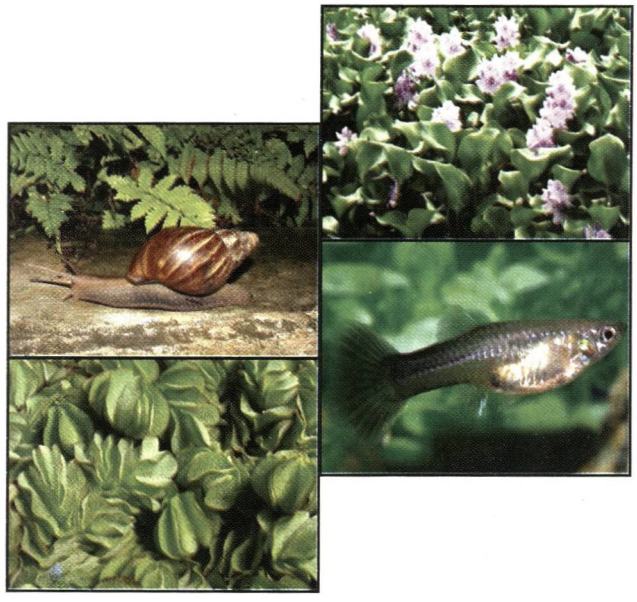
Invasive Alien Species

Strengthening Capacity to Control Introduction and Spread in Sri Lanka



Editors

Buddhi Marambe, Pradeepa Silva, Siril Wijesundara and Nihal Atapattu

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Editorial

Invasive alien species (IAS) are considered to be a main and a direct driver of biodiversity loss across the globe, and Sri Lanka is not an exception. These IAS have been estimated to cost our economies enormously every year and is a major threat to sustainable development. All alien species will not become invasive or threaten the environment. However, aliens always will have the nag with their potential to become invasive once escaped from human management. A clear policy approach is hence required for a country in order to effectively deal with the wide-ranging negative impacts of IAS, including the financial costs and irreversible effects on the environment.

Sri Lanka is a signatory to the Convention on Biological Diversity (CBD), which clearly articulates the role play of the countries (article 8(h), to overcome the threats of IAS to the biodiversity. IAS are a problem in diverse ecosystems of Sri Lanka. The Biodiversity Secretariat of the Ministry of Environment of Sri Lanka, being the focal point for implementing the CBD in the country, has taken a keen interest in activities focusing on IAS control at various levels in the society. The national action plan for the *Haritha Lanka* programme published in 2009 by the National Council for Sustainable Development (NCSD) of the Presidential Secretariat of Sri Lanka has identified management and control of IAS as a necessity under its activity 8.2, while the Cabinet of Ministers of Sri Lanka has approved (on 15th January 2009) the formulation of a Invasive Species Control act, thus indicating the high priority given by the country in this subject. However, still, it is evident that a proper coordinating mechanism with authority, responsibility and accountability, together with capacity building of stakeholders across all sectors, is a must for achieving the country's long term goals in overcoming the impacts of IAS.

This publication is aimed at providing up-to-date information to the scientists, academics, policy makers and other interested parties in understanding various aspects of IAS in Sri Lanka. This book comprises of 20 chapters out of which 13 chapters are devoted to assessing the present status in terms of definitions, national lists, risk assessment protocols, institutional arrangements, legal and policy frameworks, education and awareness strategies, IAS control efforts, etc., while the remaining 7 chapters deal with recent research activities on IAS. It is our fervent hope that this publication will provide useful information to all those who are proactively taking part in the country's efforts to free the ecosystems from the menace of IAS.

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Editors
May 2010

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Review paper

Chapter 1

Defining Invasive Alien Species

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Introduction

For many years the term 'invasive species' has been used by ecologists and others involved in biology and related fields. The spread of those species in new areas has drawn attention of different groups including the general public, scientists and even policy makers. The impact of Invasive species on biodiversity and functioning of ecosystems has been well documented (Mack *et al.*, 2000; Hobbs, 2000; Polley *et al.*, 1994) and is now recognized as a primary cause for global biodiversity loss (Czech and Krausman, 1997; Wilcove and Chen, 1998) and species extinction (di Castri, 1989).

Invasion

According to the Oxford English Dictionary, the verb "to invade" means "to enter in a hostile manner". However, the word "Invasion" was generally used in reference to human warfare, the "action of invading a country or territory as an enemy". Later this has been expanded to include "a harmful incursion of any kind". In legal terms the meaning includes "encroachment upon the property, rights, privacy, etc., of anyone".

In plant ecology, the term invasion is generally used for situations where the distribution and abundance of plants changes as a result of human activities. For other situations such as after the retreat of glaciations, the terms migration, spread, range expansion or range extension are used (Pyšek *et al.*, 2004). Some species increase their distribution and colonize new, mostly

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anthropogenic habitats in a geographical area where they are native. Such species are termed "expansive" and the process is called "expansion" (Prach and Wade, 1992).

Several terms are found in the literature on invasive species including aliens, naturalized species, non-indigenous, invaders, pests, colonizers, weeds, immigrants, exotics, neophytes, transformers and introduced species (Jarvis, 1979; Heywood, 1989; Dukes and Mooney, 1999; Lonsdale, 1999; Williamson, 1999; Brabec and Pysek, 2000; Colautti and MacIsaac, 2004). Even the term "bioterrorists" has been used in some literature (Meyerson and Reaser, 2003; Meyerson *et al.*, 2009).

Considering the different perceptions of invasions of plants depending on the disciplines and viewpoints, Rejmánek (1995) suggested that the plants encroaching new habitats can be assessed from the ecological (colonizers), biogeographical (invaders) or anthropocentric (weeds, pests, etc.) points of view. Pyšek *et al.* (2004) provide a Wenn diagram (Figure 1) showing those three view points based on impressions of di Castri, (1990), Rejmánek (1995, 2000) and Williamson (1993, 1996).

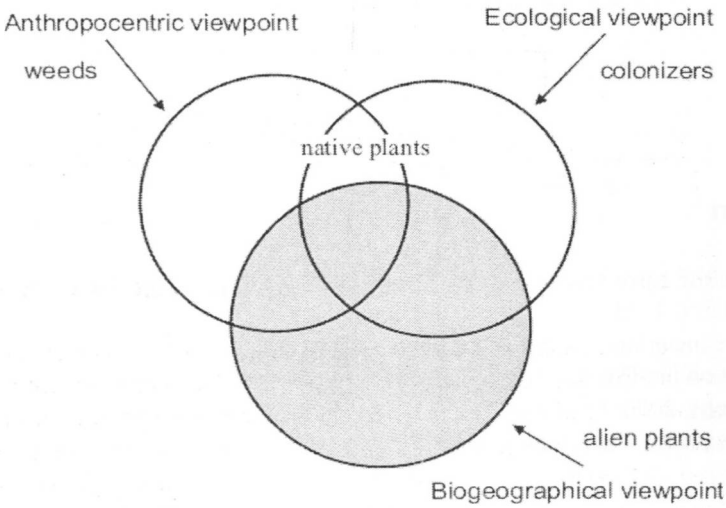


Figure 1. Approaches used to classify plants encroaching in habitats and territories where they were not present before (Pyšek *et al.*, 2004).

Whether there is any human involvement or not it is vital to define the role of man in the invasion process. It can be based either on "what is alien?" or "what is native?"

Native Species

Webb (1985), in his pioneering paper, introduced several useful criteria for presuming native status that were later extended by Preston (1986). According to Webb (1985), paleobotanical information is the only certain evidence of native status while historical records are the only evidence of introduction. The other important criteria include ease of naturalization elsewhere, character of the overall distribution area, type of habitat, and relationship with biota on other trophic levels (some alien plants were reported to harbor less pests than native species or to have brought their herbivores from the primary distribution range; Preston, 1986).

Alien Species

Alien plant species are defined as taxa in a given area whose presence there is due to intentional or unintentional human involvement, or which have arrived there without the help of people from an area in which they are alien (Pyšek *et al.*, 2004). Pyšek *et al.* (2004) classified the alien species in a hierarchical system (Figure 2).

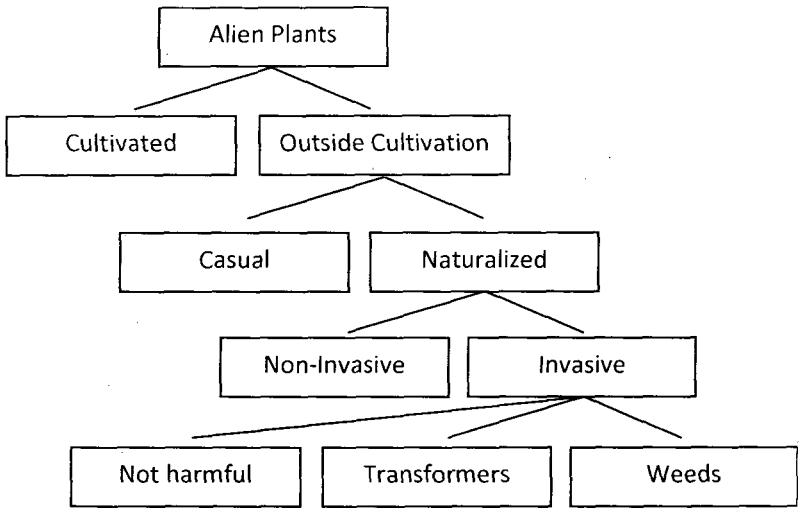


Figure 2. Hierarchical scheme of classification of alien plants suggested by Pyšek *et al.* (2004).

According to Pyšek *et al.* (2004) there are some alien species that can be termed 'casuals'. These may thrive and even reproduce occasionally outside cultivation in an area, but eventually die out because they do not form self-replacing populations, but rely on repeated introductions for their persistence. Some may become naturalized and those sustain self-replacing populations for at least 10 years without direct intervention by people (or in spite of human intervention) by recruitment from seed or ramets (tillers, tubers, bulbs, fragments, etc.) capable of independent growth.

Pyšek *et al.* (2004) defined transformers as a subset of invasive plants (not necessarily alien) that change the character, condition, form or nature of ecosystems over a substantial area. Weeds were defined as plants (not necessarily alien) that grow in sites where they are not wanted and which have detectable economic or environmental impact or both.

Invasive Alien Species

Many definitions of invaders and invasion have been proposed by various workers during the last few decades. According to Kolar and Lodge (2001) invasive species is "a non-indigenous species that spreads from the point of introduction and becomes abundant". Some definitions include the intervention of man. According to di Castri (1990) "A biological invader is a species of plant, animal or micro-organism which, most usually transported inadvertently or intentionally by man, colonizes and spreads into new territories some distance from its home territory". However, the term 'invasive' includes alien species as well as widespread species that have negative effects on the recipient ecosystem (Davis and Thompson, 2000, Mack *et al.*, 2000).

Davis and Thompson (2000) recognized eight types of colonizers and recommended that the term invader can be used for only for two types (Figure 3).

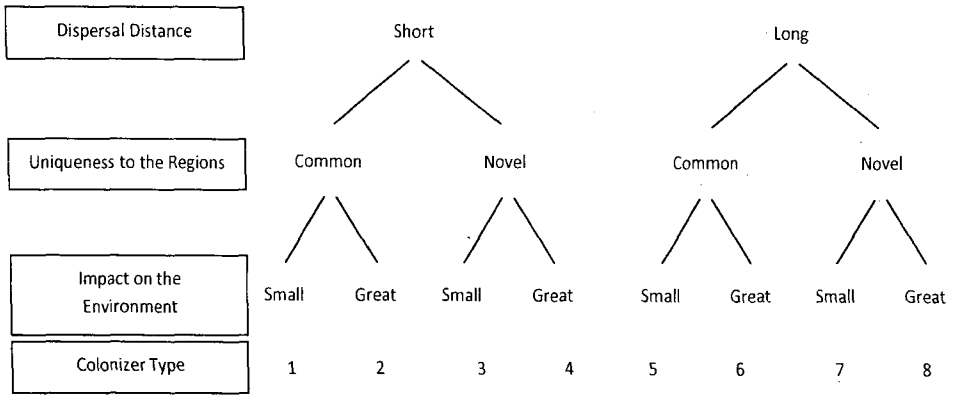


Figure 3. The eight colonizer types proposed by Davis and Thompson (2000). Types 1, 2, 5, and 6 can be considered *successional colonizers*; Types 3 and 7 can be considered *novel, non-invasive colonizers*; and Types 4 and 8 can be considered *novel, invasive colonizers*. Davis and Thompson (2000) recommended that the word *invader* can be used only for colonizer Types 4 and 8.

According to Richardson *et al.* (2000) invasions can be considered as a process in which non-indigenous species progress through 'established', 'naturalized', and 'invasive' stages. Colautti and MacIsaac (2004) proposed a neutral model in which, a non-indigenous species passes through localized and numerically rare to widespread and dominant stage (Figure 4).

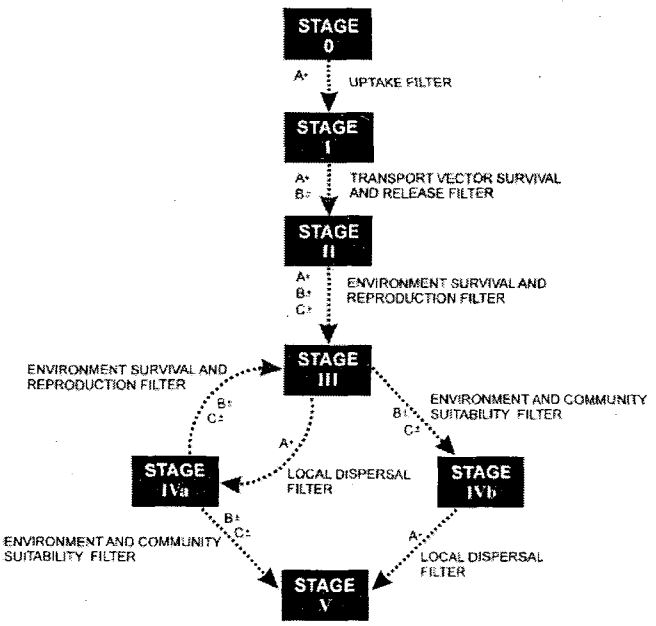


Figure 4. A neutral model of defining operationally important terms in invasion studies (after Colautti and MacIsaac, 2004).

As depicted in Figure 4, the potential invaders (stage 0), pass through a series of filters that may preclude transition to subsequent stages. The three classes of determinants affect the probability that a potential invader will pass through each filter: (A) propagule pressure; (B) physicochemical requirements of the potential invader; and (C) community interactions. Determinants may positively (+) or negatively (–) affect the number of propagules that successfully pass through each filter.

Conclusions

There are several definitions of IAS. However, standardizing ecological terminology usually fails as it is difficult to get everyone to agree on the same definition. Moreover, the older publications will keep reminding readers of previous meanings, and new meanings will creep in to all but the most concisely defined terms (Hodges, 2008).

Many definitions on IAS include 'impact' as a key term. However some ecologists consider it as a highly subjective term which obscures the scientific understanding of the ecological and evolutionary processes underlying the invasion process (Colautti and Richardson, 2009). It is also argued that invasion biologists should adopt a more objective or neutral terminology in defining invasive species (Brown and Sax, 2004, 2005; Colautti and MacIsaac, 2004). But, as Larson (2007) claims, those arguments may lead to non-action that is inconsistent with the conservation values on many invasion biologists.

Conservation of biodiversity has become a national priority. Role of IAS in relation to loss of biodiversity has been well documented (Mack *et al.*, 2000; Hobbs 2000; Polley *et al.*, 1994; Czech and Krausman, 1997; Wilcove and Chen, 1998; di Castri, 1989). Considering the pivotal importance in biodiversity, the latest definition by the SCBD, which defines IAS as "species whose introduction and/or spread outside their natural habitats threaten biological diversity" can be considered as the most appropriate one for us.

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Review paper

Chapter 2

Invasion - A Tool of Evolution

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The definitions of invasive alien species (IAS) are discussed in an elaborated manner and the anomalies in using the term in different context have been addressed in elsewhere in this publication (see Chapter 1). This chapter will record the ecological and evolutionary significance of 'invasion' in context, and comment on the geographical residential status of organisms *viz.* endemic, exotic, etc. and their diffusion in space and time with examples from Sri Lanka.

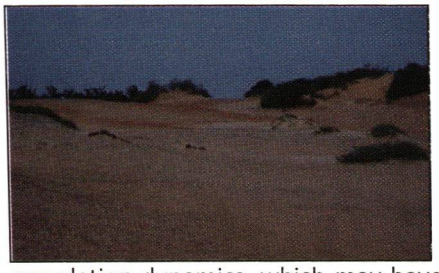
Evolution and Ecology

Darwinian theory of natural selection is considered as a prime mechanism of evolution. It is centered around the thesis that, the variety of traits (variation) found at any one location at any one time period is weighed against their ability to survive in that environment and the more suitable (fittest) survives to the next generation and such continued process leads to loss/reduction of a trait or expansion/increase/development of another trait which is succession. This is called survival of the fittest and forms the basis for evolution in nature.

Two factors are of importance in facilitating evolution, more correctly the process of selection, genetics and environment. Genetic makeup includes the intrinsic genetics of organisms and the migrations into it. These would facilitate the best or effective use of the environment (resources) and competing with all others for survival. Environment on the other hand provides the base for resources which are utilized by the genetics and every change small or big changes the resource composition, pattern, availability etc. which changes the rules of the game for the genetics that are in the location. Those that could best utilize the resources and are able to perform under a wide range of environment tend to be the preferred feature for selection.

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Two strategies of survival have been recognized in plants with different ecological behaviour called 'r' and 'K' traits. The 'r' and 'K' traits play a different role in ecological succession that regenerate the ecosystem. The theory originates from the work of Mac Arthur and Wilson (1967) on Island Biogeography. The 'r' selected species exploit empty niches and produce many off springs and each has a low probability of survival. The 'K' selected species are strong competitors in crowded niches and invest more heavily in fewer offspring each having a higher probability of survival. The species 'r' are considered as opportunistic and 'K' is considered as equilibrium. In ecological succession 'r' and 'K' play a significant role. The 'r' species colonizes the niches first, which is conquered by the 'K' over time by replacement. Typically biodiversity is maximized at this stage with the introduction of new species resulting in the replacement and extinction of endemic species (McNeely, 1994). The 'r' and 'K' strategies though extremes may also be considered as part of a continuum and there may be those which would display mixed characteristics.



Invasion is recognized by the expansion of a species into space either occupied by another species or otherwise. The former is a process of competition, which may lead to coexistence or exclusion and the latter is called primary colonization. Species may also expand into areas that were formerly occupied by another species, which would also be considered primary colonizers as opening in gaps of forest. This is a general concept in population dynamics, which may have short cycles, long cycles or unidirectional effects and all stages are referred to as a form of succession



It was well known that in the chalk grasslands of United Kingdom species were found to co-exist or lead to extinction depending on the microclimate (Tansley, 1917). Invasion signifies ones' ability to be the best under the given conditions and thus be considered as significant feature for evolution. The invasion may be a result of many factors especially the improved genetic material (modification of inherent genetics, migration, emigration, etc.) and changes in environment (*tsunami*, dry spells, large fires, human deforestations, etc.).



The drastic changes in the environment like fire, deforestation, heavy grazing etc. could make the environment so different that even a native may show expanded growth and invasion of available space. Illuk (*Imperata cylindrica*) may be one such example in Sri Lanka. It is seen to spread in areas taking over the entire grassland in some years whose exact ecology is not known. It is seen as a cyclic succession in these grasslands governed by drought and fire. But the real question is how far do any species show invasive growth in space and time before they meet the regulating mechanisms of nature.

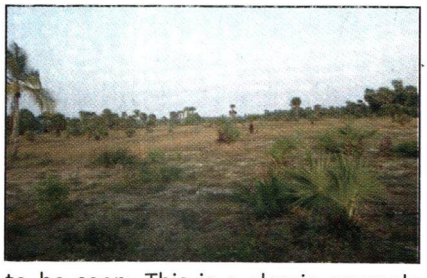
It is logical when a species finds the environment conducive for its growth it expands profusely taking every possible area as fast as possible, until it meets its regulator, competitor. Two species were the most spoken of in 1970s *viz. Pennisetum polystachion* and *Tithonia* sp. Pennisetum was leading the way into the dryzone and the *Tithonia* into the intermediate covering Kandy reaching Mahiyangana. Subsequently their spread became limited. In the dry zone perhaps *Panicum maximum* was able to outgrow *Pennisetum*. Yet, *Pennisetum* is found in large patches along the A11 near Punanai.

As we have seen in 'r' and 'K', the 'K' tends to take over after long periods in one location. Weeds in a fallow field grow fast and die/reproduce before they are removed, or give way to local flora, which is its mechanism for survival. They remain as seeds in soil for another opportunity. Similar mechanisms are seen in the desert plants and tundra plants, short life cycle, fast growth, early flowering and maturity and long hibernation (survival as seeds or rhizomes or other propagules).

They are no exotics, but do share features for invasion, to maximize their use of the harsh and unpredictable environment they share. If the environment would be less harsh (after global warming) these may invade area hitherto unoccupied. Smith and Berg (1988) illustrates that Monterey Cypress is an endangered endemic naturally occurring only in two small stands in California. But they are being exterminated as exotic invasive species less than 50 miles (80 km) from their native home. This proves the point that any species may become invasive (exotic or endemic) given the correct conditions, either positive in terms of resources available or negative in terms of absence of natural enemies) and also questions the rule of political boundaries as they could both be invasive and rare within 80 km. In the Sri Lankan case, Opuntia has been considered as an Invasive in the south, especially in Bundala national park. But the populations seen around East have been restricted in site. Tsunami may have broken them up for them to establish in many locations nearby in coasts like Sangamankandi. But how long have we monitored their progress to verify their 'residential status'.



The crow is a new bird in Horton plains, attracted by the altered environment of food and litter from tourists and alike. It went there on its own and had stayed for more than 10 years now. Will it become established there? Was it the food that kept them away all these years and not the climate? Will the residential status of the crow be same in Horton plains and rest of the country or separate in different 'ecological regimes'?



The patches of grasslands, which had grown on the potato cultivation at Horton Plains had remained for the past 40 years, different to the natural vegetation of tufted grasses. The natural grassland seems to gaining ground (invading) in many places, slow but steady. May be neither is able to replace the other under the grazing potential of the Sambhur. Whether one is going to entirely eliminate the other or coexist at a point needs to be seen. This is a classic example how natural communities gain back their ground, after disturbances.



Coconut and Palmyrah are palms that are common in the Eastern coast of Sri Lanka. Coconut is found only as a plantation and rarely do you find it growing outside. However, Palmyrah grows naturally in sea shore areas in abundance. In 1978 when the area was hit by cyclone 80% of Coconut were destroyed/ uprooted with Palmyrah having no scars. In 2004 when the Asian Tsunami hit the eastern coast the entire (more than 50%) of the Palmyrah in the coast were damaged/scorched with Coconut having none or low scars. Is it the frequency of the Tsunami and Cyclone that facilitates the occurrences of these palms in the coast?



The coast after Tsunami was devoid of vegetation at all. With time we found *Ipomoea pescapre* growing in slowly but then extending the areas beyond its pre Tsunami limits making its own new space. Will it expand further in space and time or the other/factors species limit it come back and take over? Has Tsunami helping the occurrence of Ipomoea in the coast over generations? This leads to the next question on the space and time dimensions.

Space and Time Dimensions

A score of terminologies being used to relate the spatial distribution of organisms in relation to the geography (residential status) *viz.* endemics, natives, naturalized species, indigenous, exotics/ aliens. These terminologies are being discussed below in relation to ecology and evolution.

Endemic is restricted geographically, often quoted with political boundary. For example, *Dipterocarpus zeylanicus* is endemic to Sri Lanka but is restricted to the wet zone tropical rainforest and not found in the dry zone. A species which is endemic to India has an amplitude of 3000 km from south to north and it must be appreciated even though we quote the country for endemism. The ambiguity of this has been already pointed earlier. However the geographical isolation is a key parameter for speciation and is the reason why we have high endemism in Islands. The question is, are these the best fit for the environment or the best that had reached the site?. What happens if fitter species reach on their own (naturally) or otherwise (human related events)?

Parthenium is a classic case as their origin to Sri Lanka is not sourced and remains a mystery. They could just have been blown into Sri Lanka from India (20 km distance) or arrived with cargo, around 1990 when it was detected. They have colonized extensively in Trincomalee and Vavuniya.

What is an exotic? They are species that have crossed its geographical boundaries. It is fine as long as it is not self perpetuating (reproducing in the wild). But once it reproduces in wild we have a series of questions. When will it be considered naturalized? When will it be called indigenous? When will it become native? It must be understood that these are labels on a

continuum of stages from endemic to exotic where the extremes are better defined and the others are murky.

Sri Lanka has a dark age of 3 centuries, from 8-11 centuries. What was the stock before and after the period remains unclear. The professional's advice is that, if the dry zone vegetation had been in place from the 11th century until now, they could be considered as climax forests in every sense, as calling them secondary would be meaningless. How many years or generations do we need to change residential status? It is important that we make a decision on this for operation. This does not only concern species that show invasion but many others which are found in the area. In abstract, all species that are not endemic are exotics at some point along the time line, and then may be native if there history is too long to verify, indigenous for shorter history, naturalized for more recent entry, exotic species (which self perpetuate), exotic plants (not naturalized), which needs propagation, etc. There needs to be a better way of classification of residential status as change of status too becomes essential, in many cases with time. An example of how *Pinus* sp. had turned from a plantation to colonization is elaborated in Chapter 14 of this publication. It also points out that Natural Forest species, which are unable to grow in open grasslands, grow under the pines, emphasizing role change over time. Most of our dry zone species in our natural forest are not endemic but they have arrived to this country sometime in history and so will be the species we confront today as exotics.



Ulex europaeus, Salvinia molesta, Eichhornia crassipes, Leucaena leucocephala and many other species have remained in the country for many decades, some for over a century. Some are recognized as exotics by scientists and professional but are recognized as part of their environment by the laymen as they have been with them for most or all of their life with them. It is essential that there be a more realistic 'residential status' be provided for these species. It would be difficult to eliminate them totally and more realistic would be to have them controlled until nature provides checkpoints. Same applies to animals, too.

A classic case is the 'exotic' fish in our fresh water lakes. Carps and tilapias have filled our lakes in the country as the most common or abundant fish, in cases reducing the local species to extinction. Is it possible to remove them to restore 'normalcy'? If the tilapias and carps are a major contribution to the food basket of the poor, could it or should it be eliminated? (see Chapter 12 of this publication).

Evolution is a Unidirectional Process

Evolution is a unidirectional process of selection and fitness. There is no reverse as much as 'you never step into a river twice'. All conditions would have changed by then. If a species has been on a site for many decades or many generations (not necessarily) it would have formed its own niche and established part of a food web and cycle. Removal of that species would now create a break in the chain and upset many natural linkages known or unknown. It is also true that even if that is removed the gap created may not be colonized by the species that provided the gap, but it will be a real different course altogether, which is unpredictable. Evolution is never reversed but, new paths are chosen to select the fittest of the day. It is an ecological succession all over again.



Broom/Gorse (*U. europaeus*) has been in the Horton Plains for more than a century. I have always felt that was that this had reached its zenith. Recently all the shrubs have been removed. It may promote another species to colonize the gaps. *Aristea ecklonii*, seems to take advantage of the situation (Dr Siril Wijesundera, Royal Botanic Gardens, Peradeniya – personal communication).



Increase of abundance of 'bracken' (*Pteridium revolutum*) is also seen. Whether this has direct relation to Gorse removal or the burning of the grassland remains a question. Gorse is known to provide good habit for endemic black-lipped lizard with food and cover (Prematunge, 2008), which would be void now, creating another concern. Small plants of the Broom are seen in the grasslands now, which may come back. There may also be a possibility of the expansion of the *Rhododendron arboretum* in the grassland, not hindered by the broom. We do not have adequate precise information for projection, which is a major gap.

Over time, even species that do not have their niches, which may have expanded or invaded meets its rivals/competitors and settle down with time (year or century as it may be). Removal of part of them may cause the gaps to be filled by that species with vigour (reducing the intra species competition). We may cause another species native or exotic to proliferate if the outgoing species, in its succession, had eliminated the enemies of other common enemy species. Caution is needed. Long term studies of the dynamics of plant and animal species are necessary to make appropriate interventions with certainty. We lack that type of studies.

Potential

If there is a change in climate as anticipated under global warming or sea level rise, will it be fair to presume that the 'Invasive species' would be at an advantage? There are no 'invasive species' in nature. Any species would and could become invasive under a given set of conditions favourable to their growth or unfavorable to the others (Harper, 1977). That also gives them an advantage on evolutionary potential of increased natural selection. Wijesundera (2001) had provided a species list for plants that have the potential, which may lead the race. The question remains as to when and where do they meet those conditions for expansion beyond others? For all what I know, it could be a rare endemic that takes the opportunity of the warmer climate and salinized shores. The globe has examples.

Synthesis

If introductions are natural or otherwise, and show fitness to the environment, then selection has taken place and hence, is a tool of evolution. If a species has naturalized (irrespective of its origin) its removal may not reverse the effects and the succession is unpredictable. Identifying species as alien, indigenous, etc. is not rigid, but a time bound concept. In this context, an appropriate classification of the 'residential status' of a species may be useful, and detailed

demographic studies may provide insight to the management and control of any species. Ecologically there are no 'invasive' species in nature. Every species has the potential to expand its 'space' given the correct set of conditions in space and time.

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Review paper

Chapter 3

Risk Assessment for Invasive Alien Species

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Introduction

The significance of invasive alien species (IAS) as a global problem is widely recognized and the adverse effects of these species have been well described. The identification and characterization of the adverse effects associated with the IAS is crucial, not only to prevent their introduction to new areas but also to prioritize management and control measures for already established IAS.

Risk assessment is a tool that can be used to support the exclusion of potential IAS from being introduced, as well as to assess the potential impact of those invasive species that have already become established. Risk assessment is one of the three components of risk analysis (Anderson *et al.,* 2004). It should be closely linked to the other two components of risk analysis; risk management and risk communication. The identification, qualitative and quantitative estimation of known or potential adverse effects associated with IAS, *i.e.* risk identification and characterization, are processed through risk assessments. Results of risk assessments are incorporated into risk management, a process that weighs policy alternatives and selects appropriate implementing options to accept, minimize or reduce the risks of IAS identified and characterized by the risk assessment. The information is exchanged between interested stakeholders via the process of risk communication so as to complete the risk analysis process. It involves the communication of risk assessment results so that they are clearly understood and rational decisions can be made.

In a broader context, risk analysis for IAS could be conducted through different approaches with reference to their effects on human health and biodiversity issues, and research related to the

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entry, establishment and spread of IAS. The issues related to effects of IAS on human health are dealt in medical (epidemiologic) fields in great detail. Risk analysis for effects of IAS on biodiversity is being conducted by various authorities/agencies having different responsibilities. The impacts of IAS on agro-biodiversity (and/or agricultural ecosystems) are evaluated through risk assessments by agricultural agencies using well defined 'currencies' such as crop or livestock loss, costs for control etc. In contrast, risk assessments for impacts of IAS on natural ecosystems have been difficult for environmental agencies to conduct as there is no well defined 'currency' to evaluate the impacts. However, risk assessment protocols related to impacts of IAS on native biota and natural landscapes have been developed and implemented by various international authorities for regulation of alien species introductions, early detection of IAS and implementation of control/eradication measures. Risk analysis for issues related to entry, establishment and spread of IAS are addressed through species or habitat based approaches in theoretical ecological studies such as pathway analysis, population viability analysis and by use of various mathematical models. Hence, risk assessments related to effects of IAS on biodiversity will be reviewed in this chapter.

Present Status of Risk Assessments on Impacts of IAS on Biodiversity

Risk assessments adopted at regional and global scales

It is well known that increased trade and tourism, human travel and migrations facilitated intentional and unintentional introductions of species all over the world. Thus, over the past few years there has been a growing international interest to protect agricultural, natural and urban land use systems from alien animals and plants. As a result, risk assessments related to impacts of species introductions were seriously considered in the international trade and environmental policy agendas, through a variety of international agreements. Subsequently, such risk assessments were incorporated into quarantine legislation and procedures at national borders to regulate the entry of species into new environments.

According to the International Standards for Phytosanitary Measures (ISPM No. 11, 2004) prepared by the Secretariat of the International Plant Protection Convention (IPPC) (www.ippc.int/id/13399), risk assessments are conducted among nations to restrict the movement of 'pests' (defined by the ISPM as species, strain or biotype of plant and animal or pathogenic agent injurious to plants and plant products). The ISPM provides standards and qualitative descriptions for pest risk analysis (PRA) for protection of environment and biological diversity including uncultivated, unmanaged plants, wild flora, terrestrial aquatic and marine ecosystems. It also serves as an analytical approach in which ecological knowledge is widely applied to decision making process prior to the acceptance of the new introduction. The risk assessment procedure involves screening for quarantine plant pests using available prohibition lists and standard compendia and determines whether a particular species should be permitted for entry. The ISPM are transparent, technically justified and sufficient to protect plant health of a country from weeds, pathogens, nematodes and insect pests. It has also provided provisions for incorporation of specific measures, necessary updates of 'prohibition lists', guidelines and recommendations for risk management options according to country's requirements. The ISPM standards are adopted by contracting parties of the International Plant protection Convention (IPPC), members under the 'Agreement on application of sanitary and phytosanitary measures (SPS agreement)' of World Trade Organization (WTO) and FAO member countries.

Similarly, the International des Epizooties (OIE) has established animal health standards and guidelines to be used for international trade of animals and animal products in order to protect human and animal health/life (www.oie.int). According to their regulations all imports of animal and animal products are being checked for infectious alien pathogens/diseases at the time of entry to country borders. Such screening of biological imports at the country boundaries are considered as the most cost-effective means of prevention of the arrival of pests and infectious diseases to new environments.

The risk assessment processes specially designed for impacts of IAS on biodiversity differ from the above procedures as they determine the likelihood /or the degree of given species becoming invasive in the environment. Though the prediction of invasiveness of a species is difficult, protocols have been developed and implemented for IAS by various international authorities during the recent years. Some of the risk assessments are being conducted at regional basis as for Pacific Island Ecosystems at Risk (PIER) regulating the movement of plant species among member islands (www.hear.org/pier/). It is well understood that much of the world's attention has been paid more on invasive alien flora than on invasive alien fauna with reference to many aspects. Similarly, development of risk assessment protocols has been focused more on invasive alien flora than invasive alien fauna. Most of the currently available risk assessment protocols for IAS are linked with (or included under) 'weed risk assessments'.

At present weed risk assessment protocols have been developed and adopted in many countries including the USA (United States Department of Agriculture - USDA; http://plant_materials. nrcs.usda.gov/technical/invasive.html), Australia (Downey, 2006), New Zealand (Williams *et al.,* 2000), Hawaii (Pacific Islands H_WRA system; Denslow *et al.,* 2000), Japan (Yoshiola, 2005), Canada (Anonymous, 2003), etc., where most of the weeds are non-indigenous. Similar schemes have also been adopted in Europe (by European Plant Protection Organization – EPPO; Weber and Gut, 2004) and Mexico though most of their weeds are of native origin. These weed risk assessments (WRA) protocols provide the basis for weed risk management programmes. Almost all of these protocols are semi-quantitative in nature as ranking of the noxious weeds is based on calculation of a weed risk score for aspects concerned (www.nature.nps.gov/). The biology of species, invasive potential, spread and/or distribution, impacts on the native communities and feasibility to control are the aspects taken into consideration for such evaluation.

Weed risk assessments are not only being conducted at country borders to forecast the consequences of a particular species introduction but also at post border level for those already present in the country or region, or which are likely future incursions so as to prioritize species for control and management processes (FAO, 2006). Use of such risk assessment protocols have been extended to develop 'invasive plant inventories' which are being updated time to time. These inventories developed for the use in California, Arizona and Nevada, Minnesota states of USA had categorized invasive alien flora that threatens the state's wildlands into high, moderate and limited categories based on the ecological impact, ability to invade natural vegetation communities and current extent of invasion of the species (www.invasive.org/eastern/ midatlantic).

Though less attention is given to invasive alien fauna, during the past few years risk assessments systems for introduction of animals have been proposed. Wet tropics Vertebrate Pest Risk Assessment Scheme developed by Harrison and Congdon (2002) at the Cooperative Research Centre for Tropical Rainforest Ecology and Management, Cairns, Australia is one such scheme. More recently, risk assessment models have been proposed for the introduction of exotic

mammals, birds, reptiles and amphibians in Australia and New Zealand (Bomford, 2008). The UK non-native risk assessment scheme (UKNNRA, 2005) is also based on internationally recognized procedures developed by the European and Mediterranean Plant Protection Organization for freshwater fish, marine fish, amphibians and marine invertebrates. In addition there are similar documents that could assist in identification of risks such as the documents prepared by the Center for Environment, Fisheries, and Aquaculture Science (*Cefas*) in the UK (Copp *et al.*, 2005). Guidelines are also available for utilization of species for aquaculture (Hewitt *et al.*, 2006). Code of practice for intentional introduction and transfer of marine organisms adopted by the International Council for the Exploration of the Sea (ICES, 2004) also describes a set of guidelines for risk assessment procedures.

Risk assessment protocols presently available in Sri Lanka

At present, some of the legal provisions stipulated by various Acts directly address the prevention of introduction and control of spread of IAS in Sri Lanka. Chapter 6 of this publication gives a comprehensive account of the legal and institutional provisions for IAS control in Sri Lanka. In Sri Lanka, pest risk assessment conducted at the National Plant Quarantine Services (NPQS) at Katunayake and the Seed Certification Center, Gannoruwa qualitatively investigate the likelihood of the entry, establishment and spread of aquatic or terrestrial weeds including invasive plants, pathogens, nematodes and agricultural insects via imports of plants and planting material for non consumption and consumption purposes (Mr. R.S.Y. Silva, Deputy Director/National Plant Quarantine Service, Sri Lanka – Personal Communication). The risk assessment conducted by the above authorities comply with the ISPM standards and often for this process, the National Herbarium of Royal Botanic Gardens, Forest Department, Department of Agriculture including Horticultural Research and Development institute, Plant Protection Service, Plant Genetic Resources Center and Seed Certification and Plant Protection Centre, are being consulted especially with regard to the prevention of introduction of invasive plant species to the country.

At present a more comprehensive protocol for screening of pest plants at the border of entry is being drafted at the National Plant Quarantine service (NPQS) of Sri Lanka. Though this risk assessment protocol does not directly addresses invasive alien flora, risk characterization indirectly exhibits relationships with screening for IAS. This protocol has been named as 'pest risk analysis of a particular plant as a pest' and is in accordance with the ISPM standards. This protocol consists of assessments for identification, characterization, management and communication of the risks involved with introduction of alien flora to Sri Lanka. The risk assessment protocol deals with risks associated with regard to biology and ecology of the new introduction, its current distribution, likelihood of entry and potential establishment and spread following entry to Sri Lanka, potential impacts and economic consequences, etc. However, this quantitative approach of risk analysis is scheduled to be implemented in the future.

At present there is no risk assessment procedure to regulate the introduction of invasive animal species to the country. The standard OIE procedure, though not a descriptive qualitative or quantitative risk assessment deals only with prevention of introduction of infectious disease causing agents. According to the OIE standards a consignment of animals and/or animal products is rejected without entry to the country of import if the products are found to be contaminated with an infectious disease causing agent. As far as the live fish imports are concerned, prohibition lists prepared by the officials of the Department of Fisheries and Aquatic resources are currently being implemented to restrict the import of already known invasive alien

fish species to Sri Lanka. In most situations the National Aquatic Resources Research and Development Agency (NARA) has also provided assistance in identification of such species during screening of imports. However, at present a risk assessment for fish imports for the ornamental fish trade is not being practiced under the live fish import regulations of Sri Lanka.

Currently, risk analysis for already established IAS in Sri Lanka has been poorly addressed and has not been incorporated into IAS management strategies of the country. However, two post boarder risk assessment protocols for invasive alien flora have been developed aiming prioritization of IAS for management strategies.

One of the two protocols available for prioritization of established invasive alien flora was prepared by Hafiz *et al.* (2006). The protocol categorized invasive alien plant species in Sri Lanka into priority groups, using scores assigned for impacts, biology, distribution and feasibility of control of a particular species. The protocol was validated with 20 plant species included in IUCN 2001 list and Global Invasive Species Database. The second risk assessment protocol related to invasive alien flora in Sri Lanka had been developed by Weerakoon (2007) for the Protected Area (PA) Management and Wildlife Conservation Project of the Department of Wildlife Conservation, Sri Lanka. This risk assessment protocol focuses on prioritization of invasive alien flora for removal from PAs for better management of habitats and wildlife and thus seems to serve as a vital component in risk analysis process of the proposed 'Guidelines for Management of Invasive Species in Protected Areas of Sri Lanka'.

Gaps and Gap Filling in Risk Assessment of IAS

Implementation of risk assessments to control the introduction, establishment and spread of IAS in Sri Lanka is being neglected at present primarily due to the unavailability of an acceptable assessment scheme to characterize risks associated with IAS in Sri Lanka. Even at global level risk analysis of IAS is still a developing field and has received low priority due to gaps in knowledge, access and sharing of data and lapses in policies, responsibilities and applications.

As in many other risk assessment schemes developed for IAS in various countries, the risk assessment protocol for IAS in Sri Lanka could also address the economical, ecological and social impacts, invasiveness, distribution, spread and management options of the known or potential invasive species. These aspects could be addressed in detail using easily measurable parameters that would correlate with successful introduction, establishment and spread of species (see annex 1 for proposed criteria for a risk assessment protocol on invasive alien flora and fauna in Sri Lanka). The suggestions given below will also be useful to upgrade the risk assessments of IAS in Sri Lanka. The principle state organization mandated for biodiversity conservation (the national focal point of CBD) has a major role in attending to these suggestions in order to fill the gaps in risk assessments for preventing the entry, establishment, spread and control measures of IAS in Sri Lanka.

Knowledge gaps

Risk analysis of IAS is totally based on existing scientific knowledge and thus almost all of the risk assessment protocols have been developed assuming that information on the target organism is readily available. The limitations of the existing knowledge especially on ecological aspects of IAS often hamper identification and characterization of the 'invasiveness' of a species. There could be many species of invasive aliens positioned at the early lag phase of invasions or those

that will be future/potential invaders, which have not been paid enough attention for scientific studies at present. Taxonomic relationships of a taxon, invasiveness of its relatives and history of invasiveness elsewhere are considered as integral components of prediction of invasiveness of a species. Often, the high ecological and taxonomical diversity of noxious species had brought forward difficulties in such investigations. The limited amount of available information on growth rates of species, length of juvenile period, habitat requirements, dispersal patterns, behavioral studies etc, also set constraints to the identification of invasiveness of IAS. Further, the knowledge on economical aspects related to IAS has been poorly explored compared to biological and ecological studies. Integration of economics to management and control programmes of IAS has been reported only for few well known species of invasive aliens. Hence, limitations of existing knowledge on ecological and economical aspects exist as a gap in risk assessment and risk analysis processes. Following strategies could be used to fill the knowledge gaps in risk assessments for IAS.

(a) Conducting research in poorly investigated areas/fields of IAS will assist to fill knowledge gaps in risk assessments. It would also strengthen integration of ecological and economical aspects in risk assessments.
(b) Establishing transboundary collaborations with relevant knowledge networks such as the IUCN Invasive Species Specialist Group (ISSG) and the Global Invasive Species Programme (GISP) that would assist in filling knowledge gaps in risk assessments conducted by relevant stakeholders.
(c) Establishing community vigilance network for regular monitoring of IAS and their distribution in Sri Lanka to prepare suitable maps, etc., will also fill in the voids created by lack of knowledge.
(d) Promoting awareness and education through updated IAS lists, educational material (posters), hand books for identification of invasive alien flora and fauna, newsletters and media awareness programmes on invasive species to help creating a better understanding on IAS among public and relevant stakeholders as well as access updated and upgraded information.
(e) Promoting the development of ecological and economical models to estimate potential impacts of exotic species becoming established in natural and/or managed landscapes.

Data gaps

Information needed for an assessment of invasiveness of a species and its impacts are often obtained through published and unpublished literature which are scattered throughout different institutions. In addition, much of the information is also obtained through personal communications. The absence of a repository of relevant information in an accessible form, or lack of updated information and an information management system for IAS often causes problems in completing risk assessments.

Limited facilities in institutions for easy and quick retrieval of IAS information also create difficulties in conducting successful risk assessments. This has become a major problem especially for the stakeholders involved in conducting risk assessments at national borders. Such situations would lead the authorities to make arbitrary decisions even on sanitary and phytosanitary measures increasing the risks of noxious invaders being intentionally imported. The inefficiency of data sharing mechanisms among relevant stakeholders is another major reason for the existence of gaps in data and information related to IAS. The following suggestions would help data gap filling in risk assessment procedures for IAS.

(a) Establishing a suitable mechanism and provision of institutional support to improve effective coordination and collaboration amongst specialists in IAS, universities, relevant state agencies, user groups and communities, and state agencies is needed to fill in the data gaps in risk assessments.
(b) Identifying a state institution to coordinate with necessary stakeholders and establishment of mechanisms for regular maintenance and updating of data will enable to minimize gaps on data access.
(c) Establishing a clearing house mechanism to enhance technical capacity for information exchange, collation of information within and outside the country, preservation and storage facilities of such data in relevant custodial institutions will improve the current situation with regard to gaps in retrieval of information.
(d) Providing relevant resources to departments in charge of conducting risk assessments at border and post border level. Capacity building through exposure to relevant training sessions, strengthening of infrastructural support and improvement of facilities would help to fill in the gaps with regard to the knowledge, data retrieval and exchange.

