundance, and habitat loss, and spread zoonotic diseases (Covid 19) directly or indirectly (The global assessment report on Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services 2019). Rapid changes in landscapes

Aswathy Nair, R. and Dhanya, R. 2023. A study on the distribution of invasive plant species along an urban-rural gradient, Malappuram, Kerala. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp. 96-102.

adversely affect both humans and biodiversity (Dhanya 2011). Agricultural expansion and urbanization lead to urban heat islands; intensity impacts many aspects of biodiversity (Marzluff 2001).

In India, urban ecological studies are still in the preliminary stage. The linear intrusions (roads and railways) promote the dominant spread of invasive alien species (IAS) in an urban ecosystem. Invasive species canspread mainly through the 3T's Travel, Trade and Tourism (Thomas & Moloney, 2013). IAS include animals, plants or organisms introduced through human activities that can establish and spread rapidly across large areas by replacing natural ecosystems (Deparis et al., 2022). IAS have rapid reproduction and growth, high dispersal, physiological adaptation to new conditions and the ability to survive in different environmental conditions. In India, most plant species are exotics which are natives of America, Africa, Europe and Australia. (Sharma et al., 2001) and led to the biotic homogenization of urban habitats (McKinney and Lockwood 1999). Biotic homogenization is the process of replacement of endemic or native communities by widespread exotic species (McKinney & Lockwood 1999). The spread of IAS through transportation increases the rate of extinction of native species.

The state urbanisation report shows a rapid increase in the urban population in Kerala. This depicts the growth of the economy with the high rate of foreign exchange of money as compared to other states (Lal & Nair, 2017). According to development, road density in Kerala rose each year. Kerala's total road length for 2019–20 is 3,31,904.11 km (ENVIS, Kerala). Both classified and unclassified routes are included in this. Such fragmentation of landscapes leads to a significant loss of natural habitats and water bodies, reducing open spaces in Kerala.IAS spread rapidly in urbanized areas which converts natural ecosystems, decreases the rate of native plant-pollinator interaction, and extinction of endemic plants (Kohli et al., 2004). They indirectly affect hydrology and soil quality, affecting the provisioning of ecosystem services, and due to costs incurred in their control or management.

Objective

To quantify the distribution and diversity of invasive and native plant species along an urban-rural gradient.

Methodology

Study area

Malappuram is Kerala's largest district, situated at 11.0510° N latitude and 76.0711° E longitude. The climate of the study area is tropical monsoon and the average rainfall is 3266 mm and the temperature ranges from 28^0 c to 38.8^0c. This region has a well-developed transport system with roads and railways. An intensive study was conducted along the 20 km from Tirur to Parappanangadi stretch.

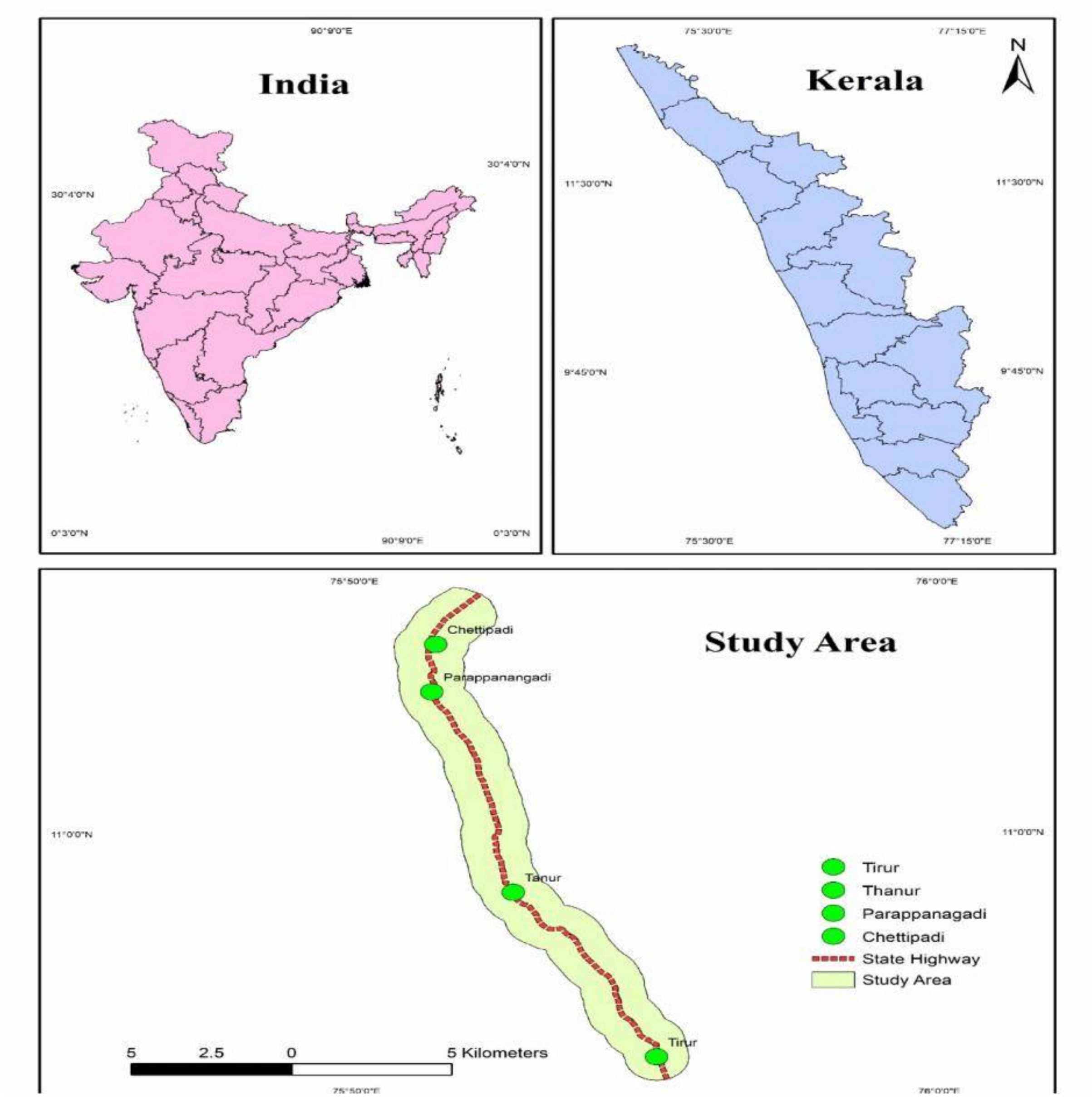

Fig 1: Study area (Source: Google earth pro)

Method

Sample plots (30m x 3m) were selected randomly along the urbanization gradient at every 1 km interval (Fig.1) All plants were identified and documented by species level with the help of the Handbook of Kerala Forest Research Institute and the International Plant Name Index (2019). The co-occurring plants in the same quadrant were identified and quantified using keys pertinent to the study area. To assess the quantitative distribution and density indices on species richness and proportional abundance (Shannon Index H') Species dominance was estimated by using Pielou's evenness index (Prasanna *et al*.2019)

Results

According to the study, the IAS in the Tirur area were intermediately diversified. There are 14 invasive plants and 12 native plants identified from the 20 plots in the study area and were representatives of six families, such as Amaranthaceae, Fabaceae, Asteraceae, Euphorbiaceae, Lamiaceae and Combretaceae (Fig.2). As for the results of the study site Shannon diversity values significantly vary. The Highest Shannon diversity index (H = 0.30) was observed in plot number 6. This point tended to show the highest IAS diversity and species distribution over all the other points. In contrast least, the Shannon diversity index (H = 0.00) was observed in plot 12, where only one species of IAS was recorded. The highest evenness value (E = 0.35) was observed in plot 6 while the lowest evenness value (E = 0.00 was observed in plot 12.

Discussion

The Asteraceae family has about 2162 individuals followed by the Lamiaceae, which has just one species (Hyptis suaveolens) but has a large number of that one species. The highest family represented in the study area was Asteraceae, followed by almost equal numbers of individuals represented from thefamilies Fabaceae and Combretaceae Similarly from the family Amaranthaceae only one species was represented in the family (Fig.1).

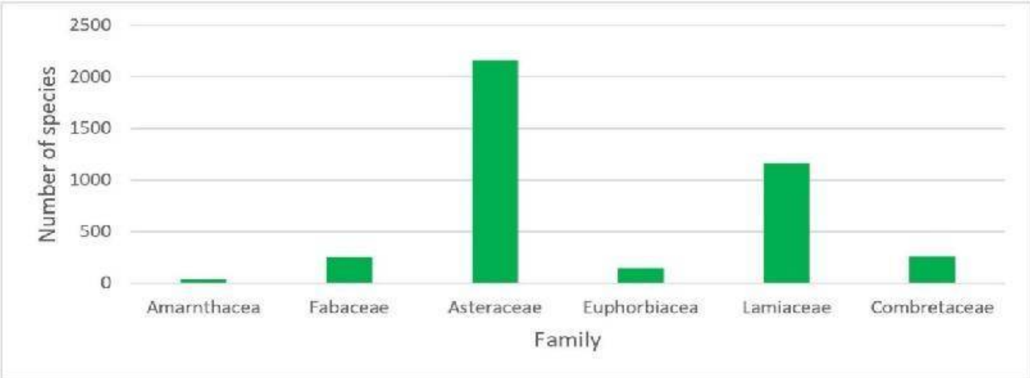

Fig 2: Graph showing Familie

The highest density occured in plot number 6 (Fig.3). This particular point was located near a vacant area with traffic passing by on both sides, the availability of water, as well as the absence of canopy coverage, may have contributed to the largest abundance of species in plot number 6. *Chromolaena odorata* and *Hyptis suaveolans* species have been found in this plot (Fig.4).

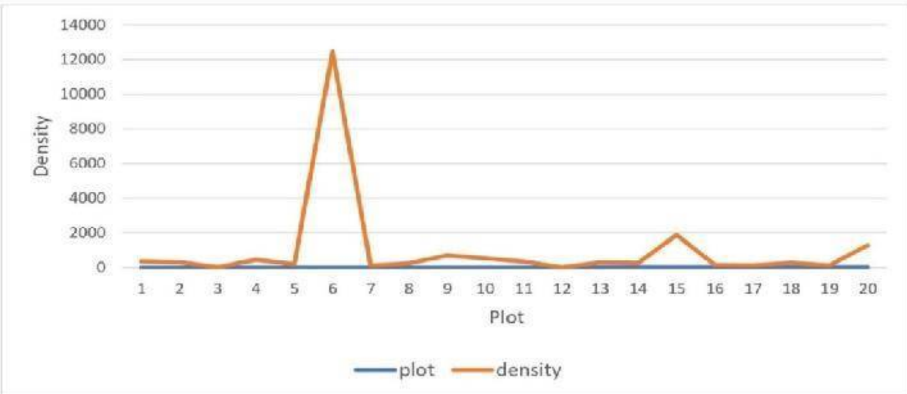

Fig 3: Graph showing Densities

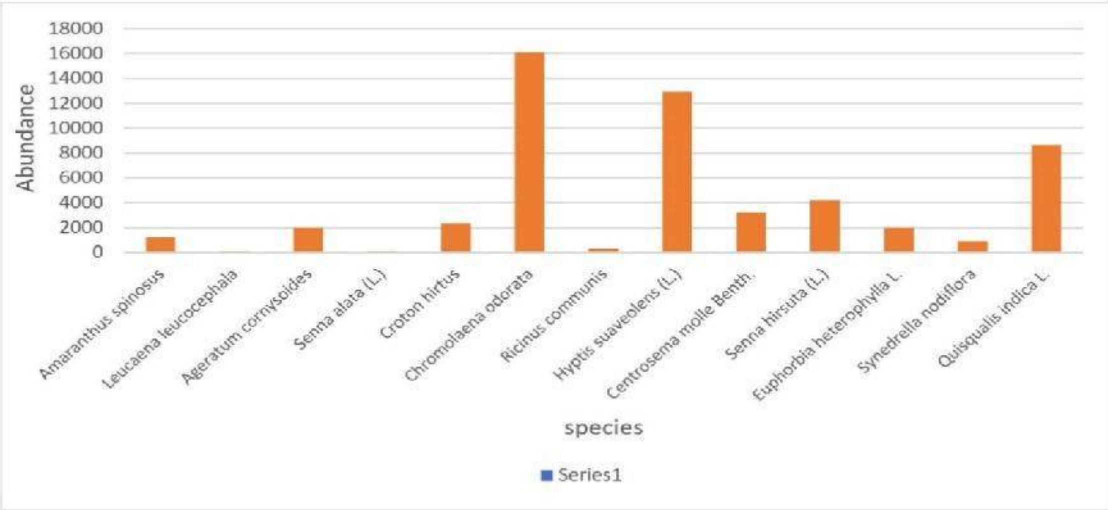

Fig 4: Graph showing abundance

The Plot number 1 has a high species accumulation due to the diversity of six species. This vacant property was close to the town of Tirur. In the research area, there is a variation in the spread of IAS. Additionally, plots 5, 10, and 15 showed high species accumulation, which was located 3m from the road, and lacked canopy cover. (Fig.6).

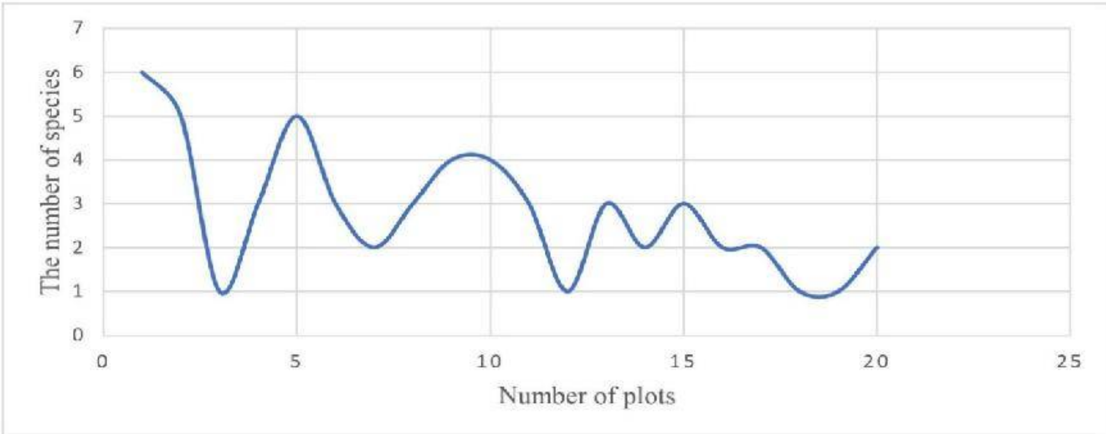

Fig 5: Graph showing abundance Species accumulation in plots

The sixth plot has the best evenness, followed by plots 15 and 19. The evenness shows an ascending and descending pattern. Because it is clear from the analysis that habitat characteristics significantly impact the dominance of plant species along the roadsides (Graph No.5).

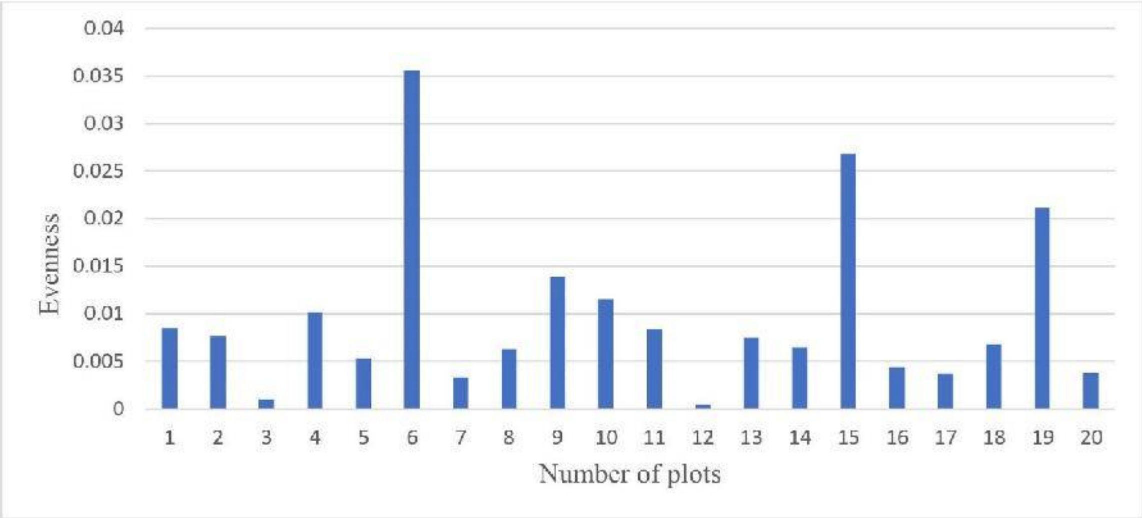

Fig 6: Graph showing Evenness

Conclusion

From the study area,14 Invasive alien species and 12 co-occurring plants were identified. According to the study site's Shannon diversity values, the results were notably different from one another. The plot with the highest Shannon diversity index (H = 0.30) was plot number 6. The Asteraceae family contained a large number of members in the study area. The most common species was *Hyptis suaveolens,* followed by *Chromolaena odorata*. This shows that invasive plants can spread quickly along urban gradients without taking into account environmental disturbance elements that occur along roadsides. The roadside also encourages the growth of IAS, which can endure in disturbed environments. Habitat characteristics have a significant impact on the growth of plant species along the roadside. Therefore, deliberate efforts should be made to control these species and inform the community about the proliferation of these plants. Public participation is necessary for the eradication of invasive plants.

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A REPORT ON THE BIOLOGICAL INVASION OF ALIEN PLANT SPECIES RED CABOMBA IN THE KOZHIKODE DISTRICT OF KERALA STATEAND ITS IMPACT ON AGRO-ECOSYSTEM

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Abstract

Globally, introduction of exotic species or organisms have created serious problems in their new environments, including India. These exotic species are also known by other names like invasive species, non-indigenous species or bioinvaders. Once introduced deliberately or accidentally outside their natural distribution areas, these alien species become 'invasive' when they out-compete the native species and upset the ecological balance. Recently a new aquatic plant species, Red cabomba (*Cabomba furcata*) attracted the attention of many people for its panoramic view, in the Avalappandi canal area, Kozhikode District of Kerala state, South India. An exploratory survey on this alien invasive species revealed that it was non-native to this agro-ecosystem of Kozhikode which is predominantly one season paddy cultivation area. Certain morphological observations were recorded on Red cabomba *i.e*. plant habit, stem width, leaf and floral characters. Moreover, the study indicated that the presence of alien species in the Avalappandi canal area not only concerns the immediately affecting paddy crop farmers but also other stakeholders of the region. Now the Red cabomba is on the invasive mode, fast spreading into the fresh waterbodies of other districts also. If unchecked, under the changing climatic conditions, it can fast spread to other ecologically sensitive areas of Kerala state leading to economic, environmental harm or even adversely affect human health. Hence, there was an urgent need to investigate the mode of spread and risk assessment on the Red cabomba aquatic plant to mitigate the menace in this agro-ecosystem of India.

Key words: Alien species, Changing climate, Epidemics, Invasion, Red cabomba

Introduction

Humans have been responsible for the introduction of exotic species or organisms throughout the world which have created serious problems in their new environments (Gopal, 1998) and India was no exception to this. These exotic species are also known by other names like invasive species, non-indigenous species or bioinvaders. An alien species become 'invasive' when they are introduced deliberately or accidentally outside their natural distribution areas,

Prabhakara Rao, G. and Syamala Rani, K.M.S. 2023. A report on the biological invasion of alien plant species Red Cabomba in the Kozhikode district of Kerala state and its impact on agro-ecosystem. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.103-109

where they out-compete the native species and upset the ecological balance. The most common characteristics of invasive species are rapid reproduction and growth, high dispersal ability. Bio-invasion may be considered as a form of biological pollution and significant component of global change and one of the major causes of species extinction (Mooney and Drake, 1987; Drake *et al*. 1989; Powell *et. al*. 2011). In India, around 173 species of invasive alien plants were identified so far (Reddy *et al*., 2008; Sandilyan, 2022), which include 33 aquatic most seriousinvasive species. Among the 33 invader species of wetlands, *Alternanthera philoxeroides, Eichhornia crassipes, Aerva javanica, Aeschynomene americana, Alternanthera paronychioides, Asclepias curassavica* were on the top of the list.The alarming situation of different plant invasions into India and their ecological impacts leading to the loss of biodiversity and also in terms of ecosystem services were well documented (Gopal, 1998; Rasmi and Balakrishnan, 1998; Powell *et. al*. 2011; The Hindu, 2022a). They also create heavy economic losses globally (Reshi and Khuroo, 2012; Pimentel *et. al*. 2001) and also to the Indian economy (Ghosh,2022).

Recently the authors have observed an aquatic plant species- Red cabomba, locally known as 'Mullan payal' in the water bodies of Avala Pandi area of Kerala state, India (Rao, 2022). It was commonly known as Red cabomba and forked fanwort. Red cabomba belongs to the clade- Angiosperms, order- Nymphaeales, family- Cabombaceae, genus-Cabomba, and species-*Cabomba furcata*(Schult and Schult, 1830). The alien species was non-native to the agro-ecosystem of Kozhikode District(The Hindu, 2022a; Rao, 2022).This can cause economic devastation, environmental harm and even adversely affect the human health of the surrounding people. Due to the changing climatic conditions, often it can spread quickly into the new environment, can cause epidemics and economic loses to the local population. Since, no studies were conducted so far on this species, a preliminary investigation was undertaken on the aquatic plant, Red cabomba to identify its basic nature and possible threats to the agro-ecosystem of Kozhikode District, India.

Materials and methods

The aquatic plant, Red cabomba was native to the Central and South America, tip of the Florida and as far north as Cuba. This alien plant was found to be growing in several canal areas of Kerala state, South India. An investigative study was conducted during 2022 at the water bodies of AvalaPandi area in Cheruvannur Grama Panchayat near Perambra in Kozhikode District of Kerala state. A map of the Avala Pandi area in CheruvannurGrama Panchayat location and shaded relief of Kozhikode District, Kerala state, India is depicted in Fig.1.Cheruvannur grama panchayat of Kozhikode district is one of the 78 panchayats with a total population of 22150 and number of households are 4663 (Census, 2001). It lies between North Latitude 11° 32′ 37.11" and 11° 36′ 4.67", East Longitude 75° 40′ 26.32" and 75° 43′ 55.22". It has a total area of 21.61 square kilometers. The adjoining grama panchayats are Thiruvallur and Velom in the north, Perambra in the east, Nochad, Meppayur, and Thurayur in the south, Maniyur and Thiruvallur in the west. The Kuttiyadi river, erstwhile known as Kotta river was flowing fromnorth to south, through the eastern side, detaches the grama panchayat from Vatakara taluk. The physiography was not planar. The ridges of smaller and medium hills and low lying valleys make the area an undulating terrain. This Grama panchayat can be divided into three, according to the physiography – *viz*, hilly area, slopes and valleys. The highest area in grama panchayat was Purakkamala noted with a height of 115 meters above sea level. Cheruvannur Grama panchayat includes some of the lowest lying places of the region and parts of these areas are often flooded during monsoon season.

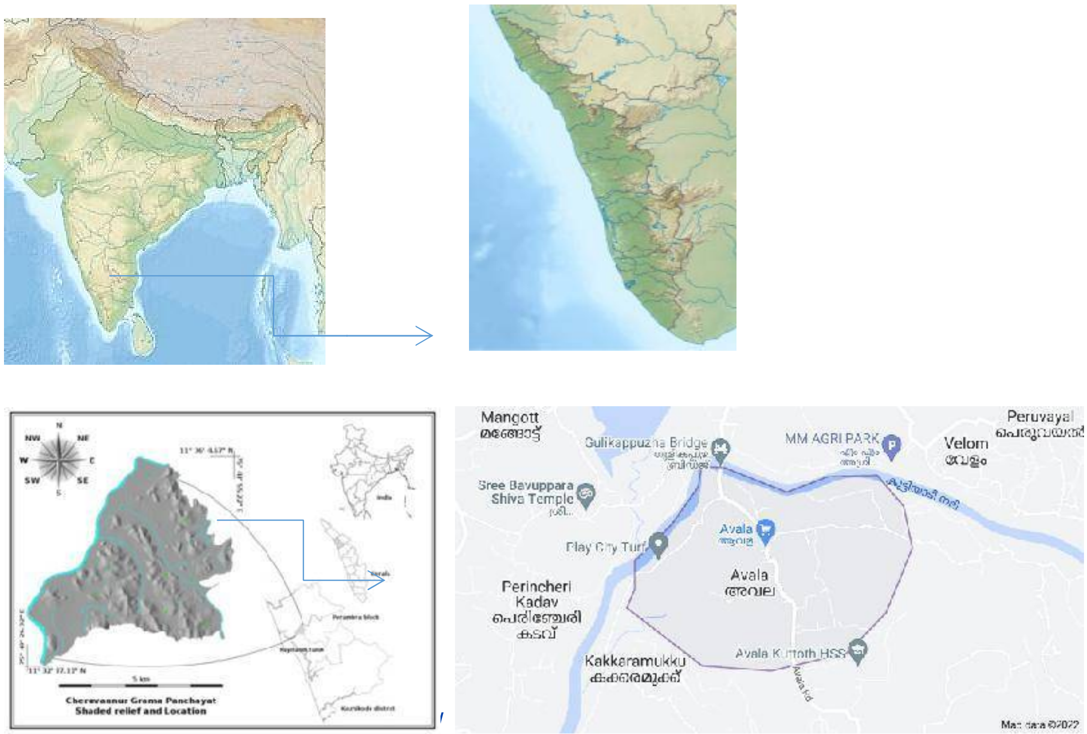

Fig.1. Geographical map of the Avala pandi area Cheruvannur Grama Panchayat location and shaded relief near Perambra in Kozhikode District of Kerala state.

During the site visit, a survey was conducted with the local farmers to know more about the occurrence of Red cabomba and its impact on their routine agricultural activities. In general, in the Cheruvannur Grama Panchayat agricultural areas get fresh water flowing through irrigation canals for their paddy field irrigation. A field view of the canal area filled with the Red cabomba and images of other plant parts were recorded by using camera.Some important morphological features of the aquatic plantswere recorded using measuring tape. Plant height (cm), stem width (mm), canopy width (cm) and flower width was measured in cm.Color of the leaf and flowers were noted.

Results and discussion

Puncha farming system is prevalent in the Cheruvannur Grama Panchayat of Kozhikode District, Kerala state. This Agro-ecosystem is specific to this area where farmers cultivate paddy crop in one season. In the Avala Pandi area farmers practice paddy cultivation during summer season which begins from October-November, since some of the low lying places of the region, are often flooded during monsoon. A total number of 65 ponds and 12.629 kilometers of irrigation canal are present now. The alien aquatic plant - Red cabomba spread in one of the water bodies of Avalappandi area in Kozhikode District is currently under study. A view of the canal area filled with the Red cabomba is depicted in Fig.2.

Fig.2: A panoramic view of the canal covered with Red Cabomba plants.

The plant grows in fresh water bodies and it reached a maximum height of 70 to 90 cm and its canopy spreads from 7 to 9 cm wide. Stem width ranged from 2-3 mm and it bears simple leaves which are in light brown in color. On the surface of water, purple colored flowers blossoms having six petals and the flower width ranged from 2-3 cm (Fig.3).This was used as an aquarium plant and usually it needs carbon dioxide addition to the aquarium water. This plant requires high light, because mostly in shaded areas its growth is low and also required regular fertilization for its optimal growth.*Cabomba furcata* is a rapidly growing invasive species in Kerala now.The ability of a species to survive on various food types, and in a wide range of environmental conditions and the ability to adapt physiologically to new conditions, is called phenotypic plasticity. Due to the panoramic view of its purple colored flowers (Fig.2), instantly, it attracted the attention of many people. Moreover, several visitors from faraway places are carrying these plants along with them, leading to the spread of the species to distant locations such as Kottayam district.

Fig.3: Images of the Red Cabomba plant with purple colored flowers

Moreover, these plants become hazardous for the water bodies due to its active stem propagation which prevents light from entering the water.Red cabomba requires huge quantity of oxygen, resulting in decline of water quality and biodiversity.The plants clog the entire canal area,causing free flow of irrigation water to the sorrounding agricultural fields (Fig.4). Views of the un-cultivated agricultural area of Avalappandi are depicted in Fig. 5. This quick growth of these plants suffocates the water bodies ecologically and hinder the growth of native aquatic plants and freshwater fish leading to considerable economic loss to the farmers. Several reports reveal the invasion by fast-growing plant species in catchments as well as aquatic weeds infestation such as water hyacinth in the water bodies which drastically reduce the flow of streams and rivers of Kerala (The Hindu, 2019) and several states in India. Moreover, several species of birds, especially migratory birds were abundant now in the area, will be affected in due course of time due to scarcity of food.

Fig.4: A view shows the entire canal clogged with the Red Cabomba plants

Fig.5. A view of the un-cultivated agricultural area of Avalappandi.

The Kerala Scenario

Floods and landslides in Kerala have brought several alien invasive species of plants into the State’s water bodies, posing a threat to native biodiversity and the aquatic environment (The Hindu, 2022). The physical routes and paths formed due to landslides and the overflow of rivers had paved the way for the establishment of primary colonies of invasive species like Nila grass (*Mimosa diplotricha*), Mikania (*Mikania micrantha*), Lantana (*Lantana camara*) and Siam weed (*Chromolaena odorata*). In many areas, seeds of invasive species have spread to new spaces from mountainous areas due to landslides. These species can grow very fast in landslide-affected areas, while native species cannot adapt to such conditions.

India is one of the mega biodiversity centers of the World. Avalappandi area in Kozhikode District of Kerala constitutes a part of Western Ghats area which is a major ‘biodiversity hotspot’ in India. The potential Agro-biodiversity is under threat in different ecosystems due changing environmental conditions. The cultivable lands are under threat due to colonization of the paddy fields by invasive species presence, and further it may lead to the conversion of marshy wetlands into dry lands. Many species of fauna including migratory birds were abundant which, may be affected badly. The invasion of *Eicchornia crassipes* and *Ipomoea carnea* in the wetland water bodies of Kerala had considerable impact on aquatic species diversity. Moreover, these aquatic weeds clogged various water bodies, causing obstruction to the inland water ways. Regular removal ofthese plants by mechanical means causing considerable financial loss at large.

The Convention for Biological Diversity (CBD, 1992) emphasis the biological invasion of alien species was the second worst threat to the agriculture, forestry and aquatic ecosystems. The present study shows that the alien Red Cabomba species may cause detrimental effect on productivity and stability of agro-ecosystem of Avalappandi area in Kozhikode District. Hence, there was an urgent need to strengthen domestic quarantine measures to contain the spread of invasive species to neighboring areas and also to develop a national database on this invasive alien species in India. The awareness at farmer's level was a pre-requisite to control the penance of plants. One of the chief control measures of these plants was by means of manual weeding and destruction in the field itself.

Conclusion

Throughout the globe including India, the native genetic resources of flora and fauna were under continuous erosion due to anthropogenic activities and changing environmental conditions. Human beings have been responsible for the introduction of exotic species or organisms, which were creating serious problems in their new environments (Gopal, 1998). These exotic, non-indigenous, alien species become 'invasive' when they were introduced outside their natural areas, where they out-compete the native species and upset the ecological balance. The Convention on Biological Diversity(1992) recognized the urgency to address the impact of invasive alien species. The present preliminary study on the alien Red Cabomba (*Cabomba furcate*) species indicated its rapid growth in Kerala. The species may become invasive on course of time, can cause detrimental effect on productivity, stability of agro-ecosystem and biodiversity of Avalappandi area in Kozhikode District of Kerala. Visitors from faraway places are also playing a role by carrying the plants along with them. This may be one of the reasons to spread the species at distant locations in Kerala. Once adequate scientific information including risk assessment on the new species accumulates, it can be included in the list of bio-invaders in the Indian provinces. R&D efforts are needed for strengthening the domestic quarantine measures to control and mitigate this alien species menace and also to develop a national database on this alien species in India.

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DIVERSITY: A REMEDY FOR WEED MENACE IN AGRICULTURE

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Weeds are the major abiotic factor that limits crop yield. It is evident from years of experimentation that the scenario of weed shift and herbicide resistance are gaining momentum. Thus, an urgency can be noticed to bring some fundamental changes to the theory of weed management. In this context, the change in weed flora diversity as influenced by weed management practices was analyzed from the thesis works done at College of Agriculture, Vellayani. The study revealed that selecting same cultural practices added to the probability of creating a dense population of a certain dominating weed species. Certain weed management practices successfully decreased the species richness in crop fields, especially due to the adoption of selective herbicides. This has paved the way for certain weed species to adapt to the situation and wreak havoc in cropping systems. Still, the weed control practices today aim to reduce the weed diversity in the field, relying predominantly on herbicides. Diversity can be used as a basis for improved weed management in two ways. Inclusion of genetic variation (different species or cultivars) within crops would render the weed population guessing and delay weed adaptation. Weed diversity in a crop field having high evenness and species richness have been found to interact and compete with each other. Not all weed species in a complex weed dynamic system have similar effect on crop yield loss. Significant crop losses are associated with dominance of few competitive species capable of high biomass production as in the case of weedy rice (*Oryza sativa* f *spontanea*). Such dominant weed species are in high risk of developing resistance to herbicides. Thus, the future of weed management needs to focus on understanding complex crop weed interactions and should aim to exclusively target a specific competitive and dominant species in order to maintain higher evenness in weed population to sustain crop yield and minimize dependence on chemical weed control while not disrupting the agro-ecological balance of the system.

Key words: Species richness, weed diversity, weed shift, herbicide resistance, crop weed interactions

Introduction

Weed menace is a major constraint in achieving potential yield and may cause yield losses up to 34 per cent, highest among all biotic factors (Oerke, 2006). Modern methods of weed control, relying mostly on the use of chemicals, have reduced the weed diversity and species

Arindam Deb and Ameena, M., 2023. Diversity: A remedy for weed menace in agriculture. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.110-118

richness to a fraction of levels recording during 1950s (Meyer *et al*., 2013). Use of simple crop rotations have also contributed to the loss of biodiversity. This has led to the increased dominance of few highly adapted weed species, that cause significant yield reduction in crop. In a typical cropping scenario, crop-weed competition is a result of competitive pressure of complex weed community that interact with each other. However, few highly competitive dominant weed species capable of producing higher biomass (hence low weed diversity), rather than all weed species in the community generate significant crop yield loss (Cordeau *et al.,* 2020). Weeds in a system also provide food, shelter and habitat for natural enemies of crop pests or for pollinating insects. They also prevent erosion and enhance soil structure, during non-cropped phases. Thus, it is being hypothesized that a more diverse weed community can prevent establishment of few dominant species and check yield loss. The importance of weed diversity in mitigating yield losses has been identified as one of the top five research priorities in current weed science (Neve *et al.,* 2018).The concept of weed diversity mitigating yield loss might sound illogical and contradicting to current method of weed control. However, the Resource Pool Diversity Hypothesis (RPDH) put forward by (Smith *et al.,* 2009) provides an interesting outlook to the situation. It states that crop-weed competition is inversely related to increasing diversity of soil resource pool. The hypothesis is based on three underlying principles: (i) degree of niche differentiation and partitioning of resources among the species dictates the inter specific competition, (ii) management practices in agricultural system, *viz.*, crop rotation, manuring, fertilization, weed management, etc., makes it a unique and (iii) management practices in agriculture directly or indirectly adds to the size and number of soil resource pools.

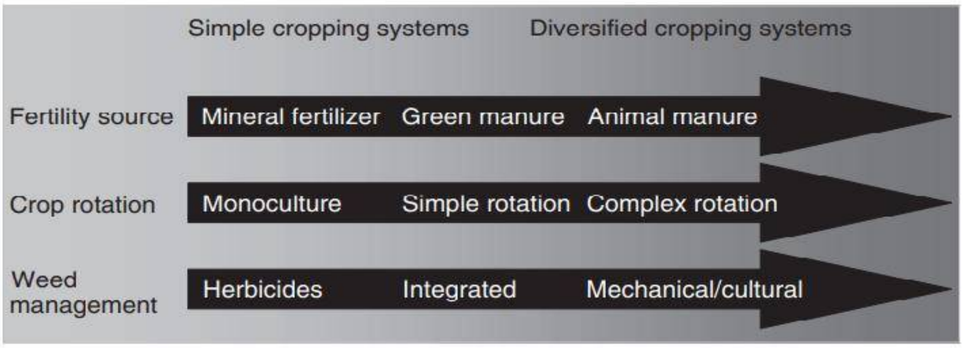

Fig. 1. Gradient in soil resource pool as influenced by fertility source, crop rotation and weed management (Smith *et al.,* 2009)

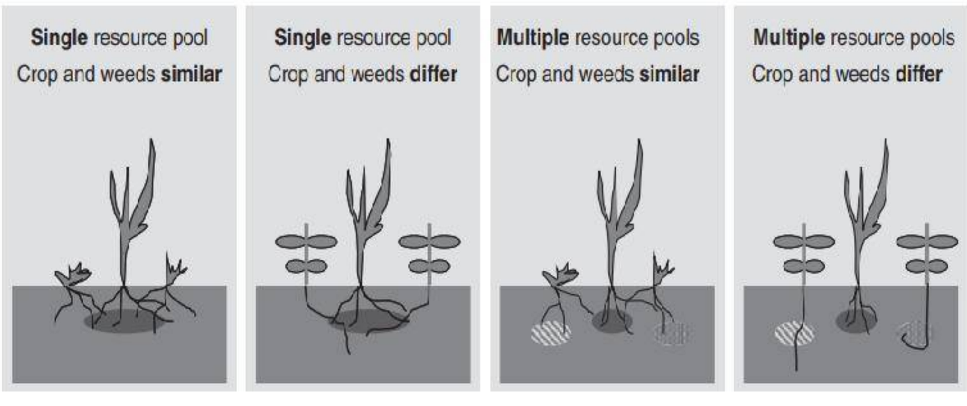

Fig. 2. Resource pool diversity and crop-weed competition (Smith *et al.*, 2009)

The second and third principle of RPDH suggests direct effect of management practices in cropped lands on the resource pools and hence on the intensity of crop-weed competition. Management decisions, such as, selection of crop species, crop rotation, intercropping, fertilization, manuring, etc., dictates the resource pool. A cropping system with intercrops and crop rotation will have higher number of resource pools as compared to monocrop. Different types of crops, would add to the resource pool by root exudations, decomposition of roots and plant parts after harvest. Even diverse weed population may contribute to overall increase in resource pools. Similarly, combined use of manures and fertilizers would also increase the resource pools (Fig.1). A system with higher resource pool would reduce competition among crop and weeds. In such a system, weeds and plants would acquire nutrients from separate resource pools, in contrast to poorly managed system (monocrop with only NPK fertilization) where weed and crops would compete for limited resource pools (Fig. 2).Weed species that utilizes same resource pool as crops would exert high competitive stress and a weed community dominated by such species (low diversity) would wreak havoc in agricultural field. A more diverse weed population in a field with higher number of resource pools, both characteristics of a diversified cropping system (Gabriel *et al*., 2006), would lead to less competitive interactions among crop and weed.

Considering the above discussion, the following objectives were proposed for the study.

1. Evaluating an existing management approach to determine the effect of weed species in a community inflicting yield loss.
2. Studying the effect of crop diversification on weed growth.
3. Investigating the effect of weed diversity in managing yield loss.

Materials and method

A field experiment conducted in two seasons, 2018 and 2019 (*kharif*) to manage *Leptochloa chinensis* in wet direct seeded rice by Sekhar (2021), was referred to determine the effect of weed species in a community inflicting yield loss. In the study various mixtures of herbicide was used to control the weeds. The weed density data 45 days after treatment in both the seasons were correlated with yield data to identify weed species contributing yield loss.

The effect of crop diversification on weed density was explained based on the meta-analysis done by Weisberger *et al*., 2019. total of 54 studies were selected for comparing the diverse and simple crop rotations in the study. Monocrop, monocrop-fallow and two-year rotation with two species were considered under simple rotations.

A study by Adeux *et al*. (2019) was referred to understand the possibility of mitigating yield loss using weed diversity in which weed data was recorded from three winter wheat growing season. Based on the weed community composition, the area under experimentation was divided into six weed clusters, C1, C2, C3, C4, C5 and C6 (Fig. 3 and Table 1). The Pielou's evenness index was used for calculating the evenness of weeds.

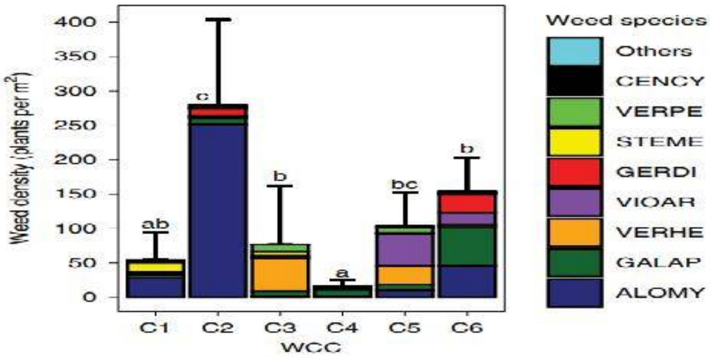

Fig.3. Weed community clusters (WCC) (Adeux *et al.* (2019)

Table.1. Weed species with their abbreviations (Adeux *et al.* 2019)

Abbreviation	**Species**
CENCY	*Cyanus segetum*
VERPE	*Veronica persica*
STEME	*Stellaria media*
GERDI	*Geranium dissectum*
VIOAR	*Viola arvensis*
VERHE	*Veronica hederiflora*
GALAP	*Galium aparine*
ALOMY	*Alopecurus myosuroides*

Pielou's evenness index= H' / ln S

Where, H' is Shannon-Weiner diversity index and S is species richness

Shannon-Weiner index = $-\sum_{i=1}^{S} p$ (ln)

Where, pi is the proportion of individual belonging to i^{th} species and S is species richness

Results and discussion

The correlation study (Table 2) revealed that in the first year, even after the application of weed management measures negative significant correlation of *Leptochloachinenis* and *Echinochloacolona* with rice grain yield was observed at 5 per cent and 1 per cent level of significance, respectively. However, in the second season when same management practices are applied again, the interference of these two weeds were decreased compared to first season. This meant that, the management measures applied was successful against *Leptochloa chinensis* and other grass weeds. When the dominant weeds in the system are removed, it gives opportunity for other weeds to explore the resources and increase their dominance (MacLaren *et al.*, 2020). In this study, as the dominance of grassy weeds were controlled other weeds such as *Sphenocleazeylanica*, *Monochoriavagialis* and *Fimbristylismiliaceae* started interfering with crops as evident by their significant negative correlation with rice yield at 1 per cent level of significance. Therefore, if these management practices are continued, it may lead to any of these weed to dominate the system and wreak havoc. Such weed shift in managed agricultural lands is very common. The classic example being the shift from a broad leaf dominated weed flora in wheat to a grass dominated one after the introduction of 2,4-D in India during 1950s. This was the reason of emergence of the notorious weed *Phalaris minor* as a major weed of wheat (Sushilkumar and Mishra, 2018). Hence, the conventional method of sole use of herbicide as a cheap method of weed control has more often led to weed shift. Thus, it traps us in a vicious cycle of a new weed emerging every few years, adopting measures to specifically control that weed which in turn favours some other weed, and the cycle goes on. Therefore, there is a need to make some fundamental changes in the concept of weed management.

Table 2. Correlation of yield with prevalent weed species (Sekhar, 2021)

Weed Species	**Yield**	
	2018	**2019**
	Pearson correlation coefficient	
Leptochloa chinensis	-.637*	-.460
Echinochloacolona	-.922**	-.668*
Ishacnamiliaceae	-.119	-.403
Sphenocleazeylanica	-.380	-.790**
Bergia capensis	-.178	-.267
Monochoria vaginalis	-.164	-.770**
Limnocharis flava	-.322	-.652*
Ludwigia perennis	-.090	-.578
Lindernia sp.	.448	-.759*
Cyperus iria	-.100	-.388
Cyperus difformis	-.256	.017
Fimbristylismiliaceae	.057	-.770**
Marsilea quadrifolia	.323	.366

*. Correlation is significant at the 0.05 level, **. Correlation is significant at the 0.01 level

The diversification of crop rotation significantly reduced the density of weeds when compared to simple crop rotations (Weisberger *et al*., 2019). The mean reduction in weed density due to diversification in 51 studies (247 observations) was found to be 49 per cent ($p < 0.001$). However, the effect of crop diversification on weed biomass showed lower (21 %) and non-significant reduction ($p = 0.22$) (Fig. 4). This might be due to the availability of lower number of studies associated with weed biomass (16 studies and 64 observations). Moreover, the weed biomass and density showed significant positive correlation (Pearson correlation coefficient = 0.67, $p < 0.001$) (Fig.5). Thus, Weisberger *et al.* (2019) inferred that, reduction in weed densities equated to lower weed biomass. Similarly, Scott and Freckleton (2022), observed that both temporal and spatial crop diversification resulted in lower parasitic weed density. The weed suppressing ability was higher for spatial diversification compared to temporal.

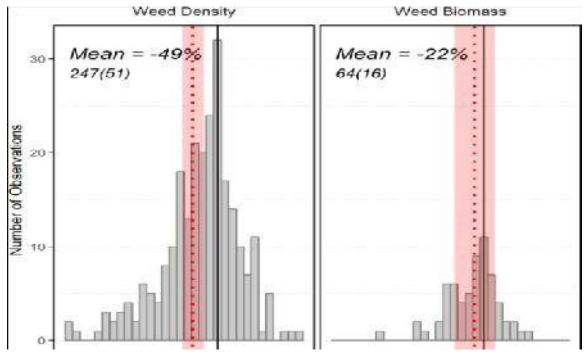

Fig.4. Effect of diversification on weeds (Weisberger et al., 2019)

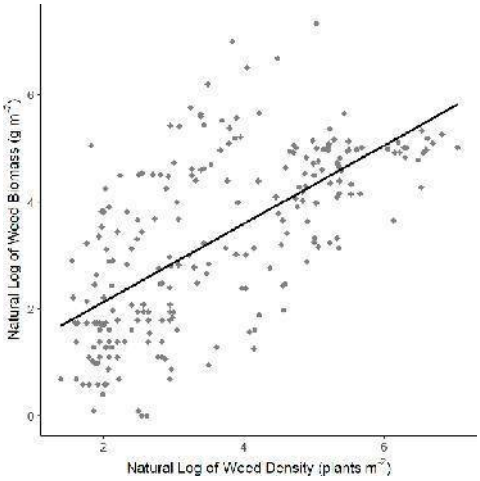

Fig. 5. Relationship between weed biomass and weed density (Weisberger *et al.*, 2019)

Adeux *et al.* (2019) reported positive significant correlation of crop biomass in all growth stages with weed evenness (Fig. 6). Negative significant correlation was observed crop biomass and weed biomass (Fig. 7 and 8). Reduction in crop biomass was also reported with increase in weed evenness. As increase in weed evenness was observed, it lowered the weed biomass which decreased the interfering ability of the weed community as a whole by not allowing any specific weed to become highly competitive and thus prevented yield losses.

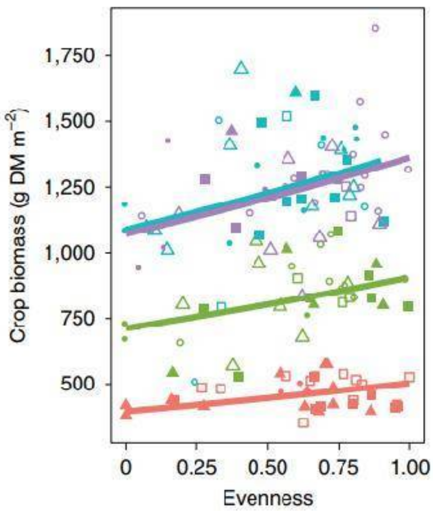

Fig.6. Crop biomass influenced by weed evenness (Adeux *et al.* 2019)

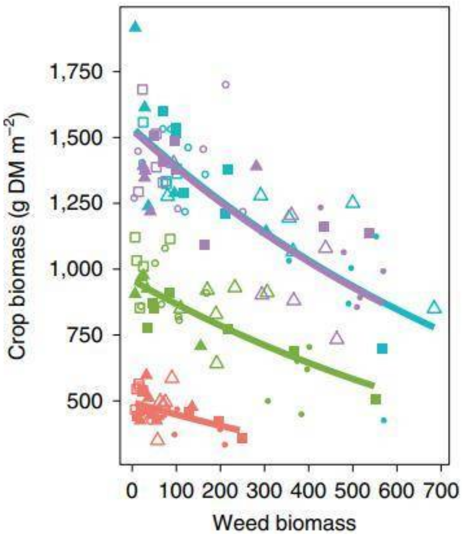

Fig.7. Crop biomass influenced by weed biomass (Adeux *et al.* 2019)

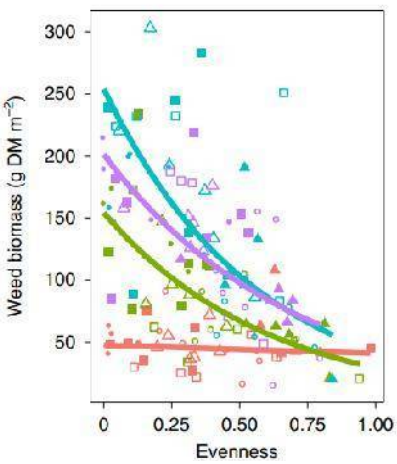

Fig.8. Weed biomass influenced by weed evenness and biomass (Adeux *et al.* 2019)

The results suggest differences in competing ability of weed community were dependent more on the weed species composition rather than weed density. Significant yield reductions were associated with C1, C2, C5 and C6 (19 % to 51 %) (Table 3). Highest reduction in yield was noticed in C2, followed by C6 and C1. C1 and C2 both the cluster have *Alopecurus myosuroides* as the most dominant species. In C6, *Galium aparine* was the most dominant species followed by *Alopecurus myosuroides*. This suggests the competitive ability of *Alopecurus myosuroides*is high and is capable of causing yield loss. This is more evident from the fact that C1 has lower weed density compared to C3 (dominated by *Veronica hederi flora*). Comparison between C2 and C6 shows that both weed communities can cause > 50 per cent yield loss, although C6 has significantly lower weed density, suggesting higher competitive ability of *Galium aparine* compared to *Alopecurus myosuroides*. Thus, the study suggests not all weed communities are detrimental to crop productivity (Adeux *et al.*, 2019). This might be due to the fact that the resource utilization from the weeds (that cause yield losses) and crop under consideration occurs from similar pools.

Table.3. Effect of WCC on grain yield (Adeux *et al.* 2019)

WCC	Grain Yield g m^{-2}		% difference	P value
	Weed free	Weedy		
C1	560±34	419±25	25	0.0007
C2	588±42	258±18	56	<0.0001
C3	534±40	522±39	3	0.78
C4	588±41	538±38	8	0.35
C5	548±33	445±27	19	0.01
C6	518±35	254±17	51	<0.0001

Conclusion

The weed management strategies based solely on the application of herbicides might trap us in the vicious cycle of weed shift. Based on various works referred for this study, it may be inferred that a holistic approach is the need of the hour for sustainable weed management. Diversified crop rotation has been found to decrease the weed density and may increase the resource pools in the soil. It has also been established that a more diverse weed population or a weed community with higher evenness increases the crop biomass while decreasing the weed biomass. Among various weeds present in a community, only a few has been found to exert higher competitive pressure to the crop. Current weed management practices suggest eradication of those dominant weeds, but from this study it may be inferred that no weed in the crop lands should be completely eradicated. Instead, more focus must be administered in maintaining a healthy weed diversity, so that the plant communities might explore diverse resource pools, reducing extravagant yield losses, saving herbicide, and making crop cultivation economically more profitable and ecologically more sustainable.

The research in weed diversity affecting yield loss is still in nascent stage. More work should be performed to differentiate and define good and bad weed diversity.

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WEEDY RICE DIVERSITY IN THE PADDY ECOSYSTEMS OF KERALA

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Abstract

Weedy rice (*Oryza sativa* f. *spontanea*), progeny of wild and cultivated *Oryza* sp. has emerged as a strong, morpho-physiologically similar competitor in the rice fields of Kerala. The main objective of the study was to assess the eco-morphology of weedy rice in the diverse paddy ecosystems in the State *viz*. Trivandrum, Kuttanad, Thrissur (Kole lands), Palakkad, Kozhikode and Kannur (Kaipad lands).Morphological similarity of weedy and cultivated rice grains, seed dormancy and early seed shattering helps the weed to replenish the soil seed bank. Weedy rice morphology showed characteristic variations in different rice growing tracts and its diversity was maximum in the un-weeded bunds. Though early-stage identification of weedy rice from cultivated rice is difficult, ligule length and culm thickness show characteristic difference upto 15 days after sowing. Presence or absence of awn, variations in awn length and awn colour (white coloured in Kozhikode, straw coloured in Trivandrum and Kuttanad, brown coloured in Kole lands, light green in Palakkad and purple awns in Kaippad lands), presence or absence of anthocyanin in the nodal region showed marked difference throughout the paddy fields of Kerala. Strong tillering habit (11 to 20 tillers plant^{-1}) distinguishes weedy rice from the cultivated rice varieties Jyothi and Uma with 10 and 9 tillers plant^{-1} respectively during active vegetative stage. At reproductive stage, taller nature (105 to 115.67 cm) and early flowering (49 to 51 DAS) compared to cultivated rice helps in the identification and management of weedy rice before seed shattering. Changes in the weed morphology in different rice growing tracts could be attributed to the hybridization of weedy rice with the cultivated rice variety of the location to suit the diverse habitats and management practices. Compact panicles similar to rice in the short weedy rice plants makes it difficult to distinguish between the two even during flowering stage. Escape of weedy rice in reproductive stage is dangerous as it potentially contaminates the seed lot, gain entry to newer areas and adds to the seed bank reserves. Increased resemblance of weedy rice to cultivated rice could be attributed to the high rate of natural hybridization and backcrossing. Microscopic analysis of weedy rice seeds showed the presence of trichomes that helps in dispersal through implements, humans, animals. The morphological traits of weedy rice strongly favour invasive growth, intrusion into newer habitats and better adaptive potential. Rapidity of natural hybridization and backcrossing in the major rice growing tracts of Kerala highlights the need for elucidating better management practices against weedy rice.

Umkhulzum, S.F., Ameena, M., Anjali, K., Jose,N., and Shalini Pillai, P. 2023. Weedy rice diversity in the paddy ecosystems of Kerala. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.119-125.

Keywords: *Weedy rice, Morphotypes, Paddy ecosystems, Kerala, Awn*

Introduction

Rice is the global staple that satiates the hunger needs of more than 3.5 billion human population (CGIAR, 2022). The escalating rate of population growth demands for increased production of rice for meeting the basic diet requirements. Weeds, the competitive counterpart of crops outperform the latter with its ephemeral nature, superiority in extraction of nutrients, water, high seed production potential and rapid adaptation to changes in environment. Among the three groups of weeds *viz*. grasses, sedges and broad-leaved weeds, grasses pose severe threat to rice being in the same family.

Weedy rice (*Oryza sativa* f. *spontanea*), the natural inter specific hybrid of wild rice and cultivated rice (*Oryza sativa*) is a major challenge to rice farmers world over. Morphological similarity with rice during early growth stages, early seed shattering and varying seed dormancy profiles attributes to the persistent invasion of the weed in paddy ecosystems (Chauhan, 2013). Yield reduction due to weedy rice infestations in paddy growing tracts of Kerala grew at an alarming rate during 2007-2008. Taller stature and profuse tillering contribute competitive advantage to weedy rice while early flowering and seed shattering replenishes the weed seed bank (Abraham and Jose, 2015). Invasive species is the second most important contributing factor for the loss of biodiversity, next to habitat destruction (IUCN, 2021).IRRI (2022) enlisted weedy rice among the twelve most troublesome weeds in the world due its potential to threaten rice cultivation.

In India, the first attempt for identification and characterisation of weedy rice diversity in paddy fields was done in Madhya Pradesh (Varshney and Tiwari, 2008). Infestation rate of 3-10 mature weedy rice plants m^{-2} cause 30-60% decline in paddy yield (Abraham *et al*., 2012). Major rice growing tracts of Kerala *viz*. Kuttanad, Palakkad, Thrissur, Trivandrum and Kozhikode have been reported to be severely invaded by weedy rice (Anjali *et al*., 2018).

Morphological similarity with cultivated rice during initial stages of growth, leaves back weedy rice after hand weeding which is otherwise the most effective weed management practice. Biochemical and genetic similarity of the weed with cultivated rice further aggravates the situation by making herbicide application impossible. However, the relative earliness in panicle emergence helps in weed identification and removal, but it will be favourable only for the next season crop due to prevention of seed addition to soil weed seed bank. Possibility of distinguishing the weed only during the reproductive stage is a major concern of paddy farmers as it causes considerable yield reduction within that period. In this background, the present study for assessing the eco-morphology of weedy rice in the diverse paddy ecosystems of Kerala was carried out.

Materials and Methods

Characterization of weedy rice morphotypes was conducted in pot culture experiments at College of Agriculture, Vellayani, Thiruvananthapuram, located at 8^0 25’49’’ N latitude and 76^0 39’04’’ E longitude at an altitude of 29 m above msl. Experimental design was

Completely Randomised Design with eight weedy rice morphotypes and two popular rice varieties, replicated thrice. T_1: weedy rice morphotype from Trivandrum with red coloured awn, T_2: weedy rice morphotype from Trivandrum with white coloured awn, T_3: weedy rice morphotype from Kuttanad with white coloured awn, T_4: weedy rice morphotype from Kole with white coloured awn, T_5: weedy rice morphotype from Palakkad with red coloured awn, T_6: weedy rice morphotype from Palakkad with white coloured awn, T_7: weedy rice morphotype from Kozhikode with white coloured awn, T_8: weedy rice morphotype from Ezhome with pink coloured awn, T_9: Ptb39 - Jyothi (short duration) and T_{10}: MO16 - Uma (medium duration). Pregerminated seeds of weedy rice @ 2 seeds per pot was sown in earthen pots of dimension 50 cm x 30 cm, filled with clayey soil collected from un-infested paddy fields, maintaining flooded situation throughout the growing period. All the cultivation practices *viz*. liming, application of fertilizers and irrigation were provided as per the Package of Practices, KAU (2011).

Comparison of weedy rice morphotypes with cultivated rice varieties were carried out by observing the pots simultaneously. The qualitative and quantitative characters such as leaf blade attitude, ligule colour and length, presence or absence of awn, awn colour and length, and anthocyanin pigmentation on nodes were scored according to the morphometric descriptors for wild rice and cultivated rice (IRRI, 2007). Grain thresh ability was determined by hand grip technique. The data was recorded and statistically analysed using ANOVA for CRD.

Results and Discussion

The morphotypes from the major paddy growing tracts of Kerala exhibited diverse morphological attributes. Mimicking cultivated rice at the initial stages of growth makesearly identification of weedy rice impossible and aids in its escape. Differences in plant height, earliness in panicle emergence, presence of awns are late identification traits. From the present study, morphological distinctness of weedy rice plants in the early growth stages *viz*. presence of ligules, attitude of leaf blade, ligule colour, ligule length and anthocyanin pigmentation in the nodes were observed (Table 1).

Out of the eight weedy rice morphotypes, five had semi erect attitude of leaf blade and three morphotypes had no anthocyanin pigmentation on nodes, same as Jyothi and Uma. This suggests the rapidity of natural hybridisation and backcrossing in the paddy fields of Kerala which confer increased morphological similarity with cultivated rice. Ligule length and culm thickness can be used for demarcating weedy rice in a cropped field. Shorter ligules during 15 DAS and thick, flat culms of weedy rice differentiate it from the longer ligules and round, brittle culms of cultivated rice. Significantly taller plants with greater LAI provides photosynthetic superiority to weedy rice over cultivated rice.

Table 1. Morphological traits of weedy rice morphotypes and cultivated rice varieties, Jyothi and Uma

Treatments	**Attitude of leaf blade**	**Ligule colour**	**Anthocyanin in nodes**	**Panicle type**	**Awn colour**
T_1: Trivandrum red	Semi erect	Yellowish green	Purple	Compact	Red
T_2: Trivandrum white	Semi erect	White	Absent	Intermediate	Straw
T_3: Kuttanad	Semi erect	White	Absent	Intermediate	Straw
T_4: Kole	Semi erect	Purple lines	Light purple	Compact	Brown
T_5: Palakkad red	Semi erect	Yellowish green	Light purple	Compact	Red
T_6: Palakkad white	Descending	White	Purple lines	Intermediate	Light green
T_7: Kozhikode	Erect	Light purple	Absent	Open	White
T_8: Ezhome	Descending	Purple	Purple	Open	Purple
Jyothi	Semi erect	Yellowish green	Absent	Compact	Absent
Uma	Semi erect	Yellowish green	Absent	Compact	Absent

Morphotypes from Palakkad and Thrissur with clear black ring at the node region, Kozhikode with bent at the node region and Kuttanad with adventitious roots points out them from other morphotypes. Presence of adventitious roots in Kuttanad morphotypes confirms the evolutionary adaptation to thrive better in submerged conditions.

Weedy rice from Kole lands flowered earlier than other morphotypes but was statistically non-significant with other weedy rice treatments. On an average, weedy rice reached 50% flowering in 51 days which was 11 days and 30 days earlier than Jyothi and Uma, respectively. Another striking feature of weedy rice was the profuse tiller production capacity (11 to 20 tillers plant^{-1}) compared to Jyothi (10 tillers plant^{-1}) and Uma (9 tillers plant^{-1}).Ferrero and Vidotto (1999) reported the identification of weedy rice during tillering stage due to the presence of numerous, long and slender tillers. All the weedy rice morphotypes were taller (105.07 to 115.67 cm) than Jyothi (96.17 cm) and Uma (91.17 cm) varieties at 50% flowering stage (Table 2).

Table 2. Growth attributes of weedy rice morphotypes and cultivated rice varieties, Jyothi and Uma at 50 % flowering

Treatments	Ligule length, mm	Culm thickness, cm	No. of tillers plant^{-1}	Plant height, cm	Days to 50% flowering	LAI	Awn length, cm
T_1	11.00	2.57	15.67	108.97	51.43	5.24	4.31
T_2	14.00	3.23	16.67	115.67	51.03	4.22	7.41
T_3	7.30	3.37	13.67	110.20	50.36	3.90	3.48
T_4	5.00	2.43	16.00	110.80	49.63	4.96	4.11
T_5	5.30	2.47	19.67	113.27	50.13	5.74	6.69
T_6	22.30	2.57	13.00	112.77	50.19	5.63	2.38
T_7	4.30	2.27	11.67	108.83	51.13	3.77	7.36
T_8	14.30	2.43	8.33	105.07	50.43	2.20	9.23
SEm (±)	**0.40**	**0.08**	**0.94**	**0.73**	**2.65**	**0.32**	**0.03**
CD (0.05)	**1.60**	**0.22**	**2.68**	**2.19**	**NS**	**0.94**	**0.12**

Jyothi	10.30 (NS)	1.93 (S)	10.33 (S)	96.17 (S)	61.58 (S)	3.30 (S)	Absent
Uma	7.70 (S)	2.27 (S)	9.00 (S)	91.17 (S)	81.88 (S)	3.44 (S)	Absent

Early seed shattering of weedy rice replenishes the weed seed bank before the crop harvest. Grain thresh ability varied with the treatments and ranged from 29.73% to 46.32% against 34.35% and 17.83% for Jyothi and Uma varieties, respectively. The grains also had different longevity periods from 5 to 15 months compared to 6 and 9 months for Jyothi and Uma, respectively (Table 3).

Table 3. Yield attributes and root characters of weedy rice and cultivated rice varieties, Jyothi and Uma

Treatments	**No. of grains panicle^{-1}**	**Grain thresh ability, %**	**Seed longevity (months)**	**Root volume, cm^3**		**Root dry weight, g**	
				15 DAS	**Harvest**	**15 DAS**	**Harvest**
T_1	59.00	35.28	12.00	21.20	70.65	0.15	7.15
T_2	57.00	37.80	10.67	7.07	84.31	0.12	9.60
T_3	50.00	46.32	15.00	35.33	77.61	0.49	14.80
T_4	45.67	34.04	9.00	14.13	70.31	0.73	9.15
T_5	53.33	30.02	14.00	28.26	84.78	0.26	13.25
T_6	59.00	29.73	10.00	7.07	77.72	0.35	7.45
T_7	60.33	30.13	8.00	14.13	70.33	0.17	9.00
T_8	48.67	41.17	4.97	14.13	84.39	0.15	12.50
SEm (±)	**3.20**	**2.02**	**0.80**	**0.78**	**0.16**	**0.02**	**0.34**
CD (0.05)	**9.60**	**6.07**	**2.41**	**5.83**	**0.49**	**0.03**	**1.01**
Jyothi	66.33 (S)	34.35 (NS)	6.00 (S)	14.13 (S)	56.48 (S)	0.21 (S)	10.10 (NS)
Uma	23.73 (S)	17.83 (S)	9.03 (NS)	7.07 (S)	63.51 (S)	0.06 (S)	6.70 (S)

Awns in weedy rice helps in distinguishing the weedy rice panicles. Colour of the awns varied from red colour in Trivandrum and Palakkad, straw colour in Trivandrum and Kuttanad, brown colour in Kole lands of Thrissur, light green colour in Palakkad, white in Kozhikode and purple in Kaipad lands of Kannur. Awn colour ranges from white to black and is the best indicator of weedy rice diversity (Anjali, 2016). Awns with straw colour, brown colour and black colour has been reported from the various agroclimatic zones of India (Rathore *et al*., 2016).Weedy rice from Ezhomepossessed the longest awns (9.23 cm) and the morphotype Palakkad white had the shortest awns (2.38 cm).Pericarp of weedy rice morphotypes also showed marked variation in colour from straw colour to red.

Microscopic view of weedy rice and cultivated rice grains showed trichomes on grain surface of the former. Awns and trichomes favour seed dispersal of weedy rice by animals, humans, implements and water (Jose, 2015).

The root volume of weedy rice morphotypes were 2.5 to 5 times and 1.3 to 1.5 times more than cultivated rice varieties at 15 DAS and at harvest, respectively. Root dry weights were also superior for weedy rice than Jyothi and Uma varieties of rice (Table 3). Changes in the weed morphology in different rice growing tracts could be attributed to the hybridization of weedy rice with the cultivated rice variety of the location to suit the diverse habitats and management practices.

Conclusion

The morphological traits of weedy rice strongly favour invasive growth, intrusion into newer habitats and better adaptive potential. Compact panicles similar to rice in the short weedy rice plants makes it difficult to distinguish between the two even during flowering stage. Escape of weedy rice in reproductive stage is dangerous as it potentially contaminates the seed lot, gain entry to newer areas and adds to the seed bank reserves. Rapidity of natural hybridization and backcrossing in the major rice growing tracts of Kerala highlights the need for elucidating better management practices against weedy rice.

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A STUDY ON THE ALLELOPATHIC EFFECTS OF AQUEOUS LEAF EXTRACTS OF *LANTANA CAMARA* ON SEED GERMINATION AND SEEDLING GROWTH OF *MACROTYLOMA UNIFLORUM* AND *VIGNA RADIATA*

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Abstract

Allelopathic effects of aqueous leaf extracts of *Lantana camara* (an internationally recognized invasive alien weed) on germination and seedling growth *Macrotyloma uniflorum* and *Vigna radiata* were evaluated. The experiment was carried out in sterilized petri dishes throughout a 24-hour photoperiod at a room temperature of 28-30°C. Seeds of *M.uniflorum* and *V.radiata* were soaked in different concentrations of *L. camara solution* (10%, 25%, 50%, 75%, and 100%) and germination, radicle length, and plumule length were measured and compared to control (i.e., distilled water). Radicle length and plumule length data were subjected to statistical analysis (Two factorial analysis) using GRAPES software. Seed germination, radicle and plumule length of *M.uniflorum* and *V. radiata* were significantly inhibited by different concentrations of aqueous leaf extracts of *L. camara*, according to the bioassay. The inhibitory impact was related to the concentration of the extracts and was more pronounced at higher concentrations. *M. uniflorum* showed more inhibitory effect than *V. radiata*. With increasing concentration, the tolerance index declined and phytotoxicity increased both the receptor plants. The results of the present study suggested that *L.camara* had a deleterious impact on agricultural crops. As a result, it is critical to prevent the spread of this poisonous weed.

Key words : Allelopathic effects, *Lantana camara, Vigna radiata, Macrotyloma uniflorum,* Phytotoxicity

Introduction

Allelopathy is a phenomena in which secondary metabolites produced by the viruses, fungi, microorganisms and plants which will cause stimulatory or inhibitory effect on germination, growth and development, reproduction and distribution of other plants and microorganisms of agriculture systems and natural communities. Rice (1984) redefined it as the beneficial or

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harmful effect of one plant on other plant including microorganisms by the production and release of biochemical substances into the environment. The biochemical substances produced by plants are called allelochemicals. These chemicals are actually secondary metabolites which are non-nutritious produced as the by-products of metabolic pathways in plants. These allelochemicals are released in different parts of plants which includes leaves, stem, roots, bark, seeds, flowers and pollen (Archana *et al*., 2019; Farooq *et al*., 2011).

These allelopathic effects favour the spreading, establishment and survival of invasive plants (Chou, 1999; Mallik, 2003; Field *et al.*, 2006; Inderjit *et al.*, 2006; Zheng *et al.*, 2015), which includes spotted knapweed (*Centaurea stoebe* L. ssp. micranthos) (Broeckling and Vivanco, 2008), garlic mustard (*Alliaria petiolata* M. Bieb) (Vaughn and Berhow, 1999), water hyacinth (*Eichhornia crassipes* Mart. Solms) (Jin *et al*., 2003; Gao and Li, 2004). *Lantana camara* L. is also an invasive plant (Kato-Noguchi and Kurniadie, (2021); Parsons and Cuthbertson, (2001).

Lantana camara L., (Verbenaceae) is also known as wild sage and red sage (Parsons and Cuthbertson, 2001).It is considered as one of the world's 100 worst invasive alien species. *L.camara* is native to tropical America. It is distributed throughout the tropical regions of earth and this weed is spreading to the pastures and Native forests of more than 60 countries worldwide (Parsons and Cuthbertson, 2001).In India lantana was introduced at the beginning of the 19^{th}century. Now it is growing densely throughout India. Studies have been conducted to explain the allelopathic effects of invasive species on native plants. The different concentration of leaf extract of *Lantana camara* inhibitory effect on seed germination of *Parthenium hysterophorus (*Mishra and Singh *et al*., 2009), and shows inhibitory effect on the seed germination, root and shoot elongation of six agricultural crops of Bangladesh which includes *Cucumis sativus* L., *Phaseolus mungo* L., *Raphanus sativus* L., *Vigna unguiculata* (L.) Walp. and *Cicer arietinum* L. (Ahmed *et al*., 2007). Allelopathic effects of *Lantana camara* in seed germination and seedling growth also studied on agriculture crops which includes rice (Bansal, 1998, Oudhia, and Tripathi, 1999) wheat (Oudhia and Tripathi. (2000); maize (Ngonadi *et al*., 2019); black gram (Nawab and Yogamoorthi, 2016); chickpea and green gram (Sharma *et al.*, 2017).

Pulses are an important part of the human diet. They are quite nutritious. *Macrotyloma uniflorum* and *Vigna radiata* are the two most important legume crops which belongs to the Fabaceae family. Mung bean (*V. radiata*) is one of the most significant pulse crops, with more than 6 million hectares cultivated worldwide, primarily in Asian countries. It is widely cultivated in many Asian nations, including China, India, Pakistan, Bangladesh, and certain South Asian countries (Dahiya *et al.,* 2015). The horse gram (*Macrotyloma uniflorum*) is an underutilized, low-cost, drought-resistant pulse crop.Within 120-180 days of planting, *M.uniflorum* completes its life cycle (Cook *et al.,* 2005). These agricultural crops are an excellent source of carbohydrates, proteins, minerals, and vitamins (Bravo *et al.,* 1998, Saroj and Manoj, 2014). Therefore, the present study was carried out to investigate the possible allelopathic effects of aqueous leaf extract *Lantana camara* on seed germination and seedling growth of *Macrotyloma uniflorum* and *Vigna radiata.*

Materials and methods

Healthy, mature *L. camara* leaves were collected from nearby areas of Kannadi, Palakkad district, Kerala in April 2022. The leaves were washed in running tap water for removing the surface contaminants and dust.

For the preparation of aqueous *L. camara* leaf extracts, 100g of fresh *L. camara* leaves was soaked in 500-mL distilled water and grind it with a mixer grinder. The aqueous leaf extract was kept in a flask and covered with aluminium foil and kept in room temperature of 28-30°C, without allowing any possible chemical changes. After 24 hrs the aqueous extract was filtered by using filter through a What man No. 1 filter paper and diluted the filtrate with distilled water to prepare different concentrations (10%, 25%, 50%, 75%, and 100%) according to the standard treatments.

The germination test was carried out in sterile petri dishes of 9cm diameter placing a Whatman® no.3 filter paper on petri dishes. The extract of each concentration was added to each petri dish of respective treatment daily in such an amount just enough to wet the seeds. The first petri dish was used for application of distilled water (control), and the succeeding received 10%, 25%, 50%, 75% and 100% extract concentrations.10 seeds of each receptor crop were placed in each petri dish. The experiment was arranged in a randomised complete block design (RCBD) replicated 3 times. About 10 mL of each concentration was added to each petri dish for the first day. The seeds were kept moist by applying about 10 mL of each extract daily for the next 5 days. The germination was recorded daily and the results were determined by counting the number of germinated seeds, and measuring the length of primary root and main shoot on fifth day of the experiment. Shoot and root length were measured using a ruler. Germination percentage (GP), Tolerance index (TI)(Turner and Marshal, 1972); Percentage of toxicity/ Phytotoxicity (Chiou and Muller, 1972) were calculated as per the standard procedures.

Radicle length and plumule length data were subjected to statistical analysis (Two factorial analysis) using GRAPES (General R-shiny based Analysis Platform Empowered by Statistics) software. Treatment means were discriminated using Least Significant Difference (LSD) test at a probability $p<0.05$.

Results and Discussion

The present study was about allelopathic effects of different concentration (10,25,50,75,100%) of aqueous leaf extracts of *Lantana camara* (donor species) on seed germination and seedling growth of horse gran (*Macrotyloma uniflorum)* and green gran (*Vigna radiata).* (receptor species) Number of seeds germinated, Radicle length (RL) and plumule length (PL) were recorded for 5 days. Seed germination percentage, tolerance index and phytotoxicity was calculated. The results indicated that the germination, radicle length and plumule length of *M.uniflorum* and *V.radiata* L. *decreased* with increase in concentration of *L.camara* solution. It was also clear that *L.camara* has a more inhibitory effect on seed germination and seedling growth of *M.uniflorum* than *V.radiata*

Aqueous leaf extract of *L.camara* shows inhibitory effect on seed germination and seedling growth of *M.uniflorum* and *V.radiata*. As the concentration of *L.camara* solution increases the germination and seedling growth of recipient species decreases and the higher concentration had the strongest inhibitory effect. For example, after five days in *M.uniflorum* the GP was maximum in T1 (100%) and minimum in T5 (60%) and that of control was 97.5% (Fig.1). Increases in concentration of the aqueous leaf extracts of *L*. camara inhibit the germination process. In case of *V. radiata* the germination was not much inhibited. After 5 days the GP of *V. radiata* was maximum in control, T1, T2, and T3 (100%) and minimum in T5 (90%) (Fig.2). The aqueous extract of *L. camara* exhibited a significant decrease in GP of *M. uniflorum* than *V. radiata*. The aqueous extract of *L. camara* exhibited a significant decrease in GP of *M. uniflorum* than *V. radiata*. The GP is not much affected in *V. radiata.* Only T4 and T5 treatment shows slight inhibition in seed germination.

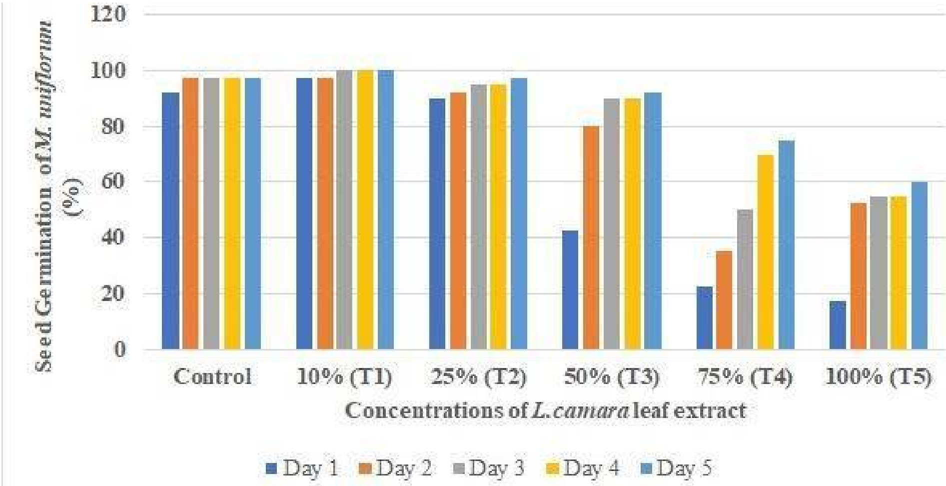

Fig.1 Seed germination percentage of *M. uniflorum* under different concentrations of *Lantana camara* solution

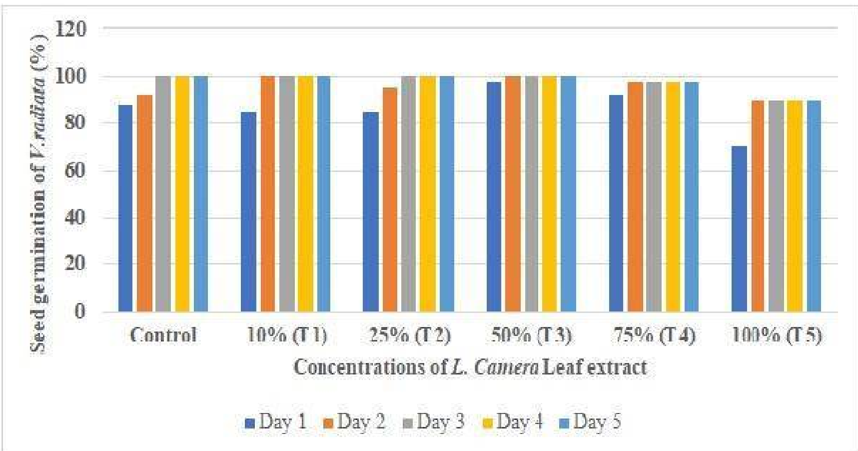

Fig. 2 Seed germination percentage of *V.radiata* under different concentrations of *Lantana camara* solution

Additionally, both plumule (PL) and radicle (RL) of two recipient species were affected negatively by the addition of different concentrations of *L. camara* leaf extract. This effect was directly proportional to the concentration of the extract. although it was more prominent in the case of *M.uniflorum* than *V. radiata*. For instance, in the case of M.uniflorum RL was reduced after 5 days of sowing from 8.57 cm (control) to 2.1 cm (T5). PL of *M.uniflorum* was also reduced from 1.61 cm (control) to 0.10 cm (T5) (Fig. 3&4).Obviously, after 5 days from seed sowing, the RL of *V. radiata* was reduced from about 10 cm (control) to 3.2 cm (T5). Similarly, the plumule length was also reduced from about 2.8 cm (control) to 0.01 cm (T5) (Fig.5&6). Also the tolerance index was found to be reduced with increase in concentration in both *M. uniflorum* and *V. radiata* (Fig.7&8). The tolerance index was maximum in control and T1 and minimum in T5. The phytotoxicity of these receptor crops increased with increase in concentration (Fig.9&10). Phytotoxicity was minimum in control and T1 and maximum in T5.

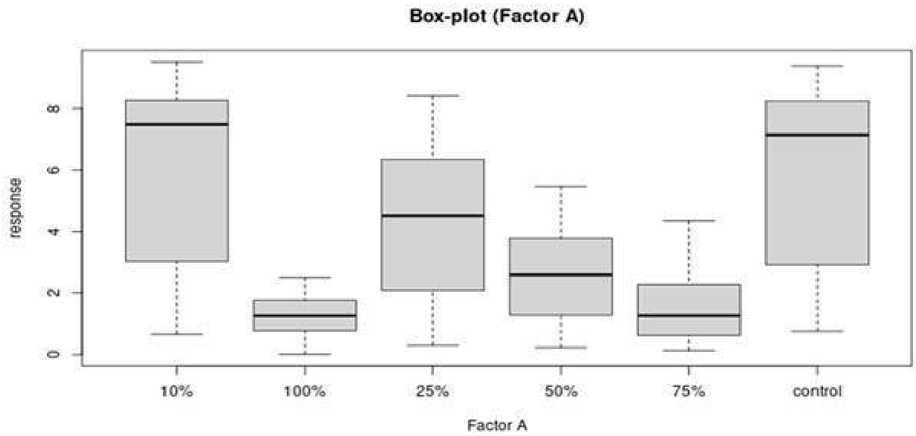

Fig. 3 Allelopathic effects of different concentrations of L. camara aqueous leaf extracts on radicle length of M.uniflorum

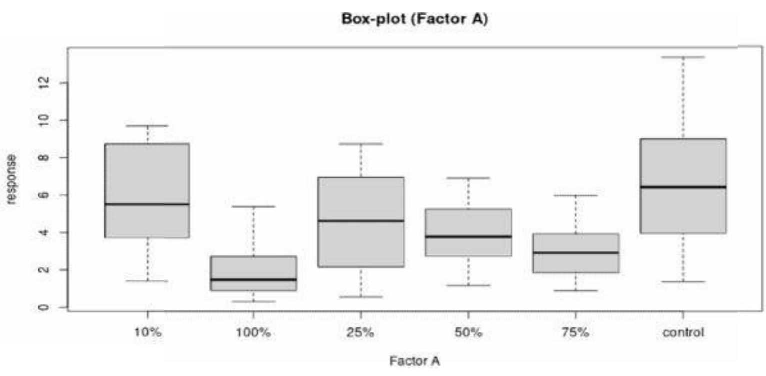

Fig. 4 Allelopathic effects of different concentrations of *L. camara* aqueous leaf extracts on radicle length of *V. radiata.*

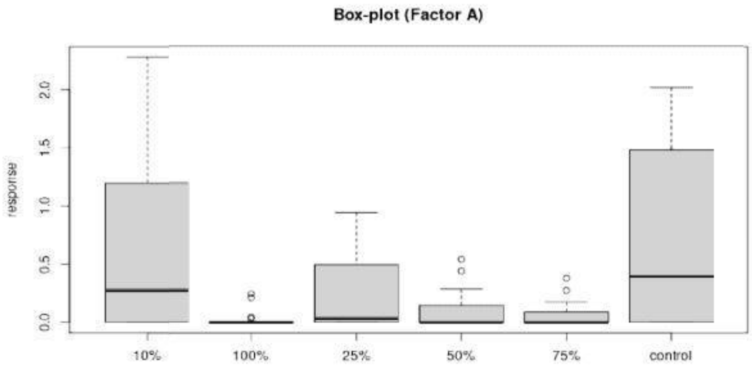

Fig. 5 Allelopathic effects of different concentrations of *L. camara* aqueous leaf extracts on plumule length of *M.uniflorum*

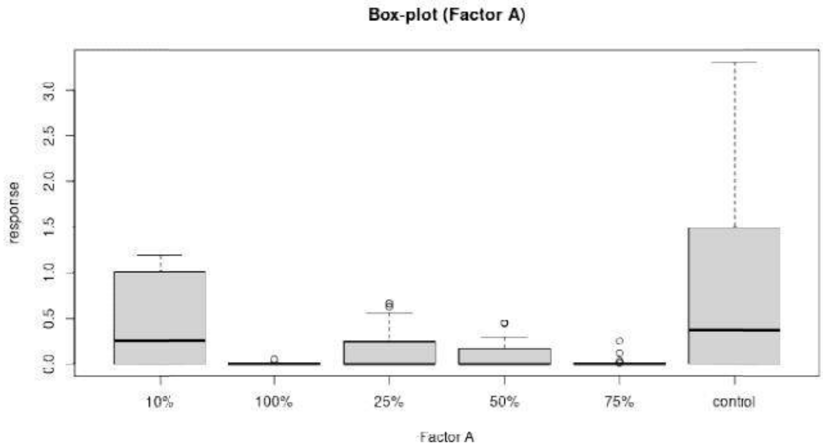

Fig. 6 Allelopathic effects of different concentrations of *L. camara* aqueous leaf extracts on plumule length of *V. radiata*

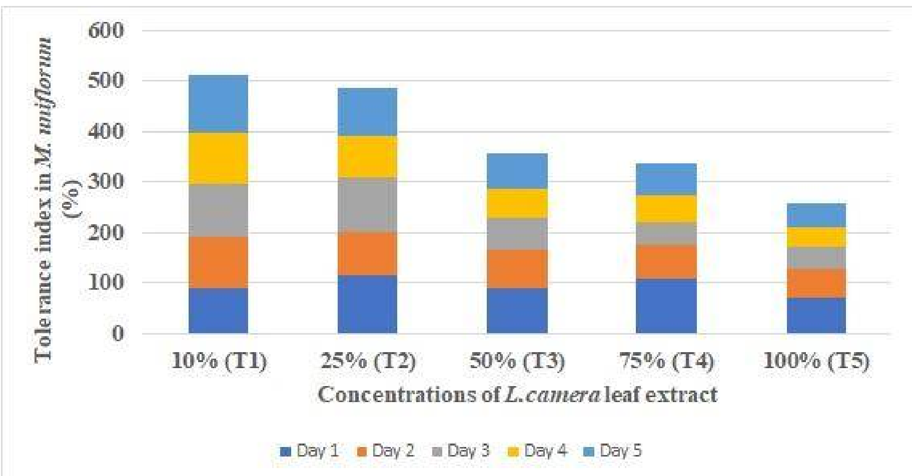

Fig. 7 Tolerance index of *M.uniflorum* under different concentration of *L. camara* solutions.

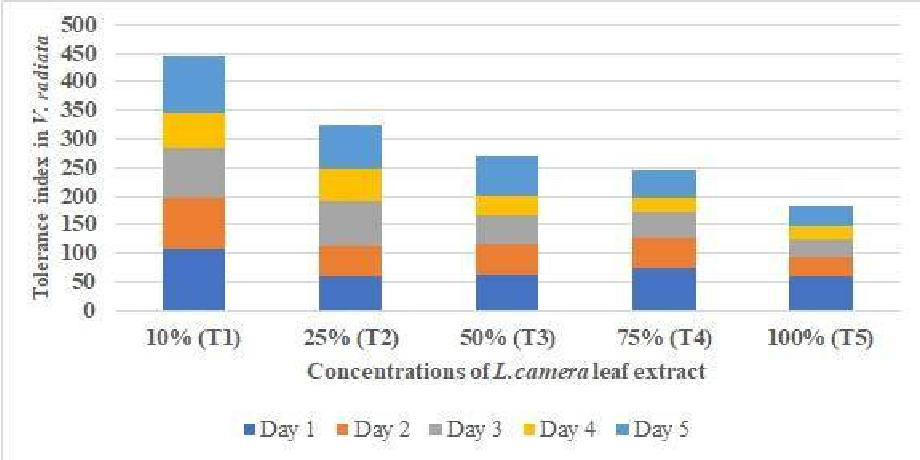

Fig. 8 Tolerance index of *V.radiata* under different concentration of *L. camara* solutions.

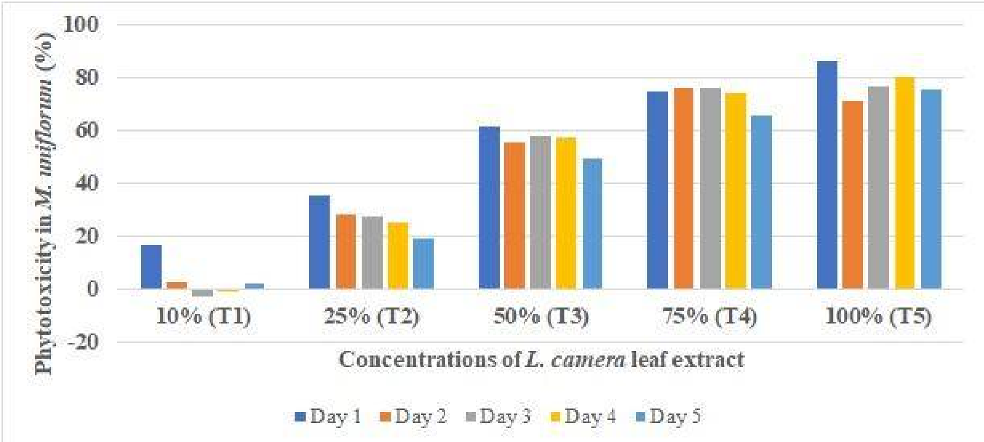

Fig. 9 Phytotoxicity of *M.uniflorum* under different concentration of *L. camara* solutions.

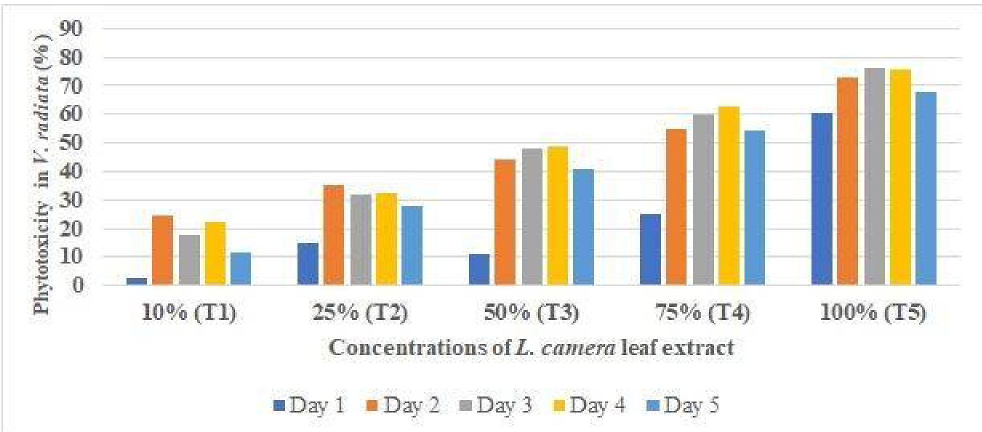

Fig. 10 Phytotoxicity of *V. radiata* under different concentration of *L. camara* solutions.

The present study found that aqueous leaf extracts of *L. camara* inhibited *M.uniflorum* and *V.radiata* seedling germination and growth. In *M.uniflorum*, the donor species has a more negative effect on seed germination and growth than *V. radiata*. Julio *et al.* (2019) found that different concentrations of aqueous leaf extract of *L. camara* inhibited germination and seedling growth of *V. radiata.* Maiti *et al.* (2010) also reported that different concentrations of *L. camara* leaf extracts and leaf leachates inhibit mung bean seed germination. As the concentration of leaf extract increased the germination, radicle and plumule length was inhibited. Maximum inhibition observed at 100% concentration (Ahmed *et al.*, 2007).

It has also been reported that different concentrations of cold and hot aqueous leaf extract *L. camara* inhibit germination, radicle and plumule length of *Phalaris minor* Retz. and *Sorghum bicolor*. All these studies indicated that as the concentration of aqueous leaf extract of *L. camara* increases the germination and seedling growth decreases (El-Kenany and El-Darier,2013; Choyal and Sharma, 2011; Abha Manohar *et al.,* 2017; Aparna and Ravindra, 2009). The results of the present study confirmed that both plumule and radicle length of *M. uniflorum* and *V. radiata* were extremely affected due to the addition of *L. camara* aqueous leaf extract. It was more significant in *M. uniflorum*. The germination was more inhibited in *M.uniflorum*, and it was less affected in *V. radiata*. Allelochemicals found in the leaf of *L. camara*, primarily phenols and triterpenes, sesquiterpenes, and flavonoids, may be responsible for the inhibition of *M. uniflorum* and *V. radiata* growth.

Conclusion

The result of the study showed that the aqueous leaf extracts of *L. camara* suppress the germination and seedling growth of *M.uniflorum* and *V.radiata*. The inhibitory effect was directly proportional with the amount of extract concentration and was more pronounced at higher concentrations. *M.uniflorum* show more inhibitory effect on seed germination, radicle length and plumule length than *V. radiata*. The experimental results also suggest that the tolerance index was found to be reduced and phytotoxicity increased with increasing the concentration of leaf extracts in *M.uniflorum* and *V.radiata.* Although, laboratory bioassay trials for investigating Allelopathy in plants are critical, a field study to confirm the allelopathic effects of *Lantana camara* on diverse agricultural crops in varied field circumstances is required.

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ALLELOPATHIC EFFECT OF AQUEOUS LEAF EXTRACTS OF INVASIVE PLANT SPECIES *CHROMALAENA ODORATA* (L.) R.M. KING & H.ROB., *MIMOSA DIPLOTRICHA* C. WRIGHT AND *COMBRETUM INDICUM*(L.) DEFILIPPS ON GERMINATION AND SEEDLING GROWTH OF SOME WIDELY CULTIVATED VEGETABLE CROPS

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Abstract

Invasive plants are non-native species that show a tendency to spread out of control. At first glance they appear pretty, but invasive plants can pose serious environments threats. Invasive plant species is found to form monotypic stand a condition whereby a plant species forms a large population, clustered within a habitat thereby preventing or replacing other plant species.Monotypic stand formed by invasive plant is due to either competition or allelopathy as proposed by different ecologist.Allelopathy includes both positive and negative effects of one plant on the other through environment, though most of the studies seem to focus on its deleterious impacts. The present study was also aimed to find out the negative impact on aqueous leaf extracts of the three invasive plants on seed germination and seedling growth of *Vigna radiata, Vigna unguiculata,Abelmoschus esculentus* seeds. The results revealed that the invasive plants *Mimosa diplotricha, Combretum indicum* and *Chromolaena odorata* have profound negative impact on the vegetable seed germination and growth. Of these three plants *Mimosa diplotricha* was found to have more growth inhibitory property than others. The leaf extract of the plant completely inhibited okra seed germination even at low concentrations. Aqueous leaf extracts of *Chromolaena odorata* at different concentrations showed that all the concentrations of leaf extracts slowed down the process of germination of seeds and led to retardation of seedling growth in germinated seeds. *Mimosa diplotricha*, the invasive weed is widely used in coconut plantations in Kerala as a green manure or cover crop. Apart from the beneficial reports of this plant our focus was on the study of its allelopathic effects when it is used as a green manure. The results revealed that *M.diplotricha* has strong allelopathic effect on inhibiting seed germination of the vegetable seeds used for the study. The present data could also be of use in ecological studies, because these species evaluated here can influence the diversity and spatial distribution of individuals in natural communities.

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Key words: invasive plants, allelopathy, germination inhibition, growth retardation.

Introduction

An invasive species is introduced as an alien, exotic, and non-indigenous species non-native to that location but very aggressive leading to damage to the other plant species, human health and economic structure, and such organisms immigrating from their native place to a new locality are referred as exotic species (Mack *et al.* 2000). Invasion is raised as one of the major causes of biodiversity loss (Inderjit *et al.* 2008, Rastogi *et al.* 2015). Invasive plants are a leading cause of declines in native plant and animal numbers. Invasive plants can reduce the amount of tree cover by preventing trees from becoming established, causing them to fall down prematurely or reducing their growth rate. They can also inflict big changes on native vegetation, altering the frequency of fires, nutrient cycling, water availability and soil erosion.

Like other living organisms, plants also compete for sunlight, nutrients, water, space etc. and this competition is the basis for allelopathy. Allelopathic plants, use their chemical tools to win the competition and use the available resources more efficiently. Most of the allelopathic plants store their protective chemicals within their leaves, especially during fall. As leaves drop to the ground and decompose, these toxins can affect nearby plants. Some plants also release toxins through their roots, which are then absorbed by other plants and trees. Allelopathy has both positive and negative effects, some positive effects are agricultural management, weed control, crop protection, or crop re-establishment and negative ones are autotoxicity, soil sickness, or biological invasion.

In this juncture the aim of the present study is to study the allelopathic effect of three invasive plants commonly found in and around the locality of our college campus on seed germination and seedling growth of commonly cultivated vegetable seeds like *Vigna radiata*, *Vigna undiculata* and *Abelmoscus esculentus.*

Materials and methods

For the present study three invasive plants were selected. *Mimosa diplotricha:* A species of leguminous woody shrub native to the Neotropics belonging to family Fabaceae, subfamily Caesalpinioideae commonly known as the giant sensitive plant, giant false sensitive plant or nila grass. *Combretum indicum*, also known as the Rangoon creeper, a vine with red flower clusters which is native to tropical Asia belonging to family Combretaceae. *Chromolaena odorata* commonly known as siam weed belongs to family Asteraceae.

Vegetable seeds selected for the allelopathic study of these invasive plants were seeds of *Vigna radiata* (green gram), *Vigna unguiculata* (cowpea) and *Abelmoschus esculentus* (Okra/ ladies finger).

Extract preparation

Fresh leaves of *Mimosa diplotricha, Chromolaena odorata* and Combretum *indicum* were collected and shade dried for 7 days. Aqueous leaf extract was prepared by grinding 10 grams leaves using mortar and pestle in 100 ml of distilled water and 10% stock solution is prepared. Using this stock solution various concentrations of solution with 2%,4%,6% and 8% solutions were prepared by proper dilution.

Experiment

Ten uniform seeds of *Vigna radiata* (green gram), *Vigna unguiculata* (cowpea) and *Abelmoschus esculentus* (Okra/ ladies finger) were kept for germination in sterilized petri-dishes lined with blotting paper and moistened with 10 ml of different concentrations of aqueous extracts (2 to 10%). Each treatment had three replicas (total number of test seeds: 10 x 3 = 30). One treatment was run as control with distilled water only. The seeds were observed daily and moistened with appropriate solution when the blotting paper were seemed to be dry. The number of germinated seeds were counted and, the root and shoot length were measured. The changes were observed for 5 days after the treatment.

Germination percentage

Germination was confirmed by the initial appearance of the radicle by visual observation. The germination percentage of seeds was calculated using the following formula.

$$\text{Germination Percentage} = \frac{\text{Number of seeds germination}}{\text{Total number of seeds sown}} \text{X100}$$

Result and discussion

The germination rates, root length and shoot length of the seeds of control and treatment with the extract are tabulated in the table below (Table 1)

Table 1 - Germination and growth of seeds in distilled water after 5 days (Control)

Seeds	Germination percentage (%)	Root length (cm)	Shoot length (cm)
Vigna radiata	100%	15.5	6
Vigna unguiculata	90%	5.7	3.7
Abelmoschus esculentus	100%	12.3	1.5

Seeds soaked in distilled water serve as control. *V. radiate* and *A. esculentus* showed 100% germination in 5 days while *V. unguiculata* showed 90% germination (Table I). The radicle emerged out of all the *V. radiata* seeds in the first day itself after soaking in distilled water whereas the plumule emerged on the second day. The same was for *V. unguiculata* seeds, while it took two days for the emergence of radicle in *A. esculentus* seeds. The length of the radicle and plumule were measured regularly and the results after 5 days are tabulated in Table I. All the seeds showed good growth in distilled water.

Different concentration of leaf extracts of *Combretum indicum* (2%-10%) showed inhibitory effect on seed germination of all the seeds analysed compared to control. All the concentrations of leaf extracts slowed the germination of all the seeds. Of the five concentrations 10% concentration showed the maximum inhibition in the three seeds. Of the three vegetable seeds *V.radiata* showed maximum resistance to the allelopathy of *Combretum.* The rate of germination of all seeds is clearly tabulated in table 2. *Abelmoschus* seeds was affected most by the inhibitory effect of the *Combretum indicum* leaf extracts. Increase in concentration of the extracts showed an increase in inhibitory effect on seed germination and seedling growth.

Screening leaf litter of *Combretum indicum* using the sandwich method by Fujii*et al*., 2003, indicates increasingly strong inhibitory activity. Resmi & Vijay, 2015,studied the effect of *Combretum* on the germination and early seedling growth of test plant material, *Vigna radiata* showed that the inhibition shown by the species is statistically highly significant (at 1% level) in terms of morphological parameters viz., shoot length, leaf length and leaf breadth when compared to the control seedlings.