Gaps in policies and applications/responsibilities

Lack of a government policy on IAS seems to be another constraint that has led to weak implementation of risk assessments for IAS in Sri Lanka. Poor understanding and awareness on impacts of IAS among politicians, policy makers, administrators and lack of collaboration among relevant stakeholders also weaken their responsibilities and limit applications of risk assessments at border and post border levels. Structural and management deficiencies in organizations/institutions also disable the institutional capabilities to conduct effective risk assessments for IAS. These situations have arisen due to shortages in financial and/or human resources.

In certain situations deficiencies that exist in international regulatory frameworks relating to international standards could also contribute to lack of policies, responsibilities with regard to applications of risk analysis process. The international convention for the control and management of ships' ballast water and sediments (2004) highlights management options for the control of spread of some marine organisms and pathogens during ballast water exchanges. But it does not specifically emphasize on invasive alien planktonic organisms or the necessity of a risk analysis process in ballast water exchange processes. Deficiencies in international regulatory frameworks can also be identified in IPPC as there is no direct provision to address IAS, which are not considered as pests. There is also a concern about the exotic pathogens and parasites that could pose risks to wildlife but that are not listed by the OIE. The following suggestions would help fill gaps in policies and applications/ responsibilities in risk assessment procedures for IAS.

(a) Formulating and implementing a national policy on IAS and their control could highlight the importance of IAS and provide guidelines for risk assessments as well as enhance the responsibilities of necessary stakeholders involved in different stages of management of IAS.
(b) Reviewing the legislation, identification of the deficiencies, clarifications of the legal issues pertaining to the import and export of fauna and flora is essential. Amendments should be done as necessary to remove anomalies and strengthen where necessary so as to provide adequate legal recognition for protection of the biodiversity against IAS.

The legal revision should strengthen capabilities to enforce existing regulations/ enforce strictly the current laws.

(c) Reviewing international protocols and guidelines related to risk assessments, and prepare suitable national risk assessment protocols and guidelines for sectors that function as pathways of introduction and spread of IAS.

Need for a Risk Assessment Process for IAS in Sri Lanka

The implementation of risk assessment protocols to prevent further introduction of IAS to Sri Lanka was first highlighted a decade ago, at the First National Workshop on IAS (Marambe, 1999). Later, the urgent need to establish a standardize surveillance and a threat assessment of IAS in protected areas was also emphasized in the proposed policy on control of invasive species in protected areas of Sri Lanka (Weerakoon, 2007). Subsequently, the addendum to the Biodiversity Conservation (MENR, 2007) has also recommended action for preparation of risk assessment protocols for prioritization of established invasive species in Sri Lanka.

Despite of the acknowledgement of IAS as a major threat to biodiversity and the urgent need for identification and characterization of the risks associated with the noxious invaders, risk assessment for IAS has not been paid adequate attention in Sri Lanka over the past few years. Though there had been attempts to identify and characterize the risks associated with invasive alien flora no such work has been reported on invasive alien fauna in Sri Lanka. During the past few decades several lists of invasive plants and animals have been proposed by scientists in Sri Lanka (Bambaradeniya, 1999, 2000, 2002; Marambe *et al.,* 2001, 2003). However, they have not been resulted through scientific assessments on invasive status. Risk assessment protocols developed for IAS will be helpful to choose species incursions that warrant immediate control as most aggressive species with high invasion risks could be identified during the screening process. Thus, there is a need for development of rating methods (qualitative and/or quantitative) to measure relative risk of IAS in Sri Lanka.

Although risks associated with alien plant introductions are being considered at the points of entry by the Quarantine officers to regulate the entry of such species, IAS have not been specifically emphasized and addressed in standard regulations enforced to facilitate the regulation of species introductions. Prevention is considered the most economical and effective management strategy against alien invaders (Wittenberg and Cock, 2001). Hence, a better prediction of whether or not a species is likely to be invasive should be conducted at the national borders. It can reduce the subjectivity in judgments, balance out optimistic and pessimistic approaches and minimize overestimates and underestimates of risks associated with IAS.

Risk assessments for IAS will be helpful to select species that warrant immediate control as most aggressive species could be identified during the screening process. The various lists of invasive plants and animals proposed by scientists in Sri Lanka have not been resulted through evaluation of risks on invasion status. Thus, there is a need for development of a rating method (qualitative and/or quantitative) assessment scheme to measure relative risks of IAS in Sri Lanka. Also there is a tremendous need for risk assessment protocols, not only for invasive alien flora and fauna, but for sectoral activities that often function as pathways for introduction. Such sectors include fisheries, agriculture, forestry, horticulture, shipping, ground and air transportation, construction projects, landscaping, ornamental aquaculture, tourism and livestock farming, etc. There is a

need to evaluate the capacity and resource availability for risk assessments by relevant government agencies.

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ANNEXURE 1

Aspects that could be considered for a risk assessment criteria for IAS prioritization

(A) INVASIVE ALIEN FLORA

Ecological and socio economic impacts

- Impact on ecosystem processes
- Impact on community structure
- Impact on community composition
- Impact on genetic integrity
- Impact on any threatened species in the habitat
- Social nuisance and injury to human health/injury risks
- Impact on landscape diversity and aesthetic aspects
- Impact on agricultural/forestry/fishery productivity

Invasive potential

- Mode of reproduction
- Time of flowering
- Frequency of reproduction
- Pollination method
- Number of seeds per fruit
- Innate potential for long-distance dispersal
- Seed banks
- Role of anthropogenic and natural disturbance in establishment
- Current local rate of spread with no management
- Potential to be spread by human activities
- Vegetative regeneration
- Direct elimination of neighboring species
- Formation of dense thickets, climbing or smothering growth habit
- Germination/establishment requirements
- Rate of germination of seeds /seeding establishment presence of allelopathy
- Presence of physical defensive structures
- Whether species of the same genus/closely related species invasive

Distribution of the invasive species

- Current global distribution
- Known level of impact in natural areas (global)
- Whether species is highly domesticated and/or a weed elsewhere
- Distributions in Asia other than Sri Lanka
- Distribution in Sri Lanka
- Recent trend in total area infested within the island
- Rate of distribution
- Diversity of habitats/ecosystems invaded in a region
- Current spatial distribution (%) in above invaded habtats/ecosytems

Management options

- Level of effort required
- Any beneficial use of the plant
- If used commercially, whether it could lead to harmful impacts
- Present control measures adopted in Sri Lanka
- Effectiveness in control methods adopted in Sri Lanka
- Negative impacts of control measures
- Costs related to control methods
- Socio-political, religious, or ethical considerations on management

(B) INVASIVE ALIEN FAUNA

Impact analysis

- Impact on ecosystem processes
- Impact on agricultural/forestry/fishery productivity
- Impact on community composition/or behaviour of other organisms
- Impact on any threatened species in the habitat
- Social nuisance and injury to human health/injury risks
- Impact on genetic integrity
- Structural damages

Invasiveness

- Production of offspring
- Survival percentage
- Time of reproduction
- Frequency of reproduction
- Number of reproductive cycles per year
- Role of anthropogenic and natural disturbance in establishment of species
- Current local rate of spread with no management
- Population growth rate
- Potential to be spread by human activities
- Environmental plasticity
- Evidence of competitive elimination of co-occurring species
- Diet type (herbivore/carnivore/omnivore)
- Whether animal have special morphological adaptations capable of inflecting harm on other animals
- Other morphological or behavioral adaptations to enhance survival rate and competitive advantage
- Whether adults of the species is migratory or sedentary for breeding and feeding purpose
- Whether the species have invasive races, subspecies, etc.?

Distribution of the invasive species

- Current global distribution
- Known level of impact in natural areas (global)
- Whether species is a known pest/predator elsewhere
- Whether species has become naturalized where introduced
- Distributions in Asia other than Sri Lanka as an exotic species
- Distribution in Sri Lanka
- Recent trend in total area infested within the island
- Pattern of distribution/abundance in Sri Lanka
- Number of habitats/ecosystems invaded in Sri Lanka
- Current spatial distribution (%) in above invaded habitats/ecosystems
- Ability to live in human disturbed/modified habitats

Management options

- Growth stages susceptible to control
- Level of effort required
- Any beneficial use
- If used commercially, could it lead to harmful impacts
- Present control measures adopted in Sri Lanka
- Effectiveness in control methods
- In general, effectiveness in control adopted in Sri Lanka
- Negative impacts of control measures
- Known economic losses incurred on control/management of the species
- Socio-political, religious, or ethical considerations on management

Review paper

Chapter 4

Invasive Alien Plants in Sri Lanka

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Introduction

Invasiveness of a species is generally understood as the ability to spread beyond its introduction site and become established in new locations where it may cause a deleterious effect on organisms already exists. There are various definitions to invasive alien species (IAS), which are described elsewhere in this publication (see Chapter 1). From among the definitions described in Chapter 1, the information provided in this Chapter is based on the definition for IAS given by the SCBD (2009), *i.e.* "species whose introduction and/or spread outside their natural habitats threaten biological diversity".

History

Invasions are a basic characteristic of nature and have occurred ever since life first appeared on the Earth. Invasion can be considered as an integral part of evolution as any other mechanism or process. However, the unprecedented and accelerating rate of species invasions caused by the removal of natural impediments to dispersal, deliberate introductions and ecosystem changes caused by man have devastated ecosystems and caused enormous ecological and economic damage.

Deliberate plant introductions date back to the early days of human civilization, that the origin of some of the most useful crops of the world is unknown. For example, according to historical information, nuts of the coconut palm (*Cocos nucifera*) have been used even in the 2nd century. The National Botanic Gardens and the Department of Agriculture (DOA) have played a major role

Wijesundara, S. (2010): Invasive alien plants in Sri Lanka. In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 27-38. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

in early plant introductions. It would be impossible to estimate what Sri Lanka owes to plants that have been introduced from other countries and successfully acclimatized. Our principal economic crops, our tastiest fruits, our best shade trees, our most beautiful flowering trees, our major vegetables and our best fodders have all been introduced from other countries. Our most venerated tree, the sacred bo tree (*Sri Maha Bodhi*) at Anuradhapura, was also introduced to Sri Lanka 2,300 years ago from India (MacMillan, 1908).

However, some of the plants introduced have become noxious weeds or invasive plants. The Royal Botanic Gardens, Peradeniya played a major role in many such introductions. One of the best examples is Water Hyacinth (*Eichhornia crassipes*). That aquatic plant species was first introduced in 1905 to the Royal Botanic Gardens, Peradeniya by Lady Blake, the wife of the Governor from Hong Kong as an ornamental plant. By June 1912 it was reported from Wattegama in the central province, in 1914 it appeared near Tangalle in the southern province, and two years later in Chilaw in the north western province. By 1917 it was found in Sabaragamuwa Province. By 1930, four ordinances were in action to control this weed, namely Water Hyacinth Ordinance No. 4 of 1909, Plant Protection Ordinance No. 10 of 1924, Village Communities Ordinance No. 9 of 1914 and Irrigation Ordinance No. 45 of 1917 (Wijesundara, 1999). Table 1 gives some of the notable IAS introduced to Sri Lanka through the botanic gardens.

Table 1. Invasive alien flora introduced through botanic gardens.

Family	Species	Country of Origin	Year of Introduction
Asteraceae	*Ageratina riparia*	Mexico	1905
Asteraceae	*Tithonia diversifolia*	Mexico	1851
Clusiaceae	*Clusia rosea*	West Indies	1866
Dilleniaceae	*Dillenia suffruticosa*	Borneo	1882
Fabaceae	*Myroxylon balsamum*	Venezuela	1870
Fabaceae	*Prosopis juliflora*	Tropical America	1880
Fabaceae	*Ulex europaeus*	Europe	1888
Iridaceae	*Aristea ecklonii*	Guatemala	1889
Melastomataceae	*Clidemia hirta*	Tropical America	1894
Melastomataceae	*Miconia calvescens*	Mexico	1888
Polygonaceae	*Antigonon leptopus*	Tropical America	1870
Pontederiaceae	*Eichhornia crassipes*	Hong Kong	1905
Solanaceae	*Cestrum aurantiacum*	Cape of Good Hope	1889
Verbenaceae	*Lantana camara*	Tropical America	*ca* 1826

Types of Invasive Plants

Invasive alien plants can be herbs (e.g. *Alternanthera philoxeroides*), shrubs (e.g. *Cestrum aurantiacum*), creepers (e.g. *Sphagneticola trilobata*) or trees (e.g. *Prosopis juliflora*). They may invade terrestrial or aquatic ecosystems. Some of these species such as *Cuscuta* are parasitic (Wijesundara *et al.,* 2001). According to current knowledge almost all invasive alien plants reported from Sri Lanka are vascular plants (Angiosperms or Pteridophytes). Although a green alga, *Caulerpa taxifolia* has been reported as a sea weed, data on invasive lower plants are scanty in Sri Lanka.

Invasive Alien Plants in Sri Lanka and Their Extent of Spread

A few researchers have previously attempted to compile lists of invasive alien flora in Sri Lanka (Wijesundara, 1999; Bambaradeniya, 2002; Marambe *et al.,* 2003a). The main drawback of these attempts is the lack of proper criteria to determine the invasive nature of the listed species. Others have either documented the spread of several invasive alien plants in a specific locality (Ratnayake, 2008), or the spread of a single invasive alien plant species in different localities (Marambe *et al.,* 2000a, 2000b; Hitinayake *et al.,* 2000; Jayasuriya, 2001; Pushpakumara *et al.,* 2001; Medawatte *et al.,* 2008). Even though there are no accurate information on the degree of infestation, Amarasinghe and Ekneligoda (1997) reported that about 8,000 ha of rice fields were infested with *Salvinia* in 1988. Area invaded by *A. philoxeroides* was reported to be more than 200 ha of land in the southern province of Sri Lanka (Marambe *et al.,* 2003a). This has now been reported in the montane areas of the island. too.

Sri Lanka is blessed with a wide array of vegetation types distributed in diverse climatic zones. Some IAS are specific to certain ecosystems or climatic zones while others are widely distributed. Some of the common IAS and their current distribution are given in the Table 2.

Table 2. Common invasive alien flora and their distribution in Sri Lanka.

Family	Species	Distribution	Affected habitats/ecosystems
Asteraceae	*Ageratina riparia*	montane zone	Open areas in montane forests, roadsides
Apocynaceae	*Alstonia macrophylla*	sub-montane zone	degraded forests, forest edge
Amaranthaceae	*Alternanthera philoxeroides*	up- / low-country wet zones	fallow fields, marshy/ riparian areas
Annonaceae	*Annona glabra*	lowland wet zone	coastal lagoons, marshes
Polygonaceae	*Antigonon leptopus*	Dry zone	Degraded areas, rock outcrops
Iridaceae	*Aristea eckloni*	montane zone	Wet patina grassland
Asteraceae	*Austroeupatorium inullifolium*	montane zone	Montane grassland/ forest ecotone
Solanaceae	*Cestrum aurantiacum*	montane zone	montane forests
Melastomataceae	*Clidemia hirta*	sub-montane wet zone	Open areas in lowland rain forest edges
Clusiaceae	*Clusia rosea*	sub-montane zone	Rock outcrops/forest edges
Araceae	*Colocasia esculenta*	island-wide	wetlands, marshes
Convolvulaceae	*Cuscuta campestris*	island-wide except in upper montane zone	wastelands, agricultural land in low country
Dilleniaceae	*Dillenia suffructicosa*	low-country wet zone	forest edges, open scrublands

Table 2. Contd....

Family	Species	Distribution	Affected habitats/ecosystems
Pontederiaceae	*Eichhornia crassipes*	island-wide	reservoirs, ponds, marshes, streams
Hydrocharitaceae	*Hydrilla verticillata*	island-wide	streams, canals, marshes
Verbenaceae	*Lantana camara*	island-wide	scrubland, degraded open forests
Melastomataceae	*Miconia calvescens*	sub-montane zone	forest edges
Asteraceae	*Mimosa invisa*	island-wide	wastelands, agricultural lands
Asteraceae	*Mimosa pigra*	dry and intermediate zones	river banks, fallow fields, irrigation canals
Fabaceae	*Myroxylon balsamum*	wet and intermediate zones	sub-montane forests
Cactaceae	*Opuntia dillenii*	arid zone	thorn scrublands
Poaceae	*Panicum maximum*	island-wide	wastelands, dry patina grassland, agricultural lands
Asteraceae	*Parthenium hysterophorus*	dry and intermediate zones	wastelands, irrigation canals
Poaceae	*Pennisetum polystachyon*	dry and intermediate zones	Wastelands, dry patina grassland
Fabaceae	*Prosopis juliflora*	arid zone	thorn scrublands, edges of dry mixed evergreen forest, sea shore
Dennstaedtiaceae	*Pteridium revolutum*	montane zone	grasslands, riparian areas
Salviniaceae	*Salvinia molesta*	island-wide	reservoirs, ponds, marshes, streams, paddy fields
Asteraceae	*Sphagneticola trilobata (Wedelia trilobata)*	wet and intermediate zones	wastelands, roadsides, abandoned paddy fields
Asteraceae	*Tithonia diversifolia*	Wet, sub montane and intermediate zones	wastelands, roadsides
Fabaceae	*Ulex europeaus*	montane zone	montane forests, wet patana grasslands

Mode of Introduction and Spread of Invasive Plants

Introduction of invasive alien plant species may be deliberate or accidental. Deliberate introduction of an alien species applies to a collection of plants, which are useful, interesting or ornamental, and also imported (through institutions such as Royal Botanic Gardens). Such plants need to be treated with special care and propagated by artificial aid. A plant is said to be

naturalized when, having become independent of artificial aid of any kind, escaped from cultivation and thrives in a wild state. Some plants, which have been deliberately introduced for a specific purpose, have escaped from cultivation and become invasive. For example, salvinia (*S. molesta)* was introduced to Sri Lanka in the late 1930's as educational material, but appears to have escaped and is currently a one of the most troublesome aquatic invasive plants, blocking irrigation canals and water bodies and also invading aquatic ecosystems and rice fields in the dry and intermediate zones of Sri Lanka (Marambe *et al.,* 2003a).

It is believed that giant mimosa (*M. pigra*) was introduced in to Sri Lanka in the early 1980s to strengthen the river banks in the Mahaweli areas. That species has now introduced into other parts of the country by irrigation water, machinery, river sand used for construction purposes, and lopping branches with mature pods, as a result of the use of the stems of the plant as fuel wood by people (Marambe, 2000b).

Many other invasive species are spread by irrigation water. In some instances even the control measures can cause further spread of the plant meant to be controlled. For example, mechanical removal of water hyacinth has resulted in its spread due to contamination of the machinery used for this purpose (Marambe, 1999b). According to Jayasinghe (2004) the parasitic invasive plant, *Cuscuta campestris* is distributed by irrigation water in the Mahaweli areas.

Mesquite (*P. juliflora)* was first introduced by the Royal Botanic Gardens, Peradeniya in 1880. It is reported that it was introduced to the Hambantota district in southern province of Sri Lanka in early 1950s to improve saline soils, and as a form of ground cover (Algama and Seneviratne, 2000). *Prosopis juliflora* has become a very serious invasive plant threatening the ecosystems in Bundala National Park, a Ramsar wetland site in southern province. The seeds of this plant are dispersed by cattle as well as by elephants that eat the pods.

One of the best examples for accidental or non-deliberate introductions of an invasive plant is the Congress weed *(P. hysterophorus).* This plant was believed to have entered the northeast of the country in the late 1980s, through goats imported from India by the Indian Peace Keeping Force (IPKF). Seeds of *P. hysterophorus* have also entered the island along with seeds of onion and chillies imported from India as a contaminant. Since the colonial times many plant species introduced into the island have become invasive. Several IAS have been reported during the last few decades. Some plants show invasive characteristics after a considerable time since the first introduction. For example, the Guinea grass (*P. maximum*) was not considered a weed in 1908 (MacMillan, 1908) even though it is believed to have been introduced around 1801-1802 (Wisumperuma, 2008). Similarly, there may be some species which may become invasive in the future. A list of such species with invasive potential is given in Table 3.

It has been reported that climate change could result in both range expansion and contraction of invasive plants (Bethany *et al.*, 2009; Kriticos *et al.*, 2003; Dukes *et al.*, 1999). Although there are no quantitative ecological studies comparing the population sizes at different intervals, some invasive species such as *Austroeupatorum inulifolium, Clidemia hirta* and *Dillenia suffruticosa* have shown a marked increase in population sizes during the last three decades in Sri Lanka. It was also observed that *Pinus caribaea,* a plantation tree species, which did not regenerate naturally before, has shown invasive behavior (Medawatte *et al.,* 2008) in the Knuckles forest region. Whether these are due to the changes in climate needs to be investigated.

Nature of Threats

The IAS can cause significant changes to ecosystems, disturb the ecological balance, and cause economic harm to agricultural and recreational sectors. These IAS compete with native species for space, resources and plant-animal interactions. Few researchers have documented the harmful impacts of invasive alien flora on native biodiversity in Sri Lanka.

Table 3. A list of potential invasive alien plant species.

Family	Species	Remarks
Bignoniaceae	*Millingtonia hortensis* *(Indian cork tree)*	Dry zone. Native to south east Asia. This ornamental tree is seen occupying gaps in degraded sites in Embilipitiya, Thanamalwila areas .
Haloragidaceae	*Myriophyllum aquaticum* (Vell.) Verdc. (Parrot feather)	Montane zone. Native of the Amazon River in South America. Only reported in Gregory's Lake at Nuwara Eliya Lake (Sujith Ratnayake, Ministry of Environment (ME), Sri Lanka - Pers. Com.). Invasive in many countries including USA, Pacific Islands, Japan, New Zealand, South Africa and European countries.
Mayacaceae	*Mayaca fluviatilis* Aubl. (Stream bogmoss)	Wet zone. Ornamental aquatic. Escaped into some water bodies in the western province near Gampaha. Invasive in some countries (Dr. Kapila Yakandawala, Wayamba University of Sri Lanka – Pers. Com.)
Melastomataceae	*Tibouchina urvilleana* Cogn. (Glory bush)	Montane zone. Native to Southern Brazil. Small population in Horton Plans near Anderson Bungalow. Invasive in Hawaii and some pacific Islands.
Onagraceae	*Ludwigia sedoides* (Bonpland) H. Hara (False Loosestrife, Mosaic Plant)	Wet zone. Native to South America. Ornamental aquatic. Escaped into some water bodies in the western province near Gampaha. Invasive in some countries.
Poaceae	*Panicum trichocladum* K. Schum. (Donkey grass, creeping guinea grass)	Wet zone. Native to Africa. Probably imported as a pasture grass. Spreading in Hanguranketha, Pelmadulla, Kadawatha areas. First observed around 2002.
Poaceae	*Setaria barbata* Kunth. (bristly foxtail grass)	Wet zone. Native to Africa. Spreading in the mid country.
Verbenaceae	*Clerodendrum quadriloculare* (Blanco) Merr. (Philippine fireworks, Valentine Plant)	All zones. Native to Phillippines. Ornamental plant grown in many parts of the country. Invasive in the Pacific.
Vitaceae	*Cissus rotundifolia* (Forssk.) Vahl (Arabian wax cissus)	Dry Zone. Native to Africa. Cultivated ornamental. Invasive in some countries.

The flowers of *C. aurantiacum* are pollinated by an endemic bird, the Sri Lanka White Eye and the fruits of this species are dispersed by another endemic bird, the Yellow eared bulbul. Due to the abundance of *Cestrum* plants in the forest fringe, these two bird species are now found mostly in those areas and the pollination and dispersal of native species in the montane forest may be affected by the altered feeding habits of them.

The spread of *P. juliflora* in the Bundala area has deprived large mammals such as elephants of important habitats. It is now spreading in the lagoon shore areas of Bundala National Park, reducing the feeding area for wading birds (Bambaradeniya *et al.,* 2002).

As documented by Bambaradeniya *et al.* (2006), a rapid increase in the spread of Thorny cactus (*O. dillennii*) in the coastal scrubland and seashore habitats in Tangalle and Ambalantota areas subsequent to the December 2004 tsunami has resulted in the loss and/or deterioration of nesting habitats of globally threatened marine turtles that visit these areas annually. The spread of the invasive cactus has also hindered the regeneration of coastal vegetation destroyed by the tsunami, such as *Pandanus odoratissimus, Scaevola taccada,* and *Spinifex littoreus* (Bambaradeniya *et al.,* 2006).

As stated in the 2007 National Red List of Threatened Species, the spread of invasive alien plants such as *A. glabra, D. suffruticosa,* and *E. crassipes* has led to further degradation of the remaining marshy habitats of threatened blind eels (*Monopterus desilvai* and *Ophisternon bengalense*) in the western province of Sri Lanka (IUCN and MENR, 2007).

According to the research findings of Gunaratne *et al.* (2008), the preferred habitat types of native aquatic birds such as the Little grebe and the Pheasant-tailed Jacana are adversely affected by the spread of *S. molesta* and *E. crassipes* in tanks and reservoirs. Similarly, Weerakoon and Athukorala (2008) have stated that the feeding habitats of globally threatened spot-billed pelicans in Sri Lanka are adversely affected by these aquatic invasive plants.

A large area in the natural montane grassland in Horton Plains was cultivated with potato in 1961 to 1978 period. The cultivation was abandoned in late1970s. Those areas were later invaded by exotic, pasture grasses such as *Pennisetum clandestinum, P. thunbergii* and *Vulpia bromoides* escaped from the nearby cattle farm in Ambewela. The original montane grassland vegetation in the Horton Plans comprised of tussock grasses such as *Chrysopogon, Cymbopogon* and *Andropogon.* The change in physiognomy and composition due to potato cultivation followed by invasive alien grass species benefited the local population of sambhurs. The presence of nutritious pasture grasses and the increased safety due to absence of tussock grass cover for predators (leopards) may have caused the apparent increase in sambhur populations in Horton Plains (Wijesundara, 1997). On the other hand, lack of tussock grasses may have negatively affected the survival of leopards that used them for cover in hunting sambhur.

As Sri Lanka is an island with sensitive ecosystems consisting of a unique biodiversity it is very important to mitigate factors affecting regeneration of species. Impact of IAS on pollination and dispersal of native species is worth studying. Data on the statistics of distribution or economics of the damages due to IAS in Sri Lanka is scarce. The goat weed or white weed (*Ageratum conyzoides*) is said to have cost the planters £ 250,000 a year to control it during the time of coffee cultivation (MacMillan, 1908).

Control and Management Strategies Adopted

Control and management of IAS need a strategic approach that encompasses prevention, eradication, control and containment. Several legislative provisions have been enacted in Sri Lanka (see Chapter 6 in this book). These legislative acts and ordinances can be used to prevent and control introduction of IAS to a considerable extent. However, there are many areas to be improved in accordance with the current needs.

In 2007 (MENR, 2007), as a part of the Addendum to the Biodiversity Conservation in Sri Lanka - a framework for action, the Ministry of Environment (ME) of Sri Lanka has proposed to formulate a National Action Plan for the Control of IAS in protected areas. A National Invasive Species Specialist Group (NISSG) has also been proposed to be appointed to deal with the issues related to the alien invasions. The Biodiversity Secretariat of the ME has conducted many awareness programmes to educate the general public on the adverse impacts of IAS. Research on biology, impact and control of IAS is also receiving attention. About five national level workshops and symposia have been conducted on IAS in Sri Lanka since 1999, where useful information related to management and control of IAS were presented (Marambe, 1999a; Marambe, 2000a; Kotagama *et al.*, 2001; Ranwala, 2008; MENR, 2009). Marambe *et al.* (2003a) presented a draft national list of IAS, and recently, Marambe (2008) has highlighted the research priorities on IAS.

The ME, together with the DOA, implemented a one year project on management of aquatic weeds in 2005/2006, with funding from the FAO. This project involved awareness raising activities and pilot scale control programmes targeting *S. molesta*, *E. crassipes* and *P. stratiotes*. The Department of Wildlife Conservation (DWLC), in collaboration with the private corporate sector has implemented a programme to manage the spread of *P. juliflora* and *O. dillennii* in Bundala National Park.

The DOA is engaged in a biological control programme for *S. molesta* using the weevil *Cyrtobagus salviniae*. This has been successful and it was introduced into many parts of the country, especially in the low-country wet zone. This species has been declared as a serious pest under the Plant Protection Ordinance. The DOA is also rearing the bio-control agents *Neochetina eichhorniae* and *N. bruchi* and releasing the organisms as a measure to control *E. crassipes*. Recently, the DOA launched a chemical control programme for *E. crassipes* in the northwestern province in collaboration with the Irrigation Department. The DOA, together with ME, universities and other governmental, non-governmental and private organizations is actively involved in programmes to control *P. hysterophorus*. An extraordinary gazette notification was released by the government of Sri Lanka in December 2000, prohibiting the movement of materials contaminated with any part of *P. hysterophorus* from the infested areas (Marambe *et al.*, 2003a). Marambe *et al.* (2000b; 2003b) also attempted the control of *Mimosa pigra* by using glyphosate, which is a total killer systemic herbicide.

Many NGOs, in collaboration with the Ministry of Environment and Natural Resources, are actively involved in campaigns to eradicate IAS. Some of the programmes conducted to eradicate IAS have become complicated due to the interactions with wildlife. For example, the eradication programmes on *U. europaeus*, were aborted due to the fact that endemic lizards and amphibians seek protection from their natural enemies in this thorny plant (Bambaradeniya *et al.*, 2001). Programmes conducted by the DWLC to remove *L. camara* from the Uda Walawe National Park were also not successful due to various practical difficulties.

In some instances the control measures are affected by conflicts in the policies. For example, the Forest Department is reported to promote planting *C. rosea* in the Knuckles reserve as a fire prevention measure (as a biological barrier). Similarly the DWLC has been promoting the planting of *P. maximum* as a food source for elephants.

Conclusions

Many alien plants that have been introduced deliberately or accidentally have become invasive as they have escaped human management. The measure adopted to control them have mostly being through a piece-meal approach rather than being comprehensive. Early detection of and rapid response to new invasive alien plants (species), identifying the factors that may influence their spread, and application of control strategies requires a well coordinated participatory approach. Several strategies, which are discussed below, could be adopted to achieve effective control of invasive alien plants (or IAS in general) to minimize their impacts on the ecosystems of Sri Lanka.

A central coordinating committee (CCC) including all relevant stakeholders such as the government departments and institutes dealing with wildlife, forests, biodiversity, agriculture, botanic gardens, customs, marine environment protection, coast conservation, and scientists from the universities, should be established under the ME. The CCC should coordinate existing and future efforts on prevention and control of IAS. It could also enhance information exchange among scientists, government and non governmental agencies, and private sector. Integration of university`-based research to optimize management and prevention activities, effective communication techniques for wider and more effective delivery of public education about biological invasions would be some of the important role plays of the CCC to effectively deal with issues related to IAS.

Geographical distribution and areas of spread needs to be recorded for all known IAS in Sri Lanka. This information could be collected at grass root level using Global Positioning System (GPS) and Geographic Information Systems (GIS). Up-to-date information needs to be collected using the Grama Niladharis and other officers at village level and at Divisional Secretary level. All data should be recorded and updated in a central data base maintained at the CCC. Lists of potential invasives and information on their invisibility, vulnerability of sensitive ecosystems and environmental factors that affect spread of IAS need to be maintained at the CCC.

As discussed elsewhere in this book, there are many gaps in the knowledge of IAS in Sri Lanka. Some of the problems could be solved by conducting appropriate research, where it becomes a necessity to improve facilities in the universities and other relevant institutions involved in IAS research. Capacity building of scientists and the necessary infrastructure facilities should be provided to the relevant institutions.

One of the main obstacles to IAS control is the lack of access to current knowledge. In many developed countries Invasion Ecology is given a special attention. It is essential to facilitate local, regional and international co-operation on information exchange through workshops, symposia, seminars, public lectures, exhibitions, poster campaigns at local level and supporting the local scientists to participate and get involved in regional and international events related to IAS. Transboundary collaborations with relevant international knowledge networks such as the IUCN

Invasive Species Specialist Group (ISSG) and the Global Invasive Species Programme (GISP) would also enable to share and acquire new knowledge on IAS.

Programmes such as press conferences, TV and radio documentaries, and publishing informative articles in the print media at the national level for building awareness among the stakeholders should be designed and carried out by the CCC. There can also be seminars, workshops, exhibitions, poster campaigns, and public lectures at local level. Universities, agricultural schools and technical colleges can also be encouraged to accommodate IAS in their curricula at an appropriate level.

The main obstacle for capacity building and infrastructure development in any discipline is lack of funding. There should be a mechanism to channel adequate funding for human resource development and improving infrastructure facilities at relevant institutions. It can also be helpful if the leading research organizations such as the National Science Foundation (NSF), Council for Agricultural Research Policy (CARP) and National Research Council (NRC) recognize IAS as a priority area for providing research funding. The relevant private sector organizations should also be encouraged to initiate an endowment for IAS research.

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Review paper

Chapter 5

Invasive Alien Fauna in Sri Lanka: Introduction, Spread, Impacts and Management

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Introduction

Sri Lanka has recognized invasive alien species (IAS) as a major threat to the native biodiversity (IUCN and MENR, 2007). They grow rapidly, compete vigorously and in the absence of their natural predators, push out native species and alter ecosystems, causing damages to the environment, human health, livelihoods and economy (IUCN, 2005). The IAS gained national level attention approximately two decades ago. However, the introduction of IAS to Sri Lanka has occurred since historical times. Although natural barriers such as oceans, mountains and rivers, facilitate species and ecosystems to evolve in isolation, such barriers have failed with globalization, where trade, transport, travel and tourism have accelerated the species movement through the barriers. The macroeconomic policies introduced by the Sri Lankan government in late 1970s have also facilitated the entry of IAS to the country (Marambe *et al.*, 2001). This report provides an overview of the status of invasive alien fauna in Sri Lanka, based on published information up to the year 2008.

Invasive Alien Fauna reported in Sri Lanka

A few researchers have documented the presence of invasive alien faunal species in Sri Lanka, especially over the past two decades. Bambaradeniya (2002) has listed twenty species of invasive alien fauna, consisting of 15 vertebrates and 5 invertebrates, which were spreading in the natural and semi-natural ecosystems in the different bioclimatic zones of Sri Lanka (Table 1).

Silva, P. and Kurukulasuriya, M. (2010): Invasive alien fauna in Sri Lanka: Introduction, spread, impacts and management. In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 39-61. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

The 15 species of vertebrates include nine species of fresh water fishes, one reptile and five mammals, and five species of invertebrates consisting of molluscs. Among the total IAS listed for Sri Lanka by Bambaradeniya (2002), 10 species of fauna are included in the list of 100 of the world's worst IAS (IUCN-ISSG, 2001). Twelve species of most troublesome invasive alien fauna in Sri Lanka has been listed in the recently updated National Atlas of Sri Lanka (Table 1; Wijesekara and Bambaradeniya, 2007). This is a sub set of the list published by Bambaradeniya (2002) and Marambe *et al.* (2003).

Table 1. The list of invasive alien fauna recorded in Sri Lanka (Bambaradeniya, 2002).

Species	Common category	Common Name	Scientific Name
Vertebrates	Freshwater fish	Rainbow Trout[1,2]	*Oncorhynchus mykiss*
		Clown Knife Fish[1,2]	*Chitala ornata*
		Plecostomus Cat Fish[2] (Tank Cleaner)	*Pterygoplichthys multiradiatus*
		Walking Cat Fish[1]	*Clarias batrachus*
		Guppy[2]	*Poecilia reticulata*
		Western Mosquito Fish	*Gambusia affinis*
		Mosambique Tilapia[1]	*Oreochromis mossambicus*
		Carp	*Cyprinus carpio*
		Snakeskin Gouramy[2]	*Trichogaster pectoralis*
	Turtle	Red Eared Slider Turtle[1]	*Trachemys scripta*
	Mammals	House Mouse	*Mus musculus*
		Ship Rat[1,2]	*Rattus rattus*
		Feral Cat[1]	*Felis catus*
		Feral Dog[1]	*Canis familiaris*
		Feral Buffalo[1,2]	*Bubalus bubalis*
Invertebrates	Mollusks	Apple Snail[1,2]	*Pomacea diffusa*
		Giant African Snail[1,2]	*Lissachatina fulica*
		Field Slug[2]	*Laevicaulis alte*
		Garden Slug[1]	*Deroceras reticulatum*
		Garden Slug	*Deroceras caruanae*

[1] species identified in the National Atlas of Sri Lanka (Wijesekara and Bambaradeniya, 2007);
[2] species listed by Marambe *et al.* (2003)

Provincial level lists of invasive alien fauna have also been published recently by the Ministry of Environment (ME) of Sri Lanka, except for the northern and Sabaragamuwa provinces. These seven provincial lists include 15 species of invasive alien fauna in the Western Province (Bambaradeniya, 2008), seven in the north western province (Weerasinghe, 2008), five in the southern province (Gunawardena, 2008), three in the north central province (Sumithrarachchi, 2008), two in the uva province (Jayasuriya, 2008) and one each in the eastern (Jeyasingham, 2008) and central provinces (Jayasuriya, 2008) (Annexure 1).

The summary of the distribution of invasive alien fauna in Sri Lanka based on that documented by Bambaradeniya (2002) and the seven provincial lists given above is summarized in Table 2. All the invasive alien fauna identified in the provincial lists have also been listed by Bambaradeniya (2002) except for one exotic fresh water fish species, Nile tilapia (*Oreochromis niloticus*) that has been identified as invasive in the north central province. It is interesting to note that four species namely, rainbow trout, snakeskin gouramy and the two garden slug species that were

identified in at least one of the previous national lists (Bambaradeniya, 2002; Marambe *et al.*, 2003; Wijesekara and Bambaradeniya, 2007) have not been reported in any of the seven provincial lists of invasive alien fauna (see also Annexure 1).

Table 2. Distribution of invasive alien fauna in the seven provinces.

Invasive Alien Fauna	NW	NC	Uva	WP	CP	EP	SP
Rainbow Trout (*Oncorhynchus mykiss*)	----------	----------	----------	NR	----------	----------	----------
Clown Knife Fish (*Chitala ornata*)	♦	♦		♦			♦
Plecostomus Cat Fish (*Pterygoplichthys multiradiatus*)	♦			♦			
Walking Cat Fish (*Clarias batrachus*)	♦			♦			
Guppy (*Poecilia reticulata*)	♦			♦			♦
Western Mosquito Fish (*Gambusia affinis*)	♦			♦			
Mosambique Tilapia (*Oreochromis mossambicus*)	♦	♦	♦	♦	♦		♦
Carp (*Cyprinus carpio*)				♦		♦	
Snakeskin Gouramy (*Trichogaster pectoralis*)							
Red Eared Slider Turtle (*Trachemys scripta*)		♦		♦			
House Mouse (*Mus musculus*)				♦			
Ship Rat (*Rattus rattus*)				♦			
Feral Cat (*Felis catus*)				♦			
Feral Dog (*Canis familiaris*)				♦			
Feral Buffalo (*Bubalus bubalis*)	♦		♦				♦
Apple Snail (*Pomacea diffusa*)				♦			♦
Giant African Snail (*Lissachatina fulica*)				♦			
Field Slug (*Laevicaulis alte*)				♦			
Garden Slug *(Deroceras reticulatum)*	----------	----------	----------	NR	----------	----------	----------
Garden Slug *(Deroceras carunae)*	----------	----------	----------	NR	----------	----------	----------

(NW – North Western Province, NC – North Central Province, WP – Western Province, CP – Central Province, EP – Eastern Province, SP – Southern Province). NR – Listed previously by several authors as nationally important, but not recorded in the provincial lists.

Several exotic invertebrates recorded from Sri Lanka are restricted to agricultural habitats, and function as pest species. Several species of European garden slugs (*Deroceras retuculatum, D. leave, D. karuanae*) have recently invaded the agricultural habitats in the central highlands above 1000 m elevations (Naggs, 2002; Mordan *et al.*, 2003; Raheem and Naggs, 2006; Kumuburegama and Ranawana, 2007). The Potato cyst nematode (*Globodera rostochiensis*), originated in South American countries, was detected in Sri Lanka in the latter part of 1980's when it became a serious pest in the Nuwara Eliya district in the central province (Ekanayake, 1999). The Beet/Potato leafminer (*Liriomyza huidobrensis*), which was reported in 1997, as well as *L. sativae* are serious pests of vegetable cultivations (Ekanayake, 1999; Marambe *et al.*, 2003). Some of the recently introduced pest species such as paddy root knot nematode (*Meloidogyne graminicola*) and *Steneotarsonemus spinki* has become serious pests of rice in Sri Lanka (Marambe *et al.*, 2003). The Coconut mite (*Aceria guerreronis*) was first reported in Guerrero State of Mexico in 1965 and was reported in Sri Lanka in 1997. *Acaphylla theae* was recorded as an exotic pest in tea cultivations (Marambe *et al.*, 2003). There are several other species such as lesion nematode (*Pratylenchus vubrus*), fruit fly species (*Braciocera dorsalis* and *B. zonata*) (Ekanayake, 1999) and *Aleurodicus dispersus* (Marambe *et al.*, 2003) that function as exotic pests of fruit cultivations and other agricultural crops. The most recently documented arthropod IAS in Sri Lanka is the Papaya mealybug (*Paracoccus marginatus*) (www.sundaytimes.lk/090412/News /sundaytimesnews _30.html).

Exotic Fauna as Potential Invasive Species

Several exotic faunal species have already established breeding populations in Sri Lanka, and could be potential invaders in the future. For example, the feral rock pigeon (*Columba livia*) was introduced to Sri Lanka by British as a pet (www.sundaytimes.lk/ 030615/funday/2.html), but the species has been identified as a pest of paddy in some Asian countries, as they form large flocks causing considerable damage during a short time. According to a recent study, a high abundance of exotic populations of earthworms has been observed in agro-ecosystems of the Uva and central provinces, compared to indigenous earthworms (De Silva and Julka, 2008). In this situation, the exotic population could impose a pressure on the local population through competition for resources. Mordan *et al.* (2003) have identified three snails namely, *Eustreptaxis kibweziensis*, *Pomacea canaliculata*, and *Bradybaena similaris* and one slug (*Milax gagates*) with the potential to become invasive in Sri Lanka. All these species are restricted to agricultural lands. Bumble bee (*Bombus terrestris*), which was introduced to Sri Lanka for the purpose of pollinating strawberries grown for commercial purposes in Nuwara Eliya, is capable of spreading in an invasive manner, displacing the native hymenopteran pollinators (Bambaradeniya, 1999). However, this species has not been recorded to-date in wild habitats of Nuwara Eliya or in any other location in Sri Lanka. Several species of piranhas have already been imported to Sri Lanka by the ornamental fish trade. Introduction of piranhas to natural water bodies, and their potential to establish breeding populations, could pose a serious threat to native fish populations (Bambaradeniya, 1999). Erythrina gall wasp (*Quadrastichus erithrinae* Kim.) and eucalyptus gall wasp (*Leptocybe ginvasa*), which are known invasives in countries in the region, have recently been identified in Sri Lanka (Dr. Anura Wijesekara, Department of Agriculture, Sri Lanka – personal communication). Continuous monitoring of these exotic pest populations is needed to understand their invasive behaviour.

Marine Invasive Species

The globalization process has facilitated international trade, especially by ships. With the increase in international trade, the invasion of alien species through ballast water in ships has become a major problem. Ballast is the water pumped in to the ballast tank of a large ship to keep it balanced and to ensure the safe travel after the removal of large weights. The life forms such as small fish, shell fish, worms, star fish, crustaceans, algae, bacteria, viruses, etc. may enter in to the ships through ballast water and released into new areas with the emptying of ballast water. Since Sri Lanka is located in the middle of the trans-oceanic route, which connects the east and west, Sri Lankan maritime zone is at a risk of invasion with alien marine species which travels through ballast water. However, there is only a single study been carried out in Sri Lanka on the invasion of alien marine species (Chandrasekara and Fernando, 2009), which reported that the effects of introducing alien species to Sri Lankan maritime zone by disposal of ballast water are not profound. However, out of the 57 different taxa of planktons found in the ballast water tanks, 30 taxa were not recorded from any of the local study sites (Chandrasekara and Fernando, 2009), which can be aliens to the country. Therefore, more studies on marine invasives are essential to overcome the potential threats on the marine ecosystems of Sri Lanka.

Black List of IAS

Apart from the identified IAS and potential invasive species in Sri Lanka, there are many species that have invaded the ecosystems of the countries in the region. Though they seem to have not

invaded Sri Lanka to-date, there is a potential risk of introduction to the country. Therefore, listing of worst IAS found in the region is essential as a precautionary measure. Such species can be included in a "Black List", and some potential candidates for such listing are given in Table 3.

Table 3. Potential Black list of invasive alien fauna for Sri Lanka.

Category	Common Name	Scientific Name
Mollusk	Golden apple snail[1]	*Pomacea canaliculata*
Mollusk	Rosy wolf snail[1]	*Euglandina rosea*
Amphibian	Bull frog	*Rana catesbeiana*
Fish	Large mouth black bass	*Micropterus salmoides*
Fish	Brown trout	*Salmo trutta*
Fish	African catfish	*Clarias gariepinus*
Bird	Common starling	*Sturnus vulgaris*
Insect	Yellow crazy ant[1,2]	*Anoplolepis gracilipes*
Insect	Cotton white fly[2]	*Bemisia tabaci*
Insect	Khapra beetle	*Trogoderma granarium*[1]
Crustacean	European shore crab	*Carcinus maenas*
Crustacean	Caribean bivalve	*Mytilopsis sallei*
Crustacean	Indian mussel	*Brachidontes striatulus*

Note: [1] Species have being introduced to Sri Lanka according to the ISSG database; [2] Species have found/reported at least once in Sri Lanka, however, with no records thereafter.

Mode of Introduction and Spread of Invasive Alien Fauna in Sri Lanka

According to the available records, the invasive alien fauna have been introduced to Sri Lanka either deliberately or accidentally. Deliberate introductions have been made for the purpose of commercial fishery, sport fishery, mosquito control, agriculture or animal husbandry and ornamental fish industry. Accidental introduction of several invasive alien fauna have occurred through pathways involving transport, trade, travel and tourism. Some others have been introduced for use in captivity, from which there is a known risk of escape or release to the wild due to negligence. The escaped species have invaded many natural ecosystems in Sri Lanka, but the published information available on distribution of invasive alien fauna in Sri Lanka is relatively low when compared to invasive alien flora.

The freshwater fisheries and the ornamental fish industry are the major sectors that have been responsible for the introduction of freshwater invasive species to Sri Lanka. The Rainbow trout (*O. mykiss*) was deliberately introduced to Sri Lanka from California in 1882 as a sport fish (Pethiyagoda, 1999). This species was introduced to some streams in the Horton plains and other up-country streams by the Ceylon Fishing club and thereafter their populations were controlled by the club. With the Ceylon Fishing club becoming non-functional, the Rainbow trout has bred in Horton plains and established in the fast flowing *"Belihul oya"* and *"Agra oya"* (www.dailynews.lk/2006/08/28/fea06.asp). Rainbow trout has been reported to be the only freshwater fish species found in the Horton plains at present (Pethiyagoda 1999; www. dailynews.lk/2006/08/28/fea06.asp). The guppy (*P. reticulata*) and western mosquito fish (*G. affinis*) have been deliberately introduced to Sri Lanka for the purpose biological control of mosquito larvae. The western mosquito fish (*G. affinis)* is indigenous to south eastern parts of the United States and the northern Mexico (Matthews, 2004). According to Pethiyagoda (1991), the western mosquito fish is well distributed among the marshes, ditches and streams of the lowland wet zone. There is no any other information found on this species. The Guppy (*P.*

reticulata) has also been introduced to several inland waters in dry zone and western province of Sri Lanka as a mosquito bio-control agent in 1930. Three different varieties of *P. reticulata* have already been neutralized in Sri Lanka. This species has expanded its range in to more riverine areas and now well established in the upper catchments areas (elevation > 1000m) of the "*Mahaweli*" and "*Kelani*" river basins (Shirantha *et al.* 2008).

The introduction of some fishes such as tilapia, carp and snakeskin gouramy was for the purpose of promoting commercial fishery, mainly as a source of protein for the rural people, especially in the dry zone. At least five species of tilapia, including Mozambique tilapia (*O. mossambicus*) that has already become invasive (Pethiyagoda, 1999), have been introduced to inland waters of Sri Lanka since 1952. Tilapia has invaded aquatic habitats throughout the entire dry zone, and is probably the most abundant freshwater fish species in this area. It occurs in many estuaries and lagoons in the dry and wet zones, and large streams, reservoirs and rivers of the wet zone lowlands up to 600m elevation. The geographical distribution of tilapia is not confined to these areas, and is also known to occur in pockets of aquatic habitats in the central hills (Pethiyagoda, 1999).

The Common Carp (*C. carpio*), which is native to Europe was also introduced to Sri Lanka in 1915 to promote inland commercial fishery. In the global scenario, it was one of the first species to be introduced outside its natural range and now has a global distribution (Matthews, 2004). The common carp has occupied many headwater streams 1500 masl elevation in Sri Lanka (Pethiyagoda, 1999). The Snakeskin Gouramy (*T. pectoralis*) was introduced to Sri Lanka from Malaysia in 1951 (www.fao.org/ fishery/introsp/ 2686/en). It is distributed throughout the dry and intermediate zones in tanks, reservoirs, marshes and streams (Marambe *et al.,* 2003).

Some fish species that have been imported to Sri Lanka for ornamental purposes have escaped into wild aquatic habitats due to negligence, and become a threat to native aquatic biodiversity. These include clown knife fish/clown featherback (*C. ornata*), tank cleaner/sucker mouth cat fish/Plecostomus cat fish (*P. multiradiatus syn. H. plecostomus)* and walking cat fish (*C. batrachus*). These species have escaped from tanks and ponds of aquarium fish breeders, and entered the waterways of the western coastal flood plain, including the "*Kalu ganga*" (river), "*Kelani*" river and "*Attanagalu oya*" (Pethiyagoda, 1999). *Chitala ornata* was first reported in "*Diyawanna oya*" in 1994 and it is widespread in streams and reservoirs in the wet zone of Sri Lanka (e.g. "*Diyawannawa oya*", "*Panape ela*" in Mellana (Horana), "*Wevita wewa*" in Bandaragama, "*Weres ganga*" in Moratuwa, Godangoda and Mathugama (Amarasinghe *et al.,* 2006). The sucker mouth cat fish is one of the accidentally introduced invasive alien fish species that occurs mainly around Colombo, Gampaha, Kandy and Kalutara districts (Wijethunga and Epa, 2008), and recently reported in Polgolla reservoir (Epa and Bandara, 2009) and "*Parakrama Samudraya*" reservoir (Shirantha, 2009) as well. The spread of this species to Polgolla reservoir is a matter of concern, as there is a high possibility of it to expand the range of invasion into the Mahaweli river basin as predicted by Amarasinghe *et al.* (2006). The walking cat fish *(C. batrachus)*, is closely-related to spotted cat fish (*C. barchysaoma*), which is endemic to Sri Lanka. The former is native to Thailand, Burma and Indonesia. Although *C. batrachus* has been introduced to many countries as a food source, this species was introduced to Sri Lanka as an ornamental fish (www.island.lk/2000/12/01/ featur02.html). It has also escaped into the natural aquatic ecosystems due to the negligence of the ornamental fish breeders. It is distributed in the marshes and streams of lowland wet zone (Weerawardane and Dissanayake, 2005). However, United States Geological Survey (USGS) fact sheet on *C. batrachus* has incorrectly included Sri Lanka in its native range of distribution (www.island.lk/2000/12/01 featur02.html).

Apart from these exotic fish species, the ornamental fish trade has been the responsible for the introduction of an invasive alien turtle; red eared slider turtle (*T. scripta)* and an aquatic mollusk; apple snail (*P. diffusa*). *Trachemys scripta* has escaped from the aquariums and invaded the wetland ecosystems mainly in the western province of the country. *Pomacea diffusa* was introduced in 1980 as an ornamental aquarium animal due to its beauty and scavenging habits (www.island.lk/2009/01/28/features3.html). Being a prolific breeder, *P. diffusa* became a nuisance to fish breeders, who eventually dumped them in to ditches and surrounding aquatic habitats (Bambaradeniya, 1999; Perera and Epa, 2008). Initially *P. diffusa* was restricted to Colombo region, but it has eventually invaded Kalutara, Kandy, Rathnapura, Gampaha, Matara and Galle districts (Perera and Epa, 2008). The major habitats of *P. diffusa* are swamps and wetlands with clean waters as well as highly polluted canals in the urban areas. According to Epa (2006), *Pomacea* sp. survives in canals in Colombo and Galle, which do not have any aquatic vegetation.

Among the land snails listed as invasive species in Sri Lanka, the giant African snail (*L. fulica*), was deliberately introduced on a tea estate near Watawala in 1900 (Mordan *et al.,* 2003). This snail is well distributed in the modified habitats and in the natural forests from coastal areas to the lower slopes of the central highlands ranging from the dry and intermediate zones to the wet zone. However, it has not been recorded from the primary forests. This species has recently spread into the semi-arid south-eastern coastal areas in the Hambantota district, probably through the transportation of organic fertilizer for agricultural purposes (Lelwala *et al.*, 2008). The garden slugs (*D. reticulatum, D. laeve, D. caruanae*) have been introduced accidentally from Europe, to the vegetable cultivation areas in the central highland (1000 m), especially in the Nuwara Eliya area, through horticultural imports. *Deroceras reticulatum* is recorded from modified habitats of highlands (>1000 m) of the wet zone (Mordan *et al.,* 2003; Naggs *et al.,* 2003). Similarly, the land slug (*L. alte*) is presumed to have been introduced with cultivated plants and is found predominantly in the hotter, lowland areas. The geographical distribution of *L. alte* includes modified habitats and the natural forests of lowlands (<1000) of wet zone, excluding the primary forests of Sri Lanka (Naggs *et al.*, 2003).

Several introduced mammals have become a threat to the native biological diversity of Sri Lanka. The house mouse (*M. musculus)* and ship rat (*R. rattus)* have probably been accidentally introduced to Sri Lanka as hitch-hikers in ships. They are distributed throughout the island in natural and managed terrestrial habitats. The domestic buffaloes (*B. bubalis*) were introduced to Sri Lanka since historical times for animal husbandry and agriculture. During the fallow period of rice cultivation, rural farmers release them to wild and recapture during the subsequent next cultivation. As a result the domestic buffalo has interbred with wild water buffaloes and has formed feral populations (Marambe *et al.*, 2001). These feral buffalo populations are distributed in the forest ecosystems throughout the country, especially in the dry zone. Other than the buffaloes, the alien domestic animals such as cats and dogs in Sri Lanka are not properly managed, especially in the rural areas closer to natural or semi-natural ecosystems. Some of these domestic pets behave as feral animals in wild habitats, causing threats to native animal species (Marambe *et al.*, 2001). However, there are no records of rapid expansion of these feral populations (Mr. H.D. Ratnayake, Deputy Director/Department of Wildlife Conservation - personal communication). Unavailability of population records and trends is a major drawback in reaching a concrete conclusion on the invasiveness of feral populations, including feral buffalo. The mode of introduction of the most recently documented invasive alien Papaya mealybug (*P. marginatus*) is still not reported (www.sundayobserver.lk/2009/03/15/new31.asp). The years of introduction of invasive alien fauna is illustrated in Figure 1.

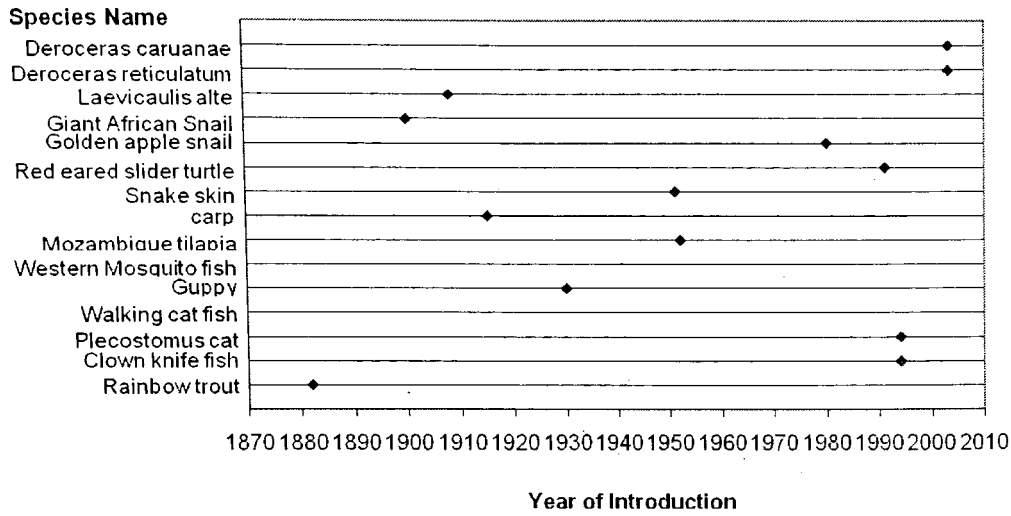


Figure 1. Years of introduction of invasive alien fauna to Sri Lanka (based on different sources).

Interestingly, six out of 13 species, whose data on year of introduction is available, have entered Sri Lanka after 1980. This information infers that open economic policies adopted by the Sri Lankan government in late 1970's resulting in an increase in international trade, transport and tourism, have facilitated the entry of IAS to the country (Marambe *et al.*, 2001, 2003).

Impacts of Invasive Alien Fauna in Sri Lanka

The IAS have resulted in major impacts on biodiversity. At a global scale, at least 39 per cent of the species extinction during the past 400 years is due to IAS (www.Indiaenvironmentportal.org.in/node/38152). Even though, some species have caused direct extinction of species, the nature of threats posed by IAS varies depending on the species. The following section highlights the impacts of invasive alien fauna in Sri Lanka, under different impact categories, with specific examples.

(1) Direct exploitation/destruction of native species

The major impact of the invasive alien fauna is direct exploitation or destruction of native species, by functioning as predators. For instance, rainbow trout (*O. mykiss*) is known to feed on aquatic organisms such as crabs, shrimps, insects and other fish. It has been responsible for the extinction of two unidentified fish species in the montane zone (Pethiyagoda, 2006). These two unidentified species of fishes was recorded from an altitude of 1800 m in the 1840s by Kelaart (1852), and subsequently disappeared after the introduction of *O. mykiss* (www.dailynews.lk/2006/08/28/fea06.asp). As the rainbow trout is known to feed on crabs and shrimps, it is possible that it may have affected the populations of the endemic shrimp *Caridina singhalensis* as well as the endemic crabs, *Perbrinckia punctata* and *P. glabra* (Bambaradeniya, 2000).

The clown knife fish (*C. ornata*) is also a large, notorious predator whose increase in populations has decreased the abundance of several small surface-dwelling fish species in Sri Lanka. The morphology of clown knife fish and its occupation of a perfect niche in the water have triggered

the destruction of habitats and disappearance of native biota (Weliange, 2009). The recent investigations done by Shirantha and Amarasinghe (2009) have indicated an ontogenetic dietary shift of *C. ornata* having potential adverse impacts on aquatic fauna, including native fish populations. The abundance of native fish species such as *Aplochielus dayi, A. parvus, Horadandiya athukorali, P. vittatus, P. bimaculatus, R. daniconius* and *Amblypharyngodon melettinus* have decreased since the introduction of *C. ornata* in 1994 (Gunawardena, 2002). *Clarias batrachus*, which is another predator, has also contributed to the direct exploitation of native species (Weerawardane and Dissanayake, 2005).

Even though the guppy (*P. reticulata*) was introduced to control mosquito larvae due to its larvivores feeding habits, its efficacy as a biocontrol agent is now questionable. Shirantha *et al.* (2008) have reported that the omnivorous feeding habits of the *P. reticulata* is changing towards carnivorous feeding habits, hence functioning as an agent for biodiversity loss in the riverine habitats of Sri Lanka. Previous observations have also revealed that *P. reticulata* are feeding on the eggs of amphibians (Bambaradeniya, 1999). The recently introduced red eared slider turtle (*T. scripta*), being a predatory carnivore, poses a potential threat to the native aquatic vertebrate fauna, including fish species (Kotagama and Bambaradeniya, 2006).

The feral populations of cats (*F. catus*) and dogs (*C. familiaris*) have also been reported to predate on wild animals such as reptiles, birds and small mammals (www.sundaytimes.lk/030615/funday/2.html). Although there are no records of rapid expansion of feral cat and dog populations in Sri Lanka, several researchers have documented there impacts on native biodiversity. *Canis familaris* was reported to attack wild animals in Bundala National Park Bambaradeniya *et al.* (2002), and avidly search and feed on the eggs of marine turtles in the coastal areas of the island (De Silva, 1999; Ilangakoon, 2000; Bambaradeniya *et al.*, 2002). De Silva (2007) has documented that *F. catus* destroy herpetofauna in home gardens.

(2) Superior competitors for resources

Some invasive alien fauna found in Sri Lanka function as superior competitors for resources over native species, and displace them. For instance, Mosambique tilapia (*O. mossambicus*) is non-selective in its diet and breeds prolifically, enabling it to colonize in the tanks, reservoirs and slow flowing rivers while displacing the native inhabitants such as *Labeo porcellus* and *L. dussumieri* (Pethiyagoda, 2000). *Oncorynchus mossambicus* breeds throughout the year, but more frequently during the rainy season, which overlaps with the breeding season of most of the indigenous fishes. The diet of small *O. mossambicus* comprises zooplanktons, which are feed resources of the indigenous fish. It seems quite possible that the drastic population decline of endemic red-in labeo (*Labeo lankae*), the distribution of which overlapped completely with the spread of *O. mossambicus*, have been due to intense competition with the latter species (Pethiyagoda, 1999). Pethiyagoda (2006) has further stated that *O. mossambicus* appears to be responsible for driving *L. lankae* towards extinction in Sri Lanka.

Recent studies by Ahamed and Dharmaretnam (2009) indicated that *O. mossambicus* occupy the same environment and habitat of the indigenous cichlid (*Etroplus suratensis*), and that *O. mossambicus* probably competes with the latter for nesting space. However, the listing *O. mossambicus* as an IAS has been challenged by many aquaculture specialists, given its adoptability to thrive through varying and harsh ecosystems and also with the claim that endemic fish species do not exists in reservoirs where *O. mossambicus* are abundant (Amarasinghe *et al.*, 2006). Furthermore, Amarasinghe *et al.* (2008) pointed out that though

populations of *O. mossambicus* have been established in some patches of non-flowing habitats of certain rivers, it is unlikely that significant dietary overlaps occur between this alien fish and the indigenous fish species. However, the impact of co-occurring populations of tilapia and indigenous fish is not clear in any of the studies due to lack of availability of temporal data. Hence, unbiased assessment on their adoptability, and the market and social values in the natural habitats is still warranted. Some studies have revealed that the tank cleaner can be a superior competitor to the native biota. It has omnivores feeding habit varying from plankton, plant matter to invertebrates. Therefore, further invasion of the tank cleaner (*P. multiradiatus*) in inland waters may pose a threat to the endemic fish species that have the same feeding habits (Wijethunga and Epa, 2008). Further, the scrape feeding habits of them could change the habitat quality, leading to detrimental effects on co-occurring species (Amarasinghe *et al.*, 2006).

The feral buffaloes (*B. bubalis*) have become competitors to the large herbivores such as deer, sumbur and elephants, mainly for food resources in the dry zone. The wallowing habits of the feral buffaloes make the aquatic habitats muddy, thereby, deterring other animals such as elephants, which comes to drink water (Bambaradeniya, 2000). A research carried out by Wijesinghe (2001) in Sinharaja rainforest has revealed a negative abundance relationship between endemic rat (*Srilankamys ohiensis*) and exotic rat (*R. rattus*) species, suggesting that these species are competing for resources.

(3) Hybridization with native species

The domestic buffaloes have interbred with the native wild water buffaloes (*B. arnee*) to form the feral populations in many protected areas in Sri Lanka (Bambaradeniya, 2002). This has probably led to the local extinction of genetically pure populations of the wild water buffalo that has been reported in locations such as the Wilpattu National Park (Deraniyagala, 1964). The three sub species of ship rat (*R. rattus rattus, R. r. alexandrianus* and *R. r. rufescens*), which were introduced to Sri Lanka accidentally have probably interbred with the two local subspecies (*R. r. kandianus and R. r. kelaarti)* to form mix populations (Bambaradeniya, 2000). However, the level of hybridization of the native and the domestic buffaloes, as well as the *Rattus* species, needs to be verified through a molecular biological study of their populations.

(4) Agricultural pests

The role of some IAS in Sri Lanka as pests of agricultural crops in Sri Lanka has also been documented. The European garden slugs (*Deroceras* spp.) are pests of agricultural/horticultural crops, especially in the highland areas (Raheem and Naggs, 2006; Mordan *et al.*, 2003). *Deroceras reticulatum* is a serious pest of many vegetables, especially of leaf crops such as cabbage and lettuce and the seedlings of root crops such as carrot. It also damages the flowers of ornamental plants such as Gerbera growing in green houses (Mordan *et al.*, 2003). The farmers have used substantial doses of pesticides to control them without any success (www.sundaytimes.lk/030615/funday/2.html).

The field slug (*L. alte*) is an important pest in the Matale region in the central province of Sri Lanka, where it attacks a wide variety of crops (Mordan *et al.*, 2003). The giant African snail (*L. fulica*) is a voracious feeder of plant matter. It feeds on vegetables, especially lettuce and cauliflower, fruits such as papaya, breadfruit and jackfruit and various ornamental plants. This snail also attacks the seedlings of some plantation crops such as tea (Mordan *et al.*, 2003). Although the common coucal (*Centropus sinensis*) is a predator of the *L. fulica*, the nocturnal

habits of the latter species has enabled its populations to avoid being regulated by the former species. The mollucides such as metaldyhide are used to control this snail, without much success (www.island.lk/2009/01/28/features3.html).

The apple snail (*P. diffusa*), which spreads in aquatic ecosystems of Sri Lanka are not categorized as an agricultural pest. Earlier the Department of Agriculture of Sri Lanka identified one specimen as *P. bridgesi.* However, it was subsequently confirmed as *P. diffusa* by Naggs *et al.* (2003). Further investigations and constant screening is needed to confirm that there is no occurrence of golden apple snail (*P. canaliculata*), which is a serious pest of rice in southeast Asia (www.sundaytimes.lk/030615/funday/2.html). Even though, the *P. diffusa* is not an agricultural pest, it is important as an aquatic plant pest as it feeds on the native aquatic plants such as Aponogeton species (www.sundaytimes.lk/030615/funday/ 2.html). Sri Lanka exports number of fresh water ornamental plants such as ruffled sword plant (*Aponogeton* spp), fanwort (*Cobomba* spp), hornwort (*Ceratophyllum* spp), *Cryptocoryne* spp, water wisteria (*Hygrophila* spp), false loose strife (*Ludwigia* spp.), and common eel grass (*Vallisnaria* spp) that earns foreign exchange to the country. Hence, the presence of *P. diffusa* might significantly affect the aquatic ornamental plant industry in the future (Epa, 2006).

The potato cyst nematode (*Globodera rostochiensis*), has been responsible for the destruction of 75 per cent potato cultivations in the Nuwera eliya district in the central province (Ekanayake, 1999). The Pea leaf miner (*Liriomyza huidobrensis*) and *L. sativae* are serious pests of vegetable cultivations (Ekanayake, 1999; Marambe *et al.*, 2003). The Pea leaf miner has been responsible for the destruction of almost entire vegetable and potato cultivations in Nuwara Eliya in 1997. Some of the recently introduced pest species such as paddy root knot nematode (*Meloidogyne graminicola*) and *Steneotarsonemus spinki* has become serious pest of rice in Sri Lanka (Marambe *et al.*, 2003). The Coconut mite (*Aceria guerreronis*), which was first reported in Sri Lanka in 1997 caused considerable damage to coconut cultivations in the north-western area. The control measures adopted against this pest were able to reduce the mite population effectively (Ekanayake, 1999). *Acaphylla theae* is an important pest of tea cultivations (Marambe *et al.*, 2003). The lesion nematode (*Pratylenchus vubrus*), fruit fly species (*Braciocera dorsalis* and *B. zonata*) (Ekanayake, 1999) and *Aleurodicus dispersus* (Marambe *et al.*, 2003) have affected the fruit cultivations and other agricultural crops.

The latest of the exotic pests recorded is the papaya mealybug (*Paracoccus marginatus*) that has affected a variety of plants in Sri Lanka. Papaya mealybug was not reported as harmful until it became a pest in Mexico and Central America in 1998, but has now spread across 25 countries including Sri Lanka (www.Sundayobserver.lk/2009/03/15/new31.asp). The main hosts of *P. marginatus* are papaw, manioc and araliya (temple tree), while brinjal, chilie and kangkung (water spinach) are recognized as minor hosts. Moreover, *P. marginatus* can affect jak, breadfruit, citrus, mango, guava, banana, Polynesian plum (*ambarella*), sesbania as well as several flower plants. Recent reports indicated that *P. marginatus* have affected papaw, manioc, chilie and brinjal cultivations in western, north western, north central and Sabaragamuwa provinces, and papaw cultivations have faced with the threat of extinction with the rapid spread of the pest (www. sundayobserver.lk/2009/03/15/new31.asp).

(5) Other impacts

Apart from these major impacts, some invasive alien fauna results in indirect influences on native biodiversity. For instance, the feral buffalos facilitate the spread of invasive alien flora,

which is a threat to the biodiversity of the country. They feed on the pods of the Mesquite (*P. juliflora*) and facilitate the spread of this plant in the arid zone. They also disturb the natural habitats allowing the establishment of invasive alien flora such as Lantana (Bambaradeniya, 2000). Certain invasive alien fauna function as vectors of diseases. The ship rat functions as a vector for leptospirosis virus while the feral cats and dogs are vectors of rabies virus (www.sundaytimes.lk/030615/funday/2.html). Increase fishery pressure and the adoption of harmful fishing practices, *i.e.* small-meshed gill nets, related to the promotion of inland commercial fishery based on exotics such as tilapia and carp have impacted non-target species such as freshwater turtles in the dry zone reservoirs (Pethiyagoda, 1994).

Management of Invasive Alien Fauna in Sri Lanka

Several actions have already been adopted to manage the spread of IAS in Sri Lanka. These include the drafting of relevant policies and legislative frameworks (see Chapter 6 for details), implementation of research targeting specific invasive alien fauna, dissemination of knowledge and adoption of effective control measures. The Biodiversity Secretariat of the ME of Sri Lanka, as the national authority for addressing issues related to biodiversity conservation, has proposed formulation of a National Action Plan for the Control of IAS in protected areas, as component of the Addendum to the Biodiversity Conservation in Sri Lanka: a Framework for Action (MENR, 2007). Further the secretariat has taken an initiative to appoint a National Invasive Species Specialists Group (NISSG) on IAS to deal with the threats of alien invasions.

Five national level workshops and symposia have been conducted to-date, apart from numerous seminars/workshops conducted at provincial or local level, on IAS in Sri Lanka, to disseminate relevant information. The first workshop was conducted by the Ministry of Environment in 1999 (Marambe, 1999). The second national symposium was conducted jointly by the National Agricultural Society of Sri Lanka (NASSL) in collaboration with Ministry of Environment in 2000 (Marambe, 2000). The "Biodiversity Review" published by the Department of Agriculture in 2001 as a result of the third national seminar on IAS issues (Kotagama *et al.,* 2001). The fourth national symposium on IAS was conducted by the Sri Lanka Association of the Advancement of Sciences in 2008 (Ranwala, 2008). The fifth national symposium on IAS was conducted recently in 2009 by the Biodiversity Secretariat of the ME in collaboration with the Agriculture Education Unit (AEU) of University of Peradeniya, UNDP and the Institute of Biology of Sri Lanka, to commemorate the International Day for Biological Diversity in 2009. A significant increase of research on specific invasive alien fauna has occurred over the past five years, as evident from the recent publications (Amarasinghe *et al.,* 2008; De Silva and Julka, 2008; Lelwala *et al.,* 2008; Shirantha *et al.*, 2008; Shirantha and Amarasinghe, 2008; Perera and Epa, 2008; Wijethunga and Epa, 2008).

Some ground level species specific actions have also been implemented to control the spread of invasive alien faunal species. For examples, the spread of the Coconut leaf miner beetle (*Promecotheca cumingi*) was regulated successfully through the use of a bio-control agent *Dimmokia javanica* in the 1970's (www.island.lk/2009/04/18/satmag4.html); the Department of Agriculture has imported a biological control agent *Acerophagus papayae* from Puerto Rico to manage the spread of the recently introduced papaya mealybug (www.island.lk/2009/04/18 /satmag4.html); the IUCN and CARE have initiated a pilot project on participatory management of the giant African snail in the Hambantota district (Lelwala *et al.*, 2009). Tables 4 and 5 summarize the status of invasive alien fauna in Sri Lanka, reported to-date.

Table 4. Summary status of the invasive alien fauna in Sri Lanka.

Species	Mode of Introduction	Spread	Nature of threat	Control
Rainbow trout (*Oncorhynchus mykiss*)	1882; Deliberate; sport fishery	Streams of Montane zone	Direct exploitation or destruction of native species	Not available
Clown knife fish (*Chitala ornata*)	1994; Negligence; Ornamental fish trade	Coastal flood plain Streams and reservoirs - wet zone	Direct exploitation or destruction of native species	Not available
Plecostomus cat fish/ Tank cleaner /Sucker mouth cat fish (*Hypostomus plecostomus*)	1994; Negligence; Ornamental fish trade	Coastal flood plain Mainly around Colombo, Gampaha, Kandy and Kalutara districts	Superior competitors for resources Scrape feeding habits-change the habitat quality	Not available
Walking cat fish (*Clarias batrachus*)	Negligence; Ornamental fish trade	Marshes and streams - lowland wet zone	Direct exploitation or destruction of native species	Not available
Guppy (*Poecili reticulata*)	1930; Deliberate; mosquito control	Lowland wet zone, expanded to more riverine areas - upper catchments areas of the Mahaweli and Kelani river basins	Direct exploitation or destruction of native species	Not available
Western mosquito fish (*Gambusia affinis*)	Deliberate; mosquito control	Marshes, ditches and streams of the lowland wet zone	Not available	Not available
Mosambique tilapia (*Oreochromis mossambicus*)	1952; Deliberate; commercial fishery	Islandwide	Superior competitors for resources	Not available
Carp (*Cyprinus carpio*)	1915; Deliberate; commercial fishery	Headwater streams 1500 m a.s.l. elevation	Superior competitors for resources Feeding habits-change the habitat quality. Direct exploitation or destruction of native species	Not available

Table 4. Contd...

Species	Mode of Introduction	Spread	Nature of threat	Control
Snakeskin gouramy (*Trichogaster pectoralis*)	1951; Deliberate; commercial fishery	Tanks, reservoirs, marshes and streams of dry and intermediate zones	Not available	Not available
Red eared slider turtle (*Trachemys scripta*)	1991; Negligence; Ornamental fish trade	Wetland ecosystems	Direct exploitation or destruction of native species	Not available
Apple snail (*Pomacea diffusa*)	1980; Negligence; Ornamental fish trade	Colombo, Kalutara, Kandy, Matara, Rathnapura, Gampaha, and Galle	Aquatic plant pest	Not available
Giant African snail (*Lissachatina fulica*)	1900; Negligence; British planter; Research/ Hobby	Island wide distribution - natural and managed terrestrial habitats	Pests of agricultural / horticultural crops	Biological control – "common coucal" Chemical control – mollucide - metaldyhide
Slug (*Laevicaulis alte*)	1908; Accidental; Horiculturists	Island wide distribution in natural and managed terrestrial habitats	Pests of agricultural / horticultural crops	Chemical control – Pesticides
Two Garden slugs (*Deroceras reticulatum Deroceras caruanae*)	2003; Accidental; Horiculturists	Island wide distribution in natural and managed terrestrial habitats	Pests of agricultural / horticultural crops	Chemical control – Pesticides
House mouse (*Mus musculus*)	Accidental; Ships	Island wide distribution in natural and managed terrestrial habitats	Agricultural pest Hybridization with the native biota Vector for leptospirosis virus	Chemical control – poisonous baits
Ship rat (*Rattus rattus*)	Accidental; Ships	Island wide distribution in natural and managed terrestrial habitats	Agricultural pest Hybridization with the native biota Vector for leptospirosis virus	Chemical control – poisonous baits
Feral cat (*Felis catus*)	Negligence; Pet owners	Rural areas closer to natural or seminatural ecosystems	Act as predators Vector for rabies virus	Not available

Table 4. Contd...

Species	Mode of Introduction	Spread	Nature of threat	Control
Feral dog (*Canis familiaris*)	Negligence; Pet owners	Rural areas closer to natural or seminatural ecosystems	Act as predators Vector for rabies virus	Not available
Feral buffalo (*Bubalus bubalis*)	Deliberate; Animal husbandry	Islandwide – Forrests	Superior competitors for resources Hybridization with the native biota Facilitate the spread of invasive alien plants	Not available
Beet leaf miner (*Liriomyza huidobrensis*)	1997; Accidental; Foriculture trade	Nuwara Eliya district, Central province	Pest of vegetable (Beet) and potato cultivations	Chemical control – Insecticide Biological control– by *Diglyphus isaea*
Coconut mite (*Aceria guerreronis*)	1997; Accidental	Kalpitiya Peninsula, Wanatha willu, Puttalam (all districts of Nothern province, many districts of North Western, Central and Eastern provinces and Gampaha district of Western province)	Pest of coconut	Cultural control measures
Acaphylla theae	1999;	-	pest in tea cultivation	Chemical control – Acaricides
Fruit fly species (*Braciocera dorsalis* and *B. zonata*)	-	-	Pest of fruits	Chemical control Biological control – *Splangia* sp.
Guava white fly (*Aleurodicus dispersus*)	1989; Accidental	Throughout the country	Fruit crops and ornamental plants	Chemical control – Insecticides Biological control– by *Encarsia transvena*

Table 4. Contd...

Species	Mode of Introduction	Spread	Nature of threat	Control
Papaya mealybug (*Paracoccus marginatus*)	Accidental	Colombo, Gampaha, Kegalle, Kurunegala, Polonnaruwa and Dambulla.	Pest of agricultural crops and flower plants. Main hosts – papaw, manioc and Araliya Minor hosts – brinjal, chilie and kangkung (water spinach) Jak, bread fruit, citrus, mango, guava, banana, amberella, sesbania and certain flower plants	Biological control- by *Acerophagus papayae*

Table 5. Summary status of the potential invasive alien fauna in Sri Lanka.

Species	Mode of Introduction	Spread	Nature of potential threat	Control
feral rock pigeon (*Columba livia*)	Deliberate; As a pet	Throughout the country	Pest of paddy - large flocks cause considerable damage during a short time	Not available
Land snail (*Eustreptaxis kibweziensis*)	1950; Deliberate; to control Giant African Snail	Single specimen recently discovered in Peradeniya	Molluscivore – Potential threat to native snails	Not available
Fresh water snail (*Pomacea canaliculata*)	Not reported from Sri Lanka		Serious pest of rice; rapidly spreading throughout tropical Asia	
Land snail (*Bradybaena similaris*)	Accidental	Widely spread and common in gardens and on cash crops from Colombo to Nuwara Eliya	Pest of legumes	Not available
Land slug – (*Milax gagates*)	Accidental	Nuwara Eliya District	Pest of root vegetables – Carrot, Potato	Not available
Bumble bee (*Bombus terrestris*)	Deliberate; for pollination of Strawberries	Nuwara Eliya – Under green house conditions	Capable of spread in an invasive manner, displacing the native hymenopteran pollinators	Not available
Piranha	Deliberate; Ornamental fish trade	Western Province – in aquarium	Voracious carnivore – Potential threat to native fish species	Not available
Exotic earth worms	Not available	agro-ecosystems of the Uva and Central provinces	Competitors for resources with the indigenous earthworms	Not available

Conclusions

Invasive alien fauna reported in Sri Lanka comprise of a variety of species, in different habitats and ecosystems. Some of these have already caused a significant negative impact on the native biodiversity, while others are on the route of destruction of the rich biodiversity of the country. Apart from already identified invasive alien fauna, there are certain species with a potential to become invasive under certain environmental circumstances. Therefore, continuous monitoring and evaluation as well as proper implementation of effective control measures are urgently needed. As the legal and institutional frameworks have already being established in the country to a certain extent, strengthening the mechanisms of prevention and control will certainly avoid further damage of invasive alien fauna to the globally significant biodiversity of the country.

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Annexure 1

Provincial lists of Alien Invasive Fauna in Sri Lanka (excluding Northern and Sabaragamuwa Provinces)

1. Invasive fauna in forest ecosystems represented in the North Western Province of Sri Lanka.

Species	Mode/source of introduction	Distribution	Affected habitats/ecosystems
Bubalus bubalis (Domestic/feral buffalo)	Deliberate; animal husbandry	Island-wide	Forests
Chitala chitala (Clown knife fish)	Negligence; ornamental fish trade	Lowland wet zone	Ponds, slow-flowing rivers, marshes
Hypostomus plecostomus (Plectosomus catfish)	Negligence; ornamental fish trade	Lowland wet zone	Ponds, slow-flowing rivers, marshes
Clarias batrachus (Walking cat fish)	Negligence; ornamental fish trade	Lowland wet zone	Marshes, streams
Gambusia affinis (Mosquito fish)	Deliberate; mosquito control	Lowland wet zone	Marshes, ditches, streams
Poecilia reticulata (Guppy)	Deliberate; mosquito control	Lowland wet zone	Marshes, ditches, streams
Oreochromis mossambicus (Tilapia)	Deliberate; commercial fishery	Island-wide	Rivers, marshes, lagoons and estuaries

Source: Weerasinghe (2008)

2. Invasive Fauna Encountered in the North Central Province.

Common Name (Sinhalese)	Common Name (English)	Latin Name
Hisa Rathu Ibba	Red Headed Tortoise	*Trachemys scripta*
Mannaya	Sword Fish	*Chitala ornata*
Tilapia	Mozambique Tilapia	*Oreochromis mossambicus*
Tilapia	Nile Tilapia	*Oreochromis niloticus*

Source: Sumithrarachchi (2008).

3. Invasive fauna in Central Province

Sarotherodon mossambicus (Tilapia) [Source: Jayasuriya (2008)]

4. Invasive fauna in Eastern Province

Cyprinus carpio (Common Carp) [Jeyasingam (2008)].

5. Invasive alien fauna established in natural ecosystems of the Western Province.

Species	Mode; Source; Purpose	Distribution	Affected Habitats/Ecosystems
Clown knife fish *Chitala ornate*	Negligence; Aquarists; Ornamental fish trade.	Col;Gam;Kal	Tanks, ponds, slow-flowing rivers, marshes.
Plecostomus catfish Hypostomus plecostomus	Negligence; Aquarists; Ornamental fish trade.	Col;Gam;Kal	Tanks, ponds, slow-flowing rivers, marshes.
Walking catfish* *Clarias batrachus*	Negligence; Aquarists; Ornamental fish trade.	Col;Gam	Marshes, streams and canals.
Guppy *Poecilia reticulata*	Deliberate; State; Mosquito control. Ornamental fish trade	Col;Gam;Kal	Tanks, ponds, slow-flowing rivers, marshes, streams.
Western mosquito fish* *Gambusia affinis*	Deliberate; State; Mosquito control.	Col;Gam;Kal	Marshes, streams and canals.
Mozambique Tilapia* *Oreochromis mossambicus*	Deliberate; State; Commercial fishery.	Col;Gam;Kal	Tanks, reservoirs, slow-flowing rivers, marshes.
Carp* *Cyprinus carpio*	Deliberate; State; Commercial fishery.	Col;Gam;Kal	Tanks, reservoirs.
Red-eared slider turtle* *Trachemys scripta*	Negligence; Aquarists; Ornamental fish trade.	Col	Marshes, steams and canals.
Golden apple snail *Pomacea bridgsi*	Negligence; Aquarists; Ornamental fish trade.	Col	Tanks, ponds, marshes
Giant African snail* *Achatina fulica*	Negligence; British planter; Research/ Hobby.	Col;Gam;Kal	Natural and managed terrestrial habitats.
Slug *Laevicaulis alte*	Accidental; Horticulturists.	Col;Gam;Kal	Natural and managed terrestrial habitats.
House Mouse* *Mus musculus*	Accidental; Ships.	Col;Gam;Kal	Natural and managed terrestrial habitats.
Ship rat* *Rattus rattus*	Accidental; Ships.	Col;Gam;Kal	Natural and managed terrestrial habitats.
Domestic/feral cat* *Felis catus*	Deliberate; Pet trade	Col;Gam;Kal	Natural and managed terrestrial habitats.
Domestic/feral dog *Canis familiaris*	Deliberate; Pet trade	Col;Gam;Kal	Natural and managed terrestrial habitats.

* Species included in the list of 100 of the world's worst invasive alien species (IUCN ISSG 2001); Col – Colombo district, Gam – Gampaha district; Kal – Kalutara district
Source: Bambaradeniya (2008).

6. Alien invasive fauna in natural ecosystems of Uva Province of Sri Lanka

Bubalus bubalis (Feral buffalo) and *Sarotherodon mossambicus* (Tilapia) [Source: Jayasuriya (2008)]

7. Invasive alien fauna in natural ecosystems of Southern Province of Sri Lanka.

Species	Mode, Source, Purpose	Distribution	Affected Habitats/Ecosystems
Wild/feral buffalo *Bubalus bubalis*	Mismanagement	Hambantota district	Forests /grasslands
Wild Pig *Sus scrofa*	Mismanagement Habitat loss, unawareness	Throughout the Province	Agricultural lands and other natural habitats
Pea fowl *Pavo cristatus* L.	Dryzone bird Spreading towards wet zone	Hambantota and Matara (even in wet regions) districts	Agricultural crops particularly paddy
Guppy *Poecilia reticulata*	Deliberate, State Mosquito control	Throughout the province	Tanks, ponds, slow-flowing rivers, marshes, streams
Tilapia *Saratheroden mossambicus*	Deliberate, State commercial fishery	Throughout the province	Tanks, reservoirs, slow-flowing rivers, marshes,
Clown knife fish *Chitala chitala*	Negligence, Aquarists, ornamental fish trade	Low land wet zone	Tanks, ponds, slow-flowing rivers, marshes
Golden snail *Pomacea canaliculata*	Unknown	Wet and Intermediate zones	Home gardens, agricultural lands where wet conditions prevail

Source: Gunawardena (2008).

Review paper

Chapter 6

Institutional Coordination, Legal Regime and Policy Framework for Management of Invasive Alien Species in Sri Lanka

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Introduction

The geographic boundaries have provided the isolation essential for species and ecosystems to evolve. However, long-distance movement of plants and animals by man have made those species overcome the geographical and political barriers, enter new habitats and become invasive in the introduced environment. Developments in tourism, transportation and international commerce, and international aid, have facilitated the movement and spread of aliens further.

Majority of the crop plants and animals in most parts of the world are introduced, and hence, alien to the respective regions. Many alien species that have established remain at low levels, integrating with the local ecosystem resulting in low impacts. However, a small proportion of alien introductions, both intentional and accidental, have become serious problems due to their invasiveness in agricultural and natural habitats, destroying or displacing crops or indigenous species. At present these invasive alien species (IAS; see Chapter 1 for definitions) have been identified as a key factor affecting the native biological diversity of the ecosystems that they have being introduced, where in terms of their level of impact on habitat degradation, they are second only to the direct negative impact caused by human beings.

The IAS have continued to spread in the natural (terrestrial, aquatic and marine) and agricultural ecosystems of Sri Lanka affecting its biological diversity and food security. Being a small island

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nation with a fragile ecosystem, more liberalized economic policies facilitating international trade, travel and transportation movement, natural and man-made disasters supporting the free movement of international aid, the threat of IAS to the Sri Lanka ecosystems and its biodiversity has become more significant over the past 2-3 decades.

At the global level, few countries have developed the legal and institutional systems that are capable of responding effectively to these invasive species. Spread of these species in terrestrial, aquatic and marine environments present exceptionally challenging conditions for their control. The rapid spread of these species in multitude of environments renders the control of bio-invasions more difficult as control options applied for a given ecosystem are difficult to apply in another.

Legal Regime to Tackle Issues related to IAS in Sri Lanka

Despite being a signatory to international and regional agreements related to trade, *i.e.* World Trade Organization (WTO) Agreements, South Asian Free Trade Area (SAFTA) Agreement, etc., and international conventions such as Convention on Biological Diversity (CBD), International Plant Protection Convention (IPPC), and International Convention for the Prevention of Pollution From Ships (MARPOL 73/78), Sri Lanka has enacted many ordinances/acts to impose laws governing import of fauna and flora to the country. The Biodiversity Secretariat of the Ministry of Environment (ME) of Sri Lanka serves as the focal point for the implementation of CBD, the Department of Agriculture (DOA) of the Ministry of Agriculture (MA) of Sri Lanka is the focal point for IPPC related activities, while the Marine Environment Protection Authority (MEPA) of the ME is the focal point for implementation of MARPOL 73/78 Convention.

The five main legal enactments that have directly assisted in controlling the entry and spread of alien invasives in Sri Lanka are given below, in the chronological order or enactment.

(1) Water Hyacinth Ordinance No. 09 of 1909

This enactment was intended to prevent the introduction of and the spread of Water Hyacinth in Sri Lanka. The long title and the short titles mention "Water Hyacinth" by name, which has made people to think that it was exclusively for to deal with this species. Although a century has passed since this enactment was brought in Sri Lanka and that the water hyacinth still exist affecting country's main water bodies, many consider it as an ineffective document. However, a perusal of the provisions of this act shows that it can be made use of to control other species of plants, too.

Section 07(1) of this ordinance makes it possible to declare (by an order made by the Minister in charge of Agriculture and published in the gazette) any other noxious plants or weeds to come under the purview of this enactment and thereafter the provisions will apply to them as well. Such a declaration makes it illegal to import any such plant, seeds or other parts and the Minister in charge of Agriculture can, by order, impose penalties on importer. When an order is made declaring a plant under this ordinance, the Customs Department can destroy such plants if detected during importation.