The effect of *Chromolaena odorata* leaf extract of different concentrations on germination and seedling growth of selected vegetable seeds showed that all the concentrations of leaf extracts slowed the germination of seeds. Here also *V.radiata* seeds showed maximum resistance to the inhibitory effect on germination. Even though the germination rate was little affected the growth parameters like root and shoot length of the germinated seedling was found to be very poor when compared to control (Table-3). In *Vigna unguiculata* a concentration dependent decrease in the germination rate of the seeds was observed with complete inhibition of seed germination at 100%. Even though germination occurred the growth of the seedlings was found to be greatly affected by the allelochemicals in the leaf extracts of *Chromolaena.*

Ajewole *et al*. (2021), investigated the effects of fresh shoot biomass of *Chromolaena odorata* on okra *Abelmoschus esculentus* the leachate of *Chromolaena odorata* resulted to a

Table 2- Effect of *Combretum indicum* leaf extracts on seed germination and seedling growth measured after 5 days

Seeds	Germination percentage					Root length					Shoot length				
	Concentration of extract					Concentration of extract					Concentration of extract				
	2%	4%	6%	8%	10%	2%	4%	6%	8%	10%	2%	4%	6%	8%	10%
Vigna radiata	100	80	60	50	30	3	1.5	1.1	1.3	0.9	3.5	2.1	1.5	1.8	1.1
Vigna unguiculata	50	40	40	30	0	2	1.3	0.8	0.5	-	2.6	1.9	1.5	1.4	-
Abelmoschus esculentus	20	10	0	0	0	0.6	0.9	-	-	-	1.2	1.5	-	-	-

reduction in radicle length, plumule length and number of roots. It also affected the food content of *Abelmoschus esculentus.* The present study results are substantiated by the above report. Okra seeds showed the allelopathic effect from the germination stage onwards. Here the rate of germination was reduced to less than 50% even at the lowest concentration of the extract. The germinated seeds showed extremely retarded growth rate for the period of analysis (5 days).Due to its high allelopathic potential this plant might therefore be used as a herbicide to control other weeds.

Table 3- Effect of *Chromolaena odorata* leaf extracts on seed germination and seedling growth measured after 5 days

Seeds	Germination percentage					Root length					Shoot length				
	Concentration of extract					Concentration of extract					Concentration of extract				
	2%	4%	6%	8%	10%	2%	4%	6%	8%	10%	2%	4%	6%	8%	10%
Vigna radiata	100	100	80	80	6	6.4	1.2	1	1.2	1.1	6	3.5	1.4	0.5	0.8
Vigna unguiculata	80	40	30	10	0	1.8	1.3	0.9	0.7	-	3	1.8	1.5	1	-
Abelmoschus esculentus	40	20	1	10	0	1.1	0.9	0.8	0.4	-	1.5	1	0.6	0.8	-

Mimosa diplotricha, the invasive weed is commonly seen in arable croplands, plantation crop farms, fallow lands, roadsides, abandoned lands and deforested areas. This plant vigorously scrambles over other plants forming dense thickets and, in this process, prevents regeneration, reproduction and growth of indigenous species. In coconut plantations in Kerala, India, an experiment was conducted using the area around the base of each palm (1.8 m radius) for raising green manure crops (Thomas and George, 1990). *M. diplotricha* was superior to other species tested in green matter production and nitrogen yield and was most effective in raising soil fertility parameters. The use of *M. diplotricha* enhanced the yield of coconuts suffering from root wilt disease by over 20%. Another study in Kerala showed benefits, but also showed that both thorny and thornless *M. diplotricha* have the potential to become weedy in agricultural and agroforestry systems (Suresh, 2014). The vigorous growth of *M. diplotricha* led to its use as a green manure or cover crop (Sankaran, 2017).

Apart from these beneficial reports of this plant our focus was on the study of its allelopathic effects when it is used as a green manure. The results revealed that *M.diplotricha* plant has strong allelopathic effect on the inhibiting seed germination of the vegetable seeds used for the study. The seed germination percentage of *Vigna radiata* seeds showed a concentration dependent decrease. Among the three invasive plants studied this plant is found to inhibit the *V,radiata* seed germination and seedling growth the most. Similar results were obtained for *Vigna unguiculata* seeds also. Interestingly the leaf extracts at different concentrations completely inhibited the germination of okra seeds (Table-4).

Even though reports on rapid invasion of this plant species is extensively available studied regarding its allelopathic effect when used as green manure is little. It is understood that the growth pattern of *M. diplotricha* forming thickets and preventing sunlight from reaching below has severely affected the growth and germination of native plant species. Methods of controlling this weed include uprooting and using it as a green manure and it is widely practiced in Kerala due to its nitrogen fixing roots enhancing soil fertility. But the present study reveals that this practice affects the germination and growth of the seeds of vegetable seeds studied. The allelochemicals present in the leaf extracts retards the germination and growth of the vegetable seeds. Hence utmost care should be given while using these as a green manure.

Table 4- Effect of *Mimosa diplotricha* leaf extracts on seed germination and seedling growth measured after 5 days

Seeds	Germination percentage					Root length					Shoot length				
	Concentration of extract					Concentration of extract					Concentration of extract				
	2%	4%	6%	8%	10%	2%	4%	6%	8%	10%	2%	4%	6%	8%	10%
Vigna radiata	80	70	70	70	40	0.4	0.3	0.3	0.3	0.1	0.3	0.2	0.2	0.2	0.1
Vigna unguiculata	50	30	30	25	20	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Abelmoschus esculentus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Conclusion

Monotypic stand is a condition whereby a plant species forms a large population, clustered within a habitat thereby preventing or replacing other plant species. Some invasive plants create monotypic stand that replace and/or prevent other plant species especially native plant species from growing there, forming a dominant colonization. Monotypic stand formed by invasive plant is due to either competition or allelopathy as proposed by different ecologist. This can occur from nutrient monopolization or lack of natural controls such as herbivores or climate that keep them in balance with their habitat and retardant chemicals exuded.

The results revealed that the invasive plants *Mimosa diplotricha, Combretum indicum* and *Chromolaena odorata* have profound negative impact on the vegetable seed germination and growth. Of these three plants *Mimosa diplotricha*was found to have the more growth inhibitory property than others. The leaf extract of the plant completely inhibited okra seed germination even at low concentrations.*Chromolaena odorata* or siam weed has been extensively studied for its allelopathic properties and it has been recorded that stems and roots of *Chromolaena odorata* contained allelopathy compounds such as eugenol; eugenol acetate; caryophyllene; isocaryophyllene; acoradiene; palmitic acid; 2,6-dimetoxy phenol and furfuryl alcohol (Agusta et al., 2000). Based on the present investigation, it is suggested that the rate of inhibitory effect on the vegetable seeds noticed can be due to the presence of these allelochemicals.

Allelopathic inhibition on hypocotyl and radicle growth on lettuce seedlings by *Combretum indicum* has been reported by Suwitchayanon *et al.,(*2017). The present investigation also showed negative impact of leaf extract of this plant on the vegetable seed germination and growth. Based on the findings, it could be speculated that low germination rate of the test species after treatment by extracts may be due to the allelochemicals present in the extracts. Allelopathic chemicals alter plant growth and seed germination through a multiplicity of effects on physiological and biochemical processes, as many of the compounds have multiple phytotoxic effects. According to Singh *et al*. (2009), phytotoxins can affect enzyme activities or plant hormones, increasing amylase activity and promoting a greater release of reserves that would otherwise be provided to the embryo, extending oxidative stress and seed dormancy through the increase of abscisic acid production and inhibiting water absorption *via* alterations in membrane permeability. Therefore, the observed difference between the control and treatment groups, in terms of the number of germinated seeds, might be attributed to the presence of allelopathic compounds. The seedling growth results for almost all of the vegetable species showed that the roots as well as the shoots were sensitive to the leaf extracts.

The present data could also be of use in ecological studies, because all the species evaluated here can influence the diversity and spatial distribution of individuals in natural communities.

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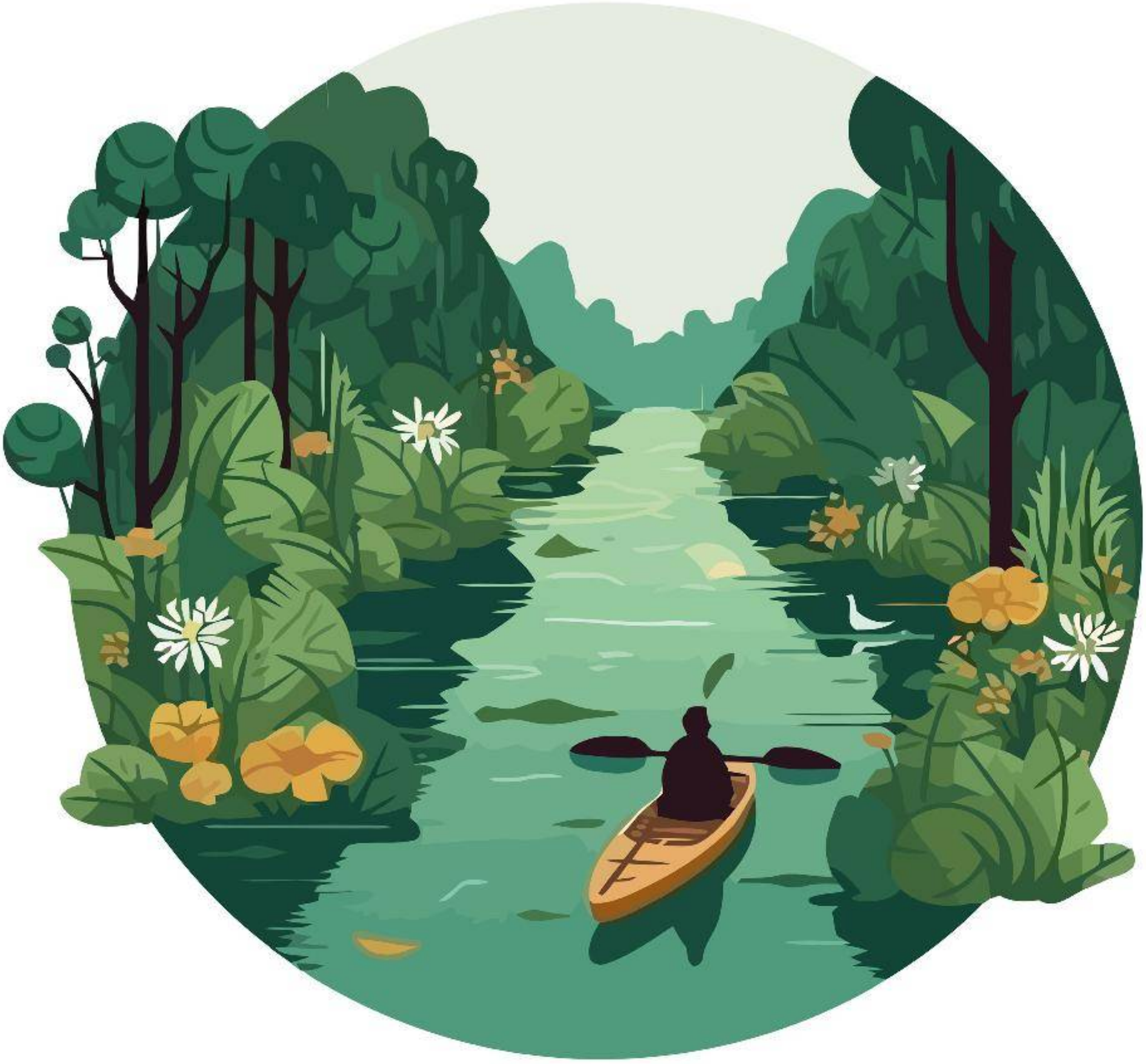

Invasion in Forest Ecosystem

EARTH OBSERVATION BASED APPROACH FOR ASSESSMENT, MODELLING AND MANAGEMENT OF BIOLOGICAL INVASIONS - SCOPE AND FUTURE

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Abstract

The three basic variables for monitoring invasion are the occurrence of alien species, the status of the species, and the impact that the species has on biodiversity. The Earth observation approach integrates observations of the planet based on in situ and remote sensing data to track changes in its conditions over space and time. Over the past five decades, geospatial technology has progressed significantly. This review provides insight into the contributions of remote sensing to the monitoring and managing of biological invasions. Remote sensing is an essential tool that, in conjunction with field data, ecological modelling and spatial analysis, contributes to the mapping, prediction and management of invasive species populations. The effectiveness of remote sensing data for detecting invasive plants depends on the spatial and spectral resolution of the sensors. Mapping of invasive plant species using multispectral and hyperspectral data is feasible when species have unique phenology and spectra. Invasive plants can be better demarcated if they are gregarious as large stands in open forest canopies, grasslands and scrublands. Significant progress has been made in understanding the physical pathways of invasion, which species invade, how they spread, and what makes ecosystems vulnerable to invasion. However, we need to identify ecological factors that are key determinants of their success and ecological variables that could significantly affect the invasion process. Unmanned aerial vehicles would provide an alternative to satellite remote sensing for mapping invasive alien plant species and evaluating management effectiveness. The application of hotspot analysis and species distribution modelling prioritizes areas for invasive species management.

Keywords: Invasive species, Invasibility, Modelling, Hotspots, Remote sensing

Introduction

Profound biodiversity changes lead to new communities where the species composition transforms into a new configuration (Pandolfi et al. 2020). Invasive alien species are non-

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Sudhakar Reddy, C. and Saranya, K.R.L. 2023. Earth observation based approach for assessment, modelling and management of biological invasions – Scope and future. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.147-157.

native plants, animals and microorganisms that are deliberately or accidentally introduced into new areas outside their original ranges and then spread beyond cultivation and human care to affect biodiversity. The Convention on Biological Diversity (CBD) (1992) presented that "biological invasion by alien species" is the greatest threat to the existence of native biodiversity (https://www.cbd.int/). Biological invasion is the process by which species with no historical record in an area breach biogeographic barriers and extend their range (Ruesink, 2020). The process of biological invasion involves entry, dispersal and impact. Iinformation on biological invasions is needed to inform three main management processes: designing surveillance and field surveys, prioritizing sites for management interventions and supporting regulatory decision-making (Sofaer et al., 2019; van Rees et al., 2022).

The CBD calls for "the collection and dissemination of information on alien species that threaten ecosystems, habitats or species to be used in context with any prevention, introduction and mitigation" (CBD 2000). The CBD's post-2020 target activities to halt biodiversity loss from invasive alien species include pathway management, species prioritization, spatial prioritization, restoration and recovery (Essl et al. 2020). The factors that account for differences in invasibility between habitats are evolutionary history, community structure, propagule pressure, disturbance and stress (Alpert et al. 2000). Catford et al. (2009) reviewed 29 hypotheses in invasion ecology. Research indicates that plant invasion is a function of propagule pressure, abiotic characteristics of a site, and biological characteristics of invaders and recipient community (Catford et al., 2009). A review by Catford et al. (2012) aimed to identify the best way to quantify the level of invasion and recommended using relative alien species richness and relative alien species abundance as ecologically meaningful indicators.

The main attributes used for designating 'species' as invasive alien species are *invasiveness*, *impacts* and *invasion areas*. Many invasive species checklists are in circulation, but the criteria used in these lists are not clearly stated (Reddy, 2008). Biological invasions and natural disasters are similar phenomena. Their causes are implicit, but their occurrences are unpredictable and uncontrollable (Ricciardi et al. 2011). The Group on Earth Observations Biodiversity Observation Network (GEO BON) has identified three essential variables for invasion monitoring: (1) alien species occurrence, (2) alien status of a species and (3) impact that a species has on biodiversity and ecosystems (https://www.geobon.org/). This is related to the concept of *Essential Biodiversity Variables*, which are the subset of biodiversity variables needed for studying, reporting and managing biological invasions. Ecological flexibility can be measured as the number of different habitats a species occupies is strongly related to impact. Blackburn et al. (2014) developed a classification scheme for invasive alien species (i.e. massive, major, moderate, minor and minimal). Overall, the impacts of alien species are heterogeneous and not unidirectional, even within specific types of impacts. Green & Grosholz (2021) proposed functional eradication as a framework for invasive species control (Fig 1). In the case of large-scale invasions, resources could be allocated to suppressing populations in high-priority locations. Invasive species management requires accurate mapping and modelling techniques at a relatively low cost.

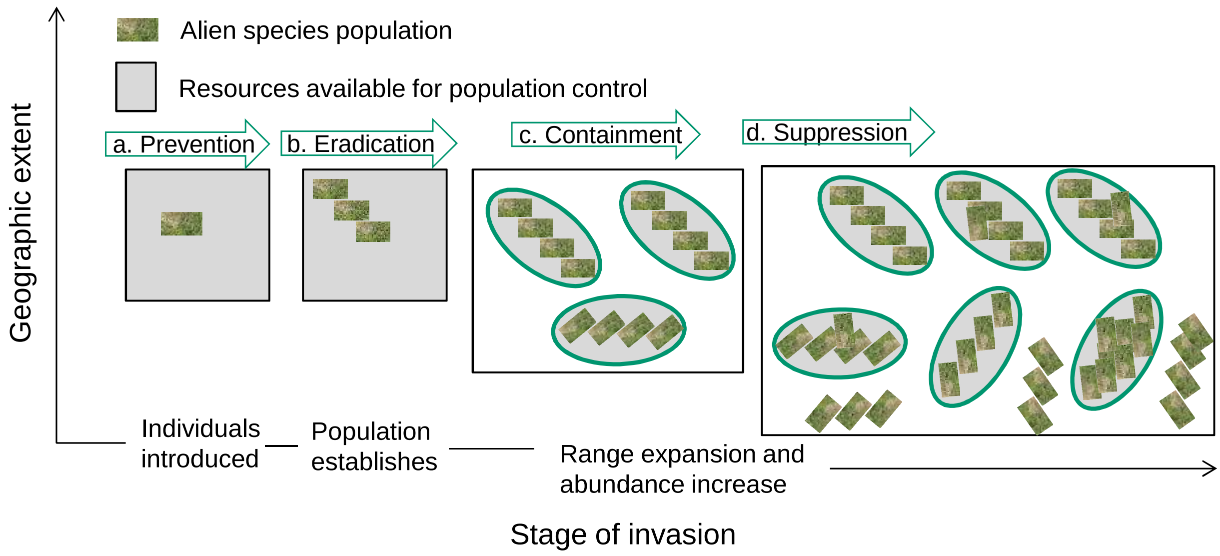

Fig 1. Relationship between stage of invasion, geographic extent and management resources available for intervention

Remote sensing applications

Earth Observation-based approach based on both in situ and remote sensing data allows efficient monitoring in space and time. Earth observation-on-biodiversity monitoring provides a framework for invasive species management by integrating remote sensing data, in-situ field measurements, and geographic information system (GIS) (Fig 2).

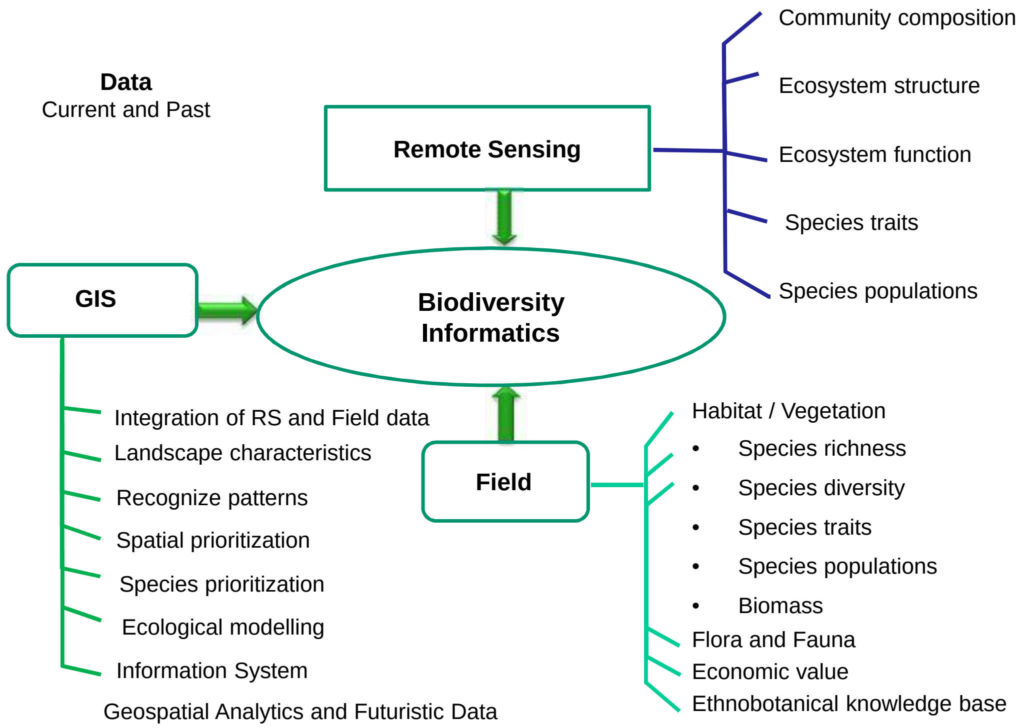

Fig 2. Earth Observation approach for biodiversity monitoring

Mapping

Inventory data are critical to prioritizing invasive species management initiatives. Areas with high potential for invasive plants may require more intensive surveys using the Global Positioning System to record the location of invasive plants, loading this information into a GIS to create species distribution maps. An essential requirement in invasive species mapping is delineating the spatial extent to understand the severity of the invasion. The mapping information is then interpreted to determine the–invasion areas extent, direction and spread rate. Invasion monitoring can be done through seasonal surveying, sampling and mapping using remotely sensed imagery. Sensors collect information in three primary domains: spectral, spatial and temporal, which are critical for mapping invasive plant species. Multi-sensor remote sensing detection strategies for invasive species mapping include the presence of large and homogeneous areas, phenological variation with coexisting plants, selecting images in the appropriate season, unique spatial patterns, unique signatures, unique biochemistry, model combination, and vegetation indices from time-series satellite data (Huang & Asner, 2009; He et al. 2015). Hyperspectral remote sensing is a powerful tool for identifying plant invasions based on their spectral characteristics. Field spectroscopy is primarily used to assess biophysical and biochemical properties to identify species. Current technologies such as hyperspectral imaging spectroscopy and light detection and ranging (LiDAR) enable the detection and discrimination of plant species within the same functional groups. Advances in image processing algorithms and geospatial technology has enabled accurate and repeatable remote sensing measurements over time (Bolch et al. 2020).

Invasive plants of open forest stands, grasslands and scrublands are most likely to be detectable based on leaf chemistry, leaf pigmentation, or flowers distinctly different from associated species (Bradley, 2014). An alternative to the visual interpretation of images is an approach based on machine learning (Blaschke, 2010). This approach evaluates the variance in reflectance within a multi-pixel moving window to identify similar objects or textures. To detect any plant species using remote sensing, the species must have a unique spectral, textural or phenological signal that can distinguish it from the surrounding native vegetation. Although spectral differentiation-based mapping is widely known, many studies use texture- and phenology-based approaches to identify invaded landscapes. Remote sensing-based products are used to map physical pathways for invasive species, such as roads and streams in forests (Secades et al. 2014). A study by Pasha et al. (2014) mapped the distribution and analysed the rate of spread of *Prosopis juliflora* in the Rann of Kachchh. Bolch et al. (2020) proposed an approach for mapping invasive species with Earth observation data (Fig 3).

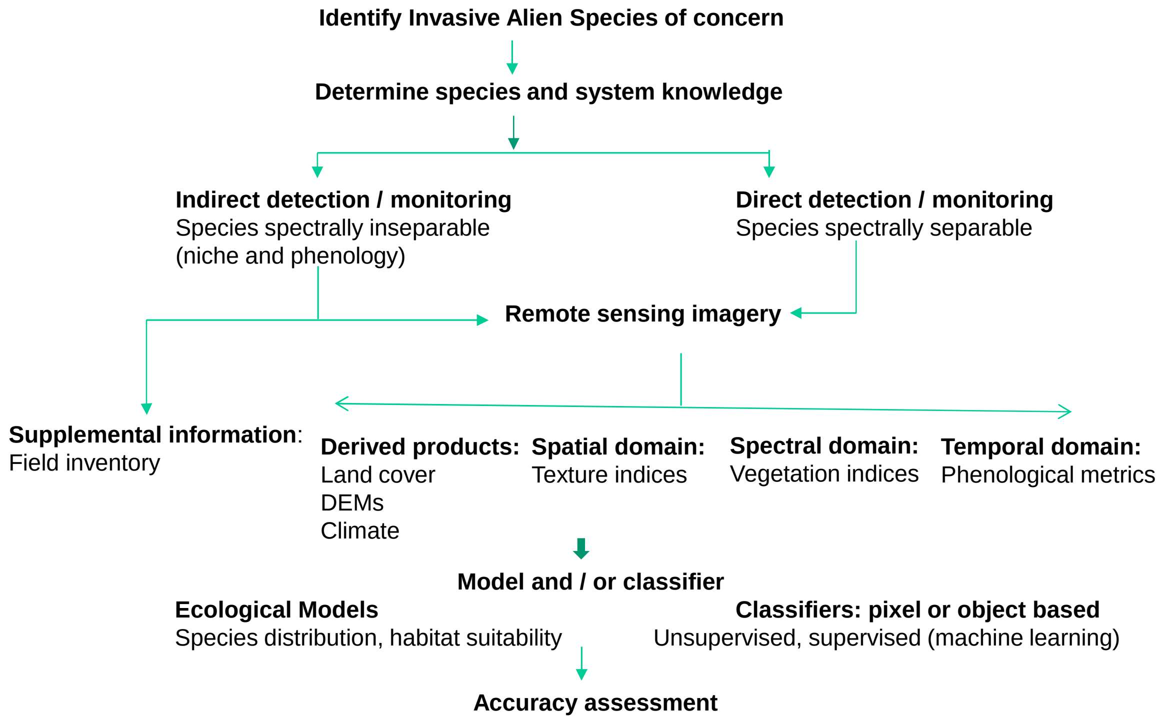

Fig 3. Earth Observation based approach for invasive species mapping (Bolch et al. 2020)

Recent species detection applications have primarily focused on using multispectral and LiDAR sensors in conjunction with machine learning algorithms (Martin et al., 2018). Unmanned aerial vehicles (UAVs) are an emerging remote sensing platform that provides an increasingly viable alternative to satellite remote sensing to detect invasive alien species. Kattenborn et al. (2019) has developed the spatial approach for three different species: *Pinus radiata*, *Ulex europaeus* and *Acacia dealbata* occurring in Chile. For each species 4 UAV flights were performed, i.e. two flights for training the semi-automatic cover mapping (MaxEnt) and another two flights as independent validation of the upscaling to the Sentinel-scale. The upscaling was performed using random forest models. An overview of the workflow is given in fig 4.

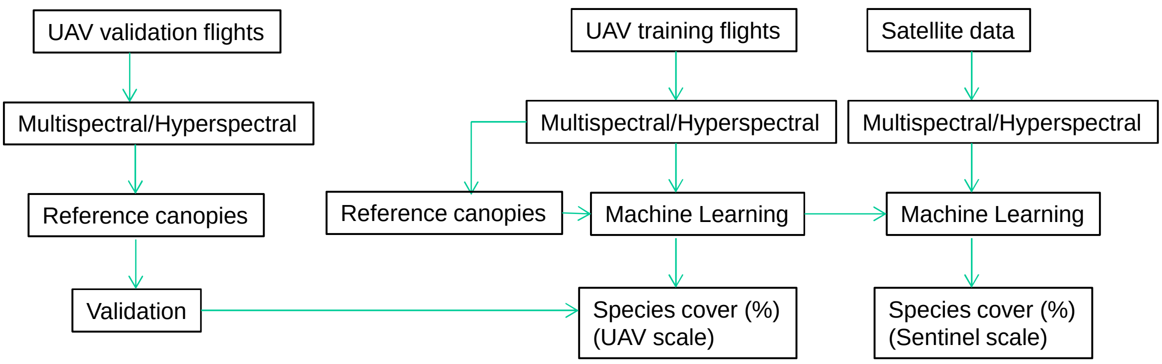

Fig 4. Workflow diagram illustrating the processing of the UAV and satellite data (Kattenborn et al. 2019)

Reddy et al. (2017) combined quantitative plot data on the percentage of individuals of alien species with vegetation type map to create spatial data on 'level of alien plant invasion'. The percentage values shown on the map represent the level of alien plant invasion in the predominant vegetation type class (Fig 5), not the total alien flora of the pixel (for which the values would be lower or higher). The level of alien plant invasions in the vegetation types of India was assessed using a database of vegetation plots previously collected for landscape-level biodiversity characterization (Roy et al. 2011). Out of 16,500 sample plots studied across India, invasive alien plant species are distributed in about 60% of the sample plots.

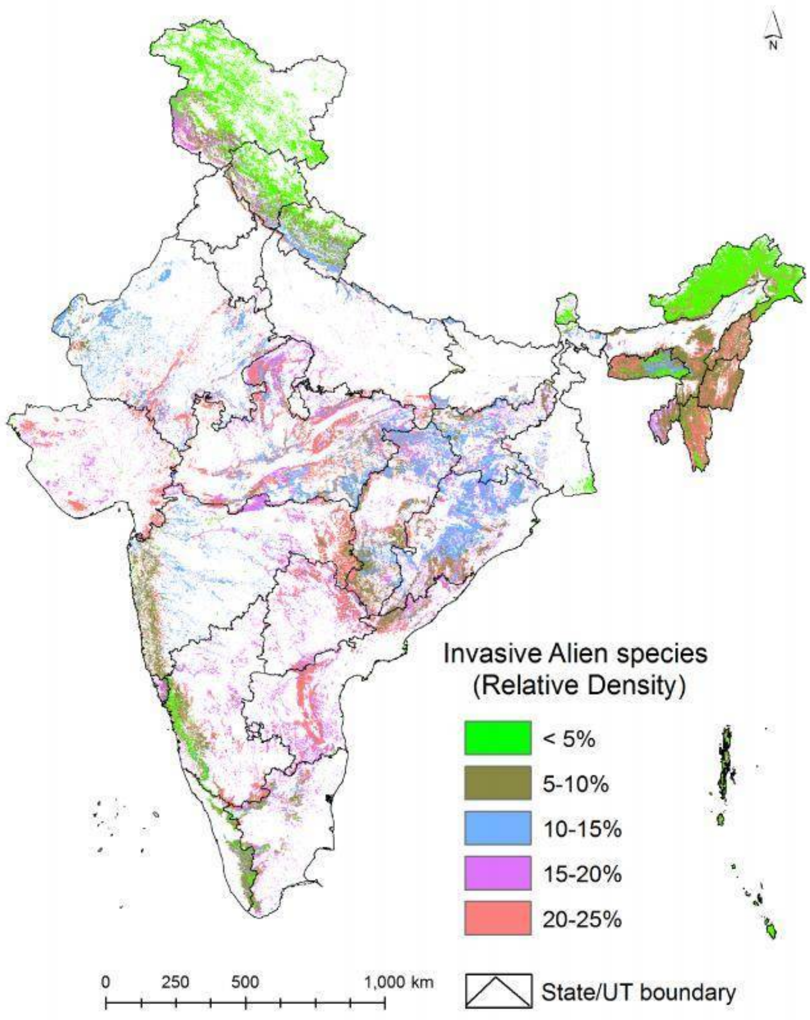

Fig 5. Map showing level of alien plant invasion in India (Reddy et al. 2017)

India's top 10 invasive alien species (*Lantana camara*, *Senna tora*, *Chromolaena odorata*, *Ageratum conyzoides*, *Sida acuta*, *Prosopis juliflora*, *Hyptis suaveolens*, *Parthenium hysterophorus*, *Mikania micrantha* and *Cirsium arvense*) were identified based on the highest population density in natural vegetation landscapes (Reddy et al. 2017). The study by Pasha & Reddy (2022) has modelled trends in invasion hotspots of *Prosopis juliflora* in the Kachchh biosphere reserve using remote sensing data from 1975 to 2020.

Forecasting biological invasion

Both fundamental and realized niches refer to species environmental position in an ecosystem. Fundamental niches (pre-competitive niche) represent all the environmental conditions where a species can live, and the realized niche (post competitive) is where the species actually lives. A broad (generalist) vs a narrow (specialist) ecological niche will have several implications for the species in question. One potentially cost-effective approach in identifying probable occurrences of invasive species is to predict their distributions using remotely sensed data and knowledge of species ecology and environmental tolerances. Identifying particular areas likely to host large numbers of invasive species populations is the common goal for ecologists (Ibanez et al. 2009). Species Distribution Models (SDMs) are used to characterize the ecological niche of species, i.e., the environmental conditions that explain their presence. The ecological niche is inherently multi-dimensional and can involve many factors articulated in a complex manner (i.e., a non-linear system) and at multiple spatial scales. From known locations to predictions requires data on climate (precipitation, temperature, bioclimatic variables), topography (slope, aspect, elevation, topographic wetness index), spectral bands (i.e. all seasons), spectral vegetation indices, resource availability variables (streams), biotic variables (vegetation type, canopy density, canopy height, canopy gap size and gap perimeter, length of greening period), soil properties variables (soil pH, soil type, organic carbon content of soil, bulk density, total nitrogen, cation exchange capacity, sand, silt and clay content), anthropogenic variables (proximity to historical or contemporary disturbance - deforestation sites, fire, plantations, agriculture, roads and settlements), and invasive species neighbourhood index.

Modern SDMs are generally correlative methods that link known species occurrence data to environmental predictors through statistical learning methods (Deneu et al. 2022). It is challenging to decide which SDM to use. SDMs provide different results for different species while projecting the appropriate climate. Therefore, it may be safer to use an ensemble of models. Bioclim is a classic "climate envelope model". The Bioclim algorithm calculates site similarity by comparing the values of environmental variables at any site to the percentile distribution of values at known sites of occurrence ("training sites"). Maximum Entropy (MaxEnt) model develops a response curve for each environmental variable indicating which particular conditions within a range are most suitable. It includes interactions between predictor variables. Random forest (RF) is an ensemble machine-learning algorithm that uses an array of randomized decision trees (Namitha et al. 2022). Random forest (classification and regression) selects observations, builds a decision tree and the majority result is considered for classification. Deep Neural Networks (DNN) are deep learning models inspired by artificial neural networks. A DNN works by multi-layer perceptron neural network whose inputs and outputs are improved with multiple hidden layers and can be optimized using gradient descent (Namitha et al. 2022).

A suitable way to improve the transferability of the model could be to develop models with an increased number of presence or reduced number of predictors (Liu et al. 2021). A study by Saranya et al. (2021) used different machine learning models to identify the potential distribution of *Chromolaena odorata* and *Lantana camara* in the Eastern Ghats of Andhra Pradesh (Fig 6). Vaz et al. (2018) identified the contribution of remote sensing and the main limitations of spatial data for plant invasion management. Vaz et al. (2018) pointed out that the cost of data acquisition or reproducible data is expensive. The spectral/spatial/radiometric resolution of the available data is insufficient to obtain accurate results along with technical limitations.

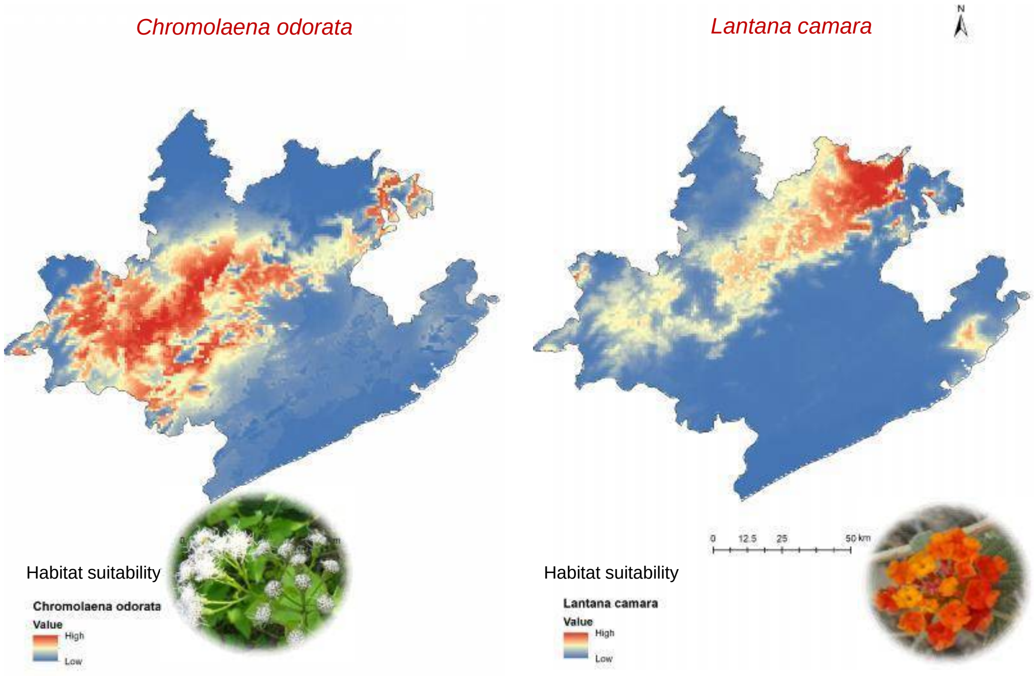

Fig 6. Habitat suitability map of selected invasive alien species in Visakhapatnam district, Andhra Pradesh (Saranya et al. 2021)

Invasive alien species information system

Early detection and rapid response focus on identifying and eradicating emerging infestations to control invasions. Reshi & Khuroo (2012) reviewed the management challenges of alien plant invasions and recommended a national alien invasive species information network for easier dissemination of information about invasive species. Four stages of development of national observation and monitoring systems for alien species include: 1. National list of exotic species, 2. Priority sites (Information System is required), 3. National extent and area occupied by species (UAV and high spatial resolution/hyperspectral data are required) and 4. Network of long-term monitoring sites (ecological studies and remote sensing) (Latombe et al. 2017). Web-based information systems are designed to increase access to species occurrence data for use in ecological research and decision-making. Modern geospatial techniques can produce new ways to view, analyse existing information and predict future situations.

Conclusion

The use of remote sensing and GIS provides a basis for monitoring invasive species management. Hyperspectral remote sensing is an effective tool to discriminate plant invasions at species level. UAVs have been considered a promising approach to mapping invasive plant species and are best suited for monitoring management effectiveness. Due to the enormous number of invasive species, predictions focused on invasibility are required. Ecological models have improved our understanding of key drivers and predicted potential areas of invasive species expansion and possible impacts under different climate change scenarios.

Acknowledgments

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PROGRESS ACHIEVED IN IMPLEMENTING AICHI TARGET 9 AND NBAP 4 IN INDIA: A REVIEW

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Abstract

Research reports have clearly established the deleterious role of invasive alien species on biodiversity, human health, economy, food security, livelihood, and the successful implementation of sustainable development goals. Considering the aforesaid, Convention on Biological Diversity (CBD) included the invasive species in the strategic plan for biodiversity 2011–2020 as one of the targets (Aichi Target 9). Pertaining to India a number of studies and reports are available about the occurrence of invasive species in different habitats. However adequate information is not available on the impacts of invasive species on Indian biodiversity, economy, livelihood, and the challenges posed by them in food production. The available reports clearly indicate that India has glaringly failed to achieve the Aichi Target 9 and Target 4 of NBAP (National Biodiversity Action Plan) 2014. It is time to rethink the current structure and also the importance of a separate agency to address the invasive issue in India in order to prevent biodiversity and economic loss and also to ensure the food security of the nation. It is the need of the hour that the National Biodiversity Authority needs to promote and be declared India’s focal point to address the invasive issues on a war footing. Otherwise, in the forthcoming years, India will face irreparable damage to its biodiversity, food security, livelihood, and GDP.

Keywords; Aichi Target, CBD, IAS, NBA, NBAP, SDG.

The fifth Global Biodiversity Outlook published by the Secretariat of the Convention on Biological Diversity (CBD) clearly established the essential ecological services provided by flora and fauna and emphasized the importance of biodiversity conservation (SCBD, 2020). On the other hand, the global research community raised concern about the ongoing unprecedented rate of biodiversity loss (SCBD, 2020). Continuous human interventions in the form of habitat destruction/conversion, poaching, pollution and the introduction of exotic species have especially increased the global biodiversity loss (SCBD, 2020). Recent reports have highlighted that the introduction of alien species has emerged as a great threat to the native diversity, food security, human health and livelihood. Besides, it also inhibits the progress of several developmental projects including the successful implementation of UN Sustainable Development Goals (SDGs) (SCBD, 2020; www1).

Sandilyan, S. 2023. Progress achieved in implementing Aichi Target 9 and NBAP 4 in India: A review. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.158-168.

The International Union for Conservation of Nature and Natural Resources (IUCN) highlighted that invasive alien species (IAS) has been identified as one of the main drivers of global biodiversity loss and also the second important reason for species extinction (www1). For instance, the invasion of the brown tree snake *Boiga irregularis* in Guam island of the Western Pacific has been identified as the only reason for the extinction of 10 bird species of the island (www1). Likewise, a large number of amphibian species in North, South and Central America and other Caribbean regions are facing extinction due to the invasion of the fungus *Batrachochytrium dendrobatidis* (www2). Further, studies from African region indicate that 80% of IUCN threat category species in Fynbos biome are at bay due to the constant invasion of alien species (www2). Moreover, a recent analysis concluded that globally 25% of flora and 33% of faunal extinctions were directly caused by IAS (Blackburn et al., 2020).

Besides, IAS gravely affects the food security by devastating agriculture and aquaculture production (www1; Paini et al., 2016). For the past few decades the global agricultural sector has been facing huge loss due to the continuous invasion of several species of pest and weed (Paini et al., 2016). Ultimately, the large-scale yield loss results in food price hike and also affects the economy and the GDP of a nation (Paini et al., 2016). In support of this, a report from the USA has said that the invasive insects and pathogens alone cause a loss of around $40 billion per year (Pimentel et al., 2005). India also attempted to assess the economic loss caused by the IAS in agriculture and forest sector around 2001 and found that it was around $91 billion/year (Hiremath & Krishnan, 2016). Obviously the loss in agriculture instantly affects the livelihood of several million people who directly and indirectly depend on agriculture and the associated sectors. The Indian Ministry of Agriculture and Farmers Welfare (MoA&FW) in its annual report (2017–18) mentioned that 54.6% of the Indian population is engaged in agriculture and allied activities (Annual Report, 2017).

Apart from denaturing the biodiversity, human health, food security and livelihood, IAS also negatively influences the progress of the UN SDGs. In particular, among the 17 SDG goals, IAS directly intervenes with 10 SDG goals (www1). The details of the goals and the influence of IAS on them are provided in Table 1.

The loss of biodiversity and its cascading impacts on food security, economy and livelihood is an age-old issue. However, in the 1980s the global community realized the impacts of biodiversity loss on ecosystem services, agriculture and human well-being. Based on several reports and case studies, a number of countries wanted to halt the biodiversity loss. In 1988 the UNEP (United Nations Environment Programme) convened the ad hoc working group of biological diversity experts in order to sustain the need for an international convention for addressing various issues of global biodiversity (www3). Later the ad hoc working group was renamed as the Intergovernmental Negotiating Committee. In 1992 the committee placed its report for the adoption of the agreed text of the CBD. In June 1993 nearly 168 countries including India signed the international agreement and subsequently CBD came into force (www3; Hiremath, & Krishnan, 2016).

The signatories of CBD recognized the deleterious impacts of IAS on global biodiversity and its concomitant impacts on agriculture and livelihood. In 2008 CBD formulated Article 8(h) which stated that each contracting party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species (www4). Further, CBD set global priorities and formulated guidelines for collecting information on IAS and also helped coordinate international action against IAS (www4).

As part of the CBD regulations, the signatories need to meet at regular intervals, known as COP (Conference of Parties). In 2010, the COP took place in Nagoya, Japan, and in the decision X/2 adopted a revised and updated strategic plan for biodiversity, including the Aichi Biodiversity targets for the period 2011–2020 (SPB, 2020). Further, the decision provides overarching framework on all the biodiversity related international conventions including the United Nations system and all other guilds that are engaged in biodiversity management and policy development (SPB, 2020). Besides, all the signatories are encouraged to include their progress on achieving implementation of the 2011–2020 strategic plans in their national reports (SPB, 2020).

The strategic plan for biodiversity 2011–2020 has 20 achievable targets, which are widely known as the Aichi Targets (SPB, 2020). In this, Target 9 has been devoted for IAS (SPB, 2020). Aichi Target 9 says that by 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment' (SCBD, 2020; SPB, 2020).

Since India is one of the signatories of CBD it has become its mandate to prepare a national biodiversity strategy and action plan for implementing the convention at the national level (NBAP, 2014). Earlier in 2008 a National Biodiversity Action Plan (NBAP) was developed after a series of inter-ministerial meetings. However after the introduction of the Strategic Plan for Biodiversity 2011–2020, India has developed 12 national biodiversity targets aligned with the CBD strategic plan after several stakeholder consultations and public contributions, which are popularly known as NBAP 2014 (addendum) (NBAP-2014). Target 4 of the NBAP addendum 2014 reiterated the Aichi Target 9. NBAP 2014 has also identified a list of responsible agencies to help achieve the target in the stipulated period (Forest departments, Directorate General of Shipping (DoS), Wetlands International-South Asia, Salim Ali Centre for Ornithology and Natural History(SACON), Indian Council of Forestry Research and Education (ICFRE) (Forest Invasive Species Cell), Wildlife Institute of India (WII), Centre for Marine Living Resources and Ecology (CMLRE), National Institute of Oceanography (NIO), Annamalai University Faculty of Marine Sciences and CABI South Asia) (NBAP-2014). Further, NBAP 2014 also listed out some vital action points to manage and control the IAS (Table 2).

Where We Are Now

The Secretariat of the CBD recently (2020) released its fifth Global Biodiversity Outlook, which mainly discussed about the progress of strategic plan for biodiversity 2011–2020 (SCBD, 2020). CBD synthesized the outlook mainly based on the 6th National Reports submitted by the signatories and other research publications and reports. After detailed analysis the Outlook expressed that, during the ten-year period, a number of countries had taken significant action on several biodiversity issues prevailing in their own provinces

(SCBD, 2020). The report also admitted that the status of biodiversity would have certainly been worse without the implementation of the strategic plan. However, at the global level, none of the 20 targets have been fully achieved and only six targets (9, 11, 16, 17, 19 and 20) have been partially achieved by the signatories (SCBD, 2020). The report also insists that our efforts have not been sufficient and sound enough to achieve the targets and also highlighted the importance of developing right policies for positive outcomes (SCBD, 2020). As a whole the Outlook concluded that the global community glaringly failed to meet the Aichi biodiversity targets and also a number of countries are not on the track to reach 2050 vision for biodiversity (SCBD, 2020).

Pertaining to Target 9 on issues related to IAS, the Outlook appreciated that there was a good progress on identifying and prioritizing IAS. Remarkable success was reported from islands; more than 800 successful invasive mammal eradications were reported from different islands across the continents. However, eradication reports from the mainland are not encouraging (SCBD, 2020). Further, Outlook mentioned that the available eradication success reports are only a small proportion when compared with global occurrences (SCBD, 2020). On the other hand, a number of countries mentioned in their 6th national reports that they have developed new legislation and regulations for monitoring the import and export and also established the phytosanitary and zoosanitary checkpoints. Further, some the countries also developed their own national guidelines for the management and control of IAS (SCBD, 2020). Although CBD has registered its concern about the increasing occurrence of new invasive species in different landscapes. As a conclusion, it says the Aichi Target 9 has been partially achieved by the signatories (SCBD, 2020).

Indian Scenario

The available ecological modelling studies disclosed that the developing countries are highly vulnerable to new invasion than the developed countries (Early et al., 2016). Obviously India as a developing country would need to have more care about the issue, but unfortunately we are not on track in achieving Aichi Target 9 and Target 4 of the NBAP addendum 2014.

In India, the subject of biological invasions is still in its infancy and has not received adequate attention of the managers, policy makers, researchers, stakeholders and the common public. Compared to less biodiversity and poorly equipped countries, the number of research work on IAS in India is extremely poor. Only about 150 studies were available before the year 2000. However, in recent years, a number of universities and government organizations have conspicuously started to address the IAS issue, though most of the investigations were at local scale and species and habitat specific. Unfortunately so far none of the organization/universities are not involved/interested in pan-India level research (Hiremath, & Sundaram, 2013; Adhikari et al., 2015). Fortunately in 2017 the National Biodiversity Authority (NBA) constituted an 18-member expert committee on IAS under Subsection (2) of Section 13 of the Biological Diversity Act, 2002 read with Rule 11 of Biological Rules, 2004 (Sandilyan, 2018). After a series of consultative meetings the committee published a list of IAS reported in important habitats of India in 2018 (Sandilyan, 2018). However, the updated information is not available after the day of its publication.

Aichi Target 9 has been divided into four elements: (1) IAS identified and prioritized, (2) Pathways identified and prioritized, (3) Priority species controlled or eradicated and (4) Pathways managed to prevent introduction and establishment. All the signatories are expected to work in this order only (SCBD, 2020). In India we have achieved only the first part of the first element, that is, identified the invasive species in the Indian region (Sandilyan, 2018). Obviously the inadequate handling of the IAS issues in the last 10 years is being reflected here. Further there is no progress in the nine action points mentioned in the NBAP 2014 addendum.

Apart from the aforementioned major lacunae, the policy makers, researchers and government have failed in some more areas. In 2016, the FAO (Food and Agriculture Organization) and CABI (Centre for Agriculture and Bioscience International) had sent a strong warning message about the chance for the invasion of the fall armyworm (FAW) *Spodoptera frugiperda* in Asian countries including India (FAO & CABI, 2019). As usual we ignored the warning massage, which resulted in the invasion of FAW in Karnataka in June 2018. Subsequently within two years FAW has been reported in almost all Indian states and Union territories except Himachal Pradesh, and Jammu and Kashmir (FAO & CABI, 2019; Suby et al., 2020). In the meantime, in 2018 alone, 2.2 lakh hectares of maize-cultivated fields in Tamil Nadu were devastated by FAW and the state government announced Rs. 186.25 crore as compensation (www5). Apparently in the forthcoming years the FAW could cause more damage than expected.

Besides, based on the available research publication, personal communication and series of discussions, NBA reported 3 viruses, 5 bacteria, 17 fungi, 1 nematode and 22 insect species as invasive to Indian agriculture crops (Sandilyan, 2018). On the other hand, there is no detailed information available about other major taxa including invasive weeds in agricultural habitats. Further, till date, there is no information available about the cumulative economic loss caused by the invasive species in Indian agriculture and how it affects the food security and livelihood of Indians. Moreover, there is no strong policy and legal framework available on different issues related to IAS in the Indian agriculture.

Pertaining to fisheries, the introduction of alien fish species is an age-old practice in India (more than 200 years), and it has continued without any hindrance. Based on the available literature so far 31 aquaculture species, 600 ornamental varieties and 2 species of larvicidal exotic fish have been introduced into India in different periods (Singh & Lakra, 2011; Singh, 2014) Due to this unscientific introduction, nearly 55 alien fish species established their reproductive population in the wild, among them 14 species (2 larvicidal, 4 ornamental and 8 food fish**)** has been designated as invasive species by the NBA expert committee (Sandilyan, 2018). However, a pan-India level scanning is required to confirm the intensity of the alien fish invasion in inland wetlands. Because very recently a number of ornamental fishes have emerged as a great threat to the native fishes and they have established a notable population even in remote and protected wetlands of India (e.g. *Gambusia affinis, Oreochromis mossambicus, Osphronemus goramy, Poecilia reticulata, Pterygoplichthys disjunctivus, Pterygoplichthys multiradiatus, Pterygoplichthys pardalis*) (Raghavan et al., 2008; Sandilyan, 2018). It is worth to mention that the ornamental fishes devastate the native diversity of the inland wetlands (Liang et al., 2006)

Indian riverine habitats have been well recognized for their rich and unique biodiversity and also for its degree of endemism. Besides, a number of Indian inland wetlands support several globally important IUCN threatened category species (Anon, 2012; Singh, 2014). Ironically such an important system is facing unprecedented problem due to the establishment of several exotic fish species. In recent decades studies from the Northern parts of India have highlighted the large-scale invasion of commercially important IAS in several rivers including the major rivers Ganga and Yamuna. Studies from ICAR-Directorate of Coldwater Fisheries Research Uttarakhand, and the National Bureau of Fish Genetic Resources, Uttar Pradesh reported about the invasion of several alien fish species including *Cyprinus carpio*, *Oreochromis niloticus*, *Aristichthys nobilis*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix* and *Clarias gariepinus* in major rivers of North India (Singh et al., 2010; 2013). Reports also established that the biomass of the alien fishes is increasing exponentially when compared with the indigenous variety; however, the commercial values are getting reduced due to their abundance. Obviously, the low market price for the aforesaid alien species will reflect on the livelihood of resident fishermen (Singh et al., 2010). Further it was reported that the presence of *C. carpio* leads to the decline of endemic species *Osteobrama belangeri* in Loktak Lake of Manipur (Singh et al., 2013).

Recently the National Inland Fisheries and Aquaculture Policy was drafted by a team of experts in order to strengthen the sustainable inland fisheries (NIFAP, 2019). However, there is no information/policy decision available about the introduction of exotic fish species as well as the solution to manage/eradicate the established invasive fish species in inland wetlands of India.

Regarding aquatic species introduction, a national committee has already been constituted by the government and they need to certify all sorts of aquatic introduction in India. Further the Agriculture ministry has enacted guidelines for the import of ornamental fishes and also emphasizes the need of pre-quarantine certificate from the competent authority of the exporting countries. Interestingly the guidelines also mentioned the need for the post-quarantine follow-up. But the rules are not adhered by the traders and the buyers/hobbyists (Tripathi, 2015). It is mainly due to poor understanding and inadequate employees in the checkpoints.

The recent evidences including the poor/no implementation of Aichi Target 9, Target 4 of NBAP (2014) and the action points, ignoring the warning massage of CABI and FAO in 2016 about the chance of invasion of FAW in India and the draft of National Inland Fisheries and Aquaculture Policy 2019 which does not address the alien fishes issue have clearly established our poor understanding on IAS issues and also emphasized the need for a separate organization to address invasive issues.

Conclusion

The global research community has clearly established the deleterious role of invasion of alien species on biodiversity, human health, economy, food security, livelihood and the successful implementations of sustainable development goals. Considering the devastative nature of IAS, CBD included the IAS in the strategic plan for biodiversity 2011–2020 as one of the targets (Aichi Target 9). CBD also asked its signatories to stick on to Article 8(h).

However recent analysis by the CBD has indicated good progress on identifying and prioritizing of IAS by the signatories. On the other hand, there is no significant development in the remaining elements, that is, identification of pathways, pathway management and controlling the prioritized invasive species (SCBD, 2020). In India a number of studies and reports are available about the occurrence of IAS in different habitats. However, there is no single detailed long-term study available about the deleterious role of invasive species in an ecosystem. Moreover, adequate information is not available on the impacts on IAS on Indian biodiversity, economy, livelihood and the challenges posed by IAS in food production. As a whole India has glaringly failed to achieve the Aichi Target 9 and Target 4 of NBAP 2014. It is time to rethink the current structure and also the importance of a separate agency to address the IAS issue in India in order to prevent the biodiversity and economic loss and also to ensure the food security of the nation.

Knowledge gaps

Based on the available research publications and reports on IAS in important habitats, it is clearly shown that there is no detailed information available about the biodiversity prevailing in a habitat before and after the invasion. Further, most of the available studies revolve around the occurrence of the invasive species in an ecosystem but fail to address the pathway of introduction, kind of loss caused by the IAS in the successive years and how it reflects on the local diversity, economy and livelihood. Besides, poor or no literature is available about the occurrence and impacts of exotic invasive microorganisms, plankton, insects, molluscs, pathogens, parasite, reptiles and birds (Sandilyan, 2018). Obviously till date we do not have any strategic plan to control and manage the invasive species in Indian habitats. Moreover, there is no single agency available to address the issue.

Recommendation

It is the need of the hour to establish an autonomous body which is responsible for coordinating all sorts of invasive issues prevailing in India. Otherwise a separate wing is needed to be established at NBA to address this issue. Since NBA has a close association with all State Biodiversity Boards (SBBs) and Biodiversity management committee (BMC), it is feasible for NBA to tap the invasion information. The SBBs are governed by a chairman and member secretary and most of the states have a forest minister, IAS, IFS or biodiversity experts as the chairman and member secretary of SBBs (NBA, 2020). Apparently, these officials naturally have good understanding about Indian biodiversity and its importance. Besides there are around 2, 53,040 BMCs supported by the states and union territories (NBA, 2020). This manpower can effectively be utilized for monitoring, controlling and managing the IAS.

People who are all associated with BMC are actively involved in the preparation of the PBRs (People's Biodiversity Registers) (NBA, 2020). In addition to NBA and SBB a Technical Support Group (TSG) provides guidance to the BMCs for preparing PBRs. In general the TSG is usually supported by subject experts from various disciplines and line departments, universities, research institutes, colleges and schools and non-governmental organizations mainly for the identification of flora and fauna, examine confidential information and advice on legal protection during the PBR formulating process (NBA, 2020).

Since NBA has already established a committee on IAS and also prepared the national list of invasive species in different habitats along with the Centre for Biodiversity Policy and Law (CEBPOL), an Indo-Norwegian programme aimed to address the emerging and current biodiversity governance and policy-related issues (NBA, 2020). Further, NBA has already published articles, reports and other awareness materials on IAS (Sandilyan, 2018; NBA, 2020). With the help of the available research material and resource persons, NBA can easily educate the SBBs and BMCs on identification, monitoring and control of IAS in different habitats. Due to this grassroots level association, NBA can easily generate the pan-India level data/mapping of IAS.

Further, according to the Biological Diversity Act, 2002, NBA may advise the central and state governments on matters relating to the conservation of biodiversity and sustainable use of its components. In addition NBA is mandated to regulate the access of the Indian biological resources and its associated knowledge for research, bio-survey and bio-utilization, commercial utilization, obtaining Intellectual Property Rights, transfer of results of research and transfer of accessed biological resources. The individual or the company shall make application to NBA for the access of the aforesaid, and NBA has different forms based on the category/need (NBA, 2020; Biological Diversity Act, 2002). In the same way NBA needs to be mandated on giving permission to introduce all kinds of alien species to India. The importers, hobbyists, researchers, including ministries need to get the permission form NBA before introducing all kind of species including fish and other cultivable crops. NBA's prior experience on regulating the access of resources will be highly helpful to regulate the new introduction too.

It is the need of the hour that NBA needs to promote and be declared as India's focal point to address the invasive issues in a war footing. Otherwise, in the forthcoming years, India will face irreparable damage on its biodiversity, food security, livelihood and GDP. Besides everyone needs to understand that it's the collective responsibility of the common public, private sector, local communities and administration and government to curb the menace of IAS.

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Table 1. Interference of IAS on the SDGs

Sl. no	SDG goal number	Theme	Impacts
1	1	No poverty	Devastating the agriculture yield, e.g. fall armyworm, Tropical race 4 (TR4) fungus
2	2	Zero hunger	Reducing the food production, e.g. Tropical race 4 (TR4) fungus, apple aphid, papaya mealybug
3	3	Good health and well-being	Tiger mosquito acting as a vector for human disease like dengue, chikungunya, etc.
4	6	Clean water and sanitation	Water hyacinth affects the water quality and fishes such as gold fish increase the turbidity level
5	8	Decent work and economic growth	Water hyacinth affects the waterways, reduce the fish availability and tourism value
6	9	Industrial innovation and infrastructure	Biofouling organisms affect the water pipeline, ships, power generating turbines
7	10	Reduced inequalities	*Prosopis juliflora* prevents the grazing of cattle of the pastoralist communities
8	13	Climate action	Coypu, water hyacinth undermine the efficacy of the wetlands, reducing their resilience of climate change
9	14	Life below water	Occurrence of invasive fish species in marine (lion fish) and freshwater (African cat fish) reduces the availability of native fishes
10	15	Life on land	Brown tree snake, African snail, rats in islands cause severe threat to native species; it is also the reason behind the extinction of species

Source: Reference www1.

Table 2. Action points of NBAP 2008 to regulate the introduction of IAS and their Management

Sl. no	Action points	Status of action points
1	Develop a unified national system for regulation of all introductions and carrying out rigorous quarantine checks	×
2	Strengthen domestic quarantine measures to contain the spread of invasive species to neighbouring areas	×
3	Promote intersectoral linkages to check unintended introductions and contain and manage the spread of invasive alien species	×
4	Develop a national database on invasive alien species reported in India	√
5	Develop appropriate early warning and awareness system in response to new sightings of invasive alien species	×
6	Provide priority funding to basic research on managing invasive species	×
7	Support capacity building for managing invasive alien species at different levels with priority on local area activities	×

8	Promote restorative measures of degraded ecosystems using preferably locally adapted native species for this purpose	×
9	Promote regional cooperation in adoption of uniform quarantine measures and containment of invasive exotics	×

Note: The symbol × indicates not achieved, √ positive progress.

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INVASIVE TRENDS ON A LATERITIC PLATEAU HABITAT OF NORTHERN KERALA, SOUTH INDIA

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Abstract

The most captivating aspect of northern Kerala is its broad, flat, to moderately sloping lateritic plateau regions, which offer extremely harsh physical conditions for life forms and have given rise to specialised plant communities with several endemic and habitat-specific species. These plateaus form a number of microhabitats due to differences in their geographic terrain and soil cover, thus forming a complex of peculiar habitats with diverse forms of plants and associated fauna. Exposed rock surfaces and crevices, perennial water sources, seasonal ponds and ephemeral pools, shallow soil areas, deep soil areas, and scrub patches are the major microhabitats on these plateaus that support a number of species associations. The area is also distinguished by the mass flowering of various species, which gives the plateaus varied hues throughout the monsoon months. By the end of the monsoon, the entire area will be covered with various species of grasses and xerophytes. The lateritic plateau of Kalliad in the Kannur district of Kerala is such one that forms a complex of peculiar habitats for diverse forms of plants. During a study to document the floristic diversity including RET species of this plateau, the authors came across some serious threats to the microhabitats such as invasion of exotic species, brick mining, construction of roads and buildings, land filling, overgrazing by cattle and waste dumping. The present paper aims to draw attention to the threats caused by invasion and their impacts on this highly fragile ecosystem and the need for conserving these habitats. Intensive floristic surveys conducted in the study area resulted in the documentation of 309 flowering plant species in 76 families, of which 59 (about 20 %)

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are endemics. Out of the total flora, 50 (about 16 %) are introduced species to India. We recorded 29 exotic invasive species from the plateau, belonging to 11 families and 23 genera. Among these, 11 species are highly invasive, 9 are moderately invasive and the remaining are potentially invasive to this area. The most frequently observed invasive habitat is scrub patches followed by deep soil areas and shallow soil areas of the plateau. Besides these, invasion by humans for mining, construction works, tourism, and other forms of entertainment, not only devastates the micro ecosystems but also serves as a source of invasive weeds to this area. The short-lived native herbaceous species of this plateau need particular microhabitats to survive. But it has been noted that the anthropogenic invasion in this area disturbs these microhabitats and promotes extensive growth of exotic weeds. These invasive trends must now be taken into account more carefully because the biodiversity of these plateaus is unique and cannot be easily restored and impossible to conserve outside their natural habitats.

Keywords: Biodiversity conservation, Exotic species, Invasive species, Anthropogenic activities, Endemism, Threatened species.

Introduction

The most notable characteristic of northern Kerala is its extensive stretches of lateritic hills, which can be found in the districts of Kannur, Kasaragod, Kozhikode, and Malappuram. In earth science literature, Kerala is known as the type locality of laterite because the term laterite was first coined and described by Francis H. Buchanan in 1807, from Angadippuram in the Malappuram district of Kerala state (Chandran *et al.*, 2005). Laterites are generally rusty red in colour due to high iron oxide content and are mainly made up of soil and rock types rich in iron and aluminium. They form as a result of the parent rock's intense chemical weathering in a leaching environment, followed by induration (Pramod & Pradeep 2020). These plateaus form a number of microhabitats due to differences in their geographic terrain and soil cover, thus forming a complex of peculiar habitats with diverse forms of plants and associated fauna. Exposed rock surfaces and crevices, perennial water sources, seasonal ponds and ephemeral pools, shallow soil areas, deep soil areas, and scrub patches are the major microhabitats on these plateaus that support a number of species associations.

The area is also distinguished by the mass flowering of various species, which gives the plateaus varied hues throughout the monsoon months. By the end of the monsoon, the entire area will be covered with various species of grasses and xerophytes. The plateaus offer extremely harsh physical conditions for life forms and have given rise to specialised plant communities with several endemic and habitat-specific species. Due to these peculiar features, lateritic plateaus have high conservation values, but nowadays lack of awareness of this aspect is leading to varied types of anthropogenic disturbances like the construction of buildings, roads and mining activities on the plateaus and leads to habitat destruction and colonisation of many exotic invasive species. The lateritic plateau of Kalliad in the Kannur district of Kerala is such one that forms a complex of peculiar habitats for diverse forms of plants, but these habitats are now under threat due to the destruction of habitat by various human activities promoting the vigorous spread and establishment of exotic species in the microhabitats by displacing indigenous flora. The present paper aims to document these invasive species of the plateau and to draw attention to these invasive trends and their impacts on this highly fragile ecosystem and the need for conserving these habitats.

Study area

Kalliad is a northern Kerala lateritic plateau, located in Padiyur grama panchayath, near Irikkur Town in Kannur District of Kerala, South India. The plateau covers an area of 4.05 km^2, between 11° 59′ 49″ –12° 01′ 14″ N and 75° 34′ 18″–75° 37′ 12″ E (Fig. 1) and forms a complex of peculiar habitats for diverse forms of flora and fauna.

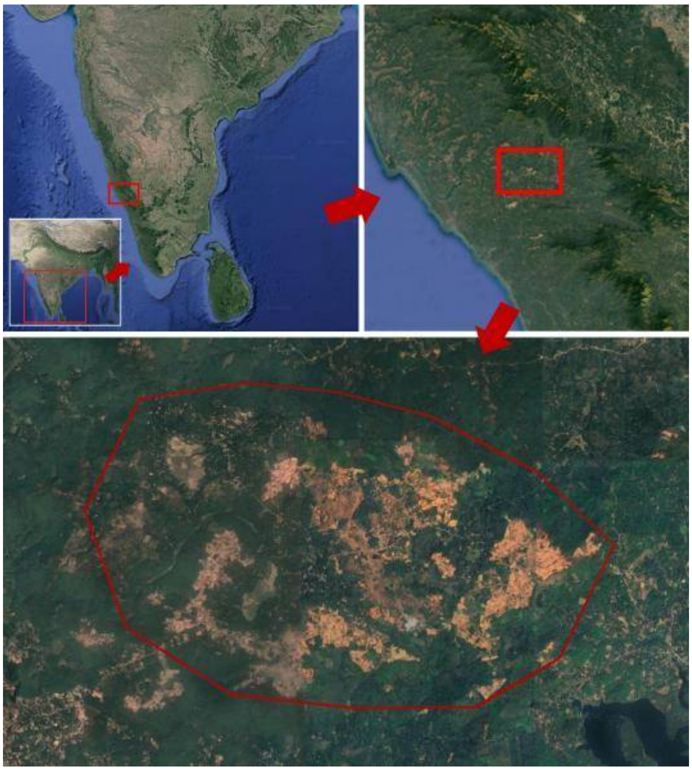

Fig 1. Location map of Kalliad lateritic plateau (Google Earth)

Materials and Methods

During a study to document the floristic diversity including RET species of this plateau, the authors came across some serious threats to the microhabitats such as invasion of exotic species, brick mining, construction of roads and buildings, landfilling, overgrazing by cattle and waste depositing. Intensive field surveys were conducted in the study area and plant specimens were collected for laboratory studies, identified by standard methods and documented. A separate list of invasive species of this plateau was prepared by field observation and the invasive status was confirmed by using invasive attributes (Table 1) suggested by Sandilyan *et al.* (2018), and with the help of available literature (Sankaran & Suresh, 2013 & Sankaran *et al*., 2013). Ecology and damages caused by invasive species were determined by field observation and with the help of literature available (Sankaran & Suresh, 2013; Sankaran *et al*., 2013). Endemic and exotic species were identified based on previous publications such as Sasidharan (2004), and online databases such as Plants of the World Online (https://powo.science.kew.org/). Botanical names were updated using the online database Plants of the World Online (POWO) and families followed the APG system of classification. Photographs of plants and habitats were taken using Nikon Coolpix L110 digital camera.

Table 1. Invasive attributes used to confirm the invasive status of the species (Sandilyan *et al.*, 2018).

Sl. No.	Invasive attributes
	Invasiveness
1	**IE-**Invasive Elsewhere
2	**RMS-**Rapid Multiplication and Spread in different ecosystem
3	**MMR-**Multiple Modes of Reproduction
4	**MMD-**Multiple Modes of Dispersion
	Impacts
1	**B1-**Affecting ecosystem functions and services
2	**B2-**Biodiversity loss
3	**B3-**Economic loss and health hazard
	Invasion areas (Continues spread)
1	**RE-**Range Extension

Results

A total of 309 flowering plant species belonging to 76 families (Table 2) were documented during the preliminary survey in this plateau, out of which 59 (about 20 %) are endemics (Fig. 2A). Out of the total flora, 50 (about 16 %) are introduced species to India (Fig. 2B). A total of 29 exotic invasive species (Table 3, Fig. 2C) were recorded from the plateau, belonging to 11 families and 23 genera. Among these, 11 species are highly invasive, 9 are moderately invasive and the remaining are potentially invasive to this area. Apart from these, 5 native species show vigorous growth and rapid spread in the microhabitats of this plateau (Table 4). They have the potential to displace the less tolerant native species in their habitats by competing for the resources.

Table 2. List of flowering plant taxa recorded from Kalliad lateritic plateau

Acanthaceae
Asystasia dalzelliana Santapau
A. gangetica (L.) T.Anderson
Hygrophila ringens (L.) R.Br. ex Spreng.
Justicia japonica Thunb.
J. nagpurensis V.A.W.Graham
Lepidagathis cuspidata Nees
L. keralensis Madhus. & N.P.Singh
Phaulopsis imbricata (Forssk.) Sweet
Thunbergia erecta (Benth.) T.Anderson
Amaranthaceae
Achyranthes aspera L.
Alternanthera brasiliana (L.) Kuntze
Amaranthus tricolor L.
A. viridis L.
Cyathula prostrata (L.) Blume
Gomphrena serrata L.
Anacardiaceae
Anacardium occidentale L.
Lannea coromandelica (Hout.) Merr.
Mangifera indica L.
Annonaceae
Uvaria narum (Dunal) Blume
Apocynaceae: Apocynoideae
Holarrhena pubescens (Buch.–Ham.) Wall. ex G. Don
Ichnocarpus frutescens (L.) W.T.Aiton
Wrightia tinctoria (Roxb.) R.Br.
Apocynaceae: Asclepiadoideae
Cosmostigma racemosum (Roxb.) Wight
Vincetoxicum indicum (Burm.f.) Mabb.
Wattakaka volubilis (L.f.) Stapf
Apocynaceae: Periplocoideae
Gymnema sylvestre Roem. & Schult.
Hemidesmus indicus (L.) R.Br.
Apocynaceae: Rauvolfoideae
Alstonia scholaris (L.) R.Br.
Rauvolfia serpentina (L.) Benth. ex Kurz
R. tetraphylla L.
Tabernaemontana alternifolia L.
Araceae
Cryptocoryne spiralis (Retz.) Fisch. ex Wydler
Arecaceae
Cocos nucifera L.
Aristolochiaceae
Aristolochia indica L.
Asparagaceae
Asparagus racemosus Willd.
Caryota urens L.
Asteraceae
Ageratum conyzoides L.
Chromolaena odorata (L.) R.M.King & H.Rob.
Crassocephalum crepidioides (Benth.) S.Moore
Cyanthillium cinereum (L.) H.Rob.
Elephantopus scaber L.
Emilia sonchifolia (L.) DC.
Mikania micrantha Kunth
Synedrella nodiflora (L.) Gaertn.
Tricholepis amplexicaulis C.B.Clarke
Balsaminaceae
Impatiens balsamina L.
Impatiens minor (DC.) Bennet
Bignoniaceae
Tecoma stans (L.) Juss. ex Kunth
Boraginaceae
Heliotropium keralense Sivar. & Manilal
Euploca marifolia (J.Koenig ex Retz.) Ancy & P.Javad
Burmanniaceae
Burmannia coelestis D.Don
Cannabaceae
Trema orientale (L.) Blume
Caryophyllaceae
Polycarpaea corymbosa (L.) Lam.
Celastraceae
Pristimera arnottiana (Wight) R.H.Archer
Cleomaceae
Cleome rutidosperma DC.
Combretaceae
Getonia floribunda Roxb.
Terminalia elliptica Willd.
T. paniculata Roth
Commelinaceae
Commelina diffusa Burm.f.
Cyanotis axillaris (L.) D.Don ex Sweet
C. burmanniana Wight
C. cristata (L.) D.Don
Murdannia crocea subsp. *ochracea* (Dalzell) Faden
M. semiteres (Dalzell) Sant.
Convolvulaceae
Camonea umbellata (L.) A.R.Simões & Staples
C. vitifolia (Burm.f.) A.R.Simões & Staples
Cuscuta europaea L.
Ipomoea obscura (L.) Ker Gawl.
I. hederifolia L.
I. mauritana Jacq.
I. triloba L.
Xenostegia tridentata subsp. *hastata* (Ooststr.) Parmar
Cucurbitaceae
Cucumis maderaspatanus L.
Solena amplexicaulis (Lam.) Gandhi
Trichosanthes cucumerina L.

Cyperaceae
Cyperus iria L.
C. maderaspatanus Willd.
Eleocharis dulcis (Burm.f.) Trin. ex Hensch.
Fimbristylis tenera Schult.
F. quinquangularis (Vahl) Kunth
Kyllinga bulbosa P.Beauv.
Scleria lithosperma (L.) Sw.
Dioscoreaceae
Dioscorea bulbifera L.
D. pentaphylla L.
D. wallichii Hook.f.
D. oppositifolia L.
Droseraceae
Drosera indica L.
Ebenaceae
Diospyros montana Roxb.
Eriocaulaceae
Eriocaulon cuspidatum Dalzell
E. eurypeplon Körn.
E. reductum Ruhland
E. xeranthemum Mart.
Euphorbiaceae
Agrostistachys indica Dalzell
Croton caudatus Geiseler
Euphorbia hirta L.
Falconeria insignis Royle
Macaranga peltata (Roxb.) Müll.-Arg.
Mallotus repandus (Rottler) Müll.Arg.
M. tetracoccus (Roxb.) Kurz
Micrococca mercurialis (L.) Benth.
Microstachys chamaelea (L.) Müll.-Arg.
Tragia involucrata L.
Fabaceae: Caesalpinioideae
Cassia fistula L.
Chamaecrista mimosoides (L.) Greene
Peltophorum pterocarpum (DC.) Backer ex K.Heyne
Senna hirsuta (L.) H.S.Irwin & Barneby
S. siamea (Lam.) H.S.Irwin & Barneby
S. tora (L.) Roxb.
Tamarindus indica L.
Fabaceae: Mimosoideae
Acacia auriculiformis A.Cunn. ex Benth.
A. mangium Willd.
Albizia chinensis (Osbeck) Merr.
Mimosa diplotricha var. *diplotricha*
M. pudica L.
Senegalia intsia (L.) Maslin, Seigler & Ebinger
Fabaceae: Papilionoideae
Abrus precatorius L.
Aeschynomene americana L.
A. indica L.
Alysicarpus bupleurifolius (L.) DC.
A. vaginalis (L.) DC. var. *vaginalis*
Calopogonium mucunoides Desv.
Centrosema molle Benth.
Crotalaria quinquefolia L.
Dalbergia horrida (Dennst.) Mabb. var. *horrida*
D. latifolia Roxb.
Geissaspis cristata Wight & Arn.
G. cristata var. *tenella* (Benth.) M.R.Almeida
Grona triflora (L.) H.Ohashi & K.Ohashi
Gliricidia sepium (Jacq.) Kunth ex Walp.
Mucuna pruriens (L.) DC.
Pseudarthria viscida (L.) Wight & Arn.
Pterocarpus marsupium Roxb.
Smithia conferta Sm.
Tadehagi triquetrum (L.) H.Ohashi
Vigna trilobata (L.) Verdc.
Zornia diphylla (L.) Pers.
Gentianaceae
Canscora diffusa (Vahl) R.Br. ex Roem. & Schult.
C. pauciflora Dalzell
C. perfoliata Lam.
C. stricta Sedgw.
Hoppoea fastigiata (Griseb.) C.B.Clarke
Hydrocharitaceae
Blyxa aubertii Rich.
B. echinosperma (C.B.Clarke) Hook.f.
B. octandra (Roxb.) Planch. ex Thwaites
Hydroleaceae
Hydrolea zeylanica (L.) Vahl
Lamiaceae: Ajugoideae
Clerodendrum infortunatum L.
Lamiaceae: Incertae Sedis
Tectona grandis L.f.
Lamiaceae: Lamioideae
Leucas lavandulifolia Sm.
Pogostemon deccanensis (Panigrahi) Press
P. paniculatus (Willd.) Benth.
P. quadrifolius (Benth.) F.Muell.
Lamiaceae: Nepetoideae
Mesosphaerum suaveolens (L.) Kuntze
Lamiaceae: Vitcoideae
Vitex altissima L.f.
Lauraceae
Alseodaphne semecarpifolia Nees var. *semecarpifolia*
Litsea deccanensis Gamble
Lecythidaceae
Careya arborea Roxb.
Lentibulariaceae
Utricularia cecilii P.Taylor
U. graminifolia Vahl
U. lazulina P.Taylor
U. reticulata Sm.
Linderniaceae
Bonnaya ciliata (Colsm.) Spreng.
Lindernia hyssopioides (L.) Haines
Torenia crustacea (L.) Cham. & Schltdl.
Loganiaceae
Mitrasacme indica Wight
Strychnos nux–vomica L.
Loranthaceae
Dendrophthoe falcata (L.f.) Ettingsh. var. *falcata*
Helicanthes elastica (Desr.) Danser
Lythraceae
Rotala malabarica Pradeep, K.T.Joseph & Sivar.
Rotala malampuzhensis R.V.Nair ex C.D.K.Cook
Malvaceae: Bombacoideae
Bombax ceiba L.
Malvaceae: Byttnerioideae
Melochia corchorifolia L.
Waltheria indica L.
Malvaceae: Grewioideae
Corchorus aestuans L.
C. capsularis L.
Grewia nervosa (Lour.) Panigrahi
Triumfeta rhomboidea Jacq.
Malvaceae: Helecteroideae
Helicteres isora L.
Malvaceae: Malvoideae
Abelmoschus angulosus Wall. ex Wight & Arn.
Hibiscus hispidissimus Grif.
H. surattensis L.
Sida acuta Burm.f.

S. cordata (Burm.f.) Borss.Waalk.
S. rhombifolia subsp. *alnifolia* (L.) Ugbor.
Urena lobata L.
Urena lobata subsp. *sinuata* (L.) Borss.Waalk.

Malvaceae: Sterculioideae

Sterculia guttata Roxb. ex DC.

Melastomataceae

Memecylon umbellatum Burm.f
Osbeckia muralis Naudin

Meliaceae

Aglaia elaeagnoidea (A.Juss.) Benth.
Azadirachta indica A.Juss.
Naregamia alata Wight & Arn.

Menispermaceae

Cyclea peltata (Lam.) Hook.f. & Thomson
Diploclisia glaucescens (Blume) Diels
Tinospora sinensis (Lour.) Merr.

Menyanthaceae

Nymphoides indica (L.) Kuntze
Nymphoides parvifolia (Wall. ex G.Don) Kuntze

Molluginaceae

Trigastrotheca pentaphylla (L.) Thulin

Moraceae

Artocarpus heterophyllus Lam.
Ficus benghalensis L. var. *benghalensis*
F. exasperata Vahl

Myrtaceae

Psidium guajava L.
Syzygium chavaran (Bourd.) Gamble
S. caryophyllatum (L.) Alston

Oleaceae

Chionanthus mala-elengi (Dennst.) P.S.Green
Jasminum malabaricum Wight
Tetrapilus dioicus (Roxb.) L.A.S.Johnson

Onagraceae

Ludwigia hyssopifolia (G.Don) Exell

Opiliaceae

Cansjera rheedei J.F.Gmel.

Orchidaceae

Acampe praemorsa (Roxb.) Blatt. & McCann
Dendrobium ovatum (L.) Kraenzl.
Habenaria diphylla (Nimmo) Dalzell
H. longicorniculata J.Graham
Zeuxine longilabris (Lindl.) Trimen

Orobanchaceae

Aeginetia indica L.
Centranthera nepalensis D.Don
Parasopubia hofmannii var. *albiflora* Pradeep & Pramod
P. hofmannii Pradeep & Pramod var. *hofmannii*
Rhamphicarpa longiflora (Arn.) Benth.)
Striga asiatica (L.) Kuntze

Passifloraceae

Passiflora foetida L. var. *foetida*
Turnera subulata Sm.
Turnera ulmifolia L.

Pedaliaceae

Sesamum indicum subsp. *malabaricum* (Burm.) Bedigian

Phrymaceae

Microcarpaea minima (K.D.Koenig ex Retz.) Merr.

Phyllanthaceae

Antidesma ghaesembilla Gaertn.
Aporosa cardiosperma (Gaertn.) Merr.
Bridelia retusa (L.) A.Juss.
B. stipularis (L.) Blume
Breynia vitis-idaea (Burm.f.) C.E.C.Fisch.
Flueggea leucopyrus Willd.
Phyllanthus emblica L.
P. urinaria L.

Piperaceae

Peperomia pellucida (L.) Kunth

Plantaginaceae

Dopatrium junceum (Roxb.) Buch.-Ham. Ex Benth.
Scoparia dulcis L.
Limnophila repens (Benth.) Benth.

Poaceae

Alloteropsis cimicina (L.) Stapf
Arundinella cannanorica V.J.Nair, Sreek. & N. C. Nair
Bambusa bambos (L.) Voss
Bhidea fischeri Sreek. & B.V.Shetty
Coelachne madayensis Pramod & Pradeep
Danthonidium gammiei (Bhide) C.E.Hubb.
Digitaria bicornis (Lam.) Roem. & Schult.
Dimeria Kalliyadense Biju, Josekutty & Augustine
Dimeria thwaitesii Hack.
Echinochloa colonum (L.) Link
Eragrostis atrovirens (Desf.) Trin. ex Steud.
E. gangetica (Roxb.) Steud.
E. unioloides (Retz.) Nees ex Steud.
Heteropogon contortus (L.) P.Beauv. ex Roem. & Schult.
Isachne bhatii P.Biju, Josekutty & Augustine
I. globosa (Thunb.) Kuntze
I. miliacea Roth
Isachne veldkampii K.G.Bhat & Nagendran
Ischaemum cannanorense Sreek., V.J.Nair & N.C.Nair
I. ciliare Retz.
I. barbatum Retz.
I. keralense Sreek., V.J.Nair & N.C.Nair
I. rangacharianum C.E.C.Fisch.
Oplismenus burmanni (Retz.) P.Beauv.
Oryza rufipogon Grif.
Pennisetum pedicellatum Trin.
P. polystachion (L.) Schult.
Sacciolepis interrupta (Willd.) Stapf
Setaria pumila (Poir.) Roem. & Schult.
Sporobolus pilifer (Trin.) Kunth
Glyphochloa acuminata (Hack.) Clayton

Polygalaceae

Polygala elongata Klein ex Willd.
Salomonia ciliata (L.) DC.

Pontederiaceae

Pontederia vaginalis Burm.f.

Primulaceae

Maesa indica (Roxb.) Sweet

Rhamnaceae

Ziziphus oenopolia (L.) Mill.
Z. rugosa Lam.

Rhizophoraceae

Carallia brachiata (Lour.) Merr.

Rubiaceae

Adina cordifolia (Roxb.) Brandis
Benkara malabarica (Lam.) Tirveng.

Canthium coromandelicum (Burm.f.) Alston
Catunaregam spinosa (Thunb.) Tirveng.
Chassalia curviflora var. *ophioxyloides* (Wall.) Deb & B.Krishna
Ixora brachiata Roxb.
Mitracarpus hirtus (L.) DC.
Mussaenda frondosa L.
Neanotis rheedei (Wall. ex Wight & Arn.) W.H. Lewis
N. subtilis (Miq.) Govaerts ex Punekar & Lakshmin.
Pavetta indica L. var. *indica*
Spermacoce articularis L.f.
S. latfolia Aubl.
S. ocymoides Burm.f.
S. pusilla Wall.

Rutaceae
Glycosmis pentaphylla (Retz.) DC.
Naringi crenulata (Roxb.) Nicolson
Zanthoxylum rhetsa (Roxb.) DC.

Salicaceae
Flacourtia montana J.Graham

Santalaceae
Santalum album L.

Sapindaceae
Allophylus cobbe (L.) Raeusch.
Schleichera oleosa (Lour.) Oken

Solanaceae
Physalis angulata L.

Urticaceae
Laportea interrupta (L.) Chew
Pilea microphylla (L.) Liebm.
Pouzolzia zeylanica (L.) Benn.

Verbenaceae
Lantana camara L.
Stachytarpheta jamaicensis (L.) Vahl

Vitaceae
Cissus heyneana Steud.
C. latifolia Lam.
C. repens Lam.
Leea indica (Burm.f.) Merr.

Xyridaceae
Xyris indica L.
X. pauciflora Willd.

Zingiberaceae
Curcuma cannanorensis R.Ansari, V.J.Nair & N.C.Nair

Table 3. List of Exotic Invasive species identified from the Kalliad lateritic plateau

(Abbreviations: IE-Invasive elsewhere, RMS-Rapid multiplication and spread, MMR-Multiple modes of reproduction, MMD- Multiple modes of Dispersion, B1-Affecting ecosystem functions and services, B2-Biodiversity loss, B3- Economic loss and health hazard, RE-Range extension)

Sl. No.	Name of Species	Family	Habit	Invasive attributes	Invasive status on the Plateau
1	*Acacia auriculiformis* A.Cunn. ex Benth.	Fabaceae	Tree	IE, RMS, MMR, MMD, B1, B2, RE	Highly invasive
2	*A. mangium* Willd.	Fabaceae	Tree	IE, RMS, MMR, MMD, B1, B2, RE	Moderately invasive
3	*Aeschynomene americana* L.	Fabaceae	Herb	RMS, MMD, B1, RE	Moderately invasive
4	*Ageratum conyzoides* L.	Asteraceae	Herb	IE, RMS, MMR, MMD, B1, B2, B3, RE	Highly invasive
5	*Alternanthera brasiliana* (L.) Kuntze	Amaranthaceae	Herb	IE, RMS, MMD, B1, B2, RE	Moderately invasive
6	*Calopogonium mucunoides* Desv.	Fabaceae	Climber	IE, RMS, MMD, B1, B2, RE	Highly invasive
7	*Camonea umbellata* (L.) A.R.Simões & Staples	Convolvulaceae	Climber	RMS, MMD, B1, RE	Potentially invasive
8	*Camonea vitifolia* (Burm.f.) A.R.Simões & Staples	Convolvulaceae	Climber	IE, RMS, MMD, B1, B2, RE	Potentially invasive
9	*Centrosema molle* Benth.	Fabaceae	Climber	IE, RMS, B1, B2, RE	Highly invasive
10	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Asteraceae	Shrub	IE, RMS, MMR, MMD, B1, B2, B3, RE	Highly invasive
11	*Ipomoea hederifolia* L.	Convolvulaceae	Climber	IE, RMS, MMD, B1, RE	Potentially invasive
12	*I. mauritana* Jacq.	Convolvulaceae	Climber	IE, RMS, MMD, B1, RE	Potentially invasive
13	*I. triloba* L.	Convolvulaceae	Climber	RMS, MMD, B1, B2, RE	Moderately invasive

14	*Lantana camara* L.	Verbenaceae	Shrub	IE, RMS, MMR, MMD, B1, B2, B3, RE	Highly invasive
15	*Mesosphaerum suaveolens* (L.) Kuntze	Lamiaceae	Shrub	IE, RMS, MMR, MMD, B1, B2, B3, RE	Highly invasive
16	*Mikania micrantha* Kunth	Asteraceae	Climber	IE, RMS, MMD, B1, B2, RE	Highly invasive
17	*Mimosa diplotricha* var. *diplotricha*	Fabaceae	Subshrub	IE, RMS, MMR, MMD, B1, B2, B3, RE	Highly invasive
18	*M. pudica* L.	Fabaceae	Herb	IE, RMS, MMR, MMD, B1, B2, RE	Highly invasive
19	*Mitracarpus hirtus* (L.) DC.	Rubiaceae	Herb	RMS, B1, RE	Moderately invasive
20	*Passiflora foetida* L. var. *foetida*	Passifloraceae	Climber	IE, RMS, MMD, B1, B2, RE	Moderately invasive
21	*Pennisetum polystachion* (L.) Schult.	Poaceae	Herb	IE, RMS, MMD, B1, B2, RE	Highly invasive
22	*Physalis angulata* L.	Solanaceae	Herb	RMS, MMD, B1, RE	Potentially invasive
23	*Rauvolfia tetraphylla* L.	Apocynaceae	Shrub	RMS, MMD, B1, RE	Potentially invasive
24	*Senna hirsuta* (L.) H.S.Irwin & Barneby	Fabaceae	Shrub	RMS, B1, B2, RE	Potentially invasive
25	*S. tora* (L.) Roxb	Fabaceae	Shrub	IE, RMS, B1, B2, RE	Potentially invasive
26	*Spermacoce latifolia* Aubl.	Rubiaceae	Herb	RMS, MMD, B1, RE	Moderately invasive
27	*Stachytarpheta jamaicensis* (L.) Vahl	Verbenaceae	Undershrub	RMS, B1, RE	Moderately invasive
28	*Synedrella nodiflora* (L.) Gaertn.	Asteraceae	Herb	IE, RMS, MMD, RE	Moderately invasive
29	*Turnera subulata* Sm.	Passifloraceae	Subshrub	RMS, B1, RE	Potentially invasive

Table 4. List of Native species showing invasiveness on the Kalliad lateritic plateau

(Abbreviations: IE-Invasive elsewhere, RMS-Rapid multiplication and spread, MMR-Multiple modes of reproduction, MMD- Multiple modes of Dispersion, B1-Affecting ecosystem functions and services, B2-Biodiversity loss, B3- Economic loss and health hazard, RE-Range extension)

Sl. No.	Name of Species	Family	Habit	Invasive attributes	Invasive status in Plateau
1	*Geissaspis cristata* Wight & Arn.	Fabaceae	Herb	RMS, MMD, B1, B2, RE	Potentially invasive
2	*Pennisetum pedicellatum* Trin.	Poaceae	Herb	IE, RMS, MMD, B1, B2, RE	Moderately invasive
3	*Triumfeta rhomboidea* Jacq.	Malvaceae	Shrub	IE, RMS, MMD, B1, RE	Potentially invasive
4	*Urena lobata* L.	Malvaceae	Shrub	IE, RMS, MMD, B1, RE	Potentially invasive
5	*Xenostegia tridentata* subsp. *hastata* (Ooststr.) Parmar	Convolvulaceae	Climber	RMS, MMD, B1, B2, RE	Potentially invasive

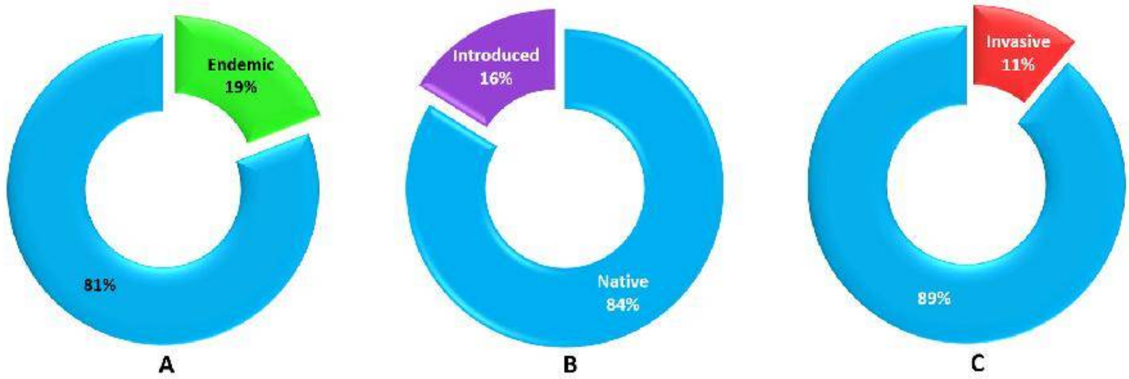

Fig 2. Diagrams showing fractions of endemic, introduced and invasive species on Kalliad lateritic plateau.

Characters of listed invasive species

***Acacia auriculiformis* A.Cunn. ex Benth.**

Common name: Australian wattle. Malayalam name: *Akkesia*

Distribution: Native to South East Maluku to New Guinea and North Australia

Fast-growing evergreen highly invasive trees grow well in the human-disturbed habitats of plateau-like mined areas. It is an aggressive coloniser preferring the dry condition of the plateau due to its hardy nature and highly competitive ability (Fig. 3A).

Threats and damage: Loss of biodiversity by replacing indigenous vegetation. Its pollen grains are reported to cause allergic reactions in humans.

***Acacia mangium* Willd.**

Common name: Hickory Wattle. Malayalam name: *Maanjium*

Distribution: Native of Maluku to North Queensland

Rapidly growing, moderately drought-resistant evergreen invasive tree on the plateau. Propagated mainly through long-lived seeds and widely established in the brick-mined soils of the plateau as a result of habitat destruction (Fig. 3B).

Threats and damage: Replace native vegetation by competing with resources

***Aeschynomene americana* L.**

Common name: American Joint-vetch. Malayalam name: *Ponthu*

Distribution: Native to Tropical and Subtropical America

Erect or decumbent herbs moderately invaded the soil-covered and wet areas of the plateau and compete with native plants for resources (Fig. 3C).

Threats and damage: Cause threats to native species by competing with them for resources and habitats.

Ageratum conyzoides **L.**

Common name: Goat weed. Local names: *Appa*, *Kaattappa*, *Murianpacha*

Distribution: Native to Mexico

It is an annual herbaceous weed elsewhere and is now distributed widely in the tropics and subtropics, exhibiting high morphological variation for adaptation to different ecological conditions. Rapid multiplication by the production of a large number of seeds (about 40,000) in a variety of soil types such as sandy, loamy and clayey and tolerates a range of pH levels. Th plant is shade tolerant and spread widely in the scrub patches and tree cover areas of the plateau. It satisfies all criteria of invasive attributes for determining invasive status in India and comes under the highly invasive category on this plateau (Fig. 3D).

Threat and damage: Due to their allelopathic nature, they can displace native plants like grasses and medicinal herbs and generate uniform monospecific stands. It also causes allergic reactions in humans and other health hazards. It causes threats to native species by reducing total biomass, changing community structure, and reducing the diversity of native species.

Alternanthera brasiliana **(L.) Kuntze**

Common name: Joy weed. Malayalam names: *Choracheera, Kaattu ponnamkanni*

Distribution: Native of Mexico to Tropical America

It is a profusely branched herb introduced as an ornamental plant, but today it is naturalized and widely spread in open areas and uncultivated land. In lateritic plateaus, they widely spread in marshy areas and scrub patches through seeds and vegetative cuttings and threaten indigenous flora (Fig. 3E)

Threat and damage: Capable of colonising a specific area within a short span of time, displacing native flora.

***Calopogonium mucunoides* Desv.**

Common name: Calopo. Malayalam name: *Manja payar*

Distribution: Native to Mexico to Tropical America

Slender creeping and climbing highly invasive herbs in grasslands of the plateau. Due to its moderately drought-tolerant nature, it is widely colonised in the native vegetation and forms dense mats over there (Fig. 3F).

Threats and damage: Smothering native vegetation by aggressive growth and formation of dense mats over the canopy.

***Camonea umbellata* (L.) A.R.Simões & Staples**

Common name: Yellow wood rose. Malayalam name: *Kolavara valli*

Distribution: Native to Tropical & Subtropical America, West and West Central Tropical Africa

Potentially invading climbers in scrub jungles. Range extensions are comparatively less in plateaus and have the potential to invade more areas in future (Fig. 3J).

Threat and damage: Threaten native biodiversity and helps the invasion of other invasive species.

***Camonea vitifolia* (Burm.f.) A.R.Simões & Staples**

Common name: Grape-leaf wood rose. Malayalam name: *Manja vayaravalli*

Distribution: Native to Indo-China and China

It is a shade tolerant fast spreading climber in shallow soil areas and in the valleys of plateaus. The area of spread in the plateaus is comparatively less than other habitats, so it is included in the potentially invasive category.

Threat and damage: Smother native flora by its aggressive twining habit.

***Centrosema molle* Benth.**

Common name: Butterfly-pea. Malayalam name: *Kaattupayar*

Distribution: Native to South Mexico to Tropical America

Highly invasive perennial climbing herb in scrub jungles of the plateau. They climb over bushes and small trees and are propagated through the production of a copious number of seeds. Human-disturbed areas on the plateau support the excessive growth and spread of this weed (Fig. 3G).

Threats and damage: Forms dense cover on bushes and small trees and interfere with their growth and reproduction.

Chromolaena odorata **(L.) R.M.King & H.Rob.**

Common names: Bitter bush, Siam weed. Malayalam names: *Assam pacha*, *Communist pacha*

Distribution: Native to Tropical & Subtropical America

It is one of the top 100 of the world's worst invaders and is fast growing scrambling perennial shrub, introduced inadvertently into the tropical regions of Asia, Africa, and the Pacific. Grows on a wide range of soils and vegetation types. Propagation by seeds and vegetative methods are both possible, and seeds can survive in the soil for up to five years. In the lateritic plateau, it is mainly spread in the scrub patches and forms dense stands that prevent the establishment of native plants. This plant meets all requirements for invasive characteristics used to determine invasive status in India, and on this plateau, it is classified as highly invasive (Fig. 3H & I).

Threat and damage: Prevent growth, development and yield of native species due to its aggressive growth, competition for light and water, efficient root system and allelopathic effects. It is also a fire hazard in summer, when the plants dry up. The plant can cause asthma in allergy-prone people. It is a nutrient-demanding species and exhibits relatively high foliar nitrogen, phosphorus and potassium content.

Fig 3. Invasive species on Kalliad lateritic plateau: **A**. *Acacia auriculiformis* A.Cunn. ex Benth.; **B**. *A. mangium* Willd.; **C**. *Aeschynomene americana* L.; **D**. *Ageratum conyzoides* L.; **E**. *Alternanthera brasiliana* (L.) Kuntze; **F**. *Calopogonium mucunoides* Desv.; **G**. *Centrosema molle* Benth.; **H, I**. *Chromolaena odorata* (L.) R.M.King & H.Rob.; **J**. *Camonea umbellata* (L.) A.R.Simões & Staples; **K**. *Ipomoea hederifolia* L.; **L**. *I. mauritana* Jacq.; **M**. *I. triloba* L.; **N, O**. *Lantana camara* L.

***Ipomoea hederifolia* L.**

Common name: Ivy-leaf morning glory. Malayalam name: *Theepori mulla*

Distribution: Native to Tropical & Subtropical America

Slender, potentially invading twining herb in scrub patches of the plateau. It was introduced as an ornamental plant in gardens but escaped and naturalized in other areas (Fig. 3K).

Threat and damage: Displace native plants in that habitat by pullover and aggressive growth.

***Ipomoea mauritiana* Jacq.**

Common name: Giant Potato. Malayalam name: *Palmutukk*

Distribution: Native to Tropical America, Africa

Fast-growing potentially invading perennial twining and trailing herb in scrub jungles of the plateau (Fig. 3L).

Threats and damage: Climbing stem smothers native plants and obstructs their growth and regeneration

***Ipomoea triloba* L.**

Common name: Little bell morning glory. Malayalam name: *Chuttithiruthaali*

Distribution: Native to Mexico to Brazil, Caribbean

Aggressive climbing invaders in the valleys and scrub patches of plateau (Fig. 3M).

Threat and damage: Weed in plateaus and suppress the growth of native plants by aggressive climbing growth.

***Lantana camara* L.**

Common name: Lantana, sleeper weed. Malayalam names: *Arippu, Kongini, Poochedi*

Distribution: Native to Mexico to Tropical America

It is a much-branched straggling shrub coming under the world's worst invaders in the global invasive species database (GISD). They possess broad ecological tolerance and are distributed widely in the world. On lateritic plateaus, this plant is widely established in scrub patches and disturbed areas due to mining and landfilling. It was observed extensively colonising those gaps, with dominant understorey species preventing succession from occurring and reducing biodiversity. In this plateau, it falls under the category of highly invasive species (Fig. 3N & O).