When an order is made under Section 07(1), it makes the other relevant provisions of this ordinance applicable to such plants [Section 07(2)], and hence, it would be unlawful to possess or keep such a plant or to grow them in any property that belongs to a person or is under the

control of management of any person (Section 03). Any person who finds any plant belonging to such a species growing in any property belonging to him/her or is under his/her management, is duty bound to destroy the plants by burning (Section 04).

This ordinance provides a simple yet effective way to deal with any real or potential invasive that is already in Sri Lanka or is likely to be imported to the country. The burden of destroying the plant is with the owner or manager of the property. The main drawback is that it does not have any other recommended method of disposal other than being destroyed through burning.

(2) Fauna and Flora Protection Ordinance (No. 02 of 1937, as amended)

The purpose of this enactment is to provide for the protection, conservation, and preservation of the fauna and flora of Sri Lanka and to prevent the commercial exploitation of them. The import of any animal, spawn, eggs, or larvae of any animal can only be done under the authority of a permit issued for the purpose by the Director General of the Department of Wildlife Conservation [Section 37(1)]. The provisions of this enactment apply to all species of animals except those domestic animals defined under Section 11. The term domestic animal means only the cattle, sheep, goats, horses, asses, mules, dogs, cats, domesticated pigs and domestic fowl reared as poultry.

According to provisions of the Section 37(2), these provisions have the same effect as they were part of the Customs Ordinance. This empowers the Customs to take action directly against any offenders.

The Minister in charge of Agriculture can, under Section 38(b), make regulations to,

i) prohibit the release of any imported animals in Sri Lanka, and
ii) prescribe areas where release of animals is permitted.

The provisions of Sections 37 and 38(b), taken together can be used to allow import of animals for research purposes and to prevent them from being released or to limit the release of them to areas where they are unlikely to be a problem.

The main strength of this is the wide applicability of it to any animal and the decision is at the discretion of the Director General of the Department of Wildlife Conservation. This discretion is subject to the limitations imposed by the Plant Protection Act No 35 of 1999 and the Fisheries and Aquatic Resources Act No 2 of 1996, and any species that are prohibited from being imported under orders made under one of those acts cannot be imported under this ordinance and no permits are issued for the import of such species. The main drawback of this act is that it does not have any provisions to deal with a species already brought in under a permit that has subsequently become an invasive or is likely to become invasive. In addition, provisions of this act do not apply as regards to plants.

(3) Fisheries and Aquatic Resources Act (No. 02 of 1996, as amended)

The intentions of this act are to provide for the management, regulation, conservation and development of the fisheries and aquatic resources of Sri Lanka. The term fish has been defined for the purposes of this act (under Section 66 - Interpretations) to mean "any aquatic animal and

inclusive of all animals from zooplankton to marine mammals". The term aquatic resource means living aquatic organisms and covers Phytoplankton, seaweed and other aquatic flora.

According to Section 30, the Minister in Charge of the subject of Fisheries and Aquatic Resources, in consultation with the Minister in Charge of the subject of Trade, can prohibit or regulate the import of any fish or aquatic resource in to Sri Lanka by regulations (these should be published in the gazette). The provisions of this section can only be used to restrict or prevent the importation, and not to allow the imports, as it is only a restrictive provision and not an enabling provision. Already, 24 species of fishes (Table 1) are prohibited from being imported through this act.

Table 1. List of species of fish prohibited to be imported in live form to Sri Lanka.

Family	Species
Ictaluridae	*Ictalurus punctatus*
	Ictalurus forcatus
	Ictalurus catus
	Ictalurus nebulosus
	Pylodictis olivaris
Characidae	*Serasalmus natterei*
	Serasalmus holandi
	Serasalmus eigenmani
	Serasalmus notatus
	Serasalmus striolatus
	Serasalmus elongatus
	Serasalmus gibbus
	Serasalmus sanchezi
	Serasalmus spilopeura
	Serasalmus antoni
	Serasalmus rhombeus
	Serasalmus serrulatus
	Catoprion mento
Notopteridae	*Notopterus notopterus*
	Notopterus chitala
	Notopterus afer
	Notopterus blanci
	Chitala blanci
	Chitala ornata

Source: www.nara.ac.lk/ybook2005/chap10.html

The main strength of this act is the applications to both aquatic plants and animals and that the species can be included through orders, quickly. However, they apply only in relation to aquatic organisms. This is not a weakness as the scope of the act is restricted to fishes and aquatic resources. The main drawback is that there are no provisions to deal with a species that has become or is likely to become an invasive in the country.

(4) Plant Protection Act (No. 35 of 1999)

The Plant Protection Act No. 35 of 1999 intends to prevent the introduction and spread of any organism injurious or harmful to plants or destructive to plants found in Sri Lanka. The definition

of the term invasive in Section 15 (Interpretations) includes all active, infective and dormant stages of life forms that could be harmful to plant life. This can include not only the plants but animals as well. Thus, the provisions of this act can be used to prevent the entry of any plant or animal that may become a pest or an invasive, which may be a potential threat to plant life.

When the Director General of Agriculture (DGA) has reasons to believe that a pest is being harboured in any premises, he/she can direct officials to inspect the premises and ascertain the situation [Section 4(1)]. Thereafter, the DGA can issue a directive to the owner or occupier of the premises to take action to eradicate the pest. If the person to whom this directive is sent fails to take action, the DGA can make his/her officials to take appropriate action to eradicate the pest and recover the expenses from the said person.

According to Section 7(1), the Minister in charge of Agriculture can, by regulations, prohibit the entry of Quarantine Pests to Sri Lanka. The term Quarantine Pest is defined under Section 15 as "a pest of potential economic or environmental importance that is either not yet present or present but not widely distributed and being officially controlled". This definition is quite broad as it not only includes those that are only potentially destructive and harmful, but also any that can be environmentally or economically important. Therefore, any plant or animal that could become an invasive in natural habitats, and not only on cultivated land, can be deemed as a quarantine pest. When the Minister in Charge of Agriculture declares an organism as a quarantine pest, it becomes unlawful for anyone to knowingly keep, sell, plant, release, deliver to others, or dispose any such plant or animal, except under the specific written instructions of the DGA [Section 7(3)]. The DGA can take necessary steps to control any quarantine pest up on the receipt of any information [Section 7(4)] and has the authority to destroy them if necessary [Section 7(3)].

The main strength of this act is that it lays down a simple procedure to deal with any pest, which can include any alien invasive species that harms or can harm any plant found in Sri Lanka or is likely to be introduced (purposely or accidentally) in the future. The declaration of pests and quarantine pests and related matters are to be enforced through regulations. The enforcement of regulations is done through an order made by the Minister in Charge of Agriculture, and is an easy, efficient and speedy way to bring in necessary controls. This act does not make provisions to control an introduced species or a species with a potential to be introduced that could be harmful to animals, which is considered by many some legal experts as a weakness. However, it is a matter out of the purview of this act and hence, cannot be considered as a weakness.

The draft regulation made under the Plant Protection Act has identified 164 weeds species under the regulation 22 of the act, as completely prohibited to enter Sri Lanka. However, the act gives authority to the Director General of Agriculture to decide on the admissibility of such consignments after consulting a committee of experts appointed on the subject.

(5) Marine Pollution Prevention Act (No. 35 of 2008)

This act, which replaced the Marine Pollution Prevention Act No. 59 of 1981, is to provide for the prevention, control of and the reduction of pollution in the territorial waters of Sri Lanka or any other maritime zone, the foreshore and the coastal zone of Sri Lanka. The Minister of Environment can make regulations under the provisions of Section 51 and according to Section 51(2)(c), to specify substances or class of substances other than oil which when added to water has the effect of contaminating such water so as to make the water unclean, noxious, impure or

detrimental to the health, safety or welfare of any person or harmful to marine life. This provision can be used to bring in necessary regulations to control and regulate the release of blest waters in the seas of Sri Lanka or to treat them in a specified way before releasing into the waters.

Other Enactments

The country has adopted several other legal instruments, which could also be used for the control of the entry and spread of IAS

(a) The Customs Ordinance (No. 43 of 1946, as amended): has no direct provision to stop the importation of an invasive species. It has powers only to stop the import if there is any ban or restriction made under any other enactment or if the import has been made without the necessary permits. If there is a permit issued Under the Fauna and Flora Protection Ordinance for the import of an animal or a permit under the Plant Protection Act, the Customs Department has no powers to stop the import even if the species is a known invasive.

(b) The Animals Act (No. 29 of 1958): This act only have provisions to deal with domestic animal species that are stated in the document.

(c) The Animal Diseases Act (No. 59 of 1992): This act intends to, among other provisions, to prevent the introduction of diseases and parasites of animals to Sri Lanka. However, this act has no provision to stop the importation of any species of animals, except those identified as parasites. It has no provisions and there are no provisions even to make regulations in order to prevent the import of any species that is known to be an invasive or which can become an invasive.

(d) The Prevention of Mosquito Breeding Act (No. 11 of 2007): This act gives provisions for the prevention of mosquito breeding, for the eradication of places of mosquito breeding and for connected matters. According to Section 2(g), it is the duty of the owner or occupier of any premises to remove shrubs and undergrowth, other than those grown for food or ornamental purposes, that have become a breeding place for mosquitoes. This could be used to destroy any of the invasive plants has been found to been conducive to the breeding of mosquitoes. According to Section 2(h), it is the duty of the owner or occupier of any premises to remove and destroy Water Lettuce (*Pistia stratiotes*) and any other water plant or other plants which may facilitate the breeding of mosquitoes. According to Section 3(1)(g), the Competent Authority can, by a written notice, order the removal of any plant that affords breeding conditions to mosquitoes or the Water Lettuce to be destroyed.

The legislative enactments (1) - (4) and (a) - (d) given above provide a considerable legal support to act against the introduction of IAS, however, interests and scopes of these enactments are limited and do not meet the total requirement of acting against invasive species.

The present laws are sectoral in nature and can therefore be used only in relation to specific types of invasive species. There is no single enactment to deal with all the different types of invasive species. Although none of the laws define or mention the terms "Invasive Species" or "Invasive Alien Species" (IAS) or "Alien Invasive Species" (AIS), there are no restrictions in the

application of the provisions for such species. It is problematic to define "Invasive Alien Species" in an enactment as most of the species would either be aliens that do not currently occurring in Sri Lanka or would be potential but not known to be invasive at present. One way out is to let the Minister in charge of the subject to declare invasive species by an order. However, this may cause a mismatch between the legal term and the scientific term of AIS (or IAS). Another possibility is to have a definition such as "Noxious Species" or "Harmful Species" or "Problem Species".

In the present enactment in Sri Lanka, there are no provisions to deal with a species of animal (other than plant pests) that has already been brought into the country legally, but have been found to be a potential invasive species or have already become invasive species. It is important to decide whether to have all possible invasive species declared, or leave the discretion with the authorities to consider them on a case by case basis if and when a species is to be imported. The problem of having lists is that they need to be updated often as soon as new species are found to be problematic. If the provisions are to call for risk assessments, the burden of providing the necessary information shifts to the intended importers. Another way is to provide a list of known invasives that are banned and to let the authorities to decide on others on a case-by-case basis. This facilitates law enforcement and also supports the importers as they would get to know those that cannot be brought into the country. It is important to note that there is no clear mandate to call for a risk assessment and risk management before the importation of an alien species, although it can be part of the decision-making effort to call for these reports.

There is no single institution to look in to the issue of AIS and the introduction of species in to Sri Lanka. At present, different institutions look into the issue on a sectoral basis and there are instances where some species have not been given due consideration as they do not evince the interest of the different bodies. It is necessary to overcome the problems by either amending the existing laws or by the adoption of a new enactment to deal with invasive species. The introduction of a new law with one focal point that can coordinate, facilitate and strengthen the role of the different institutions would be the better option. Such a law can be enlarged to even cover other types of harmful species such as those that are poisonous, have dangerous stings and other possible detrimental effects on people and the environment.

Thus, it is clear that in addition to development of appropriate legislative framework, which is a pre-requisite for effective prevention and subsequent control of IAS, awareness among legislators, entrepreneurs, importers and general public would play a crucial role in tackling the issues of IAS.

Formulation of a New National Invasive Species Control Act

Considering the importance of the development and implementation of relevant legal instruments to support the country's efforts to manage IAS, the Cabinet of Ministers, on 15th January 2009 granted approval to a cabinet paper submitted by the ME to develop a new act to prevent entry of and control of IAS. The Cabinet of Ministers has further highlighted the importance of obtaining assistance of other line ministries in this effort. The formulation of the new IAS act and the regulations for implementation would no doubt assist in the Sri Lanka's effort in preventing the introduction of and management of IAS through a well coordinated institutional arrangement and effective participation of all stake holders concerned.

Institutional Design and Coordination Mechanism in Sri Lanka to Control the Introduction and Spread of IAS

Managing IAS requires a coordinated strategy based on cooperation among all land managers (Marambe, 2001). Since IAS do not recognize political or other jurisdictional boundaries, they can only be managed if all land managers, both private and public, work together with a common goal. However, the absence of a National Strategy and an Action Plan (SAP) has affected brining in all stakeholders to a common platform in terms of IAS control and better coordination among them. Marambe (2001) has proposed a guide for a SAP for effective management of IAS in Sri Lanka.

There are several organizations actively participate in or conduct research on IAS related issues in Sri Lanka, such as Department of Wildlife Conservation (DWC), Forest Department (FD), Department of Agriculture (DOA), Department of National Botanic Gardens (NBG), World Conservation Union – Sri Lanka (IUCN-Sri Lanka), National Universities, and several other non-governmental organizations (NGOs) and community-based organizations (CBO). Although the actions in relation to IAS should be taken by many organizations, it is vital to have a specifically identified institution/committee assigned to oversee and coordinate such actions. Apart from limited activities carried out jointly to control Invasive Alien Flora in Sri Lanka as shown in Table 2 that were mainly coordinated by the ME, all other efforts have been in isolation without a proper coordinating mechanism.

Table 2. Some of the control efforts for IAS (flora) made in collaboration with different sectors in Sri Lanka.

IAS – Flora	Involvement of Stakeholders	Coordination	Period
Parthenium hysterophorus	DoA, BDS of ME, FA and FS of Univ, NGOs, CBOs	Jointly by DoA & BDS of ME	2001 to-date
Mimosa pigra	BDS of ME, MASL, NGOs, CBOs	BDS of ME	1998 to-date
Alternanthera philoxeroides	DoA, ME, NGOs, CBOs	DoA	2002 to-date
Lantana camara	ME, DWS, NGOs, CBOs	BDS of ME	2006
Salivinia molesta	DoA, ID, CBOs, NGOs	DoA	1939 to-date
Eichhornia crassipes	DoA, BDS of ME, ID, NGOs, CBOs	DoA	1909 to-date

DoA – Department of Agriculture, BDS of ME – Biodiversity secretariat of the Ministry of Environment and Natural Resources, MASL – Mahaweli Authority of Sri Lanka, ID – Irrigation Department, FA and FS of Univ – Faculties Agriculture and Faculties of Science of the Universities, NGOs – Non Governmental Organizations, CBOs – Community Based Organizations

An ability to bring all groups involved in invasive species issues together under one roof so as to maximize integration and co-operation is essential. More importantly, the respective government departments concentrate on IAS related issues only within their administrative territories and with no or little information sharing among the other state departments or general public on the efforts made on the problems faced. The recent outbreak of Papaya Mealybug (*Paracoccus marginatus*) in Sri Lanka is a classic example for lack of a coordinated mechanism and private-public partnership in such endeavours.

There is a scarcity of information on the joint efforts made to control invasive alien fauna or marine invasives at national level, with the state intervention or coordination. The MARPOL 73/78 Convention, of which Sri Lanka is a signatory, requires for every port to have a reception facility to extract ship generated waste to prevent entry of invasives through ballast water, which Sri Lanka is still to establish.

The activities carried out by the stakeholder organizations in the past also indicate that identification and prioritization of the IAS for control have been done on *ad hoc* basic due to the absence of national priorities. With the involvement of the ME, the lists of IAS of national significance have been identified (Marambe *et al.*, 2003), however, these efforts have been a waste as different stakeholder organization have no clear priority setting with respect to IAS control.

It is unfortunate that the services of the large contingency of the Environmental Assistants (under ME) who are attached to the Provincial Councils (PCs), Agriculture Monitoring Officers and the Agriculture Research and Development Assistants of the MA, and the Animal Husbandry Development Assistants attached to the Ministry of Livestock Development (MLD), totaling to more than 10,000 in number, has not been effectively utilized for IAS related activities in the country despite that all these officers are directly involved in grass-root level activities.

The role of private sector, NGOs and CBOs

The involvement of the private sector in IAS management has not been given adequate consideration in the country. Being a key sector that is mainly involved in international trade, tourism and transport, active involvement of the private sector organizations in IAS management activities would no doubt benefit and assist in achieving the ultimate objectives in relation to IAS management. It is important that their potential and role play in IAS management. The NGOs and CBOs are the direct users of biodiversity and firm advocates of conservation and sustainable use of biodiversity (Watson *et al.*, 2006), and hence have a key role to play with respect to preventing introduction and spread, and management of IAS in the country. The Central Environmental Authority (CEA) of Sri Lanka has registered more than 300 NGOs working in relation to environmental concerns, with about 50% of them involved in biodiversity conservation activities. These groups, with proper coordination could be effectively used in IAS management activities in the country.

The existing institutional setup where different ministries and departments/institutions work on IAS issues in isolation will not assist the country's ultimate goal in achieving a coordinated effort to tackle this important environmental concern. With a view to establish a coordinated mechanism, the Addendum to the National Biodiversity Conservation Action Plan – A Framework for Action (MENR, 2007) and the relevant chapter report (Marambe *et al.*, 2006) proposed the establishment of an Invasive Species Specialist Group in the country as a high priority recommendation.

All these indicate that there have been no concerted efforts to manage IAS in Sri Lanka except for several isolated attempts. The present institutional arrangement in the country is not sufficient or not effective in tackling the issues with respect to IAS in the country both at national and regional levels.

Policy Environment in Sri Lanka to Control the Introduction and Spread of IAS

The Article 14 in the Chapter 6 (Directive principles of state Policy and Fundamental Duties) of the Constitution of the Democratic Socialist Republic of Sri Lanka, clearly states that "The State shall protect, preserve and improve the environment for the benefit of the community". This governs the activities of all state, private sector and non-governmental organizations and individuals in protecting the environment of Sri Lanka.

Keeping in line with the constitutional directives and the international conventions that the country has been a signatory, several government institutions have developed policy statements of working mechanisms to tackle the issues related to IAS in Sri Lanka. Extracts of such policy statements with direct relevance to IAS are given below, in the chronological order of adoption.

(a) National Wildlife Policy (2000): The National Wildlife Policy adopted by the Department of Wildlife Conservation in 2000 clearly identifies two policy statements related to IAS or alien species as "To promote active, ecosystem-based management of all protected areas, including the eradication wherever possible of alien and invasive species, subject to though consideration of the environmental impacts of these interventions" and "To regulate the importation of alien organisms, including genetically-modified organisms, so as to minimize risks to the integrity of Sri Lanka's biodiversity".

(b) National Environmental Policy (2003): The National Environmental Policy and Strategies adopted by the ME in 2003 (policy statement 4) states that "Environmental management systems will be encouraged to be flexible so as to adopt to changing situations (e.g. climate change, invasive species and living, genetically-modified organisms) and adopt the precautionary principle".

The document also identifies the outcomes to be achieved in the biodiversity sector in this regard as "Effective measures adopted to guard the entry into Sri Lanka of noxious, invasive species (of plants, animals and micro-organisms) and environmentally harmful genetically modified organisms" and " Spread within the country of invasive and noxious species of plants, animals and micro-organisms in controlled".

(c) National Agriculture Policy (2007): The National Agriculture Policy adopted by the MA in 2007 states "Strictly adhere to plant protection regulations to prevent alien weeds, insect pests and diseases from entering the country".

Many other policies adopted by the different ministries or departments have indirect reference to IAS, which are given below.

(a) The National Forest Policy (1995): The National Forest Policy adopted by the Forest Department of Sri Lanka in 1995, although no direct policy is adopted in relation to IAS, states "To conserve forests for posterity with particular regard to biodiversity, soils, water as well as historical, cultural, religious and aesthetic values"

(b) National Wetland Policy (2004): The National wetland Policy adopted by the ME in 2004 does not have direct policy statement related to IAS. However, the relevant statements

are "To protect and conserve wetland ecosystems" and "To restore and maintain the biological diversity and productivity of wetlands"

(c) National Biosafety Policy (2005): The National Biosafety Policy adopted by the ME in 2005, with no direct reference to IAS, "Recognizes the importance of protecting its people, environment and biodiversity while promoting a sustainable social and economic development through the implementation of biosafety measures"

(d) National Fisheries and Aquatic Resources Policy (2006): The National Fisheries and Aquatic Resources Policy adopted by the Ministry of Fisheries in 2006, with no direct relevant to IAS control, gives related statements as "Conserve and enhance the coastal environment" and "Give priority to the need of protection of the environment in all activities in the sector".

(e) National Livestock Development Policy (2007): The National Livestock development Policy adopted by the MLD in 2007 does not include any IAS related policy statement. However, this policy identifies that the "Import of animals, semen and embryos is under the control of Department of Animal Production and Health" thus indicating the animal quarantine regulations will come into effect on the importation of alien species to the country.

Apart from the above policy directives, several institutions have made commitments to support IAS control in Sri Lanka. Such institutions are given below.

(a) Sri Lanka Customs – Biodiversity Protection Unit: The Biodiversity Protection Unit of the Sri Lanka Customs is committed to "Promote the development programs of the Country through sustainable imports and exports of Fauna and Flora in a manner, which will not harm the biological heritage of the Country".

(b) Marine Environment Protection Authority (MEPA) of Sri Lanka: The MEPA (formerly Marine Pollution Protection Authority – MPPA) is committed to have "A pollution free marine environment around Sri Lanka for the sustainable national development and the well being of its people and the economy by the year 2020"

(c) National Plant Quarantine Service (NPQS): The National Plant Quarantine Service (NPQS) of the Department of Agriculture focuses on "Prevention of introduction, establishment and spread of dangerous alien pests within the country"

(d) Civil Aviation Authority of Sri Lanka (CAA): The action plan of the Civil Aviation Authority (CAA) of Sri Lanka (including the draft National Policy on Civil Aviation that has been submitted to the approval of the Cabinet of Ministers do not have any direct reference to IAS. However, CAA of Sri Lanka has to follow the recommendations of the International Civil Aviation Organization (ICAO) who has decided and recommended that "Contracting states to support one another's efforts to reduce the risk of introducing, through civil air transportation, potentially invasive alien species to areas outside their natural range".

Addendum to the National Biodiversity Action Plan (BCAP) – A Framework for Action

The Addendum to the Biodiversity Conservation Action Plan (BCAP) in Sri Lanka (MENR, 2007) listed out high priority recommendations based on the chapter reports (Marambe *et al.,* 2006). The following are the high priority recommendation made in relation to IAS in Sri Lanka;

(a) Establish a National Invasive Species Specialist Group (NISSG)
(b) Prioritize IAS including GMOs, terrestrial and aquatic species
(c) Prepare a national database on IAS
(d) Provide funding for research on methods to control the spread of the prioritized IAS
(e) To establish national biodiversity information management committee to implement the computerized networking and establishment of meta-data base (including invasive species).
(f) The human resources, technical capacity and infrastructure of the BDS of the ME should be strengthened, so as to provide capacity to coordinate and monitor a comprehensive set of biodiversity indicators and programmes (including invasive species).

Haritha Lanka Programme of the Government of Sri Lanka

The national action plan for the *Haritha Lanka* programme of the government of Sri Lanka was launched in 2009 by the National Council for Sustainable Development (NCSD) of the Presidential Secretariat of Sri Lanka. This national action plan focuses on sustainability, implying meeting the current human needs while preserving the environmental and national resources required by future generation (NCSD, 2009). The action 8.2 under mission 2 proposed by this high powered NCSD chaired by His Excellency the President of Sri Lanka indicates that strategies will be adopted to "ensure management and control of IAS", thus confirming the high priority given by the country in its national level activities to deal with the issues related to IAS.

The overall analysis indicates that Sri Lanka has identified IAS as a main environmental issue to be dealt with immediately as well as in the long run. However, the key stakeholder organizations have failed to identify related institutional policies in this regard to cope up with the national strategies/action plans. Lack of awareness/ignorance on the IAS related issues could be the main factor responsible for such a situation in the country.

Monitoring and Evaluation of IAS Activities carried out in Sri Lanka

The need for appropriate structures and indicators for monitoring biodiversity components and coordination of action plans is recognized as an integral part of the national implementation commitments of the CBD (Atapattu *et al.,* 2006), and IAS related issues are no exception. Although many efforts have been made by the state institutions, NGOs and CBOs in IAS management, there is a scarcity of information pertaining to monitoring of activities and evaluation of their success. The limited information available suggest that a monitoring mechanism is in place with respect to the development projects funded by the donor agencies such as UNDP and ME, and research projects funded by the Council for Agricultural Research Policy (CARP), National Science Foundation (NSF) and National Research Council (NRC). However, almost no information is available with respect to overall evaluation of the success and failures IAS management activities conducted by various organizations. For an effective

monitoring and evaluation to take place, development and use of indicators is imperative. The Addendum to the BCAP in Sri Lanka – A Framework for Action (MENR, 2007) and the relevant chapter report (Atapattu *et al.,* 2006) have suggested list of indicators to be used in evaluation of the impact of IAS related activities (Table 3).

Proper coordination, monitoring and evaluation plans will have to be developed to with respect IAS projects in country with clearly stated objectives and indicators selected, the frequency of mentoring and evaluation including who carry out the process, outline of training and/or financial inputs, intended audience, process through which the information will be use for management decisions, and decision points at which action will be taken. The measurable monitoring indicators revealing the meaningful trends, should be precise and unambiguous, and directly related to the project activity. The monitoring and evaluation indicators could be identified for different major ecosystem types. It is important that coordination and monitoring take place as soon as the IAS projects are implemented and progress evaluation and post-evaluation carried out at various time intervals. In Sri Lanka, the post-evaluation is totally lacking in the IAS related activities. Although project steering committees/task forces at the institutional or organizational levels have been appointed by various development projects related to IAS, unfortunately the mechanism is non-functional as soon as the project ends, with no assurance of sustainability.

Table 3. Suggested list of indicators for monitoring and evaluation of IAS activities.

Number of introduced species and genomes
Number and extent of invasive species
Non-indigenous species present by group
Ratio between exotic species and native species in forest/nature reserve/wetland area
Change in presence, location, area, numbers of invasive plant or animal species
Percentage of area dominated by non-domesticated species
Percentage of area dominated by non-domesticated species occurring in patches greater than 100 km^2
Number of exotic flora and fauna species (e.g. Fish, aquatic weeds)
Area/Number of exotic invasive species eradicated
Number of elephant deaths caused by conflicts with humans
Number of flora/fauna species required to be relocated due to development projects
Amount of use of agrochemicals (in proximity to protected areas)

Source: Atapattu *et al.* (2006)

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Review paper

Chapter 7

Economics of Managing Invasive Alien Species in Sri Lanka

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Introduction

Invasive alien species (IAS) have become a threat to ecosystems world over. They have the ability to get themselves established in new ecosystems/habitats thereby threatening the native biological diversity (IUCN, 2000). Their presence affects quality of natural environments, create adverse impacts on goods and services provided by them and could be instrumental in extinction of species. According to Secretariat of the Convention on Biological Diversity (SCBD, 2002), IAS acts as a causal factor for extinction of species in forest ecosystems in the world. They bring in physical as well as social impacts.

There is evidence that IAS have created significant negative impacts in certain natural environments in Sri Lanka. Marambe (2001) described that there are several IAS in Sri Lanka, spreading at an alarming rate and causing negative impacts on the natural environment and the agricultural ecosystems. Few important species of them are water hyacinth (*Eichhornia crassipes*), salvinia (*Salvinia molesta*), giant sensitive plant (*Mimosa pigra*), alligator weed (*Alternanthera philoxeroides*), congress weed (*Parthenium hysterophorus*) and Madeira vine (*Anredera cordifolia*). Among these, water hyacinth and salvinia are the major aquatic weeds in Sri Lanka that obstruct water bodies and affect the maintenance of irrigation systems. The giant sensitive plant has become a significant problem in the banks of Mahaweli River, which is a major source of irrigation water in the country. Alligator weed has invaded more than 200 ha of land in the southern province, whereas the congress weed has occupied about 150 ha of fallow agricultural land in upcountry area including some parts of Kandy district, and Vavuniya district of the Northern Province. Madeira vine has invaded many tea lands in the mid country region of Sri Lanka. Kotagama and Bambaradeniya (2006) reported that spread of IAS is one of the major

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threats to wetlands such as tanks, marshes and estuaries. Invasive species in wetlands could cause destruction of native species, particularly endemic fresh water fish. Spread of IAS in lowland floodplains and irrigation tanks create competition for resources with native aquatic fish and plant species, resulting harmful impacts over them. Deterioration of wetlands reduces their capacity to carry out ecosystem services such as flood mitigation, retention of sediments, purification of water, mitigation of soil and coastal erosion, carbon sink role and provision of breeding habitats for edible fish. Through wetlands, IAS could spread into agricultural lands where they act as agricultural pests and weeds, creating significant economic losses. Particularly, salvinia has been invading rice fields in the north-western province of the country causing considerable impacts on rice productivity while *A. cordifolia* has shown negative impacts on the tea plantations (Marambe, 2001). This could have notable effects on the agricultural communities, who are vulnerable to income shocks. The IAS has also resulted in problems in forest plantations, especially in the wet zone of Sri Lanka (Weerawardane, 2003).

Although research have been conducted on biological and ecological aspects of IAS in Sri Lanka, economic and policy studies on IAS are scarce. From the economic point of view, there are two main aspects which need to be considered in IAS management namely, identification and quantification of benefits and costs of IAS management and formulation of most effective policies that help to generate economically efficient and environmentally sustainable outcomes.

This paper examines certain aspects related to the economics of managing IAS focusing on the context in Sri Lanka. In this exercise we attempted to assess economic benefits/costs of managing IAS using the total economic value framework, and to review suitable criteria and guidelines that should be used in selection of policies for managing IAS.

Benefits of Managing IAS

Given the multiple damages/losses caused by IAS, managing IAS could logically be expected to generate multiple benefits. A majority of such benefits are involved with protection of ecosystem services by their nature. Given the non-market nature of such benefits, economic analysis of IAS management introduces significant conceptual and empirical difficulties.

Total economic value (TEV) framework provides some guideline to overcome conceptual difficulties we face here. Few studies have used the TEV framework to estimate the benefits of IAS management (Wise *et al.*, 2007). The TEV is a useful tool as it captures both direct and indirect use values as well as non-use values of environmental goods or services. The benefits of natural environment are enjoyed both by its direct users and indirect users. The 'use' benefits are enjoyed by two categories of users namely the present users and future users. Farmers, fishermen, recreationists and polluters are some examples for present users. The direct benefits received by the present users are termed as direct use values, where as indirect benefits received by present users are termed as indirect use values. Usually, indirect benefits include eco-system services offered by natural systems. The environmental benefits received by the future users are termed as option value. For instance, potential pharmaceutical value discovered for a preserved species in the future is an option value. Present users have a willingness to pay for conservation of a given species to ensure their availability for such future values. The TEV framework identifies two types of non-use values also, known as bequest value and existence value. These are values generated due to altruistic motives rather than utilitarian motives. Bequest value implies the willingness to pay for preservation of some resource entirely for the benefit of future descendents without any expectation of own utility. Similarly, one may be

willing to pay for the continuous existence of certain resource without any expectation of own or future descendants' utility. For instance, certain donations to preserve tropical rain-forests from temperate country citizens may originate due to existence value, which can be measured in terms of willingness to pay. Figure 1 illustrates the total economic value of managing IAS by using few common benefits that can be derived from managing various IAS.

In economic terms, damages by IAS cause a net loss of social welfare (Gren, 2008). Hence, many economic benefits of managing IAS can be identified in terms of avoided net losses to social welfare due to IAS. In addition, there are some plant species which could be used to make certain products generating direct economic benefits. Various benefits of IAS management can be categorized under different value components of TEV (Figure 1). Accordingly, benefits of IAS management lie in a wide spectrum that range from direct economic benefits such as organic output from controlled biomass of IAS to various ecosystem damages avoided due to management activities.

In order to estimate the value of benefits, it needs to identify and quantify all possible impacts of IAS and then value them in monetary terms. In empirical applications, TEV can be estimated on a per unit basis, TEV per hectare for instance. Estimates are dependent on the spread and density of the IAS. The TEV could be evaluated over an appropriate period of time to determine the present value of the various control options available. However, estimation of the economic value of benefits of IAS management is not an easy task. Firstly, there is lack of reliable data and information on benefits of IAS management. Quantification of impacts and estimating the rates of spread and densification are not easy tasks. Valuation of ecological benefits needs to be based on the market approaches (if a good or a service is traded in the market system) or non-market approaches. Both of them are tedious undertakings. Despite such limitations, studies undertaken to-date have suggested that control of IAS brings in positive benefits when major benefits of IAS are taken into consideration (Wise *et al.*, 2007).

Cost of Managing IAS

Cost of managing IAS includes the cost of implementing the different approaches for managing IAS. Cost of managing IAS may vary depending on the density of the invasion, actual methods used for management, effectiveness of the methods used and other site specific criteria, etc. Gren *et al.* (2007) classified the measures of combating IAS into four categories, namely, prevention, control, eradication and damage reduction. Prevention measures may include port inspections, quarantine requirements, ballast cleaning, etc. Controlling of IAS can be done using biological, physical or chemical approaches. Creation of barriers in water and on land, harvesting of the alien species, using biological agents and containment in a local area are some of the examples for practical control measures.

Eradication measures can make use of chemical treatments and harvesting of the species. The damages caused by IAS can be reduced to a certain extent by undertaking measures such as cleaning of clogged water pipes and providing healthcare for effects on human health.The nature of costs involved could either be direct or indirect. They cover costs to the whole society that includes costs borne by individuals as well as costs for the agencies which are involved in managing IAS. The cost items that need to be considered may vary depending on the species, management approach, location, etc.

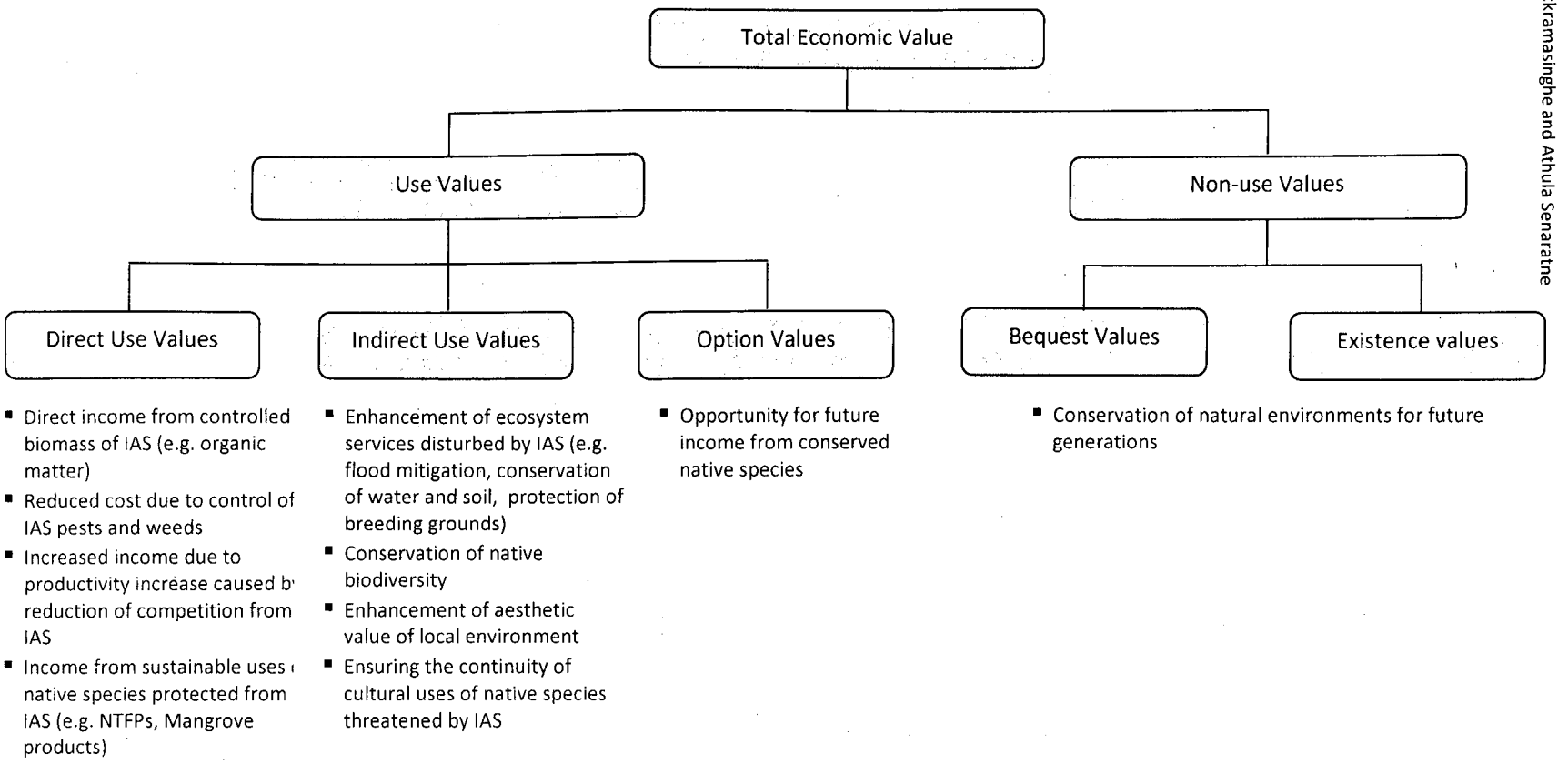


Figure 1. Total Economic Value (TEV) framework for managing IAS.

The GISP (2007), in calculating the costs of managing salvinia in Africa, considered two major types of costs, labor costs and input costs. Labor costs include sum of all costs on unskilled workers, semi-skilled workers and scientists/supervisors. The materials and chemicals used for managing salvinia were taken as the input cost. In the case of prevention measures, associated costs would include the development of quarantine control processes and protocols (including stakeholder consultation and potentially complex government review and approval processes), capital and labor requirements for enforcement (including inspection and administrative facilities at seaports, airports and border crossings), as well as prevention of border-crossing away from designated points (GISP, 2007). Olaussen and Skonhoft (2008) in deriving a cost function with regard to biological invasion considered costs in providing fishing permits, covering costs such as advertising, administration and supervision, construction and maintenance of parking lots, tracks and fishing huts, etc.

Economic Efficiency of Managing IAS

Managers usually have to consider a number of management alternatives available for a given IAS. From the economic point of view, the best option is the one that maximizes the net social welfare. Here, both total benefits and costs of respective alternatives jointly determine the economically optimal level of management that should be applied for a particular species. This is termed as the target level for optimal management. To identify the economically optimal target level, it needs to examine the behavior of benefit and cost functions. Figure 2 illustrates the behavior of total benefit (TB) and total cost (TC) functions of a particular alternative with the level of population control achieved by it.

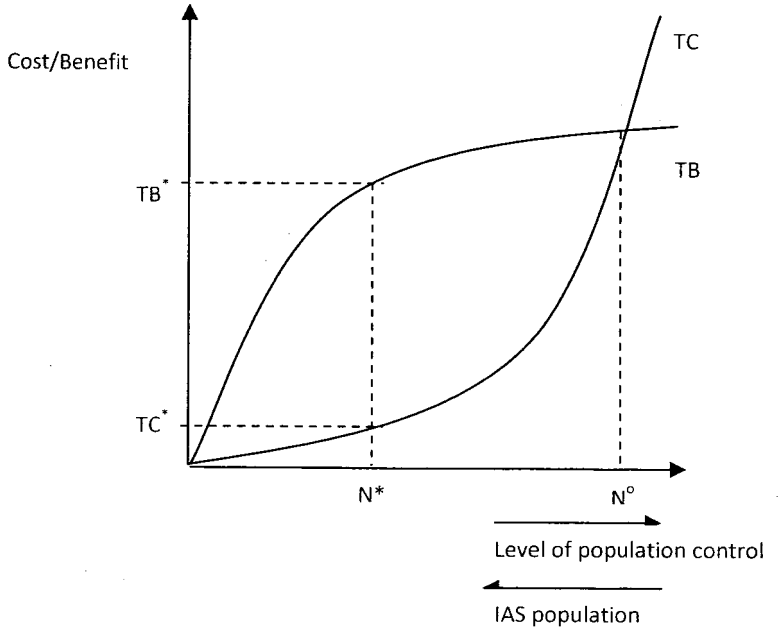


Figure 2. The behavior of total benefit (TB) and total cost (TC) functions of an alternative with the level of population control achieved.

As already stated, benefit of a particular intervention can be measured in terms of losses avoided by it whereas costs include all expenses of implementing the intervention. The total

benefit increases with the control level of population, but at a decreasing rate. In other words, the marginal benefit (the change in total benefit due to a unit increases in level of control in IAS population) diminishes with the reduction of IAS population. This indicates that for a given alternative of management, additional benefit that could be gained by controlling population is less at lower IAS population levels (higher levels of control) compared with higher IAS population levels (lower levels of control). The TC curve indicates the minimum costs incurred at different IAS population control levels. The TC increases with the level of population control at an increasing rate. This indicates that marginal cost (the change in total cost due to a unit increase level of control) increases as the population decreases. In other words, at lower population levels of IAS (higher levels of control), marginal cost of managing IAS is higher compared with that of higher population levels (lower levels of control).

Given the behavior of TC and TB curves, economically optimal target level of IAS management is found at the point where the difference between the total benefit and total cost (total benefit - total cost) is maximum. Accordingly N^* population level denotes the economically optimal target level. However, IAS reduction could be undertaken until the population decreases to N°, since the total benefit offsets total cost of intervention up to this level. At N°, total cost becomes equal to total benefit implying net social benefit to the society is zero. Beyond N°, IAS management measures should not be undertaken as interventions at such levels create negative net social benefits, or in other words net costs to the society.

Criteria for Economic Management of IAS

The management IAS is a public good (Heikkila, 2006). When IAS management strategies are in place no one can be excluded from receiving the benefits of management. On the other hand, one's consumption of the benefits of IAS management would not affect the consumption of benefits by other individuals. In other words, IAS management shows the two basic public good characteristics namely, non-excludable in production and non-rival in consumption. Further, managing IAS involves asymmetry of costs and benefits, another characteristic of a public good. Given the involvement of such public good characteristics, management of IAS provides little incentive for private sector to take up it as a profit making venture. Therefore, government intervention is usually imperative for controlling IAS and comprehensive policies are required to manage IAS.

Formulation of IAS policy requires identification of appropriate management approaches together with their costs and benefits. A major challenge for objective assessment of alternative strategies is poor availability of reliable data on benefits and costs involved with respective strategies. Two major criteria can be used to assess the economic efficiency of competing alternative strategies depending on the level of information available. They are, cost/benefit analysis and cost effectiveness analysis.

Cost/benefit Analysis

Cost/benefit analysis is a widely used economic tool that can be applied to see whether the total benefits of a particular intervention in managing IAS would offset the costs of implementing it. It provides a framework to measure net social benefits under with and

without intervention scenarios. Usually benefits and costs can be compared over a realistic time horizon corresponding with the economic life span of respective interventions. Rule of discounting is applied to capture the time effect over economic values. Among the key criteria to be used on evaluation of competing alternatives are benefit/cost (B/C) ratio, net present value (NPV) and internal rate of returns (IRR). Tools such as sensitive analysis can be used to capture uncertainty involved with benefits and cost estimates.

Cost Effectiveness Analysis

Although cost benefit analysis is a fine tool in making the decisions with regard to IAS management, conditions may not always be allow to perform complete cost-benefit analysis due to data and information limitations. On the other hand, since IAS involves a number of indirect benefits, it may not be always possible to value them accurately. In such cases, cost effective analysis serves as an alternative tool in identifying minimum cost solutions among a number of alternative strategies of management. Accordingly, total costs can be calculated for different target levels taking all benefits and costs of respective strategies into consideration. Also, partial cost-effectiveness analysis could also be performed on selected approaches, depending on the level of data availability.

Empirical Evidence

Wise *et al.* (2007) used the TEV framework to calculate the benefits of managing selected IAS. They assessed only use values whereas non-use values were not considered due to data limitations. The study aimed at establishing cost of invasions and costs of control options, focusing on five important IAS species in the African continent, namely, Nile tilapia (*Oreochromis niloticus*), water hyacinth (*E. crassipes*), large grain borer (*Prostephanus truncatus*), Congress weed (*P. hysterophorus*) and triffid weed (*Chromolaena odorata*). The cost-benefit analysis was used to compare the total economic benefits with costs of implementing control options. All the impacts were evaluated on per unit basis (unit per area, per capita, etc.). The economic impacts were evaluated over a 30-year period under with and without control situations. A range of control options and scenarios that covered variations such as the date of implementation, effectiveness of control and damage functions were allowed to change. Profitability of investing on individual control options was evaluated using benefit/cost ratios. Some of the results are presented below.