Threat and damage: Cause soil erosion, toxicity to animals due to the presence of allelochemicals, threat to several endangered plants and animals. Allelopathic effect reduce the vigour of native plants and reduce productivity, and affect the regeneration of forests. Plants provide shelter to malarial mosquitoes and tsetse flies which cause health hazards to humans.

***Mesosphaerum suaveolens* (L.) Kuntze**

Common name: Pignut. Malayalam names: *Naattappoochedi, Naarikkadu*

Distribution: Native to Mexico to Tropical America

Annual highly invasive subshrub in deep soil areas and scrub patches of the plateau and imparts threat to native flora and livestock (Fig. 4A).

Threat and damage: Threaten native flora by producing allelochemicals which inhibit seed germination of native species. Dried plants enhance the incidence of fire during the summer season.

***Mikania micrantha* Kunth**

Common names: Chinese creeper, Mile-a-minute weed. Malayalam name: *Dhritharashtra pacha*

Distribution: Native to Tropical & Subtropical America

It is a fast-growing (8-9 cm growth in 24 hours) perennial vine with climbing, creeping, and twining habits and grows well in open canopy areas with high organic matter, soil moisture, and humidity. It is one among the top 100 world’s worst invaders (GISD) They cannot tolerate shade and hence fail to penetrate undisturbed closed canopy areas. They grow well in the scrub patches of plateaus. It falls under the highly invasive category on this plateau and meets all the criteria for invasive attributes used to determine invasive status in India (Fig. 4B).

Threat and damage: They are capable of damaging plant crowns, suffocating and pulling down plants. It inhibits the growth of native plants by competing for water and nutrients, cutting out light, releasing of allelopathic chemicals and smothering them. It also acts as a fire hazard in the summer months. It is toxic to cattle.

Mimosa diplotricha* var. *diplotricha

Common name: Giant sensitive plant. Malayalam name: *Aanathottaawaadi*

Distribution: Native to Tropical & Subtropical America

It is a fast-growing perennial scandent subshrub that forms dense thickets in a short span of time in all invaded ecosystems. The weed is heliophytic in adaptation and cannot grow under a closed canopy. It is drought resistant and tolerates a wide range of soil conditions. Seeds are known dormant for up to 50 years. In lateritic plateaus, vigorous growth of this plant occurs in human-disturbed areas and is coming under the category of highly invasive species in this area (Fig. 4C & D).

Threat and damage: Thick growth prevents regeneration, reproduction, and growth of invasive species. All parts of the plant are toxic to herbivores if ingested. Cause soil degradation

***Mimosa pudica* L.**

Common name: Touch-me-not. Malayalam name: *Tottaavaadi*

Distribution: Native to Mexico to Tropical America

It is a creeping annual or perennial prickly herbaceous pantropical weed. Each plant produces up to 700 seeds. In lateritic plateaus, it spread in soil grasslands and forms dense cover and prevents the reproduction and regeneration of other plants (Fig. 4E & F).

Threat and damage: Dry thickets can be a fire hazard. Grazing can be toxic to livestock, spread in larger areas and interrupt the growth of other plants.

***Mitracarpus hirtus* (L.) DC.**

Common name: Tropical Girdlepod. Malayalam name: *Thaaval*

Distribution: Native to Mexico to Tropical America

Annual, moderately invasive herbs distributed in the soil-covered areas of the plateau. Vigorous multiplication through seeds and wide adaptation leads to the fast spreading of this species in this habitat (Fig. 4G).

Threat and damage: Spread larger areas and interrupt the growth of other plants.

Passiflora foetida* L. var. *foetida

Common name: Stinking passion flower. Malayalam names: *Ammummapazham, Poochapazham*

Distribution: Native to Tropical & Subtropical America

It is a perennial herbaceous vine that occurs in scrub jungles and patches of the lateritic plateau and forms dense ground cover and climbs over low vegetation. Now considered to be moderately invasive in this plateau (Fig. 4H & I).

Threat and damage: Smother disturbed forest areas rapidly. It can eliminate, suppress or delay the growth of other plants by shading out and thus reducing species richness in invaded areas.

***Pennisetum polystachion* (L.) Schult.**

Common name: Mission grass. Malayalam names: *Kothappullu, Chenghana*

Distribution: Native to New World

It is an annual herb that invaded in the Asia-pacific region and thrives in the tropical climate. In lateritic plateaus, it is widely spread in disturbed, dry, grasslands and forms continuous range extension. It is a frequently distributed seed propagating, highly invasive species on the plateau (Fig. 4J).

Threats and damage: Compete with native plants, alters fire regime and can be a potential seed contaminant.

***Physalis angulata* L.**

Common name: Sunberry. Malayalam name: *Njottanjodian*

Distribution: Native to Tropical and Subtropical America

Annual, shade-tolerant, seed-propagating herbaceous plant, now widespread in the Tropics. It grows best in moist, fertile soils and is distributed in the deep soil areas of the plateau. Due to its competitive behaviour, it is included in the potentially invasive category (Fig. 4K).

Threat and damage: Compete with native species for resources and negatively impacts their growth.

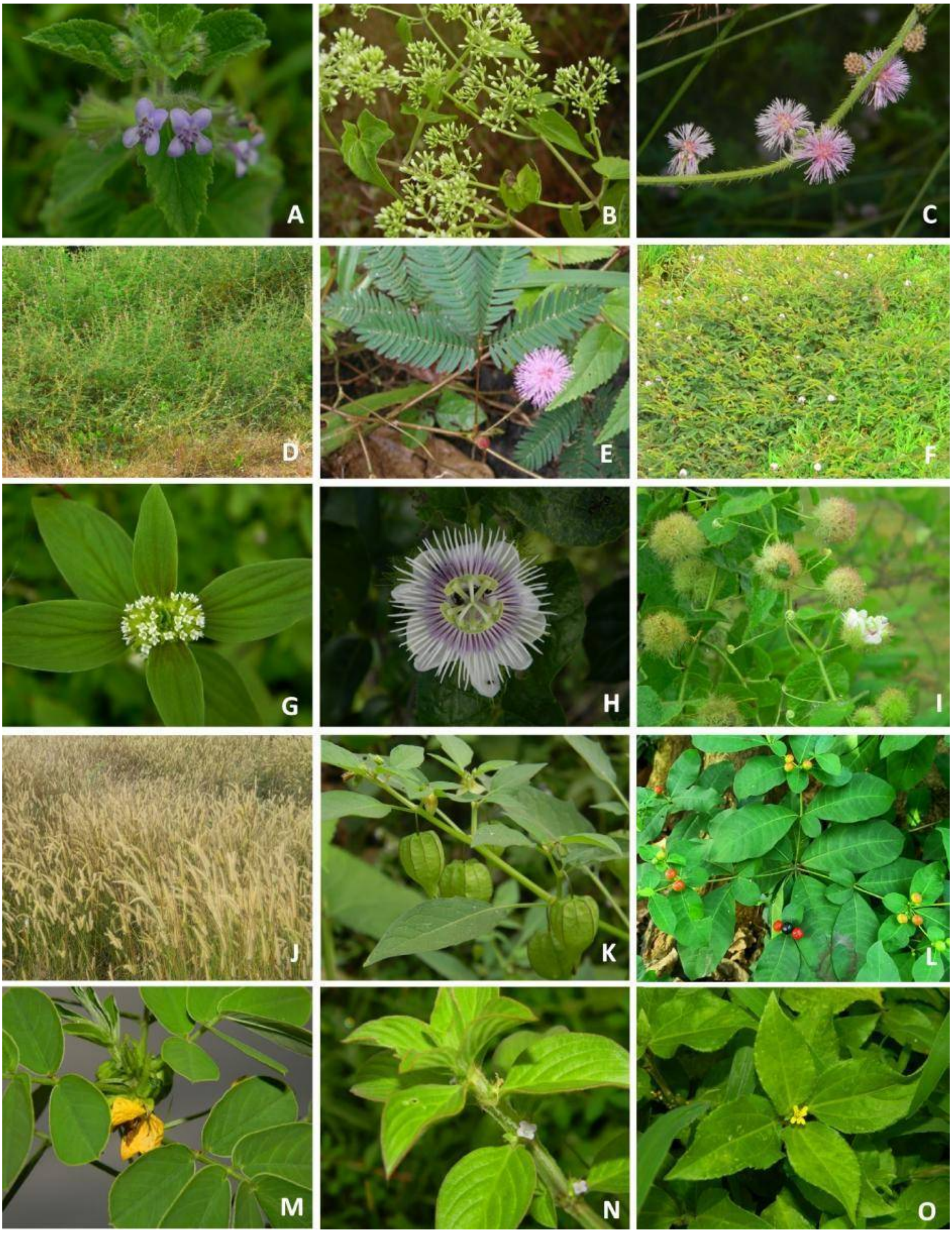

Fig 4. Invasive species on Kalliad lateritic plateau: **A**. *Mesosphaerum suaveolens* (L.) Kuntze; **B**. *Mikania micrantha* Kunth; **C, D**. *Mimosa diplotricha* var. *diplotricha*; **E, F**. *M. pudica* L.; **G**. *Mitracarpus hirtus* (L.) DC.; **H, I**. *Passiflora foetida* L. var. *foetida*; **J.** *Pennisetum polystachion* (L.) Schult.; **K**. *Physalis angulata* L.; **L**. *Rauvolfia tetraphylla* L.; **M**. *Senna tora* (L.) Roxb.; **N**. *Spermacoce latifolia* Aubl.; **O**. *Synedrella nodiflora* (L.) Gaertn.

***Rauvolfia tetraphylla* L.**

Common names: Wild Snake Root, American Serpent wood. Malayalam name: *Pambumkolli*

Distribution: Native to Mexico to Tropical America

Much branched, potentially invading shrubs in scrub jungles of the plateau and show wide adaptation to changing environment (Fig. 4L).

Threats and damage: Negatively impact the growth of native species by competing for resources.

***Senna hirsuta* (L.) H.S.Irwin & Barneby**

Common name: Woolly senna. Malayalam name: *Ponninthakara*

Distribution: Native to Tropical and Subtropical America

Erect shrub, introduced and grown as shade plant and soil improver in many tropical countries. In lateritic plateaus, it grows in shallow soil areas and has the potential to invade other microhabitats due to its aggressive colonising nature.

Threats and damage: Capable of invading natural habitats and displacing indigenous flora.

***Senna tora* (L.) Roxb**

Common name: Sickle senna. Malayalam name: *Thakara*

Distribution: Native to Central America

Aggressive quickly naturalizing annual sub shrub which can tolerate a wide range of soil and climatic conditions. It is colonised in the soil covered areas of the plateau and has the potential to continue spread in that habitat (Fig. 4M).

Threats and damage: Quickly invade natural habitats and displace native vegetation.

***Spermacoce latifolia* Aubl.**

Malayalam name: *Thaarthaaval*

Distribution: Native to Mexico to Tropical America

Annual moderately invasive herb distributed in the deep soil areas of the plateau. Rapid multiplication through seeds and wide adaptation to harsh environmental conditions of the plateau support spreading of this species in the habitat (Fig. 4N).

Threat and damage: spread larger areas and interrupt the growth of native plants.

***Stachytarpheta jamaicensis* (L.) Vahl**

Common name: Blue porterweed. Malayalam name: *Seemakongini*

Distribution: Native to South East U.S.A. to Tropical America

It is a perennial undershrub, moderately invaded in scrub jungles and also in deep soil areas of the plateau.

Threats and damage: Interrupt the growth of native plants.

***Synedrella nodiflora* (L.) Gaertn.**

Common name: Synedrella. Malayalam name: *Mudianpacha*

Distribution: Native to Tropical & Subtropical America

Erect herb, adapted to a variety of environmental conditions and widely distributed in the disturbed soil areas and scrub jungles of the plateau (Fig. 4O).

Threats and damage: Quick spread in the habitats by competing with native species

***Turnera subulata* Sm.**

Common name: West Indian Holly. Malayalam name: *Cheravathaali*

Distribution: Native to the Windward Islands to South Tropical America

It is a subshrub naturalized along the roadsides and open soil areas of the plateau. It grows profusely and is capable to increase the range of spread in future.

Threats and damage: Compete with native flora for resources.

***Geissaspis cristata* Wight & Arn.**

Common name: Eyelashes Shell Beans. Malayalam name: *Valiya poompaattachedi*

Distribution: Indian Subcontinent to China and Peninsula Malaysia

Herbs in seasonal pools and wet deep soil areas of the plateau and form thick dense cover on soil by interfering with the growth of other endangered species in that habitat (Fig. 5A).

Threats and damage: Capable of competing with endemic flora of seasonal pools for resources and displacing them by aggressive growth.

***Pennisetum pedicellatum* Trin.**

Common name: Kyasuwa grass. Malayalam name: *Poochavalanpullu*

Distribution: Cape Verde, Tropical Africa, Madagascar, Indian Subcontinent to Indo-China

The annual herb grows well in grasslands and other soil covered areas of the plateau. They have the ability to tolerate drought, acidic and alkaline soils and grow well in fertile soil by self-sown seeds (Fig. 5B).

Threats and damage: this plant can overgrow previously established vegetation and displace them.

***Triumfeta rhomboidea* Jacq.**

Common name: Burr Bush. Malayalam name: *Manja uthiram*

Distribution: Tropical & Subtropical Old World

Potentially invasive subshrub in the scrub jungles and deep soil areas of the plateau. They have the potential to annihilate other plants on the habitat by competing for resources and are rapidly multiplying (Fig. 5C).

Threats and damage: Capable of increasing their spreading area by eliminating other plants.

***Urena lobata* L.**

Common name: Caesarweed. Malayalam name: *Uthiram*

Distribution: Tropics & Subtropics

Subshrub in deep soil areas showing potential invasive nature as it continues to spread and multiply rapidly in once-established habitats by competing and displacing other plants.

Threats and damage: Capable of invading more habitats in future (Fig. 5D & E).

***Xenostegia tridentata* subsp. *hastata* (Ooststr.) Parmar**

Malayalam name: *Cheruvayara*, *Prasaarani*

Distribution: Tropical and Subtropical Old World

Potentially invasive climbers in margins of scrub jungles and shallow soil areas of plateau and form a dense cover over supporting host plants and suppress their establishment (Fig. 5F& G).

Threats and damage: Threaten supporting plants and helps the invasion of other invasive species such as *Mikania micrantha* and *Chromolaena odorata.*

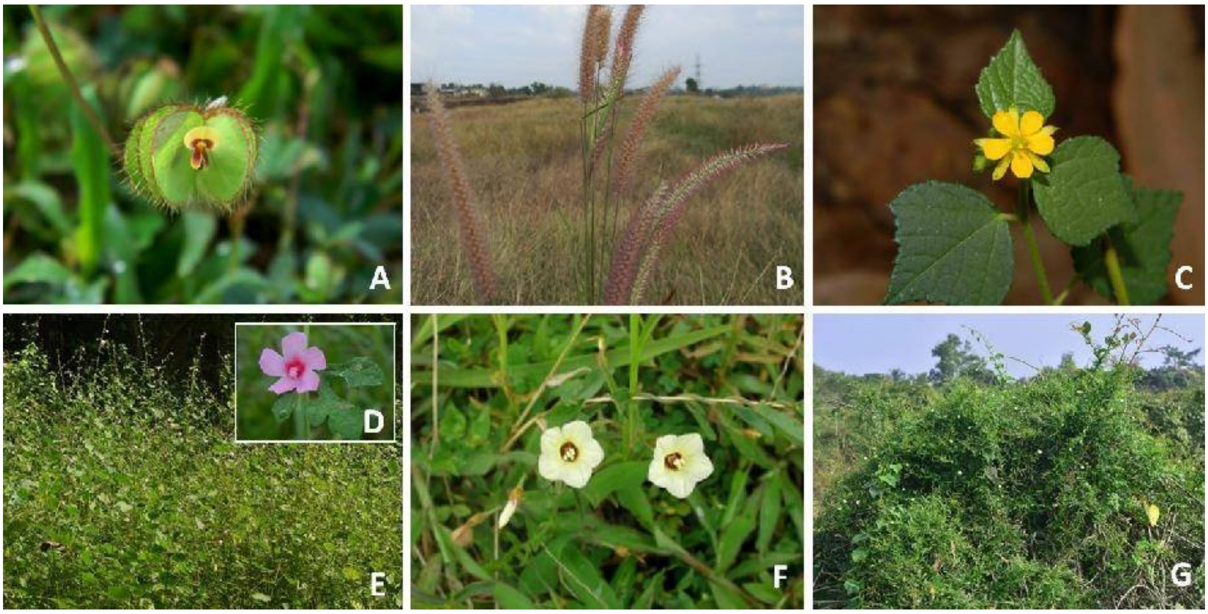

Fig 5. Invasive species on Kalliad lateritic plateau: **A**. *Geissaspis cristata* Wight & Arn.; **B**. *Pennisetum pedicellatum* Trin.; **C**. *Triumfeta rhomboidea* Jacq.; **D, E**. *Urena lobata* L.; **F, G**. *Xenostegia tridentata* subsp. *hastata* (Ooststr.) Parmar

Discussion

Among the 29 exotic invasive species documented *Acacia auriculiformis, Ageratum conyzoides, Calapogonium mucunoides, Centrosema molle, Chromolaena odorata, Lantana camara, Mesosphaerum suaveolens, Mikania micrantha, Mimosa diplotricha, Mimosa pudica,* and *Pennisetum polystachion* are highly invasive and cause threat and damage to the flora and fauna of the plateau. Species such as *Mesosphaerum suaveolens, Mikania micrantha, Chromolaena odorata,* and *Mimosa dilpotricha* are well established on the plateau and cause serious impacts on the indigenous flora and fauna.

Some indigenous species are becoming invasive on the plateau due to their extensive adaptations to the harsh environmental conditions, as well as their quick ecosystem spread and multiplication. These are excellent examples of evolutionary adaptations for survival; at the same time, this spread eliminates the plateau's endangered, less tolerant species, especially short-lived herbaceous elements resulting in loss of biodiversity. Seasonal pools on the lateritic plateau are a unique microhabitat for many endangered and short-lived species, but the rapid spread of *Geissaspis cristata* in these wet areas interferes with the development and survival of this habitat-specific species by forming a dense mat on the soil. They are categorised as potentially invasive because, if not controlled, they have the potential to cause serious impacts in the future. Nine of the exotic invasive species are also being categorised as potentially invasive due to the fact that their current area of occupancy and number of spreads are comparatively lesser than those of moderately invasive species in the plateau (Fig. 6). The ecosystem is not currently seriously threatened by them, but they could do so in the future. Moderately invasive species have less spread and occurrences than highly invasive species, but more than potential invaders. They exhibit rapid multiplication and interfere with ecosystem functions and cause biodiversity loss.

Many plants on this plateau are known to have extremely limited geographic ranges, very specific habitat needs, and are particularly vulnerable to environmental changes. Invasive species in this plateau also show specificity in this region, because some of the invasive species listed here such as *Aeschenomene americana, Mitracarpus hirtus, Spermacoce latifolia, Physalis angulata, Rauvolfia tetraphylla,* and *Geissaspis cristata* do not exhibit aggressive invasion in other parts of the world. Members of the Fabaceae family show more invasive nature in plateaus, and the majority of them prefer scrub patches for their spread, followed by deep soil areas, shallow soil areas, grassy plains and seasonal pools (Fig. 7). Scrub patches with more supporting vegetation encourage the invasion of climbers, undershrubs, and herbs in that area.

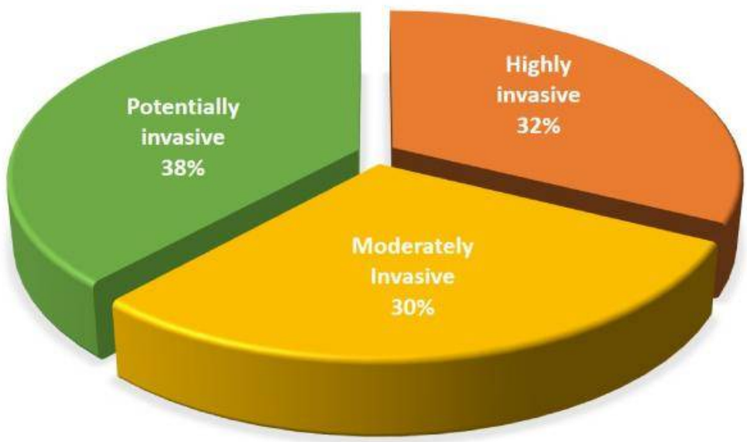

Fig 6**.** Status of invasive species on Kalliad lateritic plateau.

Threats and damages, caused by the invasive species in this plateau are due to allelopathic effects, production of toxic chemicals that harms herbivores, competition for resources like water, sunlight, and nutrients, formation of dense mat over native plants and smothering them, decreasing native plant's productivity and suppress their growth and multiplication, causing allergic reactions in organisms. Some of them (for example, *Lantana camara*) act as host for disease-causing vectors, and they will ultimately result in the reduction of biodiversity. One of the major impacts of invasive plants on the lateritic plateaus is fire. The dried biomass of *Mikania*, *Pennisetum* and *Mimosa* are prone to catch fire and lead to the loss of biodiversity on a large scale within minutes. Kalliad lateritic plateau of northern Kerala is an unfamiliar and understudied site for species diversity and recently two new species namely, *Isachne bhatii* Biju, Josekutty & Augustine and *Dimeria kalliyadense* Biju, Josekutty & Augustine are reported from here. These forms the habitats for many endemic and threatened species; threats from these invasive species may affect the status of these taxa seriously in the near future.

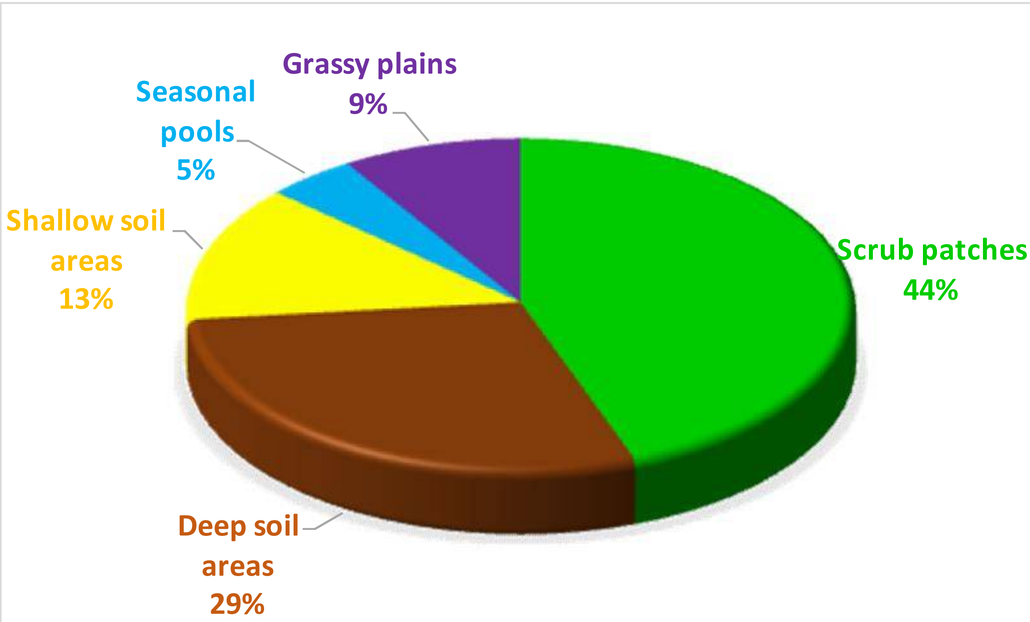

Fig 7. Distribution of invasive species in different microhabitats of Kalliad lateritic plateau.

Anthropogenic activities and invasion of exotic weeds

Laterite is extracted as bricks in Kerala and used in the construction of buildings. One benefit of using laterite as a building material is that it is soft when mined and easily cut into blocks and bricks that harden when exposed to air. The basement rocks are also a good source of construction material. According to the District survey report of minor minerals in Kannur district, permission was given for quarrying about 8 hectares of laterite land in Kalliad plateau in the year 2015-2016 by various concession holders (Anonymous, 2016). Many temporary roads are built for the mining activities, which also negatively impacts the microhabitats and threatens a number of narrow endemic species that are adapted to laterite habitats. The most notable thing about lateritic habitat is that, once disturbed or destroyed, it is difficult to restore as it is formed by a long-term weathering process. Frequent invasion of these disturbed habitats by exotic weeds such as *Acacia auriculiformis, Mimosa diplotricha*, and *Chromolaena odorata*, is noticed.

Similar is the situation in other plateaus of northern Kerala. The invasion of *Acacia auriculiformis* was reported by Pramod and Pradeep (2020) in the mining waste of the Madayipprara lateritic plateau. During monsoon, mass flowering of certain species such as *Utricularia* Spp. and *Eriocaulon* Spp. create a visual treat on these plateaus and then promote local tourism. This often adversely affects the microhabitats due to waste dumping, entry of vehicles, and spreading propagules of exotic weeds. Grazing also affect adversely, though animals were crucial for the regeneration of many habitats' specific native species. Anthropogenic invasion favours the wide spread of exotic weeds on the plateau.

Conclusion

A number of invasive species are reported and they cause serious damage to the indigenous flora and ecosystem functions in Kalliad lateritic plateau. The short-lived native herbaceous species of this plateau need particular microhabitats to survive. Anthropogenic invasion disturbs these microhabitats and promotes extensive growth of exotic weeds. These invasive trends must now be taken into account more carefully because the biodiversity of these plateaus is unique and cannot be easily restored and impossible to conserve outside their natural habitats. In order to stop these invasive trends and maintain this special habitat for the foreseeable future, appropriate policy formulation and management interventions are required.

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DIVERSITY, USES AND NATIVITY OF INVASIVE ALIEN SPECIES OF NARSAPUR RESERVE FOREST, MEDAK, TELENGANA

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Abstract

Invasive alien plant species are exotic plants which are capable of establishing and flourishing in a new ecosystem. There are many mechanisms through which these invasive alien plant species alter or disrupt natural ecosystem services and threaten biodiversity loss. Besides having a profound negative effect on plant community structure and assembly, these species also pose a significant barrier to natural restoration. It is estimated that about 40% of the species in the Indian flora are alien, of which 25% are invasive species. The aim of the present investigation is to determine the diversity of invasive flora in the dry deciduous forest of Narsapur Reserve Forest along with detailed study about their uses by local inhabitants. A total of 59 species belonging to 49 genera of 26 families have been recorded as invasives. Asteraceae was the dominant family with 8 species, followed by Caesalpiniaceae with 7 species, Amaranthaceae (4) and Poaceae (4) species each. Remaining families are represented by less than 3 species. Majority of the invasives were herbs (67.8%), followed by shrubs (16.95%), trees (13.56%) and climbers (1.69%). *Mesosphaerum suaveolens, Parthenium hysterophorous, Chromolaena odorata, Lanata camara*, *Ageratum conyzoides, Alternanthera ficoidea, Senna uniflora* are dominant invasive species in the study area. The species belong to 24 geographical regions and majority of them owe their origin to tropical America (22%), and 17 of these species (28.8%) have their natural distribution in India. Despite all the noxious effects of these species, some plants are used by local people. 16 species (27.11%) collected by local communities are used as medicines, timber, ornamentals and for consumption as well as earning. Even though these invasive plants are one of the income sources for the local inhabitants they are threat to natural recovery of tropical forests.[1]

Keywords:- Invasive plants, biotic pressure, Narsapur reserve forest, ethnobotany of invasives

Introduction

Globally, invasive plant species can be found growing in all kinds of ecosystems and has become a serious threat to plant diversity after habitat loss (Rai and Singh, 2020; Richardson

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[1] Yasaswinee Rout, Aili Naresh, Kethavath Santhosh, and Bharti Patel. 2023. Diversity, uses and nativity of invasive alien species of Narsapur Reserve Forest, Medak, Telengana. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp. 196-205.

et al., 2020). Mostly terrestrial communities are being affected by the robust proliferation of these species (Gurevitch and Padilla, 2004). The terminology "invasive plant species" characterizes non-native, exotic, or introduced plant species that possess the potential to adversely affect both the environment and the economy (Dean et al., 2000). They are characterized with rapid growth rate, higher competitiveness as well as reproductive efficiency, profuse seed production and dispersal via air and water, vegetative reproduction, production of all elo-chemicals etc; thus, these species proliferate efficiently, exploit usage of resources, and are far more ecologically adaptable than native species (Simberl off, 2005).These plant invaders not only destruct the habitat of native flora but also alter soil profile, structure, nutrient content, moisture availability, micro-floral diversity, decomposition rate; consequently alters the forest vegetation as well as affects plant-animal interaction (Panda *et al.*, 2019). According to their real effects, more than 50% of invasive species can be categorized as being environmentally damaging (Richardson et al., 2000). While invasive plant species are typically thought to be detrimental; some plants have healthy social, ecological, and economic side. These non-native plants support the local populations with food, fodder, medicine timber, etc., while certain species supply food or shelter to the winged communities.

The unique topography, soil, and climate of India contribute to its rich biodiversity. India is considered as one of the most affected countries; since a number of non-native plants were introduced into the country due to its high economic value (Pandey, 2000; Jenkins and Mooney, 2006). Some of these aggressive plants were introduced as ornamental plants; while some other was used for commercial cultivation, timber and fuel wood production, green coverage plantation etc. (Kohli et al. 2006; Muniappan *et al*., 2009; Hiremath and Sundaram 2013). In India, about 40% of the plant species are alien, with 25% of them considered invasive (Kavita Gupta; National Bureau of Plant Genetic Resources). Meanwhile, only a few investigations were conducted, in the state of Telengana, to catalogue the invading biodiversity. In light of this, a brief field visit was conducted in the Narsapur Reserve Forest to explore the phytosociology of invasive alien species.

Methods

The present study was carried out in Narsapur Reserve Forest of 3470hecters of geographical area in Medak district of Telangana and only 45 kms away from city Hyderabad (Fig. 1).The present study was conducted during 2021-2022. Intensive floristic surveys were conducted in different seasons to prepare a comprehensive list of invasive plant species in the study area. Plant samples were collected and photographed in their natural habitat and identified with the help of Flora of Andhra Pradesh (Pullaiah *et al*., 2018a, 2018b; Pullaiah and Karuppusamy, 2018; Pullaiah and Murthy, 2018)and other available (Sankaran *et al*., 2014; Nayak *et al*., 2015; Mallick et al., 2019; Kommidi *et al*., 2021). Observations were made on different field characters such as life form, habitat etc. and the interaction with local inhabitants were made to collect the information regarding the different type of uses such as food, fodder, medicinal etc. of these species. The nativity of these introduced species was noted according to The Invasive Species Compendium (ISC) (CABI) and Global Invasive Species Database (GISD) (Turbelin *et al*., 2017).

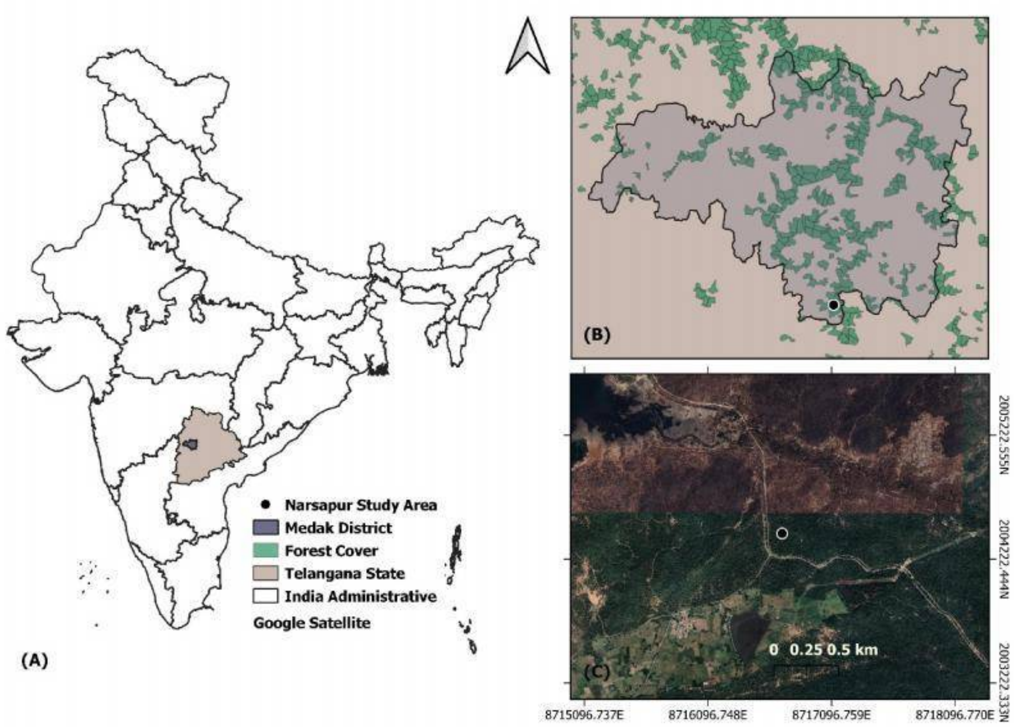

Fig. 1: Study Area Map: (A) Location in Telangana state,
(B) Forest cover of Medak district and the study area, (C) Google satellite imagery of the study area

Results and discussion

The floristic survey of Narsapur Forest Range revealed a total of 59 species of exotic and invasive plants belonging to 49 genera of 26 families (Table 1). The taxonomic analysis resulted that the family Asteraceae is dominant with 8 (13.55%) species, followed by Caesalpiniaceae with 7 (11.86%) species, Amaranthaceae and Poaceae with 4 (6.77%) species each (Table 2). Remaining families are represented by species less than 3 (Fig. 2). The number of dicotyledonous species identified in this area are 50, belongs to 41 genera under 22 families. The number of monocotyledonous species identified in this area are 9, belongs to 8 genera under 4 families. An analysis of invasive plant species by their habits revealed that 67.8% of them are herbs, 16.95% are shrubs, 13.56% are trees and 1.69% are climbers (Fig. 3). Genera wise quantitative analysis showed that *Senna* with 3 species followed by *Chamaecrista* sp. *Corchorus* sp. *Cyperus*sp. *Euphorbia* sp. *Evolvulus* sp. *Ludwigia* sp. and *Spermacoce* sp. with 2 species each. *Mesosphaerum suaveolens*, *Parthenium hysterophorous*, *Chromolaena odorata*, *Lanata camara*, *Ageratum conyzoides*, *Alternanthera ficoidea*, *Senna uniflora*, are predominant invasive species with higher impact in the study area (Fig. 4). A vast of species was observed flourishing both in grassland and woodland ecosystems. *Mesosphaerum suaveolens, Lanata camara, Urena lobata, Cenchrus pedicellatus, Emilia sonchifolia, Senna occidentalis* were mostly found invading forest ecosystem; whereas plants like *Ludwigia hyssopifolia, Ludwigia octovalvis, Alternanthera ficoidea* were having a prolific growth near the streamlines.

The contribution of different geographical regions or nativity of invasive alien species is shown in Table 3. A total of 24 native geographical regions of invasive species were recorded and 17 of these species (28.8%) have their natural distribution in India. The major geographical regions or nativities of these species were Tropical America (13 species), Tropical & Subtropical Old World, Tropical & Subtropical America (5 species each) and Central America (4 species) (Table 3).

However, the present study also recorded few invasive plant species used by the local communities of Narsapur. A total of 16 plant species were collected by the inhabitants on day today basis for various purposes. Such as fruits of *Tamarindus indica*, *Ziziphus jujube, Pithecellobium dulce*, *Annona squamosa*, *Phoenix sylvestris and* whole plant *of Portulaca oleracea* were readily collected from the forest for consumption and earning purposes. Meanwhile, *Amaranthus spinosus, Cynodon dactylon*, *Chamaecrista absus*, *Leucaena leucocephala* were being used as fodder. Whereas, plants like *Euphorbia hirta*&*Mimosa pudica*are used for medicinal purposes.

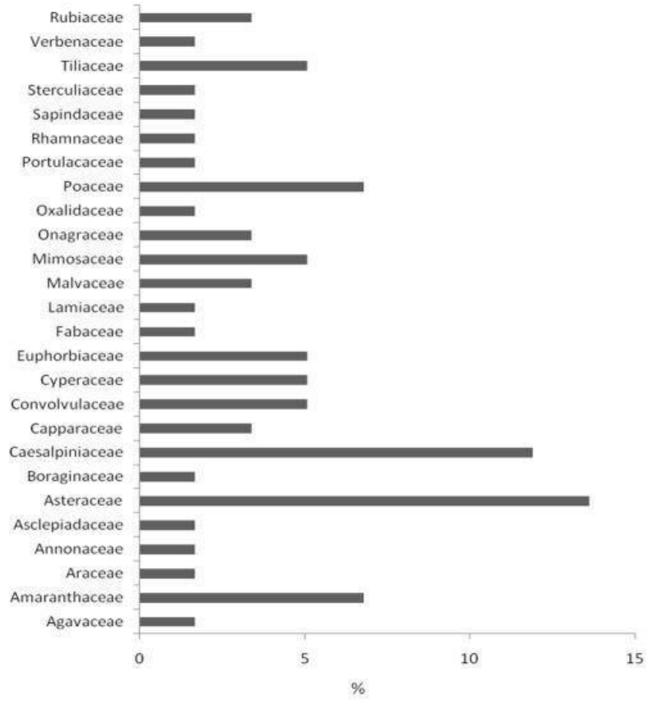

Fig. 2: Family wise distribution of invasive plant species in Narsapur Reserve Forest

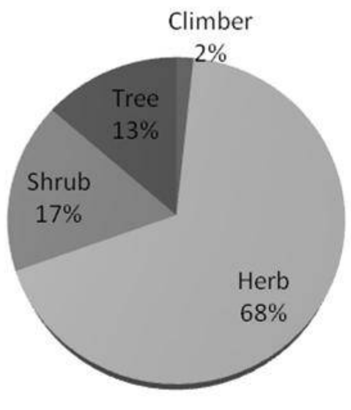

Fig. 3: Habit wise distribution of invasive plant species

Table 1: List of Invasive Plant Species found in Narsapur Reserve Forest

Scientific Name	Common Name	Family	Uses	Native
Agave americana L.	Kithanara	Agavaceae	Or	Mexico
Ageratum conyzoides L.	Vaadaichedi	Asteraceae	-	America
Alternanthera ficoidea (L.) Sm	Sanguinarea	Amaranthaceae	-	Tropical America
Amaranthus spinosus L.	Mulla totakura	Amaranthaceae	F	Tropical America
Annona squamosa L.	Sithaphalamu	Annonaceae	E	Central America, West Indies
Blainvillea acmella (L.) Philipson	Para Cress Flower	Asteraceae	-	Tropical America
Calotropis gigantea (L.) Dryand.	Tella jilledu	Asclepiadaceae	O	Tropical Africa
Chamaecrista absus (L.) H.S.Irwin and Barneby	Chanupala vittulu	Caesalpiniaceae	F	Tropical Africa
Chamaecrista pumila (Lam.) K.Larsen	Nallajeeluga	Caesalpiniaceae	-	Tropical Asia
Chloris barbata Sw.	Uppu gaddi	Poaceae	-	Tropical and Subtropical Old World
Chromolaena odorata (L.) R.M.King and H.Rob.	Kampurodda	Asteraceae	-	Tropical America
Cleome gynandra L.	Vaminta	Capparaceae	-	Tropical and Subtropical Old World
Cleome viscosa L.	Kukkavomint a	Capparaceae	-	Tropical and Subtropical Old World
Corchorus aestuans L.	Kajati	Tiliaceae	-	Tropics and Subtropics
Corchorus trilocularis L.	Bankitutturu	Tiliaceae	-	Tropical and S. Africa
Cyanthillium cinereum (L.) H.Rob.	Gariti kamini	Asteraceae	-	Pantropical
Cynodon dactylon (L.) Pers.	Ghericha	Cyperaceae	F	Temp. and Subtropical Old World, Australia
Cyperus difformis L.	Variable Flatsedge	Cyperaceae	-	Tropical and Subtropical Old World
Cyperus rotundus L.	Tunga	Cyperaceae	-	Tropical and Subtropical Old World
Digera muricata (L.) Mart.	Chencheli kura	Amaranthaceae	-	Egypt, E. Kenya and Malesia
Cenchrus pedicellatus (Trin.) Morrone	Kyasuma Grass	Poaceae	-	Africa
Dodonaea viscosa Jacq.	Bandaru	Sapindaceae	-	Tropical and Subtropical Coasts
Echinochloa colona (L.) *Link*	Chitti udara	Poaceae	-	Tropics and sub-tropics
Emilia sonchifolia (L.) DC.	Purple Sow Thistle	Asteraceae	-	China and South East Asia
Eragrostis amabilis (L.)Wight and Arn.	Japanese Lovegrass	Poaceae	-	Tropical and S. Africa, S. Arabian Peninsula, Tropical Asia
Euphorbia hirta L.	Asthma Plant	Euphorbiaceae	M	Tropical and Subtropical America
Euphorbia prostrata Aiton	Prostrate Sandmat	Euphorbiaceae	-	Tropical and Subtropical America
Evolvulus alsinoides (L.) L.	Vishnukranth am	Convolvulaceae	-	Tropical and sub-tropical regions
Evolvulus nummularius (L.) L.	Agracejo Glory	Convolvulaceae	-	Tropical America
Flueggea virosa (Roxb. ex Willd.) Royle	Mekarayi	Euphorbiaceae	-	Africa,
Gomphrena serrata L.	Prostrate Gomphrena	Amaranthaceae	-	Central America
Grewia flavescens Juss.	Bankajana	Tiliaceae	-	Tropical and S. Africa to India
Heliotropium indicum L.	Naga danti	Boraginaceae	-	Peru to Brazil and N. Argentina

Ipomoea hederifolia L.	Kasi ratnamu	Convolvulaceae	-	Tropical and Subtropical America
Lantana camara L.	Gaju pulu	Verbenaceae	-	Tropical America.
Leucaena leucocephala (Lam.) de Wit	Kainti	Mimosaceae	F	Central America
Ludwigia hyssopifolia (G.Don) Exell	Seedbox	Onagraceae	-	Tropical America
Ludwigia octovalvis subsp. *octovalvis*	Lavanga kaaya	Onagraceae	-	Tropical and Subtropical America
Mesosphaerum suaveolen (L.) Kuntze	Sirna tulasi	Lamiaceae	-	Tropical America
Mimosa pudica L.	Nidrabhunji	Mimosaceae	M	Tropical America
Oxalis corniculata L.	Pulichinta	Oxalidaceae	-	Caribbean
Parthenium hysterophorus L.	Congress gaddi	Asteraceae	-	Tropical and Subtropical America
Peltophorum pterocarpum (DC.) K.Heyne	Pacha sunkesula	Caesalpiniaceae	T	N. Australia
Phoenix sylvestris (L.) Roxb.	Pedda-ita	Araceae	E	Indian Subcontinent
Pithecellobium dulce (Roxb.) Benth.	Simachinta	Mimosaceae	E	Tropical America
Portulaca oleracea L.	Payalaku	Portulacaceae	E	Macaronesia, Tropical Africa, Medit. to Pakistan and Arabian Peninsula
Pulicaria wightiana (DC.) C.B.Clarke	Sonaphuli	Asteraceae	-	India.
Senegalia pennata (L.) Maslin	Konda-korinta	Fabaceae	-	Indian Subcontinent
Senna occidentalis (L.) Link	Pedda kasivinda	Caesalpiniaceae	F	Tropical America
Senna tora (L.) Roxb.	Tantemu	Caesalpiniaceae	-	Central America
Senna uniflora (Mill.) H.S.Irwin and Barneby	Oneleaf Senna	Caesalpiniaceae	-	Tropical South America and West Indies
Sida acuta Burm.f.	Common Wire Weed	Malvaceae	-	Tropical America
Spermacoce articularis L.f.	Madana grandthi	Rubiaceae	-	Tropical and Subtropical Asia
Spermacoce hispida L.	Natthaisuuri	Rubiaceae	-	Tropical and Subtropical Asia
Tamarindus indica L.	Chinta	Caesalpiniaceae	E	Madagascar
Tridax procumbens L.	Ravanasurudi talakaai	Asteraceae	-	Tropical America
Urena lobata L.	Caesar weed	Malvaceae	-	Pantropical
Waltheria indica L.	Boater Bush	Sterculiaceae	-	Pantropical
Ziziphus jujuba Mill.	Badari	Rhamnaceae	E	China North-Central

Abbreviations; E- Edible, F- Fodder, M- Medicinal, O- Other, Or-Ornamental, T-Timber

Table 2: Distribution of invasive plant species in top 5 families

Sl No.	**Family Name**	**No of Species**
1	Asteraceae	8
2	Caesalpiniaceae	7
3	Amaranthaceae, Poaceae	4
4	Convolvulaceae, Cyperaceae, Euphorbiaceae, Mimosaceae, Tiliaceae	3
5	Capparaceae, Malvaceae, Onagraceae, Rubiaceae	2

Table 3: Regions of Nativity of Invasive Plant Species

Sl. No.	Region of Nativity	No. of Species
1	North Australia	1
2	Africa	2
3	America	1
4	Caribbean	1
5	Central America	4
6	China and South East Asia	1
7	China North-Central	1
8	Egypt	1
9	Indian Subcontinent	3
10	Macaronesia	1
11	Madagascar	1
12	Mexico	1
13	Pantropical	3
14	Peru	1
15	Tropical and South Africa	3
16	Tropical and Subtropical America	5
17	Tropical and Subtropical Asia	2
18	Tropical and Subtropical Coasts	1
19	Tropical and Subtropical Old World	5
20	Tropical Africa	2
21	Tropical America	13
22	Tropical Asia	1
23	Tropical South America	2
24	Tropics and Subtropics	3

Fig. 4: Some Common Invasive Alien Plant Species found in Narsapur Reserve Forest, (A) *Ageratum conyzoides,* (B) *Cyanthillium cinereum,* (C) *Parthenium hysterophorus,* (D) *Alternanthera ficoidea,* (E) *Lantana camara,* (F) *Pulicaria wightiana*

In the study area, most abundant invasive plant species like *Parthenium hysterophorous, Chromolaena odorata, Lanata camara, Ageratum conyzoides* are considered as highly noxious by different reports (Tripathi *et al*., 2007; Dogra *et al*., 2009). The family Asteraceae was found to be more invasive in different parts of India (Sekar *et al*., 2012; Nayak *et al*., 2015; Sheikh *et al*., 2017; Mallick et al., 2019; Kommidi *et al*., 2021) as well as all over the world (Lambdon *et al*., 2008; Wu *et al*., 2010). In the forest ecosystem, herbaceous species are by far the most abundant invasive species, which is comparable to the invasive reports from Warangal, Telangana (Kommidi *et al*., 2021), Dhenkanal district of Odisha (Nayak *et al*., 2015). Tropical America has the largest contribution to the origins of invasive species in this study, which is comparable to the findings from other studies of Srivastava *et al.* (2014), Panda *et al.* (2018), Mallick *et al*. (2019), Kommidi *et al.* (2021).

Conclusion

Invasive plant species adversely affect forest ecosystem although few of them have economical as well as social importance. In the study area their population are expanding quickly and hence needs tremendous monitoring for control measures. These invaders are gradually becoming a huge threat to the present flora of Dry deciduous forests of Narsapur

Reserve Forest. Therefore, it is essential for conservation biologists and researchers to look into this issue in order to stop the loss of this region's phytodiversity as well as to lessen any negative effects, and to manage invasive plant species effectively.

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INVASIVE PLANTS OF THATTEKKAD BIRD SANCTUARY

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Abstract

Thattekkad bird sanctuary, known as the premier bird sanctuary of Kerala, located in Central Kerala, North East to Kothamangalam in Ernakulam district. Though the Sanctuary covers an area of 25.16 km^2, almost 9 km^2 out of this is under human inhabitation, thereby increasing the risk of invasion. In the present study, around 100 observation points were laid across the Sanctuary. Each such point was selected on the basis of visual invasive behaviour. The plant species thus observed were checked against the checklist of invasive plants of Kerala. 23 such plant species obtained were categorised into 4 group viz., high risk, medium risk, low risk and insignificant, based on the probable impact risk. Among them 9 species are of high risk, 5 pose medium risk, 7 pose low risk and 2 are insignificant with respect to the risk impact. Out of the 23 plants, 1isted, 8 are shrubs, 8 are herbs and 6 are climbers. Most of the introductions were intentional. Immediate measures are to be taken to restore habitats from alien invasive plants and eradicate the plants that are in the early phase of establishment. Also their further spread, in terms of new introductions and already established, are to be strictly checked.

Keywords: Thattekkad bird sanctuary, invasion, high risk, alien invasive plants, establishment

Introduction

Any species that is not indigenous, or native, to a particular area, can be considered as an invasive organism. They can cause great economic and environmental harm to the new area. There are several characteristics that help a species to be invasive. Most important among them is the large quantity of seeds they produce which are very small to be carried away to long distances by wind and water (Khare,1980). The gestation period of these seeds would be long and their large number increases the propagule pressure on the new habitat (Carlton, 1996). This means that the propagules of the native species will have to compete with a large number of seeds of the invasive species. Many alien invasive species are early colonizers which help them to thrive on resource poor habitats (Funk & Vitousek 2007). They have very fast establishment and growth rates (Burns, 2004, 2006) and can make use of tree fall gaps (David Gorchov *e t al*,2005), degraded forests and forest fringes better than the native species (Rojas, Isabel *et al*,2011). The allelochemicals produced by many of the invasive plants

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prevent the establishment of native plants in their vicinity (Callaway&Aschehoug2000). Majority of the invasive plants can reproduce both sexually and vegetatively that help them to spread all through the year (Silvertown2008). They exhibit phenotypic plasticity that help these plants to adapt to a variety of habitats as evidenced by *Mimosa diplotricha* var. *diplotricha* which remains a shrub in open lands but turns into a climber when trees are close by (Sultan 2001, Hulme 2008, Niklas 2008).

Invasive plants exert several impacts on the ecosystem by direct displacement of native plant species. This happens through several mechanisms like change of soil chemical profile, rewarding pollinators better than the natives species thereby reducing the reproductive success of native species, changing hydrological regimes, making the new habitats fire prone, limiting the photosynthetic efficiency of the native species by reducing light availability, and by inviting the necessity of herbicide application thereby impacting both the flora and fauna of the area (Nilsson and Grelsson, 1996; Levine,2003).The results would be reduced availability of forest resources like medicinal plants and timber from forest plantations. One of the classical examples of the impact of invasive plants is, Kaziranga national park where the movement of the one horned rhinoceros was limited by thickets of *Mimosa diploticha* var. *diplotricha*. In many other national parks *Lantana camara* causes negative impacts on the native fauna (Vattakkavan, 2002; Singh, 1976).Another indirect impact occur by the complete elimination of food plants of the fauna and by making the habitat prone to fire(CBD,2010).
Thattekkad bird sanctuary, known as the premier bird sanctuary of Kerala, is located in Central Kerala, North East to Kothamangalam in Ernakulam district. Though the Sanctuary covers an area of 25.16 km^2, almost 9 km^2 out of this is under human inhabitation, thereby increasing the risk of invasion. The present study aims to document the invasive plants of Thattekkad bird sanctuary and to review the probable impact risk by invasive plants to the ecosystem of Thattekkad bird sanctuary.

Materials and methods

Around 100 observation points were laid across the Sanctuary covering tropical evergreen forests, tropical semi evergreen forests, moist deciduous forests, riparian forests and plantations. Each such point was selected on the basis of visual invasive behavior of plants. The plant species thus observed were checked against the checklist of invasive plants of Kerala and grouped into four categories viz., high risk, medium risk, low risk and insignificant (Table1) based on the Invasive Species Assessment Protocol (Morse *et al*., 2004)

Table 1: Description of Invasive Rank used in the study

Rank	Description
High	Species represents a severe threat to native species and ecological communities
Medium	Species represents moderate threat to native species and ecological communities
Low	Species represents a significant but relatively low threat to native species and ecological communities

Insignificant	Species represents an insignificant threat to native species and ecological communities

Results

23 invasive plant species were obtained and they were categorised into 4 group viz., high risk, medium risk, low risk and insignificant, based on the probable impact risk (Table 2). Among them 9species are of high risk, 5 pose medium risk, 7 pose low risk and 2 are insignificant with respect to the risk impact. Out of the 23 plants, 1 is tree, 8 are shrubs, 8 are herbs and 6 are climbers. Most of the introductions were intentional.

Table 2: Invasive plants, their families, habit and risk category

Sl. No.	**Species**	**Family**	**Habit**	**Rank**
1	*Ageratum conyzoides* L.	Asteraceae	Herb	Low
2	*Alteranthera bettzickiana* (Regel) G.Nichols.	Amaranthaceae	Herb	Insignificant
3	*Alteranthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	Herb	Insignificant
4	*Amaranthus spinosus* L.	Amaranthaceae	Herb	Low
5	*Centrosema molle* Benth	Fabaceae	Climber	Low
6	*Chromolena odorata*(L.) King & H.Rob.	Asteraceae	Shrub	High
7	*Clidemia hirta* (L.) *D.Don*	Melastoataceae	Shrub	Low
8	*Hyptis suaveolens* (L.) Poit.	Lamiaceae	Shrub	Medium
9	*Ipomoea purpurea* (L.) Roth.	Convolvulaceae	Climber	Medium
10	*Lantana camara* L.	Verbenaceae	Shrub	High
11	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae	Tree	Low
12	*Merremia vitifolia* (Burm. f.) Hallier f.	Convolvulaceae	Climber	High
13	*Mikania micrantha* Kunth	Asteraceae	Climber	High
14	*Mimosa diplotricha* C.White ex Sauvalle var.*diplotricha* C.White ex Sauvalle	Fabaceae	Shrub	High
15	*Mimosa pudica* L.	Fabaceae	Herb	Low
16	*Mucuna bracteata* DC ex.Kurz	Fabaceae	Climber	High
17	*Pennisetum polystachyon* (L.)Schult.	Poaceae	Herb	Medium
18	*Pueraria phaseoloides* (Roxb.) Benth.	Fabaceae	Climber	High
19	*Senna alata* (L.) Roxb.	Fabaceae	Shrub	High
20	*Senna hirsuta* (L.) Irwin & Barneby	Fabaceae	Shrub	Medium
21	*Senna occidentalis* (L.) Link	Fabaceae	Shrub	Low
22	*Sphagneticola trilobata* (L.) Pruski	Asteraceae	Herb	High
23	*Synedrella nodifloa* (L.) Gaertn.	Asteraceae	Herb	Medium

Sphagneticola trilobata (L.) Pruski

Chromolena odorata (L.)King

Lantana camara L.

Mikania micrantha Kunth

Mimosa diplotricha C.White ex Sauvalle var.*diplotricha* C.White ex Sauvalle

Senna alata (L.)Roxb

Fig 1: some major invasive plants of Thattekkad bird sanctuary

Discussion

The present study identified 23 invasive plant species in Thattekkad bird sanctuary of which 9 are in high risk category. They need special attention in terms of control measures. The plants in medium risk and low risk are 5 and 7 respectively. Constant monitoring is needed to prevent further spread and new intrusions. The invasive plants exert both direct and indirect effects on the forest ecosystem. Immediate measures are to be taken to restore habitats from alien invasive plants and eradicate the plants that are in the early phase of establishment. Moreover their further spread, in terms of new introductions and already established, are to be strictly checked.

Conclusions

This study provides only a preliminary data towards the invasive plants of Thattekkad sanctuary. Quantitative study is needed to assess the actual state of invasion. Action plans are to be developed for the eradication of high risk species. Being a tourist destination, thorough checking of the belongings of tourists is needed to prevent spread and further introduction.

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DO TOURISM ENHANCE BIOLOGICAL INVASIONS IN FORESTS? A CASE STUDY AT ATHIRAPILLY, KERALA.

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Abstract

Travel, tourism and trade are on the increase worldwide paving way for spread of invasivealien plants. As per the latest Tourism Statistics report published by the Kerala State Tourism Department, Athirapilly tourist location was visited by 2,11,275 domestic and 3241 international tourists in 2019. We studied the presence and spread ecology of invasive alien plants in Athirappilly to understand if plant invasions in forests is a function of tourism along with the known factor- linear intrusions. The area falling within five kilometre radius around Athirapilly Waterfalls was selected as the study area. This area was categorized into inner, middle and outer zones where grids of 1x 1 km^2 were superimposed to conduct the survey. Sixteen grids were selected by stratified sampling procedure so as to cover locations of inner, middle and outer zones. Except for eight grids which had frequent animal sightings and heavy canopy, observations were taken at regular intervals of 500m by maintaining an observational range of 250m. Presence of invasive plants along with a visual index on a scale of ten, aggressiveness of invasives, elevation, habitat type and location sketches were the major data collected at every survey point. This covered a total of 85 geo-coordinates covering forests, stream sides, roadsides and trek paths. We recorded and classified a total of 22 invasive alien plants - *Chromolaena odorata*, *Mikania micrantha*, *Mimosa diplotricha* and *Senna alata* were assessed as high risk species; *Ageratum conyzoides*, *Calopogonium mucunoides*, *Lantanacamara*, *Merremia vitifolia*, *Pennisetum pedicellatum*, *Pennisetum polystachyon*, *Puerariaphaseoloides* and *Sphagneticola trilobata* as medium risk and *Alternanthera bettzickiana*, *Alternanthera brasiliana*, *Caladium bicolor, Centrosema molle*, *Ipomoea carnea*, *Ipomoeahederifolia*, *Senna occidentalis, Senna siamea*, *Senna tora* and *Synedrella nodiflora* as medium risk with probable less damage species. The presence of invasive alien plants across inner (17), middle (16) and outer (17) zones were comparable. However, comparison of the intensity of invasion using ANOVA followed by Tukey HSD and independent t-test showed that the middle zone had statistically significant higher intensity of invasion than the inner and outer zones. This could be attributed to the presence of high density of resorts and trek paths in the middle zone than in the other zones. The study shows that high presence of tourists has a positive correlation with the intensity of invasion by alien invasive plants.

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This calls for continuous monitoring management of invasive alien plants around tourist spots to prevent the spread of invasive species into forest areas. Increased awareness is needed among tourists, resort owners and staff regarding the identity and impact of the invasive alien species.

Key words: Biological Invasion, Forest Ecosystem, Tourism

Introduction

With the onset of new era of globalization, the immense increase in global trade, travel (Hulme, 2009) and tourism (Hulme, 2015) has increased the rate of biological invasions (Tripathi, 2009) and are generally said to be the TTTs; the primary pathways of spread (Perrings et al., 2001). These may have resulted in intentional and unintentional movement of species beyond their natural distribution and cause environmental, socio-economical or health impacts (CBD, 2004) on the native species of the invaded land. Of the three pathways, tourism play a major role in biotic exchange (Hall, 2019) where frequent movement of people and vehicles occur along geographically different locations that can deliberately introduce non- native species (Anderson et al., 2012), even to the remote parts of the world. With regard to the plant invasions in India, tourism involves in transport of invasive alien propagules by three different probable ways- either by deliberate planting of new species or reintroduction of a species to their former range; as a vector which is always an accidental introduction and by disturbing habitats (Hall and Baird, 2013). Intentional introduction of alien plant species in tourist sites are associated with tourist infrastructure such as building of foot-paths, lodges, planting of probable invasive aliens as ornamental plants in hotel gardens, resorts, public gardens and private parks. Tourism allied recreational activities like hiking, horse riding, off-road driving can also be instrumental in habitat destruction and can facilitate invasions.

Biological invasion records in Kerala can be traced back even to 19^{th} century and experiencing several waves of invasion till date. Invasive alien plant survey conducted by Sankaran et al., (2012) assessed the risk status and reported 82 invasive alien plants in Kerala where 21 species categorized as high risk, 22 as medium risk and 14 as low risk and 25 as insignificant species. They all affected the rural and urban spaces in Kerala causing significant impact on ecology as well as the economy of the state. Habitats like agricultural lands, recreational spaces, home gardens were all invaded by these species where abundance of alien plants was extremely high in tourist locations. Nature based tourism is always recognized as a key growth area of biological invasions where the loss in this particular sector can negatively impact the GDP of the state. Infestation of IAPs (Invasive Alien Plant) in tourist locations can expand quickly and establish on public lands. Since the state of Kerala is facing tremendous increase in tourism traffic, both the domestic and international tourist footfall may contribute to the introduction of IAPs in areas free of IAS or aids in the spread of IAPs.

According to the most recent tourism statistics report released by the Kerala State Tourism Department, Athirapilly is a popular nature-based tourism destination in Kerala and received 2,11,275 domestic and 3241 foreign visitors in 2019. The role of tourism in the spread of invasive alien plant species needs to be further studied in order to reduce the likelihood of introductions. Considering the state's nature-based tourism destinations, tourism can be a significant contributor of invasive alien plant species in Kerala's forests, despite the fact that linear intrusions are a known factor in plant invasions in forests.

Materials and methods

A five-kilometre radius around the Athirapilly waterfalls was chosen as the study area, and 1x1 km^2 grids were put over the area to perform the survey (Fig 1). Using a stratified sampling approach, sixteen grids were chosen in order to cover the grids all the way around the study area's radius. In order to navigate and manage waypoints, tracks, and routes, KML files of a selected sixteen grids were uploaded and opened in the GPS tool for Android called "GPS Essentials." Observations like presence of invasive plant and its visual index on a scale of ten, aggressiveness as low, medium and high, habitat type, native plants and elevation and geo-coordinates using handheld GPS were taken at regular intervals of 500m within an observational range of 250 m and were recorded in data sheets. Location sketches of each survey point was also marked along with the percent canopy cover using another android application- ‘Canopeo’. Data collected from the field was then further used for risk assessment using modified GISS and statistical analyses using SPSS and R software. To compute the data, the study area was categorized into inner, middle and outer zones where the visual intensity of invasive plants was compared using ANOVA followed by Tukey HSD and independent t-test.

Results

Except for eight grids which had frequent animal sightings and heavy canopy, observations were taken from the other eight selected grids by covering a total of 85 survey points (Fig 2).

a. Invasive Alien Plant Survey

A total of 22 invasive alien plants have been recorded from the surveyed grids (Table1).

Table 1: List of invasive alien plants recorded from Athirapilly study area

Sl.No.	Name of the Invasive Alien Plant	Sl.No.	Name of the Invasive Alien Plant
1.	*Ageratum conyzoides*	12.	*Senna alata*
2.	*Alternanthera bettzickiana*	13.	*Senna occidentalis*
3.	*Alternanthera brasiliana*	14.	*Senna siamea*
4.	*Calopogonium muconoides*	15.	*Senna tora*
5.	*Centrosema molle*	16.	*Sphagneticola trilobata*
6.	*Chromolaena odorata*	17.	*Synedrella nodiflora*
7.	*Merremia vitifolia*	18.	*Ipomea carnea*
8.	*Mikania micrantha*	19.	*Lantana camara*
9.	*Mimosa diplotricha*	20.	*Pennisetum polystachyon*
10.	*Pennisetum pedicellatum*	21.	*Caladium bicolor*
11.	*Pueraria phaseoloides*	22.	*Ipomoea hederifolia*

b. Risk assessment of Invasive Alien Plants

Risk assessment was done on the recorded twenty-two invasive alien plant species using the modified GISS (*Nentwig* et al., 2016). GISS score was calculated for each invasive plant and was categorized based on the final scores out of 60. Those plants with a GISS score of 20 and above were considered as high risk species, score between 10-19 as medium risk species and score between 1-9 as medium impact with less probable damage species. Of the total 22 recorded invasive plants, four plant species were categorized as high risk, eight as medium and ten as medium impact with less probable damage (Table 2).

Table 2: GISS scores of
Invasive Alien Plants recorded from Athirapilly Study Area

Invasive Alien Plant	GISS Score	Invasive Alien Plant	GISS Score
Ageratum conyzoides	14	*Mikania micrantha*	25
Alternanthera bettzickiana	7	*Mimosa diplotricha*	21
Alternanthera brasiliana	6	*Pennisetum pedicellatum*	14
Caladium bicolor	3	*Pennisetum polystachyon*	14
Calopogonium mucunoides	11	*Pueraria phaseoloides*	11
Centrosema molle	5	*Senna alata*	20
Chromolaena odorata	27	*Senna occidentalis*	2
Ipomoea carnea	9	*Senna siamea*	7
Ipomoea hederifolia	3	*Senna tora*	5
Lantana camara	10	*Sphagneticola trilobata*	11
Merremia vitifolia	11	*Synedrella nodiflora*	5

Using modified GISS, *Chromolaena odorata, Mikania micrantha, Mimosa diplotricha* and *Senna alata* were assessed as high risk species; *Ageratum conyzoides*, *Calopogonium mucunoides*, *Lantanacamara*, *Merremia vitifolia*, *Pennisetum pedicellatum*, *Pennisetum polystachyon*, *Pueraria phaseoloides* and *Sphagneticola trilobata* as medium risk and *Alternanthera bettzickiana*, *Alternanthera brasiliana*, *Caladium bicolor*, *Centrosema molle*, *Ipomoea carnea*, *Ipomoea hederifolia*, *Senna occidentalis*, *Senna siamea*, *Senna tora* and *Synedrella nodiflora* as medium risk with probable less damage species (Fig 3,4,5).

c. Spread analysis of IAPs

To check the spread of invasive plants from the tourism epicentre, the visual intensity of invasive alien plants was compared between inner (17 species), middle (16 species) and outer (17 species) zones (Table 3).

Table 3: Mean visual intensity and standard deviation of invasive alien plants found in inner, middle and outer zones

Zone	Mean intensity of IAPs	N	Std.Deviation
Inner Zone	4.07	114	2.495
Middle Zone	4.91	68	2.454
Outer Zone	4.57	84	1.483
Total	4.44	266	2.233

$H_0 : m_1=m_2=m_3$

$H_1 : m_1=m_2 \neq m_3$ or $m_1 \neq m_2=m_3$ or $m_1 \neq m_2 \neq m_3$

ANOVA was done keeping that the sample size of each category is reasonably large, so the normality assumption will hold due to the central limit theorem. Null and alternative hypotheses were formulated where the former says on mean intensity of three zones as equal while the latter says on at least one of the mean intensity of a zone is different.

c.1. ANOVA

The p or the significance value was found as 0.039 (Table 4); which is less than 0.05, so that the null hypothesis was rejected. Results of ANOVA says that there exists sufficient evidence to claim the significance difference between the mean intensity of three zones.

Table 4: Results of ANOVA

	Sum of squares	df	Mean Square	F	Sig.
Between Groups	32.174	2	16.087	3.281	0.039
Within groups	1289.481	263	4.903		
Total	1321.654	265			

c.2. Post hoc test for ANOVA-Tukey HSD

Each zone was compared with other two zones to check which zone has a significant higher intensity of invasive alien plants (Table 5). Null and alternative hypotheses were formulated and the test was done. Results show significant difference in intensity of invasive plants was found between inner and middle zones and no significant difference in intensity of invasive plants between inner and outer zone.

Table 5: Results of Tukey HSD

(I) Zone	(J) Zone	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Inner	**Middle**	-.842*	0.339	**0.037**	-1.64	-0.04
	Outer	-0.501	0.318	**0.259**	-1.25	0.25

Middle	**Inner**	.842*	0.339	0.037	0.04	1.64
	Outer	0.34	0.361	0.614	-0.51	1.19
Outer	**Inner**	0.501	0.318	0.259	-0.25	1.25
	Middle	-0.34	0.361	0.614	-1.19	0.51

* The mean difference is significant at the 0.05 level.
Inner-middle zone | H_o:m_1=m_2 | p=0.037 <0.05 | Null hypothesis rejected
Inner-Outer zone | H_o:m_1=m_3 | p=0.259 >0.05 | Fails to reject the null hypothesis

c.3. Independent Sample t test

Significant differences found between inner and middle zone (mean intensity of inner= 4.07 and middle zone= 4.91 were further undergone independent sample t-test to check whether m_1 or m_2 is significantly higher (Table 6). Null and alternate hypotheses were formulated as H_0: middle=inner and H_1: middle>inner, where the one-sided p value is less than 0.05 and thus concluded that the mean intensity of invasive alien plants is significantly higher in the middle zone than inner zone.

Table 6: Independent Samples Test - inner and Middle zones

Levene's Test for Equality of Variances		t-test for Equality of Means		Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
F	Sig.	t	df	One-Sided p	Two-Sided p			Lower	Upper
0.029	0.865	2.215	180	0.014	0.028	-0.842	0.38	-1.591	-0.092

Discussion

In the current investigation, 22 invasive alien plants have been identified during the survey figures the risk posed by the alien species in a tourism destination. Similar reports on vegetation survey was done by Verma *et al*., (2022) on mountain tourism and tried to study the spread of alien plant species in Himalayan Region and invasion patterns due to tourism. They have also spotted with *Ageratina adenophora, Chromolaena odorata, Lantana camara* and *Mikania micrantha* on their study sites. Even though most of the work was done based on questionnaire surveys or literature based surveys, there are some general works that followed vegetation sampling as their primary work to collect the field data. Studies by Hapsari *et al*., (2014), Tjitrosoedirdjo (2005), Sumit *et al*., (2014) and Jamil *et al*., (2022) are of this kind. The role of tourism and spread of invasive alien species studied by Anderson *et al*., (2015) showed similar results of our study; the location where tourists arrive the most have been identified with the highest number of invasive alien species than the control sites. Rogg *et al*., 2013; Viteri Mejía and Brandt, 2015 have considered visitors as a negative factor of nature-based tourism destinations and thereby introducing alien species. Similar to this work, the present study warns about the introduction and spread of IAPs in forest ecosystems. Risk assessment of invasive alien plants has been done in the present study where the same protocol has been used in Shendurney Wildlife Sanctuary (2021) to prioritize the impact category of alien plants.

Conclusion

The IAP survey conducted in Athirapilly study area has recorded a total of 22 non-native plant species, of which 17 species of plants observed in inner and outer zones and 16 alien plant species in the middle zone. Risk assessments of alien plants have shown that the study area has four high risk, eight medium risk and ten probable less damage species. Spread analysis done by comparing the mean intensity of invasive alien species in three zones have revealed significantly higher intensity in the middle zone followed by the inner zone. And also, no significant difference in intensity of alien plants was observed between inner and outer zones. The presence of resorts, trek paths towards the streamside and plantations nearby the stream could contribute towards the introduction and spread of invasive plants in the middle zone (Fig 6). Also, tourist footfall and presence of resorts are present in the inner zone may enhance the invasion further into new locations. Urgent management practices along with continuous monitoring and awareness creation is necessary to prevent the natural spread of alien plants to the adjacent forest habitats.

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BIOINVASION OF DIFFERENT SHADE TREE SPECIES IN THE CARDAMOM HILL RESERVES (CHR), KERALA

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Abstract

Cardamom Hill Reserves (CHR), Kerala, is located mostly in the high range altitude of the southern Western Ghats. The main distribution habitats of small cardamom in the Western Ghats are the shaded environment. Shade trees play a considerable role in the CHR agro ecosystem by reducing the intensity of sunlight, rain and wind speed and also enhancing the soil physical properties as well as activities of pollinating agents. A mixed population of trees that facilitate shade at more or less optimum level all through the year is desirable for the crop. Earlier studies have indicated that 56% of evergreen trees in the Western Ghats are endemic, and the southern Western Ghats have the highest species richness and species endemism. Selective tree felling in cardamom hills goes faster than other places in southern India. Now, the complex tropical forest has been converted in to a more open, simple and uniform system thereby leading to degradation of cardamom agroforestry system in India. Invasive species viz. *Grevillea robusta, Erythrina subumbrans* and *Spathodea companulata* are common features in the CHR area. In this study, we recorded the abundance of the above three invasive species and already reported dominant species in seven major cardamom growing hot spot areas under the CHR system. From each hot spot area, three plots were selected, and from each plot 50 shade trees were marked and recorded the observations. Totally 21 plots were sampled. Among the invasive species, occurrence of *G. robusta* is 11.81 per cent followed by *E. subumbrans* (8.10 %) and *S. companulata* (2.38 %). Over the years, the shade tree species composition has been changed drastically and in this study we noted that three major species viz. *Artocarpus heterophyllus*, *Vernonia arborea* and *Grevillea robusta* together contribute 50.58 per cent of the total enumerated trees. Loss of natural forest canopy has severely affected the microclimate of this area, and consequently this system cannot perform its actual ecosystem service and functions. Deliberate efforts have to be made to provide sufficient shade tree diversity and endemism in cardamom plantations to overcome the direct and indirect adverse effects on the long term stability of the CHR system.

Key words: Cardamom Hill Reserves, invasive, Western Ghats, shade trees, diversity

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Introduction

Small cardamom, a shade-loving herbaceous non - woody shrub of Indian origin, is cultivated extensively in high altitude hilly areas of the Western Ghats of Kerala, Tamil Nadu and Karnadaka states of Peninsular India for its spicy aromatic capsule (Murugan *et al.,* 2009). Since 1895, cardamom has been cultivated in the Cardamom hills, southern Western Ghats, India, which form a part of global biodiversity hot spots (Murugan *et al.,* 2009 & 2012). Cardamom, being a pseophytic crop, open condition significantly reduced plant fitness, suggesting high light intensity might not be a suitable habitat for cardamom. Therefore the main distribution habitats of small cardamom in the Western Ghats are in the shaded environment, rather than the habitat with an open environment (Alagupalamuthirsolai *et al.,* 2018).

In cardamom plantations, proper shade with filtered sunlight help to enhance the growth, flowering and fruit set by improving the plant metabolic activities. Shade requirement varies from place to place depending on the lay of the land, soil type, rainfall pattern, crop combination, shade trees etc. The microclimate prevailing under the shaded area creates a favourable environment for root development (Pradip Kumar *et al.,* 2012). Shade acts as moisture and temperature regulator, thus creating a microclimate that promotes growth and development of cardamom besides influencing the pest and disease incidence. Cardamom is a sensitive plant, and any serious disturbances in the environment, especially the climate factors will adversely affect the growth, development and production (Pradip Kumar *et al.,*2012 & 2015). Cardamom thrives well under moderate shade level (50-60% of light intensity). Protection from sunlight by maintaining an overhead tree shade is essential for cardamom in the initial stage of its growth. Thus shade requirement and its regulation is a vital cultural operation in cardamom plantations considering the number of beneficial effects provided by proper shade level in cardamom plantations.

Shade trees in cardamom fields check the surface evaporation of soil moisture, intense rainfall and surface wind, soil erosion, weed growth and some pest and disease incidence. They also play a considerable role in the CHR agro ecosystem by enhancing the soil physical properties as well as activities of pollinating agents (Prabhakaran Nair, 2006). A mixed population of shade trees that facilitate shade at more or less optimum level throughout the year is desirable for the crop (Pradip Kumar *et al.,* 2015). The Indian Cardamom Hills (ICH) were part of the biodiversity hot spot, where continuous monoculture farming of cardamom and tea has been taken up for centuries. Selective tree felling and degradation of cardamom hills go faster than other places in southern India (Jha *et al.,* 2000). Intensive cardamom production involves deliberately maintaining ecosystem in a highly simplified, disturbed and nutrient rich state. These projected changes would have a dramatic impact on the functioning of the cardamom ecosystem because of the complete loss of biodiversity and land and forest degradation (Murugan *et al.,* 2011).

Cardamom Hill Reserves (CHR) is a tropical high upland mid elevation evergreen forest in the southern Western Ghats with boundary extends up to the Periyar Tiger Reserves towards the south, Munnar high ranges towards its north, Idukki Reserve forest to the west and the Cumbum and Kothakudy valleys to the eastern side (Pascal *et al.,* 2004; Murugan *et al.,* 2006, Salish *et al.,* 2015). Fifty six percent of the evergreen trees in the Western Ghats are endemic, and the southern Western Ghats have the highest species richness and species endemism (Myers, 1988 and Pascal, 1988). The complex tropical forest has been converted to more open, simple and uniform system and thereby leading to the degradation of cardamom agroforestry system in India (Murugan *et al.,* 2009). Salish *et al.* (2015), conducted a survey of shade tree species in the cardamom cultivating areas of the CHR. Among the shade trees recorded in the study about 24.24% of the species are only endemic to the Western Ghats.

As per the survey report of Pascal *et al.*(2004), characteristic species in the mid elevation types (800-1450 m) in the southern Western Ghats were *Cullenia exarillata, Mesua ferrea* and *Palaquium ellipticum.* According to the report of Salish *et al*.(2015), *Persea macrantha* was the dominant tree species followed by *Artocarpus heterophyllus*, *Toona ciliate* and *Vernonia arborea* in the CHR. Invasive species like *Grevillea robusta* and *Erythrina subumbrance* were also recorded. According to Murugan *et al.* (2022) and Jeyaraj *et al.* (2011), only three species (*Vernonia arborea, Toona ciliata* and *Artocarpus heterophyllus)* account for more than 60% of all individuals in the CHR forest. The above studies clearly indicate the shift in shade tree diversity and endemism in the Cardamom Hill Reserves.

Materials and methods

In this study, we recorded the abundance of three invasive tree species *Grevillea robusta, Erythrina subumbrance* and *Spathodea companulata* in the cardamom hot spot areas of the CHR. Seven major cardamom growing areas (hot spots) viz. Vandanmedu, Pampadumpara, Mayiladumpara, Santhanpara, Anakkara, Anavilasam and Kattappana were selected for the study. From each hot spot area, three plots were randomly sampled, and from each plot 50 adjacent shade trees were marked. All woody vegetation above 10 cm GBH at 1.3 m height within a rectangular piece of land was considered. Enumerated the number of invasive species *G. robusta, E. subumbrans* and *S. companulata* from each plot. Totally 21 plots were sampled. Species diversity and dominant species reported in the previous studies like *Cullenia exarillata, Persea macrantha, Artocarpus heterophyllus, Toona ciliata* and *Vernonia arborea* were also enumerated from each plot during the survey. Latitude and longitude of each sampled plots were recorded using GPS.

Results and discussion

A total of 58 species were noted from sampled plots. Out of total number of trees enumerated in the study, 23.43 % is contributed by *Artocarpus heterophyllus* followed by *Vernonia arborea* (15.24 %), *Grevillea robusta* (11.81 %) and *Erythrina subumbrans* (8.10 %) (Fig. 1). Among the three invasive species, per cent occurrence of *Grevillea robusta* is conspicuous in all the sampled area and recorded maximum in Vandanmedu area followed by Aanavilasam and Santhanpara areas (Fig. 2). Major contributing species, *Artocarpus heterophyllus* per cent of occurance is very high in Anakkara area followed by Anavilasam and Kattappana area and it is low in number in Santhanpara area. Next abundant species *Vernonia arborea* is preferred by the farmers in all the sampled hot spot areas and per cent of occurrence is comparatively high in Anavilasam area followed by Vandanmedu and Santhampara (Fig.3). From the analysis of species richness in different locations sampled, it is clear that average number of species noted during the enumeration is high for Santhanpara and Pampadumpara (18.67) spots followed by Mayiladumpara (16.33), and it is very low in Vandanmedu area (7) (Fig. 4).

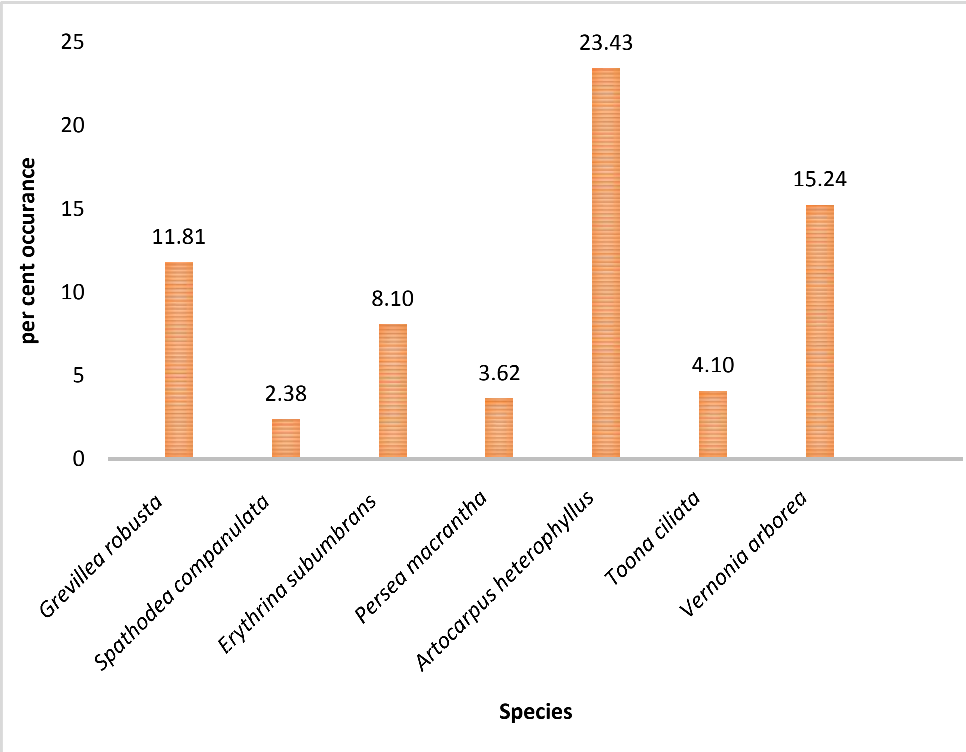

Fig. 1 Occurrence of three invasive tree species, and reported dominant species in the CHR

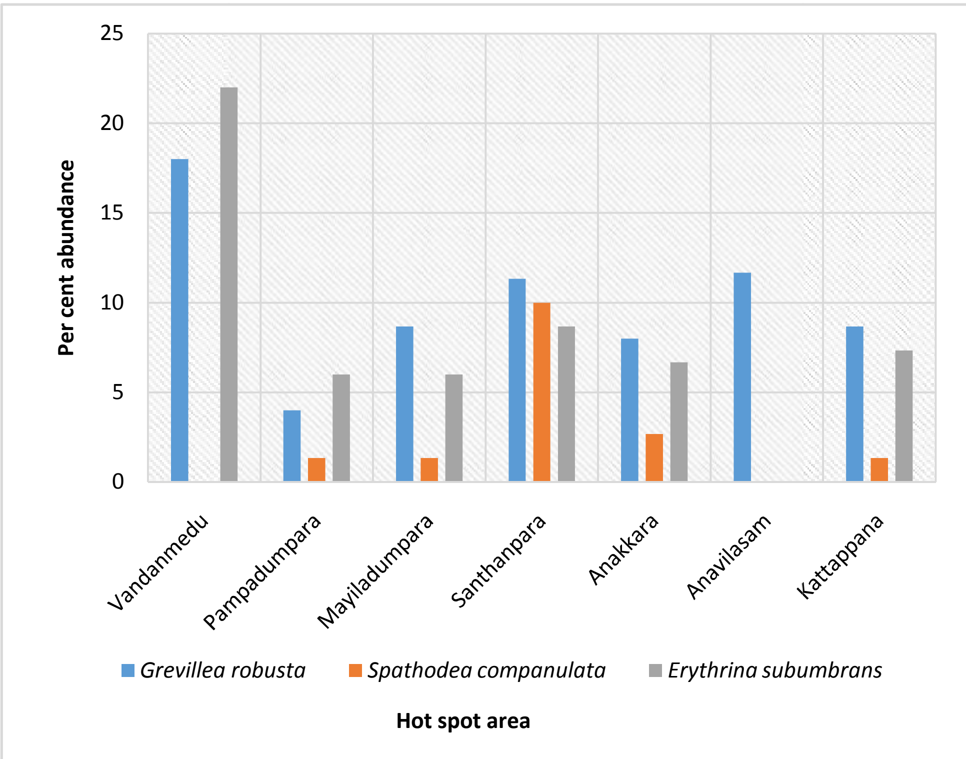

Fig. 2 Abundance of three invasive species in select hot spot areas

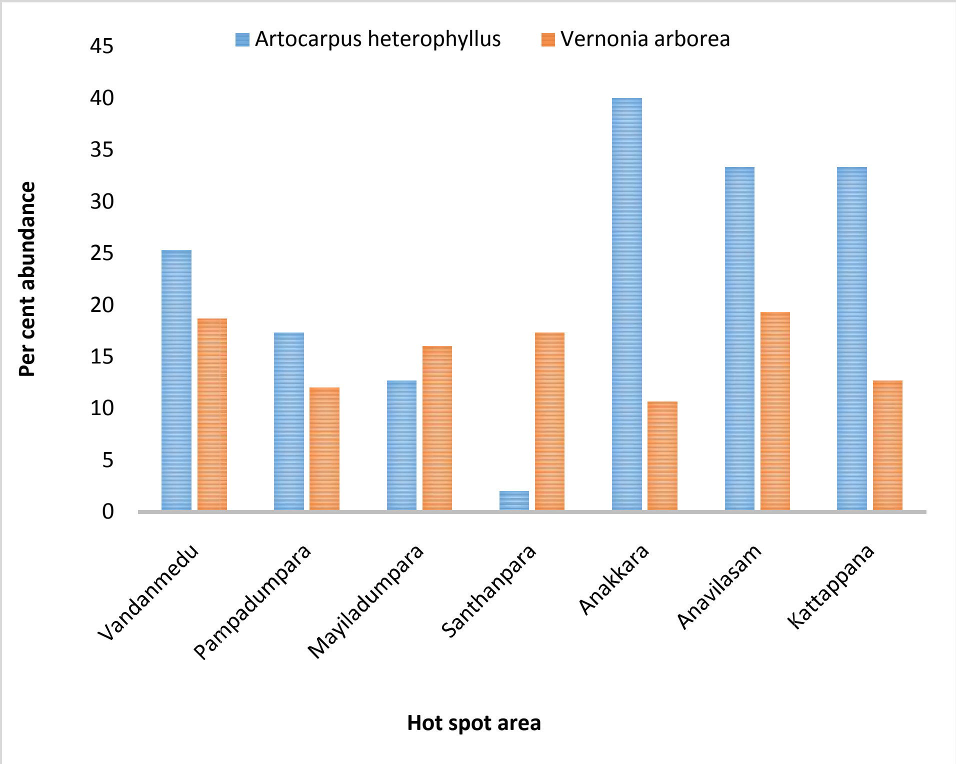

Fig. 3 Abundance of major contributing species in the hot spot areas

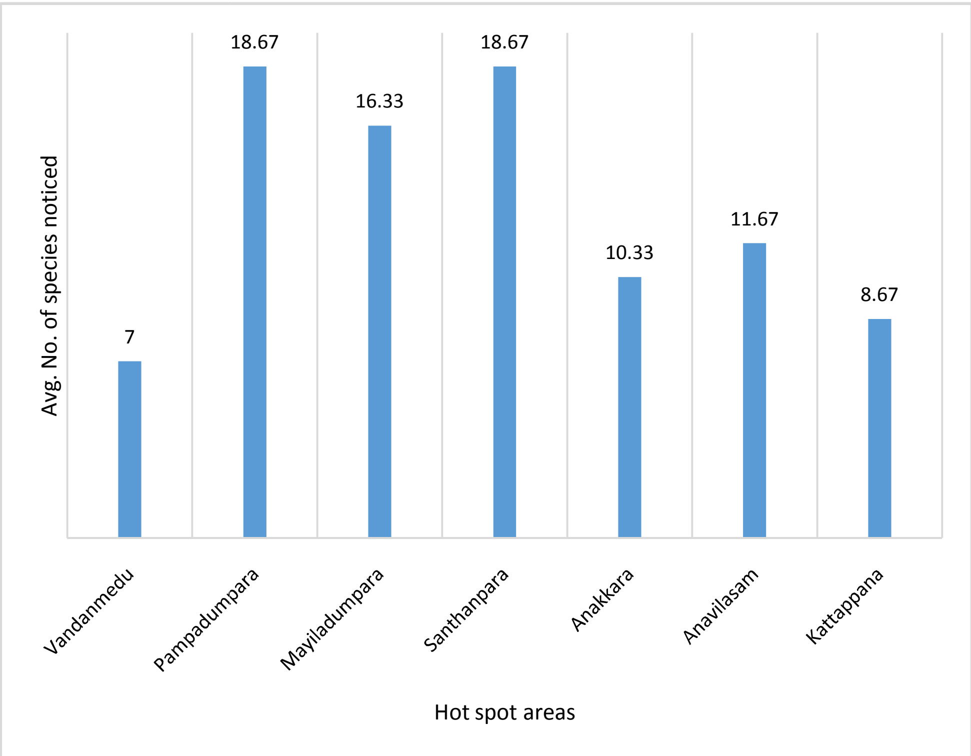

Fig. 4 Shade tree species richness in the cardamom hot spot areas

Here in Vandanmedu area, per cent contribution of two invasive species is very high and species richness is very low (Fig. 2 & 4). It is an indication of selective tree felling and replanting the area with fast growing tree species. In Pampadumpara and Mayiladumpara area species richness is comparatively high and at the same time the percent contribution by the invasive species is low. In Santhanpara area, even though the species richness is high, young trees of *G. robusta, E. subumbrans* and *S. companulata* are the common ones in cardamom planatations. In Anakkara, Anavilasam and Kattappana areas, major contributors are *A. heterophyllus, V. arborea* and *G. robusta*, species richness is also comparatively low (Fig. 2, 3 & 4).

Conclusion

The CHR system is a very unique production system in the Western Ghats, and considered one of the costliest production system in India. Cardamom cultivation in the CHR has increased pest and disease posing a serious threat. Planters believe that immersing the cardamom plantations with pesticides is necessary for managing major pest and diseases (Murugan *et al.*, 2022). According to Murugan *et al.* (2011), shade lopping and selective tree felling has resulted in significant change in microclimate system, which often increased pest especially white flies, thrips and soil root grubs and nematodes. As per the report of Sathyan *et al*. (2017 & 2018), cardamom thrips, shoot and capsule borers, mites, whiteflies and lacewing bugs showed a positive correlation with sunshine hours. Day by day the cardamom area is expanding, and most of the new plantations are planted with uniform shade giving tree species. Even though these species are found to be suitable for cardamom plantations, large scale adoption of these few tree species will cause great distortion to the original complex and balanced forest ecosystem. Loss of natural forest canopy has severely affected the microclimate of this area. Large scale adoption of invasive species should be reduced to regain the actual ecosystem functions and sustainability. Deliberate efforts have to be made to provide sufficient shade and increase shade tree diversity in cardamom plantations to overcome the direct and indirect adverse effects on the long term stability of the CHR system.

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OMICS BASED APPROACHES FOR THE MANAGEMENT OF INVASIVE MICROBIAL SPECIES IN FOREST ECOSYSTEM

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Abstract

Forest ecosystem constitutes one among the largest terrestrial ecosystems comprising all physical features as well as living things like plants, trees, insects, birds, animals and human beings. Several non-native species have been observed invading the forest ecosystem and gobbling up light, nutrients, water, space and other resources at the expense of other species. Extensive studies on invasive microflora have been undertaken till date; however invasive microflora is a topic that has received minimal attention. Omics based approaches are very useful in the identification and management of such alien microflora.

Microbiological methods are gaining popularity as an environmentally friendly and cost-effective alternative to manage various species. Omics approaches like meta-genomics, meta-transcriptomics, meta-proteomics, and metabolomics have had great applications recently. Several omics methods allegedly utilised in environmental monitoring to combat microbial invasion levels are compared and their application is discussed in this paper.

Omics technology may be used to identify the types, metabolic nature and behaviour, of the microbial communities. Based on various observations, it is shown how well-integrated omics techniques work and show new applications in the future.

The immense threat posed to biodiversity due to biological invasion has led to think about novel strategies for decontamination and clean up. Invasive micro flora also requires greater attention like macro flora. These multi-omics techniques would aid in the identification of invasive microorganisms, as well as provide excellent and novel insights into their major metabolic pathways at the molecular level.

Keywords: Xenobiotic compounds, Environmental pollutants, Omics-based approaches

Introduction

Being one among the largest terrestrial ecosystems, forest ecosystem comprises all physical features as well as living things like plants, trees, insects, birds, animals, human beings and microorganisms. Now a days the forest ecosystem is being invaded by a lot of foreign species leading to biological invasion. These alien species include different classes of organisms ranging from macro species like plants and animals to microbial species like bacteria and fungi. Most of these incursions cause major alterations by disrupting the natural resources such as nutrients, water, space, and other constituents. This is a worldwide issue, affecting both economically developed and developing nations (Andrew et al., 2017).

Majida Rahim. and Ganga, G. 2023. Omics based approaches for the management of invasive microbial species in forest ecosystem. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.227-235.

Omics comprises a group of technologies that aim to systematically analyse and quantify populations of biomolecules that translate into an organism's structure, dynamics, and function. The name "Ome" is derived from a Greek word indicating "whole" or "complete" and "Omics" is a derivative of the suffix –ome (Yadava SP *et al*., 2007). The addition of -ome to cellular molecules such as gene, transcript, protein and metabolite results in genome, transcriptome, proteome, and metabolome respectively. This method makes it possible to simultaneously analyse biomolecules such as DNA, RNA, proteins and metabolites from different types of organisms as well as the entire community (Gutierrez et al., 2018).

According to Central dogma of biology, the flow of genetic information within a biological system is from DNA to RNA and finally to proteins. The different branches of Omics technologies deals with these various aspects of molecular level information as described in Figure 1. Omics technologies basically includes genomics, transcriptomics, proteomics and metabolomics. Genomics deals with the study of the entire genome of an organism inclusive of its structure, function, evolution, and mapping (Horgan et al., 2011). Transcriptomics is the study of transcriptome, the complete set of RNA, coding and non-coding, in an organism or a population. Proteomics is defined as the large-scale characterization of the entire protein complement of a cell line, tissue, or organism (Wilkins et al., 1995) and Metabolomics is the study of small molecules known as metabolites within cells, biofluids, tissues or organisms.

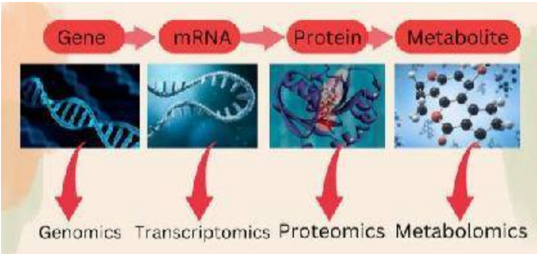

Figure 1: Types of omics approaches

Extensive studies are being carried out to study the invasion of forest ecosystem by macro species like alien plants and animals whereas minimal attention is given to microbial alien species. This review throws light into the various omics-based techniques that can be used to analyse the various alien microbial species invading forest ecosystem.

Materials and methods

Ethics Statement

This paper only analyses data from previously published peer-reviewed studies; it contains no field research or original data.

Methods

Omics technologies mainly comprises of genomics, transcriptomics, proteomics and metabolomics. Each of them is described in detail in the following pages.

Genomics

Genomics is the study of genomes. In biology, genome refers to the entire collection of genetic information in an organism, which is housed in its DNA or RNA. Microbial genomics is concerned with the identification and characterization of the genetic make-up of microorganisms. It is considered as a new branch of molecular biology emerged in order to comprehend the intricate, biological function of the genome.

A wide range of disciplines fall under genomics, including pangenomics, comparative genomics, functional genomics, metagenomics and cognitive genomics. The study of pangenomes is called pangenomics. The sciences of molecular biology and genetics defines a pan-genome (pangenome or supragenome) as the whole set of genes from all strains within a clade (Tettelin et al., 2005). Comparing the genomic characteristics of various organisms is the focus of comparative genomics. The genomic features could be the genes, DNA sequence, gene order, regulatory sequences, or other genomic structural markers (Xia et al., 2013). Functional genomics attempts to describe the interactions and functions of genes, utilising the massive amounts of data produced by genomic and transcriptome research such as genome sequencing projects and RNA sequencing. As contrast to the static aspects of the genomic information, such as DNA sequence or structures, functional genomics focuses on the dynamic aspects of the genome, such as gene transcription, translation, regulation of gene expression, and protein- protein interactions. Metagenomics is the study of genetic material obtained directly from environmental or clinical sources. This vast field is also known as environmental genomics, ecogenomics, community genomics, or microbiomics. The field of cognitive genomics deals with the changes in cognitive processes associated with genetic profiles.

Metagenomics

Metagenomics is the branch of genomics that can be used more extensively to study invasive species in a forest ecosystem since it can analyse genetic material that has been obtained directly from the environment. It makes use of the collection of genomes of environmental microorganisms, increasing the likelihood of finding novel genes, complex pathways, and new enzymes with extremely specific catalytic capabilities (Scholz et al., 2012). The majority of environmental microorganisms are not culturable in a laboratory environment (Rashid and Stingl, 2015). Such non-culturable bacteria that are prospering in specific ecosystems can also be investigated using metagenomics (Oulas et al., 2015; Bilal et al., 2018).

The fundamental process of metagenomics begins with the direct collection of samples from the forest ecosystem and the technology-assisted extraction of microbial DNA. For additional research on the retrieved genome, two techniques, functional metagenomics and metagenomics sequencing, can be used. While metagenomics sequencing is primarily based on phylogenetic anchors or conserved DNA sequences, which can be used to study microbial and functional diversity, functional metagenomics is based on the functional activity of the genome and can therefore be used for the search of specific enzymatic activities or proteins.

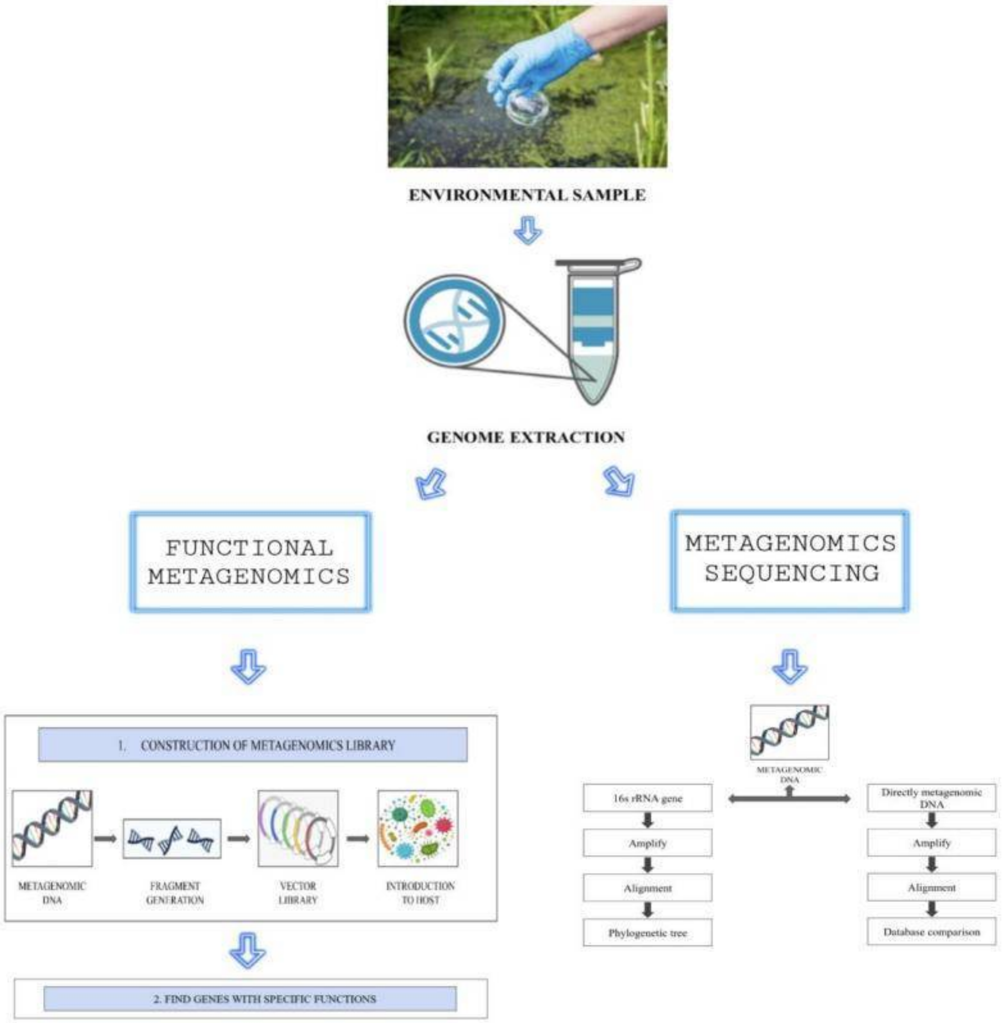

Figure 2. Process of metagenomics

The metagenomic DNA of the sample can be gathered and examined in two different ways for metagenomic sequencing analyses. The first method allows for the extraction, amplification, and subsequent analysis of the highly specific 16srRNA from the metagenome. In the next steps, sequence alignment and phylogenetic tree construction can be used to investigate the ancestry of the organism, thereby identifying and characterizing it. The second approach entails extracting and utilizing the metagenomic genome directly. It can be recognized and analysed by comparing it with specific genome databases using a variety of sequence alignment techniques. The workflow for functional metagenomics commences with the development of a metagenomics library, which involves the following steps. Firstly, the metagenomic DNA is extracted and enzymatic cleavage or other techniques are employed to separate it into discrete fragments. It is then ligated to specific vectors to form a vector library, which is subsequently introduced into microbial hosts to create a metagenomics library. This library can further be used to identify genes with particular functions.

Transcriptomics

Transcriptomics comprises the study of transcripts which are a collection RNA, including both coding and non-coding sequences. While noncoding RNAs carry out additional, varied roles, mRNA acts as a temporary intermediary molecule in the information network. The entire number of transcripts present in a cell is captured in a transcriptome. The 1990s saw the first use of the term "transcriptome" (Piétu G et.al.; 1999). Dominant contemporary techniques in transcriptomics comprises of data gathering including methods like microarray and RNA sequencing as well as data analysis using image processing and sequence analysis.

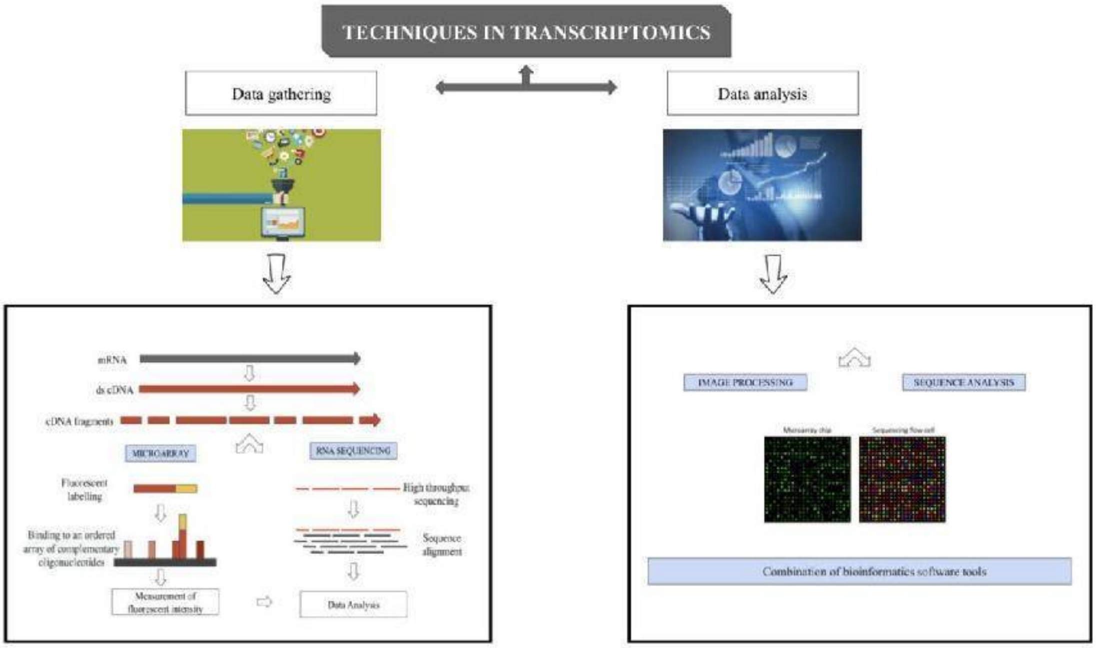

Figure 3. Techniques in Transcriptomics

Data gathering techniques like microarrays and RNA sequencing were developed in the mid 1990s and 2000 (Wangz et.al, 2009). The basic workflow of data gathering begins by converting the single stranded RNA transcript into double stranded cDNA, which is later made into tiny fragments using restriction endonucleases. These fragments can be analysed by techniques like microarray or RNA sequencing. Microarrays use a predetermined set of transcripts that have been hybridised to a variety of complementary probes to determine the abundances of those transcripts (Schena et.al., 1995). The cDNA fragments are fluorescently labelled and allowed to bind to an ordered array of complementary nucleotides. The bound samples are then analysed by measuring its fluorescent activity. In the case of RNA sequencing, the cDNA fragments are subjected to high throughput sequencing and the sequences are analysed by alignment techniques. Both the processes of microarray and RNA sequencing ends in data analysis techniques like image processing and sequence analysis. It makes use of a variety of bioinformatics tools to analyse and study the samples.

Proteomics

Proteomics deals with the examination of a whole protein complement in a cell, tissue, or organism under a particular, predetermined set of circumstances (Li Rong et.al, 2010). The method permits the investigation of protein expression patterns, rates of protein synthesis and breakdown, interactions and alterations, and protein involvement in various metabolic pathways. It has enabled to monitor and analyse the universal protein expression in microorganisms that live in contaminated environments as a result of human-caused activities (Kim et al., 2004).

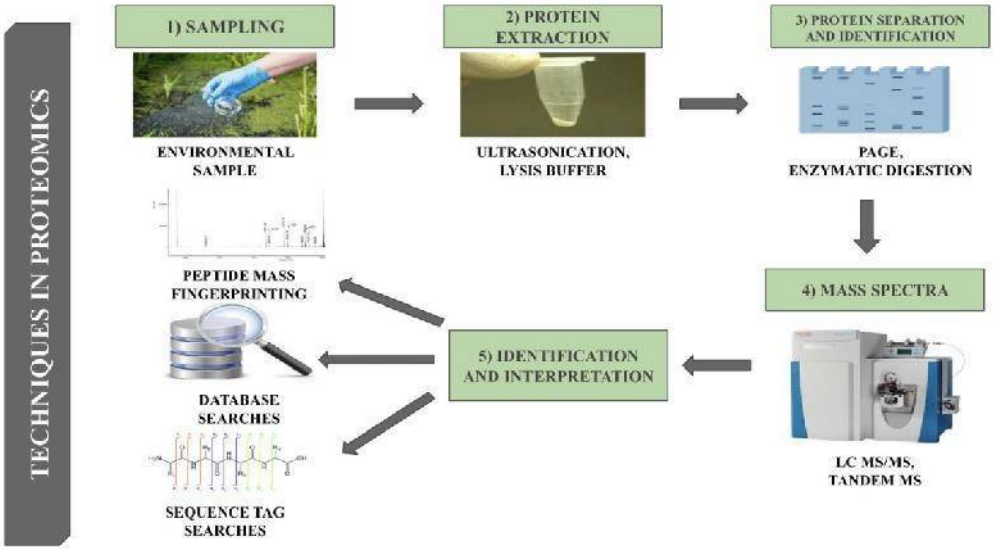

Figure 4. Techniques in Proteomics

Technical analysis in proteomics starts with the collection of environmental samples and the extraction of their protein components. Protein extraction can be accomplished using a variety of methods, including ultrasonication and the use of various lysis buffers. The extracted protein is then separated from it and put through polyacrylamide gel electrophoresis to identify it. It is subsequently subjected to mass spectra analysis utilising LC MS/ MS or TANDEM MS. Furthermore, the identification and interpretation are carried out by peptide mass fingerprinting, database searches, or sequence tag searches.

Metabolomics

Metabolomics is the large-scale study of small molecules called metabolites, which are the substrates, intermediates and products of cell metabolism. It is a branch of study which helps in establishing models that can predict microbial activities and their functional inputs to the flourishing environments. As metabolomics tries to quantify molecules with different physical properties unlike genomic and proteomic approaches, it poses a considerable analytical difficulty in practise (Kuehnbaum and Britz-McKibbin, 2013).

Derivatization and internal standards are used to extract metabolites from environmental samples as part of the basic workflow of metagenomics. The sample is then examined using chromatographic methods such as liquid or gas chromatography, either with or without mass spectrometry, or by using magnetic methods such as NMR. The information obtained through these methods is subsequently analysed and explained using statistical methods or software for data visualisation, such as MetaboAnalyst, XCMS, MetATT, Matlab, or MetScape Plugin, MetaMapp, MAVEN, and Pathomx, respectively.

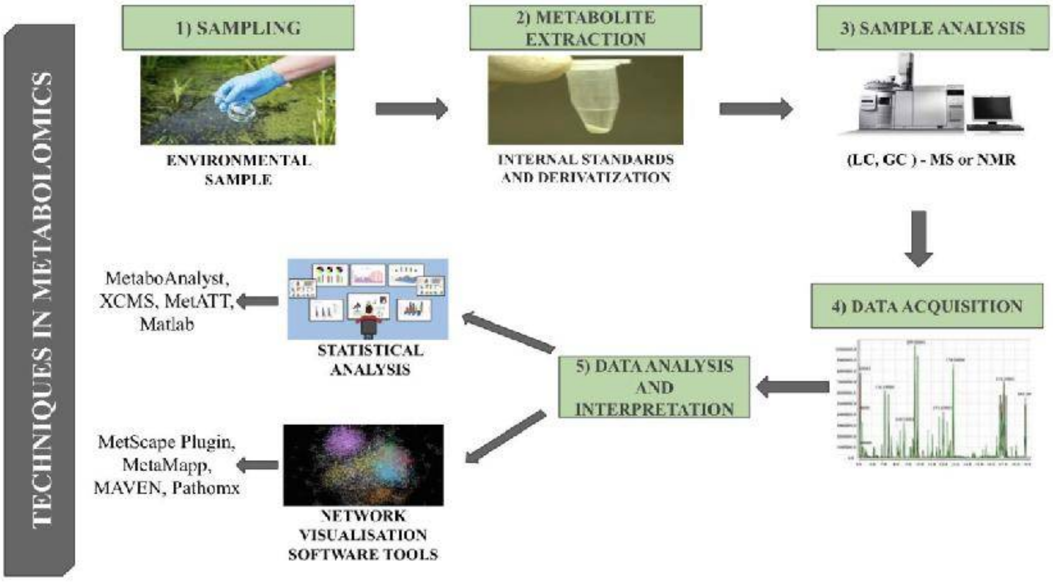

Figure 5. Techniques in Metabolomics

Results and discussion

Omics technology can be seen as a turning point in the investigation of biological invasion in the ecosystem of forests. By examining them at the molecular level, all Omics approaches, including genomes, transcriptomics, proteomics, and metabolomics, can be applied to analyze the intruding microbial species in a forest ecosystem. For example, proteomics analysis can be used to identify anthropogenically induced alien proteins from the contaminated areas (Desai et al., 2010). The effort involved in screening and growing microorganisms is reduced since metagenomics studies microbial populations directly from the ecological environment (Riesenfeld et al., 2004). Since it is difficult to reveal the functional activity of the entire microbial community by a single omics technique, multi-omics techniques are frequently used to study them (Shan et al., 2013). Thus, it can be inferred that omics technologies, either by themselves or in conjunction with other technologies, can be employed for a comprehensive examination of invasive microbial species in a forest ecosystem.

Conclusion

The immense threat posed to forest ecosystem due to invasive species has led to think about novel strategies for their removal and clean up. Omics technologies can be considered as a novel approach to study such invasive species. It enables the researchers to anticipate microbial metabolism in the ecosystem and these high-throughput analyses would aid in tracking novel organisms, provide excellent and novel insights into their key metabolic pathways at the molecular level.

Each of the omic-technologies has its own importance in the study of alien species in forest ecosystem. Genomics help in revealing DNA sequences of uncultured microbes thereby increasing the likelihood of finding novel genes, pathways and enzymes. Transcriptomics provide the understanding of up or down-regulation of genes under various environments in microbial communities. Proteomics enables the tracking and analysis of universal expression of proteins in microorganisms residing in different environments. Metabolomics permits to comprehend the potent activities of microbial communities and their functional inputs to the environments in which they flourish. In light of this, it can be concluded that the use of omics technologies will open up the possibility of a quick and easy method for studying the forest ecosystem in detail.

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LESSONS FROM INVASIVE ANT INVASIONS INTO SACRED GROVES

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Introduction

Sacred groves are the cultural forests of exceptional national importance. They preserve natural history of both the humans and biodiversity. They are seen everywhere in India. But today, they are seen in some pockets of south and northeastern India. In Kerala, they are everywhere, and in most places in the form of a temple. The deities and cultural taboos were the major drivers of sacred grove conservation (Landry-Yuan et al. 2020; Prashanth Ballullaya et al. 2019). Sacred groves of Kerala face pressure from disbelief and erosion of cultural values (Prashanth Ballullaya et al. 2019, Lowman & Sinu 2018), and urbanization and land-use change (Rajesh et al. 2017, 2020, 2022). As a result, the "forests" of many sacred groves have been either on the papers or shrunk considerably, or replaced by concrete structures. As a result, many sacred groves today have been in a land mosaic of human settlements, business districts, and agrolandscapes.

Information of biodiversity of sacred groves was limited to flora until we initiated a study on invertebrate diversity (Chandrasekhara et al. 1998; Induchoodan, 2005). We initiated monitoring insect diversity and activities of sacred groves since 2012, and began with the sacred grove of Malabar region and Kodagu part of Karnataka (Manoj et al. 2017). Later, we included the sacred groves of Trivandrum too in the study. We used ants, dung beetles, rove beetles, parasitic hymenoptera, springtails, oribatid mites, and spider as our indicator taxa in our studies.

Urbanization is always associated to invasion of invasive species. Invertebrates have a good number of invasive species too. For instance, in ants, the Yellow-Crazy Ant (*Anoplolepisgracilipes*) is the major invasive species of economic and ecological importance. There are reports from Asia-Pacific and African regions that it creates havoc to their native biodiversity Wetterer 2008; Lizona& Witte 2010; Silverman &Buczkowski 2016; Lach *et al*. 2022).

We approached our study with the hypothesis that the biodiversity of sacred groves is affected both by the urbanization and invasive species. We also enquired whether the ant community of the sacred groves was similar to that of adjoining used lands to test the hypothesis that the sacred groves conserve a unique set of rare and endemic species of ants (Hariraveendra et al. 2020). We used the same data set to examine if the sacred groves maintain a structural integrity of a forest fragment and aid in conservation of biodiversity. Thirdly, we asked

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Sinu, P.A. and Rajesh, T.P. 2023. Lessons from invasive ant invasions into sacred groves. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.236-240.

whether the native ants were affected by the abundance of invasive ants, and if that interaction was affected by the urbanization.

In the present paper, we discussthe findings of the objective, what is the impact of invasive ants, and in particular Yellow-Crazy Ant on the abundance and richness of native ants.

Methods

We sampled ants from twenty sacred groves of Kasaragod and Kerala. We used pitfall traps for sampling. Wet and dry seasons were sampled. Ants were identified to species. Since ants are social, proportional trap incidence was used in the models. Statistical models using generalized linear mixed models with appropriate fixed and random factors were used for testing the predictions.

Results and Discussion

Sacred groves of both Kasaragod and Trivandrum had similar abundance and richness of ants (Table 1). Among the invasive ant species, A. *gracilipes, Monomorium floricola, Paratrechinalongicornis, Tapinoma melanocephalum, Tetramoriumlongicornis*, and *Odontomachushaematodius* were the dominant species by their proportional trap incidence (Fig. 1). The Yellow-Crazy Ant was dominant in the sacred groves of both the districts. In Kasaragod, 43% of the traps collected Yellow-Crazy Ant. In Trivandrum, 60% of the traps had the Yellow-Crazy Ant. The remaining invasive ant species' were collected in 18% and 19% of the pitfall traps in Kasaragod and Trivandrum, respectively.

Although the Yellow-Crazy Ant is a dominant species in the sacred groves, we found that their abundance hardly affected the abundance and richness of native ants (Fig. 2 & 3). This was surprising, but a good trend for the sacred groves. Although the Yellow-Crazy Ant was a threat for biodiversity and biotic interactions of many parts of the world (see Lach et al. 2022 and references therein), our results suggest that it had no detrimental effect for fellow native ant species. One reason for this trend could the nativity of the Yellow-Crazy Ant. There are debates that this species might be a native of south Asia that include India (Wetterer 2005).

Our own study showed that the Yellow-Crazy Ant is in a surging condition (Rajesh et al. 2020). In Kasaragod, their number had tripled in a span of five years (Rajesh et al. 2020). Although they did not affect native ant abundance or richness, our another study got evidence for its detrimental effect on plant-pollinator interactions (Sinu et al. 2018). Therefore, future studies may be required to understand its ecological and economic effects on Indian biodiversity.

Table 1. Summary table of native and invasive ants in the sacred groves of Kasaragod and Trivandrum

	Kasaragod	Trivandrum
Native ant richness	52	53
Invasive species	9	7
Total species	61	60

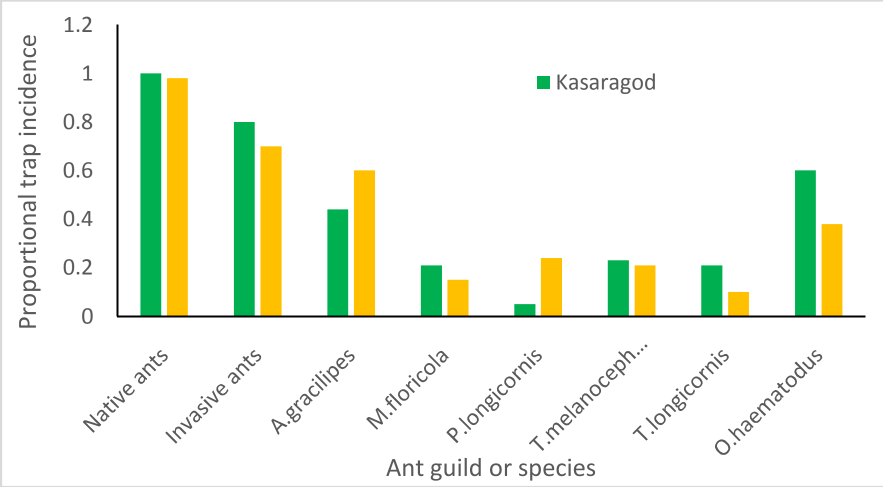

Fig. 1. Proportional trap incidence of ants of different guilds and invasive species in the sacred groves of Kasaragod and Trivandrum

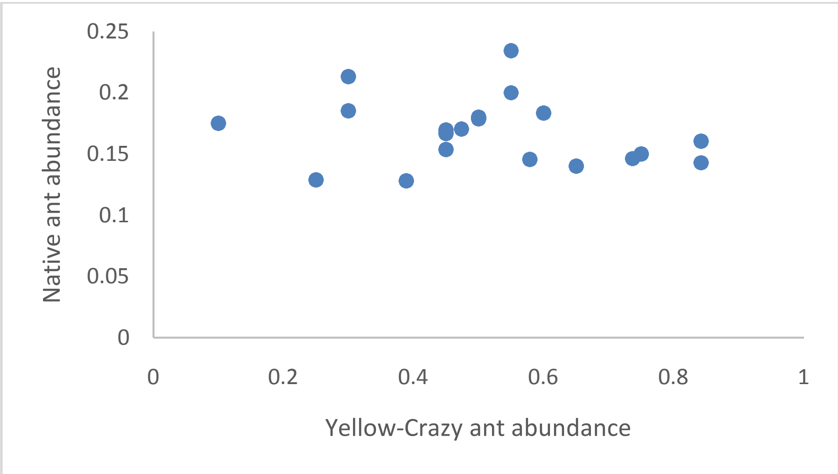

Fig. 2. Response of native ant abundance to the abundance of Yellow-Crazy Ant in sacred groves

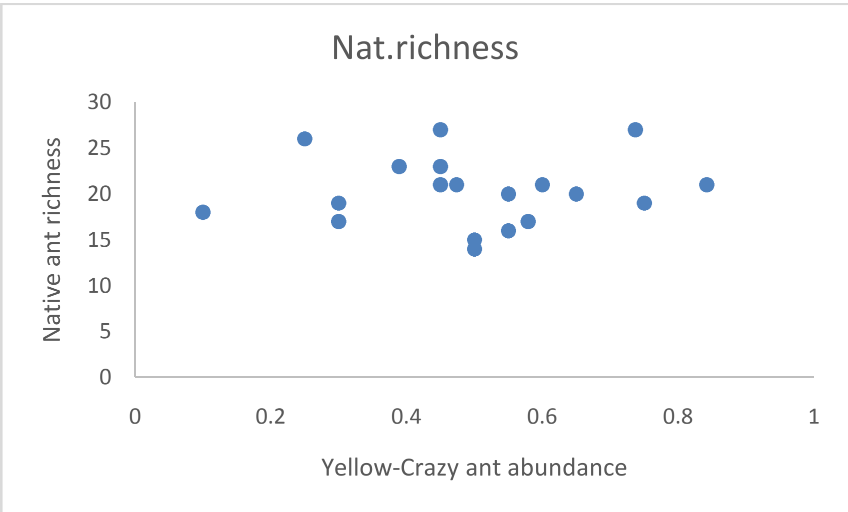

Fig. 3. Native ant richness was not affected by the abundance of Yellow-Crazy Ant in sacred groves

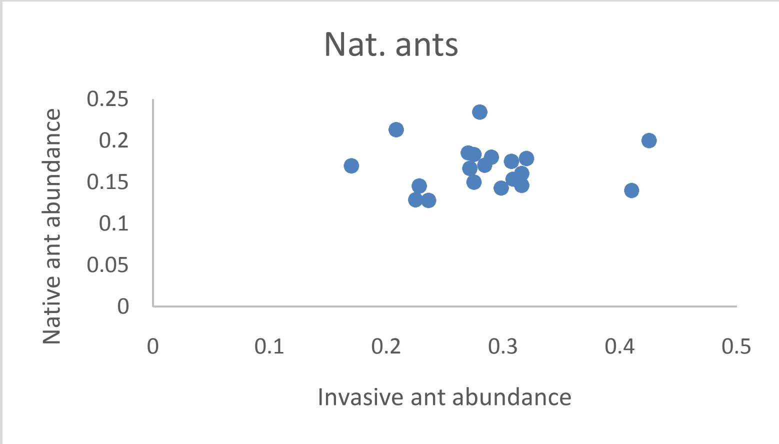

Fig. 4. Native ant abundance's response to overall invasive ant abundance in sacred groves

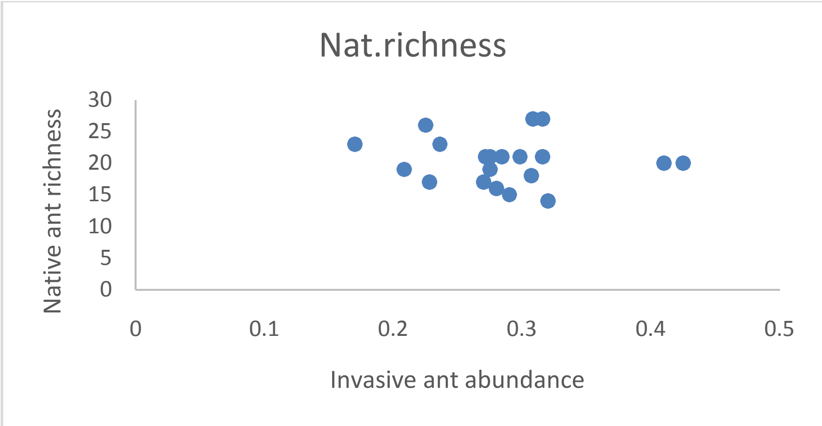

Fig. 5. Native ants' richness is not affected by the abundance of overall invasive ants in the sacred groves

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MANAGEMENT STRATEGY FOR THE INVASIVE TREE*SENNA SPECTABILIS* IN WAYANAD WILDLIFE SANCTUARY, A TROPICAL FOREST ECOSYSTEM IN THE WESTERN GHATS

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Abstract:

The exotic tree *Senna spectabilis*, native to Tropical America, is invading the Western Ghats and threatening its native biodiversity. Currently restricted to some pockets of the Ghats, it is rapidly spreading over newer areas, thus becoming a conservation challenge to the forest ecosystems. However, this matter has not yet received much conservation attention. In this paper, we present the history of *S. spectabilis* invasion, the pattern of its spread, the change in its distribution over a seven-year period in Wayanad Wildlife Sanctuary, and propose strategies for its management. *S. spectabilis*was introduced in the sanctuary in early 1980s and now it has spread over 23 percent of its area, of which 17.4 km^2 is heavily infested by the species. Invasiveness of *S. spectabilis*is largely attributed to the production of a large number of seeds and their dispersal by native mammals. This paper will help the policymakers understand the gravity of the problemand hopefully, initiate a management strategy to stop the spread of *S. spectabilis* to new landscapes in southern India.

Keywords: Biodiversity, Biological invasion, Conservation, *Senna spectabilis*

Introduction

Invasive alien species are plants or animals that are introduced by human, accidentally or intentionally, outside their native geographic range into an area where they are not naturally present and spread causing damage to native biodiversity that is being conserved (IUCN, 2013) Most of the invasive plants have similar growth strategies such as fast growth rates, short life-cycles, higher reproductive potential, high competitive capacity and allelopathic traits, which make them successful invaders of native habitats (Amith Kumar & Santhosh, 2014). Plant invasions have been recognized as one of the most serious global processes impacting the structure, composition and function of natural and semi-natural ecosystems (Mooney and Hobbs, 2000; Raizada et al., 2008; Vitousek et al., 1997). These species are invading large areas of land including Protected Areas. Inside forests, they are replacing the undergrowth and reducing the regeneration of native species. They decrease native species richness and abundance via competition and indirect effects (Gaertner et al., 2009). Also, they change

Vinayan, P.A., Anoop, N.R., Vishnu, N.M., Vaishnav, K., Ajayan, P.A., Ramith,M., and Anjan Kumar, B.N. 2003. Management strategy for the invasive tree *Senna spectabilis* in Wayanad Wildlife Sanctuary, a tropical forest ecosystem in the Western Ghats. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.241-250.

community structure in ecosystems (Hejda et al., 2009). The problem continues to grow at great socioeconomic, medical and ecological cost around the world. A total of 173 species of invasive species in 117 genera under 44 families were documented as invasive alien plant species, representing 1% of the Indian flora (Reddy et al. 2008). Nearly 3% of these plants are trees (Reddy et al., 2008).

The Western Ghats are recognized as a global Biodiversity Hotspot (Mittermeier, et al., 1999; Myers et al., 2000). In the southern part of the Western Ghats, across three southern states of India, namely Tamil Nadu, Karnataka and Kerala, lies the Nilgiri Biosphere Reserve (NBR). NBR is the first Biosphere Reserve to be declared in India (in September 1986) under the UNESCO's Man and Biosphere program. The NBR is a globally important conservation area which supports in-situ conservation of many endangered, threatened and rare species including Asian elephant, Bengal Tiger, Gaur, Wild dog, White-rumped vulture, etc. The NBR has a significant number of endemic species (248 species), supports most of the large mammals found in peninsular India, and also hosts Red Data Book species: 55 Critically Endangered species, 148 Endangered species and 127 species listed as Vulnerable (CEPF, 2004). The NBR is home to over 6000 Asian elephants (Elephas maximus) and it is the single largest contiguous population of the species in Asia. Invasive plant species pose a serious threat to conservation and management of the Nilgiri Biosphere Reserve (NBR). The exotic invasive tree *Senna spectabilis* is rapidly spreading in various PAs in NBR. A large part of the Wayanad Wildlife sanctuary in NBR is covered by this invasive species. The spread of *S. spectabilis*is one of the major conservation and management challenges in Wayanad Wildlife Sanctuary. Given this context, this study: (1) maps the pattern of distribution of *S. spectabilis* in the Wayanad Wildlife Sanctuary (2) assesses the abundance of *S. spectabilis* in different density classes.

S. spectabilis H.S. Irwin & R.C. Barneby (Caesalpiniaceae) (syn. *Cassia spectabilis* DC) is a tree native to Central and South America (Irwin & Barneby,1982).

Description: Tree. Ten or more metres high, the branchlets usually tomentose when young. Leaves moderately large, an average leaf about 20-foliolate; petiole short, pubescent, eglandular; rachis usually about 2 dm long, eglandular and otherwise like the petiole; leaflets several to many pairs, lanceolate, 3-8 cm long and usually about 2 cm wide, acute apically, obtuse basally, pubescent below, especially along the veins, puberulent to sub glabrous above and less dull than below, opposite on the rachis, with 10 or more pairs of prominent lateral veins; petioles 2-3 mm long, pubescent. Inflorescence of several terminal or subterminal several-flowered racemes; bracts lanceolate, a few mm long, caducous. Flowers yellow; sepals 5, obovate-orbicular, markedly unequal, up to 1 cm long and broad, glabrous to lightly puberulent; petals 5, mostly obovate, markedly unequal, up to 2.5 cm long and 1.5 cm broad, sub glabrous, venose, short-clawed; stamens 10, 3-morphic; the 3 lowermost the largest, their anthers oblong, about 7 mm long, short-rostrate apically and dehiscent by terminal pores, the loculi somewhat converging terminally; anthers of 4 median stamens 5-6 mm long, similar to the 3 lowermost except the rostrum reflexed and the loculi divergent terminally; 3 uppermost stamens markedly dissimilar, more or less rudimentary, the anthers distinctly bilobed, each lobe reniform and dehiscent the length of its outer margin; ovary linear, glabrous. Legume linear, turgid-quadrangular, up to 2 dm long and 1 cm wide, transversely multiseptate, tardily dehiscent along one margin (Missouri Botanical Garden, 2014).

Invasiveness, history of introduction and spread of *S. spectabilis*

S. spectabilis is a medium to large tree from tropical America (Randall, 2012). This is a rapidly growing tree, which flowers and sets seed profusely, and re-sprouts readily when cut. It is spreading as an invasive plant in many parts of the world. In Uganda, the species is considered as an invasive alien species with high risk to the native flora (Mungatana and Ahimbisibwe, 2010). It was initially planted to create shade, but later farmers grew it as living fences to prevent crop depredation by wild animals in Tanzania (Wakabira, 2002). In Australia it is considered naturalised, has been recorded as a weed of the natural environment and an escapee from cultivation, and is labelled an invasive species, indicating its high negative impact on the environment due to its ability to spread rapidly and often create monocultures (Randall, 2007). In Singapore and Cuba, *S. spectabilis* has been identified as an invasive species (Chong et al., 2009, Oviedo-Prieto et al., 2012). It is a cultivation escapee in Trinidad and Tobago (Irwin and Barneby, 1982).

S. spectabilis was present in Colombia as of 1832 (recorded as *Cassia speciosa* by Kunth and Don, 1832). Introduction of the species to the West Indies is uncertain but it was likely to have spread from its native South America some time ago. Specimens from Trinidad and Tobago were collected in 1862 as *C. spectabilis* DC (Royal Botanic Gardens Kew, 2003) and the species was being cultivated in the Royal Botanic Gardens of Trinidad by 1869 as *C. spectabilis* (Prestoe, 1870). By 1879 the species was known to occur in South Mexico, Costa Rica, West Indies and the northern parts of South America as *C. spectabilis* DC (Godman et al., 1879). The species must be a relatively recent introduction to Puerto Rico, as it was not included in Bello's flora of Puerto Rico (Bello Espinosa, 1881). The species is considered by Irwin and Barneby (1982) as a cultivation escapee in Trinidad and Tobago and both native and adventive to northern parts of the Orinoco basin, Venezuela. The lack of collections of *S. spectabilis* from the West Indies in the US National Herbarium may be indicative of the foreign origin of this species for this region. In Puerto Rico, this species is known from US collections dating from 1954 (US National Herbarium). However, it is certainly much more widespread in Puerto Rico than what is currently reported in the literature or herbaria collections; recent fieldwork in Puerto Rico indicates that *S. spectabilis* is becoming widespread in the southern flanks of the Central mountain range in the area of Salinas and Villalba (Acevedo-Rodriguez, pers. comments).

The species is thought to have been introduced to Africa by Indian sawmill operators or Europeans for firewood and live boundary marking, as a way to reverse deforestation, desertification and fuel wood shortages; however, the species has since invaded most forest ecosystems, where it has outcompeted native tree species with its fast colonisation and thicket establishments (Mungatana and Ahimbisibwe, 2010). The species was present in Tanzania prior to 1967, when it was intentionally introduced to Mahale Mountains National Park in order to create shade and later cultivated by farmers as living fences to prevent crop damage by animals. It is now recognized as an invasive alien species in parts of Kenya, Malawi, Tanzania and Uganda (Wakibara and Mnaya, 2002; Witt and Luke, 2017). This species was introduced in India as an avenue tree in the middle of 1980s. It was identified as an invasive alien species in 2012 in Wayanad Wildlife Sanctuary (Sajeev et al., 2012).

History of introduction and spread of Senna in Wayanad Wildlife Sanctuary

According to Sajeev et al. (2012) there are about 38 alien invasive species (AIS) found in the forests of Kerala. In the Invasive Ranking (I-Ranking) conducted by Kerala Forest Research Institute in 2012, *S. spectabilis* was categorised as a medium risk species. In Wayanad WLS, *S. spectabilis* was first introduced in 1986.The seedlings of the plant were raised at Ponkuzhy (11.69595, 76.39365) by the social forestry wing of Kerala Forest Department. The trees were first planted in the forest office compound at Muthanga as shade trees. Less than ten trees were planted in 1986 at Muthanga (Raghavan, Pers. Comm.). For several years this species was not identified as an invasive species. The species was noticed regenerating profusely inside Wayanad Wildlife Sanctuary after 25 years of its introduction. In 2013, after realising the impact of this species to native flora and fauna, the forest department started its management to control its further spread. The department tried to control its spread through various means such as: (1) girdling (cut through the bark all the way around a tree or branch); (2) applying kerosene in the debarked area. Initially 19500 trees were treated with this method. This control measure was assessed by a team of experts from Wildlife Trust of India (WTI). This study reported that a very small percentage of trees completely died after 8 months of the management measure. The study also reported a high number of coppice shoots sprouting from the trees that were debarked (WTI, 2014). The girdling method continued in the following years in different locations. The management effort was not successful in stopping or limiting the spread of Senna. Instead, huge amounts of seeds in the soil started regenerating, and multiple coppice shoots also started growing from each tree. Thus, the management effort only helped in increasing the spread of the invasive species.

Kerala Forest Research Institute conducted a study in 2016-2017 to manage the species through physical and chemical methods. Six physical methods and six chemical methods were tried out in the field. A detailed report on *S. spectabilis*, with management prescriptions, was submitted to Kerala Forest Department.

Materials and methods

Study area

Wayanad Wildlife Sanctuary: The Wayanad Wildlife Sanctuary (WWS) is part of a contiguous stretch of forest with Bandipur, Nagarahole and Mudumalai Tiger Reserve of NBR. The total area of the sanctuary is 344.44 Km2. Wayanad has some of the richest forests in terms of biodiversity in the Western Ghats, containing several species of endemic, threatened and endangered flora and fauna. Almost all large mammals of peninsular India occur in Wayanad. The larger herbivores include the Asian elephant (Elephas maximus), Gaur (Bos gaurus), and Sambar deer (Rusa unicolor). Wayanad is also a key landscape for large predators like Tiger *(Panthera tigiris)*, Leopard (*Panthera pardus*), and Wild dog (*Cuon alpinus*) (Narasimen, R. K et al. 2014). A large tribal population directly depends on the forests of Wayanad for daily livelihood requirements. The study area has monsoon-dependent forests showing strong seasonality with mainly two seasons. The southwest monsoon provides major rainfall to the region, and the rainfall during the northeast monsoon is meagre.

Methodology

Mapping the distribution of *S. spectabilis*: The study area was overlaid with 500 × 500 m grid cells as spatial sampling units. The presence and absence of the species was recorded by walking along paths in each grid in 2013-2014 and 2019-2020.

The abundance of Senna in the grids was categorised into different classes ranging from high to absent. The abundance data was collected in 2019-2020. This categorization was done based on the visual classification of density and percentage cover within the range of vision of the observer by walking in the grids. The areas inside the grids with no Senna were classified as ‘absent’, very sparse distribution as ‘low’ (≤10% of the canopy covered by *S. spectabilis*), the range of abundance between low and high as ‘medium’ (10-40% of the canopy covered by *S. spectabilis*), and grids with high abundance of Senna were categorised as ‘high’ (≥40% of the canopy covered by *S. spectabilis*).

Results

Change in distribution: A total of 1702 grids were sampled during the study. The study recorded the presence of *S. spectabilis* in 103 grids in 2013-2014 and 348 grids in 2019-2020 (Figure 1). The result shows an increase of 237.86% over a period of seven years. The total area covered by *S. spectabilis* in 2013-2014 shows that its presence was limited to 14.6 square kilometres.

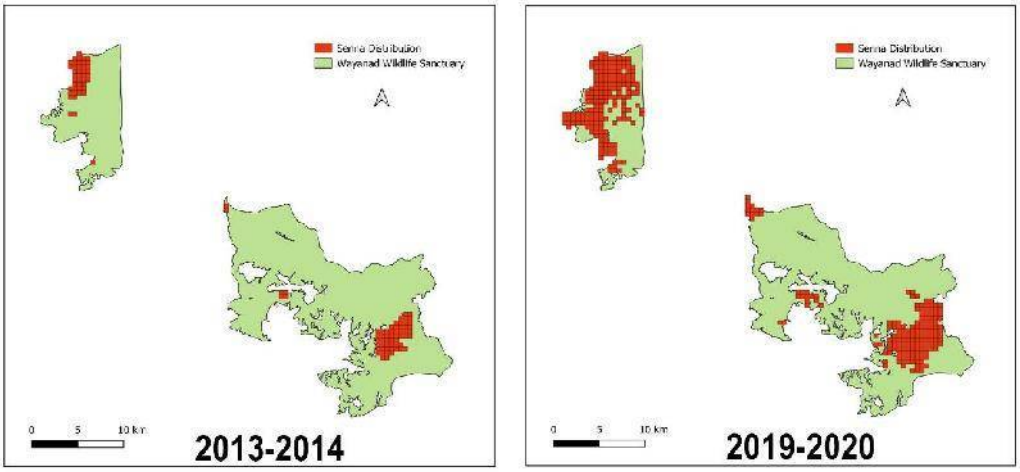

Figure 1. Change in distribution of *S. spectabilis* over a seven-year period in Wayanad Wildlife Sanctuary

Abundance: Our results show that an area of 78.93 square kilometres (nearly 23 % of the sanctuary) is occupied by *S. spectabilis* in 2019-2020, out of which an area of 53.64 square kilometres has low, 7.88 square kilometres has medium and 17.41 square kilometres has highabundance of the species (Figure 2). The degree of invasion is very high in Tholpetty and Muthanga ranges of the sanctuary (Table 1).

Table 1. Range wise abundance and extent of *S. spectabilis* invaded area in Wayanad Wildlife Sanctuary

	Extent of S. spectabilis abundance/km^2			
Range	**Low**	**Medium**	**High**	**Total**
Tholpetty	30.23	3.44	8.31	41.98
Muthanga	12.08	3.44	8.69	24.20
SulthanBathery	6.04	0.45		6.49
Kurichiat	5.30	0.55	0.41	6.26
Total	**53.64**	**7.88**	**17.41**	**78.93**

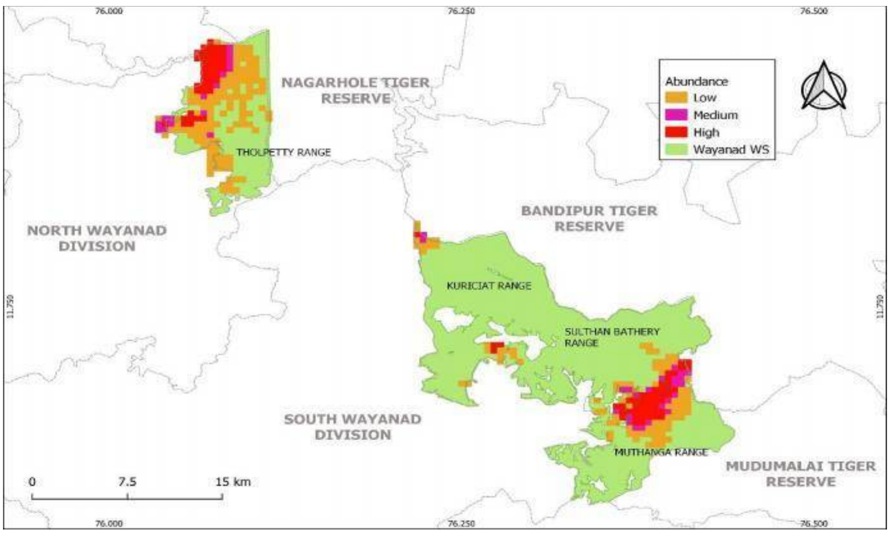

Figure 2. The abundance of *S. spectabilis* in Wayanad Wildlife Sanctuary in 2019-2020

Discussion

Biodiversity conservation is not on the top agenda for most countries in Asia, probably because the links between biodiversity protection and the broader socioeconomic welfare of human societies remain poorly understood. As such, research should possibly focus more on the socioeconomic impacts of invasive alien species (IAS) to demonstrate the impacts of IAS on livelihoods. Research should also focus on the costs and benefits of IAS management. There are very few studies which have clearly demonstrated the environmental benefits of IAS control, especially for those invasive plant species which have a negative impact on biodiversity. The forests in Wayanad Wildlife Sanctuary is one of the most important tiger and elephant habitats in India. No study on the impact of *S. spectabilis* on wildlife habitats has been carried out till date in India. Such studies need to be done very urgently in Wayanad Wildlife Sanctuary.

The Wayanad Wildlife Sanctuary covers an area of 344.44 Km^2. Presently, around 23% of the area of the Sanctuary is infested/occupied by *S. spectabilis*. Regeneration of native plant species is almost absent in the areas where the abundance of *S. spectabilis*is high. Highest density of *S. spectabilis*in the study area was found in open areas. Such open areas were previously clear-felled monoculture forest plantations of eucalyptus.

Mature *S. spectabilis* tree density is very high in areas where the trees were girdled between 2013 and 2015. More Senna seedlings started growing in the open spaces created when the mature tree trunks dried after girdling and gradually the tree density has increased. By contrast, in Mahale NP of Tanzania it was observed that there was suppressed regeneration of *S. spectabilis*, while regeneration of the native species increased in managed areas. Along with girdling, the seeds from ground were also gathered in Mahale NP (Wakabira, 2002). Studies from Kibale National Park in Western Uganda show that ring barking is an effective control measure. There is a need to re-enforce the method by uprooting seedlings from the ring barked sites, for a period of four years after ring barking (Mutonyi, 2007). In Bandipur Tiger Reserve, 64.29% of the trees girdled in 2012 completely dried after two years. Coppice shoots died there also because the Karnataka Forest Department had been regularly weeding them out after girdling (WTI, 2014).

The results of management of the species from other parts of the world shows that follow-up management is required for the complete eradication of the species from an area. Density of mature trees is relatively less in moist deciduous and dry deciduous forests of Wayanad Wildlife Sanctuary. However, the present study observed a large number of seedlings in moist deciduous forests: this hints that the fertile soil and openness of moist deciduous forest could be advantageous for the survival and growth of the seedlings. The increase of invasion in the seven-year period recorded in this study indicates that the species has the potential to affect the tropical forest ecosystem very rapidly.As the native mammals disperse the seeds of *S. spectabilis* in the Western Ghats (Anoop et al. 2022) the spread of the species will increase significantly in coming years.

Future management of *S. spectabilis* in the Western Ghats

The complete eradication of *S. spectabilis*requires a unique set of considerations. We would recommend the following strategies for the eradication of the species in the Western Ghats: (1) Removal of soil seed reserve requires continuous removal of seedlings through hand pulling. We suggest removing the saplings during the monsoon season when the soil is damp and the entire root system can be removed. (2) Debarking of adult trees during summer needs to be continued. Constant removal of adult trees and pruning of branches will lower flowering and fruiting that reduce the dispersal of seeds to new areas by the dispersers. The removal of *S. spectabilis* creates open spaces that might get infested by other invasive species such as *Lantana camara* and *Chromolaena odorata*. To avoid this, we suggest carrying out eco-restoration in the managed areas by planting native species which are ecologically suited to the site conditions. (3) The density of *S. spectabilis* is high in the areas where the plants had established in the early stages of invasion. The low-density areas have been invaded recently and the plants in such areas are younger. Hence, priority for eradication should be given to low-density areas to prevent further spread. (4) It is important to understand the interactions of *S. spectabilis* and native dispersers for its better management. (5) The ecology of *S. spectabilis* and its impact on native vegetation and wildlife needs to be investigated in detail. (6) We suggest a survey in the Western Ghats to map areas where the species is present and to monitor changes of the existing populations. This information is crucial for the management of the species in the landscape.

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A SUCCESS STORY OF GRASSLAND RESTORATION AND BATTLE AGAINST *ACACIA MEARNSII* (BLACK WATTLE) IN PAMPADUM SHOLA NATIONAL PARK, KERALA

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Introduction

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. Habitat restoration is very essential for the ecological equilibrium where extensive ecosystem modification have taken place (Hobbs & Lambeck 2002; Miller & Hobbs 2007). Eco restoration activities improve food availability for wild animals, birds etc. It ensures adequate facilitation by wild herbivores and preserves the ecosystem. National Forest Policy of 1988, envisages that the forest management should take special care of the needs of wildlife conservation and the forest management plans should include prescriptions for this purpose. It is evident that the majority of wildlife is linked to the native vegetation and it is very important to restore natural vegetation to bring up wild life of a particular area (Morrison 2001). Though habitat restoration is a very complicated process due to its practical issues, restoration of natural habitat is inevitable especially in a protected area. Integrated political, social, economical and methodological aspects are needed to upscale the restoration efforts in tropical forest. According to Bazzaz1979, succession is a process of continuous colonization and extinction on a site by species population. It is important to highlight the key role of ecological restoration for biodiversity conservation (Chazdon, 2008).

The current report depicts an eco-restoration activity undertaken by the Kerala Forest Department in Pattinagal area of Pambadum Shola National Park, Vattavada, Idukki district, Kerala, for a period of 03 years. The site specific grassland restoration, first of its kind in the state shall be used to analyse the application of different methodological actions on grassland restoration efforts and on the establishment of functional ecosystem. Grasslands are ranked as ecosystems with the highest species richness in the world and provide various ecosystem services. Grasslands can improve aesthetic and historic values, sequester carbon, retard soil erosion in hilly terrain, enhance grazing systems, conserve water and provide a unique habitat to many peculiar life forms, woven into an intrinsic grassland ecosystem. Most often we find a companion to the montane grasslands of the Western Ghats, the Shola forests, together which forms the elite Shola Grassland ecosystems.

Prasad, G. and Rajan, P. 2023. A success story of grassland restoration and battle against *Acacia mearnsii* (Black wattle) in Pampadum Shola National Park, Kerala. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.251-261.

THE PROJECT AREA: PAMBADUM SHOLA NATIONAL PARK

Pambadum Shola National Park is located on the eastern portion of the High Ranges of Southern Western Ghats of Kerala and falls in the Vattavada Grama Panchayath of Devikulam Taluk, Idukki District. The National Park liesin between the Kannan Devan Hills and the Palani Hills of Tamil Nadu. Originally notified as Pambadum shola Reserve No.55 in 1901, it was declared as a National Park in December 2003 due to its unique ecological and biogeographical significance.

The vegetation consists mostly of Southern tropical hill forest with Shola-Grassland eco system at the higher altitudes. Pampadum Shola National Park (PNSP)is11.753km^{2}inextent (asper SOI topo sheet).

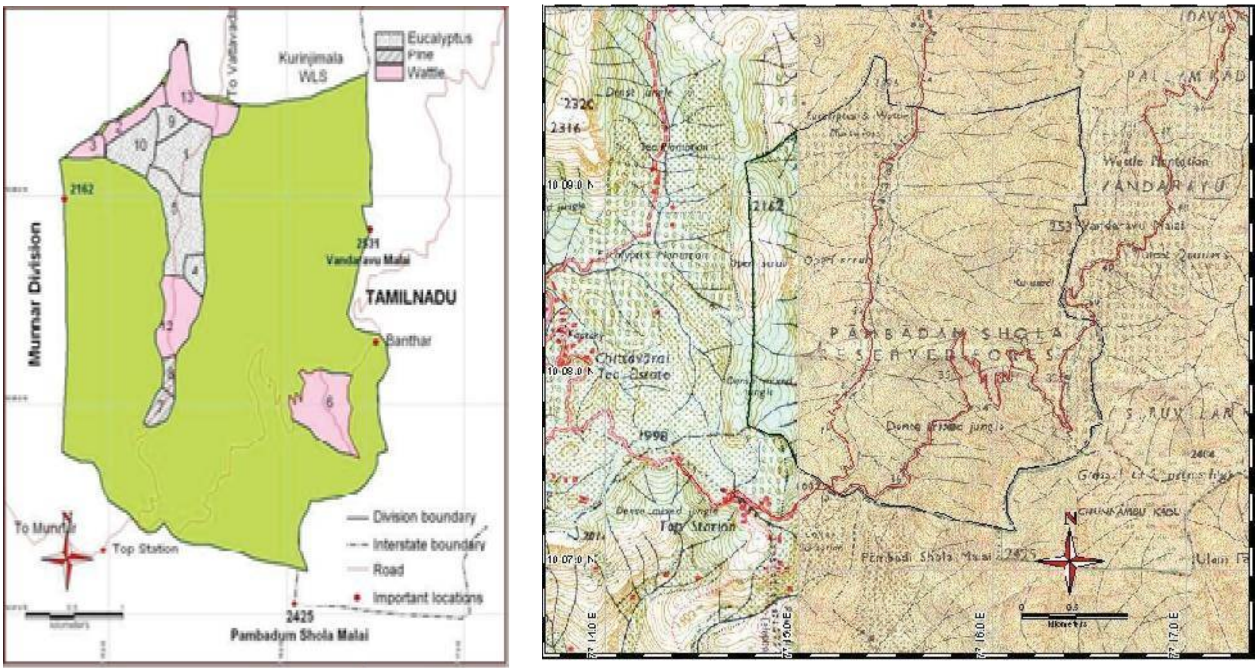

Fig 1. Project area

Forest Types

The following Forest types could be seen inside PNSP

Southern Sub tropical Hill Forests
Southern Montane wet Temperate Forests
Southern Montane wet Grassland
Southern Montane wet shrub
Plantations of pine, wattle and Eucalyptus

(Management Plan PSNP 2020-21-2030/31)

The two distinct physiognomic vegetation found within the park are Grasslands and the Shola Forests. Grass lands, Shola, Shrub land and Subtropical broad leaved hill forests are the major cover types.

The majority of area of the Pambadum Shola National Park is Wattle and Eucalyptus plantations. These are as were grassland during 1970-80s. Extraction of exotic species for commercial purpose was being carried out before the declaration of National Park. Now those exotic species are removed in the compartments as per the management plan of the park. The grassland ecosystem sustains grassland biodiversity and provides carbon storage, water infiltration, soil stability, decomposition, nutrient turn over and energy transfer. Wattle and Eucalyptus plantations were raised at Pattiyankal and Bendhar area during 1970-1990s. In 1972, 89.90 Ha wattle plantation was established at Pattiyankal and Bendhar areas. In 1968 and 1986, 40 Ha and 11 Ha respectively, were taken as alease from forest department for the wattle plantation at Vattavada. In 1984 another 14. 70 ha wattle plantation was raised at Pattiyankal. Individual area is not available in the management plan. During 2014-15, 44 Ha of wattle plantation was surveyed for wattle eradication and felled for that purpose. During fire season on 30-03-2015 a fire swept the felled wattle plantation and lasted for three days. Around 47 Ha was burned off, and all the trees and debris were burnt to ashes and charred logs.

Profuse germination of wattle seeds were seen at the top of the hill and the downhill in the following weeks after a summer shower. Eupatorium invaded to an extent of 15.80 Ha. It has attained a height of more than 6 feet in many fringes. Eucalyptus seeds which had spread from the nearby private eucalyptus plantation on the northern side had germinated in last monsoon andattainedaheightof3to5feet. They are having no competitors for growth. In the beginning we noticed that wattleregeneratedin9.48ha only.

The aim of this project was to restore grassland/shola in the wattle removed area of the National park.

Methodology

The complete methodology is detailed in the steps below.

1) Demarcation of the burnt area

Total area was divided into three regions for specific management activities since there were differences in slope and species regenerated after the fire and summer showers.

1. Burnt Area
2. Unburnt Area
3. Wattle regenerated Area

For ease of management, protection and inspection of the proposed area, formation of a new bridlepatha long the contour was necessary. Alignment of a bridle path using Ghat Tracer, for easy movement of volunteers and materials was done at first. There was no trekpathorroad in the area proposed for management. Many path ways across the slopes may lead to further erosion and make it difficult to climb.

2) Identification of sprouting wattle seedlings and segregation into compartments

Sample plots (1mx1m) were taken in the field at random to get an average figure of regeneration of wattle. Depending on the abundance of wattle sprouting compartments of high moderate and less density were formed and a rough sketch made for planning the plucking process and repetition of the plucking.

3) Eradication of the wattle seedlings

The entire area was divided into compartments of high to moderate and less wattle regeneration. Plucking can be done only after the seedlings attain a certain height. They continue to germinate even after one or two plucking for upto one or two years. The density in each compartment declines with the progress of plucking schedule. The schedule of plucking was assigned by the forest field staff under the leadership of Section Forest Officer and Range Forest Officer, Shola National parks. Eco restoration nature camps were allotted to volunteers and enthusiasts by the department with active co operation from NGOs. On every day one compartment was worked upon. Sometimes there will be different volunteer groups and they will be allotted with separate areas. Some NGO s selected a particular area for their continued removal after every three month time. Same area was again attended by same or another team of volunteers for plucking upcoming seedlings after an interval of about two to three months. Sprouted seedlings were plucked with hand using gloves and sometimes aided with a mattock. They were then placed and bundled perpendicular to the lying logs with roots exposed up. This prevented any possibility of survival of plucked seedlings. It was the major task in the proposed area and was accomplished after repeated concerted efforts.

4) Identification of associated exotic weed and degree of invasion areas (*Eupatorium*sps.,*Solanum* spp., *Pteridium* ferns etc.)

By the starting of wattle plucking, *Ageratina adenophora* had attained a height of 2-4 feet. When uprooting them, soil also was plucked with the bunch of roots. The soil was released back to the ground and the plucked plants laid with roots exposed up, across the logs as said above. *Pteridium* had been uprooted with runners and burnt off in heaps. *Solanum viarum* another invasive associate was also seen encroaching from the fringes and was treated similarly.

5) Selection of native grass clumps, implanting slips and seed dispersal methods

Native grass species were collected from the vicinity of the project area and segregated and planted as slips along the inside of the arranged logs to get a protection from hoof of foraging animals and ensuring availability of moisture. Dung piles of gaur which were seen in plenty in the area were seen to develop grass seedlings in the frost and drizzle. They had vigorous growth and could easily survive when split and planted. They were separated and all grass slips got were planted. Pellets of Sambar deer retains seeds of indigenous grasss pecies and were collected and dispersed in the proposed area. Moreover, the seeds of the mature grasses in the vicinity and inside the park were collected and dried in sun. Then they were made into balls with local soil soaked in water and the seed balls were thrown and dispersed all over the wattle removed areas during showers. This was all done with help of volunteers and self motivated forest staff.

Implantation of indigenous grasses in the projected area

Sl. No.	Species	Family	Local/English name	Endemism
1	*Zoysia matrella* (L.) Merr.	Poaceae	Cherappullu, Mascarene grass	Indo-Malesia
2	*Poa annua* L.	Poaceae	Kolappullu,Annual Meadow Grass	Cosmopolitan
3	*Centella asiatica*	Apiaceae		Asia
4	*Plantago erosa* Wall.	Plantaginaceae	Nilachakka, Njalamboori	Pantropical
5	*Drymaria cordata* ssp. diandra	Caryophyllaceae	Pipili	India, Srilanka, Bhutan, Nepal, Cosmodia
6	*Jancus inflexus* L.	Juncaceae		Indo-Malesia
7	*Carex myosurus* Nees	Cyperacea		Indo-Malesia, China
8	*Taraxacum javanicum* Soest	Asteraceae		India, Sri Lanka, Indonesia
9	*Oxalis corniculata* L.	Oxalidaceae	Puliyarila	Cosmopolitan
10	*Eleusine indica* L. Gaertn.	Poaceae	Maharanchini	India, Sri Lanka, Old World Tropics

6) Identification of ravines, rills and gullies and explore any possibility of water body or water source, for soil and moisture conservation.

There were four gullies which required plugging for arresting soil erosion. The methodology adopted was to cut down wattle logs and creation of plugs using the short logs on voluntary work basis. This will increase the water holding capacity of the soil and rebirth of rivulets. Arranging the felled tree logs (burnt) across the slopes along the contours to prevent surface erosion, rill erosion and gully formation was executed with the help of volunteers from different levels of the state and outside. This is the easiest method for preventing soil erosion and gully formation in the proposed area without much cost. Labourers were engaged in cutting the branches and laying the felled down wattle in the unburnt areas. A pond was constructed on the eastern slope to collect the run off due to barrenness of the hills in the beginning and to attract wild life to the area.

7) Identification of Shola growth

In the beginning of the study, shola patches were seen at the eastern boundary and the valleys in the project area had only few sprouted shola species. Enrichment planting was done using protection mazdoors during June - July 2015 and left to nature.

8)Repeated removal of wattle seedlings and other invasive weeds from the treatment area using volunteer so rapid labour depending on the condition of the target plants was done for two consecutive years. In addition to wattle, *Solanum viarum*, *Lantana camera* and *Ageratina adenophora* were also plucked out from boundaries.

9) Identification and monitoring of animals in the projected area

The newly planted slips attracted Gaur, Sambar deer, Barking deer etc and it was difficult to replace the casualty in the beginning. Foraging affected the planted slips, while the germination from seed balls were less affected.

ROLE OF NGOs

Volunteer activities were solicited in the study area from students of various colleges, schools cultural clubs and nature societies. They were engaged in the arrangement of burnt logs along the contour, gully plugging using logs, implantation of grasses, seed ball dispersal, removal of exotic species by repeated plucking from the study area etc. Around 70 Nature camps have been conducted in 2015 up to March with the available funds under Sanctuary head and Anamudi Forest Development Agency. Total 2320 students participated in these camps. Out of which, 51 camps were with the participation of school and college students and number of participants are 1740. There maining camps were conducted with the help of nature societies (Kottayam Nature Society, Snaachari group), Universities, Kottayam Medical College and some online units etc. So the total number of man days availed is580.00 (2320/8x2hrs) in the projected area.

OBSERVATIONIN THE STUDY AREA

Restoration is the long term monitoring programme and the observations are given below: (see also Fig. 1-6)

Burnt area

Observation of the burned area revealed that, there are two hillocks in the project area. Even though forest fire had occurred in the majority of the area the down side around the hill had not been burnt. It is easily distinguishable after the completion of the project. There were tall wattle seedlings which had to be removed with labour. Except the main bole (long wood) all branches of the felled wattle have been burnt to ashes. Top soil was almost lost in the rain along with the ash. The runoff was collected in the pond which developed shola species all around. Germination of wattle seeds is less in top as compared to the lower area. This is aided by the runoff water. Atop the hill a pond was formed which had a crowding of wattle seedlings revealing that there was water in the pond. Silt deposited need not be removed as it is helpful for water storage and clay pan formation. This area was separately marked with GPS for specific management activities in future.

Unburnt Area

Unburnt area around the two hillocks are now covered with *Eupatorium*, *Solanum* and *Ferns*.Wattle trees that had been felled are laying crisscross as such, with branches that prevents the movements of animals. Uprooting of invasive species, cut down of branches of felled wattle trees and laying of remaining long wood along the contour requires more labourers. So this area should be demarcated individually and treated with fire for removal of the debris and weeds.

Exotic Regenerated Area

In certain portions where wattle was removed, profuse regeneration of the wattle is again seen. In then orthernside of the project area seeds of the private eucalyptusplantation have started to germinate to some extent. This area has to be treated individually. This area should also be demarcated.

The fringe areas of treated area of Pattiangal are invaded with *Eupatorium, Solanum, Eucalyptus* and *Pteridium* and the site was marked with GPS for later comparison and study. Repeatedremovalofexoticsfromtheprojectedareaduringthesummerseason and implantation of indigenous grass clumps during rains was supported to recover around 40% of the plantation to grassland, and all activities were supported by volunteers and NGOs.

Regeneration success of grasses

Implantation of native grasses species for restoration, showed good response particularly during the rainy season. Regeneration of grasses on droppings of Gaur dung was also observed from the study area, which would set the nature into action over a period of time.

Quadrant methods (1m x 1m) showed that the population of Acacia seedlings of unattended outside area was very high and the average number was 5-30 per meter square, and it is very hard to uproot. Total number of Man days availed was 580 in the last year up to February 25th 2016 in the projected area.

Increased animal activity in the area which was otherwise deserted by wildlife.

Animal monitoring data shows the area is daily being used by Sambar deer, barking deer, and Gaur. Dohle, bonnet macaque were photographed from the site at day time. Many direct and indirect sightings were also reported from the restoration area after the inception. Pugmark of tiger was also observed from the study area, and a carcass of gaur was also got in the sprouting grass.

Summary

Arrangements of logs/burnt trees along the contour has prevented soil erosion during rains. Voluntary works and active participation of NGOs have reduced the cost of the project. It served to dissipate the knowledge of eco restoration into the minds of many all over the country. Implanted grasses showed fast growth during rains. Eradication of disturbances improved eco-restoration and succession. Wild animal activities has shoot up in the projected area. There is a small patch of Shola, which is developing in the east facing valley. This area should also be marked to know the extension of Shola into grasslands. Species identification can also be done through experts. This can be a model for further conversion of exotic plantations into original eco systems in the Southern Western Ghats. The process is planned to continue for a period of 3 years as the wattle seeds remain viable for a period of over 50

years and regular uprooting will be done. Water table reclamation can assure a better water availability in nearby villages, for agriculture.

Suggestion

Implantation of both palatableandnon pala table grass species in the study area increases the heterogeneity of the grasses and will make structural complexity and diversity in the field. Propagation of native Shola trees in valleys for one time may be done.

Fig.1. Area before treatment

Fig. 2. Gully plugging using wattle logs

Fig.3. Enumeration of wattle seedlings by using the quadrant method (1mx1m)

Fig.4. Restoration and regeneration of implanted grasses

Fig. 5. Animal sighting in the projected area

Fig.6. Voluntary activities in project area

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UPS AND DOWNS OF *PROSOPIS JULIFLORA* (SWARTZ) DC INVASION INTO KERALA THROUGH THE PALAKKAD GAP

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Abstract

Palakkad Gap, the major natural gap in the Western Ghats, is the most conspicuous physiographic feature in South India. It is highly responsible for regulating the climate of Kerala and neighboring Tamil Nadu and is essential in the linguistic, cultural, political and economic integration of both states. The climatic and geographic features of the Palakkad Gap help the profuse growth and wide range dispersion of invasive plants. A comprehensive road survey carried out along 4 imaginary roads transects passing through central region of the gap revealed the presence of *Prosopis juliflora* (Swartz DC)- one of the worst invasive species in history. 31 other invasive plant species were also noted from the site. The invasion of*P.juliflora* in India was the result of unscientific social and conservation forestry policies. Later this became a hot topic across proponents and opponents. But the presence of this species in Kerala is not yet explored. This study examines the current and future climatic suitability for*P. juliflora* in Kerala by focusing the Palakkad Gap using Maxent model. Occurrence points were collected and verified from field visits, GBIF, IBP and iNaturalist observations. The social and ecological context of invasion of this species from Tamil Nadu is deciphered through personal interviews and direct observation. This study has indicated that the distribution and dispersion range of *P.juliflora* provide adequate ambiance for the species to move into the inlands of Kerala and adds to the presumption of Palakkad Gap as an invasion pathway. The temperature increase and change in the rainfall patterns would also contribute to this. The data derived from this investigation will serve as a document for the current distribution status of the species and the features of its surrounding environment. It will enable to bring forth policy decisions for the early management and assessment of future invasion intensities in Kerala.

Key words:

Palakkad Gap; Invasive Plant Species; *Prosopis juliflora*; MaxEnt Model, Climatic suitability.

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Introduction

Acting as the chief corridor linking Kerala to Tamil Nadu and other regions of India, the Palakkad Gap was essential in the linguistic, cultural, political, and economic integration of South India(Raj and Azeez, 2010).So there are several chances of introduction of invasive plant species through this pathway. It is responsible of both the state's high summer temperatures relative to other regions and the state's substantial rainfall during both south west and north east monsoon seasons. The wet southwest monsoons as well as storms from the Bay of Bengal cross the mountains through the opening (Darsana, 2010). It is one of the major reasons for the high rate of endemism in the Western Ghats (Praveen and Nameer, 2012).

Invasive alien species are considered as one of the most serious ecological and economic threats for decades (Pimentel, 2002). Acting as the role of autotrophs, invasive plants disrupt the base of the food chain, affecting primary productivity and nutrient cycling. Invasive plants can reorganize existing ecological connections and change the community's future trajectory by disturbing these basic processes (Didham et al., 2007). Availability of fragmented or disturbed habitats provides suitable sites for invasion of exotic plants. The competitive ability of native species would be low in such cases allowing the establishment and spread of invasive plants (Moore, 2000). Aside from human behavior, a number of additional factors have a role in alien plant invasion success. The climatic and seraphic similarities between the original and new environments are critical for alien species to establish(Hold gate, 1986). According to Sankaran et al, (2009), Global climate change will favor the invasion of exotic species. Asia with their similar tropical climate and leached soil structure like Latin America makes ithometo Invasive plant speciesallowing them to invade and colonize suitable sites on both continents(Ramakrishnan, 1991).

P.juliflora is often known as mesquite and shows extreme aggressiveness in alien habitats (Damasceno et al., 2020). The invasion of this tree in India was the result of unscientific social and conservatory forestry policies and even favored in Five year plans (Robbins, 2001). Despite its economic value in rural areas, the *P.juliflora* tree has already invaded millions of hectares of rangelands around the world, endangering local biodiversity and rural sustainability (Nasimento et al., 2014). It was listed as one of the top 100 worst invasive species in the world in 2004 (IUCN, 2004). Apart from their negative impacts communities started adapting themselves to the Prosopis invasion by utilizing them for livelihood.It is used for coal extraction, firewood and fencing (Reddy, 2012). After its introduction to meet fuel shortage in Tamil Nadu, it became severely invasive in the southern Tamil Nadu during continues drought (Kathiresan, 2006).

Ecological Niche Models have been utilized in a number of studies to look into the climatic niche conservatism of native and invasive ranges (Atwater et al., 2018). To understand how ecological and evolutionary processes interact to affect the distribution of an invasive species under current and anticipated climate change, integration of climatic niche dynamics with Ecological Niche Modeling methodologies is necessary. Adhikari et al., (2015) used species occurrence data from the Global Biodiversity Information facility and identified hotspots of alien species invasion in India through ecological niche modeling. By comparing the area of the invaded region with the surface predicted by ENMs, it can identify areas that are subject to invasion (Suárez-Mota et al., 2016). Maxent modeling of current and future climatic suitability of *P.juliflora*revealed South India as potential hotspots of invasion except Kerala (Singh et al., 2021). Invasion of *P.juliflora* in India was subjected to several studies. But the presence and habitat suitability of this species in Kerala is not yet explored. So this study engages with the various aspects of *P. juliflora* invasion into Keralathrough the Palakkad Gap using field survey, bioclimatic variables and satellite data with the help of MaxEnt software.

In this context the present study was aimed to i) Map the distribution of *P.juliflora* in the Palakkad Gap ii) Exploring the current climatic suitability for *P. juliflora* in Kerala using Maxent iii) Predicting the probable threat of *P. juliflora* invasion into Kerala.

Materials and methods

Study Area: The Palakkad Gap

Palakkad Gap is a low natural mountain pass or gap of 32 to 40 km in width and 250 km long in the 1600 km long Western Ghats. It is the most conspicuous physiographic featureof2882 square km area between 10° 30'N to 11° 15'N and Latitude 76° 25'E to 77° 15'E in South India with an elevation range of 34m to 160m (Figure 1). High-rising Nilagirihills to its north and Anamalai Hills to the south identify the area as a potential shear zone (Rajendran, 1996; Stephen, 2016; D'cruz, 2000). The climate experienced here is tropical semi-arid with the highest average high temperature is about 36°C and the highest average low temperature is about 23.5° C. As a result of climate change, this region marked the highest temperature of about 42° C and experienced strong pre-monsoon and summer showers. 18 to 22 km/hr is the typical annual wind speed in this region. The soil of Palakkad district is mainly of four types, namely, peaty (Kari), laterite, forest, and black. Red loamy, Red sandy, and Black soils are seen in the Tamil Nadu region (Chand,2013;TNAUAgritech Portal, 2013).

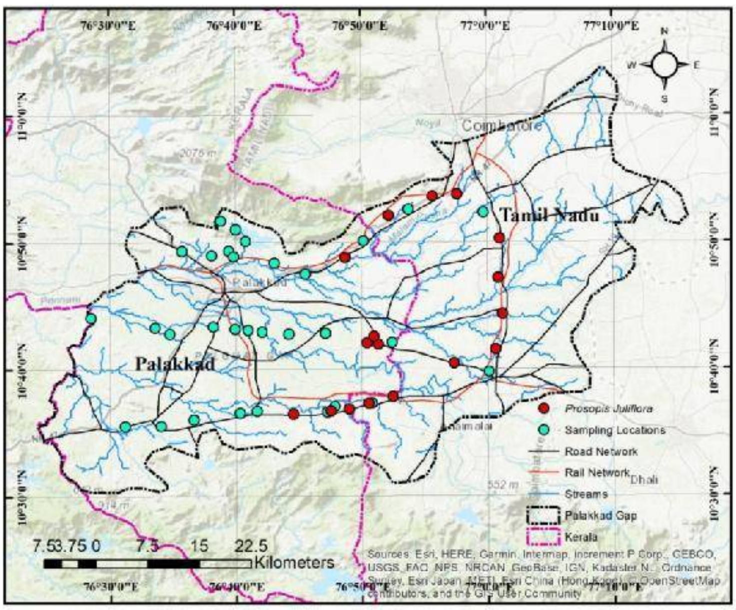

Figure 1: Sampling sites of *Prosopis juliflora* in the Palakkad Gap

Field Sampling

3 parallel lines passing through the central region of Palakkad Gap were drawn starting from Kerala to Tamil Nadu in the map extracted from Google earth. Road transects overlaying these lines were followed to identify and analyze the invasiveness of *P.juliflora*, along with it other invasive plant species were also noted (Figure 1). This field study was conducted in April 2022. 10x10msampling plots were selected throughout the roads at a distance of 2.5 to 5 km intervals based on alien plants infestation in a systematic random sampling manner(Dar et al., 2015; Thapa et al., 2018).

Atotal of 47 sample plots were generated from these 4 transects. In each plot; the number of IAPS, percentage, and aggressiveness of infestation of Prosopis and other invasive plants were interpreted visually. The latitude, longitude,and elevation of each site were noted with the help of the GARMIN Geographical Positioning System (eTrex 10x). Invasive Plants present in each plot were identified using the books: Handbook on Invasive Plants of Kerala, published by Kerala State Biodiversity Board(2013). Other properties like habitat features, location features, and invasive plants present between the two plots were also recorded.

The collected data of species were classified according to Family, Mode of dispersal, Habit, Habitat, Altitude, and Native region. These data were plotted and statistically analyzed using Microsoft excel. The spatial analysis of the collected data was carried out using QGIS. The study area was digitized from Google Earth Pro as KML file. It was converted into a shape file using QGIS. Using this platform, the plotted data in the excel sheet was georeferenced, and plotted the species distribution map(Hiregoudar et al., 2020).

SpeciesDistributionModelling

Species presence points

Species presence points were obtained from Field Surveys,iNaturalistobservations,Global Biodiversity Information Facility, India Biodiversity Portal, Published literature, and onlinesources. Species occurrence records from iNaturalist are scrutinized and selected (Table:1).A total of 602 points were generated. These points were verified using Maxent version and duplicate points and points outside the shape file were removed. As a result,502 unique points were selected in South India for climatic modeling(Thapa et al., 2018; EPPO, 2018).

Table 1: Source of species occurrence points and number of points selected from each source

Source	**No of points**
Field survey	240
iNaturalist	252
GBIF	31
IBP	21
Literature	58
Total	**602**

Environmental layers

Bioclimatic data were downloaded from worldclim(2.1). There are 19 Bioclimatic variables derived from monthly temperature and rainfall values. Of that 7 basic variables were selected to generate layers. They are BIO1- Annual mean temperature, BIO2- Mean Diurnal Range, BIO5- Maximum temperature of the warmest month, BIO6- Minimum temperature of the coldest month, BIO12- Annual Precipitation, BIO14- Precipitation of driest month.

Satellite data like Elevation, Slope, Aspect and Compound Topographic Index (CTI), and Terrain roughness were downloaded from SRTM.

Modelling algorithm – MaxEnt version 3.4.4

Given its reliance on just presence-only locations, maximum entropy (MaxEnt) modeling offers great potential for discovering wildlife distributions and habitat preferences based on climate, topography, biogeography, etc. Studies say that it performs better than other presence-only modeling approaches (Baldwin, 2009).

The model was built in two steps, with total points and half of the total presence points. For testing the model, MaxEntwas run with all the 502 available unique points. Thenthe model was trained by setting aside randomly 50% of the points (developing the model with the remaining 50% and computing the prediction accuracy with AUC values). Comparing the results of the analysis of the training and test samples is one of the ways to evaluate the model quality used in MaxEnt (Fourcade et al., 2018). The final model is built with all the available points and the prediction map is evaluated.The variable contribution was calculated using jackknife and bootstrapping procedures. Response curves for each variable were generated using permutation analysis and presented.

Questionnaire survey

A questionnaire survey was conducted to evaluate the socio-awareness and perceptions of*P.juliflora* along Kerala State highway 58(SH 58) among residents of Muthalamada,Kozhinjapara, Govindapuram, Pollachi,andGovindapuramregion. 10 *P.juliflora*infested sites,each from Kerala and Tamil Nadu were chosen. This survey aimed to collect more information regarding the invasion history, mode of dispersion, and social and economic impacts of the same, and the questions were designed according to that (Thinley et al., 2022).

Results

From the 47 sampling sites in the 4 transects, 19 sites were noted with the presence of *P. juliflora*. Of that 13 sites belongs to Tamil Nadu and 6 sites belongs to Palakkad.*P. juiflora* was found in Muthalamada, Kollengode, Kozhinjapara, Vadakarapathy, and Pudusseri Grama Panchayaths in the Palakkad district. Other than Prosopis, 31 invasive plant species belonging to 25 genera and 14 families were also documented in the study area. Of that Asteraceae is predominating with 7 species.

Prediction Accuracy and Model Analysis

The maxEnt model was run with 502 unique points and 7 climatic variables in South India predicting potential habitats of *P.juliflora* under current climatic conditions is given in figure 2. This shows high habitat suitability of the species in the Palakkad Gap region, Southern Tamil Nadu and Andhra Pradesh and moderate suitability in Thrissur, Malappuram and Idukki districts.

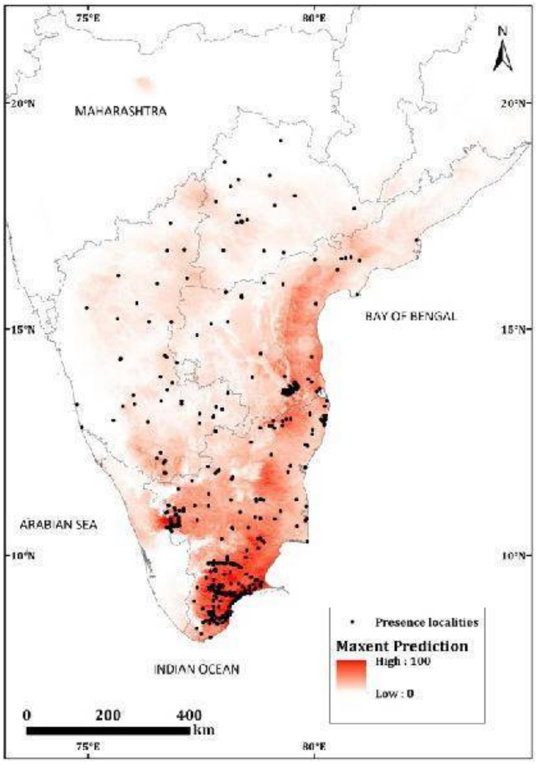

Figure 2: Maxent prediction of *P.Juliflora* distribution in South India

The AUC values depicting the prediction accuracy of the model analyzing the distribution of Prosopis juliflora under the current climatic period for training and test samples are above 0.9 (Table 2). This indicates that model performance is highly accurate (Manel et al., 2001).

Table 2: Model performance on training and testing data

Model	**N**	**AUC**	
		Training	**Test**
50% validation	250	0.935	0.934
Full set	502	--	0.927

Out of the 7 Bioclimatic variables and 3 satelite variables used, the top four variables contributing to the model prediction is given in table 3. BIO6-lowest temperature of the coldest month is the major variable determining the distribution of *P. juliflora* in South India followed by BIO1-Annual mean temperature, BIO5-Minimum temperature of warmest month, BIO14-Precipitation of driest month. From the graphs it is clearthat23^{o}C as the optimum temperature for this species in South India. Below this temperature the climatic suitability of *P. juliflora* declines and it shows no niche below 14^{o}C. The distribution of this species shows maximum temperature tolerance of 36^{o}C - 38^{o}C during summer and not depends on summer showers (Figure 3).

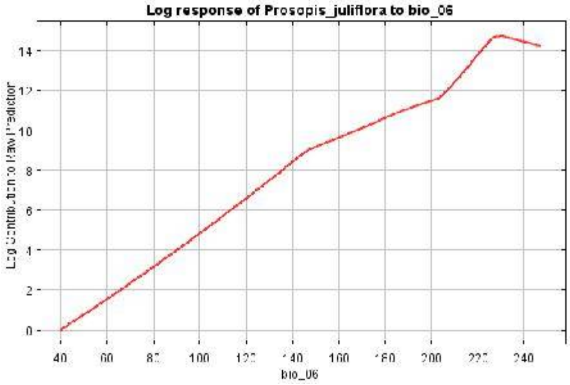

Fig 3a

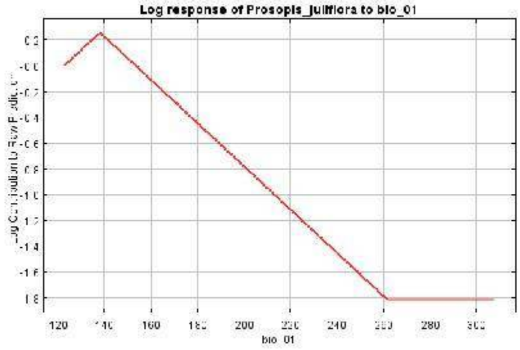

Fig 3b

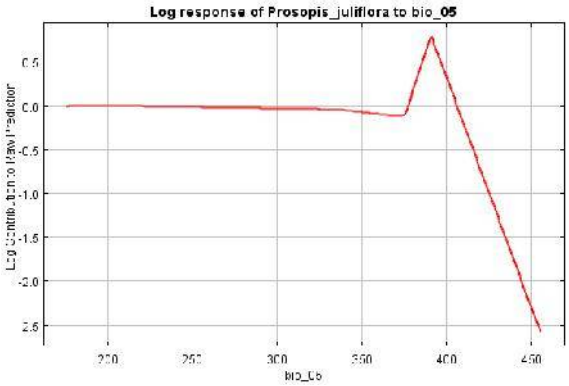

Fig 3c

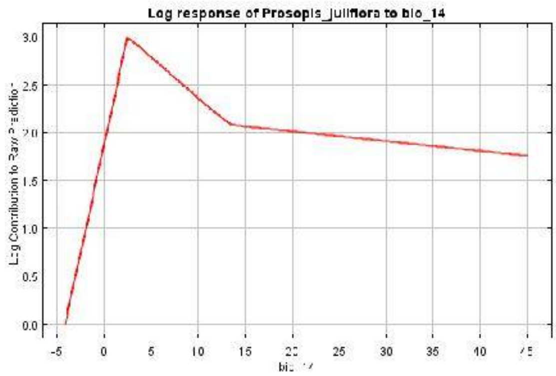

Fig 3d

Figure 3: Response curves of top four variables contributing to model prediction.

(Fig 3a: Bio 06 - Minimum Temperature of Coldest Month Fig 3b: Bio 01- Annual Mean Temperature Fig 3c: Bio 05 - Maximum Temperature of Warmest Month Fig 3d: Bio 14 - Precipitation of Driest Month**)**

Questionnaire survey

It is referred to as mullumaram, veelimullu, and karuvelam in Kerala. It is also known as company mullu/Delhi mullu (As British government introduced this plant), veelikathan, karuvelam, and seemaikaruvelam in Tamil Nadu. The names, meanwhile, are used interchangeably with the related native species Acacia Nilotica.It was widely used to construct fences, earned the name "veelikathan", which means ‘the savior of the fence’. For that seeds were sown along the boundaries of agricultural lands. These are now visible along plantation fences, especially coconut palms. Trees are managed and pruned to serve as walls. *P. juliflora* was cultivated extensively in the 1970s by Tamil Nadu residents in boundary regions of the Palakkad district like Muthalamada panchayath, initiated the spread of this tree in Palakkad. Self dispersion is triggered by cattle through the process of endozoochory. Large flocks of sheep from Tamil Nadu used to visit Palakkad in search of pastures during summer. This is another reason for the propagation of this plant. New spreads can be seen along banks of canals and rivers connecting both states. It is also dispersed through transfer of soil for road construction.

The Tamil Nadu Government has assigned agencies for weeding out *P.juliflora* with bulldozers, but most of them are regenerating as the roots are not properly removed. It is currently using for fire wood and rarely for industrial purpose. Shifting to LPG fuel decreased the demand of Prosopis wood. The infestation of Prosopis is very lesser as compare to last years. The policy of government to remove this species and over usage for fire wood and charcoal led to the decline of its spread. The expansion of highways also contributed to it. People in Tamil Nadu are very much aware of the negative impacts of this tree compare to natives of Palakkad. So they are removing it constantly within their premises.

Discussion and Conclusions

The present study was an attempt to gather baseline data on the distribution of *P. juliflora* in the Palakkad Gap region. For this 47 spots in the study area along four road transects were surveyed and analyzedaccordingly.This revealed the infestation of *P. juliflora*in the large region of the study area. To investigate the invasion potential of this species into Kerala the study has modeled the current climatic suitability of this species in South India. A questionnaire survey was carried out to evaluate the social and ecological context of invasion and dispersal of the same. Several studies focusing on the distribution modeling of invasive species has carried out in different time periods. But studies compiling social interaction to affirm the invasion possibilities are rare (Relf, 2008).

The*P. juliflora* identified sites in Palakkad district are abandoned or unaccessed lands, banks of rivers and canals and in boundaries of agricultural plantations. A habitat becomes more susceptible to invasion when unused resources are frequently available (Davis et al. 2000). Wastelands show profuse growth of Invasive plants. It is mainly due to the availability of space, light, and unexploited nutrients.Apart from that 31 other invasive plant species belonging to 25 genera and 14 families were also documented. Tropical America contributes more species to the invasion list. It can be related to the theory that the same climatic conditions play an important role in the successful establishment of Invasive species(Ramakrishnan, 1991). This region has a tropical wet-dry climate and receives very high temperatures during summer. The gap also has a significant impact on the summer temperature of the Palakkad plain (Raj, 2010). Characterized by dense road networks and heavy traffic as it is the main corridor connecting Kerala and Tamil Nadu intensifies the probability of the landform as an invasion pathway(Arevaloa et al., 2005). The high percentage of alien plant species in the roadside flora, as well as the increased number of foreign plant species adjacent to the roadways, strongly suggest that roadsides serve as anthropogenic corridors for alien plant dispersal (Dar et al.,2015). Seeds are the main reproductive method of these species. Light weight seeds are dispersed to a large distance effortlessly by the wind. This can be attributed to the strong wind blow through the gap (Chand, 2013).

Grazing livestock is the important mode of dispersion of *P.juliflora*. Flocks of sheep from Tamil Nadu in search of pastures in Palakkad are one of the important reasons for the dispersion of Prosopis which produce a lot of small, endozoochory-adapted seeds.In the crucial stage of the establishment of the seedling, the feces themselves serve as fertilizer. As the seeds in the feces disperse away from the mother plant, they can move across a large area of land (Walter, 2011). Some regions of Palakkad were under the madras regime during the early independence (Palakkad.nic.in). This is the important reason for the presence of Prosopis in Palakkad initiated by cultivation for charcoal and firewood. Later it got dispersed to the nearby regions by cattle and through irrigation canals and natural drainage systems. (Pasiecznik, 2001) also points out this.

Our model has predicted the current climatic suitability of *P. juliflora* in Kerala with high prediction accuracy with all selected climatic variables. The gap region exists as potential hotspot of high climatic suitability and adjacent regions with moderate suitability. This could be connecting with the probability of this species to invade into the inlands of Kerala through the gap and to act as an invasion pathway. The climatic variables contributing to the model prediction shows the temperature tolerance of this species up to 38^{o}C which would increase in the changing climate regime. Overall habitat suitability for this species is projected to increase in Southern India under the scenario of future climate change (Singh et al., 2021). This could be a major concern for the Nilagiri and Anamalai hills flanking north and south of Palakkad Gap. Invasion of *P. juliflora* has already reported from the lower altitudinal forest ranges of Western Ghats and has considerable influence on the protected species (Arandhara et al., 2021).So this study envisages the complete removal *P. juliflora* in the Palakkad district as an early means of management.

Being a controversial issue in Tamil Nadu, natives should be aware of the detrimental effects of *P.juliflora*. But still, some people aren't aware of this crisis. This indicates the knowledge gap between rural and urban areas. Even the natives of the Palakkad region are aware of the negative impacts of this species they have queries about the removal of a sparsely dispersed tree in the area. They are unaware of the invasive nature of exotic plants and the future impacts beyond them. Currently the rate of infestation of Prosopis is less. But the situation could be worse if the management system fails to accomplish. The management of invasive plants is a great challenge if it not cleared the establishment phase. The technique following to control *P. juliflora* in Tamil Nadu is mainly uprooting (Vijayakumar, 2017). But it didn't produce a complete result in these years. Control methods do not always lead to the eradication of species from a given area.The integration of physical, chemical, and biological techniques is necessary for the regulation of the IAPS, and eliminating these weeds with just one strategy is ineffective (Shrestha, 2016).Techniques like species distribution modelling helps in the early detection of infestation of alien species and the possibilities of this should utilize wisely for the successful management of invasive alien plant species. This study will enable to bring forth policy decisions for the early management and assessment of future invasion intensities in Kerala and calls for the involvement of different stakeholders from local sector for continues monitoring the spread of invasive plants along roadsides and drainage systems. In addition this study will promote the wide usage of such technics by the forest department to prevent such invasions into conserved land.

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EFFECT OF INVASIVE *PROSOPIS JULIFLORA* ON TREE DIVERSITY IN THE TROPICAL DRY FOREST OF SOUTHERN WESTERN GHATS, INDIA.

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Abstract

Prosopis juliflora is an invasive tree competingwith native plants for nutrients, water and light. The presentstudyassessed the effect of *P. juliflora* on tree diversity in the tropical dry forest of the Chinnar Wildlife Sanctuary (CWS), a protected area in the southern Western Ghats. Purposive random sampling method was adopted to study twenty plots (10 invaded and 10 non-invaded). The results show a significant difference in the diversity of mature tree species between invaded and non-invaded areas ($p < 0.05$). However, there is no significant difference between the regenerative phases (saplings and seedlings) in invaded and non-invaded areas ($p > 0.05$). Analysis of the scatterplot equation shows a negative relationship betweentheabundance of *P.juliflora*and tree diversity ($r = -0.59$). As a conclusion, high diversity was observed in the non-invaded areas while invaded areas have less diversity. Hence, an urgent management program to eradicate*P.juliflora*is required in CWS to conserve its biodiversity.

Keywords: Invasive species, *Prosopis juliflora*, Tree diversity, Western Ghats

Introduction

Invasive alien species (IAS)pose the second most important threat to biodiversity on Earth after habitat destruction (Genovesi et al., 2015), and it is one of the most critical environmental and conservation challenges of the current era (Cole et al., 2019). The loss of native plant community composition and diversity is the inevitable consequence of plant invasion (Cutway, 2017). Since invasive often occupies large areas where they are found, they can negatively influence the composition of native vegetation and food webs (David et al., 2017). The integrity and resilience of the native habitat have been significantly compromised by many invasive alien species (Prior et al., 2018). The majority of IAS have recently been introduced by humans either deliberately or accidentally (Gallardo and Vila, 2019).

Athamanakath, J.,Joy,S., Padmakumar,B., and Sylas, V.P. 2023. Effect of invasive *Prosopis juliflora*on tree diversity in the tropical dry forest of Southern Western Ghats, India. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.274-279.

According to the International Union of Conservation of Nature (IUCN), *P. juliflora* is one of the top invasive plant species worldwide (Howari et al., 2022). It is a small, extremely quick-growing evergreen tree indigenous to the new world and is found in Central America, northern South America, and the Caribbean Islands (Slate et al., 2020). Concerns about deforestation desertification, and fuel wood shortages in the late 1970s and early 1980s sparked a surge of projects introducing *P. juliflora* and other hardy tree species to new habitats worldwide (Mwangi and Swallow, 2008). There is a conflicting account of when *P.juliflora* was first introduced in India, but it was undoubtedly in the second half of the 19th century (Dubow 2011). The tree was able to flourish in the kind of harsh conditions and poor soils where little else survived (Patnaik et al., 2017).

Although ubiquitous in the nearby state of Tamil Nadu, within Kerala, the plant was established only in dry deciduous forest patches of the CWS (Sankaran et al., 2014).Southern tropical thorn forest (scrub jungle) is the second most prevalent forest type in the CWS according to the area and the minor typical forest type in Kerala (Padmakumar et al., 2018). Xerophytic species with short bole and low branching make up the open low forest type. The canopies are relatively open. The differentiation at the canopy level is therefore, undetectable. The hardwood trees, prickly shrubs, and climbers are the distinguishing characteristics of this type of forest. During monsoons, the undergrowth is adorned with certain herbaceous forms but mostly remains bare.

The significant species representing the forest type are *Acacia* spp., *Euphorbia* spp., *Capparis* spp., *Opuntia* spp., *Ziziphus* spp., *Grewia* spp., *Cordia* spp., *Albizia amara*, *Atalantia monophylla*, *Pleiospermium alatum*, *P.juliflora*, *Dichrostachys cinerea*, *Diospyros cordifolia*, *Pisonia aculeata*, *Carissa carandas*, *Strychnospotatorum*, *Ceropegiajuncea*, *Pergularia daemia*, *Caralluma* spp., *Helixanthera* spp., etc. The locations of this forest type include Chinnar, Champakkad, Chunkam, Nellimedu and the slopes of Alampetty, Ichampetty, Palapetty etc (Padmakumar *et al*., 2018). The objectives of the study are to determine the effect of *P.juliflora* on tree the diversity and to find the relationship between *P.juliflora* abundance and tree species diversity in the tropical dry forest of the CWS, Kerala, India.

Materials and Methods

Study area

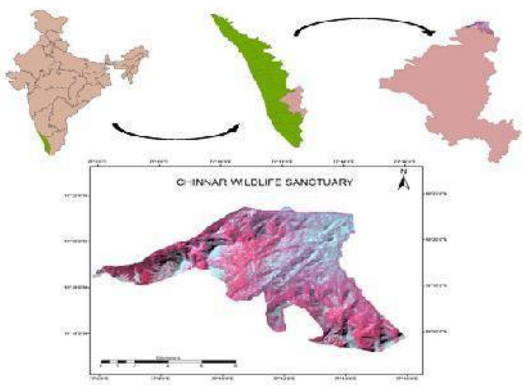

Fig 1. Showing the map of the Chinnar Wildlife Sanctuary, Kerala, India

Chinnar Wildlife Sanctuary (lies between 10°15'0" and 10°22'0" N, 77°6'0" and 77°16'0" E) is a protected region of the Kerala state in south India (Ajin et al., 2016) (Fig. 1). It has a total area of 90.44 sq km, and its altitude ranges from 400 to 2400 m.

Tree Sampling

The study was conducted in the tropical dry forest of Chinnar Wildlife Sanctuary, Kerala, India. The study area is divided into two areas, viz., invaded and non-invaded areas. A random sampling of 30×30 m quadrats were used in both invaded and non-invaded areas. A total of twenty (20) sampling plots were set up (10 invaded plots and 10 non-invaded plots). The minimum distance between two invaded or two non-invaded was 200 meters. The diameters at a breast height (dbh) of the trees ≥ 10 cmwere measured at 1.37 m from the ground level using a meter tape. The dbh of <10cm >3cmmeasured for saplings from four 5 m × 5 mquadratswhich nested within each 30×30quadrat. For seedlings, <3cmdbh measured from four $1m^2$ quadrats nested in two $5m^2$ plots diagonally opposite to each other. The location at the center of each quadrat was recorded using a Global Positioning System (GPS) device. Photographs of *P. juliflora*-infested locations were taken with a digital camera

Fig 2. Vegetative sampling in *P. juliflora* invaded area

Data Analysis

Tree species diversity of*P. Juliflora* invaded region and non-invaded region were calculated using Shannon-Wiener index.Paired't' test was performed to understand the difference in diversity and abundance of trees between *P. juliflora* invaded and non-invaded areas. The Pearson correlation coefficient was used to find the relationship between *P. juliflora* abundance and tree species diversity.

Results

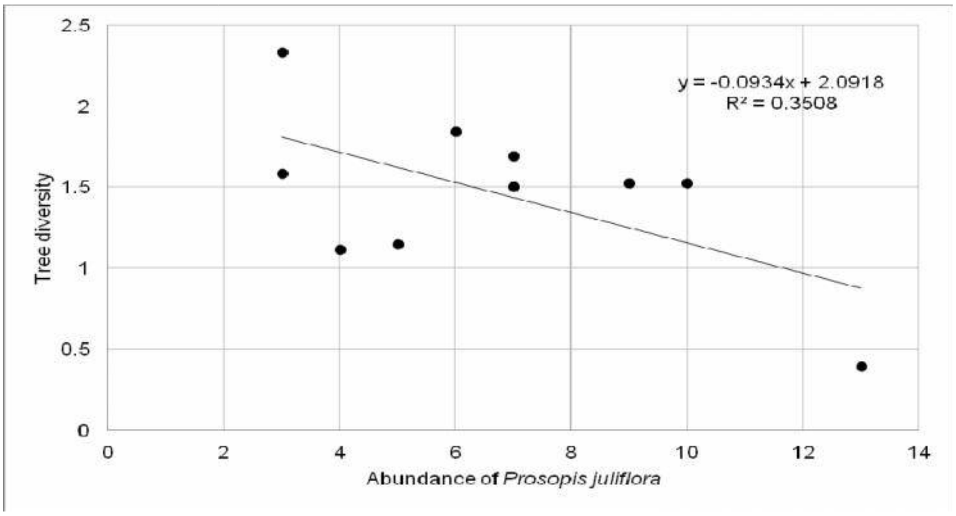

Fig 3. Scatterplot showing the relationship between the abundance of *P. juliflora*and tree diversity

The t-test shows a significant difference between the mature tree species in invaded and non-invaded areas (*p = 0.024*). However, there is no significant difference between the regenerative phases (saplings and seedlings) in invaded and non-invaded areas (*p = 0.33* for saplings and *p = 0.62* for seedlings). The result also shows a significant difference in the abundance of trees in invaded and non-invaded areas, mature tree phase (*p = 0.0003*) and sapling phase (*p = 0.044*). However, there is no significant difference in the abundance of seedlings in invaded and non-invaded areas (*p = 0.41*). Analysis of the scatterplot equation shows a moderate negative relationship betweentheabundance of*P.juliflora*and tree diversity (Fig. 3). This is shown by the equation y = 0.0934x +2.0918.

Discussion

The study shows a significant difference between mature tree species diversity and abundance in invaded and non-invaded sites ($p < 0.5$). This is supported by inverse relationship between *P. juliflora* abundance and tree species diversity in CWS (Fig. 4). However, there is no significant difference between regenerative phases (seedlings and saplings) diversity in invaded and non-invaded sites. The result of statistical analysis shows that*P. Juliflora* affect the establishment and therebyreducing the diversity of trees in tropical dry forest of CWS. A study by Naudiyal et al., (2017), challenges the widespread belief that *P.juliflora* has a deleterious influence on biodiversity. They discovered a beneficial relationship between *P.juliflora* and the native species, finding that *P. juliflora* serves as a nursing tree by supporting the regeneration of native plants beneath its canopy. However, these findings are possible in the completely degraded open ground since the area covered by *P. juiflora* will have richer soil and better micrometeorology. *P. juliflora* can displace native and exotic species (Mwangi and Swallow, 2008) by delaying seed germination and lowering plant growth in all forms, such as roots, shoots, leaf area, stem diameter, and plant height (de Souza et al., 2014). Allelochemicals found in *P.Juliflora* inhibit the germination, growth, and survival of other plant species (Humaid et al., 1998). Similarly, the present study shows significant difference in diversity among mature trees between invaded and non-invaded areas says that the *P. Juliflora* population negatively affects the establishment of native as well as exotic tree species.

A study by Kaur et al., (2012) and Murugan et al., (2020) proves the growth and establishment of local plant species and further increaseinplant diversity when the dominant *P.juliflora* population is removed. It is due to reduced competition for resources and reduced allelopathic phenolic chemicals in the litter, rhizophore and bulk soil. *P. juliflora* is now mainly found in the margin of tropical dry forest, and its population is not established in the interior region. However, in a protected area such as CWS, it can quickly spread by seed dispersal agents such as herbivores, monkeys, and birds. So if this situation continues for a few decades, there is a possibility of*P.juliflora* spreading across the sanctuary, posing a threat to other fauna and flora. This study supports the need for controlling and eradicating *P. juliflora* to keep biodiversity healthy. An effort should have to taken by the forest department through community participation to eradicate *P. juliflora* from the sanctuary to improve the habitat and protect the native tree species.

Conclusion

The present study depicts the effect of *P. Juliflora* invasion on the diversity and abundance of native tree in the tropical dry forest of southern Western Ghats, India. *P.juliflora* is mainly seen in the forest margins while it is not established in interior forest areas having high tree diversity. Since *P.juiflora* is an invasive plant, there is a need of efficient management plan to control its invasion in the context of climate change scenario. Along with climate change, it can also spread through herbivores, monkeys and other mammals etc. Therefore, if *P.juiflora* invasion is not controlled; they might alter vegetation patterns, composition and diversity. Hence forest department has to take urgent steps to manage this invasive plant from the study area through community participation.

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PERSPECTIVES ON*PTERIDIUM AQUILINUM* EXPANSION IN WESTERN GHATS

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Abstract

Pteridium aquilinum,commonly known as Bracken or eagle fern, is a fifth geographically distributed world wide invasive alien species. However, it has not been considered invasive in government records.The invasion of *Pteridium* has gained the attention of ecologists as few researchers in India have reported that it is expanding faster in the high-altitude grassland area of the Western Ghats. The rapid distribution is due to the rhizome of the plant that acts as a reservoir of Carbon which supports the plant's germination, growth, and development and is resistant to fire intensity. As per the shreds of literature, the invasion of the plant was observed in abandoned or burnt areas of the forest ecosystem. It also acts as a sink for Carbon, influences nutrient cycling, and correlates with enhancing the soil's microbial activity. The available literature suggests physic - Chemical factors, allelopathic characteristics, food uses, medicinal properties, genotoxicity, and immunotoxicity of plants. However, the evidence also shows that the concentration of allelopathic chemicals, a secondary metabolite, non-sesquiterpene Ptaquiloside, which is carcinogenic, alters the soil chemistry and significantly affects living organisms. Hence, bringing up the information together, there is a need to understand the perspectives on *Pteridium aquilinum* and carry out further research in the Western Ghats region. In this regard, the paper attempts to demonstrate the implications associated with *Pteridium aquilinum* expansion, highlights the literature gap, and suggests measures for its management.