(a) The case study on Water Hyacinth, based on Nseleni river in South Africa reported that negative impacts were created on: (i) local communities who are dependent on the river for fish and irrigation, (ii) general public who rely on a road bridge over the river, (iii) a mineral company which abstracted water from the river and, (iv) a water treatment plant which obtained water from this river. Estimated losses amounted to US$ 58,195 per annum. This amount could have been decreased to US$ 7,000 with immediate implementation of a biological control program. The net present value of the avoided costs ranged from US$ 1.5 million for immediate implementation to US$1 million, and US$ 400,000 when implementation was delayed by 5 or 15 years, respectively. The cost of biological control was US$ 48,000, yielding a benefit/cost ratio of 31:1 for the immediate implementation of control.

(b) In the case of large grain borer, the study focused on its impact over the major crop maize. There were two options available for farmers namely, storing the grains to be sold later or selling it immediately after harvesting. When the option of storing was taken, farmers faced the risk of large grain borer attack. The study found that storage of maize increased the total annual economic returns from US$ 9.6 million to US$ 14.4 million than when sold immediately, implying that there were economic incentives to take the risk of storing harvested grain. Improved storage programs with or without biological control measures have further increased these returns to US$ 17.6 and US$ 20.4 million, respectively.

(c) A case study on the triffid weed in the Ntambanana district in KwaZulu-Natal, South Africa, revealed that the spread of the weed leads to reduce grazing potential thereby reducing livestock production. The annual total economic returns from cattle sales in the presence of triffid weed infestations ranged from US$ 447,000 (for 5% invasion) to US$ 382,000 (33% invasion) and US$ 270,000 (66% invasion). The introduction of a mechanical control program saw these annual returns rising up to US$ 509,000 (5% invasion), US$ 441,000 (33% invasion) and US$ 361,000 (66% invasion), respectively. Greater the area of initial invasion the greater was the percentage improvement in average net returns.

Gren *et al.* (2007) estimated damage or control costs of 13 IAS in Sweden, which are of importance due to their impacts on aquatic environment, biodiversity, health and other. The study found that availability and quality of data differ between species. It seems that estimates on human and health impacts are more reliable while estimates on biodiversity impacts are the least reliable.

Conclusions and Policy Implications

Policies and strategies designed to manage IAS should ideally be aimed at maximizing net social benefits. To achieve this it is necessary to undertake an objective economic assessment of all associated costs and benefits involved in selected strategies of management. In determining the best management strategy based on the economically optimal targets, cost benefit analysis is the most suitable tool. However, due to uncertainties involved in IAS management as well as limitations of available information, it may not be possible in all instances to go for the economically most optimal solution. In such cases where the target level could deviate from the optimal level, cost-effectiveness criterion could be used for assessments.

The cost-effectiveness analysis could be used to select among competing alternatives of IAS management on the basis of cost minimization criteria. All strategies of IAS management may carry their own advantages and disadvantages. On the other hand, strategies and policies for managing different IAS cannot be uniform as costs and benefits involved with different species may vary subject to a number of factors. Such factors may include type of species, area of spread and density, magnitude of the damage, intensity of control, physical and socio-economic impact over local communities, etc. Due to limited available information, the appropriate economic criteria for assessment of different management strategies may vary.

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Review paper

Chapter 8

A Conceptual Framework for Quantitative Assessment of the Invasiveness of Alien Species in Sri Lanka

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Introduction

Plant and animal invasions are considered as a serious threat to biodiversity, and are second only to man-made habitat loss and fragmentation. Invasive alien species (IAS) are known to cause significant reductions in native species populations, severe alterations of native plant and animal communities, or make significant changes to ecosystem processes and parameters (Bratton, 1982; Gordon, 1998; Hobbs and Mooney, 1998; Vitousek, 1986; Wilcove *et al.*, 2000).

Identification of invasiveness prior to their introduction (*i.e.* risk assessments), and ranking or grouping of already established invasive species using predictive tools will be a crucial step in the decision making process for managing invasive species (see Chapter 3 for details). Some countries have already used qualitative criteria to develop a numerical index, which allows grouping IAS based on selected criteria to facilitate the decision-making process in their management and prioritization of species for necessary action. However, in Sri Lanka, scientifically valid qualitative or quantitative assessments of invasiveness or risk assessment of plant or animal species have not taken place formally, yet. Protocols developed by Hafiz *et al.* (2006) for plants and Weerakoon (2007) are not widely available or have limited applications. Although there are different lists of IAS reported for Sri Lanka (Bambaradeniya, 2000, 2002; Marambe *et al.*, 2001, 2003; Wijesekara and Bambaradeniya, 2007), information on qualitative or quantitative aspects of invasiveness have not been used in preparing these lists of species.

Pushpakumata, G., Thattil, R., Marambe, B., Silva, P., Athauda, S. and Weerakoon, D. (2010): A conceptual framework for quantitative assessment of the invasiveness of alien species in Sri Lanka. In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 87-94. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

Hence, this paper proposes a framework on identification of biological, ecological, social and climatological characters (variables) of IAS (flora and fauna), and mechanisms to identify appropriate ranking and weighting processes using a statistical approach, which consists of regression, ranking and development of an index using multivariate statistics and models.

Identification, Scoring and Weighting of Characters (Variables)

The first step of development of numerical ranking or modeling of invasiveness is the identification of a list of characters (variables) of invasive species, followed by development of meaningful scoring techniques for characters and an appropriate weighting process. Review of literature revealed that the identification of characteristics of invasive species is a central issue in invasion biology. Such knowledge will determine the ability to predict the invasiveness of plants (Baker, 1974; Crawley *et al.*, 1996; Kolar and Lodge, 2001; Rejmanek, 1996) and animals (Sakai *et al.*, 2001; Roll *et al.*, 2007; Wendy *et al.*, 2008). Elton (1958) argued for a niche-based view of invasion resistance and thus, the ecosystems receiving more species are less likely to be invaded as more of the resources are already accounted for. Although this idea has been supported by some experimental studies (Fargione and Tilman, 2005), observational studies tend to show the opposite effect *i.e.* ecosystems with more native species also contain more established non-indigenous species (Stohlgren *et al.*, 2003).

Over the last 30-40 years, attempts have been made to identify variables of vascular plant species that are successful invaders (Baker, 1974; Crawley *et al.*, 1996; Pysek *et al.*, 1995) and other restricted taxonomic and/or life-form groups often in geographically and ecologically isolated areas (Rejmanek and Richardson, 1996; Richardson and Rejmanek, 2004). In this regard, some generalization has been identified to a wide variety of taxa (Baker 1974; Kolar and Lodge, 2001). The occurrence of strong correlations between biological characters and likelihood of negative impacts for non-indigenous birds in New Zealand (Veltman *et al.*, 1996), non-indigenous fishes in California (Marchetti *et al.*, 2004) and non-indigenous conifers worldwide (Richardson and Rejmánek, 2004) have been reported. Other work has shown that receiving environments (environments that IAS are introduced) may be more susceptible to invasion when they are disturbed, for example by roads (Gundale *et al.*, 2005). Peterson (2003) reported that comparing environmental conditions of the areas where IAS was introduced with those in the native range of introduced species will help in predicting whether the species is likely to be established in the new environment. Although ecological studies have not resulted in developing a unified conceptual model for invasions (Sax *et al.*, 2005), several studies have used a combination of variables as a framework for predicting which species will become invasive, and where they will establish. Species will become established when their ecology matches with that of their receiving environment, but only if the species is released in sufficient numbers. Once a population is established, the influence of propagule pressure is diminished. This is due to that the propagules are, by definition, being released by the reproducing population. Hence, whether or not the species proceeds to become invasive will be determined by interactions between the species. In general, the biological and ecological characters of the species make it invasive (invasive potential). Recently, ecologists have begun to pay more attention to propagule pressure, the number of viable individuals released, in examining the success of non-indigenous species (Leung *et al.*, 2006).

Spread and distribution of the species, impacts on native biodiversity, and availability and easiness of management of populations are important in identifying characteristic parameters of invasive species. Four main criteria with several variables under each criterion have been

proposed to be used in risk assessment process of IAS in Sri Lanka (see Chapter 3). The four criteria include ecological impacts (EI), invasive potential of species (IP), distribution of the species-(DI) and management options (MO). In the case of invasive alien flora, EI consists of 8 variables, IP consists of 17 variables, DI consists of 9 variables and MO consists of 8 variables, while the corresponding number of variables for invasive alien fauna is 7, 16, 11 and 10, respectively. However, within each criterion, and possibly among them, there is a potential that many variables would correlate with each other. The Principle Component Analysis (PCA) can therefore, be effectively used to reduce the number of variables used in the analysis. However, as Breiman *et al.* (1984), Verbyla (1987), Retherford and Choe (1993), Huberty (1994) and Christensen (1997) suggested discriminant analysis, multiple logistic regression, path analysis and classification and regression trees (CART) are necessary before removing variables as these techniques are most promising statistical tools in the assessment of the biological characters responsible for invasiveness. Thus, such analysis should be carried out before the final assessment.

System/Model to Assess Invasive Potential and its Impacts

Various authors have proposed different models to assess invasive potential and risk assessment. Randall *et al.* (2008) have reviewed 18 existing systems for categorization of non-native plant species. Of these, 6 systems are predictive systems (Pheloung *et al.*, 1999; Reichard and Hamilton, 1997; Rejmanek and Richardson, 1996; USDA APHS, 2004; USDA NRCS, 2000; Williams *et al.*, 2001), and rely primarily on characteristics (variables) distinguishing species that are most likely to become established and spread if introduced. These systems are used to evaluate species prior to their intentional introduction, to screen species most likely to be established and spread, mainly for accepting or rejecting for importation of seeds or other propagules. In contrast, the other 12 systems have been designed (Hiebert and Stubbendieck, 1993; Weiss, 1999; Thorp and Lynch, 2000; Champion and Clayton, 2001; Fox *et al.*, 2001; Heffernan *et al.*, 2001; Timmins and Owen, 2001; Virtue *et al.*, 2001; Wainger and King, 2001; Orr, 2003; Robertson *et al.*, 2003; Warner *et al.*, 2003;) to prioritize non-native species that are already established, in order to carry out mitigation efforts or management and research programs at national level.

Most of the currently known risk assessment protocols for IAS are linked with plants or mainly with weed risk assessment. In the case of assessing invasive potential of animal species there is not much evidence available. A few examples could be found in risk assessment carried out in aquatic and terrestrial fauna for mitigation and management efforts (Dextras and Mandrak, 2005; Colnar and Landis, 2007; Bomford, 2008; Britten *et al.*, 2009; www.fao.org/docrep/008/y5968e/y5968e0m.htm). Three predictive systems used for plants, *i.e.* the Weed Risk Assessment model (WRA) based on Pheloung *et al.* (1999), was originally developed for invasive alien plants in Australia and New Zealand. The WRA with additional decision tree analysis (WRA+Daehler Model) resulted in from testing the WRA in Hawaii (Daehler and Carino, 2000) and other pacific Islands (Daehler *et al.*, 2004). The decision tree analysis model (Reichard and Hamilton, 1997) developed for woody plant species in north America, and Hawaii (Reichard, 2001), have been tested by Krivanek and Pysek (2006) for 180 woody plant species in the Czech Republic in the central Europe, and concluded that WRA+Daehler model as the promising template for building a widely applicable system for screening and assessing the introduction of potentially invasive plant species for a wide range of geographical regions.

There are other models available to conduct risk assessment. However, the model developed for South African fynbos vegetation by Tucker and Richardson (1995) has been designed for application to very specific conditions, such as fire prone, nutrient poor shrub lands. The risk assessment of new environmental weeds in the central Europe, conducted by the European and Mediterranean Plant Protection Organization (EPPO) and was developed by Weber and Gut (2004), has primarily been designed for plants and insect pests of agricultural habitats and cannot be used to predict invasions to natural vegetations. The risk assessment scheme developed for environmental weeds in Switzerland (Weber and Gut, 2004) is very similar to the WRA scheme. The regional risk assessment case study reported by Colnar and Landis (2007) revealed a conceptual model on ecological risk assessment using Relative Risk Model (RRM).

Recently, an Invasive Species Assessment Protocol (ISAP) has been developed to rank non-native plants by impacts to biodiversity (Randall *et al.*, 2008). In IASP, 20 questions have been identified to evaluate species for their invasiveness and impact on biodiversity. These questions represent four major categories that contribute to the total impact of species, namely (i) ecological impacts (5 questions), (ii) current distribution and abundance (4 questions), (iii) trend in distribution and abundance (seven questions), and (iv) management difficulty (four questions). The response to each question is assigned point values (intensity rating) in the proportion of 3:2:1:0, where a greater value reflects a greater impact. Parker *et al.* (1999) reported that the ecological impacts and current distribution and abundance address the per capita impacts of the non-native species on native biodiversity within species range and in areas where it is established. Trends in distribution and abundance and management difficulty addresses other factors not covered by Parker *et al.* (1999), such as the factors that determine overall level of damage a species may cause, if it continues to spread and resist control. Parker *et al.* (1999) calculated an Invasive Species Impact Rank (I-Rank) for each species. The I-Rank values are grouped into four categories, high (76-100; where species is a severe threat to native species and ecological communities), medium (51-75), low (26-50) and insignificant (0-25; where species is an insignificant threat to native species and ecological communities). The protocol and datasheet are available online (www.natureserve.org). In this process, I-Rank can be calculated as follows:

$$\text{I-Rank} = \sum a\,(\text{I-Rank EI}) + b\,(\text{I-Rank IN}) + c\,(\text{I-Rank DI}) + d\,(\text{I-Rank MO}) \quad \text{---------- Eq. 1}$$

The I-Rank of each category can be calculated as follows:

$$\text{I-Rank EI} = \sum (i^{th}\ \text{character weighting} \times i^{th}\ \text{character intensity rating}) \quad \text{---------- Eq. 2}$$

where i=1, 2....n. The '*a*', '*b*', '*c*' and '*d*' that represent the weighted values of categories (Equation 1), and the character weighting and intensity rating of individual variables (Equation 2) will be determined based on analysis of actual data on a few species from known invasive and non-invasive groups.

Accuracy and Reliability of the System/Model Used

The general criticism for system- or model-based assessment of IAS for their invasiveness is the accuracy and reliability of information derived from the system or model. As Smith *et al.* (1999) have defined, the probability of correct classification of invasive species will determine the accuracy of the system. Any sample of species rejected because of being an IAS by a screening system will include a proportion of non-invasive species inappropriately classified as invaders,

depending on the reliability of the system/model used. Accordingly, as Krivanek and Pysek (2006) suggested, the accuracy of the model used in the analysis may be identified based on the proportion of known invasive species that would be correctly assessed as invasive (A_i; Equation 3) and that of known non-invasive species that would be correctly identified as non-invasive (A_n; Equation 4) (similar to type I and type II errors used in hypothesis testing):

$$A_i = (I_r / I_t) \times 100 \text{ ---------- Eq. 3}$$

where I_r is the number of invaders that are rejected by the system, and I_t is the total number of invaders assessed.

$$A_n = (N_a / N_t) \times 100 \text{ ---------- Eq. 4}$$

where N_a is the number of non-invaders that are rejected by the system, and N_t is the total number of non invaders assessed. The overall accuracy (A_o), including both components, can be assessed using Equation 5:

$$A_o = (N_a + I_r) / (N_t + I_t) \text{ ------ Eq. 5}$$

As they suggested, reliability of the model has two components, the probability that an accepted species will become invaders (P_{ai}; Equation 6) and the probability that a rejected species would have been an invader (P_{ri}; Equation 7) (refer to Equations 3-5 for clarification on parameters).

$$P_{ai} = I_a / (N_a + I_a) \text{ ---------- Eq. 6}$$

$$P_{ri} = I_r / (N_r + I_r) \text{ ---------- Eq. 7}$$

Conclusions

Although the protocol proposed by Randall *et al.* (2008) was designed for plants and has several limitations, with a few modifications to variables and scoring technique, it provides the basic technical process for assessment of invasive potential of both flora and fauna and their impacts on native biodiversity of Sri Lanka. Much of the information necessary to complete this type of assessment is readily available for most species. Hence, application of the protocol will provide better quantitative information on invasive potential and its impact on biodiversity. If grouping can be done on the basis of the degree of invasiveness (for known cases for flora and fauna, separately) then the variables that are responsible for a species be categorized into one of the groups (e.g. highly invasive, invasive, potentially invasive, non-invasive) can be identified using descriminant function analysis, resulting in equations comprising of the most important variables that can be used to screen the other species. Thus, PCA can be used for reduction of variables followed by discriminant function analysis to identify species into known groups in the future. It is also imperative that the weightages used for the I-Ranks be based on actual data.

As recommended by Randall *et al.* (2008) the species assessment and evaluation process with weighting and rankings for invasiveness and their impact on biodiversity need to be done by a team of biologists from each taxonomic category, *i.e.* flora, amphibians, birds, reptile, fish species, etc., familiar with the type of information needed to answer each question related to the variables. A comprehensive knowledge on statistical modeling will enhance the accuracy and reliability of the results.

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Review paper

Chapter 9

A Strategic Framework for Communication, Education and Training on Invasive Alien Species

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Introduction

The concept of invasive alien species (IAS) is fairly new to science and has not received a great deal of attention until recently. However, invasion by non-native species is considered today as one of the greatest threats to the world's biodiversity, even more so than habitat loss and degradation. Most such invasive species are either pets or ornamental plants used and distributed by man, which by accident have been released to the natural environment where they have become established. Some of the species however, have been introduced intentionally by various government line agencies or non governmental entities for specific purposes without realizing the invasive potential of these organisms. During the last century, the risk of invasion has increased exponentially due to increased global trade, transport, tourism and climate change. Once established controlling such IAS is quite difficult as has been discovered around the world, as well as Sri Lanka. It is both time consuming as well as costly, which makes it a difficult task especially to a developing country like Sri Lanka.

The IAS represent one of the primary threats to biodiversity, especially in geographically and evolutionarily isolated ecosystems, such as small islands. Sri Lanka is an island state and listed as a biodiversity hotspot of the world. Number of invasive alien faunal and floral species has also been recorded in Sri Lanka (see other Chapters in this publication). These species have already invaded human modified landscapes such as agriculture land, abandoned lands, irrigation systems, and home gardens. Some of the IAS have also invaded natural ecosystems and therefore, may have an impact on the rich biodiversity of the island. In order to strengthen its

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capacity to control IAS in Sri Lanka, the governments must take steps to develop effective strategies and programmes to minimize the introduction and spread of IAS.

Importance of Creating Awareness on IAS

As the saying goes, prevention is better than cure. Prevention of IAS can be done at several stages. The best preventive practice of course is to prevent the entry of potentially invasive species to a country. However, if the species is already established in the country or manages to breach the preventive barriers in place (see Chapters 4 and 5) the next stage will be to contain the spread of species. The last stage will be to conduct programmes to control/manage or eradicate identified species. At each of this stages awareness plays an important role.

The target audience that needs to be educated varies depending on the stage of invasion. If the species has not been introduced to the country the target audience that needs to be educated is the agencies that deal with importation of alien living organisms as well as the agencies that are involved in the regulation of such imports either by issuing import permits or license or quarantine of such imported living organisms such as Department of Animal Production and Health or National Plant Quarantine Service. If the IAS has already been introduced and established in the country, educating the general public is an important step to contain the spread of the species. If the decision has been taken to control/manage or eradicate the species then the government or other agencies or individuals that undertake such activities has to be educated in the methodologies to be undertaken as there are many instances where attempts to manage species have led to further spread of the IAS, as evident in the case of management of *Ulex europeaus* in Horton Plains National Park and *Opuntia stricta* in Bundala National Park. Therefore, education and awareness on the potential danger posed by IAS and how human beings can contribute to their spread is an important aspect of combating IAS in any country.

Present Status in terms of Awareness on Invasive Alien Species

The discussion of IAS at present is largely limited to the academia, conservation community, and few government agencies such as the Biodiversity Secretariat (BDS) of the Ministry of Environment, Irrigation Department, Department of Agriculture, Forest Department and Department of Wildlife Conservation who directly deals with IAS at present. Attempts made to create awareness among general public is far below the level expected. To date several approaches have been taken to create awareness about IAS in Sri Lanka, which are reviewed below.

(a) **National symposia:** To-date 5 national workshops/symposia have been held on IAS (Marambe, 1999; Marambe, 2000; Kotagama *et al.*, 2001; Ranwala, 2008; and MENR, 2009). In addition presentations on IAS have been made on number of other National and international symposia held in Sri Lanka and elsewhere. These symposia serve to share the latest developments regarding IAS in Sri Lanka and to share research findings on various aspects pertaining to Invasive species. The information generated through these events reaches only a limited audience of which most are quite familiar with the subject. However, these symposia have also helped formulating national policy directions, future research needs and to discuss issues pertaining to IAS and therefore are vital to have periodically. Further these symposia provide an excellent platform for

young researchers to present their work and get constructive feed back. Further, the proceedings of these symposia are published and function as a source of information for interested parties.

(b) **Articles in newspapers and popular magazines**: A number of articles have appeared on the newspapers and popular magazines such as *Loris*, *Haritha*, *Soba*, etc., in both English and Sinhala medium. These articles have a much wider circulation and reach a broader audience. Further as these articles are written in simple language it is easily understood by even non-technical persons. However, majority of these articles are written in general to create awareness about what alien species are and the threat they pose to the biodiversity but have not stressed enough on the role of individuals in preventing their introduction and spreading.

(c) **Electronic media**: Compared to the print media the electronic media has been used less frequently for the purpose creating awareness. Radio has been used more frequently compared to the television, though the latter is a more powerful medium to be used for this purpose.

(d) **Posters, brochures, and pamphlets**: Several posters and brochures on IAS have been produced by both governmental and non-governmental organizations as a part of their awareness campaigns. These materials, too, have a limited audience but have been useful for awareness campaigns especially to deal with local invasions such as Mesquite (*Prosopis juliflora*), prickly pear (*O. stricta*), European gorse (*U. europeaus*), giant mimosa (*Mimosa pigra*), parthenium (*Parthenium hysterophorus*), etc., However, these material also focus mainly on awareness and not on specific actions people should take with regards to controlling IAS.

(e) **Sign boards**: Use of sign boards placed on the roadside to focus the attention of public on IAS present in the area and providing do and don't lists to prevent the spreading of the species was practiced once for control of parthenium. This strategy is useful only for species that are showing restricted distribution but not for those that show island wide distribution such as lantana (*Lantana camara*).

(f) **Workshops and public lectures**: Many non-governmental organizations, and governmental organizations such as the Biodiversity Secretariat (BDS) of the Ministry of Environment and Central Environment Authority (CEA) holds regular workshops and public lectures in various parts of the country to create awareness among school children and the general public about IAS. They too, reach a limited audience even though this method is useful in creating awareness among focal groups.

(g) **Formal education**: IAS are included in the syllabi of advanced level (secondary education) and many undergraduate and post-graduate courses. In these cases, the IAS are presented to the student in an academic context where the main focus is on biological and ecological impacts with little attention on management or control.

(h) **Non-formal education**: Many of the short-term certificate courses offered by non-governmental organizations and universities for general public on biodiversity and conservation includes a section on IAS. Here too the focus is mainly on biological and ecological aspects rather than management and control.

Continuous professional development programs for officers of the government and non-governmental organizations on IAS related activities

Even though there has been a great deal of emphasis on creating awareness very little has been done in terms of training and capacity building among officers that are involved in managing IAS or regulating importation of alien organisms to Sri Lanka. Some of these officers have had an exposure to the subject when they enroll in formal and non formal education programmes as described above. However, the exposure they get at these courses does not provide them with the necessary know how to effectively carry out their duties. As such, the capacity among enforcement agencies to combat IAS needs to be strengthened.

Private sector involvement

The education and training offered aiming at the private sector organization is totally lacking in Sri Lanka. Being the key players in international trade and tourism, it is important to design education, training and capacity building programmes to support the private sector organizations and to seek their active participation in the IAS management activities of the country.

Need for a Comprehensive IAS Communication, Education and Training Strategy

Number of strategies is used to communicate about potential hazard posed by the IAS by both the governmental and non governmental agencies with varying audiences. However, a planned approach to educate the wider general public about IAS and their impacts on well being of both humans and ecosystems, and more specifically their role in preventing the spread of IAS is imperative. It is even more important to design a specific training module for relevant line agencies in order to build their capacity to effectively manage IAS.

Communication, education and awareness has a key role in the control of IAS, as humans play a pivotal role in introduction, spread and establishment of IAS in any country. While people have some degree of understanding of ecological and economic effects of some IAS, few recognize the connection between their own activities and the accelerating rate of invasions. Hence, there is a need for development and implementation of an IAS education program to foster recognition and understanding in the wider community. In such educations programs, following aspects needs to be given priority.

- Methods of dispersal/ transportation of invaders by human agents (e.g. aquarium trade, horticulture and nursery trade)
- The importance of the public's role in the introduction and spread of IAS (e.g. deliberate or accidental translocations through dumping of weeds and aquarium animals, movements of vehicles and boats, using invasive species in their home gardens)

- Ecological, social and economic impacts of invading species (e.g. predation, competition and hybridization with native species, habitat alteration, production losses in industry, vectors of disease, cost of control, decreased water quality and availability, flooding)
- Differing potential for invading species to develop into pests and/or have detrimental impacts. This highlights the need for risk assessment as a means of identifying key species to target in educational packages (see Chapter 3 for details).
- Some invaders that have not yet become established in Sri Lanka can have potentially disastrous ecological, economic and social effects and eradication warrants a coordinated rapid response approach (see Chapters 4 and 5 for details). Education packages need to highlight these cases to emphasize the seriousness of IAS, their impacts and indicate methods of control.
- The observed connection between environmental degradation, disturbance and invasion success *i.e.* biological invasions in degraded and disturbed habitats, can be facilitated by the disturbance rather than being a cause of the problem. Addressing factors that cause degradation (e.g. clearing of vegetation, unfenced grazing, runoff) are important within an overall education program and may be fruitful in the management of invasive species. Consideration of biological invasions must form an integral component of any environmental management program.
- Control and eradication programs can be successful given effective technology, adequate resources and community support and require cooperation between groups involved. Highlighting these successes in educational material ensures positive messages are generated therefore encouraging support from the wider community.

The education programmes should address key management issues, strategies and policies in order to develop a coordinated educational strategy. This would include educational material on aquatic and terrestrial IAS. There are significant differences in public awareness about IAS and the impacts of their activities on the spread of such species, due to differences in perceptions, interests, available information and misunderstandings. While some invaders (e.g. congress weed – *P. hysterophorus*, lantana – *L. camara*, giant sensitive plant – *M. pigra*, and tilapia - *Oreochromis mossambicus*) have been the focus of educational and control campaigns, little or no information is available on other invasive species such as the snails (e.g. apple snail, giant African snail) or slugs and various ornamental plants and animals. These differences can in part be attributed to differing commercial, agricultural and recreational interests, e.g. agricultural weeds become a priority due to production losses and Tilapia is a priority due to impacts on inland fishery. Invertebrate and microbial invasive species have been overlooked due to their small size, relative invisibility and perceived unimportance compared to larger species.

Policy and associated research have been more directed to those areas of particular economic interest that also perpetuates this situation. General misunderstandings of particular aspects of invasion biology may arise through misinformation, lack of education, and confusion between native and introduced species that look similar. This emphasizes the need for a comprehensive educational package to focus on these differences in public awareness of invading species. The communication strategy should involve a broad spectrum of approaches that focus on the knowledge base and key issues relevant to target groups while recognizing and addressing key misunderstandings.

There is also a need to recognize barriers to understanding the detrimental aspects of IAS. A major barrier is the public's perception and understanding of what constitutes an alien species and this also serves to highlight the conflict of interests in the broader community. This can lead to the problem of generating mixed messages such *U. europeaus* plays an important role in prevention of predation of endemic lizards in Horton Plains National Park. Thus educational approaches need to understand and incorporate the range of values held by the public, while focusing on educating them about potential detrimental impacts of alien species.

All educational material must be accessible in a variety of forms to reach all identified target groups e.g. brochures, booklets, posters, activity and resource kits for schools, media stories. This information could include an IAS resource guide on the internet and possible hard copies as a reference tool for invasive species. In order not to overwhelm the public with huge lists of invading species which could provide an impression that no advances have been made, there is a need to target a selection of key species that have been carefully chosen to reflect what can be done, what has already been done and which actions will bring the best results.

Improving the understanding among general public on the biological invasions and increasing their awareness on IAS can have added benefits, e.g. the public can provide information on the location of IAS for which our knowledge is limited. This is of value for species which are still actively spreading in distribution and an understanding of their current distribution could assist in targeted management actions including monitoring and control.

There is also great potential for involvement of the public in actively participating in the control of IAS through modification of community attitudes and activities. The most important component in modifying attitudes involves educating the public on the impacts of invading species on the natural environment and the direct and indirect effects on their own livelihoods. In order to develop an adequate knowledge base to address the problem, it is important to undertake research and monitoring of IAS. Monitoring is the key to early detection of new IAS. Monitoring should include both targeted and general surveys. Research on IAS should include a thorough identification of the species and should document the history and ecology of invasion (origin, pathways and time-period, the biological characteristics of the species, the impacts on the ecosystem, species and genetic level as well as the social and economic impacts and how they change over time. Such information can be used to determine the benefits if any, and costs (environmental, economic and social) of the IAS, which is also crucial for the formulation of IAS management plans.

The formulation of the final communication, education and training strategy should be based on data gathered through review of existing published documents, stakeholder meetings, questionnaire surveys and personal interviews conducted with relevant government and nongovernmental organizations. This paper outlines the strategic approach that should be implemented in Sri Lanka to enhance the awareness on IAS among general public as well as government and non-governmental organization that deals with IAS issue directly or indirectly.

Objectives of the Strategy

This strategy should be constructed to achieve the following objectives

- To increase the awareness of the general public, key stakeholder and interest groups, school students etc of the issue of IAS. This includes factors that enhance their

success, their detrimental impacts and what pre-emptive management and control methods can be undertaken.

- To minimize any potential role the public and stakeholders may have in the introduction and/or spread of IAS.
- Ensure that a range of audiences are able to correctly identify IAS or have contacts for expert identification, and highlight cases where IAS could be confused with native species.
- To enable the community to provide information on the location of IAS, which can assist in the management and control of such species.
- To build capacity of relevant line agencies, which will enable them to perform duties efficiently and effectively.

Key Stakeholders

To assist in the effective implementation of the education strategy on IAS, the target audience could be grouped in to six major stakeholder groups

(1) General Public: The focus here will be to prevent or minimize the involvement of the general public on introduction, spread and establishment of IAS.

(2) Students starting from primary school to postgraduate level. Here the emphasis will be to provide an increasing level of awareness about the IAS as well as to influence research on IAS especially at the postgraduate level.

(3) Public Sector agencies involved in importation of species or regulating entry of species such as Department of Botanic gardens, Department of Zoological gardens, Department of Agriculture, Inland Fisheries Research institutes Plant quarantine, Department of Animal Production and health, Department of Livestock Development. Here the focus is going to be providing focused education and training on aspects such as risk assessment, use of databases, screening techniques etc.,

(4) Agencies involved in control/ management of IAS such as Department of Wildlife Conservation, Forest Department, Marine Environment Protection Authority and Irrigation Department. The emphasis here would be control methods, monitoring methods, and preparation of management plans for IAS

(5) Non regulatory agencies that has a bearing on introduction or spread of IAS such as Central Environmental Authority, Tourist board, Road Development Authority, Academic institutions and Board of investment. Here the emphasis will be on environment assessment, monitoring mechanisms, environmental best practices with respect to prevention of introduction and spread of IAS

(6) Private sector organizations that has a bearing on introduction or spread of IAS such as horticulturist and aquarium owners. The emphasis here will be to create awareness about actions that should be taken to prevent introduction and spread of IAS in their respective trade activities.

Key tools

The following communication tools could be used to ensure effective internal and external communication:

- Media - here printed and electronic media will be used to reach a broader audience. The main target group will be the general public.
- Seminars or workshops - this tool will be used to reach a specific stakeholder group such as academics conducting research on IAS, education sector, media, agencies that are indirectly linked to IAS such as RDA, CEA or BOI, horticulturists, aquarium owners, traders etc., The idea will be to develop a dialogue on sector specific issues and workout methods and mechanisms to address these issues
- Website - This will function as an interactive information portal which can be accessed by a wider stakeholder community from general public to research scientists. The site will have different access levels where access to information will be controlled through a password system which will enable the user to access and download or upload information to the portal
- Specialized training - These training will be focusing on specific line agencies that deals with IAS either at entry level or once established inside the country. The training modules will give a general overview of the IAS and then provide sector specific skills with relevant case studies and practical assignments which will enable the officers of these line agencies to work more efficiently
- Merchandise and promotional materials - these will include posters, brochures, booklets, bill boards, stickers etc., to promote broader public awareness to be used in places where large number of general pubic gather with the aim of creating awareness about specific issues such as aquarium fish or horticulture to be displayed at aquariums, horticulture shops or fairs.
- Academic publications - The focus here is to document technical information arising from research in the field of IAS periodically
- Curriculum reforms - the focus here will be to develop a curriculum with the relevant stakeholders to ensure the IAS is included in the curriculum from primary to postgraduate education and that the curriculum is designed in a way that will provide a incremental amount of information

Anticipated Products

In a successful ad an effective communication strategy, the following products are expected.

- A coordinated educational program for current and potential alien species
- Information packages designed for interest groups - brochures, booklets, posters, study packs, guide books to identify IAS
- Website for information, database of resources and contacts
- Specialized training modules for key line agencies dealing with prevention or regulation of IAS
- A coordinated media campaign. television, newspaper and radio advertisements

Anticipated Outcomes

The communication strategy for IAS in Sri Lanka if properly implemented, will lead to the following anticipated outcomes.

- Improved understanding within the general public of how and why particular species are identified as IAS.
- Increased public awareness of biological invasions, including factors that lead to the success and spread of alien species, their impact on the environment and the role the public can play in minimising their introduction and spread.
- Improved appreciation within government agencies and the general public of the value and importance of continuing education concerning biological invasions.
- Increased awareness of the importance of including biological invasions as an integral part of developmental activities
- Increased capacity of the relevant line agencies to deal with IAS and relevant issues

The strategic framework for communication, education and training on IAS is given in Table 1.

Table 1. Strategic framework for communication, education and training on IAS.

Target Group	Objectives	Tools
General Public	• Create general awareness • Reduce their involvement in introduction and spread of IAS • Obtain information from general public regarding IAS	• Use a series of newspaper articles • Use of electronic media for specific issues: TV programme on IAS, Radio programmes, short messages on the radio • Posters, brochures, bill boards, booklets (general and focused) • Use of other media such as street drama, role play, etc. • Training of trainers: workshop for NGO's involved in public awareness • Exhibits in the Natural History Museum
Students and Teachers	• Increase the knowledge • Bring an attitudinal change with respect to AIS • Motivate students to learn science using IAS as a vehicle • Investment on the future	• Develop curricula for different levels of the education sector • Conduct workshops for teachers to create awareness at a regional scale • Develop a mobile lecture programme and encourage follow up using competitions, web link • Develop a mobile exhibit • Network with the existing school programmes such as *Haritha* programme
Public Sector agencies involved in importation of species or regulating entry of species	• To build capacity of these organizations to effectively deal with AIS	• Specialized education and training programme: General awareness followed by specialized training on steps that should be followed in importing such species such as risk assessment, use of databases, infrastructure development, internet technologies
Agencies involved management of species	• To build capacity of these organizations to effectively deal with AIS	• Specialized education and training programme (Workshops - Central and Regional): general awareness followed by specialized training on steps that should be followed in management of species such as management plan preparation for AIS, alternate use and associated risks, monitoring methods, mapping tools etc.,

Table 1. Contd...

Target Group	Objectives	Tools
Agencies that can play an indirect role in the AIS	• To build capacity of these organizations to effectively deal with AIS	• Specialized education and training programmes (Workshops - Central and Regional): Environmental management needs, best practices to be followed, monitoring • Workshop for academics on research needs and case studies • Workshop for media on IAS and Information sources
Private sector agencies responsible for importation of organisms that has the potential to become invasive	• To minimize introduction of AIS	• Specialized training programmes: General awareness emphasizing the possibility of AIS introduction directly or indirectly through import and export of organisms or other goods and specific training on steps to be followed when importing such biological agents and line agencies that can provide them support

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Review paper

Chapter 10

Review of Databases on Invasive Alien Species

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Introduction

Invasive alien species (IAS) are organisms which successfully establish themselves and spread, threatening the biodiversity of another environment, disrupting its natural balance and causing severe economic problems marking an estimated damage of 5% of the global economy (www.unep.org/dewa/Africa/publications/AOE-2/). The dispersion is caused due to the mixing of the non-native species across biographical boundaries, due to global trade and increased tourism. Today, the threat has been identified and assessed in terms of ecology, economy and health. Many databases have been developed worldwide, categorizing the entire biosphere into many different subcategories including biological demarcations and terrestrial demarcations.

Sri Lanka is a tropical country, with a unique and enormous biodiversity, which spans through inland, marshland, aquatic, coastal to marine ecosystems. Being a bountiful island nation, the threat of IAS to the country is severe due to its exposure to international trade. The prevailing and potential IAS threat in Sri Lanka has been identified by several entities. The need to categorize them, to specify necessary management and control mechanisms and incorporation of the information to a Database is highly envisaged.

This paper examines the IAS databases available in international and national levels, with special attention to the exceptional features, data structures, and gaps of the available databases and to identify the strategies to fill the gaps of IAS databases. Under the international DBs, the online databases available through the cyber space were reviewed and the most popular (based on the number of hits) DBs at three different levels, *i.e.* one each from the global level and regional levels, and a merger between Global and State/federal DBs, were considered. Three recognized

Manawadu, L. (2010): Review of databases on invasive alien species. In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 105-113. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

national level online DBs used in other countries were also reviewed. In the Sri Lankan context, two institutional level DBs were appraised. Information collected through consultation with stakeholders engaged in the field of IAS in Sri Lanka were used to propose an appropriate IAS DB for Sri Lanka.

Global Databases

The Global Invasive Species Database (GISD)
Website: http://www.issg.org/database/welcome

This DB is managed by the Invasive Species Specialist Group (ISSG) as part of the Global Invasive Species Programme (GISP), and aims to increase awareness about the IAS and the precautions that can be taken and the necessary management practices. The DB provides up-to-date information covering all taxonomic groups from micro organisms to animals and plants in all ecosystems which is continuously updated or reviewed by the resource personnel from around the world. The DB has 2 levels of access *viz*. administrator login and user login.

The DB facilitates data mining through 2 main divisions *viz*: *standard search* and *taxonomic search*. An interactive search is provided under both of the aforesaid divisions. The standard search facilitates the scooping of relevant data *via* 4 combined fields namely, species, country/location, habitat and organism type with the last 2 fields consisting of 2 scroll-down menus covering all habitats and organism types, respectively. The required species picked up will be further categorized in to its ecology, distribution under alien region and native region, relevant management information, impact information (general and location specific), references, and links and contacts. The taxonomic search is facilitated by merging the taxonomic level and taxonomic name.

All of the non-native potential target species identified in this DB are ranked as high, medium and low priority, based on their invasive potential and impact potential. Though this database lacks the spatial component (the information is not mapped to illustrate its geographical distribution) and the search criterion used in the taxonomic data mining needs the subject knowledge to specify the taxonomic level and name, they are outweighed by the wide scope of usage and the free of charge access.

Regional Databases

Delivering Alien Invasive Species Inventories for Europe (DAISIE)
Website: http://www.europe-aliens.org

This interactive DB is a result of the Delivering Alien Invasive Species Inventories for Europe (DAISIE) project. Funded by the European Commission under the Sixth Framework Programme, the DB provides a 'one-stop-shop' for information on biological invasions in Europe with the view of assisting those who seek information on IAS and its control and prevention.

Data mining in this DB falls under 3 main categories: *search species*, *search experts* and *search regions*. The first 2 search methods require the typing of the names of the species and/or expert of interest which can be picked up under 'alien species' and 'expert'. Search is further facilitated under a classical chain subdivision of alien species under 5 subcategories: terrestrial vertebrates

(divided in to Aves and Mammalia), terrestrial invertebrates (categorized under insect), aquatic inland (Mollusca, Crustacea, osteichthyes, chondrichthyes), terrestrial fungi (divided in to fungi and chromista) and terrestrial plants (classified under Magnoliophyta). Although the current version only provides for invertebrates and fungi, DAISIE DB stands out by incorporating a GIS representation on terrestrial species and providing a graphical representation on aliens by group, pathways and vectors. This DB is being uploaded with a large quantum of data frequently.

A merger between Global and State/Federal databases

National Invasive Species Information Center (NISIC) of the United States Department of Agriculture (USDA)
Website: http://www.invasivespeciesinfo.gov/resources/databases.shtml

This database administered by the NISIC, under United States Department of Agriculture (USDA) is a highly interactive DB on invasive species providing free access to a large number of articles covering the state, federal, local and international sources. Browsing is facilitated under 2 main divisions *viz*: (a) by *Geography* and (b) by *subject*, where browsing by geography is subdivided into 2 categories namely (a) *United States* and (b) International. The search options under United States cover Plants DB, non-indigenous aquatic species by state and pest tracker. The state information is backed by three other categories *viz* state resources, multistate resources and western rangeland weeds. Under *international*, search is linked to 3 global DBs namely the GISP DB, Global Strategy on Invasive Alien Species and Invasive Forest Trees.

Search options under *Subject* are facilitated under 6 main criteria namely, (a) animals, (b) microbes, (c) economic impacts, (d) laws and regulations, (e) manager's toolkit, and (f) resource library. The data mining is further enhanced by merging these 6 criteria with the subcategories of *Geography*. The intended entity (a plant, microbe or an aquatic species) is investigated completely in terms of its biological, ecological, invasive and distributive aspects through selected online resources.

National Databases (Stand alone DBs)

National Information Sharing Mechanism on Global Plan of Action (GPA) Implementation
Website: http://www.fao.org/ag/AGP/agps/GpaEN/GPATOC.HTM

Plant genetic resources are an essential type of resources that is seriously threatened and whose loss will touch each one of us and endanger future generations. The Global Plan of Action (GPA), for the first time, provides a framework for conservation and utilization activities that will be a major contribution in implementation of the Convention on Biological Diversity in the field of food and agriculture.

About 150 countries have adopted the GPA at the Fourth International Technical Conference on Plant Genetic Resources (Liepzig, June 1996) agreeing that its implementation would be monitored and guided by the national governments and other members of FAO and recommended the establishment of a transparent and effective monitoring system. Monitoring the implementation of the GPA and its related activities is essential for establishing priorities, developing future plans and for effective use of the financial resources available both at national and international levels for implementing the GPA. This information sharing mechanism

stretches its information under 6 main divisions namely, (a) priority activity areas, (b) common tables, (c) registration, (d) merging, (e) iterations, and (f) documents.

In this database priority activity areas are categorized under *in situ* conservation and development, *ex situ* conservation, utilization of plant genetic resources, and institutions and capacity building. Under each of these categories, in for is collated under several headings tabulated with a provision to insert data pertaining to the organization and project/program along with *indicators* and *available data*, which is further tabulated into *type of activity*, *other activity type* and *number of professionals* involved. A facts sheet giving contacts of each of the participating entity is provided along with the project/program involved in. The common tables comprises of the following:

I. Organizations*:* containing the contact information on institutes, organizations and networks, as well as departments or subordinate structures within them. The field 'parent organization' is used to build hierarchies among the table entries.
II. Contact persons*:* containing the contact information on persons, including phone numbers and email addresses. Persons are usually associated with organizations in the organization table, where the mail address is stored.
III. Projects*:* collecting data on programmes, projects, activities, plans, courses, etc. A flag field indicates the context and serves for analyzing and filtering entries that belong to different priority activity areas.
IV. Taxa table*:* containing data on scientific plant names and authorities.
V. Cultivars*:* containing data on cultivated varieties, their pedigree and origin.
VI. Areas*:* storing data on geographical areas within countries. There is no attempt to be completed in the description of the area; the only required field is the area name. If longitudes and latitudes are entered they should refer to a central point within the area, which can be used to plot areas on a map. The area size field is useful for the same purpose, but is not required. It is possible to enter whole countries or even larger geographic areas into the area table, but no attempt is made to build hierarchies between such areas.
VII. Infosys*:* containing data on information system software used to store, manage and analyze PGRFA data.
VIII. Reference*:* is used to collect data on references. The structure follows the BibTex standard in order to allow easier processing with existing BibTex tools, e.g. to produce lists of references in standard format. A reference can be an electronic document, such as a web-site on the Internet, and
IX. Agreements*:* contains data on bilateral or multilateral agreements.

Access to *Registration* and *Merging* is restricted to authorized users.

Invasive and Exotic Species to North America
Website: http://www.invasive.org

This free interactive DB provides information on invasive and exotic species to North America under 4 main groups, *i.e.* plants, insects, pathogens and other species. Plants are further classified under: WEEDUS, federal noxious weeds, state noxious weeds, aquatics, herbs/forbes, grasses, shrubs, trees and vines in which all entities falling under each category are tabulated by subject name, scientific name, family and order. Further search is facilitated with images and

videos. Access is granted in different levels where some information is restricted for normal users.

Furthermore, the DB provides a large amount of identification strategies and control mechanisms relevant to the IAS.