Keywords: Ecological factors, Climatic factors, Allelopathic chemicals

Introduction

Pteridium aquilinum, commonly known as bracken fern or eagle fern, belongs to the Dennstaedtiaceae family. It is widely distributed worldwide and considered one of the five most abundant plants on earth; being very difficult to control, *P aquilinum* presents tolerance to a wide range of environmental and edaphic conditions, invasively colonizing in different types of environments such as grasslands, agricultural and forest areas, degraded or altered areas, and particularly open places with a high incidence of light (Mira *et al*., 2021). Fires, deforestations, human clearing, cattle grazing, agricultural activities, etc., are ecological disturbances that fundamentally affect an ecosystem (Cochrane and Schulze 1999; Cochrane

Madhushree, V. and Nagaraja, B.C. 2023. Perspectives on *Pteridium aquilinum* expansion in Western Ghats. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.280-287.

2001, Silva Matos *et al*., 2003). In the case of fire, a portion of the nutrients previously held in plant biomass is returned to the soil as biomass burns (Pringle 1979), and vegetation with the potential for rapid growth takes advantage of the lack of competition and quickly fills the gaps created by fire. After deforestation by fires, *Pteridium* species fast colonizes and dominate the vegetation for long periods (Silva Gallegos *et al*., 2014). In addition, these species inhibit the establishment of other associated plants (Pakeman and Marrs, 1992; Calvert, 1998; Silva Matos *et al*., 2003). The ecological attributes of this species thatmakeit a successful colonizer include an extensive rhizome system, high spore production, high resistance to fire and drought, fast and lush growth, and allelopathic properties (Mira *et al*., 2021). The storage of carbohydrates in the rhizome supports the plant's rapid growth. The growth during the spring is triggered by the reallocation of nutrients rhizome. The allelopathic chemicals are released into the soil through the different parts of the plant. Allelopathic chemicals alter the soil parameters and are responsible for hindering the growth of native species.

Pteridium ferns represent a global challenge to biodiversity management and conservation as they become dominant in degraded or anthropogenic-impacted areas (Ortuna et al., 2015; Stewart *et al*., 2008). The fern significantly affects the environment by affecting the physicochemical parameters of soil and the cycling and availability of nutrients (DeLuca et al., 2013). Production of a large amount of massive frond canopy by *Pteridium aquilinum* results in the accumulation of litter, water interception, and limiting access to light by other native species and also contributes to forest fire by acting as fuel biomass. Environmental restoration is affected due to the interference of bracken with the seed bank composition, regeneration of vegetation, and species of interest (Jatoba et al., 2016). The study aims to highlight major characteristics affecting the native species and cast a light on the establishment of *Pteridium aquilinum* in the Western ghats region of India

2. Ecological Factors

2.1 *Soil*

The soil profile is important because it relates to aeration and water supply; although *P. aquilinum* can grow on shallow soils, it grows better on deep soils in dry or humid sites (Watt 1976). It cannot tolerate waterlogging (DeLuca *et al*., 2013) because its rhizomes cannot tolerate low oxygen concentrations in waterlogged soils (Whitehead and Digby 1997).The role of *P. aquilinum* in the transformation of soil ecosystems is well recognized (DeLuca *et al*.,2012). Bracken is highly efficient at absorbing and storing phosphorus and magnesium even when these elements are deficient in the soil, and fertilizer application increases the storage of nutrients in the rhizomes, suggesting it competes strongly for soil nutrients (McGlone *et al*.,2005). The natural bracken fern biomass has an acidifying effect on soil solution (Maynard et al. 1998). Bracken is not tolerant to acidic conditions in some parts of the regions. Still, according to the study conducted by Bhat *et al*., 2016 at Kudremukh National Park, Western Ghats Karnataka, India, the soil sample collected from the fern area showed highly acidic conditions and rapid establishment .Bracken acted as a nutrient sink for N pools through the growing season and as a source or sink for C and P pools, depending on the season. Moreover, the effect on nutrient pools did not depend on bracken characteristics (area, density, or height). Bracken presence enhanced soil microbial respiration proportionally to the patch area. The control bracken exerted over nutrient pools may determine other plant species successful (or otherwise) establishment. This makes bracken a successful colonizer as no particular population threshold (area, density) has to be reached before nutrients becomes limiting to other plant species (Aira *et al*., 2021).

2.2 *Climatic factors and Topography*

In temperate climates, low temperatures, especially frosts, are critical in limiting both *P. aquilinum* distribution and the length of the frond growing season (Marrs and Watt 2006). By contrast, under tropical climates, rainfall is the most important driving variable (Portela *et al*., 2009). Studies suggest *Pteridium aquilinum* can grow from sea level up to 3000 m elevation. Topography also appears to affect performance, *P. aquilinum* commonly colonizes steeper slopes on the south and south westerly aspects at high altitudes (Hughes and Aitchinson 1986), but the aspect is less influential at low altitudes (Lloyd 1972). The plant's growth is supported by climatic factors, such as temperature, availability of sunlight, rainfall, and frost.

2.3 *Nitrogen Cycle*

The influence of invasive and ruderal plant species on nitrogen (N) availability is known to influence competitive outcomes between plant communities (Rout and Callaway 2009).Some previous studies suggest that *P. aquilinum* may stimulate N turnover and the accumulation of mineralizable N and NH4+ in rooting zone (DeLuca *et al*., 2012) and deep soils compared to that under ericaceous shrubs (Marrs *et al*., 1992; Mitchell et al. 1997). Soulsby and Reynolds (1994) investigated the relative contribution of deciduous trees, woody shrubs, and *P. aquilinum* to throughfall nutrient deposition in North Wales. They reported significantly higher N rates in throughfall under *P. aquilinum* than under the other two vegetation types (Soulsby and Reynolds 1994). In contrast, other studies have found reduced inorganic N and specifically reduced levels of NO_3^- in the soils invaded by *P. aquilinum* (Griffiths and Filan 2007; Smart *et al.*, 2007). A reduced presence of NO_3^- could be a function of the rapid uptake of NO3 - during the growing season; however, in NH_4^+ amendment experiments, Smart *et al*., (2007) found reduced nitrification rates under *P. aquilinum* compared with soils under grass. Such findings have led to the hypothesis that *P. aquilinum* influences community dynamics by maintaining a low inorganic-N concentration within the rhizosphere (Griffiths and Filan 2007). The lack of consistency in the evidence of inorganic-N dynamics in the rooting zone of *P. aquilinum* is likely to be due partially to differences in seasonal effects (mineralization versus uptake) and in part to the fact that most nutrient studies were carried out using inappropriate, incomplete, or outdated methods of assessing N turnover (Schimel and Bennett 2004).

3. *Allelopathic*

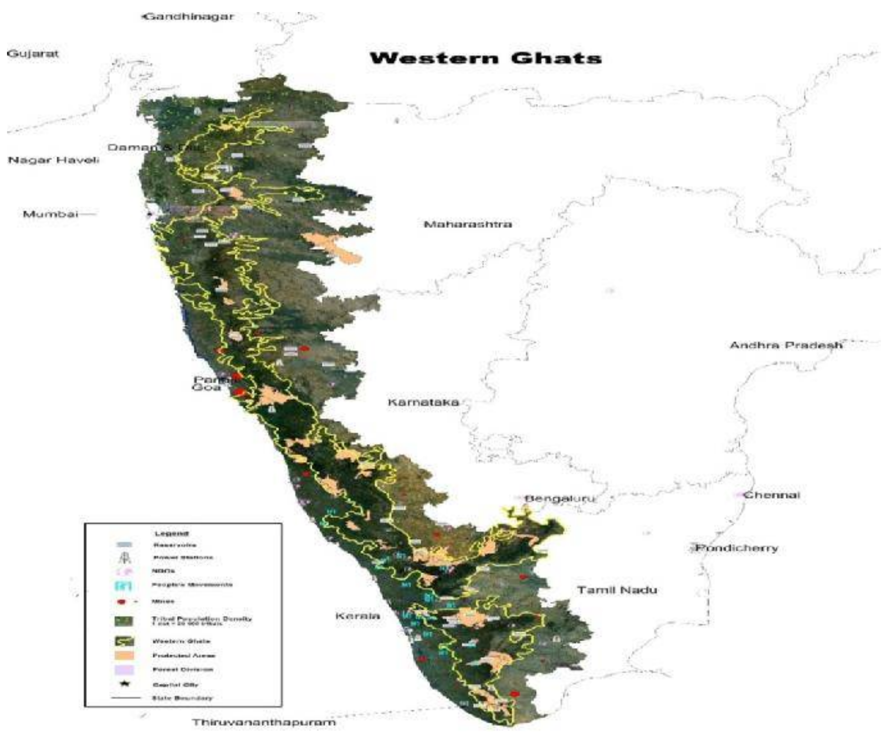
Studies suggest that the dominance of *Pteridium aquilinum* is governed by allelopathic chemicals. Allelopathy is defined as a plant's effects (stimulatory and inhibitory) on the development of neighboring plants through the release of secondary compounds (Thiebaut *et al*., 2019). Allelopathy, defined as the chemical interactions between plants or plants and microorganisms, could positively or negatively affect neighbors' performance (Rice, 1984). Allelochemicals are secondary metabolites with allelopathic potential. Allelochemicals contribute to environmental modifications and phytotoxic effects directly via phytotoxicity or indirectly (Einhelling 1986), by interfering with soil microbiota (Cipollini *et al*.,2012), nutrient cycling dynamics and availability (Kraus *et al*., 2003), or other processes. Phytochemistry study of *Pteridium* species have been performed on pharmaceutical and toxicological interest in their secondary metabolites and pterosins and pterosides activities, are the cause for carcinogenic activity, and, the compound which is responsible for the carcinogenic effects of *P. aquilinum* in mammals is the sesquiterpene ptaquiloside (Costa *et al*., 2012; Prakash *et al*., 2006).

4. *Management of Pteridium aquilinum*

*Pteridium aquilinum*represents a challenge in biodiversity conservation and management by contributing to the loss of native species. Studies revealed many control and management strategies had been applied as control measures; namely, harvesting of *Pteridium aquilinum* twice or thrice in a year and spraying asulam herbicide these two treatments were effective only for a certain period of time. Work has been carried out using endophytic fungal, phytophagous insects, and so on. Fungal endophytes treatment had no effective response in the control of *Pteridium aquilinum.*

5. Study area

Western Ghats: Brahmagiri Wildlife Sanctuary and Kudremukha National Park



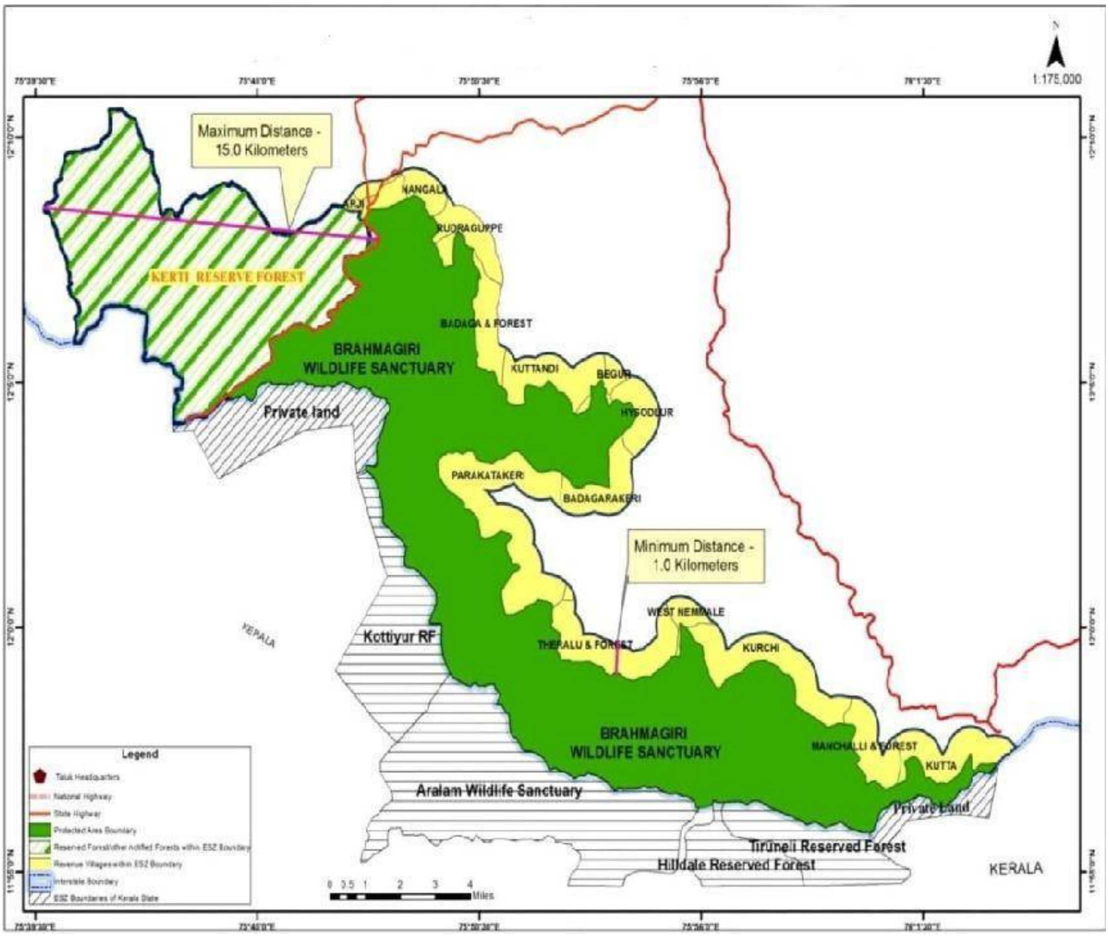
Source: B C Nagaraja and Chethan (2020)

Fig.1: Map showing the Western ghats region of India

Western Ghats is one of the world's eight hottest hotspots of biological diversity, consisting of 39 areas, including National parks, Wildlife Sanctuaries, and reserve forests. The Western

Ghats are internationally recognized as a region of immense global importance for conserving biological diversity, besides containing geological, cultural, and aesthetic value. Considering its importance in 2012, UNESCO declared the Western Ghats a heritage site. A stretch of mountains running parallel to India's west coast, approximately 30-50km inland, the ghats traverse the state of Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra, and Gujarat. These mountains cover an area of around 1,40,000 km^2 in a 1600 km long Stretch (UNESCO).

5.1 *Brahmagiri Wildlife Sanctuary*



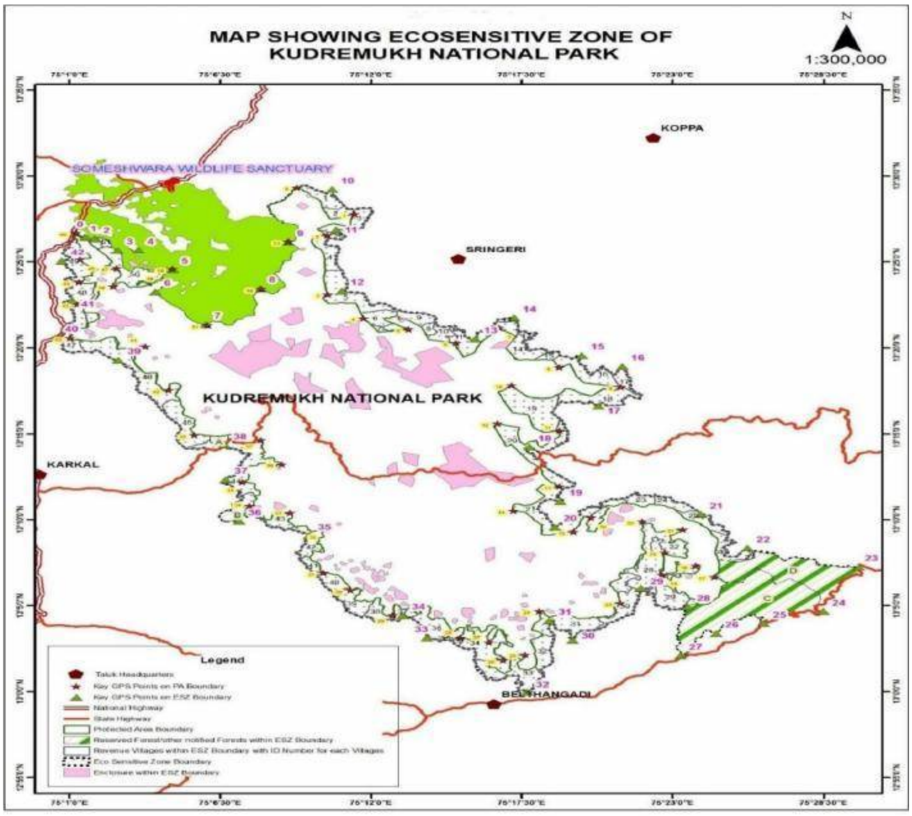
Source:Moefcc(2017)

Fig.2: Map of Brahmagiri Wildlife Sanctuary in Kodagu district, Karnataka

The Brahmagiri Wildlife Sanctuary is situated in the Kodagu (Coorg) district, Karnataka state and is part of the Western Ghats. It is situated on the border between the Wayanad district of Kerala state and Kodagu district. The Brahmagiri peak, is of 1607m in height and covers an area of about 181 km. Evergreen and semi-evergreen forest, are the major forest types and in the higher altitudes, there are grasslands with shola forest patches. The top Brahmagiri Hill is well forested and has a lot of wildlife.

5.2 ***Kudremukha National Park***

The study area lies within the Kudremukha National Park, located at the tri-junction of Dakshina Kannada, Udupi and Chikmagalur districts, Karnataka State. It falls approximately at the middle of mid-Western Ghats (the stretch between Goa and Nilgiris). The national park is a part of Sahyadri hill ranges and constitutes a geographic barrier between the coastal areas and the hinterland. The Kudremukha–Gangamoola belt of the Precambrian Dharwar Schist comprises hornblende schists, amphiboles and thick beds of magnetite–quartzites. The Tunga, Nethravathi and Bhadra are the major river flow in Kudremukha National Park.



Source: Moefcc (2017)

Fig.3**:** Map of Kudremukha National Park of Chikmagalur district, karnataka

5.3 ***Dominant species observed in Brahmagiri Wildlife Sanctuary and Kudremukha National Park***

Ageratina adenophora *Pteridium aquilinum*

Fig.4**:** Dominant species observed in the region of Brahmagiri Wildlife Sanctuary and Kudremukha National Park

Dominant species, *Ageratina adenophora and Pteridium aquilinum* had a greater influence on the native vegetation of Western Ghats. In recent years, *Pteridium aquilinum* has gained attention due to rapid distribution and establishment in the higher altitude of the grassland region of Brahmagiri Wildlife Sanctuary and Kudremukha National Park.

Conclusion

Although there have been many studies of invasive plants in protected areas, most are largely descriptive assessments of the extent of invasion, and many other invasions remain poorly explored. In the global context, the idea that species-rich communities like those in the Sholas of western ghats are less invisible than species-poor communities do not seem to hold well in recent times as new invaders like *Pteridium aquilinum* are rapidly expanding. Further, it has been shown that *Pteridium aquilinum* affects the species richness of the native flora (Stewart *et al.,* 2008).Based on the location, climatic factors, and other external and internal factors the dominating characteristics and variables, control and management of *Pteridium aquilinum*need to be assessed through further research work in the Western ghats region as the increased density may contribute to land use changes and may affect the climate change.

In global scenario, except in Antarctica *Pteridium aquilinum* is considered as an invasive species. Whereas, in the Indian context, the most common invasive species, such as *Lantana camara*, *Eupatorium adenophorum,*and parthenium are expanding faster in the lower elevations in the natural forests (GOI) have been listed in invasive species. According to the MOEF&CC 2020-2021 report, the *Pteridium aquilinum* has not been documented by Indian Council for Forestry Research & Education (ICFRE). "Important Invasive Alien Species (IAS) in Forests of India: Status and Management" (ICFRE) deals in detail with major invasive alien species in India.

Forest Department records and preliminary field visits revealed that Pteridium is spreading faster in montane forest areas in the Western Ghats region. Its expansion is hindering the grassland communities and regeneration of species on the edges of the shola forest. No studies are available on these areas' modes of expansion and regeneration. Also, frontline forest officials are not having adequate scientific information on its regeneration potential and its consequences on associated species and landscape. Hence the present study is visualized to investigate the Pteridium distribution and its influence on biodiversity and grassland ecosystem.

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DISTRIBUTION OF *LANTANA CAMARA* L., *CHROMOLAENA ODORATA* (L.) R. M. KING AND H. ROBINSONAND *SENNA SPECTABILIS*(DC.) H.S. IRWIN AND R.C. BARNEBYIN WAYANAD WILDLIFE SANCTUARY, KERALA, INDIA

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Abstract

Invasive species becomes a serious barrier for conservation and sustainable use of biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems. Although biological invasion is a natural occurrence, the current increase in invasion rates is unquestionably a result of human activity. Over the past century, the rate of invasion has accelerated due to the significant alteration of natural habitats. Increase in the number of IAS and their wide extent across the world is homogenizing the world's fauna and flora. The distribution characteristics of selected invasive alien species (IAPS) viz. *Lantana camara*, *Senna spectabilis* and *Chromolaena odorata* in three vegetation types (Plantation, Natural forest and Vayal) of Wayanad Wildlife Sanctuary (WS I and WS II) was studied. Through reconnaissance survey, five hundred 10 m × 10 m sample plots were randomly selected in each of the three vegetation types. In these 10 m × 10 m sample plots, the crown area was measured to determine the percentage of ground covered by invasive alien plant species (IAPS). This information was then used to illustrate the distribution of the IAPS in question. In disturbed natural forests, *L. camara*became the dominant understory vegetation (16.83% of the total sampled area was invaded by *L.camara)*. Wayanad's degraded fields, pastures, outskirts, and woods that are recovering from logging or fire could serve as a foundation for the growth of *Lantana*. Together with *Chromolaena*, *Lantana* invasion was widespread in WS I and WS II, with the exception of the boundaries between SulthanBathery and Muthanga ranges. The ability of *S. spectabilis* to supplant *Chromolaena* and *Lantana* is one of the reason for this. *Senna spectabilis* was mainly distributed along the boundaries of Sulthanbathery-Muthanga ranges and Kaimaram section nearer to Thirunelli RF in WS II and WSII parts respectively. *Senna spectabilis*has invaded about 10.9% of total sampled natural forest in the sanctuary. In Muthanga, *S. spectabilis*invasion was extended up to "Kakkapadam" (2.5 km from Muthanga station). *Chromolaena* has the highest rate of

Chandran, M.V., Gopakumar, S., Harilal, K**.** 2023. Distribution of *Lantana camara, Chromolaena odorata and Senna spectabilis* in Wayanad Wildlife Sanctuary, Kerala, India. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.288-296.

invasion in Plantation and Vayal. 16.34% of plantations and 30.34 % of Vayals in the Wayanad WLS have been invaded by *Chromolaena*. Mavinahalla and Kurichiat RF were discovered to have high levels of *Chromolaena* invasion. Out of the three major IAPS studied in this area *S.spectabilis* had shown maximum impact on the native species even with less percentage cover it had on the plots than other IAPS. It is now a major management challenge for forest managers all over the globe.

Keywords: Invasive Alien Plant Species, Wayanad Wildlife Sanctuary, Natural forest, Plantation, Vayal, Density, Percentage cover

Introduction

After habitat destruction, IAS (Invasive Alien Species) is considered as the second most threat to biodiversity (Pimentel *et al*., 2000). An alien species is an exotic or non-native species which was introduced by humans from one geographic region to another, intentionally or accidentally or through human agency for social or personal gain (Mandal, 2011). However, some of the alien species become invasive if they are affecting native biodiversity by competing with other organisms which are referred as Invasive Alien Species (IAS) (Reddy *et al*., 2008). Increase in the number of IAS and their wide extent across the world is homogenizing the world's fauna and flora (Mooney and Hobbs 2000). Invasion of alien plant species generate ecosystem imbalance and thus become harmful to ecological integrity and economics of the invaded area (Pimentel *et al*., 2000). The success of plant species in the alien environment has been attributed to lack of natural predators or possession of novel weapons such as allelopathy.

Materials and methods

Study area

The study was carried out in Wayanad Wildlife Sanctuary (WWS), Kerala State located in southern India, between October 2016 and February 2017. WWS is spread over 344km^{2}and comprises two discontinuous land areas of 77.67km^2(WS-I) and 266.77 km^2 (WS-II).There are three forest ranges in WS II (Muthanga, Kurichiat, and SulthanBathery) and one range in WS I (Tholpetty). The dominant natural vegetation in the sanctuary is characterized by moist and dry deciduous forest, teak and eucalyptus plantations, and bamboo brakes (Management Plan 2012–2022). Swamps, which are low lying grasslands. The land area locally known as vayals, represent an edaphic climax with its deep clayey soils and are waterlogged during the monsoon, but sustain grasses throughout the year.

Methodology

Wayanad Wildlife Sanctuary was divided into three vegetation zones viz. Natural forest (NF), Plantation and Swamps/Vayal (low lying grasslands). Through reconnaissance survey, five hundred 10 m × 10 m sample plots were randomly selected in each of the three above mentioned vegetation types. The percentage of ground covered by the invasive alien plant species (IAPS) like *Lantana camara, Chromolaeana odorata* and *Senna spectabilis* in these

10 m × 10 m sample plots were estimated by measuring the crown area. Assuming the crown as a circle, the length of crown spread was measured using a tape. The number of standing stems of these IAPS in these 10 m × 10 m plots were counted and recorded to calculate density. The density of weed species was converted to hectare. The distribution of the three IAPS in WS I and WS II was marked using GPS and the percentage cover was plotted using QGIS.

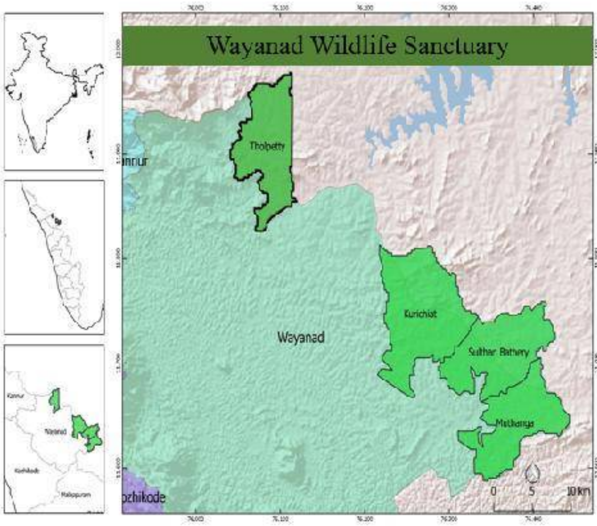


Figure 1. Location map of study area

Results anddiscussion

Density of IAPS

Density of each weed species in all the threevegetation type were calculated (Table 1). *Chromolaeana odorata* showed highest density in all the three vegetation types. There were 6700 stems of *Chromolaeana odorata* in one hectare of plantation. It was followed by *Lantana camara* (328.3 stems ha^{-1}) and *Senna spectabilis*(326.45 stems ha^{-1}). In NF there were 4365.29 stems of *Chromolaeana odorata* in one hectare. The density of *Lantana camara* and *Senna spectabilis* in NF were 573.3 and 231.92 stems ha^{-1} respectively. Maximum density of *Chromolaeana odorata* (6785.88 stems ha^{-1}) was seen in vayal.

Table1. Density of selected IAPS in each vegetation type

Vegetation type	**Density of IAPS (Number of stems /hectare)**		
	Chromolaeana odorata	*Lantana camara*	*Senna spectabilis*
Plantation	6700.52 ± 27.52	328.30 ± 1.02	326.45 ± 2.67
Natural forest (NF)	4365.29 ± 5.65	573.30 ± 2.75	231.92 ± 1.55
Vayal (Swamps/ low lying grassland)	6785.88 ± 9.74	334.71 ± 0.50	34.11± 0.21

Percentage covers of IAPS

The percentage of ground covered by IAPS was calculated in each vegetation type by measuring the crown area (Table 2). It was found that in NF about 16.83% of the total sampled area was invaded by *Lantana camara* and it is the most problematic invasive plant species in NF. It was followed by *Chromolaeana odorata* (13.07) and *Senna spectabilis* (10.9) is the least covered IAPS in NF. In vayal, *Lantana camara* and *Chromolaeana odorata* infested about 30.34% and 2.69% of the areas respectively. But *Senna spectabilis* (0.37%) infestation in vayal was comparatively lower than other IAPS.

Table 2. Percentage ground covered by selected IAPS in each vegetation type

Vegetation type	Percentage cover of IAPS (%)		
	Chromolaeana odorata	*Lantana camara*	*Senna spectabilis*
Plantation	16.34 ± 3.06	7.53 ± 1.96	5.5 ± 2.68
Natural forest	13.07 ± 3.09	16.83 ± 3.43	10.93 ± 3.85
Vayal (Swamps/ low lying grassland)	30.34 ± 4.03	2.69 ± 1.46	0.37 ± 0.24

Distribution of selected IAPS in WS I

Lantanacamara

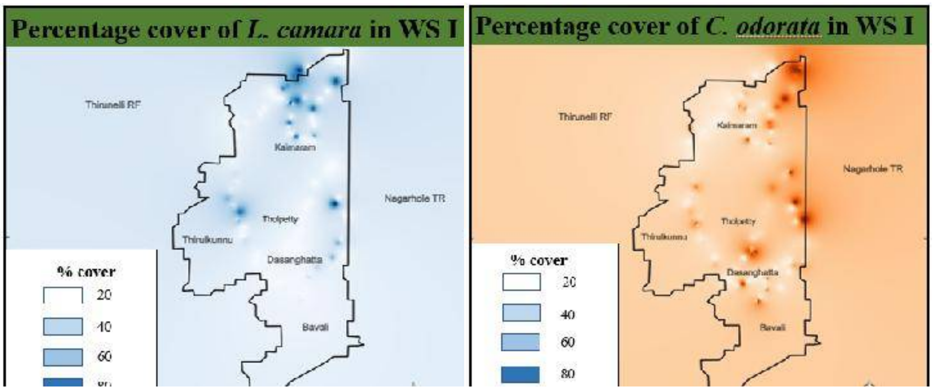
In WS I, high invasion of *Lantana camara* was seen in the Kaimaram (Image 1A) and Thirulkunnu sections (Fig. 2A). Kaimaram shares boundary with Nagarhole Tiger Reserve and Thirulkunnu section shares boundary with Thirunelli RF of North Wayanad division. Dasanghatta section had severe invasion but not like in Kaimaram and Dasanghatta sections. Bavali section which lies to the southern region had minimum invasion of *Lantana camara*.

Chromolaeana odorata

Chromolaeana odorata had invaded all parts of WS I. High invasion of *Chromolaeana* was found in Kaimaram and Dasnghatta (Fig. 7B) sections which directly shares the boundary with Nagarhole Tiger reserve of Karnataka (Fig. 7B). Maximum invasion was found within the boundaries. Thirulkunnu section that sharing the boundary with Thirunelli RF also had invasions. Bavali section had comparatively less invasion and found with in the section and not near the boundaries.

Senna spectabilis

In WS I of the Wayanad wildlife sanctuary *Sennaspectabilis* was mainly distributed in the Kaimaram section (Fig.7C) near the boundary between Thirunelli RF (Fig.3). It was also found near the boundary between Nagarhole TR and Kaimaram section. It was also found in the Dasanaghatta section. Thirulkunnu had very less invasion of *Senna spectabilis* and Bavali section had almost no traces of the invasion of *Sennaspectabilis* which is the southernmost region of WS I Sharing boundary with the Begur RF. *Senna spectabilis* infestation is on progress in these areas which could eventually took over all these regions in as shorter span of time.



A B

Fig. 2A - Percentage cover of *Lantanacamara*in WS I portion of Wayanad WS, Fig. 2B - Percentage cover of *Chromolaeana odorata*in WS I portion of WayanadWS

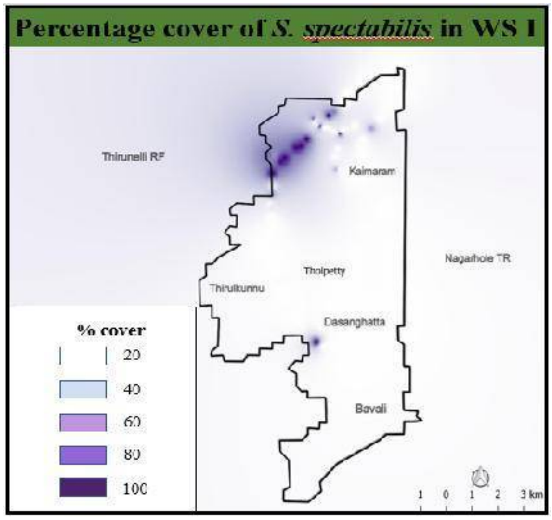


Fig. 3. Percentage cover of *Senna spectabilis* in WS II portion of Wayanad WS

Distribution of selected IAPS in WS II

Lantana camara

It was distributed all over the sanctuary except in the borders of Sulthanbathery and Kurichiat range (Fig.4). The high invasion of *Lantana camara* was seen in the Kurichiat RF (Kurichiat range), Rampur and Alathur RF in Sulthanbathery range and Edathara RF of Muthanga range. Less invasion of *Lantana camara* was seen in borders of Kurichiat and Sulthanbathery range. The borders of Mudumalai WLS and Mavinahalla RF were also free from *Lantana camara* invasion.

Chromolaeana odorata

Chromolaeana odorata invaded in all parts of WS II. High invasion of *Chromolaeana odorata* was found in Kurichiat RF of Kurichiat range, Mavinahalla and Noolpuzha RF of Muthanga range, Kallur and Rampur RF in Sulthanbathery range (Fig.5). The borders of

Kurichiat and Sulthanbathery ranges were free *Chromolaeana odorata* invasion. The borders of Mudumalai WLS and Mavinahalla RF in Muthanga range was less invaded by *Chromolaeana odorata*.

Senna spectabilis

In WS II of the sanctuary, *Senna spectabilis* was mainly distributed along the boundaries of Sulthanbathery and Muthanga ranges (Fig.6). The continuous infestation of *Senna spectabilis* extended up to “Kakkapadam” in Muthanga range (2.5 km from Muthanga station).

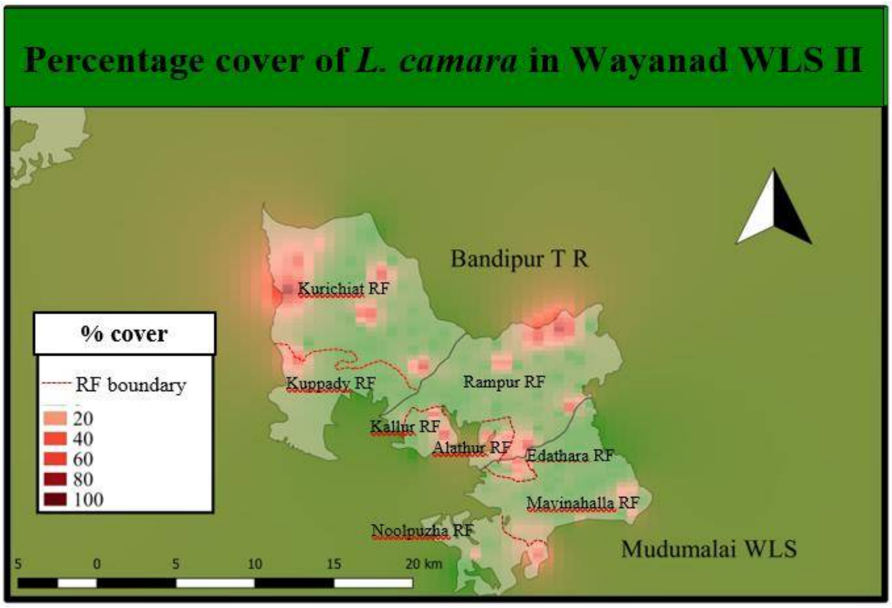


Fig. 4. Percentage cover of *Lantana camara* in WS II portion of Wayanad WS

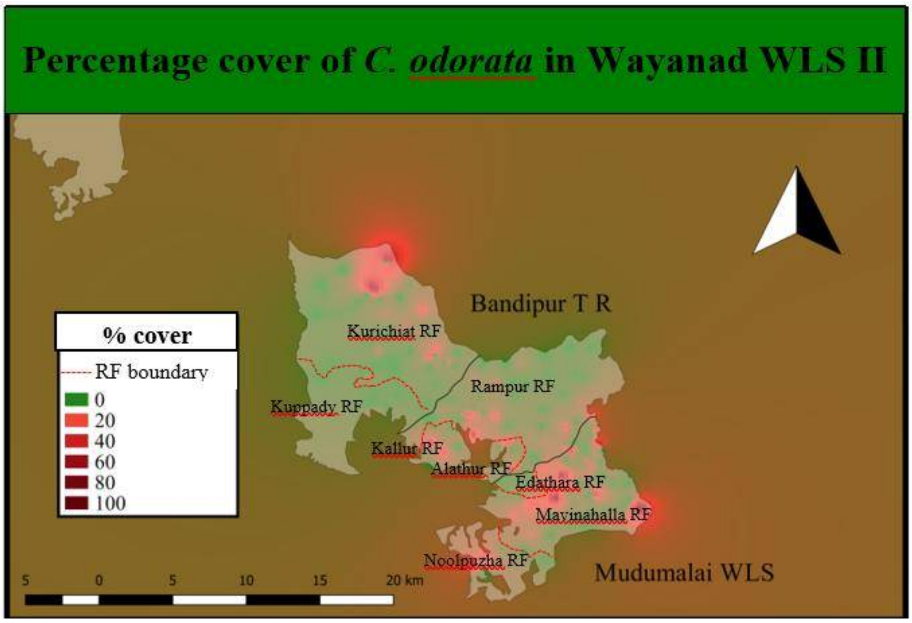


Fig. 5. Percentage cover of *Chromolaeana odorata* in WS II portion of Wayanad WS

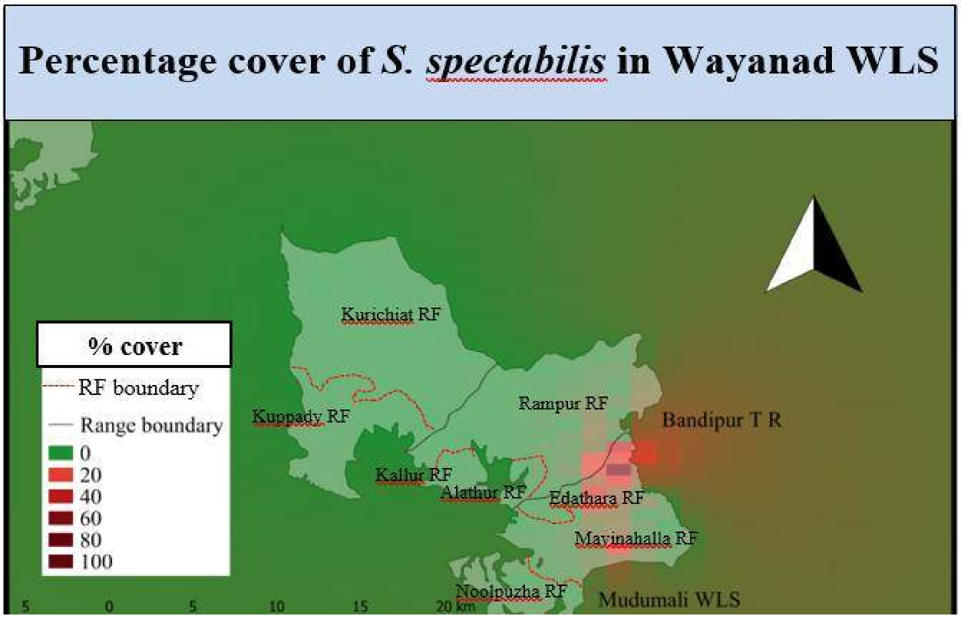


Figure 6. Percentage cover of *Senna spectabilis* in WS II portion of Wayanad WS

It was assumed that *L.camara* had been introduced to India during 1800's from Sri Lanka. As an ornamental plant, *L.camara* was introduced to National Botanical Garden in Calcutta (Mishra, 2014). In disturbed natural forests, *L. camara*became the dominant understory vegetation. Degraded land, pasture, edges of tropical and subtropical forests, warm temperate forests, and forests recovering from fire or logging could be a potential platform for the *Lantana* growth (Munir, 1996). The invasion of *L.camara* was known to be facilitated by the formation of forest openings due to fire, logging, and livestock grazing (Totland *et al*.2005), which may have concurrently led to native species loss and long-term persistence of dense *L.camara* thickets. All these factors are favorable in Wayanad WLS and these may the main reasons for invasiveness of *Lantana camara*. In WS I of Wayanad wildlife sanctuary the forest fire was recorded minimum but the grazing livestock is high and could act as a reason for the spread of *Lantana camara* like stated by Totland *et al*. 2005.

A B

Fig. 7. A-*Lantana* invasion, B- *Chromolaena* invasion

C

Fig. 7. C- *Senna* invasion in Wayanad WS

Chromolaeana odorata was the most invaded IAPS of WS I and it has now covered almost all regions. High invasion of *Chromolaeana* was found in all the forest sections viz. Kaimaram, Thirulkunnu, Dasanghatta and Bavali (Fig.2). In WS II, the borders of Kurichiat and Sulthanbathery ranges were observed to be free from *Chromolaeana* invasion. *Chromolaeana odorata*, is an Asteraceae member, introduced to many parts of the tropics is considered to be one of the most aggressive invasive plants which took over any habitat with no time in tropical and sub-tropical areas (Witkowski and Wilson 2001).*Chromolaena odorata* have the ability to establish and distribute quickly and smother native vegetation (McFadyen and Skarratt 1996).

Senna spectabilis invasion was found very serious in WS I part of Wayanad Wildlife Sanctuary. It is now a major management challenge for forest managers in the Sanctuary. Major invasion of *Senna*in WS I part was found towards the northern regions. Kaimaram section was the most effected region and Bavali section showed very less infestation. In WS II of the sanctuary *Senna spectabilis* was mainly distributed along the boundaries of SulthanBathery and Muthanga ranges (Fig.6). From Muthanga station, *Senna* invasion was extended up to Kakkapadam in Muthanga range. *Senna* was also seen invaded on the both sides of national highway from “Ponkuzhy” station to Kerala-Karnataka border.

According to the records of the Kerala Forests and Wildlife department, it was in 1986, as part Social forestry’s shade tree planting program, seedlings of *Sennaspectabilis*were first raised in “Ponkuzhy” in Muthanga range. Seedlings were first planted in front of Muthanga forest station and along the sides of Muthanga range office (Fig.8). Fifteen seedlings were planted in Muthanga and some seedlings were also planted in “Meppadi” and “Aanappara” regions of Wayanad territorial division. First flowering of *Senna*appeared seven years after planting, the beautiful yellow flowers attracted tourists. After 15 years of planting, these trees attained a GBH of 270 cm. Then it started dispersing seeds and acquired an invasive character within a short time period. In the current study, the density of *Senna* in the plantation areas was 326 trees ha^{-1} and 231 trees ha^{-1} was the density in NF (Table 1).

Fig.8. Remainings of first *Senna spectabilis planting* in Wayanad Wildlife Sanctuary

Conclusion

Lantana and *Chromolaena* are distributed all over the sanctuary and it is also creating impact on the regeneration of native species. Out of the three major IAPS studied in Wayanad WLS, *Senna* had shown maximum impact on the native species even with less percentage cover it had on the plots than other IAPS. It is now a major management challenge for forest managers in the Sanctuary.

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EFFECTS OF FRUIT ABUNDANCE OF *LANTANA CAMARA* ON THE DIVERSITY OF FRUGIVOROUS BIRDS AND ITS IMPACT ON SEED DISPERSAL AT BATHERY RANGE, WAYANAD WILDLIFE SANCTUARY, KERALA.

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Abstract

Lantana camara (Family – Verbenaceae), is a scrambling intensely scented and highly branched shrub that normally reach heights (under 4 metres). The invasion of this alien species negatively affects the diversity of the forest ecosystem in Bathery Range (76˚18’0”E and 11˚44’0”N), Wayanad Wildlife Sanctuary, Kerala. The quadrats (n=25) taken for this study shows that the invasion of *Lantana camara* was observed to be very high (73%) and elevated the number of associated frugivorous birds (62.5%). The interaction between the invasive plants and frugivorous birds can cause wide range of seed dispersal in the forest ecosystem that can result into its massive invasion. Due to its adaptability even to the adverse environmental conditions, it poses a serious threat to the existence of the native flora and fauna.

Keywords: *Lantana camara*, Bathery, seed dispersal, frugivores.

Introduction

The invasion of alien species threatens the species diversity globally (Vitousek *et al*., 1996; Wilcove *et al*., 1998; Gurevitch and Padilla, 2004). The spread of alien invasive species, particularly plants, has grown to be a significant issue since it affects ecosystem functioning and results in the loss of biodiversity globally (Gooden *et al*., 2009; Jordaan *et al*., 2011; Saha*et al*., 2018; Shackleton *et al*., 2019).*Lantana camara* L. (Family: Verbenaceae), a native of tropical America (Holm *et al*., 1977), is found in 47 countries and has been described as one of the world’s ten worst weeds (Cronk and Fuller, 1995).In India, it was introduced during 1807 as an ornamental plant at the National Botanical Garden of Calcutta (Thakur *et al*., 1992). Later, it invaded into the wild and successfully propagated throughout the Indian subcontinent. Its invasions spread over the habitats like grazing land, agricultural fields, forest area and grassland. (Priyanka and Joshi, 2013). The attributes like colorful inflorescence and nectar can attract the pollinators like butterflies, bees and thrips. However, *Lantana* produces

Jobin, M. J. and Zubair, M. 2023. Effects of Fruit abundance of *Lantana camara* on the diversity of Frugivorous Birds and its impact on seed dispersal at Bathery Range, Wayanad Wildlife Sanctuary, Kerala. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.297-302.

large number of berries that are blue-black in colour when mature and dispersed by frugivorous birds, rodents and fox (Reshmi, 2015).

Birds are considered as good ecosystem indicators (Blair 1996).In most ecosystems, frugivorous birds are the important seed dispersers. (Herrera, 1995; Stiles, 2000). They enhance the seed dispersal of many fleshy-fruited invasive plants, and it plays a significant role of the dynamics of invasion. Lantana berries attract frugivorous birds and that helps to disperse its seeds widely (Day *et al*., 2003). The massive invasion of Lantana alters the structure and composition of the forest. The present study assess that the diversity of frugivorous birds and its impact on Lantana seed dispersal.

Materials and methods

The study was carried out in the Bathery Range of the Wayanad Wildlife Sanctuary, Kerala. This area is situated between 76˚18’0’’ to 76˚24’0’’E and 11˚40’0” to 11˚44’0’’N. The total number of twenty-five, 2m x 2m quadrats that is 50m area wastaken for sampling the vegetation composition (Mason & French 2007).From the months of March to May 2022, bird foraging activity on fruits of the *Lantana camara* was monitored. Bird counting was done by line transect (Krebs, 1989).Observation of bird foraging activity was performed with binocular (Nikon, 10x42 magnification).Field guides were used to identify the birds (Ali and Ripley, 1983; Ali, 1999; Grimmet *et al*., 1999; Karmierczak, 2000). Based on the observations, the for aging guilds were categorized into frugivores, insectivores and nectarivores (Ali & Ripley, 2001).

Results

In the study area four species of shrubs were observed (Table: 1), this includes *Lantana camara*,*Cromolaena odorata*, *Helicteres isora* and *Chassalia curviflora*, of which *Lantana camara* is the most dominant species (73%). Overalltwenty-four species of birds belonging to sixteen family (Table: 2) were recorded on Lantana, among these, frugivore birds (Table: 3) are the dominant visitors (62.5%) followed by insectivores (25%) and nectarivores (12.5%) respectively.Under the frugivore category, the family Pycnonotidae were dominant (23%) (Fig.1).

Table 1: Percentage of shrub species found in the study area

Shrub species	% of occurrence of shrub species
Lantana camara	73.00
Cromolaena odorata	12.50
Helicteresisora	5. 75
Chassaliacurviflora	8.75

Table 2: List of 24 avian species on *Lantana camara*. Foraging guilds: F - Frugivores, O – Omnivores, N – Nectarivores, I – Insectivores

Family	**Species**	**Foraging guild**
Dicaeidae	*Dicaeum agile*	F
Cuculidae	*Eudynamysscolopaceus*	F
Zosteropidae	*Zosteropspalpebrosus*	F
Corvidae	*Dendrocittavagabunda*	O
Megalaimidae	*Psilopogonhaemacephalus*	F
Psittaculidae	*Loriculusvernalis*	F
Pycnonotidae	*Pycnonotusjocosus*	F
Psittaculidae	*Psittaculakrameri*	F
Nectariniidae	*Cinnyris asiaticus*	N
Leiothrichidae	*Argya striata*	F/O
Sturnidae	*Acridotheres tristis*	F
Sturnidae	*Acridotheres fuscus*	F
Pycnonotidae	*Pycnonotusluteolus*	F
Megalaimidae	*Psilopogonviridis*	F
Pycnonotidae	*Pycnonotuscafer*	F
Dicruridae	*Dicrurusmacrocercus*	I
Nectariniidae	*Cinnyrislotenius*	N
Leiothrichidae	*Argyaaffinis*	F/O
Phylloscopidae	*Phylloscopustrochiloides*	F
Nectariniidae	*Leptocomazeylonica*	N
Cisticolidae	*Orthotomussutorius*	I
Aegithinidae	*Aegithina tiphia*	I
Muscicapidae	*Copsychussaularis*	I
Meropidae	*Meropsorientalis*	I

Table 3: Percentage of foraging type in the study area

Foraging type	% of foraging type
Frugivores	62.50
Insectivores	25.00
Nectarivores	12.50

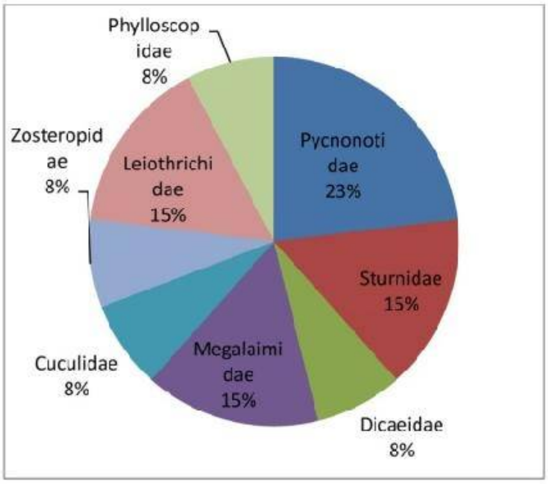

Figure 1: Percentage of frugivorous bird species on *Lantana camara*

Discussion

The invasion of Lantana is very high in the study area. This invasive species is capable of disrupting life cycle and thereby displacing the indigenous native flora of any region, which leads to a decline in floral diversity. Birds are recognized as the main dispersal agent of many invasive plant species (Dean and Milton, 2000; Stansbury and Vivian-Smith, 2003). Several highly invasive plants are fleshy-fruited and owe their invasiveness largely to mutualisms formed with local dispersers. Invasive species are sometimes preferred by frugivores and may therefore compete with native plant species for dispersal agents (Lafleur *et al*., 2007). Frugivorous birds are the dominant visitors of *Lantana camara*, among them the family Pycnonotidae had the highest (23%) frugivores in the study area. According to Aravind *et al*. (2010), the fruits of *Lantana* are fleshy and available year-round and it is a major food source of Bulbuls. The present study states that, among the frugivorous birds, Bulbuls are the most dominant species for feeding *Lantana* berries and they are the main *Lantana* seed dispersers of the study area. The mutual relationships between the frugivorous birds and *Lantana camara* increases the invasion of the plant and have a major threat to other plant communities. Similar results were seen in the studies carried out by Aslan, 2011; Jordaan *et al*., 2011; Jordaan and Downs, 2012; Vergara-Tabares *et al*., 2018; Dlamini *et al*., 2018.The continuous fruiting of this plant species is the major attraction to the frugivorous birds. By feeding on the alien species, birds increase the density and distribution of invasiveness at the expense of native vegetation thereby displacing other bird species (Day *et al*., 2003). It may alter the forest ecosystem and adversely affect the avian diversity. Avianfrugivores play a key role in dispersing many fleshy-fruited invasive plant species to different locations (Buckley *et al*., 2006; Martin-Albarracin *et al*., 2018) and often have a profound impact on the invasion dynamics through dispersal services. The fleshy-fruited invasive plant species that overcome the dispersal barriers by forming a mutual relationship with the frugivores as a seed dispersal networks that are rarely specialized (Milton *et al*., 2007; Deckers *et al*., 2008; Cruz *et al*., 2013; Ramaswami *et al*., 2016; Amodeo *et al*., 2017).

Conclusion

In the study area, the Bulbuls are the most observed avian species associated with *Lantana* berries. The fruit abundance of *Lantana camara* enhances the assemblage of frugivorous birds. The continuous fruiting of the alien plant species is the major reason for attracting the avian frugivores. Their aggregation enhances the seed dispersal and massive invasion of the alien plant species in the study area. Due to this massive invasion, it may cause a future threat to avian diversity. The fast growth of *Lantana* also has the capability of interfering with the growth of other native plant species, and thus posing a great threat to the forest ecosystem.

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MANAGEMENT OF LANTANA BIOMASS THROUGH FUEL PELLETIZATIONTECHNOLOGY IN LOWER SHIVALIK FOOTHILLS PUNJAB

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Abstract

The lower Shivalik foothill (kandiarea) spanning various states of Northern Region of the country faces various challenges impacting agricultural productivity, one being infestation with *Lantana camara*, a toxic & invasive weed. The present study has been carried out in Talwara Block (inkandi), District Hoshiarpur having abundant Lantana in agricultural& forest land with the aim to produce technology prototype for production of energy fuel pellets using combination of Lantana along with other local waste i.e. amla processing waste of the region. Theproduced pellets showed optimal physical characteristics and promising results in terms of proximate& ultimate analysis. The 100% Lantana based fuel pellets gave optimal results in terms of 3997 Kcal/kg gross calorific value, 16.56% fixed carbon, 76.20% volatile matter, 2.20% ash and 5.04% moisture content. Further, cook stove emission testing in terms of low CO & CO_2emission showed the safe usage & application of produced pellets in domestic and industrial settings. As per standard BS EN ISO 17225-7:2014, the pellets produced in present study can be categorized as Grade-A solid fuel. Two Pilot Pelletization Units specially designed & fabricated have been demonstrated in the area for use by local self help group women members. The Talwaracase study depicts the potential of utilization of *Lantana camara* weed as clean energy fuel, paving way for its utilization by local community for income generation as well as alternate fuel usage which could pay for its management in the backward kandi area.

Keywords**:** Invasive species, Lantana, Fuel Pellets, Biomass, Gross Calorific Value

Introduction

The ever growing energy demand, uncontrolled global emissions from fossil fuel and depleting fuel resources are some of the critical parameters of concern especially in today's scenario of environment & climate change. The focus is being shifted towards renewable resources, which have emerged as a potential contender for alternative to fossil fuels. Concentrated efforts are being made by scientific community for developing sustainable technologies on cleaner fuel production. Biomass is the largest source of energy with the potential to fulfil about 9% of global energy demand as per International Energy Agency (Saravanan et al. 2018).India has availability of about 500 MT of biomass which can cater to

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Arora. J.K., Bakshi. D.K., Singh. A.K., Sharma, A. 2023. Management of lantana biomass through fuel pelletization technology in lower Shivalik Foothills Punjab. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.303-309.

demand of 18,000 MW approx. electricity (Sharma et al. 2020). Scientist worldwide are working on use of energy crops, forest waste, agro residue as well as alternative sources of biomass viz. Invasive weeds etc.

Besides other weeds, Lantana is one of the invasive weed with a spread of about 13 million hectare area in the country (Mungi et al. 2020; Bhagwat et al.2012). Over the years, various chemical, biological, and manual techniques have been explored to control Lantana; however the challenge is still open-ended. The chemical methods like Glyphosate and Fluroxypyr spray, are not environment friendly and cause serious impact on human & animal health(Raj et al. 2018) while biological methods involving organisms i.e. *Teleonemia elata* (leaf-sucking bug) and *Calycomyza lantanae* (agromyzid seedfly)have not been found to be effective (Negi et al. 2019). In contrast, the manual technique has been found to be effective specifically in small areas with complete elimination of rootstocks (Dohn et al. 2013).

Lantana camara is a toxic and invasive environmental weed having presence in abundance in lower shivalik foothills of Northern India. Attempts have been made to use Lantana as biomass in its original loose form as a fuel, however, its effective utilization has been limited due to its high moisture content, irregular shape and sizes, and low bulk density. The present study involved use of pelletization technology for development of energy rich fuel pellets from abundantly available lantana in combination with other bioresources from backward kandi area of Block Talwara, District Hoshiarpur, Punjab. The study focused to develop pilot unit prototype for production of fuel pellets using different combinational treatments of biomass i.e. Amla pomace and lantana, their characterization as well as cook stove emission w.r.t. impact on climate.

Materials and Methods

Biomass Collection

The lower shivalik foothills, known as Kandi area of Talwara Block, District Hoshiarpur was scouted for the presence of biomass. *Lantana camara*was found to cover about 40% of the forest area as per data shared by Department of Forest. Further, being backward area with less agricultural productivity, *L. camara*was also found abundantly at agricultural fields replacing green pastures. Further, the target area also has 4-5 food processing units utilizing wild amla as a major bioresource and hence producing amla processing waste/pomace in huge quantity. Hence, the experimental biomass for pelletization i.e. Lantana and Amla pomace were collected from forest area and agro-processing facilities of Talwara, respectively.

Biomass Pelletization Unit

The technical design & specification of biomass pelletization unit was finalized in-house at the Council. The pilot pellet prototype developed in collaboration with the fabricator comprised of two functional components viz. grinder machine and a pellet mill as depicted in Figure-1. In the grinder unit, the raw materials are fed into a hammer mill which grinds raw materials into smaller pieces during the process. Pellet mill consists of a die with cylindrical press channels and rollers to force the biomass to flow into and through the channels. A high backup pressure is built up in the press channels to force the biomass particles which squeeze out of the opening, resulting into formation of pellets of the size of 10 mm. The technical specifications of pelletization unit are shown in Table 1.

Table 1: Technical specifications of Pilot Pelletization Unit

Functional Unit	Technical Specifications
Pellet Mill	▪ Capacity: 75 Kg/hr±10% ▪ Pellet Size: 10 mm ±10% ▪ Top drivermechanism ▪ Rated Power: Three phase A.C Induction motor (10 HP)
Grinder Machine	▪ Input size: 25-50 mm ▪ Output size: 3-10mm ▪ Requisite induction motor with accessories

Figure 1: Pictorial view of pilot pelletization unit used for experimentation

Pelletization Trials

The trial runs were initiated with different combinations of Amla pomace and Lantana biomass. The collected biomass was sun dried to reduce the net moisture content (upto5-10%). The dried biomass was further subjected to desizing with the help of grinder unit to obtain powdered biomass. The biomass combinations were mixed in proportionate ratios along with molasses as binder and fed to pellet mill for producing pellets. The brief overview and stages for processing of fuel pellets from biomass are depicted in Figure-2. The different combinational treatments of biomass for production of pellets are presented in Table-2.

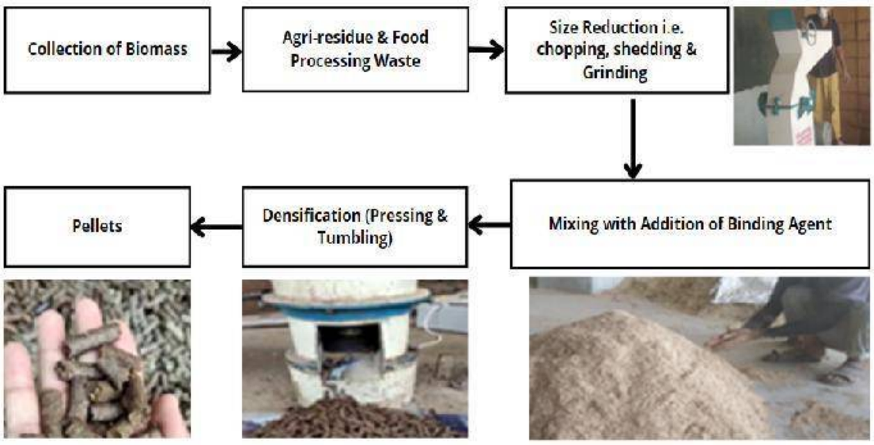

Figure 2: Process flow of pelletization

Table 2: Different combinational treatments of biomass for production of pellets

Treatment	Biomass	Combinations (%)
T1	Amla Pomace: Lantana	70:30
T2	Amla Pomace: Lantana	50:50
T3	Amla Pomace: Lantana	30:70
T4	Amla Pomace: Lantana	10:90
T5	Lantana	100

Characterization and Cook Stove Emission Testing

The produced fuel pellets were characterized using proximate and ultimate analysis. The tests were carried out in accordance with standards IS: 1350 (Part II)-1984 &ISO 17247:2020. The parameters analyzed were moisture, ash content, volatile matter, fixed carbon & Gross Calorific Value (GCV). The testing was carried out at Analytical Testing Laboratory at Thapar University, Patiala. The cook stove emission testing of fuel pellets with standard IS: 13152 (Part 1): 2013 was conducted to analyze mission values of CO & CO_2. The testing was carried out at Sardar Swaran Singh National Institute of Bio-Energy, Kapurthala.

Results and Discussion

Proximate & Ultimate Analysis of Pellets

The results for proximate & ultimate analys is of fuel pellets produced from different mixtures of amla pomace and Lantana biomass are presented in Table-3. The parameters analysed for the quality and characterization of pellets included moisture and ash for analysis of the non-combustion characteristics, volatile matter for burning characteristics, fixed carbon and GCV for energy and acceptability of pellets as suitable fuel.

Table 3: Results of proximate and ultimate analysis

Treatment	Biomass	Moisture(%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	GCV (Kcal/Kg)
T1	Amla Pomace: Lantana (70:30)	24.58	4.65	57.74	13.99	3571
T2	Amla Pomace: Lantana (50:50)	14.47	4.15	66.81	14.57	3694
T3	Amla Pomace: Lantana (30:70)	9.95	3.45	71.18	15.42	3768
T4	Amla Pomace: Lantana (10:90)	5.18	2.92	75.67	16.23	3984
T5	Lantana(100)	5.04	2.20	76.20	16.56	3997

The effect of Lantana biomass ratio on ash and moisture content of fuel pellets is plotted in Figure-3. The results clearly show that ash and moisture content of pellets dominantly decreased with rise in Lantana proportion of mixed biomass. As the Lantana proportion increased from 30% to 100%, the moisture content of produced pellets decreased from 24.58% to 5.04%, the reason being, the dried form of Lantana biomass compared to food processing waste used. This finding also correlates well with previous research for production of briquettes from Lantana with moisture content of 5.5% [8]. Similarly, the ash content of pellets decreased from 4.65% to 2.20% with upsurge of Lantana proportion from 30% to 100%. The reduced ash content in Lantana based fuel pellets highlights good quality solid fuel. The volatile matter and fixed carbon content of Lantana based fuel pellets is highlighted in Figure-4. Volatile matters are those components of fuel which can easily burn in oxygen. As the Lantana proportion increased from 30% to 100%, the volatile matter increased from 57.74% to 76.20%. The high volatile matter signifies better burning characteristic of fuel pellets. Likewise, the fixed carbon content of pellets upsurge from 13.99 % to 16.56 % with increase in Lantana proportion from 30% to 100%. The low moisture and ash content of pellets is the probable reason for high fixed carbon. Kumar and Chandrashekar (2020) found similar result for fixed carbon content of 18.6% in case of Lantana briquettes.

The GCV for pellets produced with different combination of Lantana is highlighted in Figure-5. GCV of pellets significantly increased with increase in Lantana content of biomass. The highest GCV of 3984 Kcal/Kg and 3997 Kcal/kg was observed in case of biomass pellets produced from Lantana proportion of 90% & 100% respectively. The higher GCV of fuel pellets occurred due to increase of volatile matter and fixed carbon content. The GCV of pellets i.e. 3997 Kcal/kg (~16.72 MJ/Kg) is quiet similar with previous research findings for Lantana briquettes i.e. GCV of 18.6 MJ/kg [8].

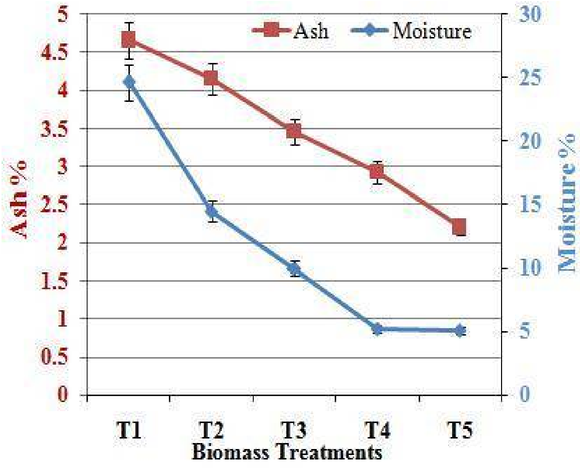

Figure 3: Ash and Moisture Content of Lantana based pellets

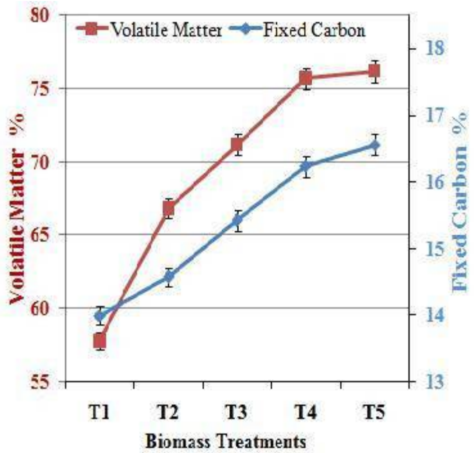

Figure 4: Volatile matter and fixed carbon content of Lantana based pellets

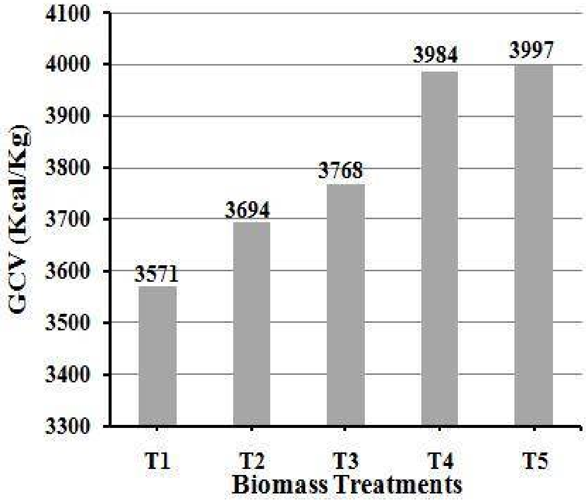

Figure 5: Effect of Lantana ratio on GCV of fuel pellets

Cook Stove Emission from Pellets

The cook stove emission test of fuel pellets were carried out in accordance with environmental permitting regulations. The detailed analysis of Cook stove emission studies of fuel pellets is presented in Table-4.The emission values of CO & CO_2 during pellet combustion lies in the threshold limit of the exposure. This reflects safe usage & application of produced pellets which can be used in domestic & industrial settings.

Further, the results of pellets were compared with the threshold limit of the standard for graded non-woody briquettes (BS EN ISO 17225-7:2014; Malik et al., 2022). As per standards, the pellets having ash content less than 6.0% and GCV of ≥14.5 MJ/Kg are categorised as Grade-A solid fuel. As reported in Table-2, the pellets produced using different combinations of Amla pomace and Lantana have ash content and GCV under the threshold limit of the standard. Therefore, the pellets produced in the present study can be categorised as Grade-A solid fuel.

Table 4: Cook stove emission testing of fuel pellets

Parameters	Result	Error	Units
CO PPM	83.59	± 10.83	ppm
CO_2 PPM	0.20	± 0.001	% Vol
O_2 PPM	16.52	± 0.01	% Vol
SPM	1.00	±0. 01	mg

Conclusions

The present study shows the potential of *Lantana camara* for utilization as a quality energy pellet with high gross calorific value of 3984 Kcal/kg (90%) and 3997 Kcal/kg (100%), which is at par with the conventional fuels used. The pellets produced were found to have excellent characteristics viz. shape, density, moisture & ash content. Further, low GHG emission in terms of CO & CO_2 during pellet combustion indicates environment friendly nature which makes it a safer & less polluting fuel. As per standard for graded non-woody briquettes i.e. BS EN ISO 17225-7:2014, the pellets produced have been categorized as Grade A solid fuel.

Further, attempt has been made to disseminate the technology in Talwarakandi belt where end-to-end approach has been followed by setting up of indigenously developed pilot production units, capacity building of local community to use the facility for producing Lantana based fuel pellets to address the rural energy demand.

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INVASIVENESS OF *TRIDAX PROCUMBENS* IN THE PALAKKAD GAP OF THE WESTERN GHATSIN SOUTH INDIA.

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Abstract

Tridax procumbens has naturalized in many areas all over the globe. The weed is native to tropical and subtropical Americas. The characteristic trait responsible for its massive spread is that it can grow under a wide range of environmental conditions. This weed has been flourishing in the Palakkad Gap, especially along roadsides, inspite of the conditions into which it has been. Hence the data has been collected for all the threeseasons. Field data is comprised of plant samples, species number from observation points and other species associated with *T.procumbens.* Geographic coordinates of the collection sites were taken. The Palakkad Gap, in South India, being a part of Western ghats is rich with its biodiversity and hence a deep interest has been taken to study the spread of *T.procumbens.* Its spread to other habitats is also beingtraced. It's seen in agricultural areas but not currently a disturbance.

Key words: *Tridax procumbens*, The Palakkad Gap, Roadsides, Weed.

Introduction

Invasive alien plant species (IAPS) is considered as a major threat to ecosystem stability and global biodiversity. Invasion has to be checked by all means and the management proceedings that prevent the spread and impacts of such a species require information of their ecological and genetic studies. The invasion studies have long been recognized as a significant subject for ecosystem preservation and conservation. Biological approaches have been resorted to and have identified many factors that are significant for successful invasions. These have led to quantitative predictions of establishment and enhance of invaders (Sakai et al. 2001; Prentis et. al. 2008).When a species gets introduced to a new area, it must be able to cope up with a range of novel environmental pressures. Invasive weeds of the Palakkad Gap provided an opportunity to study alien plants' successful biological invasion process.

The present study aims to elucidate the invasion mechanisms of *Tridax procumbens*, family Asteraceae, a native of America while a weed in many parts of tropical and subtropical regions in the world, by field observations, specimen identification, surveys and community estimates. The Palakkad Gap, part of Western Ghats is with flourishing biodiversity and hence the areas need to be well protected from IAPS.*T. procumbens* occurs in many environments but is particularly well adapted to coarse-textured soils in -the Palakkad Gap.

Rehna. E.T.and Maya.M.V. 2023. Invasiveness of *Tridax procumbens* in the Palakkad gap of the Western Ghats in South India. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.310-317.

It's aperennial herb and has been seen that it extensively spread along the habitat – roadsides, which makes it's furtherance to other areas.

World distribution of *T. procumbens*

Introduced to tropical, subtropical, and mild temperate regions worldwide.

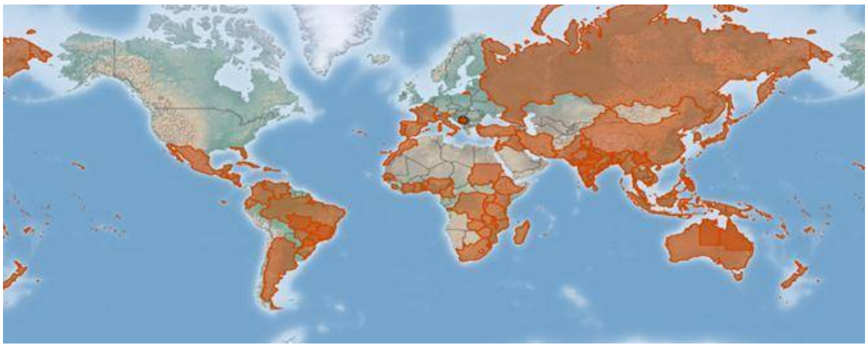

Fig.1 Distribution sites *of T. procumbens*

Study area and methods

Study area

Palakkad Gap is rich with flora and is a low mountain pass of Western Ghats in South India, between Coimbatore in Tamil Nadu and Palakkad in Kerala. Average elevation of Gap is 140 metres with a width of 24–30 kilometres. Location is in between the Nilgiri Hills to the north and Anaimalai Hills to the south - (border of Palakkad and Tamil Nadu).Coordinates of Palakkad Gap - 10.1667^{0}N, 77.0667^{0}East.

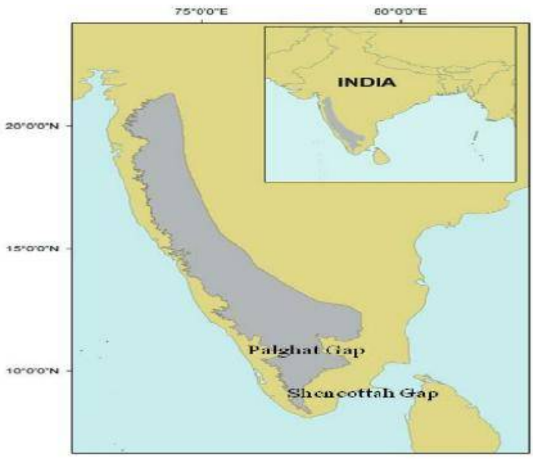

Fig.2.and Fig.3.The Palakkad Gap in the map of S.India

It has been a major trade route between the east and west coast of peninsular India and plays a significant role in the climate of the neighbouring areas of Coimbatore and Palakkad. It permits the south west monsoon to enter Coimbatore thereby moderating the summer temperature of the area and provides much rainfall compared to the other districts of Tamil Nadu.

The Gap topography is the direct product of shearing and erosion. Palakkad, formerly Palghat, city, central Kerala state, is in southwestern India. It's on the Ponnani River in the Palghat

Gap and the total area is 1080 sq.km. Area is rich with biodiversity, but invasive species are also naturalising. *T.procumbensis* the dominant invasive on roadsides of the Palakkad Gap, and its means of spread to other habitat's is also studied.

Field survey and data collection

Study of Morphology, Tridax *procumbens* L.

Synonyms. *Amelluspedunculatus* Ortega ex Willd., *Balbisia elongate* Willd.,*Chrysanthemum procumbens* (L.) Sessé & Moc., *Tridax procumbens* var. *Canescens* (Rich. ex Pers.) DC. and *Tridax procumbens* var. *ovatifolia* B.L.Rob. &Greenm.

Common names. Coat buttons and Tridax daisy

Detailed morphological characters of the species from the field were noted and confirmed with herbarium material and then compared with the taxonomic information from relevant literature. Regional floras were used to identify the plant specimens' viz., Flora of British India and Flora of the Presidency of Madras.

General habit –Perennial herb.

Underground system - Rooting at lower nodes.

Stem - Stems are soft procumbent with hairs.

Leaf-The leaves are ovate, up to 4-5 cm long, pointed at the apex and narrowing gradually to the leaf base, with marginal teeth or lobes.

Inflorescence - Inflorescence is a terminal involucrate flower head "Capitulum", which is solitary on erect peduncle, 10 cm to 25 cm long.

Flower - On erect stems, flower heads are seen. They are up to 30 cm long and12 mm across. Numerous, tubular disc florets are surrounded by a ring of short, strap-shaped ray florets in the head.

Fruits- The fruits are hairy and with long, bristles.

Propagation - By seeds with pappus hairs as sandy stream beds.

Origin - Native to the Tropical America.

Dry weight, plant height and leaf area index of T. procumbens are reduced by shade (Shetty et al., 1982).


Fig 4.Capitulum of *Tridax procumbens*, Fig 5 .Habit -*Tridax procumbens*

Survey

Extensive survey of the Gap was carried out for three seasons from January 2019 to December 2021 covering their natural habitats - roadsides, fallow lands, agricultural areas and forest lands. From preliminary observation, it has been found that the massive spread along the habitat, roadside is responsible for furthering the invasiveness of *T.procumbens* to other habitats – agricultural areas and forest areas.

For collecting information/data, observation points were selected in the Gap. Each observation point was selected on the basis of visual observations, presence of plants and their characteristic invasive behaviour (Sankaran.et.al.2012).These invasives were checked against the native ones. Regional floras were used to identify the plant specimens' viz., Flora of British India (Hooker,1876) and Flora of the presidency of Madras (Gamble,1957).

The survey is inclusive of local interactions and information from secondary data sources.

Data collection

Standard method was followed in collecting data through quadrat method. Importance value index (IVI) (Curtis,1959) was calculated based on community attributes - Density ,frequency and abundance. GPS coordinates of the sampling areas were recorded and mapped.

Results and discussion

In all the three seasons *T. procumbens* was found to dominate the habitat- roadside, along with other dominant invasives of the Gap. *Mimosa diplotricha*, *Hyptis suaveolens*, *Pennisetum polystachyon* ,*Parthenium hysterophorus*,*Chromolaena odorata*.Overall IVI of *T.procumbens* in different habitats is given in Fig.10.

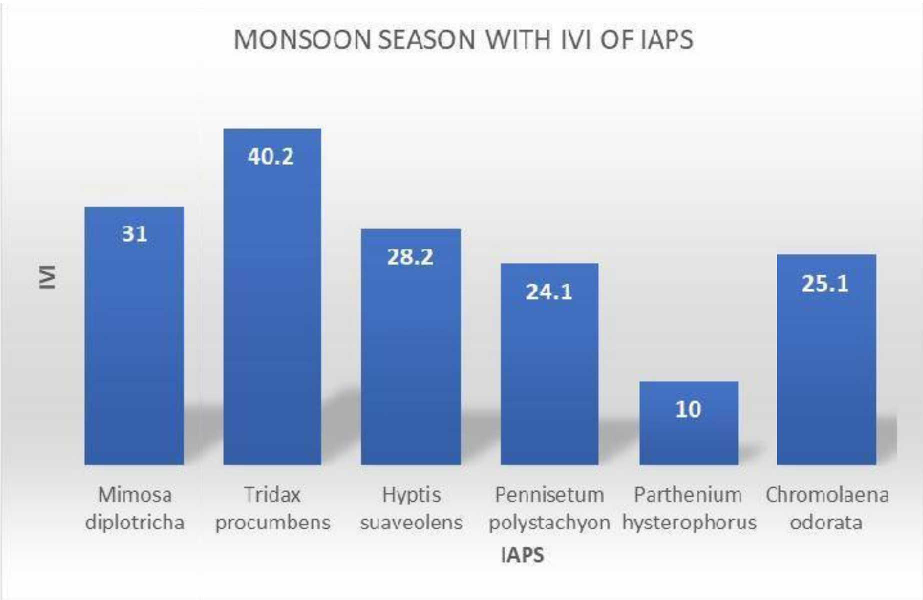

Fig.5IVI of *Tridax procumbens* in Monsoon Season

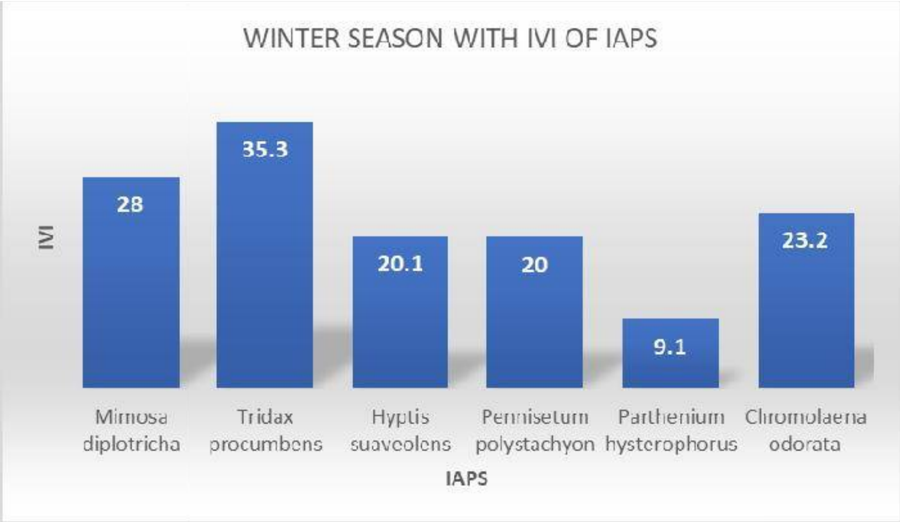

Fig.6. IVI of *Tridax procumbens* in Winter Season

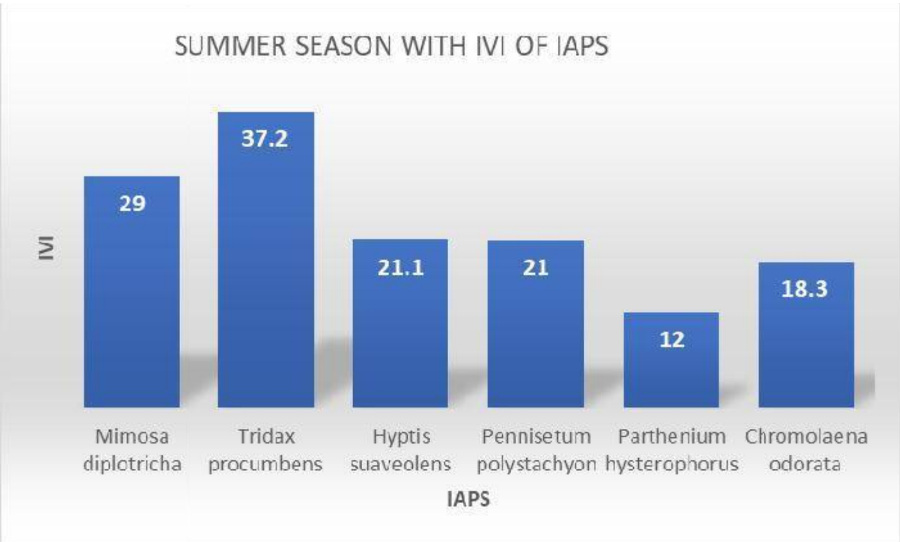

Fig.7 .IVI of *Tridax procumbens* in Summer Season

Fig.8 Overall Dominance of *Tridax procumbens* along roadsides

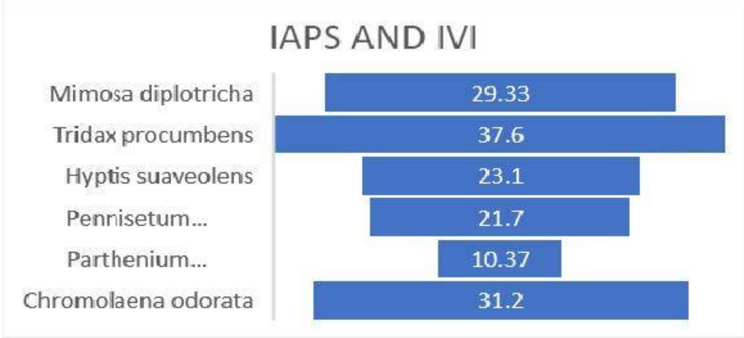

Fig.9 IVI for dominant species along roadsides

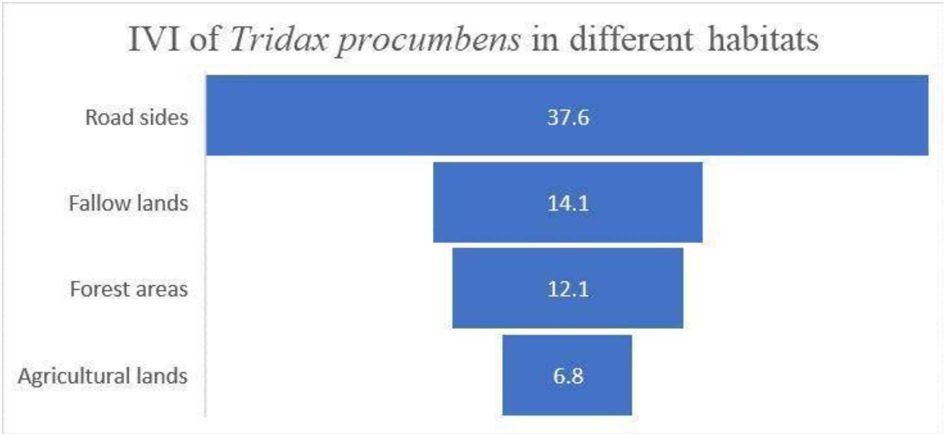

Fig.10 Overall IVI of *T.procumbens* in different habitats

Invasiveness of *T. procumbens*is mainly due toits abundant seed dispersal by wind. As to dispersal traits, literature suggests that the species have different dispersal patterns. The fruits of *T. procumbens* are carried over long distances by both wind and water with its pappus (Shaukat et al., 2005; Vanijajiva, 2014).Another means includes storage of seeds in soil seed bank, initially by falling of fruit clusters together around the mother plant .This is restricted dispersal (Shaukat & Siddiqui, 2004; Shaukat et al., 2005). It has been suggested that invasiveness may be due to the production of numerous fruits that disperse by the wind for long-distance (Vanijajiva, 2014; Amutha et al., 2019).

The fresh seed, percentage germination in the Palakkad Gap, was greatest at 30°C and at pH 6 to 8. Synchronous germination of high densities of seedlings is also seen. *T. procumbens* forms slender, wavy taproots with many lateral branches (Shetty and Maiti, 1978) aiding it's growth along the roadsides. The branches are more abundant near the soil surface and the lateral roots angle sharply downward. These are important in water and nutrient uptake,thereby enriching its growth in this habitat. Soil has been disturbed along the roadsides. This is another contributory factor to its widespread.

Tridax procumbens is a widespread weed in many countries owing to its ability to adapt to diverse environments and rapid colonization to new areas as well as its abundant seed production (Powell, 1965; Holm et al., 1997). It is a weed of 31 crops (e.g., rice and wheat) in 60 countries and has agricultural impacts (Holm et al., 1997).*T. procumbens* has high seed germination (ca, 98%) and viability of seeds extending to 450 days. Germination is high in light and wide temperatures and pH range (Chauhan & Johnson, 2008; Vanijajiva2014).In forest areas it's not able to spread much, due to difference in sol texture and canopy of trees.

Currently the weed is not a major disturbance to agricultural areas (Fig.10) in the Palakkad Gap. Butit's seen in agricultural areas and is removed manually by pulling with hands. The successful invasion of *T.procumbens*on roadsides may have been facilitated by the genotype with strong competitive abilities. In addition, history of introduction widely accepts the most important factor in genetic variations (Dlugosch and Parke 2008).

Studying the spatial distribution of this species would help to understand the invasiveness and predict its future distribution and invasion risk. And information enables the development of means of invasion control.

Conclusion

Coarse soils favour the habit and physiology of *Tridax procumbens* to have rich growth on the roadsides of the Palakkad Gap. Additive to it is, the area is being disturbed. This could be seen in the difference in IVI of *Tridax procumbens* in habitats - fallow lands and roadsides. Seeds, dispersed by pappus hairs greatly enhance the distribution to other habitats. Other traits for the spread of *T. procumbens* include-long-distance dispersal, rapid growth and regeneration, and reproductive ability. *Tridax procumbens*is reported as a weed and also has much invasive characteristics and potentials, which cannot be neglected. Therefore, regular field assessments should be undertaken to monitor its spread and population dynamics .Any threats to native plants by this species should also be observed.

Thus, it becomes more important to prevent future introductions of such alien species and their spread for safeguarding native plant diversity.

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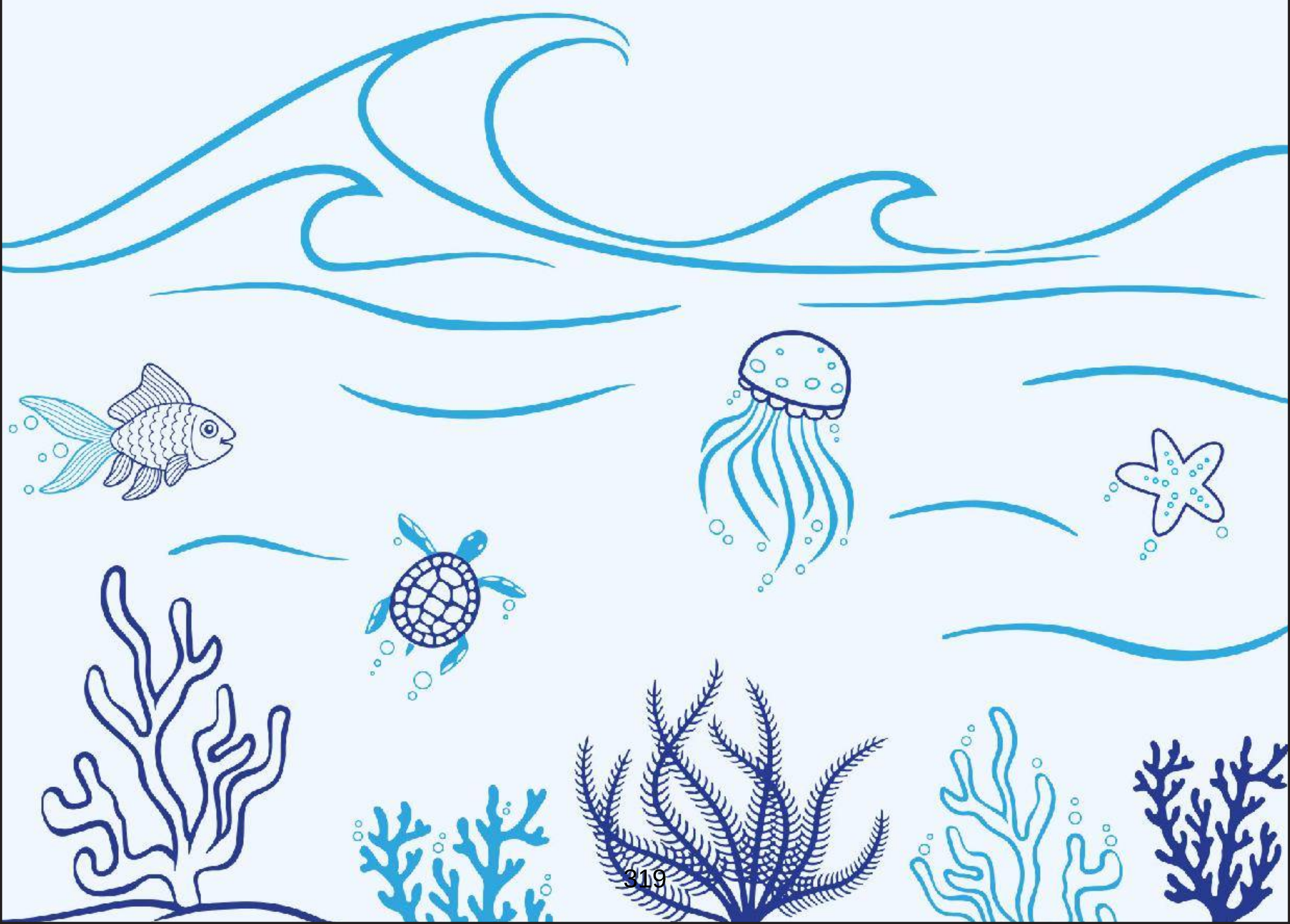
Invasion in Marine and Freshwater Ecosystem



ALIEN AND INVASIVE AQUATIC SPECIES IN KERALA: STATUS AND TRENDS

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Introduction

Alien or non-native species are the species introduced outside their natural range; the non-native species often becomes invasive alien species (IAS), once they start establishing in the introduced ecosystems, impact the biodiversity and ecosystem services and may drive the native species to local or global extinction (IUCN, 2015), primarily through predation and competition for food and space (Pimentel, 2002). The IAS is therefore defined by the International Union for Conservation of Nature (IUCN) as, "a species that becomes established in natural or semi natural ecosystems or habitats and can be an agent of change that threatens biological diversity". Biological invasion is one of the greatest threats to global biodiversity, with multiple impacts on species and ecosystem services (Pejchar and Mooney, 2009), necessitating the development of robust database and appropriate early warning systems for managing both current and possible future invasions (Liu et al., 2019). The increase in transportation of humans across the world and expanding globalisation has facilitated the large-scale introduction, spread and establishment of alien species across the globe, many of which have eventually turned into Invasive Alien Species (IAS), often threatening biodiversity and livelihoods (IPBES, 2019; WWF, 2020). Kerala is rich in water resources, including freshwater, brackish water and marine coastal waters, all are rich in bioresources. The alien and invasive in these aquatic ecosystems may have varying degree of implications on biodiversity. In some cases, the alien species may also support local economy as a tradable resource.

As freshwater ecosystems harbour the highest species richness per surface area on the planet, the impacts of biological invasions may be disastrous (Thomaz et al., 2015), including homogenisation of fauna through serving as the stepping stones or transits of alien species to nearby watersheds (Havel et al., 2015). Impacts of invasive flora and fauna may also vary between freshwater ecosystems. For example, invading macrophytes may alter hydrology, sedimentation and water quality (Gallardo et al., 2015), besides reducing the space available for co-occurring species, especially those at higher trophic levels such as invertebrates and fish (Carniatto et al., 2014).

Western Ghats (WG) mountain ranges, part of the Western Ghats-Sri Lanka Hotspot, is a distinct biogeographic unit with remarkable biodiversity and high rates of endemism

Biju Kumar, A., Smrithy Raj., and Ravinesh, R. 2023. Alien and invasive aquatic species in Kerala: status and trends. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.321-338.

(Myers *et al*., 2000). The endemic freshwater-dependent fauna of the region includes more than 130 species, of which close to one-third are at a high risk of extinction (Raghavan *et al*. 2016). In particular, the streams and rivers draining the southern region of the WG in the state of Kerala (henceforth SWG) shows exceptional diversity of fishes, many of which show ‘point endemism’ and trigger the ‘Alliance for Zero Extinction (AZE)’ criteria (Molur *et al*. 2011). Despite these striking statistics, the ichthyofauna of the region is threatened by a range of anthropogenic stressors, including habitat destruction and fragmentation, over exploitation, pollution, climate change and Invasive Alien Species (IAS) (Molur *et al*. 2011). In the recent past, climate change associated events have facilitated the entry and proliferation of many aquatic invasive species (Biju Kumar *et al*., 2019).

The World Register of Introduced Marine Species estimates that globally there are 1,711 introduced marine species, though all these species may not become invasive. Many introduced species may perish in the new habitats, while a few with high level of adaptability may survive and establish. Such species can reproduce rapidly and take over their new environment, smothering native species. The IUCN Global Invasive Species Database lists 59 invasive species in the marine realm (GISD, 2019). Marine invasions are often not given importance even in conservation discussions, though it is well recognised worldwide as a threat to biodiversity, causing considerable ecological losses. There are not much documented data on the alien species in the brackish water and coastal waters of Kerala.

The effective implementation of IAS regulation requires accurate, detailed, and timely information on occurrences and distribution for efficient prevention, early detection, rapid response, and also to allow for evaluation of management measures. While the Convention on Biological Diversity (CBD) Aichi Target 9 provides an excellent framework for identification, control and eradication, as well as managing pathways of invasive alien species, only moderate progress was made in these directions in Kerala. This paper, based on primary and secondary data, presents an overview of the occurrence, establishment and impacts of aquatic invasive species on the aquatic ecosystems of Kerala, besides recording the existing knowledge gap and required management framework for addressing the challenges of invasive species.

Data Collection

Primary data collection on alien fish was done from all freshwater ecosystems, inland water bodies of Kerala during 2016 to 2020. All 44 rivers are perennial and monsoon-fed, and only 11 have a length of more than 100 km - the largest of which is Periyar (244 km). The Palghat Gap, located at an altitudinal range of 100 to 300 m and drained by the Bharathapuzha, forms the largest break within the otherwise continuous chain of mountains of the WG. All river basins of Kerala flow through similar geomorphic and land use patterns and therefore show greater similarity in hydrology and ecology (Chattopadhyay and Harilal, 2017). The state also has 53 reservoirs built on the 44 rivers, primarily for hydropower generation and irrigation and three freshwater lakes, Sasthamkotta, Vellayani and Pookode. As defined by the IUCN: “an alien species is a species introduced outside its natural past or present distribution; if this species becomes problematic, it is termed an invasive alien species (IAS)” (https://www.iucn.org/theme/species/our-work/invasive-species).The fish collection was carried out with the help of local fishers hired for the purpose of sampling or from the local fish markets and landing centers along the rivers and reservoirs. Major inland fishing gears, including hook and line, cast nets, gill nets and traps, were used for collection. Permission from the Kerala Forests and Wildlife Department was obtained for sampling inside protected areas. The exact coordinates where alien fish were encountered were recorded using a hand-held GPS (Garmin Ltd). Data from secondary literature were also incorporated, based on information on the exact locality of the occurrence of invasive species distribution being available.

QGIS version 3.14 was used in this study to prepare the comprehensive dataset and maps of alien species (macrophytes and fish) in Kerala. Location of species along with relevant attribute information such as fauna and flora details, streams, water bodies, place names and watershed boundaries form the input data. Level 12 hydrobasins (Lehner and Grill, 2013) derived from Hydrosheds project, the highest resolution river basin vector data available were downloaded and used for mapping the distribution of invasive and alien fishes. Hydrobasin shapefiles were clipped with Kerala boundary shapefiles, and the resulting output was modified in the boundary areas to fit in the political borders of Kerala. After clipping, certain polygons that did not make any meaningful contribution to the total area were deleted, and nearby polygons were extended to its region. A list of invasive alien fishes and their distribution was prepared and mapped in GIS as a point shapefile. Using point shapefiles showing the distribution of invasive and alien fishes and level 12 hydrobasin polygon layer, the number of endemic fish species distributed in each hydrobasin was calculated using QGIS 3.14. The number of invasive alien fish existing in each hydrobasin was also calculated using the same method.

Random surveys were conducted in the brackish water areas and estuaries of Kerala for recording alien and invasive species. The secondary data available was also compiled to prepare a list of estuarine/marine alien species recorded from Kerala.

1. Freshwater Alien/Invasive species

A total of 32 alien species, including four species of plants (macrophytes) and 28 species of fish, were recorded from the SWG as part of the survey (Table 1). Of the 28 fish species, seven were identified as invasive, represented by two species within Cichlidae (*Oreochromis mossambicus* and *O. niloticus*) and Poeciliidae (*Poecilia reticulata* and *Gambusia affinis*), and one species within Loricariidae (*Pterygoplichthys pardalis*), Cyprinidae (*Cyprinus carpio*) and Clariidae (*Clariasgariepinus*).

Among plants, the most commonly distributed species was the Kariba weed (*Salvinia molesta*), occurring in all 44 rivers, four reservoirs, and three freshwater lakes in Kerala, followed by the Water Hyacinth (*Eichhornia crassipes*) recorded from 38 rivers and one freshwater lake. The Red Cabomba (*Cabombafurcata*), a native of South America, is a recent entrant to the aquatic water bodies in SWG, recorded from seven rivers and two lakes.

Distribution of invasive (Fig. 1) and alien (Fig. 2) fish species in various water bodies along SWG reveals their distribution to be confined to the highland and midland zones. Among fishes, the most widely distributed species is the Mozambique tilapia (*O. mossambicus*), occurring in all 44 rivers, 18 reservoirs and two lakes and having established abundant populations in most habitats. Common carp (*C. carpio*) was the second most common invasive species, recorded from 17 rivers, 29 reservoirs and one lake. On the other hand, guppy (*P. reticulata*) was distributed in 14 rivers and 22 reservoirs, with highly stable populations in high-altitude streams (800-1200m asl). Our study also showed that invasive species such as *C. carpio, P. reticulata, O. mossambicus,* and *C. gariepinus*had established good populations in the reservoirs, including those within the protected areas. Many alien species, especially those commonly traded in the aquarium hobby, escaped to natural waters after the catastrophic floods triggered by extreme climatic changes during August 2018 and 2019. These floods also resulted in the release or escape of large-sized predatory species such as *Arapaima gigas* and *Atractosteus spatula* into the natural water bodies.

Invasion pathways

Freshwater: Of the 32 alien species, 15 were introduced into the natural water bodies of the SWG through the aquarium hobby and trade (Fig. 3). While six species were introduced solely for promoting aquaculture, three species were introduced for mosquito control, and three species for either aquarium keeping or promotion of aquaculture. The rainbow trout, *Oncorhynchus mykiss*, was introduced during the colonial period to promote sport fishing, the only species introduced for this purpose. Three invasive plants, *S. molesta, Pistia stratiotes* and *E. crassipes* were introduced to the region as garden plants or for promotion of research, and their entry into natural systems is believed to be accidental. *Cabombafurcata* is a common aquarium plant, and this might have entered natural waterbodies either from home aquaria or from aquarium ponds adjoining the river basins, which are also used for rearing aquarium plants. While the release of most alien species may be accidental, species such as *C. gariepinus* has been illegally introduced for aquaculture. Of the 32 alien species, 11 were native to South East Asia, ten to South America, seven to Central or North America, and four to Africa.

Marine: Ballast water and international transport of vessels are the primary sources of transfer of species.

2. Marine Alien/Invasive species

Ten species of marine alien species have been recorded from Kerala coast, which include five molluscs, one byozoan, one jellyfish, one shrimp, one ascidian and one seaweed (Table 2). Of this, the invasive mussel *Mytellastrigata*is the most widespread species, causing several ecosystem damages. Recent molecular studies consider the green mussel *Pernaperna*also as an invasive species, though it has been established and exploited commercially and a traded commodity in southern Kerala. However, more studies are needed on this subject, as it is a commercial species and exploited by fishers for long time from Kerala coast.

Mytellastrigata is commonly known as the Charru Mussel. It is native to the tropical Western Atlantic from Colon, Panama to Argentina. *M. strigata* attaches to hard substrates such as rocky shores and artificial structures, including seawalls, cages, and soft sediments. This mussel can tolerate a wide range of salinities, but its tolerance to low temperatures is limited. *M. strigata* competes with other filter-feeding organisms, including other bivalves such as clams, oysters and other natives. There is evidence of a marked decline of native clams and oysters in the estuaries of Kerala due to the presence of this invasive species. It is not possible to control this mussel; however, promotion of human consumption and manual removal may be the options to reduce or manage population size.

Impacts of invasive species

Invasive macrophytes form thick mats and reduce light to submerged plants, often outcompeting rooted and submerged native plants and reducing vascular plant diversity. The formation of mats also lowers dissolved oxygen and pH, while simultaneously increasing CO_2 and H_2S. As plants in the mat die and sink to the bottom, benthos and benthic fish are impacted by changes in O_2 concentrations and water depth, as organic material accumulates. The infestations of macrophytes also contribute to human health problems as they serve as host plants for vectors and reduces the aesthetics of the habitat. Their heavy infestation may also become a social problem, particularly in the coastal zones of Kerala, where they have chocked the entire network of inland canals, severely impacting water transport and small-scale and recreational fishing. These macrophytes also tend to increase the nutrient load, velocity of water flow, promote siltation and degrade fish nesting sites.

Oreochromis mossambicus, the most common invasive species in SWG, is naturalised in most waterbodies of Kerala, where they are found to compete with indigenous cichlid *Etroplussuratensis,* both for food and breeding habitats. In areas heavily invaded by *P.pardalis,* they have destabilised bank structure by breeding in pits along the stream banks, competing with native species, and damaging fishing gears. In Thiruvananthapuram, the capital city of Kerala, this species has invaded all natural streams, out-competing native species due to their ability to survive in polluted waters with the help of accessory respiratory organs.

The species richness of invasive fish in each of the hydrobasin vary all along Kerala state (Fig. 4), and few hydrobasins harbour up to six species, and most of them associated with larger reservoirs. The Common carp, *C. carpio*introduced into Kerala for aquaculture, and primarily stocked in the reservoirs, has escaped into the natural waterbodies establishing good populations. In many ecosystems, particularly in reservoirs, they compete with indigenous cyprinids, and particularly in Kallada river they have stronger competition with the native *Tor* sp. which is considered sacred. Another dominant species in reservoirs of the SWG is *C. gariepinus*where they pose a serious threat to native species because of their predatory habits. In the Mattupetty reservoir of the Idukki district, they are the most dominant species, displacing all native species. *Poecilia reticulata,* though not regarded as a severe pest in India, have now established strong populations even inside protected areas at higher elevations. We recorded this species in many second-order streams of WG overlapping with many endemic and threatened species. *Gambusia affinis,* a remarkably hardy species introduced in Kerala for mosquito control, was observed to survive in low-oxygen waters, in high salinities and temperatures. Adult fishes were observed as too aggressive and attacking other young fish and particularly competing with indigenous killifish, *Aplocheilus* spp.

Discussion

Non-native or alien fishes were introduced to India mainly for improving food, recreational and ornamental fisheries and mosquito bio-control (Biju Kumar, 2000). Since colonial time, over 300 alien species have been imported legally or illegally into the country, including 291 species for aquarium keeping, 31 species for aquaculture and two larvicidal fishes (Singh and Lakra, 2011). Particularly in the WG, introductions dating to the colonial times have resulted in the establishment of several freshwater alien species (Jones and Sarojini, 1952; Biju Kumar, 2000; Raghavan et al., 2008, 2013; Krishnakumar et al., 2009; Biju Kumar *et al*., 2015; Roshni *et al*., 2020). Further, the recent extreme climatic events like floods have resulted in the massive entry of new alien species into the freshwater ecosystems of the SWG (Biju Kumar *et al.,* 2019). The present study adds to the existing literature on alien species in the SWG (Raghavan et al., 2008, 2013; Krishnakumar *et al*., 2009; Biju Kumar *et al*., 2015; Roshni *et al*., 2020), and most importantly, provides a comprehensive distribution pattern of alien and invasive species in the region.

Though *O. mossambicus*is extensively distributed in Kerala state, their distribution is concentrated in the coastal zone, where they have naturalised and formed part of the food chain, as prey to carnivorous species. However, *C. gariepinus* and *C.carpio*are significant stressors as they dominate fish assemblages in reservoirs (Fig. 1) and major rivers of India (Singh and Lakra, 2006; Singh *et al*., 2010; Singh, 2014). While *C. carpio*competes with native species for food and space, *C. gariepinus*feeds on many smaller cyprinids and other endemic species in the freshwater ecosystems. Though this species is banned by the fisheries department of the Kerala Government (and Government of India), they continue to represent the dominant biomass in most reservoirs of the WG. In this context, urgent management measure for their selective removal from natural water bodies is warranted (Roshni *et al*., 2020). An emerging threat is the Amazonian Sailfin Catfish *P. pardalis* and probable hybrids of *Pterygoplichthys*spp. (Biju Kumar *et al*., 2015), an aquarium-associated species that has quickly established in many natural habitats since their first record in 2009 (Krishnakumar *et al*., 2009; Smrithy *et al*., 2019).

Climate vagaries, especially extreme floods, has also triggered the massive release of alien fish into aquatic ecosystems. The recent catastrophic flood in August 2018 in Kerala resulted in the release of large-sized predators such as *A. gigas* and *A. spatula* into the natural water bodies of SWG, revealing the existence of unpredicted changes in the inland waters. Further, unregulated, unscientific, mostly illegal and thriving aquaculture and aquarium fisheries sector based on alien species along the riverine floodplains are posing uncontrolled threats (Biju Kumar *et al*., 2019; Smrithy et al., 2021). Given the increasing evidence of habitat changes (dams and the resultant flow alterations), climate change and expansion of alien fishes, further research is urgently needed to understand the spread of invasive fish, and associated declines in ecosystem services (Radinger *et al*., 2019).

Major pathways for the establishment of most alien species in SWG are aquarium trade and aquaculture, similar to those in other parts of India where major identified pathways for aquatic alien species include aquaculture, sport fishing, and mosquito control (Biju Kumar, 2000; Knight, 2010; Singh and Lakra, 2011; Raghavan et al., 2008, 2013; Sandilyan, 2016).

Among these, aquarium fish trade has been identified as the major global vector for freshwater fish invasions (Chan *et al*., 2019). Illegal transport of species such as *C. gariepinus*across the borders have also led to their proliferation in aquaculture systems and their subsequent release and escape into the water bodies (Singh and Lakra, 2006; Lakra *et al*., 2008; Singh *et al*., 2013, 2015). In addition, alien species like *P. reticulata* and *G. affinis* have been introduced for controlling mosquito larvae, despite the fact that the rich diversity of indigenous larvicidal fish in India can be effectively used for the purpose (Das *et al*., 2018).
Studies by Smrithy *et al*. (2019) and Roshni *et al.* (2020) have shown that two invasive species *P. pardalis* and *C. gariepinus*, which have established healthy populations in the water bodies of the SW Gcan be managed only by targeting smaller-sized individuals rather than large adult fish; rapid growth rate, low fishing mortality and continuous recruitment contributing to the invasion success of the two species. The impact of *P. reticulata*, which has established even in many second-order streams of SWG, can be revealed only through detailed studies on invasion biology, as previous research indicate their strong invasion potential and impact on aquatic biodiversity (Sievers *et al.,* 2012; El-Sabaawi Rana *et al.,* 2016).

Conclusion and recommendations

There are 32 species of alien flora and fauna in the water bodies of the SWG and the establishment and proliferation of 11 species (four macrophytes and seven fish). Alien species show variations in distributional patterns across the freshwater ecosystems, with the widespread occurrence of macrophytes *S. molesta* and *E. crassipes* and dominance of fish *O. mossambicus, C. carpio* and *C. gariepinus.* Aquaculture, aquarium fish trade and mosquito control were identified as the major pathways. With the increasing record of alien species in the region and projected changes in climatic regimes, the suggested interventions include development of comprehensive knowledge base invasion biology and the horizon scanning of possible invasive species for prioritising informed decisions on their management. In addition, nine marine alien species also occur in the natural water bodies, of which the bivalve *Mytellastrigata* has established strong populations in the estuaries and brackish waters of the state.

The development of an overarching policy for invasive species management and management of invasive species through collaborative monitoring, prevention, eradication and awareness involving all stake holders have been suggested, besides suggesting an institutional mechanism for implementing the policy. Considering the fact that many invasive species are traded in Kerala coast, promotion of trade is effective in managing them from highly impacted water bodies.

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Table 1. List of alien/invasive flora and fauna recorded from the water bodies along southern Western Ghats, India

Sl. No.	Common name	Species	Native Range	Pathway of introduction	Alien/ Invasive	Presence in number of water bodies		
						Rivers	Reservoirs	Freshwater lakes
FLORA (Macrophytes)								
1	Kariba Weed	*Salvinia molesta*	South eastern Brazil	GP	Invasive	44	4	3
2	Water Lettuce	*Pistia stratiotes*	Pantropical	GP	Invasive	20	2	2
3	Water Hyacinth	*Eichhornia crassipes*	South America	GP	Invasive	38	0	1
4	Red Cabomba	*Cabombafurcata*	South America	AQ	Invasive	7	0	2
FAUNA (Fish)								
5	Mozambique Tilapia	*Oreochromis mossambicus*	Tropical and subtropical Africa	AS	Invasive	44	18	2
6	Nile Tilapia	*Oreochromis niloticus*	Africa	AS	Invasive	4	0	0
7	Sailfin Catfish	*Pterygoplichthys pardalis*	South America	AQ	Invasive	5	0	1
8	Common Carp	*Cyprinus carpio*	Europe to Asia	AS	Invasive	17	29	1
9	North African Catfish	*Clariasgariepinus*	Pan Africa	AS	Invasive	7	10	0
10	Guppy	*Poecilia reticulata*	South America	MC	Invasive	14	22	0
11	Mosquito Fish	*Gambusia affinis*	North and Central America	MC	Invasive	2	5	0
12	Green Swordtail	*Xiphophorus hellerii*	Central America	AQ	Alien	1	0	0
13	Southern Platyfish	*Xiphophorus maculatus*	North America	AQ	Alien	1	0	0
14	Giant Gourami	*Osphronemusgoramy*	South east Asia	MC	Alien	2	0	0
15	Three Spot Gourami	*Trichopodustrichopterus*	South east Asia	AQ	Alien	1	0	0

16	Moonlight Gourami	*Trichopodusmicrolepis*	South east Asia	AQ	Alien	1	0	0
17	Shortfin Molly	*Poeciliamexicana*	North and Central America	AQ	Alien	1	0	0
18	Pacu	*Piaractusmesopotamicus*	South America	AS/AQ	Alien	2	0	0
19	Pirapitinga	*Piaractusbrachypomus*	South America	AS/AQ	Alien	9	0	1
20	Striped Catfish	*Pangasianodonhypophthalmus*	Asia	AS/AQ	Alien	8	0	0
21	Arawana	*Osteoglossumbicirrhosum*	South America	AQ	Alien	1	0	0
22	Rainbow Trout	*Oncorhynchus mykiss*	Asia and North America	SF	Alien	1	0	0
23	Silver Carp	*Hypophthalmichthys molitrix*	East Asia	AS	Alien	2	0	0
24	Kissing Gourami	*Helostomatemminckii*	Asia (Thailand to Indonesia)	AQ	Alien	1	0	0
25	Grass Carp	*Ctenopharyngodon idella*	Asia (Eastern China and Russia)	AS	Alien	5	0	0
26	Forest Snakehead	*Channa lucius*	Asia (Thailand to Indonesia)	AQ	Alien	1	0	0
27	Red Tailed Tinfoil	*Barbonymus altus*	Asia	AQ	Alien	2	0	0
28	Alligator Gar	*Atractosteus spatula*	North America	AQ	Alien	3	0	0
29	Oscar	*Astronotus ocellatus*	South America	AQ	Alien	1	0	0
30	Arapaima	*Arapaima gigas*	South America	AQ	Alien	3	1	0
31	Gold fish	*Carassius auratus*	Central Asia and China	AQ	Alien	1	0	0
32	Mexican mojarra	*Mayaherosurophthalmus*	Central America	AQ	Alien	1	0	0

GP: Garden Pond; AS: Aquaculture Systems; AQ: Aquarium System and Ornamental fish trade fish trade; MC: Mosquito larvae control; SF: Sport Fisheries

Table 2. Marine invasive species of Kerala

No.	Species name	References	Native Range
Phylum: Mollusca			
	Mytellastrigata (d'Orbigny, 1842)	Biju Kumar *et al*., 2019 and Jayachandran et al., 2019.	Atlantic coast of South America
	Mytiloposissallei (Recluz, 1849)	Jayachandran *et al*., 2018; Sandilyan 2018.	Caribbean islands and the Bay of Mexico
	Pernaperna (Linnaeus, 1758)	Appukuttan&Alagarswami. 1980; Kuriakose 1980; Ramachandran *et al*., 1998; Kripa 2005; Ramakrishna & Dey 2010; Bijukumar 2012; Gardner *et al*., 2016; Sandilyan 2018.	Western Indian Ocean and the west coast of Africa.
	Tenelliaadspersa (Nordmann, 1845)	Dhanya et al., 2017.	Native to the Eastern Atlantic and Western Mediterranean
	Thecacerapennigera (Montagu, 1813)	Ravinesh *et al*., 2017.	South and west of the British Isles, extending up the English Channel
Bryozoa			
	Bugula neritina (Linnaeus, 1758)	Menon & Nair1971; Ravinesh& Biju Kumar 2013.	Mediterranean Sea
Cnidaria (Jellyfish)			
	Pelagia noctiluca (Forsskål, 1775)	Nair, 1941, 1951; and Sandilyan 2018.	Atlantic ocean.
Crustacea (Shrimp)			
	Penaeus vannamei Boone, 1931	Radhakrishnan *et al*., 2012 and Sandilyan 2018.	Pacific ocean.
Ascidia			
	Didemnumcandidum Savigny, 1816	Abdul & Sivakumar 2007.	North America
Sea Weed			
	Hypneamusciformis (Wulfen) J.V.Lamouroux, 1813	Baby Usha Kiran *et al*., 2017.	Eastern and western Atlantic

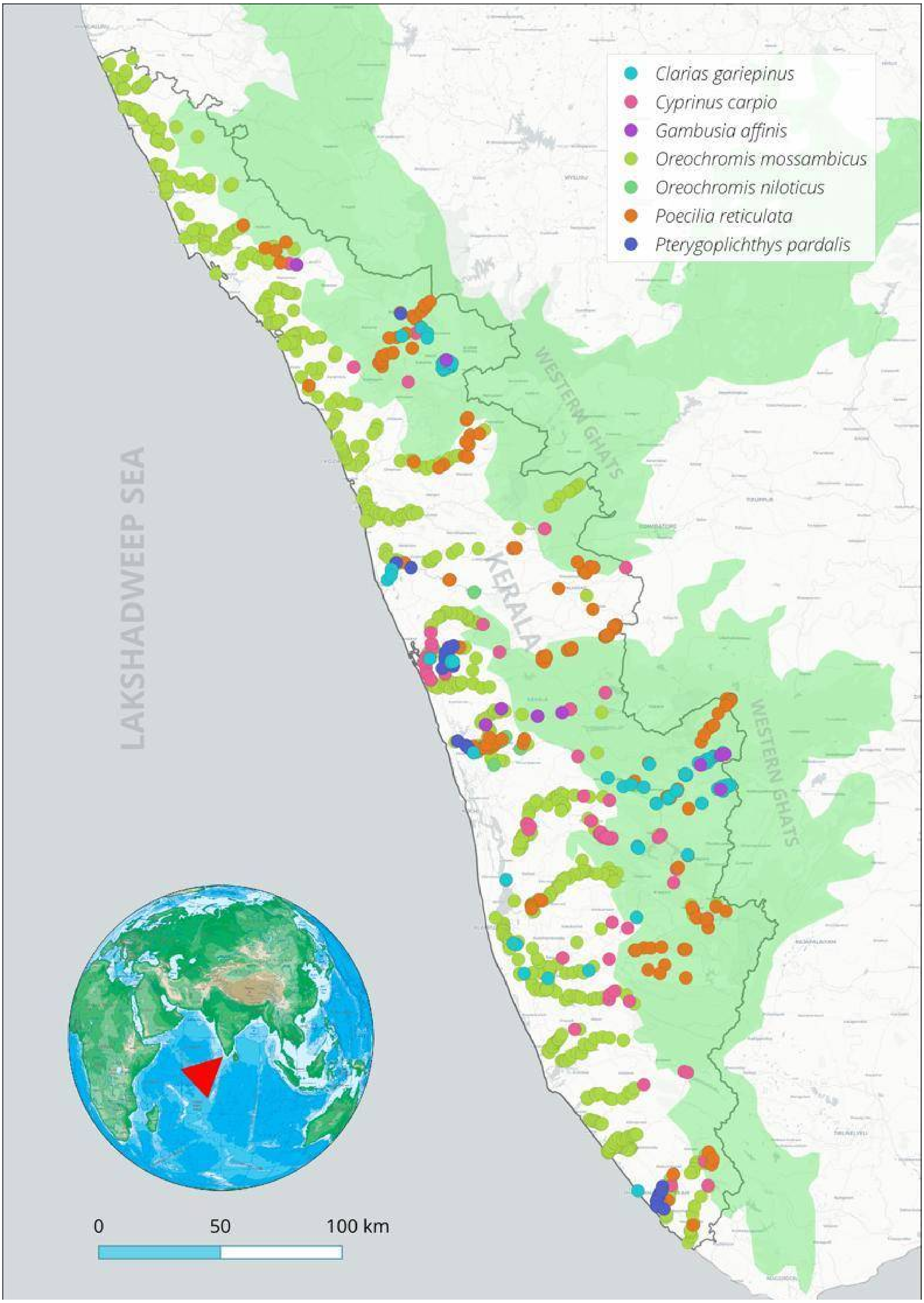

Fig. 1. Distribution of invasive fishes in the southern Western Ghats, Kerala, India

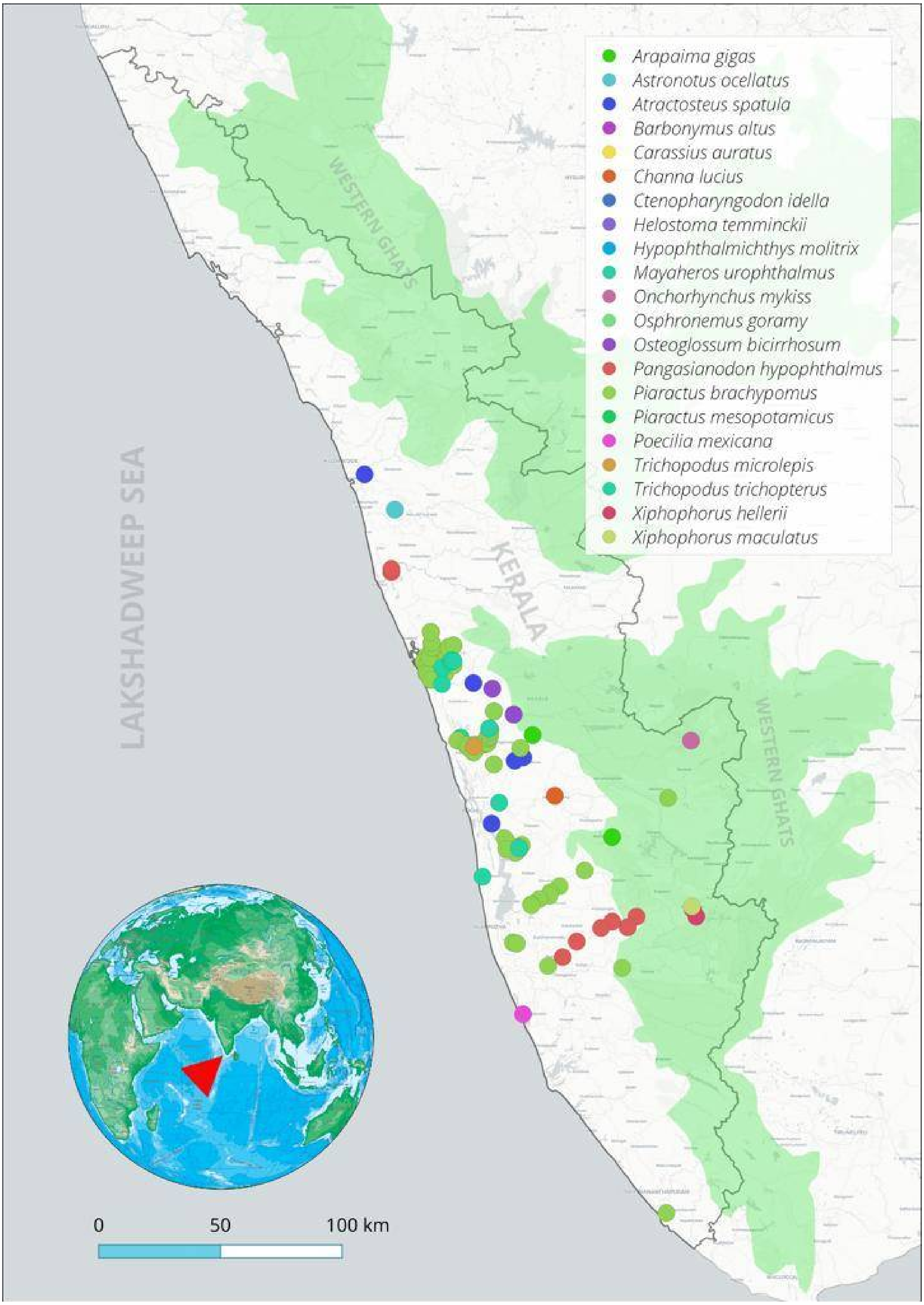

Fig. 2. Distribution of alien species (excluding invasive species) in the southern Western Ghats, Kerala, India

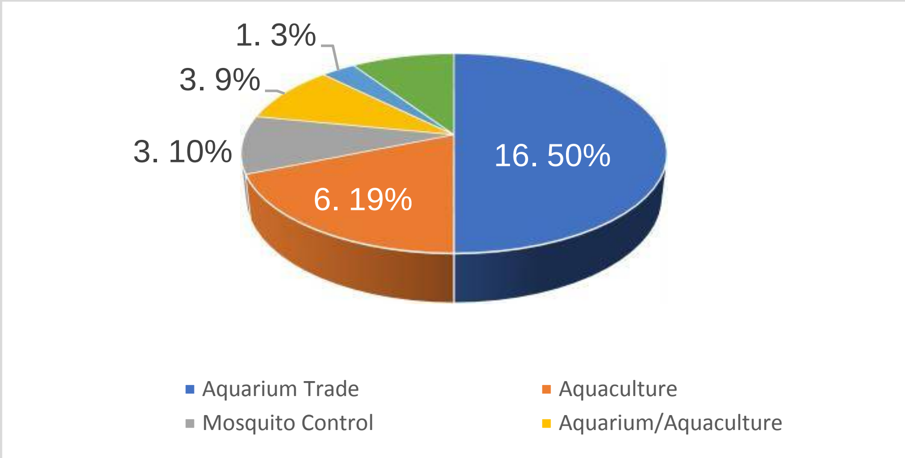

Fig. 3. Introduction pathways of alien species in the southern Western Ghats in Kerala, India

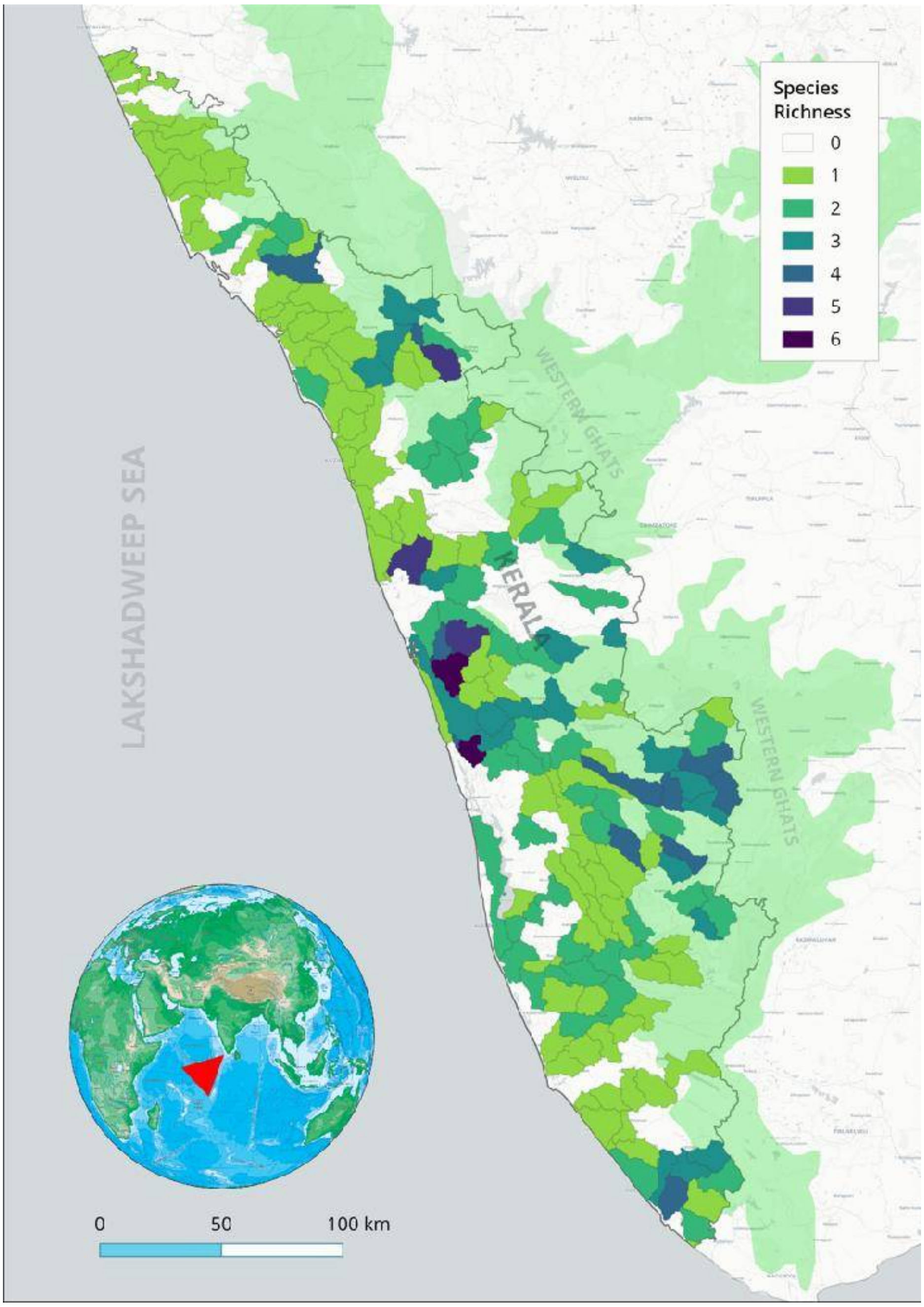

Fig. 4. Diversity of invasive fishes in different hydrobasins of the southern Western Ghats, Kerala, India

Fig. 5.*Mytellastrigata*: Emerging biofouling concern for coastal cage farmers along Kerala coast

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NON-NATIVE AQUATIC BIODIVERSITY OF INDIA, THEIR IMPACTS, POLICIES FOR PREVENTION AND PROPOSAL OF A FEW NEW TERMS

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A non-native or alien species is an animal, plant, or other organisms that are introduced by humans, either intentionally or accidentally, into places outside its natural range (CBD, 2009). Under certain peculiar situations species are also dispersed naturally to other areas and settled to become non-native. These species once naturalized may remain passive, become interactive, spread fast and also impactnegatively. Some species are farmed for food production and security. Alien species introductions are rated as a major threat to biodiversity in the world next to habitat destruction (Coblentz, 1990; Glowka *et al*., 1994; IUCN, 2021).Charles Sutherland Elton, sometimes referred to as the father of scientific study on bio-invasions has pointed out that precise scientific studies in this area is yet to be undertaken and hence understanding of this phenomenon is still incomplete and inconclusive (Elton, 1958). The book by Elton C. S. is the starting point of scientific studies on bio-invasions. The study of invasions of organisms as a result of human transfer or otherwise to areas far outside the reach of natural dispersal mechanisms has grown enormously in recent decades and is now a prominent sub discipline of ecology(Richardson and Pyšek, 2007). Investigations on bio-invasions might yield insights into numerous basic biological aspects, such as, taxonomical, ecological, evolutionary, bio-geographical, zoonotic diseases and also socio-economic topics. As mentioned by Sax *et al.*(2005) and Kovalenko *et al.* (2021) mostly inadvertent large-scale experiments, invasive species have boosted many fields of ecological research. It is disappointing that we are far away from critical data on the non-native species for management purposes (Shetty *et al.,* 1989; ZSI, 2007; Sandilyan *et al.,* 2019).

Bio-invasions and the probable threats to native species in islands had been envisioned by Charles Darwin. It was not until the 1950s that the subject gained any interest among scientific community. Bates in 1956 reported that the species which spread with human movement can become ‘Neobiota’ in different regions. Charles Elton in his book ‘The Ecology of Invasions by Animals and Plants’ (1958) stated about bio-invasions as - “ *It is not just nuclear bombs and war that threatens us. There are other sorts of explosions, and this book is about ecological explosions*” and further warned that “*Instead of six continental realms of life, there will only be one world...*”. The above observations clearly emphasize the seriousness of the problem of bio-invasions.

Jayachandran, K.V. 2023. Non-native aquatic biodiversity of India, their impacts, policies for prevention and proposal of a few new terms. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.339-361.

Ambiguity in the terminology and newly proposed terms

Several terms are used for non-native species and used in an unrestrictive manner. such species are designated by different names, namely, alien, introduced, foreign, non-native, non-indigenous, exotic, naturalized, adventives, immigrant, acclimatized, invasive and so on. Some attempts were already made to define the terms clearly (Ionnene *et al.,* 2020).Even now the usage of such names is not uniform. Therefore the names in vogue are redefined here along with proposal of a few new names for accommodating certain species based on their service (Table 1). The new name proposals are debatable.

Table 1: Various names in use for alien species are defined herein and a few new names proposed for accommodating alien species based on function and service

Sl. No.	Terms in use on alien species	Definition
1	Alien	An alien species is an animal, plant or other organisms that is introduced by humans, either intentionally or accidentally, into places outside its natural range. It also includes natural dispersal to distant places.
2	Introduced	A species that is brought to a new geographical area by humans, either intentionally or unintentionally
3	Foreign	A species belonging to one country brought to another (a new geographical area) by humans, either intentionally or unintentionally
4	Non-native	Species that occur in areas outside of their natural geographic range.
5	Non-indigenous	Species that occur in areas outside of their natural geographic range. Such species can be endemic to one area.
6	Exotic	Non-native species that do not belong to the area in which they occur
7	Naturalized	Species, taxon, or population of exotic origin integrates into a given ecosystem, becoming capable of reproducing and growing in it, and proceeds to disseminate spontaneously through an ecological phenomenon
8	Adventive	Species that are not self-sufficient, but need an episodic population assistance from their homeland; temporarily accommodated; not naturalized
9	Immigrant	A non-native species naturally arrived and become permanent residents (rare)
10	Acclimatized	Non-native species got introduced and adapted to new environment for survival
11	Invasive	Invasive species are those introduced species that spread widely or quickly and cause harm, be that to the environment, human health, other valued resources, or the economy
12	Vagrant	Species that appear from time to time beyond their normal range and are often confused with exotic species

13	Traded invasive	An invasive species after getting acclimatized become economically important
14	Fugitive - alien	A non-native species escaped from captivity and threaten to naturalize in a new environment (mostly aquarium organisms)
15	facultative-alien	An alien species after getting acclimatized become a non-influencing candidate (can be synonym of naturalized alien), rare
16	Translocated/ transplanted	Native species introduced to other regions of the same country

Table 2 provides the categorization of alien species for avoiding ambiguity. Two new terms proposed for accommodating certain sub-sections.

Table 2: Checklist for explicit definition of terms related to alien species.

ALIEN SPECIES Subsections					
Introduced Foreign Non-native Non-indigenous Exotic Naturalized Immigrant Acclimatized Facultative	Invasive	Traded - alien	Fugitive - alien	Adventive	Vagrant

History of introductions of alien aquatic species

Sir Francis Day was probably the first person who tried to introduce an aquatic species, the brown trout, *Salmo trutta fario* Linnaeus, 1758 in the Nilgiri waters in the year 1863, but his attempt was unsuccessful (Jhingran, 1975). Later Mr F J Mitchel successfully introduced brown trout eggs from Scotland to Harwan (Jammu & Kashmir) in 1900 (Mitchell, 1918). *Tinca tinca* (Linnaeus, 1758) was brought to India in 1870 for aquaculture. Thereafter a large number of fishes were introduced in the country, namely carps, tilapia, trout and ornamental fishes (Sehgal, 1999). It has been enumerated that a total of 9 fish species from temperate food fishes had been introduced in India during pre-independence (1870–1947) period, such as, *T. tinca*, *Carassius carassius* (Linnaeus, 1758), *Cyprinus carpio* Linnaeus, 1758; the salmonid game fishes, *Salmo trutta fario* Linnaeus, 1758, *Salmo gairdneri* Richardson, 1836*;* larvicidal *Gambusia holbrooki* Girard, 1859, *Poecilia reticulates* (W. Peters, 1859) and the tropical osphronemid, *Osphronemus goramy* Lacépède, 1801 (Natarajan and Ramachandra, 1988). The post-Independence India witnessed introduction of number of food fishes including carps (Chinese strain of *C. carpio*, *Ctenopharyngodon idella* (Valenciennes in Cuvier & Valenciennes, 1844), *Hypophthalmichthys molitrix* (Valenciennes, 1844), *Barbonymus gonionotus* (Bleeker, 1850)), cichlid (*Oreochromis mossambicus* (W. K. H. Peters, 1852) and *Oreochromis niloticus* Linnaeus, 1758), salmonids (*Salvelinus fontinalis* (Mitchill, 1814) , *Salmo salar*Linnaeus, 1758, *Oncorhynchus mykiss* (Walbaum, 1792), *Oncorhynchus nerka* (Walbaum, 1792)) and 35 species of ornamental fishes. However, many of these fishes were introduced without assessment of their likely impacts on ecology and fish diversity. Moreover, several exotic species are now established in the natural waters of India. Besides a number of un-authorised introductions took place in the country - African catfish (*Clarias gariepinus* Burchell, 1822), tilapia (*O.niloticus*), pangasius (*Pangasionodon hypophthalmus* (Sauvage, 1878)), big head (*Hypophthalmichthys nobilis* (J. Richardson, 1845)), pacu (*Piaractus mesopotamicus* (Holmberg, 1887)) and sucker mouth catfish (*Pterygoplichthys* spp.). *Pontederia crassipes von* Martius, 1824 was introduced during end of 19th century. *Kappaphycusalvarezii* (Doty) Doty ex Silva, 1988 is a more recent introduction. A number of aquarium plants were also introduced along with fishes. Mandal (2011) has reported that more than 300 alien fish species have been reported from India (including 291 ornamental, 31 aquaculture species, 2 larvicidal species). Khuroo *et al.* (2021) reported the alien plant species from India. Reddy (2008) reported 173 alien plants species including 33 wetland plants. Ramakrishna (2021) gave a comprehensive account on the bio-invasions of aquatic invasive species in India. Biju Kumar (2000) gave a well studied invasive species of freshwater fishes of India. Interestingly arapaima and alligator gar have been reported from Kerala waters after the flood season in 2018 (Biju Kumar *et* al., 2019) and is shocking. Serious studies are necessary to establish the impacts of these species in the environment. Table 3 provides fragmentary details of major species of fishes and plants in the country. This table doesn't contain aquarium alien fishes.

Table 3: Details of major species of fishes and plants introduced to India
(excluding aquarium fishes and plants)

Name of species	Native place/ imported from	year	Introduced to	Purpose of introduction
Salmo trutta fario Linnaeus, 1758	U.K	1863	Nilgiris (T.N.)	Sport, not established
Carassius carrasius (Linnaeus, 1758)	U.K	1870	Ooty lake (T.N)	Commercial Aquaculture
Osphronemus goramy Lacépède, 1801	South East Asia	1870-	India	Aquarium
Tinca tinca (Linnaeus, 1758)	U.K	1876	Ooty lake (T.N.)	Commercial Aquaculture
Salmo truttafario Linnaeus, 1758	U.K	1899	Harwan (Kashmir)	Sport & Aquaculture, established well
*Onchorhynchus mykiss (*Walbaum, 1792) Former name : *Salmo gairdneri* Richardson, 1836	Sri Lanka, U.K	1904, 1912	Harwan (Kashmir)	Sport & Aquaculture
Poecilia reticulates (W. Peters, 1859)	England	1908	India	Mosquito control
Osphronemus goramy Lacépède, 1801	Southern China	1900s	India	Weed control

Salmo gairdneri Richardson, 1836 (*Onchorhynchus mykiss* (Walbaum, 1792))	Sri Lanka, Germany, New Zealand	1909-1910	Nilgiris (T.N)	Sport and Aquaculture
Salmo trutta Linnaeus, 1758	U.K	1909-1938	Munnar High Range (Kerala)	Sport and Aquaculture
Gambusia holbrooki Girard, 1859 (formerly *Gambussiaaffinisholobrooki* Girard, 1859)	Italy	1928	Cuttack (Orissa)	Larvicidal, spread throughout India
Salmo gairdneri Richardson, 1836 (*Onchorhynchus mykiss* (Walbaum, 1792))	U.K, Sri Lanka	1938-1940	Munnar High Range (Kerala)	Sport and Aquaculture
Salmo gairdneri Shasta (*Onchorhynchusmykiss* (Walbaum, 1792))	U.K	1941	Munnar High Region (Kerala)	Sport and Aquaculture
*Cyprinus carpio*Linnaeus, 1758	Sri Lanka	1939	Nilgiris (T.N.)	Commercial Aquaculture
Oreochromis mossambicus (W. K. H. Peters, 1852)	Africa	1952	Yamuna River	Aquaculture
Hypophthalmichthys molitrix (Valenciennes, 1844)	Hongkong, Japan	1959	Cuttack	Commercial Aquaculture (Orissa)
Ctenopharyngodon idella (Valenciennes in Cuvier & Valenciennes, 1844)	Hongkong	1959	Cuttack (Orissa)	Commercial Aquaculture
Salmo salar Linnaeus, 1758	Canada	1960-1970	Harwan/Laribal (Kashmir)	Aquaculture
Salvelinus fontinalis (Mitchill, 1814)	U.S.A	1963	Harwan (Kashmir)	Aquaculture
Onchorhynchus nerka (Walbaum, 1792)	Japan	1968	Nilgiris (T.N)	Aquaculture
Salmo trutta Linnaeus, 1758	Japan	1968	Nilgiris (T.N)	Sport & Aquaculture
Japanese Rainbow Trout	Japan	1968	Nilgiris (T.N)	Sport & Aquaculture
Tiger Trout (Hybrid : Brown Trout X Eastern Brook Trout)	Japan	1968	Nilgiris (T.N)	Sport & Aquaculture
Albino Rainbow *Epalzeorhynchos frenatum* (Fowler, 1934)	Japan	1968	Nilgiris (T.N)	Aquaculture
Lake trout (Hybrid: Lake Trout X Brown Trout)	Canada	1968	Harwan/ Laribal (Kashmir)	Aquaculture

Rainbow trout Onchorhynchus mykiss (Walbaum, 1792)	Isle of (U.K)	1984	Kokernag (Kashmir)	Aquaculture Growing variety, Established
Coptodonzillii (Gervais, 1848)	Africa	1986	Northern states	Aquaculture
Oreochromis niloticus (Linnaeus, 1758)	Africa	1987	All states of India	Aquaculture
Orecochromis urolepis (Norman, 1922)	Tanzania	Not know n	North Inida	Aquaculture
Pangasianodon hypophthalmus (Sauvage, 1878)	Bangladesh	1994-95	India	Aquaculture Under captive conditions
Pangasianodon gigas Chevey,1931	Thailand	1997	India	Aquaculture
Barbonymus gonionotus (Bleeker, 1850)	Java	-	West Bengal	Weed control/ Aquaculture
Mylopharyngodon piceus (Richardon, 1849)	China	1990s	India	Controlling molluscks in aquaculture ponds
Piaractus mesopotamicus (Holmberg, 1887)	Bangladesh	2004	Indian states	Aquaculture
Clarias gariepinus Burchell, 1822	Africa	1990s	Indian States	Aquaculture -banned
Kappaphycus alvarezii (Doty) Doty ex Silva, 1988	Japan	1990 1995-97	Okha coast Tamil Nadu	Cultivation
*Pontederia crassipes*von Martius, 1824 (former name *Eichhornia crassipes* (von Martius, 1824)	Amazonia, Brazil	End of 19^{th} century	All Indian states	Ornamental plant, as feed for cattle Invasive

Processes of introduction

The processes of introductions can be for food related releases, aquarium trade, bio-control measures, game or bait organisms, bio-prospecting purposes, as part of global economy and R & D initiatives. The process can be summarized as: uptake of individuals from one region to transport to new areas is referred to as transport outside the native range (not translocation areas). These individuals can be kept under captivity. There are occasions in which the species may escape into the wild (fugitive alien – new name proposed). Sometimes the species can be directly transferred into the wild and we refer it as the introduction of alien species into the wild. The alien species has to face ecological, ethological, physiological, stochastic forces barriers. The succeeding ones in the wild become self sustaining and is addressed as established. Under situations the species may reproduce in spite of natural problems. It is the process by which it is gradually being spread. If it reproduces profusely it gets naturalized. Depending on the interaction with the new ecosystem it may be harmful. Certainly it is impacting the ecosystem in many ways including biodiversity loss. It becomes invasive. In spite of its invasive nature, as a control measure, efforts are on to develop products out of them (food, utility items etc.), then we have to address such species as traded invasive species (new term proposed). Sometimes the naturalized remain facultative.

The Scientific Committee on Problems of the Environment (SCOPE) on biological invasions focused on three pertinent questions, namely, what factors determine whether a species will become an invader or not?; what are the properties that determine whether an ecological community is vulnerable or resistant to invasions? And how should effective management strategies be developed? (Drake *et al.*,1989).It is important to find out reasons for the concept of alien species.

Success of establishment of Alien species

A species introduced into an ecosystem has to acclimatize and several factors play crucial roles for enabling an alien species to achieve success for establishment. Some of the major factors include : prevailing environmental conditions (e.g., temperature, salinity, pH etc); ecological conditions (food, accessibility, nutrient cycle etc.); adverse behavior of native species (predation, competition etc.); nature of introduction (time, number, status of species etc.); reproductive rate, physiological tolerance etc; survival of young ones; ability to tide over unfavourable conditions; purpose of introductions (aquaculture, mosquito control, ornamental, disease control etc.); protection available for non-native organisms; sturdiness of introduced organisms; possibilities of proliferation and dispersal in the new ecosystems; strength of out competence and many other factors. Those species which possesses some, majority or all characters may establish in the newly introduced habitat and become naturalized.

What qualifies to be an alien species?

The species that are naturalized will have the common characters, namely, tendency to outcompete, outnumber and displace native species; disrupt the eco-dynamics of the affected ecosystem; exhibit prolific reproduction, recruitment, growth, survival etc.; enhance production of noxious or pathogenic effects that cause fish mortalities; disrupt aquaculture operations; pose threats to human health; cause nuisance by fouling to boats, ships, fishing gears, equipments, jetties etc; biochemical degradation of water resources; destabilization of soil; overall collapse of indigenous flora and fauna boundaries. In many situations alien species are reported to be negatively affecting the ecosystem and at the same time there are facultative alien species.

Reported alien species of India

Status of alien species in aquatic ecosystems in India has been collected from various sources (including GRIIS, 2019) and is summarized in Table 4 :

Table 4: Reported groups of alien plants and animals in India (various sources)

Sl. No.	Group of organisms	No. of speices	Sl. No.	Group of organisms	No. of speices
Plants			15	Bryozoa	**1**
1	Tracheophyta*	**62**	16	Entoprocta	**1**
2	Rhodophyta	**3**	17	Annelids (polychaetes)*	**18**
3	Chlorophyta	**1**	18	Insects*	**2**
4	Other algae*	**2**	19	Cirripeds	**5**
5	Aquatic plants*	**8**	20	Copepods	**5**
6	Wetland plants*	**30**	21	Amphipods	**10**
Micro-organisms			22	Isopods	**5**
7	Fungus*	**2**	23	Decapoda	**1**
8	Bacteria*	**2**	24	Gastropoda*	**1**
9	Viruses*	**11**	25	Wetland gastropod*	**2**
Animals			26	Bivalves*	**5**
10	Scyphozoa	**4**	27	Echinoderms	**1**
11	Anthozoa	**4**	**Chordates**		
12	Hydrozoa	**3**	28	Ascidians	**30**
13	Cnidaria	**11**	29	Fishes*	**43**
14	Ctenophora	**3**	30	Reptiles	**1**

* Established groups of bio-invasions in wetlands and aquatic ecosystems in India

Species wise list –

<u>Fungus</u>

Aphanomyces invadans David & Kirk, 1997

Enterocytozoon hepatopenaei

<u>Bacteria</u>

Eswardsiellatarda Ewing *et al.*, 1965

Flavobacterium sp.

<u>Viruses</u>

White spot Syndrome Virus (WSSV)

Infectious Hypodermal Hematopoetic Necrosis Virus (IHHNV)

Yellow head virus (YHV)

Infectious myonecrosis virus (IMNV)

Monodon Baculo virus (MBV)

Hepatopancreatic Parvo Virus (HPV)

Laem Singh Virus

Carp Edema Virus

Cyprinid Herpes Virus

Rana virus, Tilapia Lake virus

Table 5: *Alien aquatic plants reported from marine and freshwater regions of India (various sources)*

Name of species	**Kingdom**	**Division**	**Habitat**
Acanthophora spicifera M.Vahl	Plantae	Rhodophyta	Marine
Alisma gramineum Lej.	Plantae	Tracheophyta	Fresh Water
Alisma lanceolatum With.	Plantae	Tracheophyta	Fresh Water
Alocasia macrorrhizos (L.) G.Don	Plantae	Tracheophyta	Fresh Water
Alternanthera philoxeeroides (Mart.) Griseb	Plantae	Tracheophyta	Fresh water
Azolla filiculoides Lam.	Plantae	Tracheophyta	Fresh Water
Cabomba caroliniana A.Gray	Plantae	Tracheophyta	Fresh Water
Cabomba furcata Schult. &Schult.f.	Plantae	Tracheophyta	Fresh water
Carex diluta M.Bieb.	Plantae	Tracheophyta	Fresh water/Terrestrial
Cladium mariscus (L.) Pohl	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus alternifolius L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus cruentus Rottb.	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus difformis L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus fuscus L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus glomeratus L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus longus L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus michelianus Delile	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus papyrus L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus prolifer Lam.	Plantae	Tracheophyta	Fresh water/Terrestrial
*Cyperus rotundus*L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus sphacelatus Rottb.	Plantae	Tracheophyta	Fresh water/Terrestrial
Cyperus surinamensis Rottb.	Plantae	Tracheophyta	Fresh water/Terrestrial
Eleocharis acicularis(L.) Roem. & Schult.	Plantae	Tracheophyta	Fresh water/Terrestrial
Eleocharis atropurpurea J.Presl&C.Presl	Plantae	Tracheophyta	Fresh water/Terrestrial
Eleocharis parishii Britton	Plantae	Tracheophyta	Fresh water/Terrestrial
Eleocharis pauciflora (Lightf.) Link	Plantae	Tracheophyta	Fresh water/Terrestrial
Eleocharis quinqueflora (Hartm.) O.Schwarz	Plantae	Tracheophyta	Fresh water/Terrestrial
Elodea canadensis Michx.	Plantae	Tracheophyta	Fresh water
Fimbristylis cymosa R.Br.	Plantae	Tracheophyta	Fresh water/Terrestrial
Gayralia oxysperma (Kützing)	Plantae	Chlorophyta	Marine
Gracilaria salicornia (C.Agardh) E.Y.Dawson	Plantae	Rhodophyta	Marine
Hydrocharis dubia Backer	Plantae	Tracheophyta	Fresh water
Ipomoea carnea Jacq.	Plantae	Tracheophyta	Fresh water
Kappaphycus alvarezii (Doty) Doty ex Silva	Plantae	Rhodophyta	Marine
Lemna perpusilla Torr.	Plantae	Tracheophyta	Fresh water
Limnocharis flava Buchenau	Plantae	Tracheophyta	Fresh water
Ludwigia erecta (L.) H.Hara	Plantae	Tracheophyta	Fresh water/Terrestrial
Ludwigia peruviana (L.) H.Hara	Plantae	Tracheophyta	Fresh water/Terrestrial
Ludwigia sedioides (Humb. & Bonpl.) H.Hara	Plantae	Tracheophyta	Fresh water/Terrestrial
Lythrum salicaria L.	Plantae	Tracheophyta	Fresh water/Terrestrial

Marsilea quadrifolia L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Monochoria vaginalis C.Presl	Plantae	Tracheophyta	Fresh water
Myriophyllum aquaticum (vell.) Verdc	Plantae	Tracheophyta	Fresh water
Nuphar japonicum DC.	Plantae	Tracheophyta	Fresh water
Nymphaea ×omarana Bisset	Plantae	Tracheophyta	Fresh water
Nymphaea nouchali Burm.f.	Plantae	Tracheophyta	Fresh water
Nymphaea lotus L.	Plantae	Tracheophyta	Fresh water
Nymphaea marliacea Hort.Latour-Marliac	Plantae	Tracheophyta	Fresh water
Nymphaea Mexicana Zucc.	Plantae	Tracheophyta	Fresh water
Nymphaea odorata Aiton	Plantae	Tracheophyta	Fresh water
Phalaris aquatica L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Phalaris arundinacea L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Pistia stratiotes L.	Plantae	Tracheophyta	Fresh water
Polysiphonia brodiei (Dillwyn) Sprengel	Plantae	Rhodophyta	Marine
Pontederia cordata L.	Plantae	Tracheophyta	Fresh water
Potamogeton berchtoldii Fieb.	Plantae	Tracheophyta	Fresh /Brachish water
Potamogeton pusillus L.	Plantae	Tracheophyta	Fresh/Brackish water
Potamogeton trichoides Cham. & Schltdl.	Plantae	Tracheophyta	Fresh /Brackish water
Pycreus pumilus Vahl	Plantae	Tracheophyta	Fresh water/Terrestrial
Ranunculus aquatilis L.	Plantae	Tracheophyta	Fresh water
Salvinia molesta D.Mitch.	Plantae	Tracheophyta	Fresh water
Sporobolus alterniflorus (Loisel.) P.M.Peterson & Saarela	Plantae	Tracheophyta	Fresh water/Terrestrial
Stuckenia filiformis (Pers.) Böerner	Plantae	Tracheophyta	Fresh water
Stuckenia pectinata (L.) Böerner	Plantae	Tracheophyta	Fresh water
Typha angustifolia L.	Plantae	Tracheophyta	Fresh water/Terrestrial
Typha domingensis Pers.	Plantae	Tracheophyta	Fresh water/Terrestrial
Ulva reticulata Forsskal	Plantae	Chlorophyta	Marine
*Utricularia aurea*Lour.	Plantae	Tracheophyta	Fresh water
Vallisneria spiralis L.	Plantae	Tracheophyta	Fresh water
Wolffia columbiana Karst.	Plantae	Tracheophyta	Fresh water
Zannichellia palustris L.	Plantae	Tracheophyta	Fresh water

Table 6: Alien Wet land plants reported from India (various sources)

Name of species	**Name of species**
Aerva javanica (L) L Poir	*Aeschynomene americana* L
Alternanthera paronychioides A. St.- Hil	*Alternanthera philoxeroides* Mart. Griseb
Senna alata L (Roxb.)	*Corchorus trilocularis* L
Cyperus iria L	*Echinochola colona* (L) Link
Echinochola crusgalli (L.) P.Beauv.	*Eclipta prostrate* (L) L
Fuirena ciliaris (L) Roxb.	*Gnaphalium coarctatum* (Willd.) Kerguélen
Gnaphalium pensylvanicum (Willd.) Cabrera	*Gnaphalium polycaulon* Pers.
Grangea maderspatana (L) L. Poir	*Ipomoea carnea* Jacq.
Ludwigia adscendens (L) H. Hara	*Ludwigia octovalvis* (Jacq.) P.H.Raven
Ludwigia perennis L	*Mecardonia procumbens* (Mill.) Small
Monochoria vaginalis (Burm.f) C.Presl.	*Portulaca quadrifida* L
Rorippa dubia (Pers.) H. Hara	*Saccharum spontaneum* L

Sesbania bispinosa W.F.Wight	*Sonchus asper* (L) Hill
Sonchus oleraceus L	*Typha angustata* L.

It is interesting to note that no alien species of mangrove plant is found to occur in India.

Table 7: *Alien animal species reported from marine and freshwater regions of India* (*various sources)*

Species	**Kingdom**	**Division**	**Family**	**Habitat**
Acanthaster planci (Linnaeus, 1758)	Animalia	Echinodermata	Acanthasteridae	Marine
Aedes aegypti (Linnaeus, 1762)	Animalia	Arthropoda	Culicidae	Fresh water/Terrestrial
Alexandrium minutum Halim	Chromista	Myzozoa	Gonyaulacaceae	Marine
Ascidiella aspersa	Animalia	Chordata	Ascidiidae	Marine
Barbonymus gonionotus (Bleeker, 1850)	Animalia	Chordata	Cyprinidae	Freshwater
Beroe ovate Bruguière, 1789	Animalia	Ctenophora	Beroidae	Marine
Beroe cucumis Fabricius, 1780	Animalia	Ctenophora	Beroidae	Marine
Bubulcus ibis (Linnaeus, 1758)	Animalia	Chordata	Ardeidae	Freshwater/ Terrestrial
Carassius auratus (Linnaeus, 1758)	Animalia	Chordata	Cyprinidae	Fresh water
Carassius carassius (Linnaeus, 1758)	Animalia	Chordata	Cyprinidae	Fresh waters
Carijoariisei (Duchassaing& Michelotti, 1860)	Animalia	Cnidaria	Clavulariidae	Marine
Cichlasoma trimaculatum (Günther, 1867)	Animalia	Chordata	Cichlidae	Fresh water
Clarias batrachus (Linnaeus, 1758)	Animalia	Chordata	Clariidae	Fresh/Brackish waters
Clarias gariepinus (Burchell, 1822)	Animalia	Chordata	Clariidae	Fresh water
Corbicula fluminalis	Animalia	Mollusca	Cyrenidae	Fresh water
Coptodon zilli (Gervais, 1840)	Animalia	Chordata	Cichlidae	Fresh/Brackish waters
Cossura coasta Kitamori, 1960	Animalia	Annelida	Cossuridae	M
Ctenopharyngodonidella (Valenciennes, 1844)	Animalia	Chordata	Cyprinidae	Fresh water
Culex quinquefasciatus Say, 1823	Animalia	Arthropoda	Culicidae	Freshwater/ Terrestrial
Cyprinus carpio Linnaeus, 1758	Animalia	Chordata	Cyprinidae	Fresh/Brackish waters
Didemnum candidum Savigny, 1816	Animalia	Chordata, Tunicata	Aplousobranchiata	Marine
Ectopleura crocea Agassiz, 1862	Animalia	Cnidaria	Anthothecata	Marine

Ficopomatus enigmaticus Fauvel, 1923	Animalia	Annelida	Serpulidae	Marine
Gambusia affinis (Baird & Girard, 1853)	Animalia	Chordata	Poeciliidae	Fresh/Brackish waters
Gambusia holbrooki Girard, 1859	Animalia	Chordata	Poeciliidae	Fresh/Brackish waters
Hypophthalmichthys molitrix (Valenciennes, 1844)	Animalia	Chordata	Cyprinidae	Fresh/Brackish waters
Hypophthalmichthys nobilis (Richardson, 1845)	Animalia	Chordata	Cyprinidae	Fresh/Brackish waters
Ictalurus punctartus (Rafinesque, 1818)	Animalia	Chordata	Ictaluridae	Fresh/Brackish waters
Jassa marmorata Holmes, 1905	Animalia	Crustacea	Amphipoda	Marine
Lumbrineris bifilaris Ehlers, 1901	Animalia	Annelida	Lumbrineridae	Marine
Lumbrineris japonica Marenzeller, 1879	Animalia	Annelida	Lumbrineridae	Marine
Membranipora membranacea Linnaeus, 1767	Animalia	Bryozoa	Membraniporidae	Marine
Microcosmus curvus Tokoika, 1954	Animalia	Ascidia	Stolidobranchiata	Marine
Microcosmus squamiger Michaelsen, 1927	Animalia	Ascidia	Stolidobranchiata	Marine
Mylopharyngodon piceus (Richardson, 1846)	Animalia	Chordata	Cyprinidae	Fresh/Brackish waters
Mytilopsis sallei (Recluz, 1849)	Animalia	Mollusca	Dreissenidae	Marine
Neanthes cricognatha (Ehlers, 1904)	Animalia	Annelida	Nereididae	Marine
Scolelepis squamata (O.F.Muller, 1806)	Animalia	Annelida	Spionidae	Marine
Oncorhynchus mykiss (Walbaum, 1792)	Animalia	Chordata	Salmonidae	Fresh /Brackish waters
Oncorhynchus nerka (Walbaum, 1792)	Animalia	Chordata	Salmonidae	Fresh /Brackish waters
Onuphiseremite Audouin & Milne Edwards, 1833	Animalia	Annelida	Onuphidae	Marine
Onuphis holobranchiata Marenzeller, 1879	Animalia	Annelida	Onuphidae	Marine
Oreochromis mossambicus (Peters, 1852)	Animalia	Chordata	Cichlidae	Fresh/Brackish waters
Oreochromis niloticus (Linnaeus, 1758)	Animalia	Chordata	Cichlidae	Fresh/Brackish waters
Oreochromis urolepis Norman, 1922	Animalia	Chordata	Cichlidae	Fresh/Brackish waters
Osphronemus goramy L	Animalia	Chordata	Osphronemidae	Fresh/Brackish waters
Pangasanodon hypophthalmus	Animalia	Chordata	Pangasiidae	Fresh/Brackish

(Sauvage, 1878)				waters
Pelagia noctiluca (Forsskål, 1775)	Animalia	Cnidaria	Pelagiidae	Marine
Penaeus vannamei (Boone, 1931)	Animalia	Crustacea	Penaeidae	
Perinereis nuntia (Lamarck, 1818)	Animalia	Annelida	Nereididae	Marine
Petaloproctus terricolus Quatrefages, 1866	Animalia	Annelida	Maldanidae	Marine
Phyllorhiza punctata Lendenfeld, 1884	Animalia	Cnidaria	Mastigiidae	Marine
Piaractus brachypomus(Cuvier, 1818)	Animalia	Chordata	Serrasalmidae	Fresh water
Poecilia mexicana Steindachner, 1863	Animalia	Chordata	Poeciliidae	Fresh water
Poecilia reticulata Peters, 1859	Animalia	Chordata	Poeciliidae	Fresh water
Protocirrineris chrysoderma (Claparède, 1868)	Animalia	Annelida	Cirratulidae	Marine
Protula tubularia (Montagu, 1803)	Animalia	Annelida	Serpulidae	M
Pterygoplichthys anisitsi Eigenmann & Kennedy, 1903	Animalia	Chordata	Loricariidae	Fresh water
Pterygoplichthys disjunctivus (Weber, 1991)	Animalia	Chordata	Loricariidae	Fresh water
Pterygoplichthys multiradiatus (Hancock, 1828)	Animalia	Chordata	Loricariidae	Fresh water
Pterygoplichthys pardalis (Castelnau, 1855)	Animalia	Chordata	Loricariidae	Fresh water
Puntius javanicus (Bleeker, 1850)	Animalia	Chordata	Cyprinidae	Fresh water
Puntius gonionotus (Bleeker, 1850)	Animalia	Chordata	Cyprinidae	Fresh water
Pygocentrus nattereri Kner, 1858	Animalia	chordata	Serrasalmidae	Freshwater/ Brackishwater
Salmo lavensis Linnaeus, 1758	Animalia	Chordata	Salmonidae	Fresh /Brackish/Marine waters
Salmo salar Linnaeus, 1758	Animalia	Chordata	Salmonidae	Fresh /Brackish/Marine waters
Salmo trutta Linnaeus, 1758	Animalia	Chordata	Salmonidae	Fresh /Brackish/Marine waters
Salvelinus fontinalis (Mitchill, 1814)	Animalia	Chordata	Salmonidae	Fresh /Brackish/Marine waters
Salvelinus namaycush (Walbaum, 1792)	Animalia	Chordata	Salmonidae	Fresh/Brackish/ Marine waters
Malacoceros indicus (Fauvel, 1928)	Animalia	Annelida	Spionidae	Marine
Tinca tinca (Linnaeus, 1758)	Animalia	Chordata	Cyprinidae	Fresh water

Trachemys scripta elegans (Wied, 1838)	Animalia	Chordata	Emydidae	FW/T
Trichopodus trichopterus (Pallas, 1770)	Animalia	Chordata	Osphronemidae	Fresh water
Tubastraea coccinea Lesson,1829	Animalia	Cnidaria	Dendrophylliidae	Marine
Vallicula multiformis Rankin, 1956	Animalia	Ctenophora	Coeloplanidae	Marine
Xiphophorus hellerii Heckel, 1848	Animalia	Chordata	Poeciliidae	Fresh/Brackish waters
Xiphophorus maculatus (Gunther, 1866)	Animalia	Chordata	Poeciliidae	Fresh water

Though a large number of alien species (both animals and plants) have been reported from India, the status of many has to be confirmed.

Impact of alien species

Report on the study of impacts of alien species on native species is scanty (Shetty *et al.*, 1989). This is because of lack of study on this aspect. A few examples are presented below.

The German strain of Mirror carp was first introduced to Ooty Lake in India during 1939 from Sri Lanka and well established in Nilgiri waters. This strain was not breeding freely in tropical waters. In 1946 this fish was introduced in Bhowali hatchery (Uttara Khand) for stocking the Kumaon lakes. Later, it found a home in Kashmir lakes where it invaded and heavily had infested to the exclusion of all other local species, specially the schizothoracids. It was also stocked in Gobindsagar in Himachal Pradesh where it formed a lucrative fishery despite presence of dominating silver carp. Since the species is benthic it posed great competition with indigenous fishes, *Cirrhinusmrigala, Clariusbatrachus* and prawn, *Macrobrachium rosenbergii* for space and food. Consequent to the reduction in food, the species started burrowing the dykes with the result the water became turbid and phytoplankton production was severely hampered. Due to its fast growth, this species was introduced into almost all major rivers and natural ponds of North Indian waters. Being prolific breeders, they established in these water bodies. They are prolific breeders. Reports are available on the instances of commoncarp causing the decline of fishes, namely, *Cirrhinus* spp., *Schizothorax* spp., *Osteobramabelangiri* in Krishnarajasagar reservoir, Gobindsagar reservoir, upland lakes of Kashmir and Kumaon Himalayas and Loktak lake. A study on the catch composition of carp availability along the stretches of Ganga revealed that the population of Common carp increased where as the availability of Gangetic carps has declined.

Ctenopharyngodon idella: The grass carp was introduced in the year 1959 primarily for controlling submerged vegetation. The Grass carp feeds on selected macrophytes, such as, *Hydrilla verticillata* and the floating plants, like *Pontederia crassipes, Pistia stratiotes* and *Salvinia molesta.* The negative impacts on environment by grass carps are: Alteration of water quality including an increase in turbidity, reduced dissolved oxygen, and an increase in plant nutrients.

Oreochromis mossambica: Tilapia, a native of South Africa was brought to India by CMFRI at 1952. In the same year few fingerlings were brought to Madras. For making detailed investigations a few fingerlings were brought to CIFRI centrecuttack,1953. This species is now proliferated into almost all water bodies and is causing heavy competition with native species for food, space, oxygen.

A consolidated report on alien species taxa wise is given below.

Fungus (invasive):

Aphanomyces invadans infect freshwater and brackish water fishes; epizootic ulcerative syndrome)

*Enterocytozoon hepatopenaei*retardation of growth in penaeid prawns

Bacteria (invasive):

*Eswardsiellatarda*causes septicemia in channel cat fishes, eels and flounders

*Flavobacterium*sp. Causes diseases in several organisms including fishes, plants and humans

Virus (invasive):

White spot Syndrome Virus (WSSV) causes mortality in prawns
Infectious Hypodermal Hematopoetic Necrosis Virus (IHHNV)causes prawn mortality
Yellow head virus (YHV) retarded growth and mortality inprawns
Infecitous myonecrosis virus (IMNV) moratality in *P. vannamei* prawns
Monodon Baculo virus (MBV) moratality in kaarachemmeen*Penaeus monodon*
Hepatopancreatic Parvo Virus ((HPV) retarded growth and mortality in prawns
Laem Singh Virus Monodon slow growth syndrome (MSGS)
Carp edema Virus Carp edema disease; koi sleepy disease
Cyprinid Herpes Virus fatal disease in koi and common carp
Rana virus, diseases in fish, amphibians and reptiles
Tilapia Lake virus diseases in tilapia

Fishes (traded invasive)

Pangasiodon hypophthalmus - feeding on fish and crustaceans, plants

Captodonzilli – young ones feeds voraciously on crustaceans; adult feed on a variety of organisms and plants

Salmo salar -habitat destruction, has impacted the population in some areas

Salmo lavensis - habitat destruction, has impacted thepopulation in some areas

Tinca tinca -habitat destruction, has impacted the population in some areas

Onchorhyncus mykiss -feed on aquatic and terrestrial insects, molluscs, crustaceans, fish eggs, minnows,and other small fishes; does not breed naturally

Pterygoplichthys multiradiatus - causing damage to fishing gear, competing and harming against native species and disrupting environments by its burrowing activities

Other organisms (invasive)

Mytella strigata -highly proliferating, displacing native species, competing forfood and decline in mussel production

Arcuatulasenhousia - several negative impacts of this invasive species is that it has a detrimental effect on eelgrasses; polycheates and may organisms in the soft soil of brackish waters

Physella acuta - mediators of foodborne diseases in this southern state of the country

Lissachatinafulica - It feeds voraciously and is vector for plant pathogens, causing severe damage to agricultural crops and native plants. It competes with native snail taxa, is a nuisance pest of urban areas, and spreads human disease. This snail is listed as one of the top 100 invasive species in the world

Trachemys scripta - turtles often compete with native species for food, habitat, and other resources

<u>Plants (traded invasive)</u>

Pontederia crassipes(Formerly *Eichhornia crassipes*) is invasive, casing great harm to water bodies including biodiversity loss. At the same time value added products are being produced.

Kappaphycusalvarezii -newly introduced creating damage to phytoplankton and biota in marine environment

Journals which encourage publication on alien species

The journals that encourage to publish data on alien species (not complete) include : *Aquatic Invasive Records; Bio-Invasions Records; Bioinvasivesnet; Journal of Aquatic Biology; Acta BiologicaSolvenica; Weed Research; Research Journal of Agricultural Science; PresliaBulletin de la SocieteBotanique de France; Insects; Botanica Lithuanica; Botanica Serbia; Acta SocietatisBotanicorumPoloniae; EPPO Bulletin; Pakistan Journal of Botany; Bulletin of Insectology; Journal of Insect Conservation; Acta Botanica Croalia; Journal of Pest science; Journal of insect conservation; Aquatic Invasions; Management of Biological Invasions; World Register of Introduced Marine Species (MRiMS);Environmental Management; Diversity and Distribution; Frontiers of Ecology and Management*

Future challenges:

Invasive species provide challenges to management, as well as an opportunity to explore basic ecological questions.

- How do the alien communities exhibits survival?
- How are communities assembled and how do these communities respond when new species come in?
- How commonly do niche shifts occur?
- What processes regulate dispersal?
- What is the relative importance of such regional processes with local community interactions?
- How does community succession proceed following disturbance?
- How redundant are biological communities across the planet?
- What are the main impacts of invasive species?
- How do these impacts change ecosystem goods and services?

- What is the ecosystem behaviour with multiple IAS?
- Whether eDNA helps to find out alien species, if so to what extent correct?

Policies

The following policies are proposed for the prevention, control and eradication of alien species from the ecosystems of Kerala. This also may be helpful for other parts of the country. The 46 policies are grouped under 14 sections and are presented below.

Section1: Uniform usage of terminologies related to alien species.

Policy1:Several terms are in use while discussing non-native species, such as, alien, introduced, foreign, non-native, non-indigenous, exotic, naturalized, immigrant, acclimatized, facultative, vagrant, adventives, invasive (new terms : traded invasive and fugitive alien). Decision should be taken to bring uniformity in the usage of different terms.

Section 2: Reported species and their taxonomic validity and identity

Policy 2: Strict scientific approach is to be adopted on a time bound basis to reconfirm the species of status of reported alien species. Taxonomic validation is absolutely essential.

Policy 3: Many species have been reported to be alien. The scientific data to prove these species as alien is lacking and hence measures are to be taken to establish the reported species as alien.

Policy 4: Evolve methods to address an alien species as invasive (of any category under it). For this committed data collection, studies and analysis to prove it as invasive has to be devised.

Section 3: Introduction of species

Policy 5: No intentional introduction should take place without proper authorization from the relevant national/state authority or agency. The agency / authority should make sure that the new introduction is unlikely to cause unacceptable harm to the ecosystems, habitats or species.

Policy 6: The burden of proof that a proposed introduction is unlikely to cause such harm should be with the proposer of the introduction.

Policy 7: Authorization of an introduction be accompanied by conditions, such as, preparation of a mitigation plan, monitoring procedures and/or containment requirements. Precautionary measures must be strictly followed in such introductions.

Policy 8: Unintentional introductions should be managed with proper statutory and regulatory measures, institutions and agencies with appropriate responsibilities and with the operational resources required for rapid and effective action

Policy 9: Intentional introductions that have established and become invasive should be managed with proper statutory and regulatory measures, institutions and agencies with appropriate responsibilities and with the operational resources required for rapid and effective action.

Policy 10: Common pathways leading to unintentional introductions need to be identified and appropriate provisions to minimize such introductions should be in place. As far as possible pathways are to be developed for each species for regulating prevention and control of alien species.

Policy 11:Proper data is to be developed sectoral wise, pathways for unintentional introductions, such as fisheries, agriculture, forestry, horticulture, shipping (including the discharge of ballast waters), ground and air transportation, construction projects, landscaping, ornamental aquaculture, tourism and game-farming.

Policy 12: Separate strategies are to be formulated for microbial introductions

Section 4: Strict vigil at border points and quarantine measures in a country

Policy 13: Country should implement border control and quarantine measures to ensure that intentional introductions are subject to appropriate authorization and unintentional or unauthorized introductions of alien species introductions must be reduced to bare minimum. Regulations must be developed at airports and seaports and also at other entry points.

Policy 14: These measures should be based on risk assessment posed by alien species and their potential pathways of entry. For this government departments and agencies should be strengthened and technically equipped. Regional co-ordination is highly essential. Early detection will help to improve the strict vigil over the issue.

Section 5: General precautionary guiding policies

Policy 15: Introduction of alien species should be based on ground reality of unpredictability of the impacts on biological diversity, unintentional introductions of such species must be prevented. Intentional introduction should also be on a precautionary approach above.

Policy 16: Lack of scientific certainty about the environmental, social, health and economic risk posed by a potential alien species or by a potential pathway should not be used as a reason for not taking preventing action against introduction of alien species.

Policy 17: Lack of certainty about the long-term implication of invasion should not be used as a reason for postponing eradicating, containment or control measures.

Section 6: Responsibility of member country

***Policy 18*:** Source country should recognize the risk of a species to be alien to other countries and appropriate actions taken to minimize the risk

Policy 19: Receiving country should collect information about the risk of a potential alien species under conditions of transfer.

Section 7: Education and public awareness

Policy 20: States should facilitate education and public awareness of the risks associated with the introduction of alien species. When mitigation measures are required, education and public-awareness-oriented programmes should be set in motion so as to inform local communities and appropriate sector groups on how to support such measures. Media should involve in the process

Policy 21: Awareness programmes developed by local people has to be consolidated for effective implementation of eradication

Section 8: Co-operation and capacity building

Policy 22: In respect of an alien species, for control and / or eradication, co-operation of countries may be required and, in such situations, policies must be developed to suit and tackle the issue.

Policy 23: Counties of origin and receiving should exchange information about alien species. Agreements to that effect may be developed for the purpose

Policy 24: Country should support capacity building programmes to assess introduction of alien species and subsequent effect. Such capacity building may involve technology transfer and development of training programmes.

Section 9: Data base development and exchange of information

Policy 25: Only fragmentary data is available on the subject. Precise data on alien species has to be developed, stored and disseminated through adequate mechanisms and exchange to other countries and also to global initiatives.

Policy 26: Data should be generated on ecosystem approach

Section 10: Risk assessment studies and analysis

Policy 27: Alien species threaten ecosystems, habitats and species. Risk assessment due to alien species has not been precisely investigated and result consolidated and hence it has to be seriously looked into.

Policy 28: Information on the performance of alien species in native country has to be collected and compared with the threat caused to the new environment.

Section 11: Research and development

Policy 29: In order to create an appropriate knowledge base enabling to address the problem, adequate emphasis on research and development and monitoring of alien species should be undertaken with sufficient budgetary provisions.

Policy 30: Research should concentrate on surveys, history of invasions (origin, pathways and time-period), characteristics of alien invasive species, ecology of invasion and associated ecological and economic impacts and how they change over time and monitoring.

Policy 31: Alien species under trade are to be brought under investigation for its retention or eradication. Reasons may be consolidated.

Policy 32: Use a landscape-level, watershed-level, or ecosystem level approach, whenever possible, to achieve resource management goals at multiple spatial scales.

Policy 33: Evolve an ecosystem-based management system to restore or recover ecological communities, balancing economic, cultural, and environmental priorities

Priority 34:This technology is recent one but labor intensive may also be included in the eradication programmes

Priority 35:Evolve integrated pest management (IPM) principles in a manner that balances risks to human health and the environment from invasive species management activities with the related consequences of failure to act expeditiously to control invasive species.

Section 12: Invasive, Traded invasive and fugitive alien species

Policy 36: Several species have been introduced for farming, ornamental culture, food security, food processing and many other purposes and support economy of the state/ country and similarly other invasive and fugitive alien species performance also are to be discussed thoroughly. Regulations are to be developed accordingly.

Section 13: Mitigation and impacts

Policy 37: Prevention is generally far more cost effective and environmentally desirable than measures taken following introduction of alien species. Priority should be given to prevention of entry of alien species.

Policy 38: If introduction has already taken place, eradication is to be carried out without any delay. If it is not feasible and / or cost-effective, long-term control measures to be adopted with the final intention of eradication. Hence early detection of new introduction of alien species is of utmost importance.

Policy 39: Cost effective eradication should be given priority over other measures to deal with established alien species. The best opportunity for eradicating alien invasive species is in the early stages of invasion, when populations are small and localized; hence, early detection systems focused on high-risk entry points can be critically useful. Community support, built through comprehensive consultation, should be an integral part of eradication projects.

Policy40: Under the situation when eradication is not practical, limitation of spread (containment) can be adopted as pragmatic strategy to confine it within defined boundaries.

Policy 41: Regular monitoring outside the control boundaries is essential, with quick action to eradicate any new outbreaks

Policy 42: Control measures should focus on reducing the damage caused rather than on merely reducing the numbers of the alien invasive species.

Policy 43: Many alien species have brought in a large number of diseases in aquatic ecosystem as new to natural resources and man and are to be monitored with great precaution.

Policy 44: Use best management practices in all activities to reduce risks associated with invasive species. Activities include but are not limited to natural resources management, construction or development, fire management, permitting, and monitoring.

Section 14: Integrated approach

Policy 45: Considering the high impacts on environment and multiple ways of utilization of the alien species, integrated planning process is the solution. When planning projects or activities, consider invasive species risks and provide for alternatives or mitigation measures, to the extent practicable, to reduce risks associated with the introduction, establishment, and spread of invasive species

Policy 46: Importance may be given for publication of results in quality journals

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FISH INVASIONS IN INDIA- CHALLENGES AND CONTAINMENTS

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Abstract

626 exotic fish species have been introduced to India deliberately or unintentionally and they have the ability to establish, invade, out compete native fish species and take over the new environments. Many of the introductions were unauthorised and unaided while only few were deliberate introductions such as *Pangasianodon hypophthalmus*, *Oreochromis niloticus*, *Litopenaeus vannamei* and some ornamental fish species. Many exotic fish species turned invasive in Indian inland waters and 25 such invasive fish species have been identified and listed. It has been observed that good invaders are thriving in disturbed environments. In unfavourable conditions, such as hypoxic and polluted conditions, invasive species are better adapted in their physiological and behavioral responses towards the stressor. Risks of invasion are now shifting rapidly owing to expanding trade, transportation, technological advancements. We have generated scientific information on the distribution of invasive exotic fish species available in different freshwater aquatic bodies and their adverse ecological consequences such as decline of native fish species for food and feeding, space and spawning; threats to species integrity and ecosystem besides resource competition. The paper presents a decision support system which helps screening of the invasive species to quantify the level of risks the invader possesses. Large scale environmental alterations such as climate change, impoundments in aquatic ecosystems, and wide distribution of introduced non- native fishes in inland waters increased the likelihood of biotic homogenization in the anthropocene. The study highlighted a kind of biotic homogenization, ongoing with trophic downgrading due to overwhelming presence of invasive species. The detection of invasive species, their regular monitoring and surveillance is important for their management. In India, risk assessment, risk management, quarantine, biosecurity and regulatory mechanisms are available for control of IAS. However, it is important that the issues associated with rapid spread of invasive species are put on the national agenda for developing action to regulate fish invasions to minimise their adverse impacts. A National Policy on prevention of invasive species is urgently needed to deal with harmful impacts of aquatic invasions.

Keywords: Invasive fish, aquatic biodiversity, risks and threats, aquatic ecosystem, impact, management

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Introduction

Global production of farmed fish and shellfish has increased more than double in the past decade and it is believed that such growth was possible due to the aquaculture of fast growing introduced exotic fish species (De Silva et al. 2006, 2009). In India, the inland aquaculture is predominantly a carp farming entity (Jena et al. 2002). However, recent ventures of culturing many internationally moving introduced fish species such as pangasius sutchi, tilapia, African catfish, pacu, and some others have badly affected carp culture which may become at the verge of breaking point due to incessant efforts of the farmers to diversify the aquaculture using fast growing species and strains of exotic fishes (Singh & Lakra 2006; Lakra et al. 2008; Singh and Lakra, 2011; Singh, 2021a). In view of attaining higher production and picking the changing pattern of market, the fish farmers are now fascinated by culturing exotic fish species such as *Pangasianodon hypophthalmus, Clarias gariepinus, Oreochromis niloticus, Piaractus brachypomus, Litopenaeus vannamei* for commercial level aquaculture productions both for domestic consumption as well as for export purpose (Lakra et al. 2008; Singh and Lakra, 2011; Belton et al., 2017).

Some of these exotic fish species have been introduced deliberately or unintentionally to India outside their natural habitats where they have the ability to establish, invade and outcompete native fish species and take over the new environments (Lakra et al 2008; De Silva et al. 2009; Singh and Lkra, 2011; Singh, 2021a). Today, some of these exotic fish species are widely spread in wild and are found in all types of ecosystems (Singh and Lakra, 2011; Singh, 2014). They are known to affect biological diversity even within or outside protected areas and have potential to influence ecosystems, natural habitats and surrounding populations (Garcia-Berthou, 2007; Lakra et al. 2008; Singh and Lakra, 2011; Singh, 2021a). Some of these exotic species have turned invasive which can cause significant irreversible environmental and socio-economic damages at the genetic, species and ecosystem levels (Lakra et al. 2008; De Silva et al. 2006; Singh and Lakra, 2011; Singh, 2021a). This paper has generated scientific information on the distribution of exotic invasive fish species in different natural aquatic bodies and assessed their plausible ecological impact i.e., decline in native fish species, competition for food and feeding, space, spawning. In addition, the paper also addressed the issues of IAS such as establishment in fresh water natural water bodies posing threats to the local fish species integrity; may raise resource competition and impact on fish diversity. These impacts may further be aggravated by the climate change.

Invasion pathways identified in India

Exotic species may arrive and enter a new region through three broad mechanisms: importation, arrival, and/or natural spread from the initial place of its presence where the species is itself alien. These three mechanisms result in six principal pathways: release, escape, contaminant, stowaway, corridor and unaided. The major invasion pathways have been worked out and identified as inadvertent or deliberate releases, escapes, contaminant from hatcheries where multispecies fish are bred in the same facility and river corridors (Singh, 2021). Exotic species transported as commodities may be introduced as a deliberate release or as an escape from captivity. Many species are not intentionally transported but arrive as a contaminant of a commodity, for example pathogens and pests. Stowaways are directly associated with human transport but arrive independently of a specific commodity, for example organisms transported in ballast water, cargo and airfreight. The corridor pathway highlights the role, transport infrastructures play in the introduction of exotic species. The unaided pathway describes situations where natural spread results in alien species arriving into a new region from a donor region where it is also exotic. Such invaders exhibit all three of the notable aspects of biological invasion: "population spread, community dominance, and range expansion".

Brief methods adopted for risk assessment

Information on the distribution of exotic fish species in different aquatic bodies was generated and compiled through an extensive survey, frequent interaction with farmers, state fishery officials and other stakeholders. The presence of exotic invasive fish species in aquatic systems such as rivers, lakes, reservoirs and wetlands was examined. The exotic invasive fish species collected from different locations were identified as per the details given in Fish base (www.fishbase.org) as well as the species identification field guide of FAO (2001). The risks of the identified exotic invasive fish species was assessed on the basis of their abundance in different aquatic bodies, information available on the history of the species introductions in the Database of Introduced Aquatic Species (DIAS) (http://www.fao.org/figis/servlet/ static?dom=root& xml=introsp_s.xml), a Food and Agriculture Organization (FAO) database on the introduction of aquatic species (DIAS 2004), Fish Base (http:// www.fishbase .org), Global Invasive Species Database (GISD) (http://www.issg.org/ database/welcome) and the database on National Biological Information Infrastructures in the USA (http://www. invasivespecies.nbii.gov). Various biological and ecological characteristics that enabled a species to reproduce, spread and persist were examined on the basis of available reports, field studies at different private farms where the species were cultured and bred. Feeding guild was also examined on the basis of preferences for food as studied at farms and also in the laboratory. Overall life history (fecundity, spawning requirements, gamete viability, reproductive strategy) and phenotypic plasticity were examined based on the field data (Singh, 2021a). Further a scoring system based on 27 attributes of the exotic fishes was adopted to determine the invasion risks on quantified terms which served to provide decision support system for the adoption/rejection of that exotic invasive fish in aquaculture (Table 1 and Figure 1).

Table 1:Determination of invasion Risks based on Scoring System

Number	Question Category	Question	Response -1 to 5
1.1	**Biology**	Domestication/Culture	5
1.2		Niche breadth	5
1.3		Dispersal	5
2.1	**Status**	National distribution	5
2.2		Abundance	5
2.3		Invasion history	3
3.1	**Breeding**	Seed Production	5
3.2		Breeds with hormone injection	5

3.3		Natural breeding in wild	3
3.4		Potential to hybridize	3
3.5		Existence of Natural population	3
4.1	**Food & Feeding**	Piscivorous	5
4.2		Omnivorous	5
4.5		Benthivorous	5
4.6		Planktivorous	3
5.1	**Environment**	Plasticity to temperature	5
5.2		Plasticity to salinity	3
5.3		Environmental versatility	5
5.5		Narrow environmental tolerance	0
6.1	**Level of Threats**	Carnivorous	5
6.2		Loss of Biodiversity	4
6.3		Broad climate adaptation	5
7.1		High susceptibility for disease	1
7.2		Carrier of OIE listed diseases	2
7.3	**Management**	Illegal introduction	5
		Regulated culture	0
		No regulation	5
			105

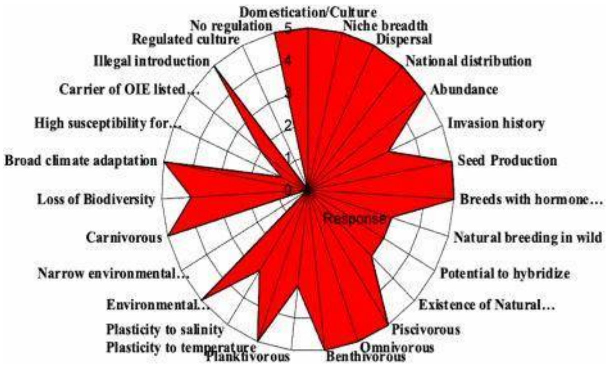

Figure 1: Excel based module to determine invasion risks shown in red ink based on various attributes scored on a scale of 1 to 5.

Screening of exotic invasive fish species and assessing their impacts

The commonly available fish diversity in commercial important inland fishery is exhibited by the presence of about 120 fish species of which nearly 60 species were widely distributed in most of the aquaculture and breeding activities (ICAR Technologies : Breeding and Seed Production of Finfishes and Shellfishes, July 2019). The important ones are *Catla catla, Labeo rohita, Cirrhinus mrigala, L. calbasu, L. dyocheilus, Wallago attu, Chitala chitala, Tor tor, T. putitora, Clarias batrachus, Heteropneustes fossilis, Channa marulius, C striatus, Anguilla bengalensis, A. bicolour, Mugil cephalus, Lates calcarifer, Rhinomugil corsula and Chanos chanos.* Besides these prawns *Macrobrachium rosenbergii, M. malcolmsonii* and shrimps *Penaeus monodon, P. indicus P. merguensis* are also present. Some of the important endemic cultivable food fishes of Western Ghats are *Labeo dussumeri, Horabagrus brachysoma, Etroplus suratensis, Gonoproctopterus curmuca, Tor khudree, Labeo fimbriatus,* *Punitus pulchellus.* Similarly in the north eastern areas, *Neolissocheilus hexagonolepis, Cyprinus semiplotum, Chagunius chagunius, Osteobrama belangeri, Channa berca* are some of the important endemic fishes of the region. The collected information on exotic invasive fish species revealed the presence of twenty eight aquaculture fish species in the country. Many of them were illegally introduced and their historical information was not available. Some of these introduced exotic fishes were now found in different aquatic water bodies. The detailed information generated on their present distribution in natural waters is given as follows (Table-2).

Table-2: Spread and status of exotic fish species in Indian open-waters (Modified after Singh, 2014)

Name of Exotic fish species	**Reasons of their introduction**	**Occurrences in natural water bodies**			
		Rivers	**Reservoirs**	**Lakes**	**Wetlands**
Cyprinus carpio (C. carpio communis, C. carpio specularis, C. carpio nudus)	Introduced for broadening the species spectrum in aquaculture	Ganga, Yamuna, Godavari, Gomti Damodar, Ghaghra, Rapti, Panba, Tons	Most of the reservoirs	Most of the freshwater lakes	Bihar, West Bengal, Assam, Uttar Pradesh
Hypophthalm-ichthys moltrix	Do	Yamuna, Sutlej, Mahanadi, Pumba, Gomti, Tons, Ganga	Some reservoirs in Himachal Pradesh, Madhya Pradesh, Kearala, Uttar Pradesh	Some freshwater lakes in Himachal Pradesh, Madhya Pradesh, Uttar Pradesh, Uttarakhand	Wetlands of Bihar, West Bengal, Assam, Uttar Pradesh
Ctenopharyn-godon idella	Do	Pumba, Gomti, Yamuna, Ganga	Some reservoirs	Some freshwater lakes in north India	Wetlands of Bihar, West Bengal, Assam, Uttar Pradesh
Hypophthalm-ichthys nobilis	Illegally introduced but widely cultivated. It is a banned species	Yamuna, Ghaghra, Rapti, Gomti, Ganga, Sarayu	Uttar Pradesh	Some freshwater lakes in Uttar Pradesh, Madhya Pradesh, Karnataka	Wetlands of Bihar, West Bengal, Assam, Uttar Pradesh
Clarias gariepinus	Illegally introduced but widely cultivated. It is a banned species	Yamuna, Gomti, Godavari, Pamba, Ganga	Karnataka, Uttar Pradesh, Andhra Pradesh	Some lakes in Andhra Pradesh, Karnataka Kerala, Meghalaya, Uttar Pradesh	West Bengal, Bihar, Andhra Pradesh, Uttar Pradesh

Oreochromis massambicus	A nuisance species widely distributed	Yamuna, Subarnarekha, Kavery, Damodar, Periyar, Ken and Betwa	Most of the reservoirs in Tamil Nadu and some reservoirs Karnataka and Kerala, Jaisamundsagar (Rajasthan), Getalsud reservoir (Jharkhan)	Some lakes in West Bengal, Assam and Madhya Pradesh	West Bengal and Assam
O. niloticus	Introduced for aquaculture. Popular in sewage fed fisheries.	Yamuna, Ganga Subarnarekha, Kavery, Damodar, Periyar, Ken and Betwa	Many reservoirs in West Bengal, Bihar, Madhya Pradesh and Uttar Pradesh	Some lakes in West Bengal, Assam and Madhya Pradesh	West Bengal, Biharand Assam
Pangasianodon hypophthalmus	Considered potential species for aquaculture promotion	Churni river, Godavari, Krishna	No report	Some lakes in Andhra Pradesh and Kerala	West Bengal
Oncorhynchus mykiss	A good candidate species of aquaculture in hills	Pamba, Periyar, Bharathapuzha, Bhilangana, Asi Ganga	No information	Some river strems and lakes in upland waters	Himalayan region
Salmo trutta	A very good candidate species for aquaculture in hills	Beas Sutlej, Asi Ganga		Some river streams and lakes in upland waters	Himalayan region
Piaractus brachypomus	Unauthorised culture and distributed in many states including coastal areas	Periyar river Kearala and some Other states	Maharashtra, Andhra Pradesh and Tamil Nadu	-	West Bengal and Andhra Pradesh
Pterygoplichthus spp. (*P. perdalis*, *P. disjuntivus*)	Unauthorised culture and distributed widely	Ganga and Gomti rivers	-	-	West Bengal and Andhra Pradesh
Pygocentrus naterreri	Unauthorised culture and a banned species	Periyar	Maharashtra	Kerala	-

The state of West Bengal is the hub of seed production of several exotic fishes. As per the survey information it was found that more than 44.6% fry and fingerlings were of exotic fishes. An assessment of culture production of exotic fishes which included mainly *Pangasianodon hypophthalmus, Clarias gariepinus, Hypophthalmichthys nobilis, Litopenaeus vannamei, Piaractus brachypomus* and others was over 40% of total fish production of the country. The rapid expansion of culture of exotic species was found to facilitate the escape of the exotic fishes into natural water bodies. There has been an alarming increase in the number of exotic fish species being captured in the rivers, lakes and reservoirs in recent years. Some of the introduced fish species were widely distributed across several states/union territories e.g. common crap *Cyprinus carpio*, Chinese carps *Ctenopharyngodon idella, Hypohthalmichthys molitrix,* koi carp *Cyprinus carpio,* African catfish *C. gariepinus*, while others were localized in specific regions e.g. Nile tilapia *Oreochromis niloticus*, sutchi catfish *Pangasianodon hypophthalamus*, Pacu *Piaractus brachypomus*, piranha *Pygocentrys nattereri, Pterygoplichthys spp and* many ther ornamental fishes. While aquaculture promises economic and social benefits for potential exotic species, escape of exotic fishes especially those becoming invasive have seriously posed ecological risks to the receiving aquatic environments. The distribution of different invasive exotic fishes and their perceptible threats as well as recorded impact has been synthesized/generated and presented.

The introduced exotic/non-native fish species available in inland waters have been screened for their invasiveness based on a developed science-based simple risk assessment protocol developed 'Fish Invasiveness Screening Test' (FIST) (Singh and Lakra, 2011) and also through the Excel based developed risk assessment module (Figure 1). The procedure includes quantifying the risks of invasive species based on the potential biological features such as growth, culture level, history of establishment, breeding in the wild, phenotypic plasticity (tolerance to a range of salinities and temperatures), ability to live off a wide range of food types, competition with local species, diseases, dispersal ability (propagule pressure) (Singh *et al.,* 2013; Singh, 2021a). Out of several fish species screened, a list of 25 potential aquatic invasive species has been prepared (Table 3). These identified and listed invasive fish species were found to develop naturalized population in inland waters and they displayed a range expansion besides causing array of adverse ecological impacts.

Table 3: List of aquatic invasive species (AIS) bursting in Inland freshwaters, India (Modified after Singh, 2021a).

Sl No	**Name of fish species**	NP+RE	AI
1.	African catfish *Clarias gariepinus*	√	√
2.	Bighead *Hypoththalmichthys nobilis*	√	√
3.	Silver carp *Hypophthalmichthys molitrix*	√	√
4.	Common carp *Cyprinus carpio* Communis.	√	√
5.	Leather carp, *Cyprinus carpio* Nudus.	√	√
6.	Mirror carp *Cyprinus carpio* Specularis.	√	√
7.	Black carp *Mylopharyngodon piceus*	√	√
8.	Mozambique tilapia *Oreochromis mossambicus*	√	√
9.	Nile tilapia *Oreochromis niloticus*	√	√
10.	Western Mosquito fish/ Topminnow *Gambusia affinis*	√	√

11.	Eastern Mosquito fish *Gambusia holbrooki*	√	√
12.	Guppy *Poecillia reticulata*	√	√
13.	Vermiculated sailfin catfish *Pterygoplichthys disjunctivus*	√	√
14.	Amazon sailfin catfish *Pterygoplichthys pardalis*	√	√
15.	Sucker mouth armoured catfish *Pterygoplichthys multiradiatus*	√	√
16.	Parana sailfin catfish *Pterygoplichthys anisitsi*	√	√
17.	Red Piranha *Pygocentrus nattereri*	√	√
18.	Three spot cichlid *Cichlasoma trimaculatum*	√	√
19.	Giant gaurami *Osphronemus goramy*	√	√
20.	Three-spot gourami *Trichogaster trichopterus*	√	√
21.	Green swordtail *Xiphophorus helleri*	√	√
22.	Platy *Xiphophorus maculatus*	√	√
23.	Gutum *Lepidocephalus guntea*	√	√
24.	Golden Apple snail *Pomacea canaliculata*	√	√
25.	Charru mussel *Mytella strigata*	√	√

Note: NP-Naturalised population; RE-Range Extension; Adverse Impacts (AI)-Included Biodiversity loss, Habitat alterations, Human health hazards and Impaired Ecosystem Services.

The studied impacts of exotic fishes revealed that *O. niloticus* displaced carps from the Ganga, and *Puntius dubius* and *Labeo kontius* from rivers of southern rivers. Its prolific breeding habit and parental care helped it to multiply every three months causing space overlap with other local species. The fish is now a part of the fish fauna of the Godavari, Krishna, the Cauvery, the Yamuna and the Ganga rivers where all stages of its life cycle are available. Present commercial fishery of the Yamuna and the Ganga rivers in the State of Uttar Pradesh are found to be dominated by the presence of exotic fishes particularly *C. carpio, Oreochromis* sp. (both *O. niloticus* and *O. mossambicus*) and also few specimens of *C. garipinus, H. nobilis, H molitrix* and *C. idella*. The frequency occurrence of different sizes and the proportion of male and females in different catches revealed that the existing populations had sufficient number of both the sexes to breed naturally and to form feral population. Bighead *H. nobilis* strongly competed with *C. catla* and was found to have potential to hybridize with *Catla* and silver carp (*H. molitrix*). The common carp *C. carpio* naturalized in rivers, lakes and reservoirs displaced local spp. like mahseer *Tor putitora*, *Schizothorax* spp. etc (Table 4). It also displaced an endemic fish species *Osteobrama belangiri* from Loktak Lake (Manipur). The silver carp formed a breeding population in Govind sagar Reservoir (Himachal Pradesh) and Kulgarhi reservoir (Madhya Pradesh) and changed the trophic structure thereby replacing *catla* fishery.

The extensive culture of African catfish *C. gariepinus* throughout the country has threatened the existence of local magur *Clarias magur* which is now not sighted usually in most of its habitats throughout the country. The potential of African catfish to hybridize with local *C. batrachus* has been reported (Rahman et al. 1995; Sahoo et al. 2003). Hybrids between the indigenous and exotic African catfish are being produced in the hatcheries (Rahman et al.

1995) and the seed smuggled into the bordering north-eastern States as well as Assam and West Bengal and as far as Bihar forms the basis of a flourishing trade of exotic African catfish.The unregulated spread of *P. hypophthalmus* in India was found as a matter of great concern particularly with regard to the diseases such as haemorraegic septicaemia, bacillary diseases, *Flavobacterium columnarae* disease, Trichodinal disease affecting biodiversity as well as socio-economic conditions. Some of the exotic fishes such as *P. hypophthalmus* and *Piaractus brachypomus* were used both for food as well as ornamental purpose and hence their release into natural habitats was doubled. We captured some live specimens of piranha *Pygocentrus nattereri* and pacu *P. brachypomus* from Periyar river of Kerala and from Dimbhe reservoir near Pune, Maharashtra. There were incidences of some people bitten when they entered into the reservoir for their day to day work. Two highly invasive fish species *Pterygoplichthys dijunctivus* and *P. perdalis* were also recorded to breed in large number in rivers, reservoirs and wetlands of different states such as Andhra Pradesh, West Bengal, Bihar and Uttar Pradesh where thousands of live specimens were captured.

Table-4: Impact of exotic fishes available in Inland waters

Fish species	**Potential impacts**
Oreochromis mossambicus	Naturally breeding population exists in rivers, reservoirs and lakes. Declined catches of Gangetic carps from Ganga river system, replaced *Puntius dubius* and *Labeo kontius* from the reservoirs in southern part.
Aristichthys nobilis	Displacement of *Catla* and possibility of natural hybridization with silver carp and *Catla catla*
Cyprinus carpio	Naturalized population in rivers, reservoirs and lakes displacing Indian major carps from Ganga river and of local spp. particularly *schizothorax richardsonii, Tor putitora* in hill stream, lakes and reservoirs
Pangasianodon hypophthalmus	Disease risks of haemorraegic septicaemia, bacillary diseases, *Flavobacterium columnarae* and *Trichodina* parasitic infection. Threats to biodiversity and socio-economic conditions due to preferred species over local species.
Oreochromis niloticus	Naturally breeding population in rivers, reservoirs and lakes is existing. Declined catches of Gangetic carps in Ganga river system. Introgression with other species of tilapia and reduced catches of indigenous fishes including *Etroplus suratensis* from Kerala rgion in South.
Clarias gariepinus	Highly carnivorous causing loss to biodiversity. Naturalized in some reservoirs and also available in some rivers (Ganga, Yamuna, Godavari);
Carassius auratus	Hybridization with common carp in nature
Hypophthalmichthys molitrix	Naturalized in some reservoirs (Govind sagar and Kulgarhi) displacing *Catla* fishery.
Salmo trutta	Eradication of local spp. from hill streams.
Gambusia affinis	Its presence reduced natural zooplankton population thereby displacing many local fish species.

Pygocentrus nattereri	Becoming invasive in natural water bodies in Kerala. Incidences of biting the fishermen are also found in Maharashtra
Pterygoplichthys perdalis and P. disjunctivus	Breeding population in wetlands of of different states were found and tonns of fishes found at different locations. Local species got significantly reduced. Live specimens have been captured from, the Wembenad lake, Kolleru lake, the Gomti river, Godavery and the Ganga river.