Hawaiian Ecosystems at Risk project
Website: http://www.hear.org/species

This DB focuses on disseminating information, providing methods, creating awareness on harmful non native species of Hawaii and the Pacific, among resource personnel and general public. The DB is divided in to 4 main groups, *i.e.* plant, vertebrates, invertebrates and other species. Plant information is supported by means of images, maps and reports. A further categorization under plants has been made available *via* other DBs such as Plants Native to Hawaii, Plants of Hawaii. *Kalaupapa* Herbarium, and Botany DBs with information pertaining to all species categorized under the first three categories listed above (*i.e.* plant, vertebrates and invertebrates) are available in terms of their description, taxonomy, images, distribution and other resources. Information regarding vertebrates and invertebrates are supplied under a common format based on description, taxonomy, images, distribution and other resources where as information regarding the "other species" category is tabulated under species, common names, native to Hawaii, present in Hawaii and established in Hawaii. This main category is supported by 2 other supplementary links *i.e.* pathogens of plants of Hawaii and Ohia rust information. This DB facilitates the dissemination in information on PDF format as well.

The global databases (*e.g.* http://www.issg.org/database) and most of the regional databases on IAS provides up to date information on invasive species covering a large span of plant, animal and micro organism species in all ecosystems. These sites are continuously reviewed by resource personnel around the world and this is significant. These databases provide access in flexible authority levels, without creating any hindrances for data mining of general users. Further these are supported with spatial data which are illustrated on maps. This way the analysis is easier and hence forecasting of spread and decision making is easier.

IAS Databases in Sri Lanka

Today, Sri Lanka faces a threat and fears the potential risk of IAS in a substantial level (see Chapters 3 and 4 for details). The threat has been identified and data have been gathered regarding IAS and related areas but are still not applied effectively to address the rising threat in an interactive form, with the use of information collected in the printed and/or written formats. Being a global issue, the issues related to IAS are being addressed by many countries worldwide with modern tolls and technologies incorporating the information to online interactive DBs where they are continuously updated in different access levels making awareness among the resource personnel and the general public. A number of professional entities are currently working towards building up an online interactive DB to address the demanding need.

With the development of a management information system (MIS) on IAS of Sri Lanka, the expertise and knowledge of IAS of resource personnel around the world could be obtained and shared. This information can hence be disseminated among the public to promote awareness and to acquire active participation in controlling the current IAS threat. Information regarding the IAS of Sri Lanka along with a listing of the established species is available in the traditional

format *i.e.* printed version, which is much time consuming and ineffective to address the current level of threat from IAS.

Two DBs currently developed in Sri Lanka at institutional level and in use, sfocussing on the invasive alien plants (IAP) are presented below.

The Invasive Plant Database of Sri Lanka (IPDSL)

The Invasive Plant Database of Sri Lanka (IPDSL) developed by the University of Colombo, Sri Lanka, is found in a compact disc (CD) form providing details on IAP of the Western Province of Sri Lanka. The DB contains 4 table types consisting of: details of plants, details of members/users, details of new plants (allowing registered users to add new content), updated details of the plants (details updated by the registered users). The IPDSL unfolds a healthy categorization of its information under trees, shrubs, herbs, family, plant image, plant map, control method, district, province and also additionally ember and login account. The DB is supported with a rich GUI consisting of login window, search window, search results window, control methods window, map viewer window, update details window, add new invasive plant window, add new control window, member registration window, my profile window, login registration window and administrative tasks window.

Search criteria are facilitated with multiple options in the search window with, scientific name, common name, family, habitat, origin, image, identification details, distribution map, habit, methods of propagation, status, invasive potential, adverse effects, current management details, other uses, control methods that can be merged and searched by scientific name, common name (English), common name (Sinhalese), and common name (Tamil). The DB's functionality is enhanced by the availability of a GIS component, which facilitates viewing of distribution maps and also 3 simultaneous windows can be viewed on control methods under biological, chemical or physical IAP control techniques.

Invasive Alien Species Database (IASDB) – Invasive Species

This database, which is available in a CD form, unfolds facts about the IAS of Sri Lanka under 3 main categories in a point format, *viz.* detail form, plants, common names. The category on "detail form" comprises of the main identification (ID), location, divisional secretariat, botanical ID, common ID, plant type, extent, distribution, density, plant contaminations, name of water body, kind of water body, water flow, ownership, inflows, and outflows. It is supported by 4 browsing tabs, *i.e.* first, next, last, close. Navigation of a previous record is facilitated by the bottom most arrow keys. The functionality of the aforesaid first 3 tabs is repeated by the arrow key navigation. Most of the fields are displayed in terms of a pre-defined alpha-numeric coding system. The category on "plants" is inactive although it provides for the browsing option 'Record' with arrow keys. The "common names" category defines the common ID and common name supported by arrow keys. The DB is non-interactive and lacks the detailed descriptions, images or any mapping component. The unavailability of links among the 3 category windows is a drawback.

Gaps and Needs of Databases on IAS in Sri Lanka

Sri Lanka is a tropical island in the Indian Ocean, with a unique climate and an unparalleled biodiversity ranging across microbes, plants and animals in terrestrial and aquatic habitats.

Owing to its propitious climate and location near the equator Sri Lanka is home to a variety of indigenous, native and introduced species of plants and animals. Falling on a hotspot on the Silk route in ancient trade, Sri Lanka has been a country that has been transacting continuously with the outside world and yet enjoying the demand for its location in the use of modern shipping routes.

With a strong history of international relations and active involvement in world trade, Sri Lanka continues to be a tourist paradise. Owing to this enormous exposure to the outside world it has been experiencing changes in its ecosystem with new additions and also extinctions of its native/homogeneous species. In this context, the impact caused by the IAS is ecologically disturbing and economically alarming. The need for immediate measures to address the issue and taking precautionary measures is thus of high priority. Awareness should be made across the country at all levels regarding the threats of IAS and means by which their negative impacts could be removed. One of the best identified methods in this regard is the construction of a national level IAS database, which can be utilized to share data, knowledge and lend a hand to the knowledge economy of the country. In Sri Lanka substantial amount of IAS data are available at individual and institutional levels. However, these are not published and are not available in the public domain. The present situation on the IAS DBs in Sri Lanka is given below.

- Lacks a national level DB - Sri Lanka lacks a national level DB. Most of the data/information on IAS available with institutions are found in CDs or paper formats, which makes the dissemination of its knowledge more difficult. This creates a vacuum in pooling up researchers' involvement in updating and spanning up these data.

- Absence of a data sharing mechanism - The data collection in the country is done mostly by means of personal contacts. Some issues have arisen pertaining to this technique as some have refrained from providing required information. In addition, due to the absence of the coordinating mechanism and interaction, the data available with personnel and institutions are mostly duplicated.

- Technical gaps – There is a deficiency in modern technology, in terms of GIS (Geographical Information Systems), GPS (Global Positioning Systems), and RS (Remote Sensing). The software and equipments available are not sufficient. These equipments and software being expensive, is a main constraint for the use of aforesaid technologies.
- Knowledge and information deficiency - The construction of a national level DB demands a blend of the technical expertise in many fields of study such as biology, ecology, GIS, and MIS, and networking to device a rich output. The global level DBs incorporate GIS and GPS coordinates in a wider scale and thus, illustrating necessary patterns and retrieval of information in necessary formats have become easier. This has facilitated the decision making procedure. In Sri Lanka, there is a deficiency in information available in these areas and also a shortage of technical expertise.

- Unavailability of time-series data – Global level DBs are rich in images and spatial illustrations. Hence, the spatial changes and patterns of IAS could be clearly identified resulting in high reliability of the DBs. However, due to the absence of time-series data on IAS in Sri Lanka, identification of their spatial changes, spread and direction would be very difficult.

Several strategies could be formulated to overcome the above mentioned gaps on IAS DBs in Sri Lanka:

- Fully-fledged database and data sharing - One of the main requirements for increasing awareness on IAS is the need to create a national level DB. Once the DB is created, the purpose will be fulfilled only if there is a proper and well coordinated data sharing mechanism. Currently, most of the scientific information is available amongst few technically qualified personnel at a professional level. In accomplishing the target of developing a national level IAS DB, the DB should be freely accessible by the public under a controlled authority level. Thus, the people could be educated and the information available with them can be extracted into the DB for further strengthening its information pool.

  Public participation in viewing has to be free and should make them feel comfortable in accessing the information. The data downloading should be made available free of charge in order to facilitate hardcopy generation for distribution and further use amongst the public. Editing or adding data by the public can be monitored under certain control by promoting them to submit their login number given by the authorized person of the DB. Such editing should first go to a temporary storage without being imaged in the DB, and after a confirming the reliability and validity of the contents by committee of experts consisting of professionals in the IAS field and in relevant disciplines, the amendments could be done to the database. The experts committee should also monitor, regulate, oversee the use and developments in the DB to make decisions.

- Availability of modern technologies: Reliable data communication is important in exchanging the information, with modern technologies such as GIS, GPS and RS, and a dedicated internet service and modern hardware to facilitate a faster and cheaper communication mode. The most crucial factor of all is addressing the deficiency in hardware, software and other relevant equipments and techniques. Due to the cost factor involved in, access to these software and techniques and using these equipments could be centralized and be best sustained at universities and institutional levels where they are made available.

- Capacity building of human resources: Information teams should be formed and trained in providing comprehensive subject knowledge on IAS where they can disseminate their knowledge in public awareness sessions. In addition, these personnel should be trained on the latest software and equipments for them to acquire experience in using them and merging them with their subject knowledge to deliver a dynamic public awareness. Undergraduates of universities of Sri Lanka from relevant fields of study can be chosen for this training and can be dispatched to villages along with a few professionals in the teams.

The Special Features to be incorporated to the Proposed National Database on IAS in Sri Lanka

The proposed national IAS DB in Sri Lanka should include some specific features, as discussed below. With a proper and well-coordinated data sharing mechanism, the proposed DB intends to

provide access to IAS information at 3 levels *viz:* Administrator – with authority to access and edit, Registered User–with authority to edit and access under Administrator's control and General User–with permission to access only.

Online IAS DB

An online IAS DB, which is interactive, and can be regularly accessed at any location and time, is an urgent requirement for the country. The users should be able to retrieve the necessary subset of data by providing several conditions without moving case by case in the DB. For example, if any user wishes to retrieve only the IAS data related to the any geographical region or administrative division in Sri Lanka, the DB should be able to extract the subset requested by the user. Data should be retrieved not only based on the geographical or administrative regions but also base on any field available in the DB. The DB should be designed with user friendly browsing options to ensure frequent access. Data filtering at different levels (e.g. provincial, district, GS divisions) should be facilitated.

Incorporation of spatial and aspatial data

Data on distribution of IAS important in decision making on their control and hence, the proposed DB should be have facilities to identify the spatial pattern of IAS in Sri Lanka. The existing spatial pattern, periodic changes, direction of spread of a particular IAS could be extracted from the DB. The DB should be strong enough to acquire, update, manipulate and process the locational data in addition to the attributes.

Locational data has to be collected in terms of points, lines or polygons. Therefore, it is proposed to use the Google Map as the base cover to collect spatial data rather than GPS receivers, which are not practical with the technical and practical limitations of the users. The users should be able to retrieve the other geographical features, roads and the administrative boundaries built on the system on top of the Google Map and identify the desired location. One click on the mouse button on the identified location, system should be able to generate the coordinates and user has will fill up other necessary attributes.

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Review paper

Chapter 11

Invasive Alien Species of Agricultural Importance in Sri Lanka: Have We Managed Them Properly?

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Introduction

When an organism lands itself in a new territory with a suitable climate and hosts it could establish in the new area and spread at epidemic proportions mainly due to the absence of its natural enemies in the introduced environment. Increasing of international travel and trade has facilitated the movement of invasive alien species (IAS; see Chapter 1 for definitions) around the globe.

The most preferred and effective way of dealing with IAS is to prevent their introduction. This is being done by legislative means (see Chapter 6). The Department of Agriculture (DOA), as the implementing agency of plant quarantine regulations, has been vigilant to prevent the entrance of many alien species to the country (De Silva, 2001; De Silva *et al.*, 2005, 2006). However, the quarantine authorities have not fully succeeded in preventing unauthorized importation of plant and plant parts through which IAS could enter the country. Such unauthorized importations include using unethical methods to get detained imports released and seemingly benign act of bringing plant and plant parts by airline passengers in their luggage.

Many agriculturally important alien species have invaded and established in Sri Lanka in the recent past (Wijesekara, 2001). Though all these organisms can survive in non-agricultural habitats, their main adverse effects are on agriculture. Therefore, it is the DOA that has taken the initiative to manage these pests. Combat against IAS include early detection to eradicate, containment if established, and control of the species. Public awareness plays a major role in all

Wijesekara, A. (2010): Invasive alien species of agricultural importance in Sri Lanka: Have we managed them properly? In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 115-122. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

these activities. The DOA has resorted to intensive public awareness programs for eradicating, containing or controlling invasive alien pest species (Wijekoon, 2001). Probably the most important method of controlling IAS is by the use of classical biological control, where introduction of natural enemies from the areas of origin of the pest has proven to be successful in many occasions. Control of coconut leaf minor (*Promecotheca cumingi*) in Sri Lanka demonstrate a complete eradication of an IAS through biological control (Dharmadikari *et al.*, 2006). Mechanical control and use of insecticides have also given varying degree of success in combating IAS. The Sri Lanka DOA has utilized all of the available techniques and technologies to overcome the problem of invasive agricultural pests. The objective of the present article is to review such actions taken for the management of selected IAS of agricultural importance in Sri Lanka, examine their effectiveness and to suggest means of improving IAS management.

Invasive Alien Species in Agriculture Ecosystems

Among the IAS, which invaded Sri Lanka during the past two decades, the papaya mealybug, (*Paracoccus marginatus*, Homoptera: Pseudococcidae), the spiraling whitefly or guava whitefly, (*Aleurodicus dispursus*, Homoptera: Aleurodidae), tomato leaf miner, (*Liriomyza sativae*, Diptera: Agromyzidae), and potato/beet leaf miner (*Liriomyza huidobrensis,* Diptera: Agromyzidae) can be considered as the most injurious insect species. The congress weed or parthenium (*Parthenium hysterophorus*, Asteraceae) and alligator weed (*Alternanthera philoxeroides*, Amaranthaceae) were two noxious weedy invaders in agricultural ecosystems. Somewhat less prominent alien species which have invaded recently includes rice root knot nematode (*Meloidogyne graminicola*), potato cyst nematode (*Globodera rostochiensis*) and apple snail (*Pomacea diffusa*).

Management Efforts and Present Status

The spiraling whitefly (Guava whitefly)

This highly polyphagous species, known to survive on more than 253 plant species, first came to attention in April 1989 as it started spreading fast throughout Sri Lanka. The DOA studied the biology of the pest and recommended application of insecticides to safeguard the economically valuable plants (Wijesekara and Kudagamage, 1990). Unlike today, at the time of whitefly invasion, the major host of the spiraling whitefly, guava (*Psidium guajava*) was only a home garden plant. Therefore, priority given for managing the alien species was relatively less. Although no systematic program was carried out to manage guava whitefly, its population gradually subsided to an insignificant level. Subsequent observations showed that the most probable cause for the population reduction was parasitism due to *Encarsia sophia* (=*Encarsia transvena*) (Hymenoptera: Encyrtidae). Since this parasitoid has not been recorded from Sri Lanka prior to invasion of guava whitefly it is not known whether it was introduced along with the pest or already present in Sri Lanka and switched hosts. Guava whitefly has now naturalized and present in both agricultural and non agricultural ecosystems albeit in low populations.

Tomato leaf miner

Tomato leaf miner is an invasive pest that received attention of scientists and practitioners, first in 1992. It was incorrectly identified as *Liriomyza trifolii* and its morphology, biology and damage was studied (Abeywarna, 1992). The same study recorded 15 crop species attacked by the alien

leaf miner. The spread of tomato leaf minor pest throughout the country was gradual. Although there were outbreaks reported the DOA has not given much attention to treat it as an IAS. The DOA conducted insecticide screening and recommendations were given but no published records are available of that work. However, the presence of the pest on wild plants and crops in the Batticaloa district has been reported recently (Niranjana *et al.*, 2006). Apparently local parasitoids have shifted on to the invasive species (Niranjana *et al.*, 2005; Nagalingam *et al.*, 2007). Lack of attention for the pest may be due to the comparatively less importance given to the crops this pest attack. Currently *Liriomyza sativae* is a serious pest of many vegetable crops including tomato, all cucurbitaceous crops, beans and other legumes throughout the country. Substantial amount of insecticides are used to reduce its damage. *Liriomyza sativae* is also found on weeds in agriculture ecosystems. Its presence in other ecosystems has not been investigated.

Potato/Beet leaf miner

A leaf miner outbreak was reported in 1997 from Nuwara Eliya area. Almost all crops grown in Nuwara Eliya area including potato were heavily damaged by this insect and a coordinated effort was made by the DOA to manage the pest outbreak. First thought to be the same species that has already been reported (tomato leaf miner) it was later identified as *Liriomyza huidobrensis* and referred to as beet leaf miner, as beet seems to be its preferred host (Wijesekara, 1997). The commonly available insecticides were not found to be very effective in controlling the pest. The DOA recommended a couple of new insecticides along with some mechanical methods of control this pest, including the use of sticky yellow polythene (Nugaliyadda *et al.*, 2000). In addition, a commercially available parasitoid, *Diglypus isaea* (Hymenoptera: Eulophidae) was imported, mass reared and periodically released by the department of agriculture DOA for biological control. Pest population has gradually receded to a level that could be managed with insecticides. *Diglypus isaea* was released in Nuwara Eliya area in 1997/1998. Evaluation of its effectiveness in 2001 revealed that the introduced parasitoid has well established. Its parasitism varied from 1.3-65.7% in different areas (Nugaliyadda *et al.*, 2001a). The same study found that a local parasitoid, *Hemitarsonemus semialbiclavus* (Hymenoptera: Eulophidae), has also shifted on to the alien species with a parasitism of 1.8-45.4%. In addition different aspects of pest and the parasitoid biology and behavior have been studied (Kumara, 2005; Nishantha *et al.*, 2005; Niroshan, 2006). Despite the work carried out *Liriomyza huidobrensis* remains a serious pest of potato and beet in Nuwara Eliya area.

Papaya mealybug

This is the most recent invasive alien insect that has established in Sri Lanka. Similar to already mentioned alien pests, the papaya mealybug is also a highly polyphagous insect known to survive on more than 80 plant species. Reports from the field staff in Sri Lanka indicate that it prefers papaya as the host but attacks many other species in the agroecosystems including cassava, jak, bread fruit, Jatropa, and *Solanum* spp. It has also been found attacking another alien species, *havari-nuga* (*Alstonia macropylla*). First reported from Gampaha District in the western province in mid 2008, papay mealybug has already invaded central, Sabaragamuwa, north central and north western provinces. The population density of the insect was high enough to kill many papaya trees in Colombo and Gampaha districts. By the time the DOA started to work on this alien species, it has passed the potential eradication stage and containment and control was the strategy to follow. Mechanical control such as burning the damage plants and plant parts and control with insecticides as the first line of defense have been recommended although they have given only a partial reduction of the population. Due to

the polyphagous nature of the pest and nature of the plant species it attacks, substantial control of the pest population is not possible. Therefore, possibility of biological control using a known natural enemy of the pest *Acerophagus papayae* (Hymenoptera: Encyrtidae) has being pursued. Despite control measures the pest is expanding its geographical range within the country. However, field observations in the western province indicate that the pest population has dramatically receded in the areas where it was first found. To-date, one generalist predator, larvae of Lycaenid butterfly (*Spalgis epius*) has been found to attack papaya mealybug, but no parasitoids have shifted to the new pest. Therefore, the population reduction may be due to the effect of changing abiotic factors.

Congress weed (Parthenium)

Possible arrival of Parthenium weed in Sri Lanka was forewarned and possible control measures were suggested in 1982 (Peries, 1982). *Parthenium hysterophorus* was first recorded in July 1999. The DOA launched a massive public awareness program encouraging mechanical and chemical control trying to eradicate the weed. An extraordinary gazette notification (No. 1163/23) issued by the then Hon. Minister of Agriculture, under the Plant Protection Act No 35 of 1999, identified several regulations including penalties in support of eradication of *P. hysterophorus*. However, the weed has continued to spread to different areas of the country. Adopting an integrated approach to control Parthenium the DOA, through the National Plant Quarantine Service (NPQS), imported from Australia and released two biological control agents, namely a fungus (*Puccinia melampodii*) and a gall forming moth (*Epiblema strenuana*, Lepidoptera: Tortricidae) (Jayasuriya, 2005). In addition a Parthenium eating beetle (*Zygogramma bicolorata*, Coleoptera: Chrysomelidae) was imported by the Plant Protection Service from India in 2004/2005 and released. Irrespective of the massive control efforts, Parthenium still survives in different areas of the country as small populations. Repeated releasing or monitoring of released biological control agents have not continued and there is no information regarding their establishment or effects. Unsubstantiated reports indicate that the weed is gradually integrating into non-agricultural ecosystems too.

Alligator weed

Alligator weed was first reported in the year 2000 from southern province of the country. Leafy vegetable cultivating farmers had started to grow alligator weed considering it as a better variety of 'Mukunuvenna' (*Alternanthera sessilis*) due to the morphological similarity of alligator weed and mukunuwenna. The DOA launched public awareness and chemical control programs to eradicate the weed from the agricultural ecosystem (Amarasinghe, 2001). Eradication efforts have not been successful although leafy vegetable farmers no longer grow alligator weed misidentifying it as mukunuwenna. The weed prominently grows by the waterways in Nuwara Eliya urban area. No records are available to show its presence in other areas of the country at present, but there is a high probability that it survives in other areas of the country as well. As long as it survives the chance of the weed becoming noxious cannot be excluded.

Apple Snail

An Apple snail was found fast spreading in paddy fields of Colombo, Kalutara, Ratnapura, Kegalle and Kandy districts in the year 2000. The DOA, being alerted of spreading snail, took prompt actions to study the situation as there is a notorious paddy pest, Golden apple snail (*Pomacea canaliculata*) reported in the south east Asian countries (Nugaliyadda *et al.*, 2001b). However,

the snail was later identified as *Pomacea bridgesii* (new valid name *Pomacea diffusa*), which is not a pest of rice and hence, no further studies were conducted by the DOA. It has been recorded that apple snail was introduced to the country probably in early 1980s (Bambaradeniya, 2001). Therefore, it can be considered that species has established in Sri Lanka. Although there is a threat of negative impacts of the alien species on local biological diversity, the present status of *Pomacea diffusa* (=*Pomacea bridgesii diffusa*) in the country is unknown.

Have We Done Enough?

The proper approach to deal with IAS is well established. The conference of parties of the CBD has adopted 15 guiding principles as non-binding recommendations for countries to deal with IAS. There is a three-stage hierarchical approach to minimize the risk and spread of IAS. They are prevention of alien species introduction; early detection and rapid action (e.g. eradication) in the event of an introduction, and containment and control when eradication fails (Lopian, 2003).

Prevention of introduction

The prevention of alien species introduction is mainly done through legislature. It is well recognized that there are shortcomings in presently available legislations to prevent IAS introduction (Amarasinghe, 2001). The need for addressing the IAS challenge and steps to be taken has been pointed out years ago (Bambaradeniya, 2001). Unfortunately the country has not adopted any of the measures anew and we are being pushed towards a situation similar to "reinventing the wheel".

Early Detection

Since agricultural extension became a responsibility of the provincial councils the dialogue between research and extension arms has weakened to a certain extent. Appearance of new pest problems are usually communicated to the plant protection or research division only twice a year through the Provincial Technical Working Group (PTWG) meetings held prior to each cultivation season. This translates to a considerable delay in reporting of new pests. Even if early detection is made of the presence of a new pest, lack of taxonomic expertise for identification has also delayed the recognition of the danger and in turn delays activation of the control mechanism. Incorrect identification or delay in identification of the pest has increased the response time substantially in all alien agricultural pest invasions.

Containment and control

Containing has basically tried through public awareness only, except in the case of congress weed, which was gazetted as a quarantine pest. One weakness that is prominent in the case of papaya mealybug management approach is that majority of the awareness programs are directed at areas already invaded by the pest. More emphasis should be made on potential areas of invasion when organizing awareness programs.

Both mechanical and chemical control programs have been introduced to control IAS. In the case of weeds, uprooting and burning have been adopted and for insects pests, the yellow sticky traps, washing them off the plants and destroying the affected plant parts have been used as mechanical means of control. Effects of insecticides on IAS have been tested and new insecticides have been recommended for chemical control of these pests. These control

measures have succeeded in reducing the IAS populations to manageable levels in relation to crop production.

All IAS discussed in the present paper have integrated into our ecosystems to varying degrees. Although substantial attempts have been made to manage the invasive pests in the agricultural ecosystems, the management approaches taken for these invasive species are irregular and incomplete. This indicates that the country has not done enough to manage IAS. In adopting biological control in particular, planned releases and monitoring of biological control agents to gain maximum benefit have not been done. In all cases of agricultural IAS once the novelty of the problem dies down researchers have shifted their attention leaving the IAS problem intact. Another interesting observation is that once the IAS found not to be agriculturally important, no agency has shown sustainable interest in managing or studying the alien species as shown by the case of *Pomacea diffusa*. The economic impacts of these species have not been calculated. Yet, frequent application of insecticides to control two insecticide resistant leaf miner pests in Sri Lanka indicates that both social and environmental costs can be very high.

The actions taken for management and present status of above mentioned species clearly show that we have not approached the problem of IAS in agricultural ecosystems in a systematic manner. Amarasinghe (2001) very appropriately described the situation; *"Many sectors in the society and state sector have an inadequate perception about the magnitude and economic cost of the problem. As a result, responses are too often piece meal, late and ineffective"*. This description was for invasive weeds but is exactly true for all IAS. Irrespective of conducting two national workshops on IAS and recommendations given (Marambe, 1999, 2000), the situation remains same to date

What Needs to be Done?

One of the recommendations for managing IAS is to 'set up a coordinating body which could oversee all aspects and issues pertaining to IAS' (Marambe, 1999, 2000; Bambaradeniya, 2001). It is still the foremost important action to be taken. Marambe (2001) even proposed a national action plan for alien invasive plants identifying the need for coordinated actions.

The DOA has a system to combat IAS of agricultural importance and the system needs to be strengthened and streamlined. The NPQS of the DOA make efforts to prevent alien species introductions that could happen through legitimate trade of agricultural commodities (De Silva *et al.*, 2005, 2006). However, the potential of introductions through plants and plant parts brought into the country by travelers also need to be curtailed. Lack of proper mechanism at present to examine possible introduction of IAS through live plant material imported for consumption is a weakness in the system. The plant protection service of the DOA together with the research division can handle mechanical, chemical and biological control procedures to manage the invasive species. Still a protocol should be developed within the department to tackle IAS management activities systematically with proper coordination among different divisions and outside agencies as well. There is no single agency responsible for facing the challenges of non-agricultural IAS or when agricultural IAS crossed into other ecosystems. The Ministry of Environment and Natural Resources and line departments under it should be the responsible government agencies in such cases but there is no evidence to show any management effort for recently introduced IAS into non-agricultural systems.

Study of the biological control attempts made on various agriculturally invasive pests indicates that the process of importing beneficial organisms is not a streamlined process. The Department of Wildlife Conservation has the authority to approve importation of organisms to the country, but there is no protocol for risk assessment or host specificity testing that should essentially be a part of the approving process. Examination of impacts on non-target organisms before biological control agent is released in the country is essential as it has been shown that such introductions may have adverse impacts on non target organisms (Louda *et al.*, 2003; Simberloff and Stiling, 1996).

The governing body of the International Plant Protection Convention (IPPC) has recognized that IAS could be considered as quarantine pests and should be subjected to IPPC provisions. The CBD and IPPC have established a Memorandum of Cooperation to develop a joint work plan regarding IAS (Lopian, 2003). Therefore, to mange IAS the environmental and phytosanitary authorities of the country should cooperate with each other. The IPPC has prepared various International Standards for phytosanitory Measures (ISPM). It is suggested that relevant ISPM guidelines be utilized for dealing with IAS and importing biological control agents to tackle the problems of IAS to the country.

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Review paper

Chapter 12

Management of *Salvinia molesta* in Sri Lanka

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Introduction

Salvinia molesta is a free-floating water fern, native to Brazil (Senaratne, 1943). It was widely introduced as an ornamental plant for ponds and aquaria, and has become a serious weed in many of the warmer regions of the world. In Asia, it is classified as invasive in a number of countries, including India, Pakistan, Indonesia, Malaysia, the Philippines and Sri Lanka.

Salvinia plant thrives in nutrient rich standing water or slow moving water bodies. The plant grows rapidly, and in ideal conditions it may double its biomass within every three to five days. When the plants are crowded in mature infestations, they form mats on the water surface sometimes up to a thickness of 1 meter. Those heavy infestations of salvinia have resulted in serious economic, social and environmental problems for communities associated with irrigated forming, fresh water fisheries and certain urban populations living close to open drainage canals. They impede access to water by rural communities and their livestock, clog intake pipes for water supply facilities, irrigation schemes and hydroelectric power plants, and pose a health risk as they provide habitat for disease carrying mosquitoes. Apart from these socio-economic impacts, the dense mats have a variety of negative effects on the environment. They out-compete indigenous species by crowding out floating weeds and reducing the light and oxygen available to submerged plants and phytoplanktons and seriously affects on the natural equilibrium. The overall effect is a decline in water quality and a reduction in biodiversity.

Salvinia reproduces vegetatively, and is able to regenerate from any fragment that includes a node. This facilitates its spread by water currents, by floods, by fishermen, by buffaloes and by

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boats that enter infested waters. Vegetative propagation strategy adopted by salvinia also renders its control more difficult, as a small piece left behind can cause a re-infestation.

Past Experiences on the Control of Salvinia

Salvinia molesta was introduced to Sri Lanka in 1939 by the Department of Botany in University of Colombo (Senaratne, 1943; Wijesundara, 1999) for research purposes, but appears to have escaped and has since been spreading throughout the country invading most of the stagnant and slow moving water bodies. Due to the detrimental effects of this plant on agricultural ecosystems, salvinia was declared as a weed in 1952, under the Plant Protection Ordinance (No. 10 of 1924). Thereafter, the then Minister of Agriculture and Food published a regulation in the government gazette prohibiting any person for any purpose whatsoever to transport this weed or any part thereof from one place to another.

Physical Control of Salvinia

Physical removal is historically the most widely used form of salvinia control. For the poorer rural communities to whom salvinia is often a threat, removal by hand is the only available option. In Sri Lanka, soon after declaring salvinia as a weed, the then Ministry of Agriculture launched a scheme to collect the weed by physical means, which proved to be a slow, costly and even cumbersome (Dias, 1967).

The rate of growth and infestation by salvinia usually exceeds the rate at which it can be physically cleared. Re-infestation from plant fragments generally occurs rapidly and the process of removal should be repeated continuously. The material removed from the water bodies should be transported away from the site and disposed of appropriately. So far it was observed that the physical removal was successful only on small infestations.

Chemical Control of Salvinia

In 1957, the Department of Food Production, which is presently known as the Department of Agrarian Development, organized a campaign to eradicate the salvinia weed by chemical means, with the help of private companies such as Shell® (Williams, 1956). The herbicide used was Pentachlorophenol (PCP), which is a non-selective chemical. However, even after three years, no appreciable progress was made in eradication and the weed continued to spread. This situation compelled the then Minister of Agriculture and Food to seek some foreign technical advice to overcome this menace. Therefore, the service of an expert was obtained from United States in the latter part of 1960, and based on the recommendations given, the then Minister of Agriculture and Food reorganized the salvinia control programme in 1961. With that, the Department of Agriculture (DOA), which is a technical department, took over the salvinia eradication campaign from the Department of Agrarian Services (which is mostly performing administrative duties) and conducted it under the supervision of the Deputy Director - Development. In addition, an agricultural officer from each district was appointed as in-charge of the campaign at district level (Dias, 1967).

Immediately, steps were taken to obtain statistics on infestations of salvinia in each district and a map was prepared giving the locations and extents. In case of districts which were reported as free of salvinia, were requested to maintain as free of salvinia thus, preventing fresh

infestations. In the districts that were infested with salvinia, an eradication campaign was initiated with the community participation. Rural development societies and young farmers clubs were formed and used in those eradication works on a self-help basis. They were supplied with equipments, herbicides and technical advice by the government. Huge publicity has been given through the mass media on the above activities to get the public support. In addition, a research unit was established to work on the problems of aquatic weeds. Researchers experimented on several herbicides and finally recommended paraquat, which was found to be more effective and cheaper than the herbicides already in use.

Statistics of infestations collected after three years revealed that the total infested area had been reduced to a certain extent. However, the salvinia eradication programme was abandoned in 1964 due to financial difficulties. As a result re-infestations of areas hitherto controlled occurred and the later statistics revealed that the affected extent has nearly doubled during the next one and a half years (Dias 1967). This shows that the short-term control activities such as chemical or mechanical control are ineffective to keep weed population at lower level.

To-date, the cost involved in the management of salvinia was high for both the economy and ecology. Environmentally safe and economically sustainable control strategies are necessary to provide long-term solutions to weed infestation. However, herbicides such as paraquat and glyphosate have proven to be somewhat effective for control of salvinia, but these may put other species at risk as they are non-selective and being toxic to fish and other aquatic life. The application of these compounds requires skilled operators, strict spray regimes, long-term vigilance and frequent re-application to provide effective, long-term control over the weed and any re-growth. In most situations, chemical control is unacceptably costly in terms of chemicals, equipments, labour and environmental impact.

Biological Control of Salvinia

Various control methods tried shows that the reproductive capacity and adoptability of salvinia make it impossible to eradicate and even difficult to control. Therefore, the use of biological control agents to reduce salvinia population resurgence was highlighted. International experience has shown that the biological control offers sustainable, environmentally friendly, long-term control of salvinia. Therefore, a biological control programme was initiated in 1986 by a project carried out under the National Science Foundation (NSF; formerly NARESA) in collaboration with the University of Kelaniya and the DOA. A host specific biological control agent *Cyrtobagous salviniae* was imported from Australia to initiate the programme. The host-specificity of the insect has been tested and confirmed by observations after their test release (Amarasinghe, 2000).

Observation studies have indicated that the weevil has become established on numerous salvinia infestations in north western and north central provinces and their impact on salvinia has been significant. Survey conducted by Amarasinghe and Ekneligoda (1997) showed that the success rate of the biological control agent introduced into infested tanks was about 80% in the wet zone and 60% in the dry zone. Another survey conducted by the Plant Protection Service of the DOA in 2008 confirmed those results. Although biological control with *C. salviniae* was successful to-date in the wet and dry zones in the country, it has failed in cooler climates and in areas with low water levels and high temperatures. In addition, the local experience revealed that in some cases, there is no survival of the insect after cleaning of salvinia-infested water

bodies. This is due to the host specificity of the *C. salviniae* on *S. molesta*. Thus, any subsequent introduction of salvinia has to be controlled through re-introduction of the insect. Where as in most of the other cases, extensive mats of salvinia plants have been replaced by open water and salvinia remains as scattered patches. A low population density of weevils persists, holding the salvinia population in check. Doeleman (1989) reported returns to investment from biological control of salvinia in Sri Lanka at 53:1 in terms of money and 1671:1 in terms of labour.

Conclusions

The complete removal of salvinia is an impossible task in most areas of Sri Lanka. Therefore, the aim of any control programme should be to manage, rather than eradicate this weed species. The control methods attempted to-date are under three main categories, *i.e.* physical, chemical and biological. Application of these methods is not mutually exclusive and the 'best practice' is to formulate a management strategy incorporating some or all of these methods, with reliance on biological control as the most significant component or the long term objective. In addition, good watershed management also will help to reduce the salvinia problem. High nutrient levels of water, brought about through processes such as deforestation, agricultural and urban run-off and discharge of industrial and urban waste, promote the growth of salvinia. Reducing nutrient inputs from these sources will slow the rate of growth and spread of the weed, and further improve the effectiveness of biological control agent.

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Review paper

Chapter 13

Is Tilapia Becoming An Invasive Fish in Sri Lanka?

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Introduction

Sri Lanka is one of the most important biologically diverse hotspots in the world despite being a small island nation covering an area of 65,610 km^2. The country possesses a high proportion of endemic aquatic fauna and flora, which contribute to its rich biodiversity. Among the total invasive alien species (IAS) documented in Sri Lanka, 10 species of fauna are included in the list of 100 of the world's worst IAS (www.indiaenvironmantportal.org.in/node/38152). In the case of invasive alien fish species, both the freshwater fisheries and the ornamental fish industry are responsible for their introductions to Sri Lanka.

Two tilapia species namely, *Oreochromis mossambicus* and *O. niloticus* were introduced to Sri Lanka in 1952 and 1956, respectively. This was done in order to enhance the freshwater food-fish production, but they have now become the dominant group of fishes in freshwater bodies of Sri Lanka. The introduction of tilapia has triggered the development of inland fisheries in the country. Though tilapia is the dominant group of fishes in Asia, including Sri Lanka's inland water bodies, and has invaded habitats ranging from saline estuaries to rivers, its performance as a commercial table fish in Asia has been declining mainly due to dwarfing as a result of over-population (Eknath *et al.*, 1993). Apart from this aspect, tilapia has also been identified to cause problems for native aquatic flora and fauna in several ways due to its presence in large number in the water resources. However, any effort to eradicate tilapia species, without having any alternate cheaper animal protein source especially for low income earning groups, is the challenge for present day scientists, economists as well as conservationists.

Athauda, S. (2010): Is tilapia becoming an invasive fish in Sri Lanka. In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 127-130. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

Biology of Tilapia makes it more Resilient

Tilapia is a superior competitor for the natural resources. Being non-selective in diet and a prolific breeder, it can live in many different types of water bodies from lakes and rivers to sewage canals. Tilapia is considered as a freshwater species, however, it has shown a great tolerance towards salt and can be found in both estuaries and coastal lakes under brackish condition. It inhabits a temperature range of 13.5-33 °C and has a fast growing ability in many different types of waters. Among the tilapia species, the Mozambique tilapia (*Oreochromis mossambicus*) that was introduced to Asia in late 1940s is a highly adaptable species that can survive and even thrive in many different environments (Eknath and Hulata, 2009). They can tolerate a wide range of water temperatures and also highly tolerant when it comes to poor water quality that is polluted or with low oxygen levels. This is definitely a good natural adaptation for the fish itself, but it is also what makes tilapia such a risky introduction to non-native waters.

Tilapia can cause problems for native flora and fauna in several ways, *i.e.* compete with other species for food, disrupt the ecological balance of the aquatic ecosystem and cause turbidity in clear waters as they are fond of digging the water bed. Turbidity will reduce the amount of available light in the water affecting all organisms relying on photosynthesis. Tilapia species are also famous for their feeding style. It is an opportunistic omnivore that will explore a wide range of different food sources, from plankton and rooted plants, to invertebrates, and fish fry to decomposing organic matters. In addition, many species of tilapia breed rapidly and grow fast. It will for instance breed even in environments where food is scarce, and each female can raise several large broods in one breeding season. The offspring can start breeding when they are no older than 3-4 months. These specific characteristics make them more resilience in any aquatic ecosystem, creating food scarcity for other creatures sharing that ecosystem. The Mozambique tilapia is included in the "100 of the World's Worst Invasive Alien Species" (www.issg.org).

Tilapia as an Invasive Species

Global scenario

In the USA, established populations of tilapia are found in different parts of the country. A thriving population of *O. mossambicus* has been reported in the Salton Sea, an inland saline lake in southern California. Fifteen states of USA have taken measures to control the tilapia populations. Further, tilapia has been introduced to the environmentally sensitive Galapagos Islands where a very high degree of endemism is found as a result of the remoteness. It was reported that the endemic aquatic species are now threatened by the introduction of alien species, such as tilapia.

Recently, the Fiji islands declared tilapia as a problematic invasive species, which has threatened their native fish (www.thefishsite.com/newsletter/5Mpublishing portals). In Singapore, tilapia was introduced by Japanese during World War II (De Silva *et al.*, 2004), Upon introduction, tilapia has become a common fish in both fresh and brackish water, as well as in the sea off the northern coast of the country. Since late 1980s, these feral populations have been declining dramatically and this is believed to be caused by the introduction of other tilapias, probably the hybrid *O. mossambicus* x *O. niloticus*, and also *O. urolepis hornorum* and *O. aureus*.

Sri Lankan scenario

There are about 35 species of fish, which have been introduced to Sri Lanka since 1880s. All these alien species are now thriving and naturalized in Sri Lanka's aquatic ecosystems. Among them, tilapia is now the dominant group of fishes in the rivers of Sri Lanka, and has invaded the entire dry zone, many estuaries and lagoons in the dry and wet zones, and the large streams, reservoirs and rivers of wet zone lowlands up to 600 m elevation (Pethiyagoda, 1999). The only tilapia-free habitats are the shallow, shaded rainforest streams in the hill country, where for some reason(s) these fish have not still invaded. Superior in competition, non-selective in feeding and prolific in breeding allow tilapia colonize easily in the tanks, reservoirs and slow flowing rivers, while displacing the native inhabitants such as *Labeo porcellus* and *L. dussumeiri* (Bambaradeniya, 2000). Tilapia breeds throughout the year, but more frequently during the rainy season, which overlaps with the breeding season of most of the indigenous fish species. The diet of small tilapia comprises of zooplanktons, which are the feed resources of indigenous fish. This creates afood scarcity for some indigenous fish species, and as a result, they tend to prey on their own young causing a threat to the native population. It seems highly probable that the decline of red-in labeo (*L. lankae*) and the spiny-eel (*Macrognathus aral*) have been due to the competitive pressure imposed by tilapia (Pethiyagoda, 1999). Therefore, it appears that tilapia has been responsible for the extinction of at least one native fish species in Sri Lanka (Pethiyagoda, 2006; www.indiaenvironmentportal.org.in/node/38152). However, no control measures have been adopted against tilapia. Moreover, no critical assessment has been made of the impact of tilapia on the indigenous fishes, since its introduction to Sri Lanka in 1950's.

The presence of native fishes in the river systems have dwindled whenever the presence of tilapia was found in large numbers due to re3asons described earlier in this paper. However, food habit of tilapia populations in Sri Lanka's reservoirs does not confirm to a particular pattern, but was found changing in different seasons also according to the condition of the reservoir; for example, the dietary habit of tilapia has changed from a complete detritivory habit in the wet season to phytoplanktivory in the dry season. Nevertheless, blue-green algae are not reported as an important component of the diet in tilapia except for those living in highly eutrophic 'Colombo Lake' (*Bere Wewa*), where the blue-green algae are the main food of Tilapia. Though tilapia is reported to inhabit in a temperature range of 13.5 to 40°C, its growth declines rapidly in temperatures below 20°C. This might be the reason that has restricted its population spreading to hill country water streams in Sri Lanka, where water temperature is low with a fast rate of water flow.

Over the last two decades the contribution of tipalia to the inland fishery in Sri Lanka has gradually declined from over 70% to just over 50% and replaced by the Indian major carps, which was introduced to Sri Lanka in 1980s. However, tilapia still plays a major role in inland fishery sector as a dominant group of fishes, especially in areas where societies are largely dependent on freshwater fishery and also where low income earning rural communities are found in the country. Therefore, instead of eradicating the fish species, adoption of mitigatory measures to reduce the effect of their undesirable characteristics, and making them less invasive but high productive fishes is the challenge for scientists, conservationists and economists.

Strategies to make Tilapia a Non-invasive Fish Species in Sri Lanka

In view of the above considerations, the initial approach is to produce monosex (all male) tilapias through hybridization. The cross between the female *O. mossambicus* and male *O.*

hornorum generates a nearly all-male hybrid population of tilapia. This technique is based on creation of males with two "Y chromosomes" (super males). Mair *et al.* (1997) adopted this technology in 1991, which gave relative advantages including commercial viability of producing genetically all-male tilapia (GMT) population over hormone-induced sex-inversion. Thus, the hybridization strategy could minimize overpopulation in the culture environments and also increase the productivity of populations because of the faster rate of growth of male tilapia. It has been proven that the yield of GMT was 30-40% high when compared to the normal mixed-sex cultured tilapia. In addition, the mean grow-out period is also short compared to the GIFT (Genetic Improvement of Farmed Tilapia) fish and sex-reversed tilapia, which is presently cultured in commercial level (Eknath and Hulata, 2009). Hybridization followed by a hormonal sex-reversal method can be applied to produce all-male seed stock in large scale. This can be practiced in the breeding stations of National Aquaculture Development Authority (NAQDA) of Sri Lanka, where seeds are produced at present for stocking in seasonal tanks as well in the perennial water resources in the country.

Conclusions and Policy Implications

The production of all-male tilapia systems could be introduced as a remedial measure to overcome the invasive behavior of tilapia in fresh water bodies in Sri Lanka. Feeding or immersion of steroid hormones, hybridization and YY super male technology are the technologies to be adopted as mitigation measures to bring down the present population levels of tilapia in Sri Lanka to produce a non-invasive male-skewed population. These changes in tilapia population would make it the most promising fish species in Sri Lanka by fulfilling the socio-economic and environmental aspects of the people of the country, as well as the inland capture fishery through high production.

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Research paper

Chapter 14

Is Caribbean Pine Invading Grasslands in the Knuckles Range?