Challenges of Fish Invasion:

Risks of invasion are now shifting rapidly owing to expanding culture and transportation networks of exotic/ non-native fish, farmer's fascination towards technological advancements for culture and breeding of potentially introduced fish species, increased international trade and landscape transformation as well as climate change. Since there is no sign of slowing down of aquatic invasion under the influence of diverse and dynamic forces, there is a crucial need for generating advanced information to manage all such introduced exotic fish species through modern risk assessment tools (Singh et al. 2013; Jennifer *et al.,* 2016; Lorenzo et al., 2021). Excessive delays in recognizing, preparing for, and responding to emerging problems of fish invasion will result in irreversible harm. Assessment of impact of several hybrids of catfish, pacu, tilapia, bighead, ornamental fish which have invaded have not been done and there are scientific evidences that they will behave insidiously if no action is taken to contain them. The poorly regulated international pet trade will give entry to future invasive ornamental fishes. However, we lack methodologies to predict the invasion risks and likely ecological impacts of such potential invaders which have little or no information on invasion history. Moreover, our information on invasive ornamental fish is also very limited since risk assessment for them have been inadequate so far.

Containment approaches

The first regulatory guideline was developed during 2002 and subsequently implemented. Nevertheless, *O. niloticus* and *C. carpio* invaded largely into the Ganga river basin during 2004 and many other fish invasions in several other river streams, reservoirs and lakes has been reported. As a signatory to the Convention on Biological Diversity, India is committed to managing its major biological invasions. Invasive species have been found to exert varying scale of ecosystem effects. Responses to control them throughout the invasion range has been limited and the existed regulatory mechanisms and the scale of implementation also need to be improved. In absence of any legislation to regulate invasive species, aquaculturists and aquarium fish traders usually express an attitude of denialisms of the ill-impacts caused by invasive fish in the interest of immediate gains from aquaculture which prevails. It reflects that conservationists are lagging behind in action while aquaculturists are actively fostering introduced exotic/non-native fish culture consequently invasive species are escalating in the inland waters in the country. Fish invasions are on the rise in recent times even after implementing protocols and guidelines available to manage them (Singh, 2021b). It is essential to ensure stringent operation and compliance of appropriate regulations, procedures, policies and even legislation to effectively manage AIS. Since the existing guidelines and regulatory mechanisms are now old, there is a need to revisit, improve and refine them for stringent implementation for managing the nuisance of invasive species and their adverse impacts effectively. At the same time, continued cooperation and compliance within central and state governments, academia, and the private sector are also mandatory to be contrived, arranged, and devised together to fight out biological invasions. A separate National Policy on prevention of invasive species is urgently needed to deal with nuisance and scathing impacts in India.

Conclusion

India, a megadiverse tropical country is grappling with the issue of aquatic invasions although research on invasion science continued over the last two decades, helping to improve scientific knowledge and contributing towards policy formulation and implementation of management. In this paper, only 25 aquatic invasive species are assessed whereas the number could be larger. The assessment of many more species especially ornamental fish and shellfish need to be done following modern risk assessment protocols (Singh et al., 2013; Dominguez *et al.*, 2020; Lorenzo et al., 2021). Aquatic invasions, with the threats they pose to aquatic biodiversity, represent particularly difficult challenges to the society in general and to decision makers in particular. Information on aquatic invasive species is limited hence there is urgent need to update information and to generate scientific skills and knowledge as transfer of credit to manage them.

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INVASIVE ALIEN PLANT SPECIES (IAPS) IN THE AQUATIC ECOSYSTEMS OF KERALA

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INTRODUCTION

Aquatic ecosystems including wetlands support a wide array of flora and fauna and deliver many ecological, climatic and societal functions and provide livelihood to the residents in the area in the form of agricultural produce, fish, fuel, fiber, fodder, and a host of other day-to-day necessities. It is also considered as the largest terrestrial carbon sinks due to their carbon sequestration capacity for a longer time scale in the past as well as future potential. The wetlands alone store more than 30% of the estimated global carbon emissions (Nahlik & Fennessy, 2016). Thus, conserving and restoring aquatic ecosystems, including the coastal wetlands, is a critical climate mitigation strategy.

The aquatic (wetland) plants are commonly defined as plants “growing in water or on a substrate that is atleast periodically deficient in oxygen as a result of excessive water content (Cowardin et al.1979). Many authors do not make a distinction between *wetland plants* and *aquatic plants*. For example, Barrett et al. (1993) use the term aquatic plant in its broadest sense to include all plants that occur in permanently or seasonally wet environments. However, other authors such as Cook (1996) define (vascular) aquatic plants as those Pteridophytes (ferns and fern allies) and Spermatophytes (seed-bearing plants) whose photosynthetically active parts are permanently or semi-permanently submerged in water or float on the surface. Other authors make a similar distinction with regard to species they consider to be *true aquatics,* a term sometimes used to denote species that complete their lifecycle with all vegetative parts submerged or supported by the water (Best 1988). Examples of families with submerged and floating-leaved species that fall in this category include the Nymphaeaceae (water lilies), Potamogetonaceae (pondweeds), Lentibulariaceae (bladderworts), and Najadaceae(naiads).

The aquatic plants, wherever they grow, play an important role in the ecosystem. As long as human interventions are minimal, the aquatic plants regulate the quality of the water and provide food and shelter for its inhabitants. If nature is upset, they can disappear altogether or grow and spread at an alarming rate and directly threaten the human life

Biological invasions are considered one of the major threats to the conservation of biodiversity (Macketal.2000, IPBES2019). At a global scale, plants are among the most widespread invasive organisms as they are frequently introduced for agriculture, agroforestry and ornamental purposes (Pyšek et al. 2012). The IAS are considered as the

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primary cause of recent extinctions in most taxonomic groups (Bellard, and Ricciardi 2019). IAS also cause substantial negative impacts to human health, livelihoods and economies (Prattet al. 2017). The sixth Conference of Parties (Decision VI/23) of the United Nations Convention of Biological Diversity (CBD) defined alien species as a species, sub-species or lower taxon, introduced outside its natural past or present distribution, which includes any part, gametes, seeds, eggs or propagules of such species that might survive and subsequently reproduce (CBD, 2002). CBD is also taking major steps to check the growth and spread of Invasive Alien Species all over the world. International Union for Conservation of Nature (IUCN) highlighted that, invasive species are widely distributed in all kinds of ecosystems throughout the world and harbor all major taxonomic groups including viruses, fungi, algae, mosses, ferns, higher plants, invertebrates, fish, amphibians, reptiles, birds and mammals (Sujay et al., 2010).

The aquatic IAPS have adapted to living in, on, or next to water, and that can grow either submerged or partially submerged in water. With respect to the aquatic ecosystems, the IAPS have been identified as a major threat to the local biodiversity, ecosystems and human livelihood. This was evident for the last few years, many aquatic plants have invaded new areas, some were deliberately planted because of their economic or decorative value or were accidentally introduced with other plants have become aggressive weeds in the aquatic ecosystems. According to Moorhouse and Macdonald (2015), the freshwater aquatic habitats appear to be disproportionately vulnerable to and negatively affected by invasive species compared to terrestrial habitats.

The riparian zones are also among the natural habitats more prone to be invaded by exotic plants. Riparian zones receive a high propagule pressure of exotic plants, their abiotic conditions are benign for plant life, and their biotic resistance from native vegetation is released by natural (floods) and anthropic (hydrological changes) disturbances. The convergence of these factors explains the high invasion rate of riparian zones (Pilar Castro-Díez∗ and Álvaro Alonso, 2017).

The aquatic IAPS severely effect and alter the environmental conditions, ecosystem processes, plant and animal communities and human uses of water bodies. A comprehensive review on the impact of invasive plants in aquatic systems is done recently by Albert et.al (2021). The major ecological and environmental impacts aquatic invasive macrophytes are summarized here:

- One of the major impacts of invasive aquatic plants is loss of plant diversity. It affects the growth and distribution of native plant species by hindering the light availability, altering the microclimates and modifying the pattern of plant succession, causing eutrophication through high rate of decomposition, depleting dissolved oxygen etc.
- Invasive species have the potential to alter the structure and functioning of the recipient community, either by causing the local extinction of native species and/or by adding novel functional traits to the community (Castro-Díez et al.,2016). A decline on the local diversity is the most often reported impact of plant invasions.
- Dense growth of non-native vegetation disrupts movement of water and sediment can be trapped at higher rates and cycling of carbon, nitrogen, and other nutrients can be altered. This may also have impact on water quality.

- The invasive plants are known to have high impact on agriculture by increasing the cost of cultivation to prepare the land by removing the IAPS.
- The changes in dominant vegetation following invasions influence the food webs and flow of energy through aquatic systems (Kelly and Hawes 2005). The impact on fish and other wildlife are of great concern. By reducing dissolved oxygen, dense growth of invasive plants can drive of for cause mortality of invertebrates and fish (Madsen 1997). Nesting, growth and foraging success of plant-loving fish are highly influenced by plant composition and density. Aquatic birds come in an almost infinite number of sizes and shapes and require many different resources to complete their life cycles.
- They can also harm human health and wellbeing spreading more diseases by providing habitats for vectors and through water pollution. The uncontrolled growth of invasive plants often provides an undisturbed habitat that mosquitoes prefer and where they can proliferate.
- The water-logged soil in aquatic ecosystems formed by high degree of eutrophication emits high concentration of methane to the atmosphere.
- Dense mats of floating and submersed plants restrict navigation and impede water movement important for flood control, irrigation, and hydro power (Eiswerth and Johnson 2002).
- Recreational uses of lakes and rivers are disrupted when nuisance vegetation fouls boat motors or interferes with waterskiing, fishing, or wildlife viewing (Gettys etal.2014).
- Decreased aesthetic value and interference with recreation reduce property values and tourism income (Charles and Dukes 2008).

There exists a huge knowledge gap with respect to the damages caused by the invasive species and its impact on ecology and economy. A recent study by Alok Bang et.al (2022) on the economic loss biological invasion in India is helped to resolve the knowledge gaps to a greater extend. The study found that IAS have cost the Indian economy between atleast ₹8.3 trillion to 11.9 trillion over 1960–2020, and these costs have increased with time. Despite these massive recorded costs, most were not assigned to specific regions, environments, sectors, cost types and causal IAS, and these knowledge gaps are more pronounced in India than in the rest of the world. The study also found that the semi-aquatic and aquatic taxa (mostly semi-aquatic/ riparian) have been causing a greater monetary burden to the economy compared to taxa inhabiting terrestrial ecosystems. The number and total impacts of invasive species will likely continue to increase despite increased management efforts. Other factors like global climate change, will affect the distribution and impacts of invasive fresh water species and in many cases will make those impacts more severe.

Across the world there are a several policies, legislations management approaches and awareness campaigns involving citizens to deal with invasive alien species (Piria et al., 2017). However, in India, there is no comprehensive plan to tackle the growing menace of invasive alien species, especially in the case of aquatic invasive species. Local based more coordinated studies, intervention and policies in this direction are the need of the hour.

INVASIVE ALIEN PLANT SPECIES IN THE WETLANDS OF KERALA

By virtue of its unique location (sandwiched between the Arabian Sea on the west and the Western Ghats on the east), topography (ranging from the coast allow lands to mountain regions intervened by vast expanse of undulating midlands) and high rain fall, Kerala provides a wide variety of aquatic habitats like rivers, streams, pools, ponds, lagoons, estuaries etc. harboring unique types of vegetation of their own. The wetlands of Kerala are treated as sites of exceptional biodiversity in the country and are characterized by several endemic species. The coastal plains have been ravaged since early times of human habitation and most of the land is now used for housing and agriculture. Even these disturbed habitats are potential location for rapid speciation which has been amply proved from the long list of new taxa discovered and described from here during the last two decades.

Like geographical distribution diverse types of wetlands, Kerala is also well known for its and high diversity of wetland macrophytes. Even though the plant diversity of Kerala is well studied, the aquatic ecosystems of Kerala to some extend are the least explored. So is the case with aquatic IAPS also. The first and foremost study invasive plants of Kerala published by Kerala State Biodiversity Board (Sankaran et.al., 2012) contain 82 plants. The list mainly dealt with the terrestrial IAS, mainly in forest areas of Kerala. However, 5 species in the list are commonly found in aquatic ecosystems (*Alternanthera philoxeroides, Ipomoea aquatica, Ipomoea carnea subsp. fistulosa, Ludwigia peruviana* and *Sesbania bispinosa*) also. Another around 40 plants mentioned in the list are found growing luxuriously in the riparian areas of major rivers of Kerala (Sabu et.al., 2019).

A recent study sponsored by Kerala State Biodiversity Board (SuharaBeevy S and Kamarudheenkunju M, 2019) has listed 19 aquatic plants as IAS in Karthikapilly Taluk of Alappuzha district. However, 9 plants mentioned in the report as aquatic IAPS are seems to be native species of India (*Ceratopteris thalictroides, Colocasia esculenta, Hygrophila schulli, Pontederia vaginalis* (*Monochoria vaginalis, Nelumbo nucifera, Persicaria barbata, Riccardia multifida, Utricularia aurea* and *Wolffia globosa*)

Another study in Kole wetlands (Praveen Kumar, 2018) listed 11 species of which 6 are indigenous/naturalised species (*Cyperus cephalotes, Pistia stratiotes, Sacciolepis interrupta, Sesbania javanica, Sphaeranthus indicus, Spirodela polyrhiza* and *Utricularia aurea*).

The Pampa Parirakshana Samithy (2014) in a project by KSBB has attempted Management of Aquatic Invasive species in Pampa Riverine System, with special emphasis to Cabomba. The Report contains locations and tributaries of River Pampa where the Cabomba is visibly spreading and the major ecological damages due to spreading of Cabomba. Also, it proposed some management strategies to eradicate the invasive species. According to the authors, the study is preliminary in nature and detailed scientific studies are inevitably needed for finding out practical process for eradication of invasive species from natural water-bodies.

Kerala Forest Research Institute (KFRI) has initiated detailed studies in IAPS which include aquatic plants also. Species specific detailed studies with respect to the distribution, spread and management of *Pontederia crassipes* is very much advanced in

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The National Biodiversity Authority India has published a checklist of Invasive Alien Species (Sandilyan, 2019). The list contains 60 plants of which 53 terrestrial and 7 aquatic species including the floating aquatic plant *Cabomba caroliniana* which is included in the terrestrial list.

The present attempt is to enumerate the IAPS in Kerala is based on the analysis of the findings of various studies on wetland plants the author the involved (CED, 2002, 2010 and 2019; CED and JNTBGRI, 2017, Sabu 2008a, 2008b, 2009; Sabu and Babu, 2007; Sabu et al., 2020). The present analysis considers only aquatic invasive vascular plants. The presence of Invasive algae species in the water bodies in Kerala is an area mostly unexplored and needs special attention.

Invasive plants are found throughout the State of Kerala across a wide variety of aquatic habitats, including lakes, ponds, rivers, streams, estuaries, paddyfields, marshy lands etc. There are three main growth forms of aquatic invasive plants present in the water bodies of Kerala, i) freefloating (Eg. *Pontederia crassipes*, *Pistia stratiotes*), ii) rooted under water but potentially floating on water surface (Eg.*Cabomba caroliniana*) and iii) emergent plants with erect stems above or on the surface of the water/saturated soils (Eg. *Limnocharis flava*).

With respect to growing habitats, two categories of plants are described here. First one is plants growing in truly aquatic or permanently moist areas like marshy lands and paddy fields and the other one occurs in the margins of wetlands, mainly in the riparian zones of rivers. These plants also grow in terrestrial habitats; however, the growth rate of the plants is very high in the riparian zones compared to the same species growing in other terrestrial habitats.

The major literature used to ascertain the invasive alien status of the plants are: Sankaran *et.al.*, 2012; Sandilyan, 2019; CABI, 2022 and GISD, 2022). The Botanical nomenclature and native distribution areas are as per the data from Plants of the World Online by Royal Botanic Gardens Kew (POWO, 2022). Table 1 provides the list IAPS found in the truly aquatic ecosystems in Kerala like rivers, streams, estuaries, paddy fields and marshy areas.

Table 1: IAPS found in the truly aquatic ecosystems in Kerala

S. No	Bot. Name	Common Name	Family	Habitat	Distribution-Kerala	Native Country	Category*	Reference
1	*Alternanthera philoxeroides* (Mart.) Griseb	Vellamkanni - Alligator weed	Amaranthaceae	Wet/Marshy areas and paddy fields	Coastal Districts from ALP to KNR	Trinidad to N. Argentina.	D	Sandilyan, 2019; Sankaran et.al, 2012; CABI, 2022, GISD, 2022
2	*Azolla pinnata* R.Br.	Mosquito fern	Salviniaceae	Coastal water bodies and paddy fields - Free floating		Tropical &Subtropica l Old World.	C	CABI, 2022; GISD, 2022

3	*Cabomba caroliniana* A.Gray	Mullenpayal - Carolina fanwort	Cabombaceae	Fresh water canals, ponds and rivers - rooted/ floating	All Districts	Central & E. U.S.A. to NE. Mexico, Brazil to Central Argentina	A	Sandilyan, 2019; CABI, 2022; GISD, 2022
4	*Cyperus aromatics* (Ridl.) Mattf. &Kük.	Navuasedge	Cyperaceae	Wet/Marshy areas and paddy fields	ALP, EKM	Tropical Africa	C	CABI, 2022
5	*Dactylocteniumaegyptium*(L.) Willd.	Kavarapullu - Crow foot grass	Poaceae	Wet/Marshy areas and paddy fields	All Districts	South America	C	CABI, 2022
6	*Ipomoea aquatica* Forssk.	Kozhuppa – Swamp morning glory	Convolvulaceae	Ponds, streams and lakes	All Districts	Pantropics	B	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
7	*Ipomoea carnea subsp. fistulosa* (Mart. ex Choisy) D.F.Austin	Neyvelikatta - Bush Morning Glory	Convolvulaceae	Wet/Marshy areas and River/stream sides	All Districts	Mexico to S. Tropical America	A	Sandilyan, 2019; Sankaran et.al, 2012, CABI, 2022
8	*Lemna perpusilla* Torr.	Duckweed	Araceae	Stagnant waters- Free floating	All Districts	E. Canada to Central & E. U.S.A	B	Sandilyan, 2019; CABI, 2022
9	*Limnocharis flava* (L.) Buchenau	Nagapola - Water cabbage	Alismataceae	Wet/Marshy areas, paddy fields and streams	All Coastal Districts	Mexico to Tropical America	A	CABI, 2022, GISD, 2022
10	*Ludwigia peruviana* (L.) H.Hara	Clavo	Onagraceae	Wet/Marshy areas and paddy fields	ALP to KNR	Mexico to Tropical America	B	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
11	*Marsilea quadrifolia* L	Water clover	Marsilea ceae	Wet/Marshy areas and paddy fields	All Coastal Districts	Canary Islands, Europe to Japan and Iran	C	Sandilyan, 2019
12	*Pistia stratiotes L.*	Water letuce	Araceae	Ponds and tanks- Free floating	All Districts	Tropics &Subtropics	A	CABI, 2022, GISD, 2022

13	*Pontederia crassipes* Mart. (Syn. Eichhornia crassipes (Mart.) Solms.)	Kulavazha-Water hyacinth	Pontederiaceae	Backwaters, ponds, lakes, rivers and rice paddy fields-Free floating	All Districts	Tropical America	A	Sandilyan, 2019: CABI, 2022
14	*Salvinia molesta* D.Mitch	African Payal - Kariba weed,	Salviniaceae	Coastal/Near coastal water bodies-Free floating	All Districts	S. & SE. Brazil to Argentina	A	Sandilyan, 2019:CABI, 2022;GISD, 2022
15	*Sesbania bispinosa* (Jacq.)W.Wight	Prickly sesban, Dhaincha	Fabaceae	Marshy/paddy fields	ALP, EKM, TSR, PKD, MPM	Pantropics	A	Sankaran et.al, 2012, CABI, 2022
16	*Spermacoce remota* Lam.	Button weed	Rubiaceae	Wet/Marshy areas and paddy fields	ALP, EKM, KKD, WYD	Tropical &Subtropical America	C	Narasimhan eta. al. 2011
17	*Struchium sparganophorum* (L.) Kuntze	Oreille-mouton	Asteraceae	Wet/Marshy areas and paddy fields	TVM to TSR	SE. Mexico to Tropical America	C	Suhara Beevynd Kamarudheen kunju, 2019
18	*Urochloa mutica* (Forssk.) T.Q.Nguyen (Syn. *Brachiaria mutica*(Forssk.) Stapf)	Para grass	Poaceae	Shallow water, banks of stream, backwaters and rivers	TVM, KLM, ALP, KKD	Sahara to Angola, N. Africa to Syria, SW. Arabian Peninsula	B	CABI, 2022, GISD, 2022

*A-High Risk, B-Medium Risk, C-Low Risk and D-Insignificant

The present analysis enlisted 18 truly aquatic IAPS (16 Angiosperms and 2 Pteridophytes) belonging to 16 families. All the aquatic IAPS listed here except *Ipomoea carnea sub sp.fistulosa*, are herbaceous plants. 6 out of the 18 species are floating plants and others are rooted plants found in marshy/wet areas and shallow waters. Most of the plants are distributed all over Kerala and some are restricted to coastal areas only (Table 1. The risk of invasiveness is based on the classification mainly by Sankeran *et.al.* (2012) and field observations during various studies wetland flora. Accordingly, 7 species are included in the high-risk category (A), 4 under medium risk (B), 6 in low risk (C) and 1 species in insignificant (D) category. However, there is a need for more studies with respect to the categorization of plants.

Ipomoea aquatic is included in the IAPS list of Kerala (Sankeran *et.al*, 2012). However, as per the literature available the native distribution range of these plants include India (POWO, 2022; Sasidharan, 2022), and needs further examination for including the plants in truly IAPS category. In the case of *Pistia stratiotes* also most of the literature shows the native geographic range of the plants include India (Eg.POWO, 2022). The 17th -century botanical treatise, *Hortus Malabaricus* by Hendrik van Rheede also described this plant from India (*Kodapayil*,Vol.XI). Hence, including this plant in the IAPS list also need a re-check.

Hanguana anthelminthica is one exotic plant now widely spreading in the margins of the backwater areas of Alappuzha and Kottayam district which needs more study to include in the aquatic IAPS list of Kerala. There are also some species like *Cyperus prolifer, Ludwigia sedoides, Myriophyllum aquaticum* etc. which are widely grown in gardens and aquarium in Kerala which may become a future threat to the aquatic habitats when released into the natural systems.

World over it is found that riparian zones are among the natural habitats exhibiting a higher proportion of invasive plants. The plants growing in riparian areas very much linked with aquatic fauna and flora and the effects of invaders may propagate across the food webs altering the structure and functioning of fluvial and riparian animal communities. In Kerala also we can find many terrestrial IAPS growing luxuriously in the riparian zones of almost all rivers in Kerala. Some plants like *Bambusa vulgaris* is planted as part of river bank stabilization is seems to be giving opposite results. Since it affects the river biodiversity as well as bank stabilization, it is expressive to consider these plants also as the aquatic invasive alien plant species. Table 2 provides the list IAPS found in the riparian ecosystems in Kerala during various studies.

Table2: IAPS found in the riparian ecosystems in Kerala

S. No	Bot. Name	Common Name	Family	Habitat	Distribution-Kerala	Native Country	Category*	Reference
1	*Acacia auriculiformis* A.Cunn. ex Benth.	Acasia-Ear Pod Wattle	Fabaceae	Banks of streams, Paddy fields	All Districts	SE. Maluku to New Guinea and Australia	B	Sandilyan, 2019; Sankaran et.al, 2012; CABI, 2022
2	*Ageratina adenophora* (Spreng.) King & Robins	Crofton weed	Asteraceae	Banks of streams	KLM, PTA, IDK, TSR to KNR	Mexico	B	Sandilyan, 2019; Sankaran et.al, 2012, CABI, 2022, GISD, 2022
3	*Ageratum conyzoides*(L.) L.	Kummini pacha - Marrubio	Asteraceae	Banks of streams	All Districts	Mexico	C	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
4	*Ageratum houstonianum* Mill.	Neelappa - Goat weed	Asteraceae	Banks of streams	All Districts	Mexico to Central America	D	Sankaran et.al, 2012, CABI, 2022
5	*Alternanthera brasiliana* (L.) Kuntze	Joy weed	Amaranthaceae	Banks of streams	All Districts	Mexico to Central America	C	Sandilyan, 2019; Sankaran et.al, 2012

6	*Amaranthus spinosus* L.	Mullanchera - Spiny pigweed	Amaranthaceae	Banks of streams	All Districts	Mexico to Tropical America	C	Sankaran et.al, 2012, CABI, 2022
7	*Antigononleptopus* Hook. &Arn.	Thenpoovalli- Coral vine	Polygonaceae	Banks of streams	All Districts	Mexico to Central America	A	Sandilyan, 2019; Sankaran et.al, 2012; CABI, 2022; GISD, 2022
8	*Asclepias curassavica* L.	Kammalchedi- Blood flower	Apocynaceae	Banks of streams	All Districts	Mexico to Tropical America	D	Sankaran et.al, 2012
9	*Bambusa vulgaris* Schrad. ex J.C.Wendl.	Seema mula - Yello bamboo	Poaceae	Banks of streams	All Districts	China (Yunnan) to Indo-China		CABI, 2022, GISD, 2022
10	*Calopogonium mucunoides* Desv.	Wild ground nut	Fabaceae	Banks of streams	All Districts	Mexico to Tropical America	B	Sankaran et.al, 2012, CABI, 2022
11	*Camonea vitifolia* (Burm.f.) A.R.Simões& Staples *(Merremia vitifolia* (Burm. f.) Hall. f.)	Manjavayaravalli-Grape-leaf Wood Rose	Convolvulaceae	Banks of streams	All Districts	Indo-China and China	A	Sankaran et.al, 2012
12	*Cenchrus purpureus* (Schumach.) Morrone *(Pennisetum purpureum* Schumach.*)*	Elephant grass	Poaceae	Banks of streams and backwaters	ALP, KTM, KNR, KSD	Sahara to Tropical Africa, Aldabra, Arabian Peninsula	B	CABI, 2022
13	*Centrosema molle* Benth.	Kattupayar - Spurred Butterfly Pea	Fabaceae	Banks of streams	All Districts	Mexico to Tropical America	C	Sankaran et.al, 2012
14	*Chromolaena odorata* (L.) R.M.King&H.Rob.	Communistpacha - Siam weed, Bitter Bush	Asteraceae	Banks of streams	All Districts	Tropical &Subtropical America	A	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
15	*Combretum indicum* (L.) DeFilipps *(Quisqualis indica L.)*	Thookuchethi - Rangoon creeper	Combretaceae	Banks of streams	All Districts	Myanmar	A	Sankaran et.al, 2012; CABI, 2022
16	*Croton bonplandianus* Baill.	Ban Tulsi - Riverside Weed	Euphorbiaceae	Banks of streams	TSR, PKD	S. Bolivia to Uruguay.	D	Sankaran et.al, 2012

17	*Gomphrena celosioides* Mart.	Neervadamalli - Water globehead	Amaranthaceae	Banks of streams	All Districts	Ecuador to N. Argentina	D	Sankaran et.al, 2012
18	*Hyptis capitata* Jacq.	Knobweed	Lamiaceae	Banks of streams	All Districts	Florida, Mexico to Tropical America	B	Sankaran et.al, 2012
19	*Ipomoea cairica* (L.) Sweet	Railway creeper	Convolvulaceae	Banks of streams	All Districts	Paleotropics	A	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
20	*Leucaena leucocephala* (Lam.) de Wit	Ippilippil - Subaul	Fabaceae	Banks of streams	All Districts	Mexico to Central America	C	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
21	*Mesosphaerum suaveolens* (L.) Kuntze *(Hyptis suaveolens* (L.) Poit.)	Nattapoochedi - Pignut, Wild Spikenard	Lamiaceae	Banks of streams	All Districts	Mexico to Tropical America	B	Sankaran et.al, 2012, CABI, 2022
22	*Miconia crenata* (Vahl) Michelang. *(Clidemia hirta* (L.) D. Don)	Soap bush	Melastomataceae	Banks of streams	TVM to PKD	Mexico to Tropical America	C	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
23	*Mikania micrantha* Kunth	Vayara - Bitter vine	Asteraceae	Banks of streams	All Districts	Tropical &Subtropical America	A	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
24	*Mimosa diplotricha* C.Wright ex Sauvalle	Anathottavadi - Giant sensitive plant	Fabaceae	Banks of streams	All Districts	Tropical &Subtropical America	A	Sankaran et.al, 2012, CABI,2022, GISD, 2022
25	*Mimosa pudica* L.	Thottavadi - Touch me not	Fabaceae	Banks of streams	All Districts	Mexico to Tropical America	C	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
26	*Neustanthus phaseoloides* (Roxb.) Benth. *(Pueraria phaseoloides* (Roxb.) Benth)	Thotta-payar - Tropical kudzu	Fabaceae	Banks of streams	All Districts	Tropical &Subtropica l Asia	A	Sankaran et.al, 2012, CABI, 2022

27	*Parthenium hysterophorus* L.	Congress pacha - Carrot Grass	Asteraceae	Banks of streams	All Districts	Tropical &Subtropical America	B	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
28	*Passiflora foetida* L.	Poodapazham - Stinking passion flower	Passifloraceae	Banks of streams	All Districts	Tropical &Subtropical America	B	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
29	*Ricinus communis* L.	Aavanakku - Castor oil plant	Euphorbiaceae	Banks of streams	All Districts	NE. Tropical Africa.	B	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
30	*Senna alata* (L.) Roxb.	Puzhukkadithakara - Golden Candle sticks	Fabaceae	Banks of streams	All Districts	SW. Mexico to Tropical America	A	Sankaran et.al, 2012, CABI, 2022
31	*Senna hirsuta* (L.) Irwin & Barneby	Woolly Cassia	Fabaceae	Banks of streams	All Districts	Tropical &Subtropical America.	B	Sankaran et.al, 2012, CABI, 2022
32	*Senna occidentalis* (L.) Link	Poniionthakara - Coffee-senna, Negro coffee	Fabaceae	Banks of streams	All Districts	Tropical &Subtropical America	C	Sankaran et.al, 2012, CABI, 2022
33	*Senna tora* (L.) Roxb.	Ponthakara - Sickle Senna	Fabaceae	Banks of streams	All Districts	Central America	B	Sankaran et.al, 2012
34	*Sphagneticola trilobata* (L.) Pruski	Singapore daisy	Asteraceae	Banks of streams	All Districts	S. Tropical America and Trinidad	A	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
35	*Synedrella nodiflora* (L.) Gaertn.	Mudianpacha - Synedrella	Asteraceae	Banks of streams	All Districts	Tropical &Subtropical America.	D	Sankaran et.al, 2012, CABI, 2022
36	*Tithonia diversifolia* (Hemsl.) A. Gray	Velisooryakanthi Mexican Sunflower	Asteraceae	Banks of streams	All Districts	Mexico to Central America.	B	Sankaran et.al, 2012, CABI, 2022, GISD, 2022
37	*Aeschynomene americana* L.	American Joint Vetch	Fabaceae	Banks of streams	KLM, PTA, EKM, TSR, MPM, KKD, KNR	Tropical &Subtropical America	C	Sankaran et.al, 2012, CABI, 2022

38	*Alternanthera ficoidea (L.) P.Beauv.*	Rabit meat	Amarant haceae	Banks of streams	PTA to MPM	Tropical America	C	Sandilyan, 2019; CABI, 2022
39	*Alternanthera paronychioides* A.St.-Hil	Pampera - Smooth joyweed.	Amarant haceae	Banks of streams	KLM, IDK, TSR, PKD, WYD	Tropical &Subtropi ca l America	D	Sandilyan, 2019; CABI, 2022
40	*Tridax procumbens* L.	Kumminip acha - Tridax daisy	Asteracea e	Banks of streams	All Districts	Mexico to Tropical America	D	Sankaran et.al, 2012, CABI, 2022

*A-High Risk, B-Medium Risk, C-Low Risk and D-Insignificant

There are 40 riparian IAPS, all Angiosperms, belonging to 12 families found in the riparian areas of Kerala. Majority of the species belongs to Fabaceae (12), Asteraceae (10) and Amaranthaceae (5) Here also majority are herbaceous plants. Most of the plants are distributed all over Kerala. 10 species are there in the high-risk category (A), 13 under medium risk (B), 10 in low risk (C) and 7 species in insignificant (D) category. A good number of plants in the high-risk category is a matter of concern. *Lantana camara* L is also found growing in some riparian areas but grow this not so vigorous as seen in the open forest areas.

DEVELOPING MANAGEMENT STRATEGIES

A diversity of management strategies and policy options are practiced all over the world to prevent, contain, control and eradicate aquatic invasive species and the COP decision V/8 of CBD provides guidelines for invasive species management. One major aspect we have to keep in mind when developing management strategies for aquatic IAPS is that the risk posed by invasive plants to a given aquatic habitat depends mainly on the geography, climate, propagule pressure from source populations, habitat characteristics that influence susceptibility to invasion, and management efforts. Based on the abundance of the invasive plants in an aquatic habitat, their potential impacts on environmental conditions increase. Attempts to manage invasive species can have unintended negative consequences when those complex interactions are poorly understood.

In managing the IAPS in Kerala, one major gap noticed is the lack in depth studies with respect to the impact of various IAPS on the local biodiversity especially with respect to the local species affected. Major aspects to consider while developing management strategies to control aquatic IAPS in Kerala are:

- To provide a more objective and accurate approach for managing and predicting biological invasions, understanding the process by which alien species become naturalized or invasive.

- Developing any management strategies require reliable scientific information regarding invasive alien species of most concern, its habitats and distribution pattern etc. This has to generated through scientific studies including baseline taxonomic studies based on which an information system has to be developed. The potential pathways of entry IAPS also has to identified through the studies.

- The identified IAPS has to be prioritized for prevention, eradication, early warning rapid response, long-term control, and monitoring, and implement effective and well-resourced measures.
- IAPS risk analysis has to be undertaken with stakeholder participation. This may include both ecological and socio-economic impacts, and how they change overtime.
- It is found that most invasions of non-indigenous species are caused by human disturbance of the ecosystems. Thus, the management strategy should also consider the changes in physical and chemical characteristics of a water body through human intervention and its influence on invasion risk. Data regarding the external factors for spread has to be collected and mitigation plans to reduce human intervention like waste disposal (both solid and liquid) to the aquatic systems, soil erosion etc. should also be a part of management strategy.
- Measures to deal with invasive alien species should, as appropriate, be based on the ecosystem approach, as described in decision V/6 of the Conference of the Parties. Species specific appropriate steps for eradication, containment and control, to mitigate adverse effects has to planned and the control measures should focus on specific biodiversity conservation outcomes at landscape level.
- Effective control will often rely on a range of integrated management techniques, including mechanical control, chemical control, biological control and habitat management. However, the techniques used for eradication, containment or control should be safe to humans, the environment and agriculture as well as ethically acceptable to stakeholders in the areas affected by the invasive alien species.
- Mechanical control along with using the plant resources for livelihood activities by developing value added products is an area needs more attention. Dr Nagendra Prabhu at Centre Research of Aquatic Resources, SD College Alappuzha has undertaking various research inthisareaandhasdevelopedvariousvalue-addedproductsusingwaterhyacinth.
- Community support is often essential to achieve success in eradication and this has to be developed through series of consultations with all stakeholder classes. The role of environmental NGOs for management action also to be considered.
- It is always better to undertake mitigation measures in the earliest possible stage of invasion. Monitoring of the water bodies involving local communities will help in early detection of new introductions of potentially or known invasive alien species. However, for this proper awareness creation using scientific data is very essential. Thus, public awareness of the causes of invasion and the risks associated with the introduction of various alien species has to be a part of the management strategy.
- The use of newly developed tools to improve early detection like GIS and remote sensing, environmental DNA, decision support systems, improved models to predict invasion and spread etc. has to be promoted. A project by University of Sterling in collaboration with Dr Nagendra Prabhu is now ongoing in Kerala in this regard.

CONCLUSION

A holistic, ecologically based, invasive plant management framework that integrates ecosystem health assessment, knowledge of ecological processes, and adaptive management is provided by Sheley *et.al.* (2010). Species specific management measures are also available in various international databases on invasive species like CABI (2022), GISD (2022) etc.

World over, IAPS are considered as a significant threat to biodiversity, ecosystem services and the economy. The CBD Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) has recognized the need for developing methodology for comprehensive estimation of invasive species impacts. It is very relevant that the Kerala State Biodiversity Board is now initiating action in this regard.

Coordinated management actions including policy formulations is an urgent need in controlling aquatic IAPS in Kerala**.** It should facilitate research as well as development of technologies to manage the aquatic IAPS.

Developing a comprehensive information system covering all aspects of aquatic IAPS management based on field level participatory research shall be an immediate action program in this regard. There is also an immediate need for more researches to elucidate the importance of a particular plant species to particular animal/ plant species in aquatic systems is needed in order to better predict how aquatic plant invasions will affect animal communities. The impacts of various invaders on native communities across spatial and temporal scales also to be studied. The vulnerable areas have to be identified and prioritised.

Available studies have shown that the riverine ecosystems are most affected with respect to IAPS. Thus, the future health of our rivers will greatly depend on how we manage current invasive species and whether the arrival of future invasive species can be successfully prevented, or their impacts minimized.

Under the present circumstances, impact of climate change on aquatic IAPS should be another priority for research. The environmental impact of human interventions and development pressure on the invasion is another aspect which need special attention.

The impacts of aquatic invasive plants depend greatly on the effectiveness of monitoring and management intervention. Early detection and rapid response efforts can identify new infestations at stages when eradication may still be feasible. In areas where invasive populations are already well established, sustained active management efforts can achieve effective control and conserve ecological structure and function. Thus, it is essential to ensue with clearly defined goals, ensure most modern control technologies and robust monitoring program.

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INVASIVE ALIEN MARINE SPECIES – INVERTEBRATES

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Introduction

Invasive alien species (IAS) are animals, plants or other organisms that are introduced into places outside their natural range, negatively impacting native biodiversity, ecosystem services or human well-being. Invasive alien species, introduced and/or spread outside their natural habitats, have affected native biodiversity in almost every ecosystem type on earth and are one of the greatest threats to biodiversity. Since the 17th century, invasive alien species have contributed to nearly 40% of all animal extinctions for which the cause is known (CBD, 2018).The Convention on Biological Diversity and its current 196 members recognize that there is an urgent need to address the impact of invasive alien species. Article 8(h) of the CBD states that, "Each contracting Party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species". The CBD sets global priorities, guidelines, collects information and helps to coordinate international action on invasive alien species.The CBD has adopted guidance on prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species. At the 2010COP of the Convention on Biological Diversity at Nagoya, Japan, almost all countries of the world adopted the Strategic Plan for Biodiversity, which laid down 20 targets, known as the Aichi Targets that were to be achieved by 2020. Amongst these was Target #9 which particularly focused on invasive alien species:

"*Target 9: By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment"* (CBD, 2010).

This commitment by world governments was reiterated in the UN 2030 Agenda for Sustainable Development with its 17 SDGs or Sustainable Development Goals. SDG # 15 *Life on land* specifically mentions. "*By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species".*

In compliance with the CBD and the Aichi target implementation, the National Biodiversity Authority of India has included IAS control and management in its National Biodiversity

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Target #5 (2008), revised to #4 (2014) which states " By 2020, invasive alien species and pathways are identified and strategies to manage them developed so that populations of prioritized invasive alien species are managed."

Biological invasions in marine environments have received less attention and the impacts and susceptibility of coastal waters to alien species scantily documented. In marine ecosystems, invasions by the alien species cause extensive biodiversity loss and lead to severe challenges in the conservation of biodiversity and natural resources. *An invasive alien marine species* can be unintentionally introduced to a new area via the ballast water of oceangoing ships, biofoulers on hulls and intentional and accidental releases of aquaculture species, aquarium specimens or bait, and other means.

Causes and Impacts

Globally, increased trade, transport, travel and tourism has facilitated and resulted in the introduction and spread of species into new environments. Species which mange to adapt to their new surroundings and eventually establish themselves can cause significant ecological and economic damage. For a species to become invasive, it must successfully out-compete native organisms for food and habitat, spread through its new environment, increase its population and harm ecosystems in its introduced range. Most countries are grappling with complex and costly invasive species problems. For example, the annual environmental losses caused by introduced pests in the United States, United Kingdom, Australia, South Africa, India and Brazil have been calculated at over US$ 100 billion (CBD, 2006). It is estimated that there are already over 12,000 alien species present in Europe, of which around 10–15% are invasive. They occur in all major taxonomic groups, ranging from mammals, amphibians, reptiles, fish, invertebrates and plants to fungi, bacteria and other micro-organisms. They are also found in every type of habitat, both on land and in the surrounding seas. A well-known example is the Zebra mussel (*Dreissena polymorpha)* which is native to the Caspian and Black Seas and has affected fisheries, mollusc diversity and electric power generation in the Great lakes in North America and Mississippi Basin. The ship rat (*Rattus rattus*), a native of the Indian sub-continent has spread throughout the world and caused extinctions and drastic declines of native birds on islands.

Invasive alien species impact adversely upon native diversity, including decline or elimination of native species through competition for food, predation and spread of pathogens which ultimately disrupts the ecosystem services and functions. Such invasive spreads have resulted in the biodiversity loss in almost every ecosystem type on earth.

Invasive alien marine species in India

The transportation of alien barnacles by ships in Mumbai port was first report of Marine Invasive alien species by Bhatt and Bal (1960). The first detailed list of organisms introduced through ballast water into ports and near shore areas was compiled by Anil *et al*. (2002). However, the extent of establishment or invasiveness of these species was not indicated in this list (Anil *et al*; 2002). Further additions to this list were made by Anil *et al* (2003).

In alien species compiled by the Centre for Biodiversity policy and Law (CEBPOL) and National Biodiversity Authority (NBA), (2018) 169 species were listed as invasive. A study has also reported that India has lost $127.3 (INR 8.3 trillion) in the last six decades to invasive species mainly contributed by 10 invasive alien species out of the listed invasive species in India. This indicates that India has to address a huge knowledge gap to develop policy and legislation for the control and prevention of invasive alien species. Among the listed invasives, the invertebrates include the hydroids, anemones, scyphozoans, Anthozoans, hydrozoans, ctenophores, ascidians, polychaetes, bivalves, wood borers, bryozoans, barnacles, amphipods, isopods, decapods. Macroalgae also often spread on invasive scale and establish in new environments. *Mercierella enigmata*, a hydroid was introduced from Australia into the Indian Ocean (Chandramohan and Aruna, 1994). *Phyllorhiza punctata and Pelagia noctiluca*(Forsskal, 1775) Scyphozoans reported to be introduced into Indian waters, based of field observations. *Ectoplura crocea*a pink-mouth hydroid, *Carijo ariisei (*Snowflake coral / Branched pipe coral), and *Tubastrea coccinea* (Orange soft coral) are invasive anthozoans in India. Roy and Nandi (2017) published the first list of marine invasive crustaceans in India based on earlier works. It included 9 species of amphipods, 7 cirripedes, 6 isopods, 5 decapods and 5 copepods.

The Zoological Survey of India (2017) listed 99 species found in Indian marine ecosystems as invasive aliens which included ascidians (31 species), arthropods (26 species), annelids (16 species), Cnidarians (11 species), bryzoans (6 species), molluscs (5 species), ctenophora (3 species), and entoprocta (1 species) during the National Conference on Status of Invasive Alien Species in India held in Kolkata. The most recent list of marine IAS has been published by Sandilyan (2018) and published by the National Biodiversity Authority, MoEFCC, GoI, where 19 species are listed and their invasiveness and impact indicated. As these aspects are covered, it is considered to be the most acceptable of the various lists available.

The Global Invasive Species Database (GISD) managed by the Invasive Species Specialist Group of the IUCN lists only 11 species as alien invasives to India amongst the marine species. *Pelagia noctiluca, Beroe ovata, Vallicula multiformis, Ficopomatus enigmaticus, Jassa marmorata, Penaeus vannamei, Membranipora membranacea, Microcosmus curvus* and *Didemnum candidum* are not included in GISD as invasives in India. In some cases the invasiveness has been established only in the last five years in India and this may be a cause for non-inclusion in the international database.

In India, in recent years, extreme climate events and drastic change in water quality of water bodies has led to the establishment of invasive alien marine species. Over the last decade, the shifts in onset of monsoon, especially south west monsoon has triggered invasion of alien species in biodiversity hotspots altering the flora and fauna and ecosystem functions. A typical example has been the invasion of the alien South American mussel *Mytella strigata* into the major estuaries and backwaters along both coasts. It was first noticed in 2019, in major estuaries of Kerala. It was probably introduced through ballast water. However, due to the floods in 2019 to 2020, during the incessant south west monsoon it was transported and established in major estuaries along Kerala and other States. It was found in Tamil Nadu, Andhra Pradesh, Orissa, Karnataka and Maharashtra. It has severely impacted the bivalve fisheries, edible oyster and mussel farming and finfish farming in cages.

Table 1: Inter- and intra-translocation of organisms in Indian waters

Common name	Species	Native of	Introduced to	Reference
Alga	*Monostroma oxyspermum*	Northeast Atlantic, Northwest Pacific	West coast of India	Untawale. *et al*., 1980
Hydroid	*Mercierella enigmata*	Australia	Indian Ocean	Chandramohan, and Aruna., 1994
Anemone	*Eugymnanthea*	?	East coast of India	Raju,*et al*., 1974
Mussel	*Mytilopsis sallei*	Atlantic waters	East coast and west coast of India	Karande *et al.*,1975 and Raju *et al.*, 1988
Wood-borer	*Lyrodus medilobata*	Indo-Pacific, Hawaiian Islands, Marshall Islands, New Zealand, Australia, Virginia, Bermuda	West coast of India	Santhakumaran, 1986
	Nausitoradunlo pei	Cochin	Goa	Santhakumaran, 1985
	Teredofulleri	Gulf of Mannar	Okha	Santhakumaran, 1985
Barnacles	*Balanus Amphitrite* var. *stutsburi*	West coast of Africa	West coast of India	Wagh, A. B., 1974
	B. Amphitrite hawaiiensis	Malay Archipelago and Persian Gulf	Mumbai	Bhatt and Bal, 1960
Isopod	*Cilicaea lateraillei*	Indonesia, the Philippines, Sri Lanka, S. Africa, Red Sea, Australia	Arabian Sea	Venugopalan, V.P. and Wagh, A.B., 1987
Amphipod	*Stenathoe gallensis*	East coast of India	West coast of India	Venugopalan, V.P. and Wagh, A.B., 1986
	Maera pasifica	East coast of India	West coast of India	Venugopalan, V.P. and Wagh, A.B., 1986
	Podocerus brasileusis	East coast of India	West coast of India	Venugopalan, V.P. and Wagh, A.B., 1986
	Erichthonins brasileones	East coast of India	West coast of India	Venugopalan, V.P. and Wagh, A.B., 1986

Bryozoa	*Barentsia ramose*	Pacific, California, Belgium	Indian Ocean	Satyanarayana Rao,. *et al*., 1988
Ascidian	*Styela bicolor*	Gulf of Siam, Java, North Austra- lia, Banda Sea, Ambonia and the Philippines	Eastcoast of India	Renganathan,198 1
	Phallusia nigra	Bermuda, Brazil, Red Sea, Gulf of Eden	Tuticorinharbour	Meenakshi, 1998
	Eusynstyela tincta	Atlantic, Mozambique, Red Sea, Gulf of Suez, Africa, Sri Lanka	Tuticorinharbour	Meenakshi, 1998

Adapted from: Anil et al.(2002), *Current Science*

Table 2: List of alien crustaceans recorded from Indian water and their threat status

Sl. No.	Group and Species	Family	Native/Exotic/ Cryptogenic	Threat Status	Source
	Decapoda				
1	*Litopenaeus vannamei* (Boone, 1931)	Penaeidae	Exotic, Introduced	Not suspected	Dev Roy, 2007
	Isopoda				
2	*Cirolana hardfordi* (Lockington, 1877)	Cirolanidae	Exotic	Not suspected	Anil *et al.*, 2003
3	*Cilicaea latreillei* Leach Limnoriidae, 1818	Cirolanidae	Exotic	Not suspected	Anil *et al.*, 2002
4	*Paradella dianae* (Menzies, 1962)	Sphaeromatidae	Exotic	Not suspected	Anil *et al.*, 2003
5	*Sphaeroma serratum* (Fabricius, 1787)	Sphaeromatidae	Exotic	Not suspected	Anil *et al.*, 2003
6	*Synidotea laevidorsalis* (Benedict, 1897)	Idoteidae	Exotic	Not suspected	Anil *et al.* 2003
	Amphipoda				
7	*Monocorophium acherusicum* (Costa, 1853) as *Corophium acherusicum* Costa, 1853	Corophiidae	Exotic	Not yet assessed	Shyamasudari, 1997
8	*Jassa falcate*	Ischyroceride	Exotic	Not yet	Shyamasundari,

	(Montague, 1808)			assessed	1997
9	*Jassa marmorata Holmes*, 1905	Ischyroceride	Exotic	Not suspected	Anil *et al*., 2003
10	*Elasmopus rapax* Costa, 1853	Maeridae	Exotic	Not yet assessed	Shyamasundari, 1997
11	*Quadrimaera pacifica* (Schellenberg, 1938) as *Maera pacifica* Schellenberg, 1938	Maeridae	Exotic		Anil *et al*., 2002
12	*Paracaprella pusilla* Mayr, 1890	Caprellidae	Exotic	Not yet assessed	Guerra-García,2010
13	*Stenothoe gallensis* Walker, 1904	Stenothoidae	Exotic	-	Anil *et al*., 2003
14	*Stenothoe valida* Dana, 1852	Stenothoidae	Exotic	Not yet assessed	Shyamasundari, 1997
15	*Podocerus brasiliensis* (Dana, 1853)	Podoceridae	Exotic		Anil *et al*., 2003 Shyamasundari, 1997
	Cirripedia				
16	*Amphibalanus eburneus* (Gould, 1841) as *Balanus Amphitrite eburneus*	Archaebalane	Cryptogenic	Not suspected	Anil *et al*., 2003
16	*Amphibalanus reticulates* (Utinomi, 1967) as *Balanus reticulatus* Utinomi, 1967 and *Balanus Amphitrite hawaiiensis* Broch	Archaebalane	Exotic	Not suspected	Anil *et al* 2002,2003
17	*Fistulobalanus pallids* (Darwin, 1854)= *Balanus Amphitrite stutsburi* (Darwin)	Balanidae	Exotic	-	Wagh, 1974, Anil *et al*. , 2003
18	*Megabalanus tintinnabulum* (Linnaeus, 1758)	Balanidae	Exotic	Known harmful species	Anil *et al*., 2003
19	*Megabalanus zebra* (Darwin, 1854)	Balanidae	Cryptogenic	Not suspected	Anil *et al*., 2003
	Copepoda				
20	*Nannocalanus minor* (Claus, 1863)	Calanidae	Exotic	-	Gaonkar *et al*., 2010
21	*Cosmocalanus* sp.	Calanidae	-	-	Gaonkar *et al*., 2010

22	*Paracalanus* sp.	Calanidae	-	-	Gaonkar *et al*., 2010
23	*Tortanus* sp.	Tortanidae	-	-	Gaonkar *et al.*, 2010
25	*Euterpina acutifrons* (Dana, 1847)	Euterpinidae	Exotic	-	Gaonkar *et al.*, 2010

The invasive alien marine mussel *Mytellastrigata*: a case study

Mytilid *Mytella strigata* (Hanley, 1843) (previously known as *Mytella charruana* (d'Orbigny, 1842), native to Central and South America has established recently in backwaters of Kerala, blocking nets in fish or cage farms. This species was recently reported from the Philippines, Singapore and Thailand, where its population has expanded exponentially in the last two years. *M. strigata*, the newly introduced marine invasive species was recorded from various places in Kerala such as Vembanad Lake (Jayachandran *et al*., 2019), Kadinamkulam, Paravur, Edava-Nadayar, Ashtamudi Lake, Kayamkulam, Chettuva and Ponnani (Biju Kumar *et al*., 2019).Their northward introduction has been reported by Sanil *et al*., (2020).

Morphological features of *Mytella strigata:* Dominant category belonged to shells that were almost entirely black externally with a purplish, while the rest possessed lighter colours with a purple, bluish or white interior; Umbos low, beaks sub terminal; Outline wedge shaped and margin smooth. Anterior region very small with distinct radial ridges corresponding to 2–4 teeth on the inner margin. Anterior adductor scar small on inner edge behind the toothed margin, posterior adductor scar large rounded. Byssus threads are very fine. The species was also identified using molecular tools. A phylogenetic tree constructed based on the maximum likelihood method. It branched with the *M. strigata* from other parts of the world.

Population structure of *M. strigata* from the east and west coasts of India were studied using mitochondrial Cytochrome C Oxidase 1 (COI) gene. Samples of *M. strigata* were collected from mussel beds of eastern (Orissa (Chilka lake), Andhra Pradesh (Bapatla), Tamil Nadu (Karapad Bay, Tuticorin and Cuddalore), and western (Kerala (Vizhinjam, Padanna and Kochi)) coasts of India. DNA was extracted from adductor muscle and the COI sequence information was generated. The sequences were aligned using MEGAX and a phylogenetic tree constructed. Three highly divergent clades were present in the dataset. Samples from the west coast of India, Tuticorin and few samples from Cuddalore, recorded 100% identity with *Mytella strigata* samples reported from Singapore retrieved from NCBI, Gen Bank. The second highly divergent lineage was found in the samples from Cuddalore (82% identity with *M. charruana*). The third highly divergent lineage was recorded from Andhra Pradesh (Bapatla) and Orissa (Chilka lake) (81% identity with *M. charruana*). K2P distance values between these highly divergent clades varied from 14-17%. These highly divergent samples indicate the presence of two other species of this genus along the Indian coast mainly along eastern coast of India. Invasive mussels exhibit high adaptive variation due to the plasticity of their genomes as they occupy alien habitats quickly. This may be the reason for the high levels of divergence between samples collected from different localities. This need to be further investigated using morphological comparisons and advanced molecular markers.

Mytilids typically have a high fecundity, rapid growth rate, are filter feeders and tolerant to a wide range of environmental conditions *M. strigata* was initially reported from major ports, establishing the route of introduction to new areas through ballast waters transport or hull fouling on ships. It is a potential threat to lucrative bivalve aquaculture as they could out-compete native mussels as well as cage farming.

Impact assessment

Central Marine Fisheries Research Institute, Kochi undertook a detailed study to understand the impact of the invasive alien mussel on fisheries, bivalve farming, cage farming and livelihood. Rapid surveys were conducted to assess the extent of invasion of *M strigata* along the coast. Samples were collected from bivalve fishery sites to understand the impact on the fishery as well as livelihood of fishers. Samples were collected from bivalve farms and finfish cage farms to understand the impact on farming activities. Fishers and farmers were also interviewed with structured questionnaires to study the socio-economic impacts.

Distribution

Along north Kerala, the invasive species *M strigata* occurred in Beeyamkayal, Kadalundi, Mampuzha and Puthiyappa. It was also found in the Kavvayii estuary in Ori, Padanna and Punchakkadareas.It was observed in the green mussel farms (*Perna viridis*) as well as the finfish cages. The invasive mussel was more widespread in the estuaries of Central Kerala. Of the 32 water bodies surveyed, it was observed in 41% of the areas. The size of *M strigata* ranged from 1.4 mm to 84.5 mm. It was found on the bottom substrate and attached to bamboo poles, bridge pillars, fish cages and ropes. The density ranged from 32-12,400 nos/sq.m.

In Vembanad Lake, *M strigata* was found in the northern parts where the salinity is higher. The invasive species were found along Njarakkal, Keethedom, Moothakunnan, Cherai, Pullut, Kadanakudi, Gothuruthu,Chendamangalam,Perumbalan, Panavally and Aratupuzha. It was not found in the southern part where freshwater conditions prevailed, not conducive for the invasive species.

In Chettuva estuary, it was extensively distributed. In Ashtamudi Lake the invasive species was distributed wide across the Ashtamudi kayal and Kayamkulam kayal, affecting the green mussel and oyster farming activities causing economic loss and affecting livelihood. In southern Kerala, the invasive species was recorded in Kadinamkulam kayal, Achenthengu kayal, EdavaNadayara and and Paravur backwaters.

Adaptive traits

The invasive species *Mytella strigata* possesses certain traits which are favorable for adaptation to new environments and easily establish itself in the new habitat. It is highly euryhaline, tolerating salinities between 2 to 20 psu **(**Yuan et al. 2010; Rice et al. 2016). It lives optimally in brackish waters too and water temperatures between 6 and 31^{o}C

(Brodsky *et al*., 2009). Minimum size (shell length) of sexually reproductive mussels is 12.5 mm (Stenyakina et al. 2010).

Impact on fisheries

The invasive mussel *M strigata* had established itself extensively in the Ashtamudi, Chettuva and other estuaries along north Kerala and this had a tremendous impact on the clam, oyster and mussel fisheries. In Ashtamudi Lake, it was found extensively along with the oyster *Crassostrea madrasensis. Paphia malabarica*is collected from the deeper areas;however the occurrence of *M.strigata* was less in these areas. In Chettuva estuary the invasive mussel was found along with the green mussel *Perna viridis*. In Ashtamudi Lake *M.Strigata* was picked by the mussel pickers and sold in the market in place of the green mussel with *M.strigata* comprising nearly *39% of* the mussel fishery and sold at Rs. 80-120/120-65 numbers shell-on. Nearly 852 t of *M.strigata* was sold during 2019 in Kerala.

Impact on farming

The impact of the invasive mussel *M.strigata* on farming activities was very high not only disrupting the farming but also affecting the livelihood of the farmers. In bivalve faming oyster and mussel farms were severely infested by the mussel. The bamboo poles, the oyster ren and the nylon ropes were infested by the mussel. The profuse settlement of the invasive mussel resulted in reduced settlement of oyster spat and also affected growth of oysters to market size. This in turn affected the returns in terms of increased labour charges for cleaning the oyster rens to remove the *M.strigata* attached along with the oysters. In the mussel ropes also, the settlement of *M.strigata* was very high impacting growth and causing economic loss.

The settlement of the invasive mussel on finfish cages was so severe that the cleaning of the nets, both outer and inner was labour intensive. Bio fouling of the inner and outer nets required frequent cleaning, thereby increasing expenditure on labour charges. The manual cleaning of the nets and discarding the mussels back into the water body again facilitated rapid spread of the invasive species and additional expenditure. Frequent cleaning of nets also led to damage of nets, and additional expenditure to replace nets. Cleaning of nets by sun drying caused foul smell, raising environmental social issues in the vicinity. Ignoring the bio fouling caused by the invasive species on the nets increased the weight of the nets, clogging, reduced water circulation, net damage there by resulting in poor growth of the fin fish reared in the cages and economic loss. During 2019-2022, farming activities were reduced due to the economic loss caused by the invasive mussel along with the Covid- 19 pandemic issues.

Control and management

As per the CBD guidance on prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species the following measures were suggested for preventing and controlling the establishment of *M. strigata.* A webinar was conducted by CMFRI for fishers and farmers and other stakeholders to create awareness on the practices to be adopted by them to minimise the ecological and economic loss.

- ✓ All-out efforts should be taken to prevent, control and eliminate *M. strigata* from establishing in our waters.
- ✓ Since the species is edible (though not as tasty as green mussel) they can be heavily fished and consumed.
- ✓ *M. strigata* should not be used for farming, as it will promote further spreading. Strict monitoring should be done by the Department of Fisheries to ensure that this species is not used for any farming activity.
- ✓ If found attached to cages/nets or any other materials they should be removed and kept out of the water body to ensure its eradication.
- ✓ It can also be utilized as ingredient in fish /animal feed
- ✓ Boat hull fouling by *M. strigata* is a major concern. Periodic scrapping of biofoulers from boat should be undertaken outside the water body

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ALTERNATE LIVELIHOOD PROGRAMMES USING AQUATIC WEEDS – NEED FOR A TOP DOWN APPROACH

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Abstract

Aquatic plants are plants that normally grow in water, in soil covered by water, or in soil that is normally saturated with water. In nature, these plants perform many important functions in maintaining a balanced aquatic environment. But at the same time, their uncontrolled growth has multiple impacts on the water bodies. Their growth has been explosive in many parts of the world, especially, Asia, Africa and Latin America because of favourable climatic conditions and suitable habitats for its unchecked growth. In India, it has been estimated that more than two lakh hectors of water bodies are infested by aquatic weeds such as water hyacinth. While the approach of the developed nations is mainly focused on *control* and *eradication*, the third world countries have approached this problem in a different manner. They have been able to derive many positive benefits from these weeds by their innovative approaches. Thus the perceived negative economic impacts of the aquatic weeds have been transformed into positive income - generating enterprises. Some of the alternative approaches such as making of furniture, handicrafts, paper and packing material, mulching and composting, biogas production, organic manure, animal feed, bio-active compounds etc, by researchers in these countries are discussed. The author's own innovations in making value added products from the troublesome aquatic weeds of Kerala are presented. The need for our policy makers to have a top down approach is highlighted along with the factors that are advantageous for Kerala and a road-map for future.

Introduction

Aquatic plants are defined as plants that normally grow in water, in soil covered by water, or in soil that is normally saturated with water. They can be classified into several broad groupings namely, free-floating, emergent and submerged aquatic. In nature, these plants perform many important functions in maintaining a balanced aquatic environment (Cook, 1996).But at the same time, the uncontrolled growth of these plants has manifold impacts on the water bodies. Their growth has been explosive in many parts of the world, especially, Asia, Africa and Latin America because of favourable climatic conditions and appropriate habitats for its unlimited growth (Gopal and Sharma, 1981).

Prabhu, G. N. 2023. Alternate livelihood programmes using aquatic weeds – need for a top down approach. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp. 402-414.

There are no reliable statistics on the scale of infestation of aquatic weeds in India. One reported estimate is that more than two lakh hectors of water bodies in India are infested with aquatic weeds, especially water hyacinth at a given time (Gopal, 1987). Kerala, God's own country is blessed with multitudes of water bodies like lakes, rivers, canals, irrigation channels, paddy fields, ponds etc, both natural and man-made. They are a part of the day-to-day life of majority of Keralites, either directly or indirectly and play an important role in the social, cultural and economic aspects of the people. Now their beauty is being marketed through tourism and related activities, but at the same time, our callous attitude is slowly and steadily damaging them beyond repair. A cursory glance is enough for everyone to see that all these waters are infested with one kind of aquatic weed or the other. The major one is *E. crassipes,* commonly known as Water Hyacinth. It is an exotic weed which has colonized many parts of the world. Other major weeds include *Salvinia molesta* and *Pistia stratiotes*. New threats like *Cabomba sp*. are also emerging in the country. India, being a sub-tropical country, is a fertile ground for the aquatic weeds and Kerala with its abundant sunshine, rains and water bodies, offers them an excellent habitat for explosive growth.

Impact of Aquatic Weeds

Gallardo *et al*. (2016) demonstrated that invasive specie strigger strong and relatively consistent ecological impacts on aquatic ecosystems. Under favorable growth conditions, these weeds may double within about a week's time and cover the entire surface of the water which degrades natural habitats in many ways. They reproduce by both vegetative (by sprouting of new plants from existing ones) and also by producing seeds which sink to the bottom and wait till conditions are favourable for germination. Mats of floating plants prevent atmospheric oxygen from entering the water. Further, the decaying plants drop to the bottom, greatly consuming dissolved oxygen needed by fish and other aquatic life. This also prevents the entry of sunlight to the bottom layers, and slowly kills the natural, endemic flora & fauna. Thus it causes serious damage to biodiversity of the aquatic ecosystems (William, 2003).Their growth prevents the natural flow of water in irrigation channels, obstructs smooth navigation & interferes with hydroelectric power generation. Disease spreading vector species of mosquitoes breed freely in the static waters. The decomposition of the dead plants results in obnoxious smell, decreases clarity of water and depletes the dissolved oxygen content of the water, making it unsuitable for human use. Local fishermen have found it impossible to cast their nets into water covered with dense mats of these weeds. In Kerala, these weeds adversely affect water transport, agricultural activities, inland fisheries, and promotion of lake tourism, on which the people of Kerala depend on for their livelihood.

Aquatic weed infestation is a national and global problem and many approaches have been tried to eradicate them. Physical removal, chemical control, biological control *etc* have been tried unsuccessfully not only in India but also elsewhere in the World. Scientists have reached a conclusion that it is not possible to eradicate this weed from our water bodies. The only possible approach is the concept of "eradication through utilization" and considering them as "opportunities" rather than "threat".

The Third World Approach on Aquatic Weeds

While the developed nations have tried to eliminate the weeds from their waters, the people in the "Third World" have approached this problem in a different way.The people have realized that the only hope lies in the economic utilization of these plentiful "natural resources" by simple and economically viable techniques - the concept of eradication through utilization or use to reduce (NSA Report, 1974). Many researchers have been striving to make use of these aquatic weeds for creative purposes. Some suggested uses include, manufacture of paper, packing material, fodder for cattle, manure, feed for fishes and ducks, mulching & composting, biogas production, waste water treatment, mushroom production and manufacture of mats, handicrafts, furniture etc.

There are many reports on the possible use of these weeds for economic benefits from around the world. In Nigeria, water hyacinth is used for making handicrafts like hand woven baskets which earn them valuable foreign exchange. Similarly, in Thailand, the furniture manufactured from *E. crassipes* is of much benefit for the local communities. Researchers from Egypt have separated and identified nine active fractions from water hyacinth and showed their promising therapeutic activities. Several compounds such as alkaloid, phthalate derivatives, propanoid and phenyl derivatives were identified in the extract of water hyacinth (Ahmed *et al*., 2011). A Japanese research group has isolated novel acylated delphinidin glycoside from the blue-purple flowers of *Eichhornia crassipes* as a major pigment and was identified as [6''' -O- (delphinidin 3-O- (6''-O- (beta-D-glucopyranosyl)-beta-D-glucopyranosyl) (6''-O- (apigenin 7-O- (beta-D-glucopyranosyl) malonate] by spectral methods (Toki *et al.*, 1994). A report from Portugal deals with the production of protein concentrate from water hyacinth. The protein in water hyacinth concentration was of better quality compared to other vegetable protein products, such as alfalfa and soybean flour. The amino acid composition was favorable, especially the presence of tryptophan is valuable since it is commonly low in plant protein products. The presence of all essential amino acids in the concentration suggests its possible use in the production of animal feeds and food supplements for humans (Medeiros *et al* 1999). Similarly, the roots of water hyacinth are known to remove heavy metals and radioactive molecules from the aquatic environments. Heaton *et al*. (1987) have reported lead uptake by the water hyacinth. Rui *et al.* (2015) have reported polar and lipophilic extracts of roots, stalks, leaves and flowers of water hyacinth and suggested methods of value addition.

A convenient and economical process for extraction and separation of β-carotene from water hyacinth has been developed by researchers from India and a US Patent obtained for this process (Vinita et al., 2005). National Environmental Engineering Research Institute, Nagpur had reported that the slurry obtained from aquatic weeds like water hyacinth could be used as a source of cellulose for microbial growth and enzyme production. In Kerala, some efforts have been made in the past for using these weeds for beneficial purposes, but no coordinated actions have been taken and no solutions have been identified to solve this infestation. Our own work at the Centre for Research on Aquatic Resources, S. D. College for the last 25 years have shown that all parts of the plant can be used in one way or the other – similar to the coconut palm. It is possible to use the plant as a raw material for the production of industrial enzyme like cellulase, bio-ethanol, for the preparation of beds for mushroom cultivation, vermi-composting, biogas, feed for fish, ducks and pigs, as pulping material for paper and a variety of pulp based products, briquettes for fuel, pigments from their flowers (Suresh Chandra *et al*., 2005, Snishamol *et al.*, 2011, Nagendra Prabhu and Suresh Chandra, 2012, Anoop *et al*., 2014). Our lab has also developed many such innovative technologies for validation and adoption by unskilled labourers. Floating agriculture or modified hydroponics is another exciting area which can easily be adopted by our State in view of climate change and the focus on climate resilient agriculture practices. The colors from the water hyacinth flowers can be extracted and used as organic dyes (Gopika *et al*., 2018). The high growth rate of water hyacinth triggered research on its potential use for biofuel production. This being grown on water surface, unlike terrestrial macrophytes, does not compete with food crops for agricultural land (Bhattacharya & Kumar, 2010). Water hyacinth biomass can also be used as mushroom cultivation media (Chen *et al*., 2010, Anoop Kumar *et al*., 2014), Utilization of water hyacinth biomass has been reported for preparing special cements as super-plasticizer (Alagu *et al*., 2019). Cellulase production by native bacteria using water hyacinth as substrate under solid state fermentation has also been reported (Suresh Chandra Kurup *et al*., 2005, Nagendra Prabhu & Suresh Chandra Kurup, 2012). The benefits of water hyacinth for Southern Africa and its potential for the production of energy through anaerobic digestion has been extensively reviewed by Obianuju *et al* (2020, 2021).

Pictures of some of the innovative products made of water hyacinth pulp in our laboratory are given below as figures 1 to 9.

Fig. 1 Handicrafts

Fig. 2. Fruit Tray

Fig. 3. Disposable Plates

Fig. 4. Models of Cartoon Characters

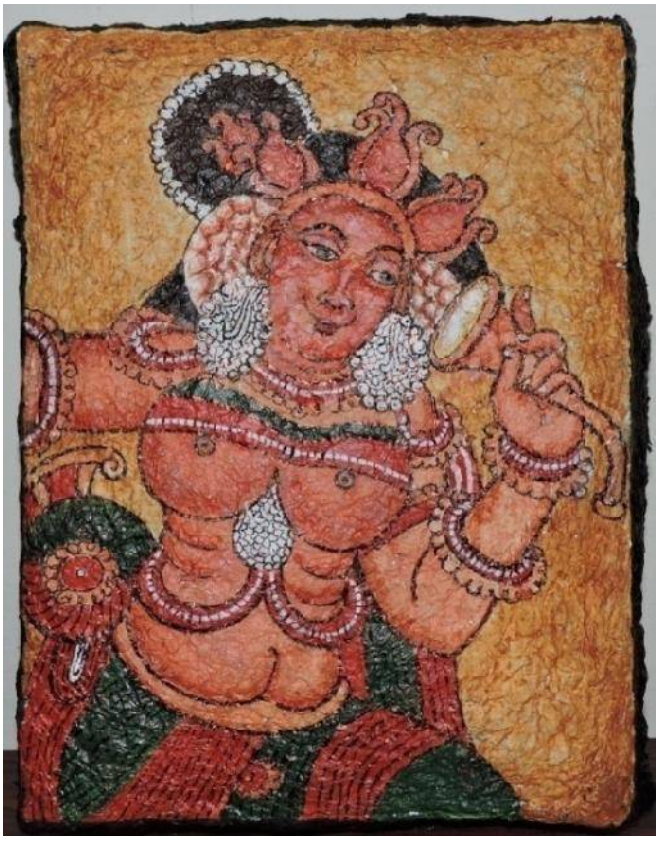

Fig. 5. Mural Painting on special canvas made of water hyacinth pulp

Fig. 6. Ready to plant Biodegradable Nursery Pots

Fig. 7. 3-D Model of Dr. A. P. J. Abdul Kalam made of water hyacinth pulp

Fig. 8. X’mas Cribs made of water hyacinth

Fig. 9. Fridge Magnets

Pictures of mushroom cultivation and briquette manufacturing using aquatic weeds in our laboratory are provided as figures 10-11.

Fig. 10. Mushroom Cultivation using aquatic weeds

Fig. 11. Aquatic weed based Biomass Briquettes

Some Innovative Products from Water Hyacinth by EichhoTech, start-up mentored by the author and incubated at S. D. College are provided below:

Fig. 12. Range of high value products from water hyacinth

Fig. 13. Lamp shades from water hyacinth based hand-made paper


Fig. 14. Journal, Pens, Clock and Table Calender from Water Hyacinth

Advantages for Kerala

Any proposal for using these weeds has the advantage that the raw materials are available almost free of cost and throughout the year. In fact, Kerala has lot of beneficial factors that can effectively be used to tap these "resources". Some of them include:

- High literacy and science awareness, even among farmers.
- Interest and involvement of media (TV, Radio and Newspapers) in agriculture and related areas. Farmers' meets are organised by newspaper groups and the various Government Departments every year and awards presented to the best farmers.
- Availability of skilled and unskilled labour.
- Geographical peculiarities & fairly good network of road/rail and waterways. This facilitates the transportation of raw materials and products to and from any corner within a few hours.
- Experience in successful implementation of Group Farming, People's Planning & Co-operatives. Strong influence and machinery of Farmer's Co-operatives, Kerala Sasthra Sahithya Parishad, (KSSP), Agency for Non-conventional Energy and Rural Technology (ANERT) etc.

This means that any technology can easily be dispersed to the common man and applied to the field in a relatively short span of time, when compared to other States in India.

The development and use of simple rural technologies will lead to economic utilization of weeds resulting in their removal from the aquatic environments. This can generate local level employment & value added products. Ultimately, this will increase the States' revenue through lake tourism, water transportation, fisheries, production of goods for tourism industry, etc. besides reducing the occurrences of mosquito-borne diseases and water contamination. Such technologies are simple to be used and can be performed by unskilled labourers and women, thereby supplementing women empowerment programmes. These can be considered as "alternate livelihood programmes" in these times of disruption and change due to a number of socio-economic factors and climate change. Kerala should formulate clear policies on the utilization of these weeds by various means. Research on the utilization strategies, adoption of existing technologies, providing support to entrepreneurs, start-ups and NGOs through various incentives and funding are to be provided for in the vision document. A specific action plan with time line and deliverables should be developed. The need of the hour is "out of the box thinking". As the saying goes "extraordinary situations demand extraordinary solutions".

Priorities for Action – a roadmap for the future

What is needed is the willingness and sustained efforts to convert this bane into a boon, especially as part of the rehabilitation programmes in the post flood, post COVID 19 scenario.

It is suggested that a coordinated action plan is developed to utilize these weeds for the production of a multitude of produces and process using the traditional and newly developed technologies. Government, Universities, Research Institutions, Farmers and Rural Innovators should be directed to join hands together to make these weeds into *Kalpa Sasyas*. The technologies for value addition of aquatic weeds that are abundantly available in the water bodies can act as alternate livelihood programmes for the affected people.

Some specific suggestions:

1. Formation of a Task Force under the leadership of Govt. Agencies/Departments like KSCSTE, Kerala Biotechnology Commission or Kerala State Biodiversity Board. Can be included under the existing programme (s) of the Biodiversity Board such as the "Comprehensive Plan for Self Employment" or under the *Haritha Keralam* Mission or similar projects.
2. Appointment of a Special Officer to coordinate the activities and ensure interdepartmental collaborations and cooperation.
3. Conduct of Brain Storming Sessions to discuss and finalize the future course of action. Set Immediate, Short Term and Long Term Goals.
4. Organize problem specific "Hackathons" and encourage Student Start-ups and Village Start-ups.
5. Initiate "Top-down Projects" on the utilization of aquatic weeds with specified areas/topics and set deadlines/deliverables that have been decided earlier by the Task Force.
6. Lab to Land programmes of existing technologies and R & D for other technologies /processes that need further refining.
7. Ensuring funding from National/International Funding Agencies and various State Govt. Departments.
8. Ensuring people-participation like farmers, SHGs, NGOs, agencies like ANERT, Kudumba sree, NREGP and the common man.
9. Conduct of Awareness Programmes / Training Programmes / Workshops for specified target groups, including those affected by the floods, COVID pandemic and climate change.
10. Creation of a dedicated website/social media pages and ensuring the participation of newspapers and electronic media for a massive campaign on the issue.
11. Other appropriate steps necessary to implement the project.

Conclusion

It is clear from the history that it is nearly impossible for mankind to completely eradicate the aquatic weeds that grow and cause problems to our water bodies. The only solution is to popularize the concept of "eradication through utilization". As already mentioned, all parts of the plants have manifold uses. Hence they are the new Wonder Plants or "Kalpa Sasyas". Research into appropriate technologies, suited for local level needs, should be encouraged at Universities and Research Laboratories. The development of economically viable, eco-friendly and simple technologies that can be operated by unskilled labourers will generate employment opportunities besides producing useful range of consumables and products.

Many of the technologies are women friendly thus promoting gender equity. Disadvantaged sections of the society and differently-abled persons can also carryout many of the methods of using these weeds. Another advantage is that the negative impact of these weeds on our aquatic systems will be greatly reduced, if they are removed from these environments regularly. With coordinated action, it is possible and feasible to implement such schemes in areas infested with these weeds. This will help the Government in its post flood and post COVID rehabilitation programmes as well as production of eco-friendly products as a replacement for plastics and similar harmful materials.

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ROLE OF CLIMATE CHANGE IN THE SPREAD AND EFFECTS OFMARINE INVASIVE ALIEN SPECIES

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Introduction

Marine habitats are biologically rich with high economic values. People depend on finfish, shellfish and seaweed resources provided by oceans and coasts for survival and well-being. Marine transportation and tourism provide employment and generate income. However, the oceans are under threat due to overexploitation, habitat degradation, pollution and climate change. These threats are driving biodiversity loss. While marine organisms have no geographical boundaries and can move without restriction theoretically, different species of animals, plants and microorganisms have been separated by natural barriers like depth, habitat types, water temperature, other physico-chemical factors and availability of food. These natural barriers have restricted the movement of organisms to their home range, where they are adapted to live. However, anthropogenic activities like international shipping, mining and fishing are transporting marine organisms outside species' home range. Historically, ship ballast water, and hull foulers and borers are known to transport, spread and establish invasive alien species (IAS) in new areas, away from their native areas. An estimated 7000 species are carried around the world oceans in ship ballast water everyday (IUCN, 2009). Many of them perish in their new environment, but some thrive and start affecting native biodiversity, thereby reducing the resilience of natural habitats, making them vulnerable. With increasing globalisation, the rate of new introductions is increasing with major impacts on livelihoods and food security, undermining the progress towards achieving many of UN Sustainable Development Goals (IUCN, 2018).

With increasing intensity of climate change, evidences are accumulating on the negative effects of climate change on biodiversity. Changes in biodiversity lead to changes in the ecosystem, leading to arising of novel ecosystems. In recent decades, it has been understood that climate change can facilitate spread and establishment of IAS (Occhipinti-Ambrogi, 2007; Vilizzi et al., 2021), thereby compounding the impacts from other sources of transport and spread. The present paper is a brief overview on the impact of climate change on marine biodiversity in the Indian seas; inventory of IAS in the Indian seas; spread and influence of marine IAS; and the potential approaches to address marine IAS issue in the context of climate change. The paper also discusses the limitations on the availability of information on IAS and the need for a concerted effort to manage the IAS in the Indian seas.

Vivekanandan, E. 2023. Role of climate change in the spread and effects of marine invasive alien species. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp.415-423.

Climate change impact on marine biodiversity

Unequivocal evidences are accumulating on the role of increasing greenhouse gas (GHG) emission in driving the warming of the surface of the Indian seas by about 0.7^{o}C in the last 120 years(Table 1; MOES, 2020). Consequences of this warming have already manifested into several changes such as increasing tendency of extreme weather events, changing precipitation pattern, sea level rise and ocean acidification that impose negative effects on marine organisms and human populations. Changes in ocean currents and deoxygenation of seawater are the other events that will have great negative impacts on marine organisms. These changes are projected to continue through the twenty-first century, as the GHG concentrations continue to rise.

Table 1. Major climate change events in India (Source: MOES, 2020) that will impact marine biodiversity

Parameter	**Change so far**	**Prediction**
Seawater temperature	+ 0.7^{o}C (1900-2018)	+2.4 to 4.4^{o}C in 2100; unprecedented spells of hot weather
Rainfall pattern	Decline in some, heavy in other locations	Frequent droughts & floods; dry areas will be drier, wet areas will be wetter
Sea level rise	+ 0.3 m (1901-2015)	+0.4 to 1.0 m in 2100; largescale damage to properties
Ocean acidification	pH: – 0.1 (1900-2018)	pH: – 0.4 in 2100
Cyclone	No change in number; increase in intensity	Cyclones > 100 km/h to become frequent; large scale destruction to life and properties

In the terrestrial and freshwater ecosystems, the physical boundaries are well marked and environmental variabilities are rather wide. Consequently, the terrestrial and freshwater organisms have developed internal mechanisms to cope up with ecosystem variabilities. In contrast, the oceans have large thermal capacity, and exchange of water and organisms between deep and near shore waters for millennia. Hence, the physical variabilities of marine ecosystems are narrow and they extend over very long-time scales. Consequently, the marine ecosystems are more vulnerable to large-scale environmental changes because they do not have the internal adaptability inherent in the terrestrial and freshwater systems.

The following are a few significant changes reported among marine organisms as a consequence of seawater warming in the India seas (Vivekanandan, 2011, 2013):

- Change in geographical distribution is one of the confirmed consequences of climate change on marine species globally. Along the Indian coast, for example, the commercially important oil sardine *Sardinella longiceps* has extended its northern and eastern boundaries of distribution, resulting in expanded fishery all along the coasts within the last three decades.
- The Indian mackerel, *Rastrelliger kanagurta*, in addition to extension of northern boundary, is found to descend to cooler, deeper waters.

- Growth rate of fish is reported to have increased with increasing temperature within the optimal temperature window.
- Phenological changes have been observed in the spawning periodicity of a few fishes (for example, the threadfin bream *Nemipterus japonicus*) as a response to increasing seawater temperature.
- Corals are extremely sensitive to seawater temperature. During summer, if the seawater temperature increases above the summer maxima, coral bleaching occurs in the Indian seas. It is predicted that bleaching will be a frequent phenomenon in future if the summer maximum temperature continues to increase, and that may lead to demise of corals.

As the tolerance and adaptation capacities are different between species, the species that have the capacity to adapt and gain from warming are increasingly becoming dominant. On the other hand, those species, which are already at the threshold limits, are vulnerable and lose to adaptable ones. At community level, this is reflected as changes in species composition over the years. All these changes have the potential to alter the structure and function of marine ecosystems.

IAS in Indian seas

The most common characteristics of invasive species are their high dispersal ability, rapid reproduction and growth, ability to survive on various food types in a wide range of environmental conditions and ability to physiologically adaptto new conditions. Zoological Survey of India has identified 99 marine IAS, of which the genus *Ascidia* accounts for the maximum number (31), followed by Arthropods (26), Annelids (16), Cnidarian (11), Bryzoans (6), Molluscs (5), Ctenophora (3) and Entoprocta (1) *(www.indiatoday.in)*. Nandi and Rot (2017) listed 32 species of crustaceans consisting of 5 species of decapods, 6 isopods, 9 amphipods, 7 cirripedes and 5 copepods. They reported that these species were introduced into the Indian waters by ship ballast water. Only one species of decapod, namely, *Litopenaeus vannamei* has been introduced intentionally for aquaculture purpose. The invasive status of some of these species, however, is yet to be determined. So far, no ecological impact of these species to native ecosystems is ascertained.

Concerned by the confusions, biased definitions, and information in identifying and listing the IAS, the National Biodiversity Authority (NBA) realised the need to avoid ambiguity and developed the following a criteria for designating a species as IAS (Sandilyan et al., 2018): The species should have been (i) introduced from outside the political boundary of India; (ii) established as a reproductive population within the political boundary of India; (iii) reported as IAS in scientific studies conducted in India; and (iv) well-recognised for its negative impacts on biodiversity/ecosystem functions and services/economy, health, social, and cultural system. Following the above four criteria, 19 marine species consisting 2 species of algae, 2 scyphozoans, 2 anthozoans, 3 ctenophores, 2 bivalves, one hydrozoan, 2 polychaetes, one species each of amphipod, decapod and bryozoan and 2 species of ascidians were identified as IAS. In their report, important attributes including invasiveness, impacts and range extension were considered by consulting experts for designating the IAS. However, the authors suggested that there may be many more invasive species which may satisfy the above criteria, but due to lack of adequate information of the concerned species, they were not included in the list.

Analysis of the above publications brings to light the vast differences in list of marine IAS. Data availability on invasion (rate of multiplication and spread and mode of dispersion), impacts (affecting ecosystem services and functions, biodiversity loss, economic loss and health hazards) and range extension are difficult to assess, particularly for marine species. Consequently, there is lack of comprehensive and readily accessible knowledge about fundamental dimensions of biological invasions, such as the rate of new species arrivals, the impacts they cause, and knowledge about their occurrences in the Indian seas. More so, information on the emerging role of climate change in the spread and effects of marine IAS is unavailable.

Effect of climate change on spread and influence of IAS

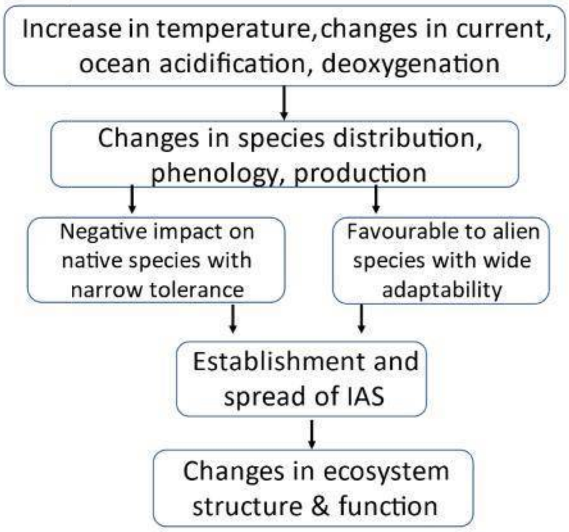
Increase in seawater temperature, ocean acidification and changes in ocean currents, cyclones and deoxygenation will result in a cascade of biological changes that will facilitate spread of marine IAS (Fig. 1).Climatic change is known to affect many ecological properties and interact with IAS in the following possible ways (Occhipinti-Ambrogi, 2007; Capdevila-Argüelles and Zilletti, 2008; Vilizzi et al., 2021):

I. With increasing evidences on latitudinal range expansions of species correlated with changing temperature conditions, alien species with invasive characteristics may spread and provoke multiple effects such as extinction of native species, negative effects on species richness, and impact overall ecosystem structure and function (like primary production and trophic flow). As such, tropical species that have narrow temperature ranges, are likely to expand/shift poleward into temperate regions. Species with broad distributions have wide thermal tolerance and they are likely to expand their ranges. Other critical points to be answered are (a) whether there are southern contractions of species that move northwards (as in the case of the oil sardine *Sardinella longiceps* in the Indian seas that has extended the distributional range from the southwest coast towards the northwest coast) and (b) whether those species extending the distributional boundaries become invaders.

II. Extreme climatic events resulting from climate change, such as hurricanes, floods and ocean currents can transport IAS to new areas and decrease the resistance of habitats to invasions.

III. Climatically driven changes in current patterns and ocean acidification may affect species dispersal mechanism locally, and involve in competitive interactions between IAS and native species. Alien species that are regularly introduced through other sources (like shipping), but have so far failed to establish may succeed due to climate change, creating new sets of invaders. In other words, alien species transported anthropogenically to a locality, may find the changing sea conditions favourable for invasion.

IV. The above three effects on individuals and populations will lead to changes in diversity and production.



While commercial shipping, fishing, aquaculture, drilling platforms, canals (Bax *et al*., 2003) and climate change (Capdevila-Argüelles and Zilletti, 2008) have been recognised as the sources of marine IAS, it is a challenge to segregate the impact of climate change from other sources on the spread and impact of IAS. It is difficult to predict how climate change will affect invasive processes *per se* as well as in combination with other anthropogenic factors of global change (biotic changes, land use changes, etc.). As it is understood that climate change facilitates the establishment, spread of many alien species and their effects, it is imperative to develop a clear understanding on the pathways that facilitate the spread of marine IAS due to climate change and other factors by initiating dedicated studies in India. It is also necessary that the studies should develop unambiguous criteria to distinguish invasive and non-invasive species across aquatic organisms based on thermal tolerances and response of marine organisms to temperature increase (Vilizzi *et al*., 2021).

Approach to manage marine IAS in the context of climate change

As invasive species and climate change are considered as two main threats to biodiversity, the two operating together could be expected to produce extreme negative outcomes. For addressing the marine IAS issue, a heuristic framework needs to be developed (Table 2). For developing the framework, the following general guidelines may be considered:

I. Overall principle of establishment, spread and potential management of terrestrial, freshwater and marine IAS are the same, but the uniqueness of marine environment needs special attention.

II. Climate change produces compounded effect of marine IAS, and hence, the issues have to be jointly addressed with other causes, but with special focus on the pathway related to climate change.

III. Management strategies have to be clearly defined for (a) Prevention, (b) Eradication, (c) Containment and (d) Protection (if the IAS can be beneficially utilised).

IV. The approach should not be restricted to minimising the IAS number, but also to reduce the impact on native species and ecosystems.
V. As information availability has to be improved, research projects are priorities to answer specific questions.
VI. Good practices adopted elsewhere may be followed with suitable changes.

Table 2. Outline for developing a heuristic framework for managing marine IAS

#	Broad strategy	Specific action	Remarks
1	Research	Identifying marine IAS, biological characteristics, causes, pathway, hotspots; Developing indicators; Identifying 'donor' localities (including other country EEZ and high seas);	Assessing species distributional boundaries, reproductive capacity, trophic flows and impact on native species; thermal sensitivity, and adaptability to climate change events;
2	Monitoring, dissemination & awareness	Developing proper methods of monitoring; Engaging appropriate government, non-government agencies and fishermen	Creating facilities for long-term monitoring
3	Management	Following species-by-species approach; Focusing on hotspots and localised approach rather a country-wide approach; Developing implementation mechanism; Adapting by monitoring the efficiency of management measures	Identifying management actions by considering effectiveness, feasibility, acceptability and cost; Exploring commercial use; engaging with stakeholders; consulting countries in the region
4	Mainstreaming and budgeting	Integrating with other management strategies such as Biodiversity Acts, Marine Fishing Regulation Act, Ecosystem Approach to Fisheries Management (that will address multiple objectives)	Defining the role of government and non-government agencies; strengthening coordination between government departments

1. The first strategy is to identify the marine IAS that are likely to pose threat to native species and ecosystems. Aquatic species that are likely to become invasive, usually possess life-history traits such as high reproductive capacity, long life span, ability to cope up with available food resources, and a history of invasion success (Vilizzi et al., 2021). In addition, these species tolerate broader environmental temperatures, salinity, pH and higher levels of organic pollution than native species. If the species with the above characteristics had been introduced from outside the political boundary of India and established a reproductive population with negative impacts on biodiversity/ecosystem functions and services/economy, health, social, and cultural system (Sandilyan et al., 2018), they may be designated as IAS. It is also important to develop indicators that will separate the IAS from native species.

Research should find out the causes and pathway of transportation like shipping, fishing, climate change, etc. In the context of climate change, the IAS can expand their range because of elevated temperature and change in ocean current. As ongoing global warming promotes invasion of warm-adapted species into new habitats by range extension, a key to understand future processes of invasions and biogeographical expansion of different species is to study the difference in temperature sensitivity between invasive species and native species from the information on thermal range of distribution of the species in the latitude-longitude grid they normally inhabit.

2. The second strategy is long-term monitoring, dissemination of information and building awareness among the public. Long-term monitoring of IAS will enable identification of hotspots, provision of scientific advice, and adoption of management measures, including fisheries management measures. For monitoring the IAS, proper methodology has to be developed. As monitoring the sea is challenging and creating facilities is expensive, cost-effective methods should be identified. Engaging the fishermen in a suitable way will be cost-effective.

3. The third strategy is to manage the IAS. At large, unrestricted marine spatial scales, effective options have not evolved globally. Working in a marine environment places unique technical constraints on options for control of IAS and faces daunting logistical difficulties. The best way is to prevent the IAS by early detection. Fishermen can substantially contribute to the early detection of new invasive species and disseminate the information. The prospects of physical removal are possible if detected early. Use of biocides, exotic viruses, genetically modified viruses or generalist predators as control agents will result in undesirable outcomes (Thresher and Kuris, 2004).

   In most cases, the IAS are solely perceived as pests, but it is possible that commercial opportunities could be created depending on the species (Gücü et al., 2021). This is a crucial aspect of facilitating successful adaptive management. For example, the possibilities of utilising invasive bivalves, jellyfishes and puffer fishes for human food or fish meal could be explored. Creative commercial or biomedical opportunities should be sought wherever possible. However, this measure has to be adopted carefully, as this may amount to accepting the IAS.

   Implementation of measures should focus on smaller spatial scales instead of country approach. This is because the shift range of species are different under changing climate, and case-by-case approach should be put in place.

   Stressed environments are easily invaded by alien species (Occhipinti-Ambrogi, 2007).Rehabilitating the ecosystem by protection and restoration will be a preferred option. Marine Protected Areas (MPAs), no-take marine reserves, Ecosystem Approach to Management and Co-management are important tools for marine conservation and will address multiple issues like overfishing, land use change, pollution and climate change. Native organisms in restored ecosystems will be able to overcome fresh challenges than those inhabiting unmanaged and depleting ecosystems. Awareness and education to the public, particularly to the fishermen, should be a priority. Substantial efforts should be invested in the engagement of stakeholders aiming at the prevention and control of invasive species (Giakoumi et al., 2019).

4. The fourth strategy is to mainstreaming and budgeting IAS management. Number of agencies is charged with preventing the introduction of invasive species and for management and control of invasive species. These include the Ministry of Environment, Forests and Climate Change, National Biodiversity Authority, State Biodiversity Authorities, ICAR - National Bureau of Fish Genetic Resources, the Plant Quarantine Organisation of India and various departments of the Ministry of Agriculture. Considering the huge task of managing the IAS, such as documenting the alien species, the pathways by which they were introduced, the ecological characteristics that make them invasive, their ecological and economic impacts, and developing management measures, there is need for adequate budgeting and a coordinated national/state-level effort jointly by government and non-government agencies, universities, and research institutes. This will enable better monitoring, regulating and minimising the impact. A comprehensive legal and policy framework on invasive species is also needed.

Small-scale fishers should be at the forefront of adaptive management of this kind of resource. They should be encouraged and supported in monitoring the IAS and pursuing new commercial initiatives. They can do this in various ways, including through modifying their fishing activities (e.g. gear, period, etc.) and developing of new fisheries.

Conclusion

Climate change is expected to exacerbate the issue of IAS in the marine environment. A changing climate may directly or indirectly influence biological invasions by altering the likelihood of introduction or establishment, as well as modifying the geographic range, environmental impacts, economic costs or management of alien species. Thus, the combination and interaction between climate change and IAS is expected to reshape marine ecosystems. Sound scientific knowledge of the IAS and their impact on ecosystems, as well as an in-depth understanding of the socio-economics, and institutional limitations are important components required to achieve a flexible adaptive response (Barange *et al*., 2018). Continued data collection and monitoring are at the basis of this approach with the involvement of the fishing sector in implementing measures. In order to become effective, these elements need to be implemented over longer time periods.

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ECOLOGICAL IMPACTS OF INVASIVE SPECIES ON TRUE MANGROVES: A CASE STUDY FROM SELECTED MANGROVE RICH SITES OF KANNUR DISTRICT, KERALA

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Abstract

Mangroves are among the most productive and biologically complex ecosystems on Earth. Invasive species have significantly spread in the mangrove ecosystem over the past few decades. However, little consideration has been given to how plant invasions contribute to the destruction of mangrove forests. The current study aimed to document the invasive species present, as well as their rate of invasion (RI) and their ecological impacts on mangrove plant species distributed in the selected study sites of Kannur district. The study stations include Kuppam (S_1), Kuttikkol (S_2), Mullool (S_3) and Vellikkeel (S_4). Sampling of plant species were done through quadrat study. Quadrats sizes of 10×10 m^2 were set after every 15m distance. Mangrove species were identified and described by using Tomlinson (1986). A total of 40 plant species including 9 true mangroves and 14 invasives were documented from the study. Climbers such as *Volkameria inermis*, *Derris trifoliata*, *Ipomoea cairica*, *Mikania scandens*, and *Camonea vitifolia* have been found to be highly invasive. *Acacia mangium*, *Annona glabra*, *Gliricidia sepium* and *Lantana camara* are exotic invasives. *Derris trifoliata*, *Annona glabra*, and *Mikania scandens* are some of the most significant invasives with a high RI value. True mangroves such as *Avicennia marina*, *A. officinalis*, and *Sonneratia caseolaris* were completely invaded and encircled by woody lianas such as *D. trifoliata*. The recorded invasive species compete with indigenous plants for nutrients and light, cause physical damage to the native species and their natural regeneration is hampered. Besides the mentioned facts, the invasives with allelopathic effects accumulate toxins, affecting germination of mangrove seedlings, biota and poisoning animals. The uncontrolled spread of invasives may lead to reduction in mangrove biomass production and alter the natural balance of the ecosystem. Invasive plants and their ecological impacts must be studied in depth and this fragile wetland ecosystem should be continuously monitored. Proper policy formulation and management interventions are also required to control the invasive plants on mangrove wetlands for its conservation.

Keywords: Invasive species, Invasion, Mangroves, Wetland

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Introduction

The spread of invasive species continues to be one of the major threats to natural ecosystems and their species diversity. Mangroves are among the most productive and biologically complex ecosystems on Earth. Mangrove wetlands are the most vulnerable ecosystems worldwide and are immediately affected by plant invasion. However, it is usually assumed that mangrove forests are resilient to plant invasion since mangrove species are largely found in the salty and intertidal environments. However, several salt-tolerant aquatic, terrestrial, and epiphytic plants have been observed to invade mangrove forests. But little is known about the functional features of these invasive species, invasion patterns and their ecological impacts (Biswas *et al*., 2018). Invasive species have significantly spread in the mangrove ecosystem over the past few decades. However, little consideration has been given to how plant invasions affect the productivity and how it contributes to the destruction of mangrove forests. The current study aimed to document the invasive species present, as well as their rate of invasion (RI) and their ecological impacts on mangrove plant species in the selected mangrove rich sites of Kannur district.

Methodology

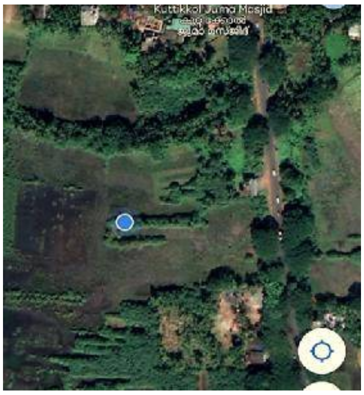
The selected biodiversity rich study stations from Kannur district include Kuppam (S_1), Kuttikkol (S_2), Mullool (S_3) and Vellikkeel (S_4). Satellite google map images of study stations were given in figure 1.1. Sampling of plant species were done through quadrat study. Quadrats sizes of $10 \times 10\ m^2$ were set after every 15m distance. The processes were replicated for all study stations. A total of 60 quadrants were studied from the Four study stations. Special plots were taken in those stations criss-crossed by water bodies. Mangrove species were identified and described by using Tomlinson (1986). Mangrove associates and invasive species were counted and identified (Gamble, 1936). Density, frequency and abundance were calculated and the vegetation data analyses were done by using Raunkiaer (1934) method. Intensity of invasiveness, ecological association and their impacts were also studied by direct observation. is calculated by

Rate of invasion using the following equation:

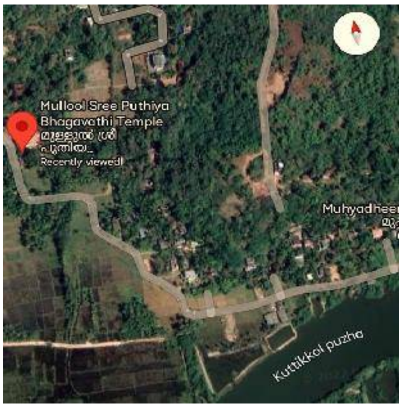
$$RI = \frac{\sum \left| Db - Dm \right| / d}{n}$$

Db = Density of invasive species at the border of the forest
Dm = Density of invasive species at the middle of the forest
d = distance between initial and end plot in meters
n = number of sample lines covered

The results were analyzed and found out the intensity and rate of invasion.



(a) (b)



(c) (d)

Fig. I: Satellite google map images of study stations (a) Kuppam S_1 (b) Kuttikkol S_2 (c) Mullool S_3 (d) Vellikkeel S_4

Results

From the selected four study stations a total of 9 species of true mangroves and 20 mangrove associates were recorded. The complete list of plant species identified and recorded, Life form, family and their status were given in the Table 1. Among these, 14 species were identified as invasive belonging to 14 genera and 8 families. The major 3 families in which the invasive species reported from the study area belongs to Fabaceae, Asteraceae and Convolvulaceae. The list of invasive species and their rate of invasion (RI) were given in Table 2.

Table 1: List of plant species, life form, family and status

Sl No:	Plant species	Life form	Family	Status
1	*Acanthus ilicifolius* L.	Shrub	Acanthaceae	T
2	*Acacia mangium* Willd.	Tree	Fabaceae	E, I
3	*Acrostichum aureum* L.	Herb	Pteridaceae	I

4	*Aegiceras corniculatum* (L.) Blanco	Tree	Primulaceae	T
5	*Annona glabra* L.	Tree	Annonaceae	E, I
6	*Avicennia marina* (Forssk.) Vierh.	Shrub	Acanthaceae	T
7	*Avicennia officinalis* L.	Tree	Acanthaceae	T
8	*Bruguiera cylindrica* (L.) Blume	Tree	Rhizophoraceae	T
9	*Carallia brachiata (*Lour.) Merr.	Tree	Rhizophoraceae	FM
10	*Caryota urens* L.	Tree	Arecaceae	A
11	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Shrub	Asteraceae	I
12	*Volkameria inermis* L.	Shrub	Lamiaceae	A, I
13	*Cocos nucifera* L.	Tree	Arecaceae	A
14	*Cosmostigma cordatum* (Poir.) M.R.Almeida	Herb	Apocynaceae	A
15	*Derris trifoliata* Lour.	Shrub	Fabaceae	I
16	*Exoecaria agallocha* L.	Tree	Euphorbiaceae	T
17	*Ficus hispida* L.f.	Shrub	Moraceae	A
18	*Gliricidia sepium* (Jacq.) Kunth	Tree	Fabaceae	A, E, I
19	*Hibiscus surattensis* L.	Herb	Malvaceae	A
20	*Ipomoea cairica* (L.) Sweet	Climber	Convolvulaceae	I
21	*Ixora coccinea* L.	Shrub	Rubiaceae	A
22	*Kandelia candel* (L.) Druce	Shrub	Rhizophoraceae	T
23	*Lantana camara* L.	Shrub	Verbanaceae	E, I
24	*Macaranga indica* Wight	Tree	Euphorbiaceae	A
25	*Melastoma malabathricum* L.	Shrub	Melostomataceae	A
26	*Mikania scandens* (L.) Willd.	Climber	Asteraceae	I
27	*Camonea vitifolia* (Burm.f.) A.R.Simoes & Staples	Shrub	Convolvulaceae	I
28	*Mimosa pudica* L.	Shrub	Fabaceae	A, I
29	*Physalis angulata* L.	Herb	Solanaceae	A
30	*Pongamia pinnata* (L.) Pierre	Tree	Fabaceae	A
31	*Pothos scandens* L.	Epiphyte	Araceae	A
32	*Premna serratifolia* L.	Tree	Lamiaceae	A
33	*Rhizophora mucronata* Lam.	Tree	Rhizophoraceae	T
34	*Salvinia molesta* D.Mitch.	Aquatic fern	Salviniaceae	I
35	*Sonneratia caseolaris* (L.) Engl.	Tree	Lythraceae	T
36	*Terminalia catappa* L.	Tree	Combretaceae	A
37	*Thespesia populnea* (L.) Sol. ex Correa	Tree	Malvaceae	A
38	*Wattakaka volubilis* (L.f.) Stapf	Climber	Apocynaceae	A
39	*Sphagneticola trilobata* (L.) Pruski	Herb	Asteraceae	A, I
40	*Ziziphus oenoplia* (L.) Miller	Shrub	Rhamnaceae	A

The true mangroves present in the study area includes *Aegiceras corniculatum* (L.) Blanco, *Acanthus ilicifolius* L., *Avicennia marina* (Forssk.) Vierh., *A. officinalis* L., *Bruguiera* *cylindrica* (L.) Blume, *Exoecaria agallocha* L., *Kandelia candel* (L.) Druce, *Rhizophora mucronata* Lam. and *Sonneratia caseolaris* (L.) A. Engl.

S. caseolaris and *A. ilicifolius* are the most abundant mangrove species in S_1 and $S_{2.}$ Mangrove species diversity was highest in $S_{3,}$ *A. ilicifolius* and *R. mucronata* are the most abundant species.

Discussion

In $S_{1,}$ 10 species of invasives were reported. *A. aureum*, *C. odorata* and *D. trifoliata* was found to be the most abundant. *A. aureum*, *A. glabra* and *D. trifoliata* are the most abundant invasive in S_2 and S_4. Out of the 5 invasive reported in S_3, *A. aureum* was the most abundant species. % Frequency, Density and Abundance of Invasive plants recorded from S_1, S_2, S_3 and S_4 were given in Figure 3.

Climbers are found to be highly invasive including *V. inermis, D. trifoliata, I. cairica, M. scandens and C. vitifolia.* Out of the 14 species of invasive recorded, *A. mangium, A. glabra, G. sepium* and *L. camara* are exotic invasives. Density of the species like climbers was high in border of the forest followed by *A. aureum*. Woody lianas like *D. trifoliata* completely invaded and encircled the true mangroves like *A. marina, A. officinalis* and *S. caseolaris*. In the case of *D. trifoliata* invasion was observed in the canopy of the mangroves. But in *M. scandens* invasion was observed in border and canopy. *S. molesta* was another recorded invasive from the study station Kuppam, which was spread over the ground floor of forest near the river and also found to associated on the stilt roots of *R. mucronata. S. molesta* cause physical damage and affects the natural regeneration of the mangrove seedlings. *A. aureum* is widely spread in all the study stations and this is an indicator species of disturbed area. The intensity of invasiveness and physical damage to mangroves caused by invasive plant species were shown in the Fig 2.

Table 2: Rate of Invasion (RI) of invasive plant species in $S_{1,}$ $S_{2,}$ S_3 and S_4

SI NO:	Invasive Species	Rate of Invasion (RI)			
		S_1	S_2	S_3	S_4
1	*Acacia mangium* Willd.	0	0	0	1.7×10^{-3}
2	*Acrostichum aureum* L.	6×10^{-3}	1.68×10^{-2}	4.5×10^{-3}	1.5×10^{-3}
3	*Annona glabra* L.	0	8.8×10^{-3}	3.4×10^{-4}	7.6×10^{-3}
4	*Camonea vitifolia* (Burm.f.) A.R.Simoes & Staples	0	0.01	0	0
5	*Chromolaena odorata* (L.) R.M.King & H.Rob.	3.6×10^{-3}	0	0	0
6	*Derris trifoliata* Lour.	4.9×10^{-3}	7.2×10^{-3}	2.4×10^{-3}	1.9×10^{-4}
7	*Gliricidia sepium* (Jacq.) Kunth	1.8×10^{-4}	1.4×10^{-2}	0	3.8×10^{-4}
8	*Ipomoea cairica* (L.) Sweet	5.1×10^{-5}	2.9×10^{-3}	2.4×10^{-3}	0
9	*Lantana camara* L.	0	6.6×10^{-4}	0	0
10	*Mikania scandens* (L.) Willd.	4.6×10^{-4}	6×10^{-3}	0	0

11	*Mimosa pudica* L.	4.6×10^{-4}	1.12×10^{-2}	0	0
12	*Salvinia molesta* D.Mitch.	0	0	0	0
13	*Sphagneticola trilobata* (L.) Pruski	5.6×10^{-3}	0	0	0
14	*Volkameria inermis* L.	1.6×10^{-3}	4×10^{-4}	2×10^{-3}	2×10^{-3}

The site selected in Kuttikkol face high risk of invasion, developmental activities and waste dumping. This wetland is now invaded by *A. glabra* by replacing native true mangrove species. About 60% of the area is cleared for construction of road. This is the western part of Arabian Sea with low salinity and the station supports *S. caseolaris, K. candela* and *E. agallocha*.

S. caseolaris is one of the major mangrove tree species distributed in the station Kuppam and is highly affected by the invaded climber species. But when we consider Mullool, all true mangrove species are equally affected. *S. caseolaris* in all the study stations is associated with *D. trifoliata* and *M. scandens. V. inermis* observed along with *B. Cylindrica and E. agallocha. A. glabra* was fast growing and replacing mangrove species in borders and abundant in center of the forest. *A. ilicifolius* was less affected by invasive species recorded.

(a) (b)

(c) (d)

Fig 2: (a) *S. molesta,* rapidly spreading on the forest floor (b) *S. molesta*, attached to germinating seedling of *R. mucronata* (c) Mature seeds of *D. trifoliata*, which completely invaded and damage *A. officinalis* (d) woody *D. trifoliata* climbing on *A. officinalis.*

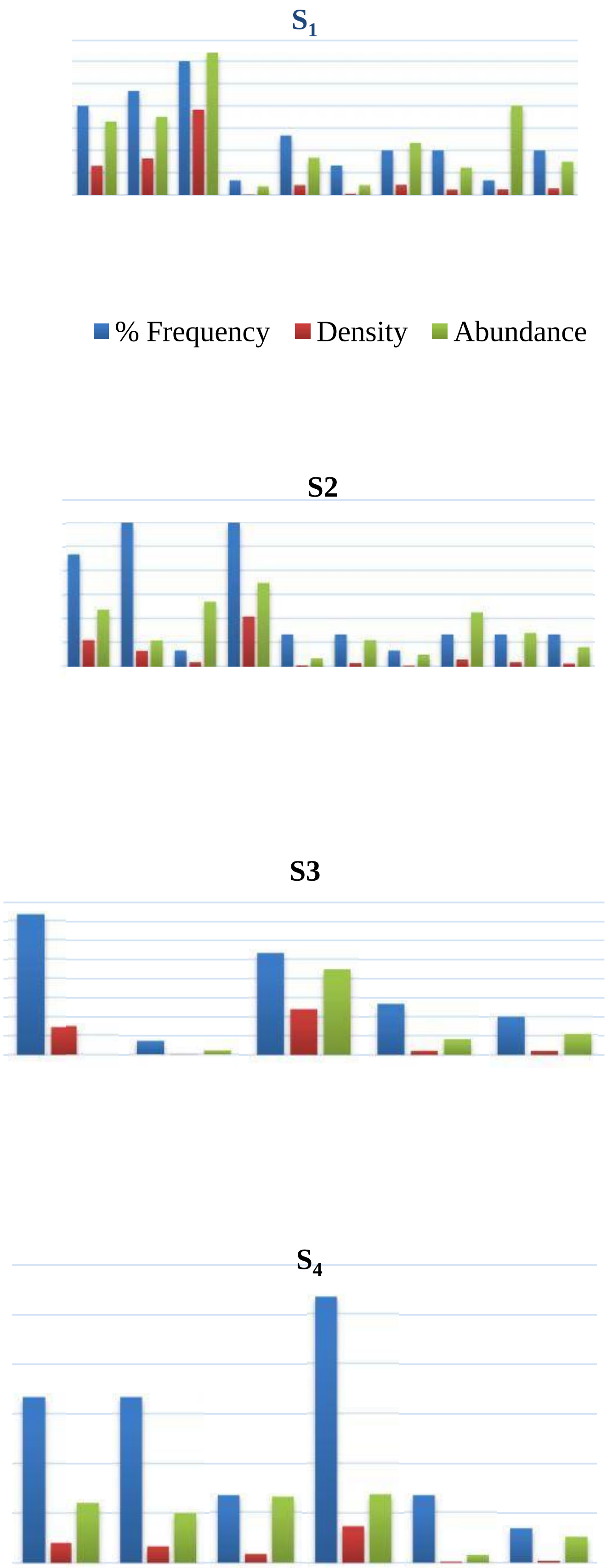


Fig 1.3: Percentage, Frequency, Density and Abundance of Invasive plants recorded from S_1, S_2, S_3 and S_4.

Fig. 4 shows major threats to mangroves in the study area. Along with the plant invasions the mangroves are also threatened by many factors such as construction of road as a part of NH extension, Anthropogenic disturbances including exploitation for firewood and timber, dumping of non-biodegradable wastes, land reclamation for urbanisation and industrialisation, nearby wood factories and other developmental activities.

(a) (b)

(c)

Fig. 4: Threats to mangrove wetland (a) exploitation for firewood and timber (b) mangrove destruction for the construction of road as a part of NH extension (c) disposal of plastics and other non-biodegradable wastes

Conclusion

The uncontrolled spread of invasive leads to reduction in mangrove biomass production and alter the natural balance of the ecosystem. The recorded invasive species compete with indigenous plants for nutrients and light, cause physical damage to the native species and their natural regeneration is hampered. Invasive plants and their ecological impacts must be studied in depth and this fragile wetland ecosystem should be continuously monitored. Proper policy formulation and management interventions are also required to control the invasive plants on mangrove wetlands for its conservation.

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INVASION OF EXOTIC SPECIES AND ITS DELETERIOUS EFFECTS ON WETLANDS.

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Abstract

Invasive species reduce both the plant and animal diversity in an ecosystem (Werner, 2002.). Sustainable conservation and development depend heavily on strengthening the capacity of local individuals and communities to implement conservation initiatives (IUCN,1996). The invasion of exotic species has been considered as the leading cause of species extinction in wetlands. The species invasion outcomes are detrimental and the wetland becomes dominated by invaders which also invites to invade more invasive species.

Invasive species *Oreochromis mossambicus* and *Clarius garipieinus* were collected during the present study.*O. mossambicus* dominates over all other fish species in Veli lake wetland. The dominance of indigeneous fauna like *Etroplus suratensis, E.maculates, Channa striates, Mugil cephalus* and *Puntius* spp. richness was affected due to exotic species invasion. Exotic species invasion lead to the sharing of niches inhabited by indigenous fauna. In recent times sucker fish also reported in Kerala wetland ecosystems in Veli and Vellayani lakes. Invasive species can affect the distribution of native species by decreasing their abundance through predation and change their natural habitat. The wetland ecosystem was also affected by exotic weed *Eichhornia crassipes* which is a major threat to the water resources which enhances pollution load of the lake. The invasive species alter the structure of ecosystem. The integrity of native species is lost multi dimensionally. Invasive species affect the food webs in numerous ways by modifying the quantity and quality of food resources.

Key words: Wetlands, invasive species, species extinction, indigenous fauna, biodiversity, species conservation.

Introduction

Invasive species reduce both the plant and animal diversity in an ecosystem (Werner, 2002.). Sustainable conservation and development depend heavily on strengthening the capacity of local individuals and communities to implement conservation initiatives (IUCN, 1996). The invasion of exotic species has been considered as the leading cause of species extinction in ecosystems.

Fouzia, J. 2023. Invasion of exotic species and its delitireous effects on wetlands. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp. 433-437.

Ramsar Convention on Wetlands define wetlands as: “areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres (Ramsar Convention,1971).Wetlands are defined as lands transitional between terrestrial and aquatic eco-systems where the water table is usually at or near the surface or the land is covered by shallow water. Wetlands are one of the most biologically diverse ecosystems on the planet (UNEP, 2013).

Invasive species are capable of causing extinctions of native plants and animals, reducing biodiversity, competing with native organisms for limited resources, and altering habitats. This can result in huge economic impacts and fundamental disruptions of wetland ecosystems. To be invasive, a species must adapt to the new area easily. It must reproduce quickly. It must harm property, the economy, or the native plants and animals of the region. Many invasive species are introduced into a new region accidentally.

Invasive alien plants multiply rapidly once they are established in an area, which increases adverse effects on the aquatic environment.

Methodology

The study was conducted on lake wetlands with sampling surveys (APHA,1999)and standard identification keys of Jhingran and Talwar, (1991) and fish base of species identification. Data analysis conducted with the help of software SPSS and Palstat. The study area Veli lake a small estuarine wetland in the southwest coast of Kerala situated at Trivandrum. The lake wetland connected with Kadinamkulam lake with Channankara canal. On the south the lake is connected with Akkulam lake with Chakkai canal. The study was conducted onVeli lake and wetlands associated with nearby waterbodies.

Results and discussion

Scientific name	**Habitat status**
Oreochromis mossambicus	**(invasive)**
Etroplus suratensis	R
Etroplus maculatus	R
Anabas testudineus	R
Glossogobius giuris	R
Megalops cyprinoides	R
Sillago sihama	R
Liza parzia	M
Liza macrolepis	M
Caranx carangus	M
Stolephorus indicus	M
Ambassis commersoni	M
Liza tade	M
Puntius filamentosus	R

Puntius sarana	R
Mugil cephalus	R
Mystus gulio	FW
Rasbora daniconius	FW
Anguilla biclolorbicolor	R
Anguilla bengalensis	R
Ichthyocampus carce	R
Channa striatus	FW
Channa marulius	FW
Gerres filamentosus	M
Lutjanus argentimaculatus	R
Oxyurichthys microlepis	R
Clarias gariepinus	FW(invasive)
Heteropneustes fossilis	FW
Terapon jarbua	FW
Puntius vittatus	R

Fresh water, resident, marine and invasive species

The species invasion outcomes are detrimental and the wetland becomes dominated by invaders which also invites to invade more invasive species. Invasive species *Oreochromis mossambicus* and *Clarius garipieinus* were collected during the present study .*O. mossambicus* dominates over all other fish species in Veli lake wetland. The dominance of indigeneous fauna like *Etroplus suratensis, E.maculates, Channa striates, Mugil cephalus* and, Puntius sps. richness affected lost due to exotic species invasion.

Exotic species invasion lead to the sharing of niches inhabited by indigenous fauna. Recent times sucker fish was also reported in Kerala wetland ecosystems also, in Veli and Vellayani lakes. Invasive species can affect the distribution of native species by decreasing their abundance through predation and change their natural habitat. The wetland ecosystem also affected by exotic weed *Eichhornia crassipes* was also reported as a major threat to the water resources which enhances polluted load of the lake.

The Mozambique tilapia, is resistant to temperature and salinity levels, and has been successfully introduced in over 90 countries on five continents. When released into new habitats, either intentionally or unintentionally, the Mozambique tilapia tends to take over the native species. It's an omnivorous species that can eat everything from plants to small fish. The health of our wetlands is threatened by a range of factors, including invasive species, over exploitation, illegal fishing, pollution and climate change.

Invasive alien plants are known for excessive water consumption due to their high transpiration rates. The impacts are devastating during drought, and this is a major threat to wetland water security. Invasive alien plants introduced either intentionally or unintentionally were brought into the country for horticulture, aquaculture, agriculture and forestry.

Exotic species naturalise to the local conditions, including climate factors. They accomplish this through superior competitive capabilities, over the native species which includes fast growth, high reproductive output and the ability to adapt to a wide range of physical environments. Water hyacinth is a type of invasive floating plant found in water bodies across the world. These invasive species block the sunlight reaching and oxygen level in water systems, which results in damaging water quality and affecting various life forms in the ecosystem.

Invasive species, whether plant or animal, occupy ecosystems and can cause devastating impacts to the native environment causing irreversible damage. Water hyacinth is very hard to remove due to is rapid reproduction rates and its dense layers which form a mat over the water's surface, which threatens the diversity of native species and can cause changes to the physical and chemical structure of the aquatic environments they invade which eventually leads to a disruption in food chains and nutrient cycling (Wright A and Purcell, 1995.).Water hyacinth is also able to spread to new areas quickly because of its ability to regenerate. It forms floating mats that shade and crowd out important native plants. Thick mats reduce oxygen content and degrade water quality for fish and other aquatic organisms.

Clarias gariepinus has all the qualities of an aggressive and successful invasive species. Its high fecundity, flexible phenotype, rapid growth, wide habitat preferences, tolerance to extreme water conditions and the ability to subsist on a wide variety of prey can devastate indigenous fish and aquatic invertebrate populations (Bruton, 1996).

Sailfin sucker mouth catfishes (Pterygoplichthys spp.) are capable of surviving mesohaline conditions for extended periods of time, allowing for the use of estuarine and coastal areas for dispersal (Capps et al. 2011). South American sucker mouth sailfin catfish Pterygoplichthys spp. have successfully invaded inland water bodies of various countries across the world. *Salvinia molesta* grows rapidly to cover the surface of lakes and streams, spreading aggressively by vegetative fragments.

Like every ecosystem, the existence of species in wetlands also depends on a delicate balance of nature. However, when non-native species introduced by humans invade such ecosystems, it might lead to a misbalance in the existing system. Such species compete with the native ones for natural resources. When one native species start dying off as a result of this competition, the entire food cycle of the ecosystem gets disrupted

Conclusion

The invasive species alter the structure of ecosystem. The integrity of native species is lost multi dimensionally. Invasive species affect the food webs in numerous ways by modifying the quantity and quality of food resources.

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REPORT OF INVERTEBRATES WITH INVASIVE NATURE FROM LAKSHADWEEP ISLANDS, ARABIAN SEA, INDIA

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Abstract

Coral reef stretches of Lakshadweep are endowed with diverse and rich flora and fauna. The invasive species can be a threat to this ecosystem due to its fragile and sensitive nature. Invasive species are organisms that can cause economic or ecological damage or negatively impact human health. Collection of samples are carried out from the islands; Kavarati, Agati, Bangaram, Kadmat, Androth and Amini through SCUBA diving and snorkelling. In this study, we are reporting some non-native species from Lakshadweep that show invasive nature in other geographical areas. These species include *Anemonia alicemartinae, Pelagia noctiluca*, *Palythoa* sp. (Phylum Cnidaria), *Eurythoe complanata (*Phylum Annelida). The discharge of ballast water and the introduction of ship-fouling organisms are the major sources of the introduction of these invasive species. According to previous reports, these species show a highly invasive nature as they compete with native species for food and space. This study discusses the possible stresses caused by these species if their number surges. Management measures are inevitable to control the invasive species in the coral biota of Lakshadweep.

Keywords- Invasive species, Lakshadweep, Arabian Sea, India, coral reef

Introduction

Lakshadweep is a unique and ecologically fragile ecosystem due to its high degree of endemism in species composition. Natural and native species will be in threat due to the presence of invasive species. Invasive species are any biological organisms that can cause economic or environmental harm or adversely affect human health (Raghunathan *et al*., 2021). They compete with native species for nutrients, light, space, water, food, feeding preferences and reproduction. Process of competition and predation allow the invaders to proliferate quickly and finally threaten biodiversity, ecological services, economy and livelihood. Introduction of invasive species may be anthropogenic or by natural dispersal through intentional or unintentional modes. Ship mediated invasions, especially ballast discharge and ship hull fouling are the major source of invasions as these islands are located

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in the vicinity of the international sea route. There are four invertebrate species documented as invasive from Lakshadweep (Raghunathan et al., 2021) till now. It includes a hard coral; *Tubastrea coccinea, polychaetes; Perinereis nuntia* & *Protocirrineris chrysoderma* and a bivalve, *Martesia striata.*

Lakshadweep is endowed with rich biodiversity, so invasive species may threaten its biodiversity, ecological services, economy and livelihood of the fishermen community. Also depletion of native population and alteration in ecological and environmental attributes is also important. Invasive species can easily proliferate quickly and their competitive and predatory nature leads to the decline of richness and diversity of the endemic species. In this study we are reporting four invertebrate species from Lakshadweep that shows invasive nature in other areas. Long term monitoring for recording the status and degree of invasion of this type of invasive species from this fragile coral ecosystem is very essential. We are discussing the possible deleterious effects of these species on the native species if their number surges.

Materials and methods

Invertebrate samples were collected by SCUBA, snorkelling and intertidal hand picking from the islands Kavaratti, Amini, Bangaram, Agatti, Kadmat and Androth of Lakshadweep during 2021 March to April and 2022 January to March. Tissue samples were preserved in Himedia Diluent for DNA extraction and the voucher specimens are deposited in the Marine Taxonomy Reference Laboratory (MTRL) of the Department of Science and Technology, Kavaratti, India. Samples were identified using molecular taxonomic approach and morphological analysis. DNA extraction was done from preserved tissue using PureLink Genomic DNA Mini Kit by Thermo Fisher Scientific as per the manufacturer's protocol. PCR reactions were performed in a 25 µL volume with the Universal DNA primers LCO 1490 and HCO 2198. The PCR products were run on a 0.8% agarose gel and verified the bands. Column purification and Sanger sequencing of PCR products was done commercially by Agrigenome Labs Pvt Ltd, Cochin, India.

Results and discussion

In this study, we are reporting some non-native species from Lakshadweep that show invasive nature in other geographical areas. These species include one jelly fish; *Pelagia noctiluca,* one sea anemone; *Anemonia alicemartinae,* one zoanthid; *Palythoa* sp. (Phylum Cnidaria),one polychaete; *Eurythoe complanata (*Phylum Annelida) (Figure 1 and Table 1). The discharge of ballast water and the introduction of ship-fouling organisms are the major sources of the introduction of these invasive species. According to previous reports, these species show a highly invasive nature as they compete with native species for food and space. This study discusses the possible stresses caused by these species if their number surges. Management measures are inevitable to control the invasive species in the coral biota of Lakshadweep.

Fig 1: *Pelagia noctiluca, Anemonia alicemartinae, Palythoa* sp., *Eurythoe complanata*
(From left to right)

Table 1: Alien Invertebrates reported from Lakshadweep with invasive effects

SL. No.	Species	Native	Distribution range
	Phylum Cnidaria		
1	*Anemonia alicemartinae*	Chile, South America	Southeast Pacific: Chile.
2	*Pelagia noctiluca*	North Atlantic region	Mediterranean and the Atlantic Ocean
3	*Palythoa sp.*	Hawaiin Islands	Atlantic and Pacific Oceans
	Phylum Annelida		
4	*Eurythoe complanata*	Mediterranean	Atlantic, Pacific, and Indian oceans

1. *Pelagia noctiluca*

Common name- Purple striped jellyfish

- Kingdom: Animalia
- Phylum: Cnidaria
- Class: Scyphozoa
- Order:Semaeostomeae
- Family: Pelagiidae
- Genus: Pelagia
- Species: *Pelagia noctiluca*

Pelagia noctiluca is known as the most notorious jellyfish in the Mediterranean sea as it exhibits heavy blooming with increased frequency (Brotz & Pauly,2012. Its massive aggregation disrupts mariculture operations and severe fish kills in the Atlantic ocean- (Doyle et al., 2008). Heavy blooms may affect fishing operations and compete for nutrients with native species.

2. *Anemonia alicemartinae*

- Kingdom: Animalia
- Phylum: Cnidaria
- Class: Anthozoa
- Order: Actiniaria
- Family: Actinidae
- Genus: Anemonia
- Species: *Anemonia alicemartinae*

Anemonia alicemartinae is a cryptogenic bright red coloured sea anemone with no accepted common name. It is native to the west coast of South America and its distribution range expand to around 2000 km by ship mediated transport (Pinochet et al.,2019). This species inhabits shallow intertidal pools and subtidal zones. It exhibits both short distance and long distance dispersal mechanisms according to the high variability in temperature and salinity (Lopez et al., 2013). Release and reattachment ability is easy for these anemones and is helpful for this organism to use ships as carriers. Hausssermann & Forsterra, 2001 described the sudden southward spread of *A. alicemartinae* in Chile due to climatic variations and with sea squirt cultures. Reproduction can be possible by fission (Lopez et al., 2013) and the passive migration is a part of their life history stage (Riemann-zurneck, 1998). They will compete for nutrients and space if the number surges as they feed on plankton and dissolved organic matter.

3. *Palythoa* sp.

Common names- Moon Polyps, Button Polyps and Sea Mats

- Kingdom: Animalia
- Phylum: Cnidaria
- Class:Hexacorallia
- Order: Zoantharia
- Family: Sphenopidae
- Genus: Palythoa
- Species: *Palythoa* sp

Palythoa sp. is a potential competitor in Brazilian waters due to its overgrowth as a main competitive strategy(Suchanek& Green, 1981). It exhibits strong biotic resistance to other invasive species (Mendonce- Nieto & Da Game, 2009) and aggressive competition due to toxin production. Highly competing for space even with invasive species in Brazilian waters as it is symbiotic with zooxanthellae.

4. *Eurythoe complanata*

Common name- Iridescent fireworm

- Kingdom: Animalia
- Phylum: Annelida

- Class: Polychaeta
- Order: Aciculata
- Family: Amphinomidae
- Genus: Eurythoe
- Species: *Eurythoe complanata*

Eurythoe complanata is a shallow water polychaete showing invasive nature in Mediterranean Sea (Arias et al., 2013). It is included in the Global Register of Introduced and Invasive species of Greece and can thrive in warm water. Larvae is free floating and asexual means of reproduction is through fragmentation. Broadcast spawning is the peculiarity of sexual reproduction. It exhibit antipredator adaptation or aposematic with its neurotoxin bearing bristles.

Competition for food and space, easy proliferation are the major factors that may affect native species if their number is rising. Long term monitoring programme on invasive species is required on a global and regional level. Studies on these species are scarce, especially from Indian waters. Frequent assessment on the impacts of these species on endemic organisms are necessary. The degree of invasion can be identified using ecological niche model approaches and GIS tools. Ballast disposal should strictly follow the International Convention for the Control and Management of Ships (IMO) norms.

Conclusion

The reported species from phylum Cnidaria and Phylum Annelida are not showing invasive nature in Lakshadweep now. But long term monitoring of these species are essential to check whether their number is multiplying fast. Surge in numbers will highly affect native species and finally will threaten ecosystem services and the economy. Because these species are showing serious impacts on other geographic areas.

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INVASIVE PLANTS IN THE POOVAR REGION OF NEYYAR RIVER

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Abstract

Invasive alien plants threaten biological diversity by causing population declines of native species and by altering key ecosystem processes. It can cause changes to native biodiversity and ecosystem functioning. It is important to study about invasive species for the protection of native species and biodiversity. Poovar is a tourist place in the Thiruvananthapuram district of Kerala, a part of Neyyar river passing through Poovar. The plant communities along the Neyyar river on poovar give special attraction to the place. A comprehensive study to document invasive plants in this area highly needed to evaluate the conservation status and future threats. The floristic analysis resulted in the documentation of 41 invasive species belonging to 34 genera of 20 families. Among these 5 plants are aquatic. Out of these 41 species 14 species are very noxious to study area. Sometimes aquatic invasive species act as barriers to water transport. It is important to prevent uncontrolled growth of invasive plants in this area for the conservation of biological diversity and development of ecotourism. Preventive measures should be taken to restrict further spread of these plants.

Keywords: Invasive alien plants, biological diversity, native species, Poovar, Neyyar river

Introduction

Biodiversity is completely linked with ecosystem services and human welfare. For the past several decades, the invasive alien plant species (IAPS) have posed severe threats to the local biodiversity. Ecological perturbations caused by biotic invasion have been identified as a growing threat to global sustainability. Invasive alien plants species (IAPS) are considered to be one of the major drivers of biodiversity loss, thereby altering the ecosystem services and socio-economic conditions (Kumar and Singh, 2019). Loss of native plant diversity through invasive plant pathogens may indirectly affect human health through perturbations in the environmental quality (Jones and McDermott, 2018).

The invasion of alien species of plants into a natural ecosystem or habitat is a complex problem. Invasive species can also affect the soil and its microorganisms. This may affect not only the biodiversity of the flora but also the fauna of the affected area. Competition, hybridization, disease transmission, poisoning/toxicity are some of the ecological impacts of

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invasion (Langmaier and Lapin, 2020). A key component of biological invasions are human activities that modulate the introduction and spread of alien species, and a large number of human activities supporting the spread of alien plant species have been identified (Richardson et al., 2000; Richardson et al., 2007).

Identifying new invasive plant populations through early detection and rapid response (Westbrooks, 2004) can be effective for preventing a widespread invasion. So, it is essential to document invasive species in a particular area. Poovar is a tourist place in the Thiruvananthapuarm district of Kerala. A Part of Neyyar river pass through Poovar. The plant communities along the Neyyar river on poovar give special attraction to the place. A comprehensive study to document invasive plants in this area is highly needed to evaluate the conservation status and future threats. It is important to prevent uncontrolled growth of invasive plants in this area for the conservation of biological diversity and development of ecotourism.

Materials and methods

The present study was under taken to document the invasive plants from the Poovar region of Neyyar river. For the collection of specimens field work were conducted. The field data concerning habit, habitat, color, and morphology, of the collected specimens, were noted in the field book. Photographs were taken at the time of collection to observe habits and localities.

The specimens were provisionally identified by using pertinent literature and some specimens are cross-compared with authentic herbarium specimens of the Jawaharlal Nehru Tropical Botanical Garden and the identification is authenticated by experts. Herbaria prepared during the present work are deposited at the Herbarium of our Department (KUBH).Pertinent literatures are used for the better identification of invasive species.

The area of study

Neyyar river

Kerala is the land of rivers. Rivers play an important role in human progress by providing drinking water, making the earth fertile, and serving as a medium for transport. The benefits provided by rivers are utilized by humans while not knowing the functions and vitality of the river (Naiman, 1992). The Neyyar River is one of the 44 west-flowing streams of Kerala. It flows from the Agastya Mala (also known as Agastyarkoodam) hills which are situated on the border of Tamil Nadu and Kerala. It has a total length of 56 km. Neyyar pass through Kallikkadu, Ottasekharamangalam, Aryancode, Kezaroor, Marayamuttom, Neyyattinkara, and Poovar and finally ends at the Arabian Sea near to Poovar. It has numerous small canals along the river and "Neyyar Dam" is an irrigation project, situated in this river.

The river basin lies between 8° 17′2″ N to 8° 53′2″ N latitude and 76° 40′2″ E to 70° 17′2″ E longitude. The total drainage area of the sub-watershed is 497 km^2. The Neyyar River basin is spread over 18 panchayats of the Thiruvananthapuram district. It originates from the

Agasthyamala at an elevation of about 1860 m above mean sea level (MSL). It then flows quickly following the steep land and reaches the flat plains. The general elevation ranges from 1500 m in the upper region, 200 m in the middle region, and therefore less than 2 m in the lower region. The broad landforms contain medium hills and isolated hill rocks in the upper region, lateritic mounds, and uplands at the lower region of the watershed. The mean summer temperature is around 35 ° Cand the winter being around 16° C. The average rainfall from the Southwest monsoon between May and July and the Northeast monsoon between October and November. Annual rainfall in the basin is from 1400 (plains) to 2400 mm (hills). Rainfall is fairly spread over the entire year.

Poovar

Poovar is a tourist place in the Thiruvananthapuram district of Kerala. Poovar is almost at the southern tip of Thiruvananthapuram while the next village, Pozhiyoor, marks the end of Kerala. This village beach attracts tourists throughout the year. Neyyar flows into the sea near Poovar. Unlike other parts of Kerala, there are no coastal canals for navigation from Poovar northwards due to the low hills near the coast. It is the miniature version of Kuttanad with the Neyyar river, Arabian sea, and the mesh of canals interlinked. The canals are flanked by dense mangroves hosting numerous bird species. The Poovar beach separates the river Neyyar from the sea. The Neyyar river is connected southwards along the coast after the estuary.

Poovar has a climate that borders between tropical savanna climate and tropical monsoon climate. Thiruvananthapuram district experiences a tropical monsoon climate. The annual variation of mean air temperature at Poovar is from 21 ° C to 34°C. The humidity rises about 90% during the monsoon season. The average annual rainfall of Thiruvananthapuram is 2035mm. Significantly, the place gets benefits of both monsoon – southwest monsoon and northeast monsoon.

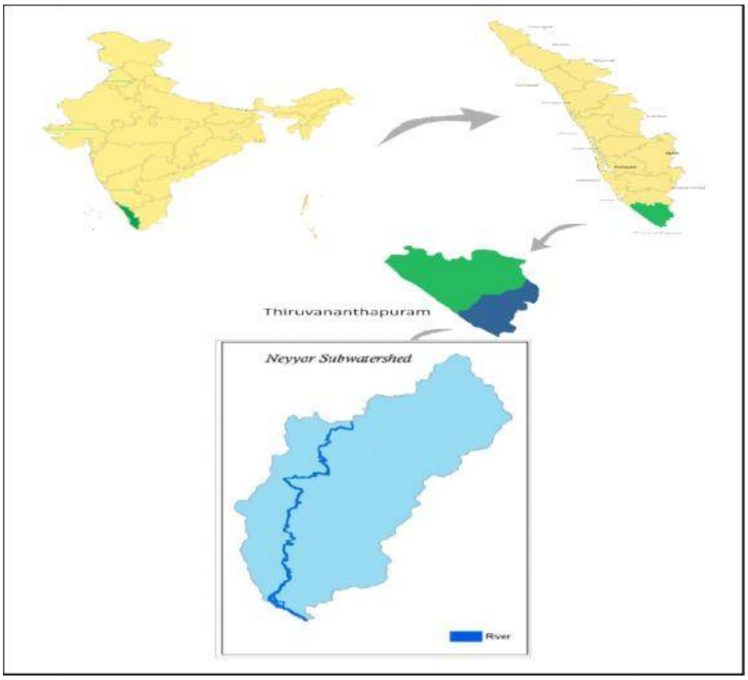

Fig.1. Map showing the study area

Results

The floristic analysis resulted in the documentation of 41 invasive species belonging to 34 genera of 20 families. Families, genera and species have been arranged alphabetically (Table 1).

Table 1: Invasive species documented

Family	**Species**
Angiosperms	
Acanthaceae	*Ruellia tuberosa* L.
Amaranthaceae	1.*Alternanthera philoxeroides* (Mart.) Griseb. 2. *Alternanthera tenella* Colla. 3. *Alternanthera bettzickiana* (Regel) G. Nicholson
Araceae	*Pistia stratiotes* L. *Syngonium podophyllum* Schott.
Asteraceae	*Chromolaena odorata* (L.) R.M.King & H.Rob. *Eclipta prostrata* (L.) L. *Sphagneticola trilobata* (L.) Pruski *Synedrella nodiflora* (L.) Gaertn. *Tridax procumbens* L.
Ceratophyllaceae	*Ceratophyllum demersum* L.
Convolvulaceae	*Ipomoea carnea fistulosa* (Mart. ex Choisy) D.F.Austin *Ipomoea obscura* (L.) Ker Gawler
Cyperaceae	*Cyperus digitatus* Roxb. *Cyperus javanicus*Houtt. *Rhynchospora corymbosa*(L.) Britton
Euphorbiaceae	*Euphorbia hirta* L *Euphorbia heterophylla* L.
Fabaceae Subfamily:Caesalpiniaceae	*Senna tora* (L.)Roxb.
Fabaceae Subfamily: Mimosaceae	*Acacia auriculiformis* Benth. *Mimosa pudica* L. *Mimosa diplotricha* Sauvalle. *Leucaena leucocephala* (Lam.) de Wit
Fabaceae Subfamily: Papilionaceae	*Centrosema pubescens* Benth.
Hydrocharitaceae	*Hydrilla verticillata* (L.f.) Royle
Lamiaceae	*Hyptis capitata* Jacq. *Hyptis suaveolens* (L.) Poit.
Malvaceae	*Sida acuta* Burm. f. *Triumfetta rhomboidea* Jacq. *Urena lobata* L.
Nymphaeaceae	*Cabomba aquatica* Aubl.
Poaceae	*Saccharum spontaneum* L

Polygonaceae	*Antigonon leptopus* Hook. &Arn.
Pontederiaceae	1.*Eichhornia crassipes (*Mart.*)* Solms. 2.*Monochoria vaginalis (*Burm.f.*)* C.Presl.
Solanaceae	1.*Datura metel* L. 2.*Solanum torvum* Sw.
Sterculiaceae	*Melochia corchorifolia* L.
Verbenaceae	*Lantana camara* L**.**
Pteridophytes	
Salviniaceae	*Salvinia molesta* Mitch.

Floristic Analysis

- Poovar region of Neyyar river has 41 invasive species belonging to 34 genera of 20 families, of which 40 species are angiosperms and one is pteridophytes.
- There are 6 aquatic invasive species reported from the study area which includes *Eichhornia crassipes (*Mart.*)* Solms, *Cabomba aquatica* Aubl, *Ceratophyllum demersum* L, *Hydrilla verticillata* (L.f.) Royle, *Pistia stratiotes* L and *Salvinia molesta* Mitch.
- *Alternanthera philoxeroides* (Mart.) Griseb, *Chromolaena odorata* (L.) R.M.King & H.Rob, *Sphagneticola trilobata* (L.) Pruski, *Ceratophyllum demersum* L, *Hydrilla verticillata* (L.f.) Royle, *Ipomoea carnea fistulosa* (Mart. ex Choisy) D.F.Austin, *Acacia auriculiformis* Benth, *Mimosa pudica* L, *Cabomba aquatica* Aubl, *Eichhornia crassipes (*Mart.*)* Solms, *Monochoria vaginalis (*Burm.f.*)* C.Presl, *Salvinia molesta* Mitch and *Lantana camara* L are very noxious to study area.

Discussion

The present study aimed to understand the invasive flora of this area and conservation of biodiversity.41 invasive species are recorded from this area. These species have different types of adverse effect on native species and biodiversity. *Alternanthera philoxeroides* (Mart.) Griseb has the capacity to displace native vegetation and easily become the dominant species and it can produce dense growths in shallows and shorelines, and dense floating masses in shallow water. These floating mats reduce the penetration of light and circulation, increasing accumulations of debris and sediment, promoting anoxic conditions (Sankaran et al., 2013).*Chromolaena odorata* (L.) R.M.King & H.Rob is another species which may become the dominant species (Sankaran et al., 2013) The aquatic invasive species act as barriers to water transport. *Lantana camara* L, *Sphagneticola trilobata* (L.) Pruski, *Ceratophyllum demersum* L. has allelopathic effects on other plants. *Salvinia molesta* Mitch produces mats on water bodies it reduces the amount of light and oxygen penetrating the water surface, preventing submerged aquatic plants from photosynthesizing efficiently (Sankaran et al., 2013). So it is important to prevent the uncontrolled growth of invasive plants in this area for the conservation of biological diversity. In addition to prevention (including preclearance, exclusion, and detection of infestations), containment, eradication, and biological control are all important and necessary strategies (Westbrooks and Eplee 1996) for the growth control of invasive plants.

Conclusion

The present study for the documentation of invasive plants in the poovar region of Neyyar river have never been attempted by any other so it provides an information on the invasive plants present in that area. These invasive plants adversely affect the native species and biodiversity of that area. Some of them are very noxious to study area. Sometimes aquatic invasive species act as barriers to water transport. So preventive measures should be taken to restrict further spread of these plants for the conservation of biological diversity and development of ecotourism.

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POPULATION CHARACTERISTIC OF ANALIEN FISH RED BELLIED PACU (*PIARACTUS BRACHYPOMUS*) (CHARACIFORMES; SERRASALMIDAE) FROM CHALAKUDY RIVER, WESTERN GHATS, INDIA

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Abstract

The massive flood event in August 2018 in the state of Kerala, India, due to extreme climatic events resulted in the release of many exotic fish species in to natural waters from aquaculture ponds and ornamental fish farms located along the river flood plains. Red bellied pacu, *Piaractus brachypomus*, native to North America has been illegally introduced into India for promoting ornamental fish trade and aquaculture. The fishes escaped into the Chalakudy river from the aquaculture ponds during the massive floods. This study was carried out to determine the growth and mortality of an alien red bellied pacu right after its establishment in the river system. Samples of *P. brachypomus* were collected monthly from various fish landing centres of Chalakudy River, Western Ghats-a hotspot for endemic aquatic biodiversity during 2018-2019. A total of 352 specimens in the length range of 104-386 mm were measured. The growth parameter; asymptotic length (L_∞) and growth coefficient (K) were estimated as 394.8 mm and 0.46 yr^{-1} respectively. Growth curve showed that the population of the species comprised a single cohort originated during July to August. Total mortality(Z), natural mortality (M) and fishing (F) mortality coefficients were 1.08 yr^{-1}, 0.50 $yr^{-1}$and 0.54 yr^{-1} respectively based on length converted catch curve analysis. The size at first capture was estimated as L_c = 115.87 mm. The annual exploitation rate (E) was estimated as 0.50. The recruitment pattern of *P. brachypomus* revealed only one peak of recruitment from October to February. Further studies on reproductive biology, ecology and invasion biology of *P. brachypomus* will help to develop proper management strategies for species.

Keywords: Chalakudy river, Alien species, growth rate, threats

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Introduction

Climate change and invasive species are the two important threats to global freshwater biodiversity, capable of significantly affecting ecosystems and their species (Bijukumar et al., 2019; Barbarossa et al., 2021). Freshwater species are especially vulnerable to climate change given their limited ability to disperse, in the wake of changing climatic conditions. Floods have impacts on freshwater biodiversity through the displacement or mortality of species and changes to either the shape and/or form of the river (Death et al., 2015). Catastrophic floods can seriously damage in-stream and riparian habitats and their resident fish populations especially in mountain streams (George et al., 2015).Altered flow regimeas a result of climate change is one of the major pathways by which alien species are introduced into new aquatic ecosystem. The state of Kerala was impacted by acatastrophic flood in August 2018, considered to be the worst in 100 years resulting in 498 human deaths, displacement of millions, altering the morphology and flow patterns of many rivers. The massive flood event resulted in the release of many alien fish species in to natural waters from aquaculture ponds and ornamental fish farms along the river flood plains.

Piaractus brachypomus (Cuvier, 1818) or Red bellied pacu, native to the Amazon River basin; Bolivia, Brazil, Colombia, Ecuador, and Peru (Escobar et al., 2019), has been illegally introduced into India for aquaculture and ornamental fish trade and has been reported from various natural water bodies (Chatterjee and Mazumdar 2009; Singh et al., 2010; Singh and Lakra 2011; Roshni et al., 2014; Laxmappa, 2016;Dharan and Sherly2017; Singh, 2018; Raj et al., 2021).Red bellied pacu was introduced in to 9 river systems of Kerala after 2018 floods (Raj et al., 2021) and also introduced in to Chalakudy river from the aquaculture ponds during the massive floods. Management riverine fisheries where there is Red bellied pacu infestation therefore requires reducing population sizes of this species. As it is difficult, if not impossible, to eradicate these invasive species, one of the feasible alternatives is to increase their market value. However, no studies have been hitherto reported on any aspect of biology and population dynamics of alien *Piaractus brachypomus* species in Indian waters. This study was carried out to determine the growth and mortality of an alien red bellied pacu right after its establishment in the river system.

Materials and Methods

Study area

The Chalakudy River (10°10′–10°33′N, 76°17′–77°4′E) is the fifth-longest among the 44 perennial rivers of state of Kerala, India that originates from the Anamalai Hills of the Western Ghats biodiversity hotspot and empties in the Arabian Sea (Myers et al., 2000). The river harbours a rich and diverse fish fauna of 98 species, and many of them are endemic (36%) and threatened (33%) (Raghavan et al., 2008).

Data collection and analysis

Monthly samples were collected during August 2018 to July 2019with the help of small-scale artisanal fishermen from Chalakudy river, Kerala, India. The fishing method employed in this area by local fishermen mainly include gill nets of variable mesh size (20–60 mm mesh size). Specimens were collected (n=352) and brought to the laboratory in ice filled boxes. Standard lengths ($L_{T,}$ to the nearest mm) were measured for each specimen to the nearest 0.01 mm using a digital vernier caliper and body weight (M_B, to the nearest g) was determined to the closet 0.01 g using digital weighting balance.

Growth, mortality parameters and exploitation level were then estimated from the length-frequency data using the Electronic Length Frequency Analysis I (ELEFAN I) incorporated in the FAO-ICLARM Stock Assessment Tools II (FiSAT II) software (Gayanilo et al.,2005). As there was no strong influence of season in the study sites, the von Bertalanffy Growth Formula (VBGF),$Lt = L\infty\ [1- e^{-KD\ (t-t_0)}]^{1/D}$where, $L\infty$ is the asymptotic length, K is the growth constant, t is the time, Lt is the length at time t, t_0 is the hypothetical time when the length is zero and D is the positive constant was used (Pauly 1984).

Based on the L_∞ and K values, growth performance index (¤) and potential longevity ($3/K$) were estimated (Pauly and Munro., 1984). Total mortality (Z) was estimated using length-converted catch curve (Pauly 1984) and natural mortality (M) was determined by Pauly’s empirical formula (Pauly 1980), In (M) = -0.0152-0.279 In (L_∞) + 0.6543 In (K)+0.4634 In (T), where T is the annual mean temperature of the water in which the fish occurs (28°C for the study area). Fishing mortality (F) was computed as $F=Z–M$ and the exploitation rate (E) as $E=F/Z$ (Gulland 1970). The E_{max} (maximum yield per recruit) and E_{50} (exploitation that retains 50% of the biomass) were predicted using relative yield per recruit (Y/R) and relative biomass per recruit (B/R) analysis using knife-edge selection method (Pauly 1984). Alength-converted catch curve was used to determine the length at first capture (Lc). Growth parameters were used to determine the reproductive pulses per year, and the relative strength of each pulse using recruitment analysis (Moreau and Cuende 1991). Growth and mortality parameters were used to perform virtual population analysis (VPA) (Hilborn and Walters1992). Fishing mortality was considered as the terminal fishing mortality Ft. To understand how the population in different size classes might be affected by an increase in the fishing mortality, VPA was performed with different values of Ft. To develop an effective eradication plan for the local *P. brachypomus* population, the threshold value of E_{max} above which the population would be overexploited in Y/R analysis was plotted against L_c.

Results and Discussion

The Pirapitinga or red-bellied pacu, *Piaractus brachypomus* is a neotropical fish distributed in the Amazon River basin (De Silva et al., 2009) and introduced to India for aquaculture possibly in 2004 from Bangladesh (Singh and Lakra 2011). After theunprecedented and catastrophic floods in August 2018 in Kerala, this species has reached in Chalakudy river from aquaculture farms in large numbers. This study provided the first evidence of population dynamics of exotic *P. brachypomus* from natural waters.

Table 1. Growth and mortality parameters of *Piaractus brachypomus* from Chalakudy River

Population parameter	Value
Asymptotic length ($L\infty$, cm)	39.48

Growth coefficient (*K*; y–1)	0.460
Growth performance index (¤)	4.25
Longevity (3K–1)	6.52
Instantaneous total mortality rate (Z; y^{-1})	1.08
Instantaneous natural mortality rate (M; y^{-1})	0.54
Instantaneous fishing mortality rate (F; y^{-1})	0.54
Length at first capture (Lc; cm)	11.59
Exploitation (E)	0.50
E_{50}	0.318
E_{max}	0.515

There is no targeted exploitation of the species; however, inthe experimental fishing, we obtained a total of 352 specimens within year, ranging from 10.4 to 38.6 cm L_s and 88 to 1860 g. The VBGF fitted to the length frequency data (Fig 1) estimated the asymptotic length L_∞at 39.49 cm and a growth coefficient K of 0.46 $year^{-1}$. Among the morphologically congener, the estimated growth parameters for the native yellow piranha, *Serrasalmus spilopleura* from Amazon floodplains were L_∞=23.10 cm and *K* =0.34 $year^{-1}$, and for Red-bellied Piranha *Pygocentrus nattereri* in Negro River, Brazil were L_∞=31.8 cm and *K* =0.45 $year^{-1}$ (de Sousa et al., 2013; Vicentin et al., 2013). Comparison of growth coefficients indicates that *P. brachypomus* from Chalakudy river grows rapidly to its asymptotic length compared to population in Amazon and Brazil.The estimated growth performance index (¤) was 4.25 (Table 1) is also higher than that of *Serrasalmus marginatus* in Brazil (2.75) (Vicentin et al., 2018). However, the estimated longevity 6.52 year for the Chalakudy river population is comparable to *Pygocentrus nattereri* in Negro River, Brazil (6.9 years)(Vicentin et al., 2013).Growth curve showed that the population of *P. brachypomus* comprised a single cohort originated during July to August (Fig 1). Total mortality(*Z*), natural mortality (*M*) and fishing (*F*) mortality coefficients of *P. brachypomus* were 1.08 yr^{-1}, 0.50 yr^{-1} and 0.54 yr^{-1} respectively based on length converted catch curve analysis (Fig. 2). The natural mortality rate of 0.50 $yr^{-1}$is lower than the native population in Brazil (1.05yr^{-1}) (Vicentin et al., 2013), suggesting that *P. brachypomus* has no natural predators in its invasive habitat in the Western Ghats of Kerala. The low fishing mortality and exploitation rate (Table 1) which is much below the optimal exploitation rate (E_{max}=0.515) indicate minimal fishing pressure favouring population expansion.

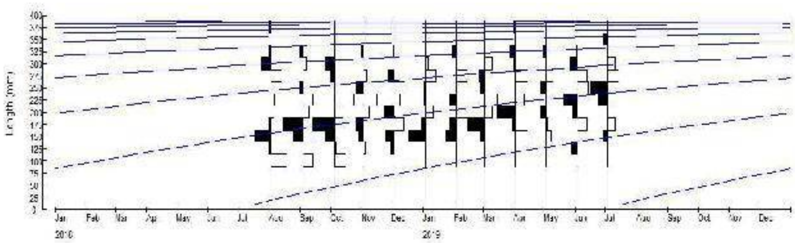

Fig 1. von Bertalanffy growth curve drawn on restructured length-frequency sample for *Piaractus brachypomus*

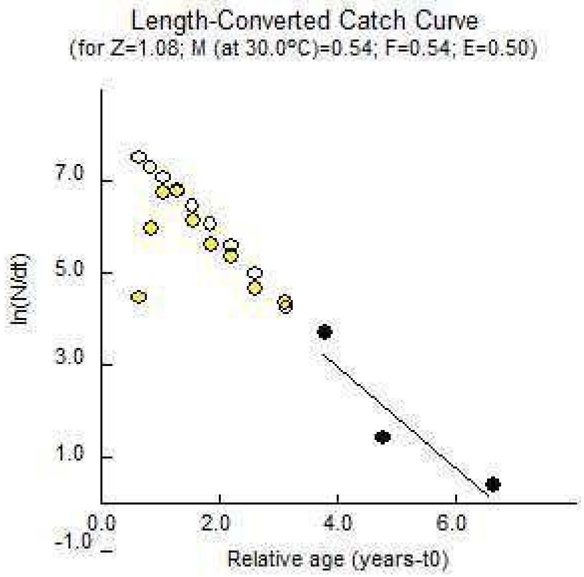

Fig 2. Length-converted catch curve of *Piaractus brachypomus*

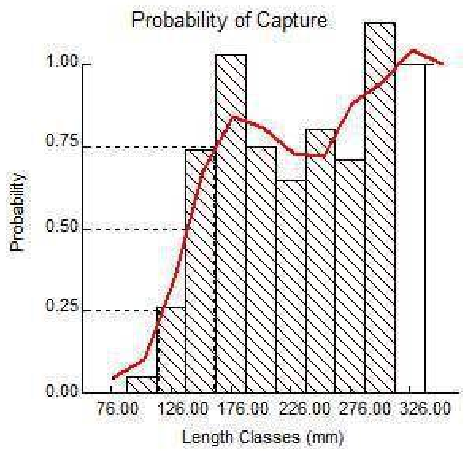

Fig 3. Length at first capture of *Piaractus brachypomus*

The size at first capture for *P. brachypomus* was estimated as L_c = 11.59cm (Fig 3),ie. 29.35% of the asymptotic length. Reducing this value to below 10 cm will no doubt to the best management strategy for eradication, if they will attain maturing population. Virtual population analysis (VPA) suggests that higher survival rate of the species (Fig 4) due to low natural mortality and fishing pressure. Our analysis suggests that using experimental fishing regime will not result in eradication of the local *P. brachypomus* population. Exploitation levels estimated using relative yield per recruit (*Y'/R*) and relative biomass per recruit (*B'/R*) analysis using knife-edge selection were found to be 0.318(E_{50}) and 0.515 (E_{max}) respectively (Fig 5). Recruitment analysis suggested that only one peak of recruitment from October to February (Fig 6). The present recruitment varied from 0.00% to 16.73%.

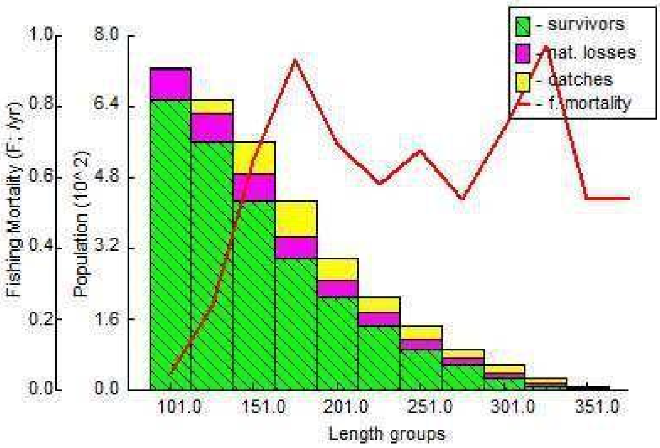

Fig 4. Length based virtual population analysis of *Piaractus brachypomus*

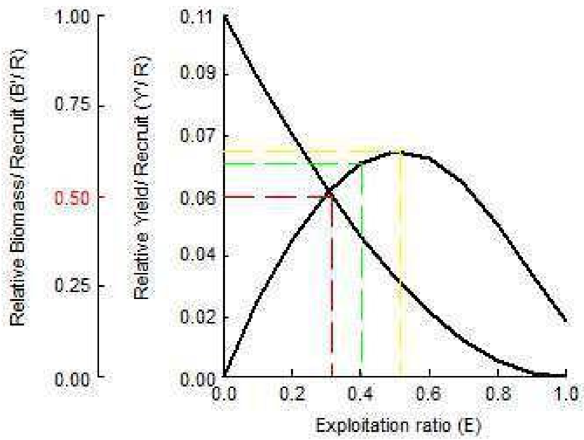

Fig 5.Relative yield-per-recruit (Y/R′) and relative biomass-per-recruit (B′/R) curves of *Piaractus brachypomus*, as estimated by FiSAT software using a knife-edge selection procedure

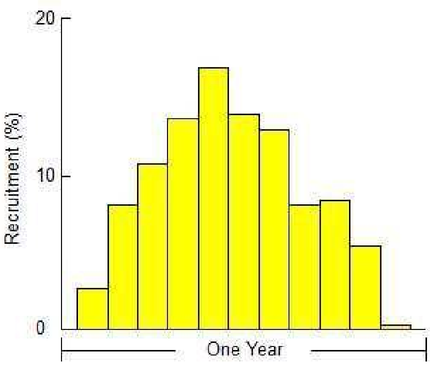

Fig 6. Recruitment pattern of *Piaractus brachypomus*

Conclusion

P. brachypomus is highly capable of thriving in various aquatic environments. Rapid growth and high growth performance index significantly contribute to the invasion of this species. Low natural mortality and absence of commercial fishing pressure suggest that curbing the populations of *P. brachypomus* will be a challenge. Further studies to understand the reproductive biology and ecology, and its links to the demographics of *P. brachypomus* will help inform improved management measures for this invasive species.

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ARCUATULA SENHOUSIA (BENSON, 1842), AN INVASIVE BIVALVE SPECIES IN THE COCHIN BACKWATERS AND ITS PROBABLE IMPACT ON ECOSYSTEM

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Abstract

Arcuatula senhousia (Benson,1842) is an invasive mussel found in Cochin Backwaters. Earlier the species is known by the name, *Musculista senhousia* (Benson, 1842) but according to WoRMS (World Registry of Marine Species) this species is now renamed as *Arcuatula senhousia. A. senhousia*, native to the West Pacific Ocean, was first studied in Cochin backwater in 1991. The species was found in abundance in Cochin backwaters, covering the bottom mainly from intertidal to subtidal habitats having a depth of about 2m. It is small and short-lived mussel with a maximum length of 2.5 cm and has fast growth. The mussel lives in high densities, build nests using byssus threads and sediment, thus create a byssal mat. The presence of these mats dramatically alters the nature of the benthic habitat, changing the local physical environment and thereby preventing the growth of other resident benthic organisms. The paper describes the species, *A. senhousia*, its occurrence and probable impact on the ecosystem. High population density of this species demand further studies on probable impact of this invasive species in the ecosystem.

Keywords: *Arcuatula senhousia*, invasive, bivalve, mussel, Cochin backwater

Introduction

Arcuatula senhousia (Benson, 1842), commonly known as the Asian mussel, Asian date mussel or Bag mussel belongs to the bivalve family Mytilidae of the phylum Mollusca. This small mussel, having a length of about 2.5 cm, is native to the West Pacific Ocean (ranging from Siberia to Singapore) (Carpenter and Niem, 1998). It has also been accidentally introduced and become an invasive species in numerous other areas worldwide. *A. senhousia* shows several characteristics typical of invasive species, such as high fecundity and rapid growth, a fairly long planktonic larval stage, rapid maturity, a short lifespan, and external fertilisation (Kovalev *et al*., 2017; Faasse, 2018).

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A. senhousia has successfully colonised in various areas of the world, including the Pacific coast of North America, Australia, New Zealand, the Mediterranean Sea, the French Atlantic coast, the English Channel, West Africa, the Sea of Azov, the Black Sea, and Western Mediterranean (Bachelet *et al*., 2009; Chartosia *et al.*, 2018; Watson *et al*., 2021; Zhulidov *et al*., 2021; Hamza *et al*., 2022). The invasion history of *A senhousia* is available in literature. The impact of *A. senhousia* on ecosystem services and biodiversity varies depending on location (Katsanevakis *et al.,* 2014). In its native range in Japan and China, *A. senhousia* can grow on cultivated clams. In its introduced range, *A. senhousia* can significantly impact native macrophyte and benthic invertebrate communities (Crooks and Khim,1999; Allen and Williams, 2003).

The present paper describes the species, *A. senhousia*, its occurrence and probable impact on the ecosystem. The mussel, *A. senhousia* lives on soft, muddy bottoms and in sheltered areas such as bays, coastal lagoons and estuaries, from the intertidal zone down to a depth of 20 m. This sessile, filter-feeding, benthic organism uses byssal threads to attach to substrate in soft-bottom sediments.

Materials and Methods

Extensive beds of the mussel are located at the north of the Wellington Island close to the vicinity of bar mouth. The mussels and sediment samples were collected using two jaw van Veen grab during pre-monsoon and monsoon months. Standard method for the estimation of salinity was followed. The sediment samples were analysed by pipette analysis (Krumbein and Pettijohn, 1938). The species characteristics, its occurrence and distribution pattern of the mussel are described based on the observation during the study.

Results and Discussion

Description of the species

Synonym of the species

Brachidontes (Arcuatula) senhousia, Kira, 1959
Brachidontes (Musculista) senhousia, Kira, 1962
Brachidontes aquarius, Grabau and King, 1928
Modiola bellardiana, Tapparone-Canefri, 1874
Modiola senhausii Reeve, 1857
Modiola senhousia, Benson in Cantor, 1842
Modiolus senhousei, Hanna, 1966
Musculista senhausia, Morton, 1974
Musculus (Musculista) senhousia, Yammamoto & Habe, 1958
Volsella senhausi, Smith, 1944
Modiola arcuatula, Hanley, 1844

Diagnostic Features

Specimens collected from the Cochin backwaters exhibited the typical characteristics of *A.*

senhousia: two oval yellow-green or greenish-brown valves, a smooth thin shell, and a smooth, shiny periostracum, which has radial lines extending towards the edges, and concentric, dark -brown wavy or zigzag lines that were sometimes visible inside (Figure 1).

The mussel is characterised by elongate and oblong shell with sub-terminal umbos. Umbos conspicuous, edentulous, located somewhat close to the anterior end; anterior margin markedly extending beyond the umbos. Anterior end bluntly rounded; dorsal ligamental margin almost straight; posterior margin arcuate and ventral margin slightly concave (Figure 1 & 2) (Kuriakose, 1973; Sreedhar, 1991).

Fig 1. *A. senhousia*

Lunule well developed with radial striae which makes the margin crenulated. Teeth like crenulations present on the dorsal shell margin behind the ligament. Interior of the shell valves white or purplish-white, iridescence, limited to the area of muscle scars. Anterior adductor long, thin, and arcuate; anterior byssal retractors nearly circular. Posterior adductor slightly oval-shaped. Posterior byssal-pedal retractors partially or entirely split into two main bundles and inserted to the dorsal shell margin along with the posterior adductor. Pedal retractor is well developed. Foot digitiform, highly extensible and byssal apparatus located close to the base of foot. Byssus threads many, long, very thin and silky in nature (Figure 2) (Kuriakose, 1973; Sreedhar, 1991).

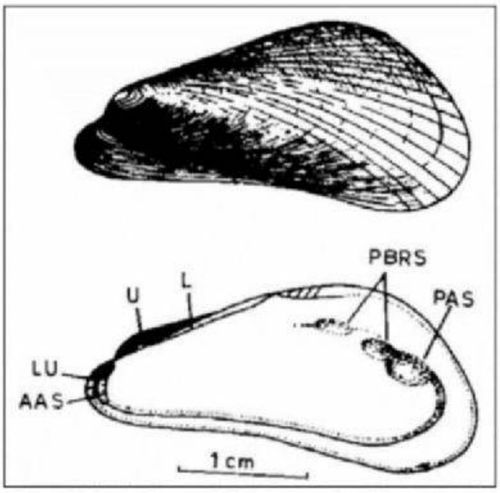

Fig 2. External and internal view of the shell of *A. senhousia* showing the muscle impressions – AAS & PAS (Anterior Adductor Scar and Posterior Adductor Scar), PBRS (Posterior Byssal Retractor Scar), Lu (Lunule),
U (Umbo), and L (Ligament).

Occurrence and Distribution of *A. senhousia* in Cochin backwater

A. senhousia is found in abundance in Cochin backwaters, covering the bottom, attached by byssus threads. The animals burrow into the mud exposing only the posterior siphonal area outside Temperature, salinity and the nature of the bottom deposit are the significant factors that may affect the distribution of bottom fauna (Jones, 1950). Distribution of the mussel, *A. senhousia* is controlled mainly by the salinity change of the medium. During pre-monsoon months thick beds of the mussel were seen in the bottom sediments. Mussel was seen invading to the inner part of the estuary with the increase in salinity and found aggregated in different regions of the backwater. A marked difference in salinity values between pre-monsoon and monsoon periods was observed. The river discharge during the period of southwest monsoon results in drastic decrease in the salinity. During the peak period of the southwest monsoon, it is almost close to freshwater condition. During this period remarkable change in the distribution of *A. senhousia* could be encountered. The population was totally absent in the study area (Sreedhar, 1991). Desai and Kutty (1967) observed that the salinity of the water governs the abundance of bottom fauna of the Cochin backwater.

Those animals which are acclimated to changing salinities through several years of physiological adjustments survive wide fluctuations in salinity, while less tolerant forms are completely eliminated or they migrate to the adjacent suitable area and the area left bare by the organisms is subsequently recolonised by the larvae of these organisms brought in by tidal currents when optimum condition is re-established (Batcha, 1984). Madhupratap (1978) found higher numerical counts and biomass of zooplankton in Cochin backwaters during high saline premonsoon period and a decrease with the onset of monsoon. Ajithakumar (1984) found difference in the distribution of *Perna indica* and *Perna viridis* according to salinity fluctuation.

Nature of the substratum also controls the distribution of the species. The most suitable substratum for the vigorous growth of the species was found to be a mixture of sand, silt and clay. During late monsoon periods when the sediment appears to contain more sand and less silt, no mussel could be observed. Silty sand and thick clay are also found to be not suitable for the existence of the species (Sreedhar and Radhakrishnan, 1994; Sreedhar and Radhakrishnan,2009). Vizakat *et a1.* (1991) also obtained similar results in the study on the distribution of benthic community in the subtidal region of Konkan coast.

The mussel, *A. senhousia,* is fished in large quantities from different parts of the backwater and extensively used as poultry feed and manure. Though *A.senhousia* enjoys wide distribution in the backwaters of Kerala, it is quite surprising to note that, it is not considered as a food mussel, and hence not ranked in the fishery list. Several hundred kilograms of this species are fished from backwaters and merely used as poultry feed (Sreedhar, 1991).

Probable impact on this ecosystem

A. senhousia is a species with high fecundity, rapid growth, a short life span and good dispersal ability, making it a successful invader. It lives endobenthically just below the sediment

surface, filters phytoplankton from the water column with a short siphon (Morton, 1974; Allen and Williams, 2003).

The mussel, *A. senhousia* like benthic ecosystem engineers inhabiting coastal sediments can cause a multitude of biogenic habitat transformations. The mussel lives entirely within the sediments, surrounded by a bag of byssal threads. In high densities individual byssal bags coalesce to form a continuous mat or carpet on the sediment surface. The presence of these mats dramatically alters the natural benthic habitat, changing both the local physical environment and the resident macroinvertebrate assemblage. The species create a new habitat which can be colonized by some organisms, but can have negative impacts on other native species. *A. senhousia* can dominate the benthic communities and potentially exclude native species. Thus it results in the decline, and sometimes disappearance of some suspension feeding bivalves and polychaetes. The mussel mats serve as biogenic habitat for a variety of small macrofauna, whose abundances within this structurally complex area are higher than in sediments without mats (Crooks 1998, Crooks and Khim 1999). The mats protect the mussel from predation, and also concentrate organic matter favouring some deposit feeders. Crooks and Khim (1999) found that the effects of *A. senhousia* appear to be scale dependent. At larger scales, surface-dwelling, suspension-feeding clams are competitively inhibited. At smaller scales, however, the mussel benefits a variety of biota.

Negative impacts may also include the alteration of sediment structure and texture, interfering with burrowing. *A. senhousia* deposits large amounts of organic matter in the sediment (Takenaka, et al., 2018). Result is the accumulation of toxic metabolites such as sulphide, which can have adverse effects on other benthic fauna**.**

A hazard ranking of potential domestic target species based on invasion potential from infected to uninfected bioregions identifies *A. senhousia* as a medium priority species - these species have a reasonably high impact or invasion potential. This may locally prevent the mussel from establishing dense, habitat-modifying beds with potential effects on native species**.** (Reusch, 1998). Non-native species are increasing in abundance throughout the world, and biological invasions now represent one of the most serious threats to the integrity of ecosystems (Vitousek *et al*. 1997, Mooney and Hobbs 2000).

Conclusion

The impacts of most non-native species are poorly understood. The International Union for the Conservation of Nature (lUCN) reported that 625 (51%) of known endangered species are threatened because of invasive (alien) species (Pastoret and Moutou, 2010). Non-native species cause changes in the ecosystems to which they are introduced. They can be manifold and potentially damaging to ecosystems and biodiversity. The implications of changes to biodiversity and ecosystems caused by the non-native species demand further studies to know its impact on the ecosystem.

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DIET CHARACTERISTIC OF AN ALIEN CATFISH, *PANGASIANODON HYPOPHTHALMUS* (SAUVAGE, 1878) FROM PERIYAR RIVER, SOUTHERN INDIA

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Abstract

One of the significant threats to aquatic ecosystems is introducing non-native species in natural environments. *Pangasianodon hypophthalmus,* commonly known as freshwater iridescent shark, native to the Mekong and Chao Phraya River basins in Southeast Asia was introduced to India in 1997. 2018 massive flood in Kerala state have caused introduction of many non-native fish species in to Periyar River of Western Ghats biodiversity hotspot. The present study was carried out to analyse the diet pattern of introduced alien catfish, *Pangasianodon hypophthalmus* in Periyar River. The qualitative analysis of the gut contents showed that the fish is an omnivore with fish remains (33.74%), crustaceans (20.65%), higher plants (19.57%) insects (8.07%), soil particles (5.82%), algae (2.88%), molluscs (1.42%) and others (7.85%) in the diet. These findings show that the introduced *P. hypophthalmus* shared a common feeding characteristic with indigenous catfishes *Horabagrus brachysoma, Heteropneustes fossilis* and *Ompok malabaricus* in Periyar River which may result in an undoubtful dietary partitioning and competition causing potential threats to these native fishes.

Key words: Alien fishes, diet pattern, Periyar River, competition

Introduction

Biological invasions after either intentional or unintentional introduction of exotic fish species is a worldwide ecological problem of growing concern. Human beings have provided a variety of pathways (e.g. unauthorized stocking, water transfer systems, ship ballast water, angling and ornamental fish release) by which exotic fish species can circumvent biogeographic barriers (Rahel, 2007). Among the most dramatic effects of exotic fish species that may lead to the decline of native species are; predation that results in displacement or density reduction of native species populations, competition for food and habitat often

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through aggressive behaviour, hybridization among closely related species that threatens genetic integrity, faunal homogenization when a few cosmopolitan species come to dominate communities at the expense of unique native species, habitat alteration and degradation, pathogen and parasite transmission (Leunda et al., 2008).The state of Kerala was impacted by an unprecedented and catastrophic flood in August 2018, one of the most significant threats to the indigenous freshwater fish diversity of Kerala due to the release of many alien fish species in to natural waters from aquaculture ornamental fish farms. *Pangasianodon hypophthalmus,* commonly known as freshwater iridescent shark, native to the Mekong and Chao Phraya River basins in Southeast Asia was introduced to India in 1997 (Castellanos-Mejíaet al., 2021).

The use of dietary analysis to infer feeding strategies and habits of native and exotic fish species within a food web is an effective tool to study the impact of invasive species and conservation of native populations (Pilger et al., 2010). Stomach content analysis is useful for understanding the functional role of organisms in a food chain and is an important tool for elucidating trophic differences between phylogenetically related fishes (Eloranta et al., 2015). The results of dietary studies can be used to define trophic niches and have become an important predictor of the impacts of invasive alien species (Agostinho et al., 2015).The present study evaluated the dietary preferences of exotic catfish *Pangasianodon hypophthalmus* and three most abundant and aquaculture preferred native catfish fish species (*Horabagrus brachysoma, Heteropneustes fossilis* and *Ompok malabaricus*) in the Periyar River, Kerala, India. Understanding the dietary preferences of these species may help to explain the exotic species impact native species. We used dietary analyses to test our hypothesis, the results of which should provide new insight regarding coexistence of species in the environment and help to develop strategic management plans for the conservation and management of native species in the Periyar River.

Materials and Methods

Study area

The Periyar, the longest and largest among the 44 rivers of Kerala harbours a rich icthyo diversity of 139 species, among them 33 species are under threatened category and 61 species are endemic to Western Ghats (Renjithkumar 2015).

Sample collection

Fish samples (*P. hypophthalmus* =106, *H. brachysoma* =121, *H. fossilis*=68 and *O. malabaricus*=33) were collected from different landing centres from Periyar River for the period October 2018-September 2019. Fish were caught during both day and night, primarily by gill netting (mesh size: 2-6 cm, total length: 75–150 m), and hook and lines. Species were identified using standard literature (Jayaram 1999). The total length (TL, to the nearest 0.1cm) was measured using Vernier Caliper and total weight (to the nearest 0.1g) using a using digital balance. The fishes were then dissected out and gut contents were separated and identified to the lowest possible level using a stereomicroscope.

The percentage of empty gut was calculated using the following the equation: *EG (%)*

$$E \quad = \frac{N_F}{N_T} \times 100$$

Where, N_F is the number of specimens with empty guts and N_T is the total number of specimens examined.

Dietary analysis

Feeding habits of the four species were quantified using three different indices: percent frequency of occurrence *(% O)*, percent number (% *N*) and percent volume (% *V*) (Hynes, 1950; Hyslop, 1980):

Percent frequency of occurrence *(% O)* = number of stomach containing prey *i* /total number of stomachs × 100

Percent number *(% N)* = number of prey *i*/ total number of prey × 100

Percent volume *(% V)* = volume (point) of prey *i*/ total volume (points) of prey items x100

To obtain a better representation of various prey items in the gut, these three indices were then combined with the index of relative importance (IRI) (Pinkaset al.,1971).

IRI_i= (% N_i +% V_i) % $O_{i,}$ where

IRI_i =index of preponderance of the food item *i*;

N_i= percentage of number index of the food item *i*;

V_i= percentage of volume index of the food item *i* and

O_i= percentage of occurrence index of the food item *i*

The dietary overlap between the fishes was estimated following Schoener (1970) index of niche overlap, which is the most commonly used index for trophic niche overlap (Wallace, 1981) given by the formulae: $C_{xy} = 1\text{-}0.5 \sum | p_{xi} - p_{yi} |$), Where,C_{xy} = The degree of diet overlap, p_{xi} = The proportion of ith food item used by species x and p_{yi} = The proportion of ith food item used by species y. Index values range from 0 to 1; were 0 indicate no sharing of prey types and 1 reprents completely identical prey utilizations. Values exceeding 0.6 represent ‘biologically significant’ diet overlap in resource use (Wallace, 1981).

Results and Discussion

In total, 106 guts of *P. hypophthalmus*, 121 of *H. brachysoma*,68 of *H. fossilis* and 33 of *O. malabaricus* were examined and the percentage of empty guts recorded were 13.9%, 10.8 % and 9.9% respectively. All three native species had a greater number of empty guts during the monsoon season which could likely be due to the low feeding activity coinciding with their spawning period (Padmakumar *et al*.,2011; Saika et al., 2022).

The food spectrum of the four species in Periyar River was broad and consisted of 10 items. The qualitative analysis of the gut contents showed that the four catfishes is an omnivore feeder with fish remains, crustaceans, plants particles, insects, soil particles, algae, molluscs, detritus, semi digested matter and miscellaneous items in the diet. *P. hypophthalmus*, *H. brachysoma* and *O. malabaricus* fed predominately on fish remains, plants and crustaceans whereas *H. fossilis* preferred crustaceans and plant particles (Table 1). Percentage occurrence of various prey items in the gut of the four catfishes, which consumed approximately 60 ± 15% of both plant and animal food is suggestive of an omnivorous feeder (Das and Moitra 1956, 1963), while the presence of sand and molluscan components in the gut also suggests a benthic feeding habit. The bentho-omnivorous dietary habit of *H. brachysoma*, *H.fossilis* and *O. malabaricus* has previously been recorded (Sreeraj *et al*., 2006; Kumary and Athira, 2019; Renjithkumar *et al*., 2020).

Diet overlap among fish species or among size classes of a single species help explain community structure or to clarify competitive relationships (Richard and Wallace, 1981). The dietary overlap resulted from fish introductions can impair severe impact on indigenous fishes in their native ranges (Cecilia and Ricardo, 2012). Significant diet overlap existed between the one exotic and three native catfish species, with highest diet overlap index values between *P. hypophthalmus* X *O. malabaricus* (0.90), compared to *P. hypophthalmus* X *H. brachysoma* (0.80), and *P. hypophthalmus* X *H. fossilis* (0.64) (Table 2). Diet-overlap values varied considerably between species but showed no significant seasonal variation ($p < 0.05$). Null models constructed through Monte Carlo simulations revealed significant diet overlap indicating considerable resource partitioning (MC-P<0.05).

Table 1. Index of relative importance of different food items consumed by *P. hypophthalmus*, *H. brachysoma*,*H. fossilis* and *O. malabaricus*

Species	*P. hypophthalmus*	*H. brachysoma*	*H. fossilis*	*O. malabaricus*
Food contents	IRI (%)	IRI (%)	IRI (%)	IRI (%)
Algae	2.88	0	4.75	4.79
Crustaceans	20.65	7.66	40.96	23.16
Detritus	0	1.03	2.44	0
Fish remains	33.74	37.43	14.64	29.9
Plant particles	19.57	35.02	20.96	16.54
Insects	8.07	3.72	5.35	4.32
Molluscs	1.42	1.58	7.01	5.54
Semi digested organic matter	0	11.73	0	0
Soil particles	5.82	1.83	3.89	6.57
Miscellaneous	7.85	0	0	9.17

Table 2. Diet overlaps between index between *P. hypophthalmus, H. brachysoma, H. fossilis* and *O. malabaricus* in Periyar river

Species involved in dietary overlap	**Schoener index value**
P. hypophthalmus X H. brachysoma	0.80
P. hypophthalmus X H. fossilis	0.74
P. hypophthalmus X O. malabaricus	0.90

Conclusion

Our study confirms the hypotheses that not only does interspecific resource sharing between catfish species lead to trophic displacement of less competitive groups, but that it also allows larger-growing species to effectively utilize available food. Though the long-term invasion success of *P. hypophthalmus* and its impact on the populations of *H. brachysoma, H. fossilis* and *O. malabaricus* could not be ascertained, it is more likely that depletion of food resources and changes in microhabitats in the future may turn detrimental to the native species due to its inability in adapting to changing ecological conditions. Comprehensive research on the dynamics of resources and adaptations that both invasive and native species develop during unfavourable environmental conditions will help in better understanding the nature of invasions and development of effective management strategies in Periyar River and in similar ecosystems. Eradication through selective fishing and prohibition of its eventual cultivation directly in rivers must be accompanied by educational programs to help consumers understand the impact non-native species have on aquatic biodiversity, and to encourage fish farmers to use good practices to reduce the impact of their activities on natural aquatic environments.

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ANNONA GLABRA L. INVASION IN MANGROVE RICH WETLANDS - A CASE STUDY FROM KANNUR DISTRICT

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Abstract

Wetlands seem to be vulnerable to invasions. Studies of the characteristics that relate to the invasive potential of species and those that relate to the invasion of the community may provide information that helps to curtail further spread. In Kannur district recently it was found that an invasive species namely *Annona glabra*, commonly called pond apple fastly spread in the mangrove rich wetlands. Through this study an attempt was made to understand its distribution, stress tolerance ability and other adaptive features of *Annona glabra*, that make them a successful invader. It is regarded as the worst weeds in many countries because of its invasiveness, potential for spread, and economic and environmental impacts. For this study frequent field visits were conducted to all the parts of mangrove rich as well as other riverine and coastal wetlands. Samples were collected from different sites and interview was carried out with some stake holders. Microscopic sections of leaf, stem and root was analyzed for studying anatomical features. Stomatal index of leaves from selected sites was determined by taking the epidermal peels of leaves collected from study sites. The striking fact recognized by the socio-economic survey is that most of the local people are not bothered about the weed and they are not giving much importance to *Annona glabra* L. The anatomy of stem showed a wavy outline with thick epidermis and hard periderm with lenticels. Mechanical tissues like sclereids and stone cells was prominent. The physico chemical analysis of soil and water shows their capacity to adapt maximum in high as well as low saline conditions. It is a very troublesome invasive species that grows in swamps and salt tolerant. Once the plant gets invaded it is very difficult to remove. Therefore, it is very essential to control its spread. The effective utilization of this species helps minimize the risk created by this species to the ecological balance.

Key Words – Mangrove, Annona, Invasive

Sreeja, P. 2023. *Annona glabra* invasion in mangrove rich wetlands - a case study from Kannur district. In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp. 471-475.

Introduction

The coastal wetlands of Kerala are characterized by the presence of different species of true mangroves and mangrove associates. In Kerala few decades ago there were about 70000 of mangroves. According to an estimate, Kerala once supported about 700 km^2 of mangroves along its coast. In Kerala only Kannur has good natural patches than that in other districts. However, it has declined to 17 km^2. Wetland habitats are very productive and support a large number of threatened and endangered species, unfortunately, these habitats are being altered and destroyed by invasive species. In Kannur district recently it was found that an invasive species namely *Annona glabra*, commonly called pond apple are fastly spreading in the mangrove rich wetlands. Through this study an attempt was made to understand its distribution, stress tolerance ability and other adaptive features make them a successful invader.

Annona glabra L. commonly known as pond apple, belongs to the family Annonaceae and the genus *Annona,* is a semi-deciduous exotic tee from North, Central and South America which has invaded freshwater swamplands, creek banks, seasonally flooded areas and the upper edges of mangrove swamps along the Queensland coastline (Swarbrick and Sakarratt, 1994). Pond apple is considered a serious threat to Australia and is listed as a Weed of National Significance (WoNS) (J.T.Swarbrick *et al*., (1994). It was also the highest ranked weed species in a Wet Tropics bioregion assessment. Since its introduction into Australia in 1886, it has invaded thousands of hectares of wetlands, riparian ecosystems and manmade landscape structures such as agricultural and domestic drainage systems. A number of control programs now exist throughout northern Queensland. Since its introduction into Australia in 1886, Sugars et al. (2006), pond apple has invaded thousands of hectares of wetlands, riparian ecosystems and man-made landscape structures such as agricultural and domestic drainage systems

The plant is adapted to flooded environments, including brackish- and saltwater, native from tropical America and West This species forms clusters along coastal wetlands and its fruits produce several seeds that germinate better in sunny conditions. *A. glabra* has been reported to have parasiticide and insecticide activity, which supports its use in traditional medicine. Some of its isolated compounds have antimicrobial, antifungal, and anticancer properties.

(a) (b) (c)

(d) (e)

Fig. 1: (a) *A. glabra* open flower (b) *A. glabra* ripened fruit (c) *A. glabra* cut open fruit (d) & (e) *A. glabra* habit showing its adventitious roots

(a) (b)

Fig. 2: (a) multi-stemmed appearance in *A. glabra* tree, (b) spread of *A. glabra* replacing true mangroves in the study area

Materials and methods

The study was carried out in Kannur district of Kerala state for a period of 5 years from 2017 onwards. Frequent field visit to different parts of Kannur district to find out the distribution of *Annona glabra* was done. Samples were collected from different sites and interview was carried out with some stake holders. Morphological characters of the plant were determined. Microscopic sections of leaf, stem and root was analyzed for studying anatomical features. The dependency of animals, birds and humans to *Annona glabra* was also studied. Continuous observation of wetlands and interaction with local people was the effective method in its study.

Results and discussion

From our study, it was found that the plant was distributed mere in the river beds of Payangadi and Kuppam. Less and scattered plants were reported from Perumba, eastern part of Payangadi River, Valapattanam River etc. The wetlands of Kuppam River in Kuttikkol and Vellikeel support rich growth. The density of the plant species was much greater at Kuttikkol. Due to the extension work of NH -66, the data in 2021 -22 showed less distribution in some areas. But the transportation of soil from construction site to new wetlands also resulted in the dispersal of seeds and thereby rapid germination of seeds. Few plants were observed in most of all mangrove rich wetlands of Kannur district. Some of the fresh water crop lands were completely under threat of *Annona glabra*.

The morphological features of stem, leaves, fruit, seeds, roots were studied. The species can grow up to 3m or taller. Stems were softwood with a thin grey bark bearing prominent lenticels (pores). Leaves were alternate with a prominent midrib. The leaves are light or dark green on the upper surface and paler on the underside. It emits a distinct smell when crushed, a distinguishing feature. Flowers were short lived and rarely noticed. It is pale yellow to cream, and consist of three leathery outer petals and three smaller inner petals. The inner base of the flower is bright red in color. This species can produce fruit n the early stages of growth. It contains approximately 200 seeds resembling pumpkin seeds in both appearance and size. The anatomy of stem showed a wavy outline with thick epidermis and hard periderm with lenticels. Mechanical tissues like sclereids and stone cells was prominent. Anatomy of leaf is of typical dicotyledonous pattern with thick epidermis and sunken stomata. Anatomy of root shows epidermis, homogeneous cortex and vascular bundles. The adventitious roots from the base of the stem appear fibrous and are firmly bound to the soil. Usually, it forms a monotypic appearance in habitat by replacing all native and crop plants. They were commonly appearing as multistemmed thickets. The local people near the habitats are unaware about its invasive nature. Some family use this for preparing compost. This plant can be utilized for preparing jams, jellies, squash etc. It can be also applied for paper pulp manufacturing. Urgent measures need to be taken for reducing the seed dispersal. Bats are the main feeders of its fruits. The seeds are found to be poisonous. The study shows rise in the spread of this plant within five years, as they were equally adapted to survive in fresh water and saline water rich wetlands, thereby creating threat to both mangrove as well as non mangrove plants.

Conclusion

Annona glabra, one of the common weed in Australia, is now widespread in mangrove wetlands and crop lands of Kannur district. It establishes along the riverside and invade the crop lands. Some special morphological, anatomical and physiological characters help in its invasion. They form thick vegetation by completely replacing the existing vegetation. A single tree produces several fruits each with about 200 seeds. The seeds germinate in groups and bunch of seedling appears within few days which grow competitively and invade the entire area. Once the plant gets invaded it is very difficult to remove. So, it is very essential to control its spread.

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A PRELIMINARY ANALYSIS ON THE UTILIZATION OF *SALVINIA MOLESTA* AND *EICHHORNIA CRASSIPES* SUPPLEMENTED DIETS IN *GALLUS DOMESTICUS (*LINNAEUS 1758)

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Abstract

Salvinia molesta and *Eichhornia crassipes* are highly invasive aquatic weed plants. However, the former is considered to be a potential plant protein source whereas the latter as a growth promoter, inspite of its serious invasive nature in freshwater ecosystem. The objective of this study was to utilize both the plants at appropriate concentrations in a mixed form with the diet in *Gallus domesticus'*s feeding process. A total of 20 chickens of 28 days of age were observed with initial mean body weight of 115gms for an experimental period of 20 days. The feeding process comprised of 4 dietary treatments T0 (control diet), T1 (diet with 2.5% *Eichhornia crassipes*), T2 (diet with 6% *Salvinia molesta*) and T4 (diet with 2.5% *Eichhornia crassipes* and 6% *Salvinia molesta*) and each treatment was tested on five chicks. The parameters measured were feed intake, body weight gain, feed conversion ratio and final live weight. The data was analyzed by using F-test. The maximum mean body weight gain/bird/day (30.3g) on T3 diet chicks which was statistically significant to birds fed with T0, T1 and T2 diets. Chickens with T2 diet also attained a significantly higher body weight gain (30.25g) to treatments T0 (29.5g) and T1 (27.7g). Better feed conversion ratio was observed with chickens fed with T2 (1.91) and slightly lesser ratios in T0 (2.47), T3 (2.52) and T1 (3.88) which were significant. Maximum mean final live weight (721g) was gained with chickens on T3 diet followed by T2 (720g), T0 (705g) and T1 (668g), the differences were significant. Based on these results, the supplementation of 2.5% of *Eichhornia crassipes* and 6% of *Salvinia molesta* in mixed form or individually in *Gallus domesticus* diet can be further studied and recommended as its effects are similar and positive, compared to control diet which is very promising.

Keywords: *Gallus domesticus*, *Salvinia molesta*, *Eichhornia crassipes,* invasive aquatic weed.[1]

INTRODUCTION

Alien species are non-native or exotic organisms that occur outside their natural adapted ranges and dispersal potential. Several alien species provide significant assistance to our

[1] Lysamma, S. and Zubair, M. 2023. A preliminary analysis on the utilization of *Salvinia molesta* and *Eichhornia crassipes* supplemented diets in *Gallus domesticus (*Linnaeus 1758). In: Biological Invasions: Issues in Biodiversity Conservation and Management. Proceedings of a National Conference, Bioinvasions, Trends, Threats and Management held from 3rd to 4th December, 2022 at Thiruvananthapuram. Kerala State Biodiversity Board, Thiruvananthapuram, pp. 476- 481.

farming and forestry systems. But certain alien species can become invasive when they are mistakenly or knowingly brought outside of their normal habitats and into new places where they have shown the ability to develop, invade and out compete native species. About 40% of the species in the Indian flora are alien, of which 25% are invasive. Due to interactions with other changes including the expansion of global trade, travel and tourism as well as the increasing globalisation of markets, biological invasions now occur on a global scale and will experience a rapid growth in this century. Understanding the ecology, morphology, phenology, reproductive biology, physiology and phytochemistry of invasive species is crucial for their effective control. Many of the invasive species can be used for economic benefits. (Sharma G.P *et al*., 2005)

Utilizing aquatic plants in diet can lower the cost of feed because they are numerous and the least expensive sources of protein for animals. Diet plays a critical role in the health and productivity of poultry. A large variety of food additives in the feed for chickens are used to improve their performance (Elnaggar *et al*.,2021). Chicken meat is a source of protein for humans and increasing demands for meat have contributed to an increase in chicken production (National Bureau of Plant Genetic Resources). The cost of feed, which is high due to the numerous additives in commercial feed, is one issue with the chicken-rearing technique that contributes to the high cost of chicken production. In particular, reducing the cost of feed may increase income and ultimately render the chicken-rearing business profitable. People prefer to consume products of native chicken rather than those of broiler because of its egg and meat's taste are better. In addition to the better taste, egg and meat of a native chicken are believed to contain higher nutritional values, hence the selling price is relatively more compared to that of broiler chicken products. However, native chicken productivity is low dueto the use of a relatively simplistic raising style and genetically low feed utilisation efficiency. Nutritional supplies, especially protein, for poultry, should be adequate and meet requirement level. The adequacy of protein requirement is always connected with dietary metabolizable energy, so called the balance ratio between energy and protein(B. Marifah *et al*., 2013), therefore it is reliable to find an alternative local feedstuff with high enough protein content. The table1 listed below shows the composition of nutrients of commercial feeds for reference.

Table 1: Nutrient composition of commercial poultry feed(Husna *et al*., 2017)

Nutrient	Starter (1-12 days)	Grower (13-23 days)	Finisher (24-up to sell)	Pre Starter (1-16 days)	Starter (18-28 days)	Finisher (29-up to sell)	Starter (1-12 days)	Grower (13-23 days)	Finisher (24-up to sell)
	Provita Feeds Ltd.			Nourish Feeds Ltd.			Newhope Agrotech Bd. Ltd.		
ME (kcal/kg)	3050	3100	3150	2950	3000	3050	3000	3100	3150
Cp%	23	22	21	21	20	19	22	21	20
Ca %	1.1	1.2	1.2	1	0.95	0.90	1.1	1.2	1.2
P %	0.45	0.50	0.50	0.45	0.45	0.42	0.45	0.50	0.50
CF %	3.5	4	4	5	5	4	3.5	4	4
Lysine %	1.25	1.20	1.15	1.15	1.05	1	1.25	1.20	1.15
Methionine %	0.55	0.50	0.50	0.48	0.45	0.42	0.55	0.50	0.50
Vit. & mineral %	Adli.	Adli.	Adli.	Adli.	Adli.	Adli.	Adli.	Adli.	Adli
Humidity %	11	11	11	12	12	12	11	11	11

ME = Metabolizable energy, Cp = Crude protein, Ca = Calcium, P = Phosphorus, CF = Crude fiber, Vit. = Vitamin, Adli. = Adlibitum

Salvinia molesta is a type of free-floating aquatic fern that mostly grows rapidly in marshes, rivers, and also rice field area. *Salvinia* contains 32% crude protein and 42% crude fibre. The high fibre content of certain ingredients is a major factor in their use in conventional feed (Dwiloka *et al*.,2015).

Water hyacinth (*Eichhornia crassipes*) is popular as an ornamental plant. However, it is also considered invasive aquatic weed plant in tropical and subtropical regions, and many attempts have been made to eradicate or control these plants. Its proximate analysis revealed that water hyacinth is constituted of 50% protein and 33% carbohydrates, while the remaining nutrients are made up of fat, ash, and fiber (Adeyemi and Osubor 2016). As a result of its high protein content and enough amounts of xanthophylls, carotenes, unsaturated fats, carbohydrates, and vital minerals including calcium, phosphorus, and iron, Water Hyacinth Leaf Protein Concentration (WHPLC) can be used as a food supplement. (Kateregga and Sterner 2007) and due to this most of the farmers rely on commercial poultry feed and self-mixed feed to feed chicken.

Materials and methods

The study was carried out at the Department of Zoology, University of Calicut, Malappuram district, Kerala.A total of 20 chickens of 28 days of age were observed with initial mean body weight of 115g for an experimental period of 20 days. The feeding process comprised of 4 dietary treatments T0 (control diet), T1 (diet with 2.5% *Eichhornia crassipes*), T2 (diet with 6% *Salvinia molesta*) and T3 (diet with 2.5% *Eichhornia crassipes* and 6% *Salvinia molesta*) and each treatment was tested on five chicks. The parameters measured were feed intake, body weight gain, feed conversion ratio and final live weight. The data analysis was done by using F-test.

Feed consumption: Feed consumption during the treatments was measured by weighing the feed offered and then subtracting the weight of the unconsumed feed. Total Feed consumption was measured using the following formula: Total amount of feed consumed / total birds.The feed conversion ratio value was calculated as follows: Amount of feed consumed /Body weight gain.

Salvinia molesta and *Eichhornia crassipes*, both the plants were collected according to their availability, from the ponds located in the nearby vicinity of the Calicut University. The green plants were harvested freshly from the water surface, roots were cut manually. Shoots (stems and leaves) were washed and carefully removed all the unwanted debris and sun-dried for about three days. The dried plants were then grinded using a mixer grinder and sieved, which was then stored in air tight plastic containers until needed. (Alshukri*et al*., 2018)

Results and discussion

The maximum mean body weight gain was more in T3 diet chicks which were statistically significant to birds fed with T0, T1 and T2 diets. As shown in table 2, chickens with T2 diet also attained a significantly higher body weight gain to treatments T0 and T1. Better feed conversion ratio was observed with chickens fed with T2 and slightly lesser ratios in T0, T3 and T1 which were significant. Maximum mean final live weight was gained with chickens on T3 diet followed by T2, T0 and T1 and the differences were significant. All the birds consumed the same amount of feed therefore no significant differences in the feed consumption were observed among the different treatments.

Table 2: showing the measurement of parameters

Parameters	**T0**	**T1**	**T2**	**T3**
Body weight gain	29.5g	27.7g	30.25g	30.3g
Final live weight	705g	688g	720g	721g
FCR	2.47	3.88	1.91	2.52

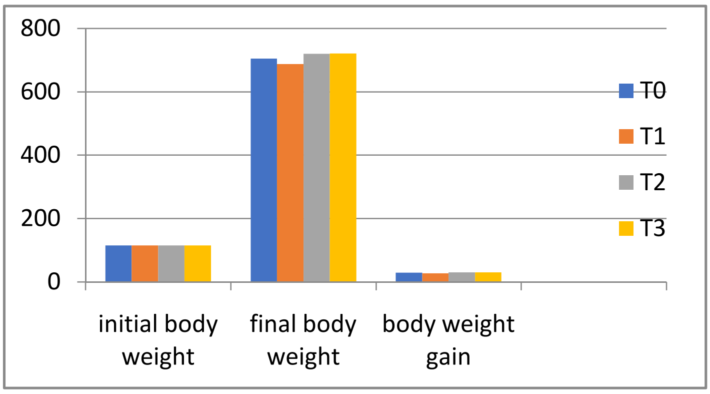

Fig. 1: Showing the growth pattern

The higher body weight gain on T3 diet (mixed form) that is more than the T0 (control diet) shows the effect of 6% of Salvinia as a protein source and 2.5% water hyacinth as a growth promoter which is similar to the findings of (Ma'rifah *et al*., 2013) which claimed that supplementing crossbred native chicken with *Salvinia molesta* up to an 18% concentration can boost nitrogen retention and performance. The higher supply of dietary protein can ensure the better nutritional as well as hormonal balance and brought about lower protein degradation and higher rate of protein synthesis, producing higher muscle protein mass and finally leads to gain in body weight (Suthama *et al*., 2010). Patrick and Schaible (1980) stated that final body weight gain is the least result of the growing process and so that when the feed consumption on treatment with Salvinia (2%, 6%,and 18%) is higher than control, so its resulting in better body weight gain which is similar to the results of T2 diet supplied with 6% *Salvinia molesta* which is higher than the control diet.

Better feed conversion ratio was observed with chickens fed with T2 (1.91) which is supported by the observations of (Suthama *et al*., 2010) that the body weight gain of the three treatments (2%, 6%, and 18%) due to the feeding effect of Salvinia can be categorized good because it was supported by the low value of feed conversion ratio. Feed conversion ratio

(FCR) is a crucial factor in determining how well broilers function. FCR is a rate measuring the efficiency with which the bodies of livestock convert animal feed into the desired output, which means that the lower the value, the more efficient the birds are in converting feed to live weight (Ampode *et al*., 2020).

Though the T1 diet with 2.5% Water hyacinth have shown least body weight gain, it has enhanced the chicken growth when given in combined form in T3 diet which is similarly observed by Igbinosun and Talabi (1982), that water hyacinth in combination with concentrate of other feeds has proved to be a good quality protein source for animal feed. According to the findings of Dumaup HJ and Ampode KM. 2020, the feed composition with 2.5% Water Hyacinth meal showed a sufficient amount for the higher final body weight and the rest of the growth performance parameters such as weight gain, feed intake, and feed conversion ratio in broiler chicken diets which is in contrast to the results in the present study where T1 diet supplied with 2.5% water hyacinth showed least body weight gain and FCR.

Conclusion

Utilizing aquatic plants in diet can lower the cost of feed because they are plentiful and the cheapest source of protein for animals. Therefore, a noxious water weed that needs a bundle of money and effort for its control and is available in any season all year round could be utilized as a feed resource in chicken rearing production systems. Specifically including *Salvinia molesta* up to 6% of the diet may reduce feeding costs and thus increase profit while *Eichhornia crassipes* enhances growth when mixed along with *Salvinia* in a mixed diet.Based on these results, the supplementation of 2.5% of *Eichhornia crassipes* and 6% of *Salvinia molesta* in mixed form or individually in *Gallus domesticus* diet can be further studied and recommended as its effects are similar and positive, compared to control diet which is very promising. Therefore these noxious water weed could be incorporated into the diet with no adverse effect on chicken production performance.

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