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Abstract: Since 1967, about 27,115 ha of *Pinus caribaea* Morelet (Caribbean pine) plantations have been established in abandoned tea lands, scrublands and fern lands in the wet and intermediate lowlands and lower montane areas in Sri Lanka. This has been done with a view to reforest degraded lands and to meet the long-fibre requirement of the paper industry. Since its introduction, the natural spread of *P. caribaea* has not been reported in the island although this exotic species has been listed in the Global Invasive Species Database. Recent studies have shown that populations of seedlings, saplings and even mature trees have established in grasslands abutting *P. caribaea* plantations in the Knuckles (Dumbara) range (KR) of the country. An understanding of the invasive potential of *P. caribaea* in different vegetation types in the KR and research into the management of invasion are of significant importance at this crucial stage of its natural spread. Preliminary investigations have revealed that the grasslands adjoining eight *P. caribaea* plantations in two agro-ecological zones (AEZ) *viz.* (i) intermediate mid country 1b (IM1b) and (ii) wet mid country 3b (WM3b), around the KR were more vulnerable to *P. caribaea* regeneration compared to that in home gardens, tea plantations, scrublands and forests. In two separate pilot studies carried out in *P. caribaea* plantations (near the NW boundary of the Sinharaja World Heritage Site and in Lower Hantana in the Peradeniya campus), it was revealed that pine plantations can be successfully replaced with native and naturalized plant species of ecological and economic significance to rural communities. These studies provide insights to (i) the manipulation of the stand structure of established *P. caribaea* plantations to create suitable above ground environments favourable for establishment of native species, and (ii) to match suites of plant species to appropriate sites in different agro-ecological regions. These models could also be extended into the naturally regenerating *P. caribaea* populations. However, it is essential to have a sound ecological understanding of the regeneration ecology of native species, for successful conversion of invading *P. caribaea* populations and plantations into mixed native species stands.

W.W.M.A.B. Medawatte, K.U. Tennakoon, P.E. Hulme, C.V.S. Gunatilleke and I.A.U.N. Gunatilleke (2010): Is Caribbean pine invading grasslands in the Knuckles range? In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 131-140. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

Introduction

The negative impact of invasive alien species (IAS) upon biodiversity has become a serious threat to natural systems of the world (McNeely *et al.*, 2001; see Chapter 1 for the definitions of IAS). The threat of IAS on biodiversity is second only to that of habitat loss. The impact of IAS on native species, the ecosystems and the economy has been immense and more acute in geographically and evolutionarily isolated systems such as island communities (www.cbd.int /doc/meetings/sbstta/sbstta-6/information/sbstta-06-inf-11-en.pdf) like those in Sri Lanka. In addition, the impact of IAS on the economy is now estimated to range from millions to billions of dollars (Sharma *et al.*, 2005). Thus, IAS is a serious crisis to conservation and sustainable use of biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems. The IAS are widespread in the world and can be found in most taxonomic groups such as microbial, plant and animal species. Among invasive plant species in the world, woody species in particular have major impacts on ecosystem structure and function (Richardson *et al.*, 2004).

Pinus caribaea (pine) forests are the dominant vegetation in many parts of North America, Europe and Asia (Richardson and Higgins, 1998). Due to their economic importance, many pine species have been introduced to areas well outside their natural range as a foundation of exotic forestry enterprise, e.g. parts of Australia, New Zealand and especially in South Africa. In these countries invasive pines have caused problems for managers of grasslands, watersheds (catchment areas) and protected areas. Reports show that pines contribute to an overall decrease in native biodiversity, suppress native plants, contribute to habitat loss for wildlife, decrease stream-water flow, bring about fire induced changes in vegetation structure and cause changes in nutrient cycling in invaded habitats. Invasive pines have caused direct impacts on humans by reducing the ground water supply levels in countries like South Africa (Richardson *et al.*, 1994; Richardson and Higgins, 1998). Additionally, the impact on the economy of South Africa by pine is now estimated to the billions of dollars (McNeely *et al.*, 2001).

During field visits to the Knuckles range (KR) of Sri Lanka, the authors observed that *P. caribaea* has escaped from the original plantations to the neighboring habitats. The locals living in the KR have complained that *P. caribaea* has caused major impacts to the hydrology of the catchment areas by lowering the water table and disturbing wildlife as well. Furthermore, many large mammals, such as wild elephants, sambar, deer, wild buffalo and domestic cattle feed on grasslands in the KR. It is widely accepted that these problems can become more severe, where some grasslands have already been invaded by *P. caribaea* trees that have escaped from the original plantations, e.g. in Riverstone in the KR. Consequently, the ability to predict the invasive potential of new introductions could help to take measures to reduce the level of threat to natural areas (Reichard and Hamilton, 1997).

Taking the above factors into consideration, this study investigated how the invasion of *P. caribaea* takes place in the KR. Evidence from contemporary studies of *P. caribaea* dynamics in the KR will be extremely useful to predict the main factors pertinent to its regeneration and whether it has the ability to successfully invade the adjoining natural habitats and alter the natural vegetation types. The information gathered will contribute towards the development of protocols for restoration of degraded lands, *P. caribaea* plantations in the KR and this could be used as a guide to manage similar habitats elsewhere in Sri Lanka.

Methodology

According to the Agro-ecological Zone (AEZ) map of Sri Lanka, the KR falls into five AEZs (Figure 1), namely WM3b (wet zone, mid country 3b), IM1b (intermediate zone, mid country 1b), IM3c (intermediate zone, mid country 3c), IL2 (intermediate zone, low country 2) and IU1 (intermediate zone, up country 1).

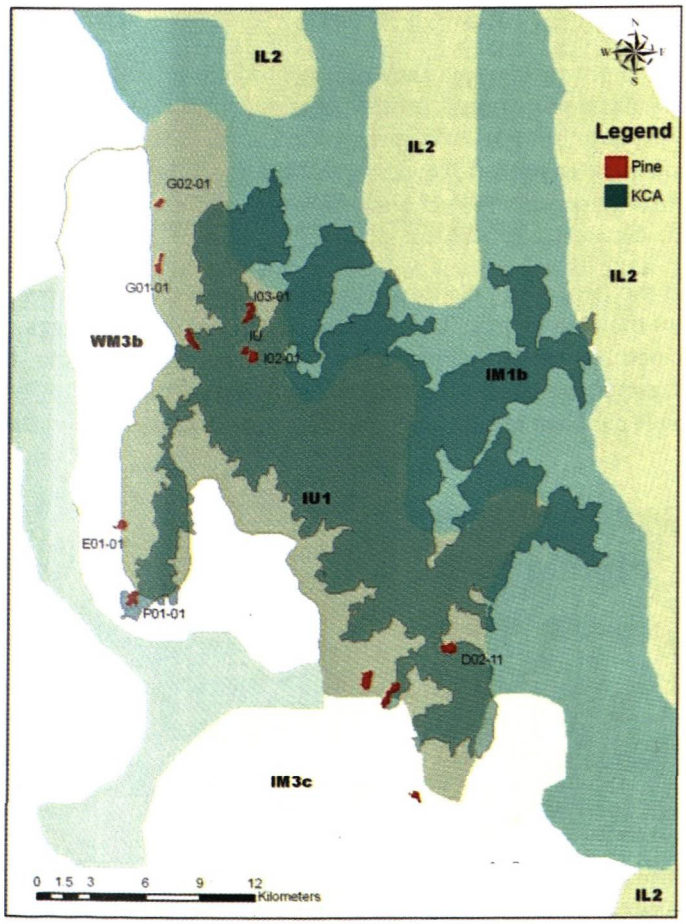


Figure 1. Map of KR developed to depict the locations of the *P. caribaea* plantations selected for the present study. *Pinus caribaea* plantations studied in the WM3b zone are G 02-03, G 01-01, E 01-01, P 01-01; those in the IM1b zone are I 03-04, I 03-03, I 02-01 and D 02-11.

Most of the *P. caribaea* plantations in the KR have been established around the demarcation contour (900 m amsl) separating the mid country zone and up country zone. Consequently, *P. caribaea* plantations in the Elkaduwa, Gammaduwa, Panwila and Rattota forest beats represent intermediate agro-ecological features of WM3b and IU1; Illukkumbura and Dumbara *P. caribaea* plantation beats represent intermediate agro ecological features of IU1 and IM1b. Furthermore, *P. caribaea* plantation beats in Karalliyadda and part of Dumbara represent intermediate agro-ecological features of IU1 and IM3c. For this reason, *P. caribaea* plantations in the KR experience three agro-ecological conditions, namely WM3b - IU1, IM1b - IU1 and IM3 - IU1. For easy reference, these *P. caribaea* plantations in the three agro-ecological zones are hereby classified

as WM3b, IM1b and IM3c, as IU1 agro-ecological condition is common to all three agro-ecological conditions (Table 1).

Table 1. Forest beats in the different AEZs and details of the eight *P. caribaea* plantations selected for the present study in the KR.

Forest beat	Plantation Number	AEZ	Area (ha)	Age (Years)
Illukkumbura	I 03-04	IM1b	28	29
Illukkumbura	I 02-01	IM1b	18	23
Illukkumbura	I 03-03	IM1b	10	29
Dumbara	D 02-11	IM1b	28	22
Elkaduwa	E 01-01	WM3b	15	22
Panwila	P 01-01	WM3b	25	29
Gammaduwa	G 01-01	WM3b	17	29
Gammaduwa	G 02-03	WM3b	10	23

Habitat types around the *P. caribaea* plantations selected for this study were mapped using Arc GIS software and with the help of aerial photographs and Google earth images. History of these habitats was examined by aerial photographs. In order to investigate the progressive spread/escape of *P. caribaea* outside the original plantations, three 50 m belts around the perimeter of parental *P. caribaea* plantations were demarcated as depicted in Figure 2a.

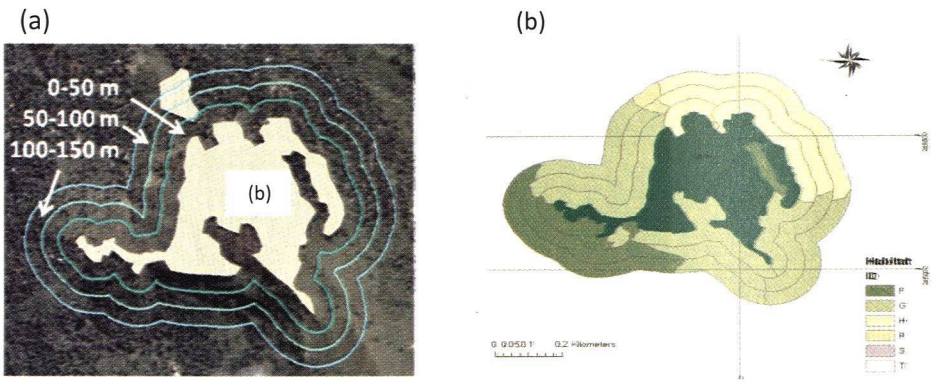


Figure 2. Demarcation of three consecutive 50 m belts around the perimeter of a parental *P. caribaea* plantation (a) and demarcation of different habitats (b) [forests - F, grasslands - G, home gardens – H, and scrublands – S] inside the belt transects sampled].

Different habitats present inside the 50 m belts were digitized as belt transects (Figure 2b). The habitats within each transect were recorded as grasslands, scrublands, tea plantations, home gardens or forests. The width of each belt was 50 m, however, the length of the belts varied from plantation to plantation depending on its perimeter and extent of each habitat type. Subsequently, the area of each transect was determined by Arc GIS software in order to calculate the density of naturally spread *P. caribaea* (*P. caribaea* trees per ha). The boundaries of the consecutive transects were clearly demarcated in the field in order to quantify the density of naturally growing *P. caribaea* in each of them with the help of a GPS and a digital range finder (Bushnell Laser Range Finder, Elite 1500).

The density of invading *P. caribaea* was measured in relation to the distance from the plantation edge. All individuals of naturally growing (newly established) *P. caribaea* (1-4 m tall) in each of the belt transects and within each belt in different habitats were counted by the use of a pair of binoculars and a range finder. Height from the ground to the third branch from the top of the crown was measured as the parameter of tree height.

Results

In the KR, there are five different major land use types adjacent to the *P. caribaea* plantations selected for this study. These are grasslands, scrublands, forests, tea estates and home gardens. Most of the scrublands and grasslands have grown after unprofitable tea plantations were abandoned around 1956 (Humbel 1990). There were two forest types adjacent to the selected *P. caribaea* plantations in the KR, *viz.* semi-evergreen and lower montane forests.

Comparison of the density of *P. caribaea* plants that have invaded different land use types adjacent to selected plantations of the KR showed that grassland had extremely higher *P. caribaea* densities than the other four habitat types (Figure 3).

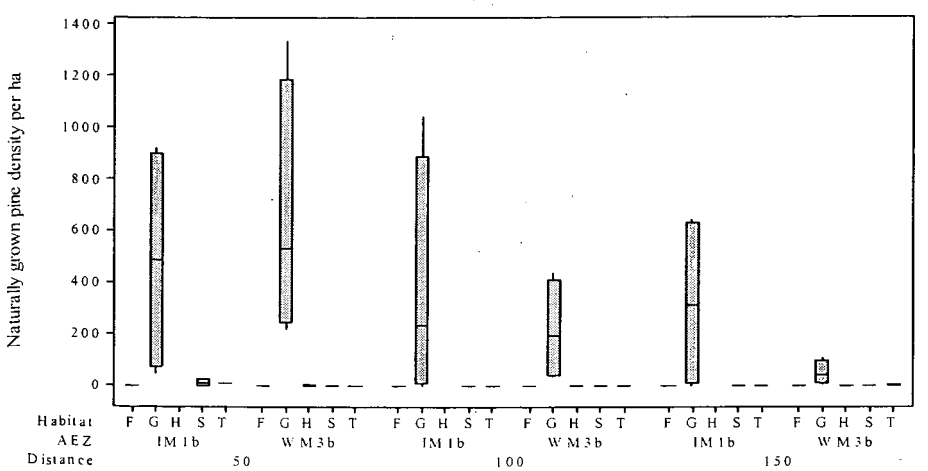


Figure 3. Box plot showing the vulnerability level of the different land use types adjacent (<50, 50-100 and 100-150 m belt) to invasion of *P. caribaea* in the KR.

Forest around the *P. caribaea* plantations were not subjected to *P. caribaea* invasion. However, *P. caribaea* saplings were recorded in the narrow area between the forest and the *P. caribaea* plantations. Most home gardens and tea plantations that were well maintained were hardly invaded by *P. caribaea*, but a few poorly maintained home gardens and tea plantations were very sparsely invaded by *P. caribaea* seedlings and saplings.

Discussion

Among the selected habitats in the KR, grasslands are the most vulnerable to *P. caribaea* invasion. Semi-evergreen and sub-montane forests in the KR showed resistance to *P. caribaea* invasion. Scrublands also showed much resistance to *P. caribaea* invasion compared to grasslands.

Under the forest canopy, limited light availability is unfavourable to both seed germination and seedling growth (Denslow, 1987). *Pinus caribaea* seedlings and saplings are not able to compete with native forest species for light. The seedlings of *P. caribaea* are light demanding, and this may be the main reason why these seedlings are unable to establish inside the natural forest patches in the KR. However, biotic resistance may be variable over time and space due to natural and artificial disturbances. For example, increasing human disturbance in forests, logging and fire can make these forest habitats vulnerable to *P. caribaea* invasions in the future (Richardson *et al.*, 1994).

In grasslands *P. caribaea* regeneration was observed on sunlit soils with low grass cover, eroded places and in areas recovering from fire damage. Such different features of grasslands may account for the high variability of *P. caribaea* regeneration in the two AEZs. Intensity of ground cover, disturbance and density of migrating *P. caribaea* seed into grasslands are among the factors most affecting *P. caribaea* invasion. *Pinus caribaea* seedlings are able to compete with grasses for light compared to that of forest species. Hence, these grasslands may be more vulnerable to establishment of *P. caribaea* than under the shade of the ground layer in forests. Inside the grasslands there are patches with rocks and low grass cover, which act as an invasion window.

The secretariat to the Convention on Biological Diversity (SCBD, 2009) has defined IAS as 'species whose introduction and/or spread outside their natural habitats threaten biological diversity'. In the KR, *P. caribaea* is invading grasslands by suppressing native plants. Therefore, based on the criteria in the above definitions, it can be concluded that *P. caribaea* is an invasive alien plant in Sri Lanka. The findings of this study also reflect the criteria given by Richardson *et al.* (2000), who classified IAS as introduced species having the ability to produce reproductive offspring in areas distant from sites of introduction (approximate scales: > 100 m over <50 years for taxa spreading by seeds)". In grassland habitats in the IM1b AEZ seedlings, saplings and mature trees of *P. caribaea* had invaded grasslands 100 m away from the parent plantation. These *P. caribaea* plants have arisen from seeds produced in the plantation and dispersed by wind. Therefore, according to the definition proposed by Richardson *et al.* (2000), *P. caribaea* could also be considered as invasive in grassland habitats in the KR where there is densely grown *P. caribaea* at 100 m away from the parental stock.

The dynamics of range expansion and population growth of an invasive alien plant typically follow the pattern shown in Figure 4 (Richardson, 2001).

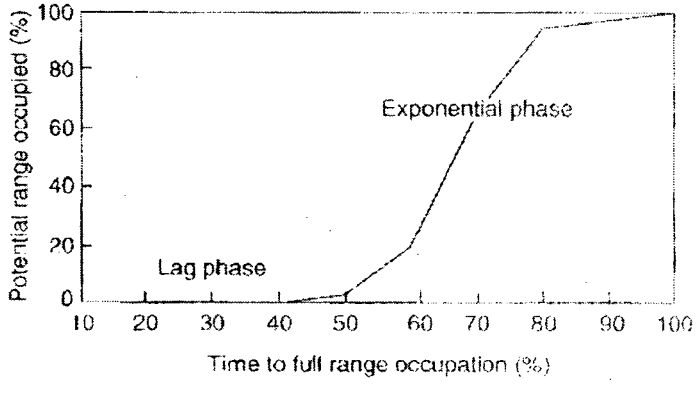


Figure 4. Model of the spread of an invasive alien plant over time (Richardson, 2001).

There is frequently a time lag between the arrival of an alien species in a new habitat and start of widespread invasion. The lag phase is followed by an exponential phase of sudden growth during which the population increases at an exponential rate, which generally becomes noticed as invaders. Therefore, the spread of *P. caribaea* need to be monitored in the long term and management of *P. caribaea* plantations in the KR needs to be addressed immediately at this very early stage rather than waiting until it reaches the exponential phase.

Can *P. caribaea* invasion be managed?

Though the KR represents < 0.5 % of Sri Lanka's land area, it has a high biodiversity (almost 33% of the islands angiosperm flora), some unique to Sri Lanka. There are 1033 flowering plants, of which 160 (15%) are endemic to the island, and about 3% are nationally threatened. With respect to the fauna, 70 species are endemic and 72 are nationally threatened (Bambaradeniya and Ekanayake, 2003). However, grasslands in the KR are highly vulnerable to *P. caribaea* invasion as compared to other vegetation types. Perspectives on the biological characteristics of *P. caribaea* and the factors that influence invasibility of habitats in different AEZs in the KR have important implications for management. The evidence emerging from this study suggests that the incidence of *P. caribaea* invasions can be reduced by considering the following factors: local land managers and state officials should recognize that grasslands are potential sites for *P. caribaea* invaders; they should develop long-term strategies to minimize invasion in grasslands; grasslands and *P. caribaea* plantations of high risk should be identified and should take measures to control *P. caribaea* invasion immediately.

Invading *Pinus* has received considerable attention in other parts of the world where much attention has been paid to its control. Moran *et al.* (2000) emphasised that use of seed and cone feeding insects and mite agents, as reducing the seed bank has the potential of decreasing the invasiveness of alien *Pinus* sp. However, application of biological control agents to control IAS is highly controversial among scientists in the world. Physical removal is the main control measure used in Australia to control *Pinus* invasion. In the Kosciusko National Park at New South Wales of Australia, the complete removal of plantations of *P. contorta, P. nigra* and *P. ponderosa* was supposed necessary to eliminate the seed source for potential invasions. Pulling out of established seedlings or manual cutting of already grown saplings and mature trees before they set seed are effective control measures of *Pinus* sp. However, this method is a labour-intensive and less-efficient technique. Chemical controls can also be used to control *P. caribaea* invasion in the KR. In Australia, physical removal was sometimes complemented by herbicide applications. This method involves the use of inorganic/organic herbicides. Disadvantage of this method is the high cost and danger to other native plant species.

The increasing human disturbance in forests, logging and fire can make these forest habitats vulnerable to *P. caribaea* invasions in the future (see Richardson *et al.*, 1994). Grasslands subject to man-made disturbances are the most affected. The level of activities such as fire, heavy grazing, erosion and trampling, which creates openings in the vegetation, should be reduced where the natural vegetation receives an input of *P. caribaea* seeds. Anthropogenic fire incidence in the two AEZs facilitates recruitment of *P. caribaea* seedlings, which in turn adversely affect the establishment of native tree species in these grasslands. Controlling fire in grasslands in the area may be one option of controlling *P. caribaea* invasion and increasing fire resistant native tree species in the grasslands. In areas of other parts of Sri Lanka where *P. caribaea* plantations were established, managers should expect invasions in future.

Restoration with native species

A restoration trial was set up in 1991, in an attempt to convert monoculture *P. caribaea* stand in the buffer zone of Sinharaja Forest to a mixed plantation using multi-purpose rain forest species. In this previous study, the late succession and mature phase canopy dominant tree species as well as gap colonizing non-timber forest (NTF) species were used (Ashton *et al.*, 1997, 1998; Gamage, 1998; Gunatilleke *et al.*, 1996). This study showed, for the first time in Sri Lanka, that a forest plantation of mixed species of multipurpose value could be grown in the wet zone of Sri Lanka, using *P. caribaea* as a nurse crop.

The second enrichment trial in a part of Hantana Mountain in Sri Lanka, *P. caribaea* plantation has also shown much promise (Figure 5). *Pinus caribaea* stands offer an environment that can be manipulated to suit the conditions required for growth of selected indigenous species. By removing one, two, three or five rows of pines and creating lengthwise gaps in pine stands, preferably in N-S direction to simulate forest-gap light condition, the required above ground conditions can be created for planting indigenous species (Figure 6).

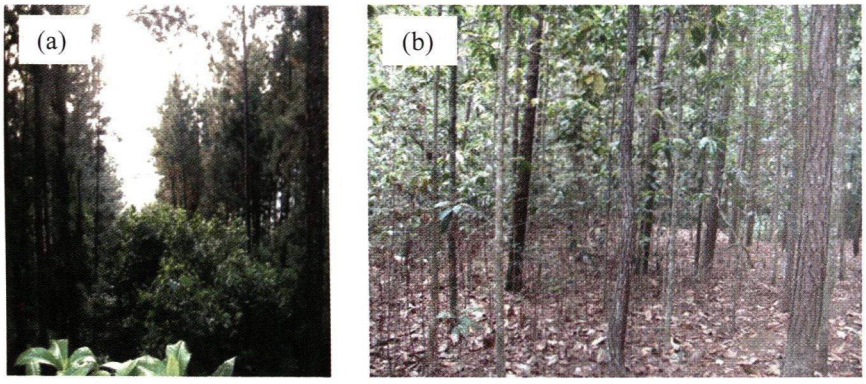


Figure 5. (a) Enrichment of *P. caribaea* plantation with natural broad-leaf forest species in Hantana and (b) *D. zeylanicus* growing naturally in *P. caribaea* plantation in Morahella, Panwila.

Four broad-leaved tree species, namely *Artocarpus nobilis* Thw. (Bedi del), *Madhuca longifolia* L. Macbride (Mee), *Michelia champaca* L. (Gini sapu) and *Terminalia bellirica* (Geartn.) Roxb. (Bulu) were introduced to the Hantana enrichment trial. Ambagahaduwa (2008) reported that the enrichment trial after 28 months of growth, can be successfully applied to the silvicultural restoration of these monoculture plantations of *P. caribaea* and to convert them into mixed species plantations with multipurpose species. *Michelia champaca* can be grown successfully under canopy removal treatment (three *P. caribaea* rows removed), while *A. nobilis*, *T. bellirica* and *M. longifolia* prefer to grow under higher light levels. These species performed better in larger gaps. This method can be applied to restore original *P. caribaea* plantations as well as grasslands (Figure 5b) with different densities of invaded Pines in the KR by using appropriate native and naturalized plant species. If appropriate gaps could be created in these stands and fire is controlled, even natural regeneration of native forest species such as *Dipterocarpus zeylanicus*, *Cosnium fenestratum*, *Syzygium* and *Calamus* spp. can be facilitated (Figures 5 and 6).

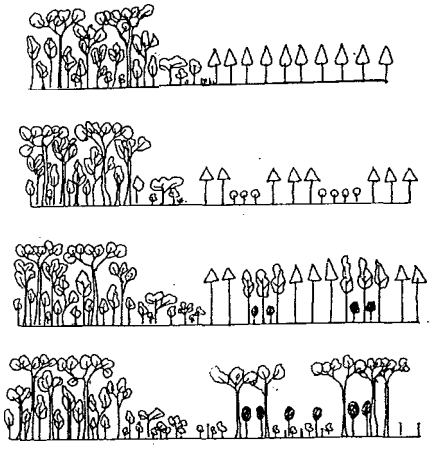


Figure 6. How *Pinus* stands can be enriched with natural forest species.

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Research paper

Chapter 15

Misidentification of *Pteridium revolutum* (Blume) Nakai as an Invasive Alien in Sri Lanka

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Abstract: Two Pteridophytes, namely *Salvinia molesta* D.S. Mitchell (Salvinia) and *Pteridium aquilinum* (L.) Kuhn. (Bracken fern) have been reported as invasive alien species (IAS) in Sri Lanka by several authors. The invasiveness of *S. molesta* and its impact upon biodiversity is well known, including in Sri Lanka. However, no studies have been conducted on the invasiveness of *P. aquilinum* in Sri Lanka. The objective of this study was to identify the taxonomic status, distribution and invasiveness of *P. aquilinum* in Sri Lanka based on current information and field-assessments. The study revealed that the genus Pteridium consists of a single taxon in Sri Lanka, *P. revolutum* (Blume) Nakai, which has been misidentified previously as *P. aquilinum*. The *P. aquilinum sensu stricto* is a well known invasive, which occurs only in Africa and Europe and is absent from the Indian subcontinent. *Pteridium revolutum* is significantly different in morphology from *P. aquilinum* in its markedly stiffer fronds with more convex pinnae and the segments more densely hairy beneath. It also has a different vernation with the pinnae uncurling more quickly and completely than the frond-apex. In contrast to *P. aquilinum* in Europe, *P. revolutum* is not particularly invasive, nor in general does as much damage to natural plant communities. It is not an adventive alien but is indigenous to Sri Lanka where it is locally known as '*Werella*', '*Monara kekilla*' and '*An kekilla*'. Similar to *P. aquilinum*, *P. revolutum* is a pioneer species, and common in burnt areas of patana grassland, open areas and roadside banks and may thus be used as an indicator-species for recognising forest clearings created by fire. According to the records of the National Herbarium at Peradeniya, and other herbaria worldwide, the past distribution of *P. revolutum* on the island was limited to three administrative districts: Kandy, Nuwara Eliya and Badulla, at mid (600 m) to higher elevations (2,300 m). The present field assessments have also revealed that *P. revolutum* is common in the same localities where it was observed in the past. Its widest areas of distribution occur in some parts of Nuwara Eliya district including grassland vegetation of Horton

R.H.G. Ranil, G. Pushpakumara, C.R. Fraser-Jenkins and S. Wijesundara (2010): Misidentification of *Pteridium revolutum* (Blume) Nakai as an invasive alien in Sri Lanka. In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 141-149. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

Plains. Because of the controversial claims of its invasion, monitoring of populations of *P. revolutum* in selected areas to identify its potential as an IAS and removal of this native species from the list of IAS in Sri Lanka are suggested.

Introduction

Thirty eight plants in Sri Lanka are considered as invasive alien species (IAS), which includes two Pteridophytes namely, *Salvinia molesta* D.S. Mitchell, commonly known as salvinia, and *Pteridium aquilinum* (Lin.) Kuhn, commonly known as bracken fern (Bambaradeniya, 2001; 2002). The taxonomy and invasiveness of the aquatic species, *S. molesta*, has been well studied. The information on impact of salvinia upon biodiversity and human livelihood is also well known, including in Sri Lanka (Ashton and Mitchell, 1989; Cronck and Fuller, 1995; Oliver, 1993). The genus *Pteridium* consists with 11 taxa worldwide (Annexure 1) of which *P. aquilinum* is considered as one of the most successful IAS in the world (Taylor, 1990). It occurs in cold regions of the world, from woodlands to grasslands habitats. Once established, the species becomes a troublesome and difficult to eradicate because of its persistent underground rhizome (Fletcher and Kirkwood, 1979). *Pteridium aquilinum* establishes on areas dominated by fires, deforestation and agricultural activities, causing severe problems (Page, 1986; Pakeman *et al.*, 1994).

High resistance to diseases and pests, the presence of allelopathic substances, aggressive vegetative reproduction and resistance of the rhizome to fire and adverse weather conditions, the high density of the frond canopy and litter suppressing of the ground flora, and tolerance to a broad range of climatic and edaphic conditions are considered as the main strategies for *P. aquilinum* to arise and succeed as an effective IAS (Fletcher and Kirkwood, 1979; Gliessman and Muller, 1976; Page, 1986). Several report stated the occurrence of *P. aquilinum* in Sri Lanka (Bambaradeniya, 2001, 2002; Marambe *et al.*, 2003; Pethiyagoda and Gunatilleke, 2006). The collection made by Wu Zheng-yi and Raven (1999) from Bambarakanda falls of Nuwara Eliya district has also been named as *P. aquilinum ssp. revolutum* and also used in subsequent studies (Robertson, 2002). However, the information of the genus *Pteridium* in the country is vague in terms of taxonomy, distribution, ecology and invasiveness. Consequently, the objective of this study was to discuss the taxonomic status, distribution and potential of invasiveness of members of the genus *Pteridium* in Sri Lanka based on current information and field assessments.

Materials and Methods

Published and unpublished information on *Pteridium* in Sri Lanka was reviewed. The specimens of the genus *Pteridium* at the National Herbarium at the Royal Botanic Gardens at Peradeniya (PDA), Sri Lanka were examined and notes were made on their identity, locality, date, collector in order to obtain information on the overall distribution in Sri Lanka. Similar information about Sri Lankan *Pteridium* specimens that are not found at the PDA was obtained from Zink (2006). Field surveys were conducted at the Hunnasgiriya range and Deenstone and Corbet's Gap areas of Knuckles region in Matale district, the Hantana range and Loolecondera forest in Kandy district, Horton Plains and Kande Ela areas in Nuwara Eliya district, and the Namunukula range in Badulla district of Sri Lanka. During field-survey, visual observations were made on the relative abundance and distribution of *Pteridum* in different populations in the above areas. Specimens were also collected for taxonomic study and are deposited in the PDA. The taxonomic classification followed in this study follows Fraser-Jenkins (1997, 2008) and Zink (2006).

Results and Discussion

Taxonomy of the genus *Pteridium* in Sri Lanka

The genus *Pteridium* belongs to the family Dennstaedtiaceae, and globally consists with 11 taxa, of which *P. aquilinum* is the most known species of the genus (Brownsey, 1989; Fletcher and Kirkwood, 1995; Page, 1986). *Pteridium aquilinum* is an herbaceous perennial fern species where fronds are produced from underground rhizome and grow to 1-3 m in height. The species is considered as one of the old but most successful ferns in the world. It is categorized as an IAS. Although majority of the herbarium specimens available at the Royal Botanic Gardens at Peradeniya, Sri Lanka has been named as *P. aquilinum*, the present study revealed that all *Pteridium* specimens collected from Sri Lanka to-date are *P. revolutum*, as the characteristics of the specimens available did not match with the characteristics of *P. aquilinum*. Thus, it is clear that *P. revolutum* has been mis-identified in the past as *P. aquilinum*, which, *sensu stricto*, occurs only in Europe, southern and tropical Africa, Madagascar and the Mascarene islands and further West Asia (in Turkey and Iran) (Fraser-Jenkins, 2008). *Pteridium aquilinum* does not occur in the Indian subcontinent, including Sri Lanka (Fraser-Jenkins, 2008). In the Indian subcontinent, the genus *Pteridium* represented by mainly *P. revolutum* with another species confined to the furthest North West Himalaya, *P. brownseyi* Fras.-Jenk. The African plant has often been treated as *P. capense* (Thunb.) Krasser (synonymous to *P. centraliafricanum* (Hieron.) Alston), but this is much closer to and is probably con-specific with *P. aquilinum* (Fraser-Jenkins, 2008). *Pteridium revolutum* (Figure 1), the most common *Pteridium* species in the region, is significantly different in morphology from that of *P. aquilinum* in its markedly stiffer fronds with more convex pinnae and the segments more densely hairy beneath.



Figure 1. Luxurious growth of *Pteridium revolutum* in Kande Ela educational park in Nuwara Eliya district.

Pteridium aquilinum also has a different vernation where the pinnae uncurl more quickly and completely, before the vernation of the young frond-apex (Table 1). Further, *P. revolutum* is not an adventive alien but is indigenous to Sri Lanka where it is locally known as *'Werella'*, *'Monara kekilla'* and *'An kekilla'*. It is also found in north and south India, southern China, east to Taiwan, southern Japan, from Myanmar and Thailand throughout south east Asia to New Guinea, including the Philippines and northern Australia (Fraser-Jenkins, 2008).

Earlier treatments on the genus *Pteridium*, many based on Tryon (1941), were of a single species with a number of geographical varieties around the world, and the Sri Lankan plants have not

usually been differentiated from the type-plant even as a variety (Fraser-Jenkins, 2008). Of the varieties treated in the middle of the last century, the south Indian name *P. aquilinum* var. *wightianum* (Wall. *ex* J. Agardh) R. M. Tryon, described from south India, refers to *P. revolutum*, but it has seldom been used in Sri Lanka (Fraser-Jenkins, 1997, 2008).

Table 1. Comparison of distribution and morphological characters of *Pteridium aquilinum* and *P. revolutum*.

Character	*P. aquilinum*	*P. revolutum*
Distribution	Southern and tropical Africa, Madagascar, the Mascarenes and widespread in Europe and furthest West Asia.	India, Sri Lanka, China, Taiwan, southern Japan, Myanmar, the Philippines, Thailand throughout South East Asia, New Guinea and Australia.
Rhizome	5-10 mm thick.	10-20 mm thick.
Rhizome scales	5 mm long.	1 mm long.
Stipe	Up to 0.5 m.	Up to 1 m.
Frond	Herbaceous to slightly stiff, with less convex pinnae (from above).	Very stiff, with more convex pinnae.
Lamina	Pubescent, but sparsely so on costae, costules and the lower surface of the lamina.	Densely pubescent on costae, costules and the lower surface of the lamina.
Length of lamina	1-2 m.	1-3 m (usually 1 m in Sri Lanka).
Indusium	Pseudoindusia *ca.* 0.5 mm wide.	Pseudoindusia *ca.* 0.2 mm wide.

It appears that most of the South Indian plants have slightly smaller segments and thus appear slightly more finely dissected than in much of the *P. revolutum* in north India, south east Asia and Sri Lanka, but there is considerable morphological overlap and this may be expected to represent no more than slight geographical variation within the species, of little or no taxonomic significance. Even though use of the name *P. aquilinum* has been corrected by a number of authors including Zink (2006) in Sri Lanka, it is still being perpetuated as a common taxonomic error in many south Asian studies (Wu Zheng-Yi and Raven, 1999; Bambaradeniya, 2001, 2002; Dawra *et al.*, 2002; Marambe *et al.*, 2003; Fraser-Jenkins, 1997, 2008). The results suggest the importance of proper identification of species and their taxonomy prior to naming them as an IAS.

Habitat of *Pteridium revolutum* in Sri Lanka

According to the current observations, *P. revolutum* is commonly occurred in open and sunny areas, on roadside banks (Figure 1), forest edges and in grassland vegetations as a pioneer species. It is commonly occurred in burnt areas of patana grasslands, and may be used as an indicator-species for recognizing forest clearings by fire. It has a deeply buried rhizome, which help to withstand fires. Accordingly, patana grassland with a cool climate at rather high altitude may be the most preferable habitat for *P. revolutum*, thus explaining its abundance on Horton Plains. *Pteridium aquilinum* is also identified as a pioneer species dominated in fire prone and open areas of cool climates (Page, 1986). Further, *P. aquilinum* also occurs in moist, open grassland at higher altitudes in the cooler regions in Africa, or at higher latitude in Europe and West Asia (Burrows, 1990; Fraser-Jenkins, 1997, 2008). This may be the reason to misidentify *P. revolutum* as *P. aquilinum* in the IAS list in Sri Lanka.

Past and present distribution of *Pteridium revolutum* in Sri Lanka

The first Sri Lankan collection of *P. revolutum* we have been able to see was by Alexander Moon from Uva province in 1819. According to herbarium-material preserved in the National Herbarium (PDA) and other herbaria (Table 2), the distribution of *P. revolutum* in Sri Lanka is limited to three administrative districts namely, Kandy, Badulla and Nuwara Eliya at mid (600 m) to higher elevations (2,300 m) (Table 2).

Table 2. The past records on distribution of *Pteridium revolutum* in Sri Lanka.

District & Locality	Elevation (m)	Date	Herbaria*	Collector
Kandy district				
Near Hellbodde	1,000	28/05/1967	PDA	Mueller-Dombis
Gombaniya mountain	1,300	04/09/1993	K	Fraser-Jenkins
Corbet's Gap	1,000	14/10/1993	K	Fraser-Jenkins
Roseneath	671	20/11/1950	K	Ballard
Badulla district				
Top of Namunukula	NA	12/03/1907	PDA	Silva
Haputale	NA	04/01/1970	PDA	Fosberg
Balangoda-Haputale road	875	31/12/1976	PDA, K	Faden & Faden
Nuwara Eliya district				
Nuwara Eliya	1,829	NA	BM	Gardner
Horton plains	2,270	7-8/03/1954	BM, G	Schmid
Ambewela	NA	15/05/1968	PDA	Mueller-Dombis
Piduruthalagala	2,286	26/12/1950	PDA, K	Ballard
Ramboda Pass	975	17/12/1950	K	Ballard
Horton plains	2,134	20/12/1950	K	Sledge
Without locality				
Without locality	NA	1819	BM	Moon
Without locality	NA	1853	BM	Thwaites
Without locality	NA	1843	BM	Gardner
Without locality	NA	1875	BM	Barkly
Without locality	NA	1962	PDA	Amaratunga
Without locality	NA	NA	GH, US	Beokett
Without locality	NA	1875	NY	Wall

Note: NA=Not available; Herbarium acronyms are standardized according to *Index Herbariorum*

*BM - The Natural History Museum, United Kingdom, K - Royal Botanic Gardens, Kew, United Kingdom, G - Conservatoire et Jardin botaniques de la Ville de Geneva, Switzerland, GH - Gray Herbarium, Harvard University, Cambridge, NY - New York Botanical Garden, New York, US - United State National Herbarium, Smithsonian Institution, Washington.

Only herbarium specimens with acceptable information available are listed here.

The present assessment has also revealed that *P. revolutum* is common in the same localities where it was observed in the past (Table 3). Although it is limited to three administrative districts in Sri Lanka and a few localities within each district, it is relatively more widely distributed in some areas of Nuwara Eliya District, especially in the grassland areas of Horton Plains.

Table 3. The present records on distribution of *Pteridium revolutum* in Sri Lanka.

District	Location	Elevation (m)	Date
Kandy	Dolosbage	590	20/05/2007
	Gombaniya mountain	1,120	12/09/2007
	Corbet's Gap	985	09/03/2009
	Hunnasgiriya	890	16/01/2008
	Alagalla	610	12/10/2007
	Hantane	650	25/06/2008
Badulla	Namunukula	1,275	08/12/2007
	Tangamalee	NA	27/11/2008
	Passara	NA	27/11/2008
Nuwara Eliya	Pattipola	1,980	27/09/2008
	Horton Plains	2,150	27/09/2008
	Kande Ela Park	1,520	27/09/2008
	Piduruthalagala	2,100	10/02/2007
	Hakgala	1,700	02/11/2007

Uses of *Pteridium revolutum* in Sri Lanka

Although controversial, local people in Nuwara Eliya, Kande Ela and Horton Plains areas indicated that *P. revolutum* provides a source of fodder for Sambar and Deer. However, no detailed studies have been carried out so far on this issue. Nevertheless, it is well known in India as a seriously toxic species for domestic cattle (Personal observation by C.R. Fraser-Jenkins). *Pteridium aquilinum* was once widely used as bedding for animals in Europe, but its use has been largely discontinued in favour of straw, especially in view of its high toxicity. *Pteridium esculentum* (G. Forst.) Cockayne, which is apparently non-toxic, is used as a vegetable in China. Even in China the uses of *P. revolutum* are confined only to provide animal bedding, particularly for chickens. It is normally avoided by cattle, except following winter-confinement in the Himalayan region where it causes serious threat to animal life. Investigation of its utilisation in Sri Lanka and collection of indigenous knowledge associated with this native species should be carried out hand-in-hand when the management strategies are to be designed, if necessary.

Is *Pteridium revolutum* invasive?

In contrast to *P. aquilinum* in Europe, *P. revolutum* so far does not normally show invasive behaviour and/or cause serious damage to natural plant communities. Further, in comparison with the rapid and substantial growth-pattern and distribution of a few other ferns, such as *Dicranopteris linearis* (Burm.f.) Underw. (*Kekilla*) and *Blechnum orientale* L. (*Barukoku*) in lowland vegetation of Sri Lanka, *P. revolutum* does not show excessive or invasive growth or distribution. However, according to the observations made by the surrounding communities of the Horton plains, *P. revolutum* has shown some form of invasive growth and distribution, though hazily, in the area. Patana grassland with a cool climate at rather high altitude may be the most preferable habitat for *P. revolutum*, hence grows in abundance on Horton Plains. Excessive colonization of Bracken in Horton Plains has also been reported by Pethiyagoda and Gunatilleke (2006).

The present study was limited to selected areas where specimens were collected for taxonomic purposes and does not generate information on the ecology, abundance, pattern or rate of distribution of *P. revolutum* in Sri Lanka. Apart from few personal assessments, there is no

quantitative data available to determine its invasiveness. Further, available records do not show a complete picture of its geographical distribution in Sri Lanka. Thus, it is required to study and monitor existing populations of *P. revolutum* in grassland vegetations and forest edges of Horton plains. It is therefore advisable to conduct a long-term monitoring program on the rate of spread of *P. revolutum* in grassland areas and forest edges of Horton Plains to identify its ecology, level of invasiveness and potential impact on grassland vegetation.

Conclusions

Pteridium revolutum, an indigenous plant to Sri Lanka, has been misidentified by many researchers as *P. aquilinum*, which is an alien to the country. Therefore, it is suggested that the genus *Pteridium* be removed from the IAS lists of Sri Lanka, until further studies are carried out to assess the potential impacts of the species, if any, especially in the Horton Plains.

Acknowledgements

The authors are indebted to the staff of the National Herbarium of the Royal Botanic Gardens, Peradeniya, Sri Lanka for their generous support. The support provided by the British Overseas Development Aid for C.R. Fraser-Jenkins to carry out the study in Sri Lanka is gratefully acknowledged.

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Annexure 1

Checklist of *Pteridium* species recorded in the world

Pteridium aquilinum (L.) Kuhn (Adlerfarn or Southern Bracken)
ssp. *aquilinum* (L.) Kuhn
ssp. *japonicum* (Nakai) A. Löve & D. Löve)
Pteridium arachnoideum (Kaulf.) Maxon
Pteridium brownseyi Fraser-Jenkins
Pteridium capense (Thunb.) Krasser
Pteridium caudatum (L.) Maxon
Pteridium centrali-africanum (Hieron. ex R.E.Fries) Alston
Pteridium esculentum (Forst.) Nakai (Bracken)
var. *decompositum* (Gaud.) comb. ined.
Pteridium feei (W. Schaffn. ex Fée) Faull
Pteridium latiusculum (Desv.) Hieron. ex Fries
ssp. *latiusculum* (Desv.) Hieron. ex Fries (Northern Bracken)
var. *pseudocaudatum* (Clute) Maxon
var. *pubescens* (Underwood)
ssp. *pinetorum* (C.N. Page & R.R. Mill) Fraser-Jenkins
Pteridium psittacinum (Presl) Maxon
Pteridium revolutum (Bl.) Nakai (Hairy Bracken)
Pteridium x semihastatum (Wall. ex J. Agardh) S.B. Andrews (Northern Bracken)

Research paper

Chapter 16

Some Eco-physiological Characters of *Austroeupatorium inulifolium* (Kunth) R.M. King & H. Rob.

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Abstract: Alien plants are invading the natural and semi-natural ecosystems causing much damage to the biodiversity. For the past few years, *Austroeupatorium inulifolium* has invaded aggressively within the Knuckles Conservation Area of Sri Lanka. However, *A. inulifolium* is still to be identified as an invasive plant in Sri Lanka, hence no scientifically valid data are available on its impact on the ecosystem. The baseline information on the ecology of *A. inulifolium* is important to undertake future management practices successfully. In the present experiment the morphological plasticity of *A. inulifolium* when exposed to different nutrient pulses and intra-specific competition was investigated. Two pot experiments were set up under glasshouse conditions at the Department of Botany, University of Peradeniya, Sri Lanka. In the first experiment, seedlings were transplanted (1 plant/pot) and nutrients were added to create 'spatial', 'temporal' and 'homogeneous' pulses for five weeks. After 8 weeks of growth, plants were harvested. In the second experiment, seedlings were exposed to 3 density levels; 1, 2, and 4 seedlings/pot (x1, x2 and x4 respectively; n=10). Plants were harvested after 9 weeks. Results were statistically analyzed using Minitab 14. The seedlings of *A. inulifolium* exposed to 'temporal' nutrient enrichment showed higher shoot, root, total biomass and growth rates than plants given with homogenous nutrient-enrichment, suggesting plants have the ability to capture unpredictable 'temporal' pulses more efficiently than predictable nutrient pulses. However, the root weight ratio (RWR) and root:shoot ratio showed no significant difference between treatments indicating that their better growth under temporal pulses is mainly through physiological adjustments rather than morphological. In the second experiment, shoot, root and total biomass at high density (x4) showed significantly lower values ($p<0.05$) than the low density treatments. The relative height ratio and growth rate of *A. inulifolium* also showed similar trends to biomass measurements. *A. inulifolium* responded to intra-specific competition by lowering its growth with increase in competition. The results suggest that *A. inulifolium* is physiologically more plastic to unpredictable

Inoka Piyasinghe, Sumedha M. Weerasinghe and Jagath Gunatilake (2010): Some Eco-physiological characters of *Austroeupatorium inulifolium* (Kunth) R.M. King & H. Rob. In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 151-160. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

nutrient pulses than predictable pulses (spatial and homogeneous), which is considered as an important competitive trait possess by invasive species.

Introduction

Invasive species persist and spread in ecosystems and alter the basic ecosystem processes such as hydrology, nutrient cycling, soil erosion rates (Vitousek and Walker, 1989), fire frequency and intensity (D'Antonio and Vitousek, 1992), and recruitment of native species (Mooney and Drake, 1989). A number of introduced non-native (alien) species also can become locally dominant (Levine *et al.*, 2003) and change relatively diverse communities into near monocultures. Natural and semi-natural ecosystems of Sri Lanka have been threatened by the invasion of alien species and their rapid distribution is mostly attributed to human activities. Invasive alien species (IAS) are able to survive under a wide range of climatic and soil conditions, and reproduce, spread at alarming rates across the landscape. Eco-physiological information of alien invasive plants and their impact on native plants are scarce. Scientific information on these aspects would be imperative to assess the damages and develop strategies to overcome the problems.

Experimental and inadvertent manipulations of resources have shown that the availability of resources such as mineral nutrients and water are important determinants of the invasibility of communities by plants. Adding nutrients (Wedin and Tilman, 1996; Bakker and Berendse, 1999) and water often promotes invasion (Milchunas and Lauenroth, 1995; White *et al.*, 1997). Decreasing soil water availability has also promoted invasion (Cleverly *et al.*, 1997).

Soil nutrient patches are spatial or temporal in nature (Fitter, 1994). Plants respond to such environmental heterogeneity by altering growth and/or adjusting biomass partitioning to various organs (Dale and Causton, 1992; Reynolds and D'Antonio, 1996). Plants seem to adjust physiologically to capture unpredictable, short-term temporal pulses, while long-duration, predictable nutrient pulses are captured through morphological adjustments. Fransen *et al.* (2001) suggest that physiological plasticity is more critical for long-term competitive advantage of a plant than morphological plasticity.

According to Casper *et al.* (2000), localization of nutrients within patches would increase the intensity of competition, as nutrient-rich patches can contain roots of several plants. Nitrogen capture by competing plants in nutritionally heterogeneous conditions strongly correlates with their rates of root proliferation in nitrogen-rich patches. Thus, the species with faster root proliferation gain a competitive advantage over the other plants (Robinson *et al.*, 1999). This also suggests that nutrient heterogeneity may affect intensity of competition.

The competitive ability of invasive plants could be different when they are in a mixed population rather than in monoculture stands. When plants face competition, they tend to adjust morphologically and physiologically. Studies suggest that invasive species may be more plastic than non-invasive species as this will decide their competitive advantage over the neighbors (Williams *et al.*, 1995; McDowell, 2002). Populations in the introduced range of an invasive species have evolved greater plasticity than populations in the native range because of their high competitive ability over other species (Sexton *et al.*, 2002; Parker *et al.*, 2003).

Austroeupatorium inulifolium was introduced to Asian countries during the World War II, and Sri Lanka and the Western Ghats in India were infested by this plant probably through military troops and their equipment returning from Assam and the Burma front (McFadyen, 2003). The

species has aggressively invaded the Knuckles Conservation Area of Sri Lanka in the recent years invading many landuse types including forest clearings, disturbed lands, grasslands, plantations, forest edges and roadsides forming dense thickets and choking out other vegetation. No vegetation survives beneath the *A. inulifolium* plants and tree seedlings cannot penetrate the dense growth. Grasslands have also been invaded, resulting in complete shading out of the grasses. Following fire hazards (during the dry season), the *A. inulifolium* plants show rapid establishment through induced seed germination. Knowledge on the eco-physiological features of *A. inulifolium* could be used to adopt judicious management strategies to control its invasion.

This paper reports the extent of morphological and/or physiological plasticity of *A. inulifolium* when exposed to heterogeneous nutrient pulses and intra-specific competition.

Materials and Methods

Austroeupatorium inulifolium (Kunth) R.M. King & H. Rob. (Synonym: *Eupatorium inulifolium* H.B.K.; family – Asteraceae) plants of similar age (3-4 leaved stage) collected from the nursery, were planted in pots (1 plant per pot) filled with a mixture of nutrient rich garden soil and river sand (1:3 ratio). Pots were hypothetically divided into four sections and nutrients were added (ALBERT'S nutrient solution; N 11%, P_2O_5 8%, K_2O 15%, CaO 14% and MgO 4%, Zn, Cu, Mo, Fe, Mn, B are in balanced form) in such a way to create natural nutrient pulses such as 'spatial', 'temporal' and 'homogeneous' in pots (100ml/pot) (Figure 1).

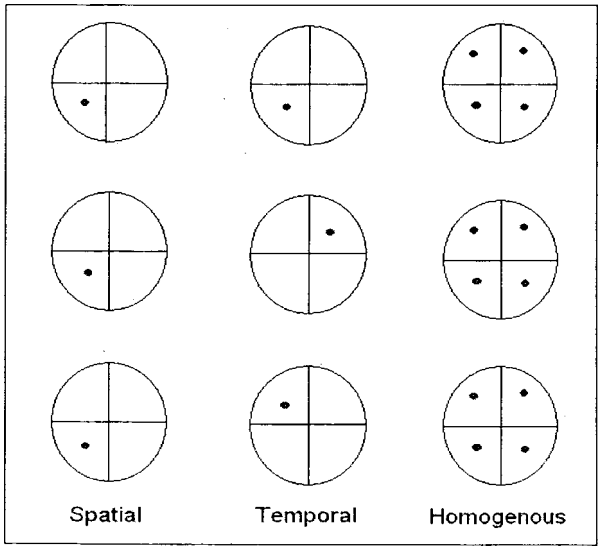


Figure 1. Nutrient application patterns to create 'spatial', 'temporal' and 'homogeneous' (control) nutrient pulses.

After four weeks of initial growth, nutrient pulse treatments were started and continued once a week for five weeks. To minimize the position effect, pots were randomly rearranged every other week. At the end of 9th week, plants were destructively harvested, and the fresh and dry weights (oven dried at 40°C for 48 hrs) of root and shoot samples were recorded separately.

In the second pot experiment, *Austroeupatorium* seedlings (raised from seeds) were transplanted at three different densities (1, 2, and 4 per pot) in pots containing the mixture of garden soil and sand (1:3 ratio). Plants were placed in the pot equidistant to each other. Each treatment had 10 replicates, totaling to 30 pots. Data were collected from 4 weeks after transplanting. Pots were watered daily and kept at the field capacity. Nine weeks after planting, plants were harvested, fresh weights of root and shoot samples were recorded, and the dry weights were recorded after oven drying at 40°C until a constant weight. The initial seedling weight was calculated using the dry weight of 10 randomly picked seedlings, which were oven dried at 40°C for 48 hrs. The plant heights were recorded every fortnight starting from 4 weeks after planting. The growth rate and root/shoot ratio were also calculated. The root weight ratio (RWR) and relative height ratio (RHR) were calculated using the following equations (Xiao *et al.* 2006).

$$RWR = (\text{root weight}/\text{total weight}) \times 100$$

$$RHR = \frac{[\ln(\text{harvest stem height}) - \ln(\text{initial stem height at transplanting})]}{\text{Time in growth (days)}}$$

Data analyses

Data were analyzed using the MS-Excel and the Minitab 14 statistical software packages. Mean values and standard error of means were calculated using MS-Excel software. The results were analyzed using one-way ANOVA and Tukey's family error test was used for mean comparisons.

Results and Discussion

Experiment – I

The shoot and root dry weights (Figure 2) of *A. inulifolium* are significantly higher ($P < 0.05$) in plants exposed to 'temporal' nutrient pulses than plants with homogenous supply of nutrients. Higher root growth indicates root proliferation when plants are given temporal nutrient pulses.

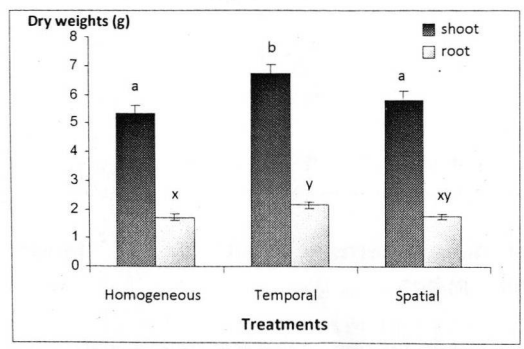


Figure 2. Root and shoot day weights (g) of *A. inulifolium* in homogenous (control), spatial and temporal nutrient treatments. Different letters indicate significant differences between treatments at $p<0.05$ levels; for shoot biomass: $p=0.019$, $F=4.86$; for root biomass: $p=0.028$, $F=4,29$.

The total biomass (Figure 3) also showed significantly higher values ($p<0.05$) in plants exposed to temporal nutrient-enrichment when compared to plants exposed to homogenous nutrient enrichment.

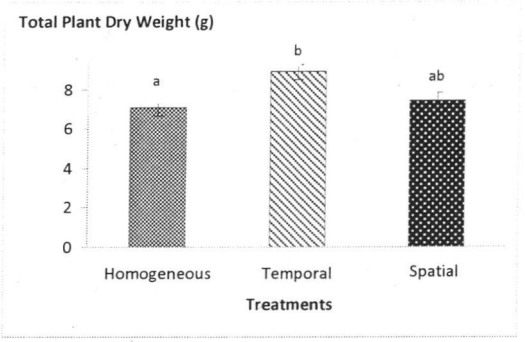


Figure 3. Total dry weights (g) of *A. inulifolium* in homogenous, spatial and temporal treatments. Significant differences are indicated using different letters (at p=0.05).

Previous studies have shown that when plants were given heterogeneous nutrient pulses (spatial or temporal), plants acquire and produce more biomass compared to those supplied with homogenous nutrient pulses (Hutchings and de Kroon, 1994). As under field conditions most nutrient pulses are unpredictable (temporal) in nature hence present results suggest that *A. inulifolium* is more effective in acquiring nutrients from unpredictable pulses than predictable pulses (spatial and homogeneous).

The shoot to root (S/R) ratio and RWR showed no significant differences between treatments (Figure 4). This indicates that though plants performed differently under varying nutrient pulses, their biomass allocation pattern to above- and below-ground parts seems to be almost same. This result suggests that *A. inulifolium* did not proliferate roots when in contact with temporal nutrient pulses. The growth rate (Figure 5) also follow similar trend to other parameters tested where plants exposed to temporal patches showed significantly higher rates than that of predictable nutrient pulses such as 'homogeneous' and 'spatial'.

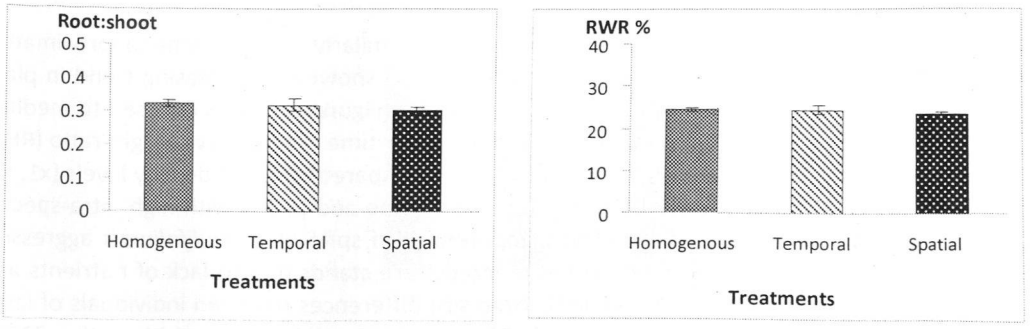


Figure 4. Shoot:root and root weight ratios of *A. inulifolium* in homogenous, temporal and spatial treatments.

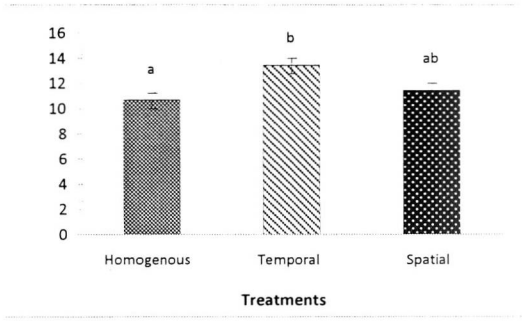


Figure 5. Growth rate per week *A. inulifolium* in homogenous, spatial and temporal treatments (bars represented by the same letter are not significantly different at p=0.05).

Experiment-II

The performance of *A. inulifolium* when exposed to different density levels (intra-specific competition) are illustrated in Figure 6.

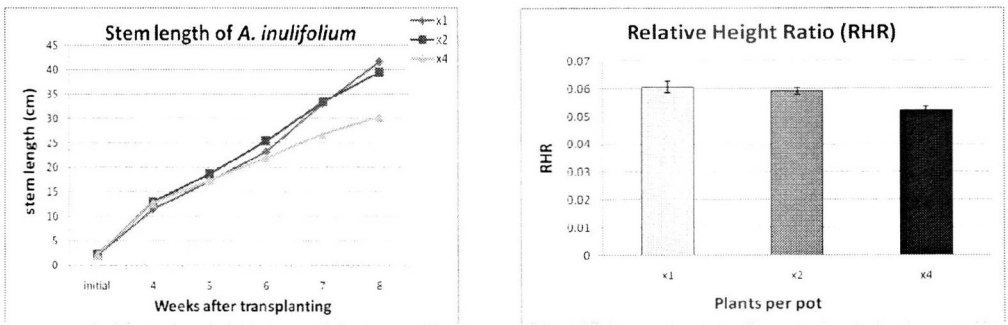


Figure 6. Stem length (cm) and relative height ratio of *A. inulifolium* under low (x1), medium (x2) and high density (x4) treatments (bars represented by the same letter are not significantly different at p=0.05).

At early stage of growth, *A. inulifolium* performed almost similarly and with time (approximately after the 6th week) the plants exposed to high density (x4) showed a decreasing trend in plant height compared to plants exposed to lower density levels (Figure 6). Plants exposed to medium (x2) and low (x1) increased their plant height gradually over time. The relative height ratio (RHR) showed significantly lower values at higher density (x4) compared to lower density levels (x1, x2) (Figure 6). The plants experience limited nutrients with time and plants with high intra-specific competition suffer more compared to low competition. In spite of *A. inulifolium's* aggressive nature they seem to suffer when they are in mono-culture stands due to lack of nutrients and other resources. Under natural environment, large size differences between individuals of large populations are probably due to their intra-specific competition (Meekins and Macarthy, 2000). Xiao *et al.* (2006) suggested that the mean height of plants will decrease with increasing density when the population density reaches a certain value. When there is competition for light between neighbors, height growth will help individual plants avoid the shading effect of its neighbors and enable it to acquire more of the light resources (Schmitt and Wulff 1993; Dudley and Schmitt, 1996; Xiao *et al.*, 2006).

The increasing density levels (or intra-specific competition) show decreasing total biomass per plant in *A. inulifolium* (Figure 7). This result also confirms the intensity of intra-specific interactions among individuals which reflects in the plants' overall performance. Grace and Tilman (1990) noted that plant density possibly influence the individual plant biomass due to competition for factors such as nutrient, water, light and physical space. Casper and Cahill (1998) found that overall (i.e. not necessarily individual) biomass of *Abutilon theophrasti* was low when plants were grown in monospecific stands under high density conditions.

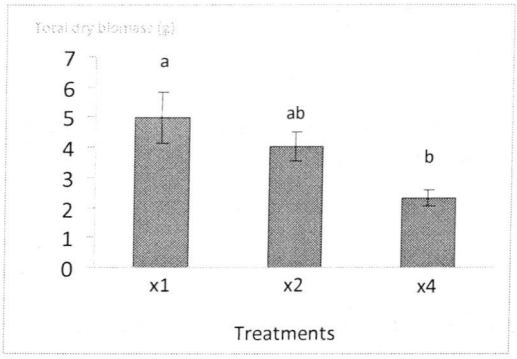


Figure 7. Total dry biomass (g) of *A. inulifolium* under low (x1), medium (x2) and high density (x4) treatments after 8 weeks of planting (bars represented by the same letter are not significantly different at p=0.05).

Shoot and root biomass also depicted similar trends when exposed to different density levels (Figure 8). Weiner (1990) suggested that competitive above-ground advantage is important since above ground interactions are intense as each individual attempts to obtain limiting light resources. There is evidence that shading can reduce root growth and resource uptake within as few as 24 hours (Massimino *et al.,* 1981; Caldwell *et al.,* 1987). However, in the present experiment plants did not show differences in their biomass allocation patterns (root:shoot and RWR) when they exposed to different density levels (Figure 9). Growth rates also showed significantly lower values under high density treatment compared to other treatments (Figure 10).

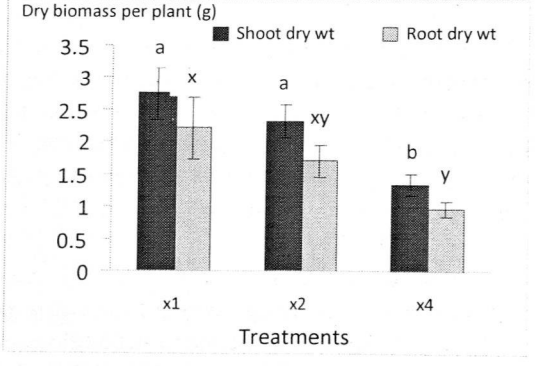


Figure 8. Root dry weights (g) and shoot day weights of *A. inulifolium* under low (x1), medium (x2) and high density (x4) treatments (bars represented by the same letter are not significantly different at p=0.05).

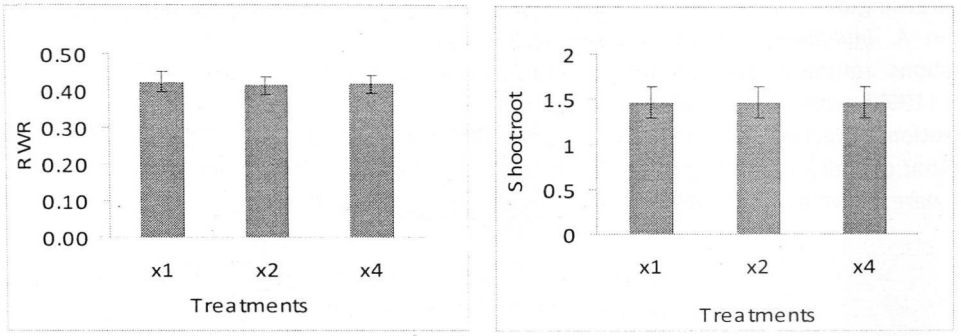


Figure 9. The RWR and Shoot:root ratio of *A. inulifolium* under low (x1), medium (x2) and high density (x4) treatments.

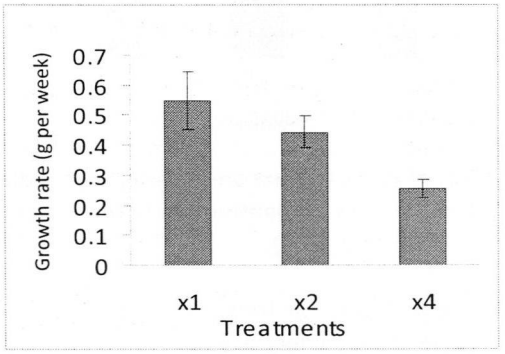


Figure 10. Growth rate per week *A. inulifolium* under low (x1), medium (x2) and high density (x4) treatments. Different letters indicate significant differences between treatments at p<0.05 levels; p=0.012, F=5.24, ANOVA.

Conclusions

A. inulifolium seems to be positively responding to unpredictable nutrient pulses and this character is important for their invasive nature. Fire incidents are common in the Knuckles Conservation Area, hence can result unpredictable nutrient pulses. Therefore, ecosystems with frequent fire incidents could be more vulnerable towards invasion by *Austroeupatorium.* Results also suggest that *Austroeupatorium* is physiologically more plastic than morphologically making them aggressive in competing for soil nutrients with other slow growing native plant species. However, intra-specific competition seems to affect the overall growth of *Austroeupatorium*.

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Research paper

Chapter 17

Predicting Invasiveness of Fish - An Ecomorpholgical Approach

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Abstract: All animals or plants that are introduced intentionally or inadvertently do not successfully colonize in the new environment. This is particularly due to lack of the perfect niche. According to the available records, about 20 out of the 25 fish species introduced to Sri Lanka's fresh waters have successfully invaded the native habitats. Less than 10 species have not been able to maintain their populations' naturally in Sri Lanka. There is a scarcity of information on the ecological impact of introduced fish species on the local fish fauna, ecosystem functions and goods and services provided. This paper attempts to predict invasiveness of introduced fish species by identifying their body shapes and ecology, which is an eco-morphological approach. Body morphology of fish can be measured using various methods as vertical and horizontal distances. Location of body organs, their shapes and the orientation or the direction from the center of the body can be considered as mensural measurements. Height, length and width of the body indicate important aspects of the ecology of fish. Proportions of the height, length and width are important parameters to show the ecomorphology of fish. Gross Body shapes that can be defined as P_1 (Height of the body/Width of the body) and P_2 (Total length/ Height of the body) are known to be useful parameters to predict the niche of the fish, particularly food habits and the ecology. The present analysis is based on the P_1 and P_2 values obtained from about 35 Sri Lankan freshwater fish species. According to the P_1 and P_2 values, the native carnivorous freshwater fish in Sri Lanka have dorso-ventrally flattened slender, long-bodies (low P_1 and higher P_2) whereas the herbivores have short, deep bodies (high P_1 and low P_2). *Chitala ornata* (family; Notopteridae) *is* an accidentally introduced exotic fish and has a short and deep body (high P_2 and low P_1). According to the gross body morphology, *C. ornata* would share a niche that would belong to native herbivore, and segregate niche with native carnivores. In two ecological dimensions *C. ornata* is showing its positive invasiveness with less competition. *Chitala ornata* is a voracious piscivorous fish representing an outlier in the P_1 and P_2 relationship of freshwater fish community in Sri Lanka. This "outlier nature" is the success of the *C. ornata*. It can be concluded that *C. ornata* will further invade the freshwater bodies and be a major threat to the littoral herbivores, and eventually

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to the freshwater fishing industry based on the exotic Tilapia. Therefore, strict control measures are needed to prevent range expansion of this invasive alien fish species in Sri Lankan freshwaters.

Introduction

Invasive alien fish species are a significant part of the biota (Cohen, 2002) in streams, lakes and estuaries worldwide at present. It is not known exactly that how many fish species have invaded the water bodies in Sri Lanka, as many fish species are being imported for aquarium industry. According to recent estimates, 30 fish species have been introduced accidentally or deliberately (www.fishbase.org). Depending on the reproductive ability of the exotic species, it can be assumed that about 25 fish species have established populations in Sri Lanka. Several cyprinids have not established as they are not able to maintain natural populations in Sri Lankan water bodies. However, *Catla catla*, which is a deliberate introduction that did not have natural populations for about 15 years has started breeding in the upstream of the Walawe Ganga River (Table 1). Although there is a considerable amount of exotic fish in Sri Lanka, their impact on the ecosystem is not yet known.

Table 1. Deliberately and accidentally introduced fish species in Sri Lankan freshwater habitats.

Family	Species	Fishbase name	Local Name
Cichlidae	*Oreochromis niloticus niloticus*	Nile tilapia	Tilapia
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	Tilapia
Cichlidae	*Oreochromis urolepis hornorum*	Wami tilapia	Na
Cichlidae	*Tilapia rendalli*	Redbreast tilapia	Tilapia
Cichlidae	*Tilapia zillii*	Redbelly tilapia	Na
Cyprinidae	*Aristichthys nobilis #*	Bighead carp	Bighead carp
Cyprinidae	*Carassius carassius*	Crucian carp	Goldfish
Cyprinidae	*Catla catla #*	Catla	Catla
Cyprinidae	*Cirrhinus cirrhosus #*	Mrigal	Mirigal
Cyprinidae	*Ctenopharyngodon idella#*	Grass carp	Grass carp
Cyprinidae	*Cyprinus carpio carpio*	Common carp	Rata pethiya
Cyprinidae	*Danio rerio*	Zebra danio	Na
Cyprinidae	*Hypophthalmichthys molitrix#*	Silver carp	Silver carp
Cyprinidae	*Labeo rohita*	Rohu	Rohu
Helostomatidae	*Helostoma temminkii*	Kissing gourami	Kissing gourami
Kuhliidae	*Kuhlia marginata* ?	Dark-margined flagtail	Gal pulunna
Loricariidae	*Hypostomus plecostomus*	Suckermouth catfish	Na
Notopteridae	*Chitala chitala*	Clown knifefish	Mannawa
Osphronemidae	*Osphronemus goramy*	Giant gourami	Seppali
Osphronemidae	*Trichogaster trichopterus*	Three spot gourami	Theppili
Osphronemidae	*Trichogaster pectoralis*	Snakeskin gourami	Theppili
Poeciliidae	*Gambusia affinis*	Mosquitofish	Mosquito fish
Poeciliidae	*Poecilia reticulata*	Guppy	Guppy
Poeciliidae	*Xiphophorus maculatus*	Southern platyfish	Platy
Poeciliidae	*Xiphophorus hellerii*	Green swordtail	Green swordtail
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	Rainbow trout

"#" - not established yet; "?" - not known whether this species is introduced or not. Identification of *Chitala* is controversial. According to www.Fishbase.org it is *C. chitala*, but Shirantha and Amarasinghe (2009) recorded as *C. ornate*; na = Not available.

Bright (1999) showed how the introduction of an alien fish directly attributed to the loss of more than 200 cichlids in Lake Victoria. The unpublished traditional knowledge base in Sri Lanka highlights that species such as *Tor kudree* has significantly reduced from the fish catches from the country's inland water bodies. It is not known whether it is an impact of alien species, however, environmental degradation also is a possible cause.

Efforts to prevent the spread of unwanted fish species, however, are still minimal compared to the size of the problem in global scale (Meyerson and Reaser, 2003), which is also true for Sri Lanka. If the responsible parties are not made aware of the seriousness of the scientific predictions, invasions would undergo until the ecological and economical crashes outburst. Global scale and continental level models are available for predicting the invasiveness of fishes which would result in limited predictive ability (Ruesink, 2005). But, the reliability of the models tested for other species rich areas of the world would not fit to the small islands like Sri Lanka. Therefore, regional or area specific studies based on the native and introduced species would be important in predicting the invasiveness of fishes.

Accurate predictions could be made when scientists understand the nature of invaders, the invasion process, and the impact of invasions, and communicate that knowledge effectively (Moyle and Marchetti, 2006). A successful invasion happens when an invader's symbiotic traits, biological characteristics, and invasion site (at multiple scales) are all favorable (Williamson 1996). There is no universal set of characters that can predict which aquatic invasions will succeed or which fish are likely to become nuisance species (Moyle and Marchetti, 2006). Any species can invade and any environment can be invaded (Moyle and Light, 1996). Somehow availability of the perfect niche in the introduced habitat would be a critical factor in establishing the exotics. Thus, ecomorphological studies are a need to know whether the perfect niche is available for the introduced species or possible introductions.

Morphology is the physical adaptation of the body of an organism in order for it be successful in a given habitat. A body shape or morphology fits only to a particular niche in the habitat. There is a strong link between morphology and ecology of fishes. Keast and Webb (1966) stated that morphology is relative to feeding ecology of fish, while Karr and James (1975) found that morphological differences are related to resources use. The relationship between morphology and ecology was defined as Ecomorphology (Karr and James 1975).

Morphological features such as body length, diameter of eye, mouth gape and length of the gut can be measured. Mensural variables such as orientation and position of mouth, location and shape of fins, etc., cannot be measured. However, both measurable and non-measurable variables are important in predicting the ecology of fishes. Hence, it could be hypothesized that ecomorphology of introduced fish can be used as a tool to predict the niche and the power of invasiveness. Knowledge on the ecomorphology of native fish community would assist in predicting the possible inter-species relationships and invasiveness of exotics. The predictability of ecomorphology has been discussed by Weins and Rotenberry (1980), Weliange and Amarasinghe (2007) and Weliange *et al.* (2008b).

Large number of morphological variables (Winemiller *et al.*, 1995; Piet, 1998; Hugueny and Pouilly, 1999; Weliange *et al.*, 2008b) as well as few simple measurements (Catella and Petrere, 1998; Weliange and Amarasinghe, 2007) can be used in ecomorphological studies. Simple body shapes, measured as body proportions (the proportions of body width and height relative to total length) are related to their feeding habits in Sri Lankan reservoir fish fauna (Weliange and

Amarasinghe, 2007). This study is an attempt to predict the invasiveness of accidentally introduced *C. ornata* using an ecomorphological investigation.

Materials and Methods

Fish for this study was collected from two streams; Eswathu Oya Stream (6º 53′ 15″ N, 80º 11′ 38″ E - 203 m a.s.l) and Yan Oya Stream (7º56′ 77″ N, 80º45′ 42″ E -186 m a.s.l.), and from three reservoirs; Minneriya reservoir (8°02' N; 80°53' E), Udawalawe reservoir (6º27' N; 80º50' E) and Victoria reservoir (7º13' N; 80º47' E). Fish sampling was done during two other investigations at the sites states above. Findings of those two investigations are available elsewhere (Weliange and Amarasinghe, 2003, 2007; Weliange, 2007; Weliange *et al.*, 2006, 2008a, 2008b).

Dietary habits and three morphological features (total length, maximum height and width of the body) were measured for all fish species. Trophic index (T_i) was calculated for each species based on the gut contents. For calculating the T_i, food items eaten by fish were classified into four trophic classes (T) as follows;

1. plant food (primary producers) were coded as T = 0.0 (eg. detritus, phytoplankton)
2. herbivores prey were T = 1.0 (e.g., algae, detritus and diatom feeders)
3. secondary consumers that eat exactly half plant and half herbivore prey were T = 1.5, and
4. tertiary consumers that eat herbivorous tissues and secondary consumers were T = 2

The T_i was calculated using the following equation according to Adams *et al.* (1983) and Winemiller (1990).

$$T_i = 1.0 + \sum_{j=1}^{n} T_j(p_{ij})$$

where T_j is the trophic class of prey species j and p_{ij} is the fraction of the consumed food (proportion by volume) of species i consisting of prey species j. Based on the three morphological measurements following body proportions were obtained as defined by Catella and Petrere (1998).

P_1 = Maximum height of the body/ Maximum width of the body
P_2 = Total length/ Maximum height of the body

The relationship between P_1 and P_2, and also P_2 and T_i were determined separately.

Results

The P_1, P_2 and T_i of native fish examined from the study sites are presented in Annexure 1. The relationship between P_1 and P_2 of the native fish fauna including exotic *C. ornata* is negative curvilinear (Figure 1a). The relationship between P_2 and T_i is a positive logarithmic (Figure 1b). This indicates that laterally compressed (high P_1) fish species with deep bodies (low P_2) feed on lower tropic level food and dorso-ventrally flat (low P_1) and longer (high P_2) fish feed on higher

trophic level food. *Chitala ornata* is an outlier in eco-morphological space and also in the trophic dynamics of the Sri Lankan fish fauna (Figure 1).

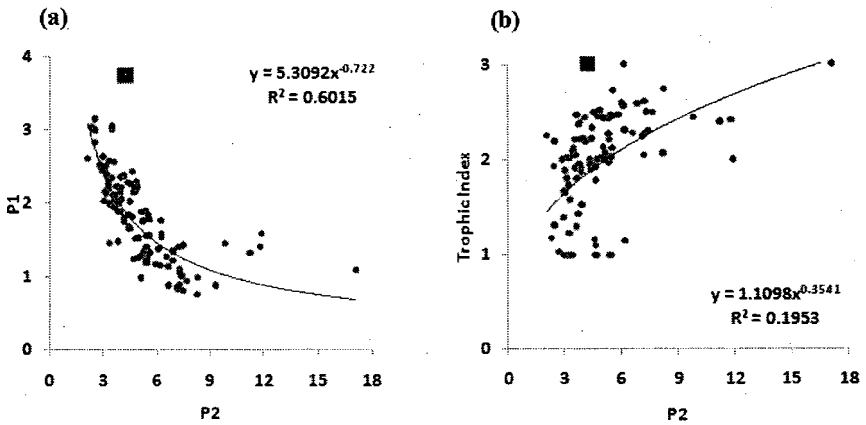


Figure 1. Relationship between P_2 and P_1 (a), and P_2 and Trophic index (b). The values related *to C. ornata* is shown in a rectangle.

Discussion

The relationship between P_1 and P_2 indicates that Sri Lankan freshwater fish fauna has no species with laterally flattened long body (high P_1 and high P_2) or dorsoventrally flat – short body (low P_1 and low P_2). This is an indication that Sri Lanakan native fish fauna has very limited body shapes or it is also possible that some species have not been yet identified. *Chitala ornata* has a completely different body proportion which does not fit into the morphological as well as trophic spectrum of the native fish fauna. *Chitala ornata* morphologically mimics as a native herbivore but by behavior it acts as a predatory carnivore. This extraordinary ecomorphological pattern could be the success of *C. ornata*.

Present analysis of the native fish fauna indicates that the body proportions of a fish shows a relationship to feeding habits. Similar pattern has been found in Baía da Onça, a floodplain lake in Brazil (Catella and Petrere, 1998) and also in three Sri Lankan reservoirs (Weliange and Amarasinghe, 2007).

According to literature *C. ornata* is an exclusive carnivore which grows up to maximum of 1 m in length in its native range (www.fishbase.org). Being a predator *C. ornata* is not sharing the niche with native predators such as gobies, snake heads and the cat fishes because morphology of the *C. ornata* is an adaptation to the littoral – water column. All native predatory fish inhabit in the bottom of the water body where they perform as "lie –in – wait predators". The body shapes of Sri Lankan predators, which have flattened head equipped with a large and superior mouth, dorsally oriented eyes, and the torpedo shape body fall under the category of 'lie-in-wait predators' (Moyle and Cech, 2000) which are essentially piscivores. Compared to native predators, *C. ornata* is totally different; it has a large-inferior mouth, and lateral eyes. These mensural characteristics are an indications that *C. ornata* is not a bottom dwelling and ambushing but cruising in the water column and capturing the prey which are living below its

moving plane. Therefore *C. ornata* is spatially segregated from the native predators, which is an advantage to minimize the competition for food and space.

On the other hand *C. ornata* find its niche in the water column in the littoral area where most of the native fishes inhabit, because *C. ornata* has a low P_2 and highest P_1, and also lateral eyes and inferior mouth. In the littoral water column *C. ornata* is benefitted by the abundance of native fish, and in this water column, it does not encounter predators.

Chitala ornata has the highest P_1 value and a low P_2, although it looks like a long fish. Niche segregation of *C. ornata* is the most important factor of its success in invading Sri Lankan freshwater habitats. Body proportions and two other mensural characters such as orientation of mouth and the position of eyes of *C. ornata* indicate that it is litoral – water column species there it behave as a perusing predator. But according to the dietary behavior *C. ornata* is predominantly a carnivorous predator. As none of native predators find their niche in the litoral-water column *C. ornata* is spatially well segregated from the native carnivores, hence minimizing the competition for resources.

Accordingly it can be predicted that *C. ornata* would be the most dangerous invasive fish in Sri Lankan freshwaters. Particularly *C. ornata* would be very successful in Sri Lankan reservoirs where there is an extensive littoral area.

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Research paper

Chapter 18

Community-based Management of Giant African Snail (*Achatina fulica*) Populations in an Agricultural Landscape

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Abstract: The Giant African Snail (*Achatina fulica*, Ferussac 1821), considered as one of the world's worst invasive alien species (IAS), was introduced to Sri Lankan around mid 1840s. The spread of this species in the Hambantota district in the southern province of the country was first observed three years ago, and is currently considered as a serious agricultural pest in the area. A study carried out in collaboration with the local community in Kurudana village of the Hambantota district revealed that mechanical control of the IAS is more effective than the chemical control. However, 53% of the sampled households) still rely on molluscicide to control the snail population. The study also revealed that community-based interventions to control the spread of IAS such as *A. fulica* take considerable time and effort to achieve the desired target. Continuous monitoring and regular community interactions and awareness on the benefits of the initiative is mandatory.

Introduction

The Giant African Snail *Achatina fulica* (Férussac 1821), locally known as the "*Kaluthara Golubella*", is considered as one of the world's 100 worst invasive alien species (IAS) (Lowe *et al.*, 2000). The species has been introduced to Asia, and Pacific and Indian Ocean islands, and to the West Indies. According to historical records, this species was introduced to Sri Lanka in 1846 either from Mauritius or from India. It had initially been released by a tea planter in an estate near Watawala, and later it had appeared on the coastal areas of Beruwala. Favourable environmental conditions in these areas had resulted in a rapid proliferation of this species

S. Lelwala, T. Ranasinghe, S. Wijesundara, K. Karunasena, and C.N.B. Bambaradeniya (2010): Community-based management of giant African snail (*Achatina fulica*) populations in an agricultural landscape. In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 169-177. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

(Naggs, 2002). The species has subsequently spread throughout the island (Bambaradeniya, 2000), and become a serious agricultural pest in Sri Lanka.

Major reasons for the species to become a pest species in its introduced range is lack of natural enemies in human modified landscapes and its intrinsic adaptability. Being a voracious herbivore, the species has become a severe agricultural pest and also out-compete the indigenous mollusk species (Raut and Barker, 2002). Animals such as the common coucal (*Centropus sinensis*), mongoose (*Herpestes spp.*) and the land monitor (*Varanus bengalensis*) feed on this species in Sri Lanka. However, these predators have failed to keep its population under control.

It has become a serious agricultural pest in Kurudana village of the Hambantota district, causing considerable economic damage to vegetable crops such as chillie, tomato, brinjal, spinach, beans, okra, yams such as cassava/manioc, cereals such as green gram, cowpea, groundnut, and fruit crops such as papaya and banana (Lelwala *et al.*, 2008). This invasive alien mollusk has arrived in this area during the past decade, probably through the transportation of coconut leaves and organic fertilizer from the wet zone of Sri Lanka. Farmers have used a variety of pesticides to control the spread of this species, without much success. The overuse of broad spectrum pesticides in the Kurudana village to manage this pest is also a major environmental concern. This paper presents the interim results related to the management of *A. fulica* carried out in Kurudana village in collaboration with non-governmental organizations and the local community.

Methodology

A rapid risk assessment was carried out at the beginning of the project in April 2008, to determine the population density, distribution and socioeconomic implications of this species to the rural farmer community in Kurudana at the Hambantota district in the southern province of Sri Lanka. Subsequently, a systematic strategy was prepared to manage the spread of this species in Kurudana. The main components of this management strategy included prevention of further spread, early detection and warning, and a combination of control methods (see appendix 1 for further details). A compendium of indicators was designed to monitor the progress of the management strategy on a regular basis. The implementation of the management strategy was undertaken by the villagers, under the technical guidance of IUCN and CARE.

During April 2009, a midterm assessment was conducted with the objective of monitoring the progress of the interventions. This included the assessment of snail population densities, and an economic assessment to value the financial gains from controlling this snail population. Snails were sampled using 25 quadrates (5 m x 5 m) to represent the two different management regimes namely, home gardens where the snails were collected once, and home gardens where snails were collected more regularly, to find snail density and distribution patterns. The microhabitat conditions in the quadrates were also recorded. A household survey was conducted using a questionnaire with 15 households, which is about 62.5% of the total number of households in the Kurudana village. The economic assessment was carried out using information related to reduction of crop damages, increase in the area cultivation, introduction of new crop varieties and reduction in costs of pesticides and labor time.

The data gathered were analyzed and compared with those from the rapid risk assessment conducted in April 2008. The net present value (NPV) was calculated for a 10-year time period at a 10% discount rate to understand the present value of future gains, with and without project scenario.

Results

This section highlights the results of the rapid risk assessment, and the subsequent midterm assessment of snail populations and socio-economic aspects, done seven months after carrying out management interventions.

Rapid risk assessment

The study revealed that the snails damage a wide range of crops ranging from green chillie, tomato and curried pumpkin (*Cucurbita maxima*), green gram (*Vigna radiata*), groundnut (*Arachis hypogeae*) and a variety of fruit crops. In agricultural lands, including home gardens, the density of snails was estimated at approximately 9,825 individuals per ac (Rs. 24,268 individuals per ha). The main hiding places of the snails during daytime were identified as garbage dumps, brick piles, roofing tile piles, bases of coconut tree crown, firewood piles, etc.

The household survey results showed that the mean cost incurred for molluscicides per household per one cultivation season was Rs 5,538. Mean crop loss during a cultivation season was Rs. 23,450 per ac (Rs. 57,922 per ha). The total estimated mean loss for one cultivation season was Rs. 28,840 per ac (Rs. 7,135 per ha) over a period of six months. The NPV of average expenditure per household per season on Metaldehyde (a molluscicide) to control *A. fulica* for a 10-year time horizon was estimated at Rs 34,031 (at 10% discount rate per household). The NPV of the average cost was estimated at Rs 26,813 per ac (Rs. 66,229 per ha). The NPV of the forgone benefits due to crop losses calculated under 10% discount rate for a 10-year time period to estimate the present value of future crop losses due to *Achatina* was Rs. 695,425 per household and Rs. 1,956,599 per ha. The lost opportunities could contribute to a much higher value than the current losses.

The mid-term assessment after management interventions

During the household survey in April 2009, it was found out that the majority of households employed regular manual collection of snails, while some households had relied mainly on chemical control. The snail population density in regularly collected lands was about 3,424 individuals per ac (8,459 individuals per ha) with a few mature snails. Conversely, the snail population density in lands where regular collections were not carried out, was about 21,664 individuals per ac (53,010 individuals per ha).

About 60% of households in the sample have manually collected snails repeatedly and destroyed them using Metaldehyde/burning/burying. The remaining 40% of the households had collected the snails only once, and used Metaldehyde to control the snail population. The population density of snails before and after the interventions were compared, and a significantly lower snail density was recorded in farmlands where snails were collected regularly compared to farmlands where collection was done only once (Figure 1). On the other hand, a statistically significant positive linear relationship was observed between snail population density and

percentage of litter and garbage cover of the land (Figure 2). Furthermore, a statistically significant positive linear relationship was observed between population density of snails and percentage of weed cover (grass+herbs) (Figure 3).

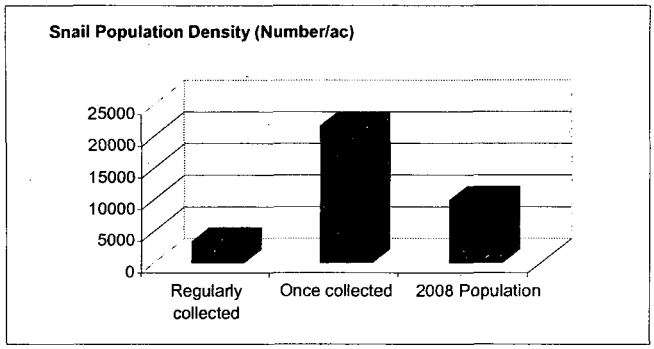


Figure 1. Snail density under different management regimes.

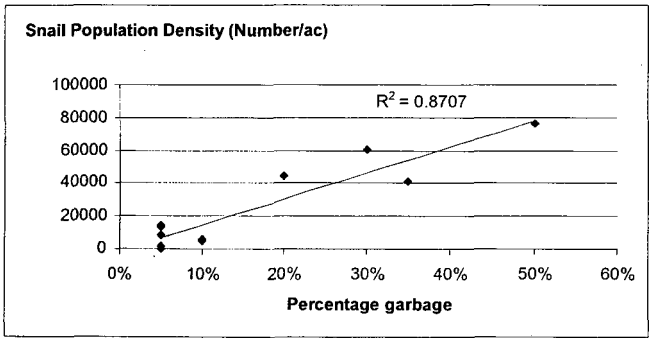


Figure 2. Positive linear relationship between litter/garbage cover and snail density.

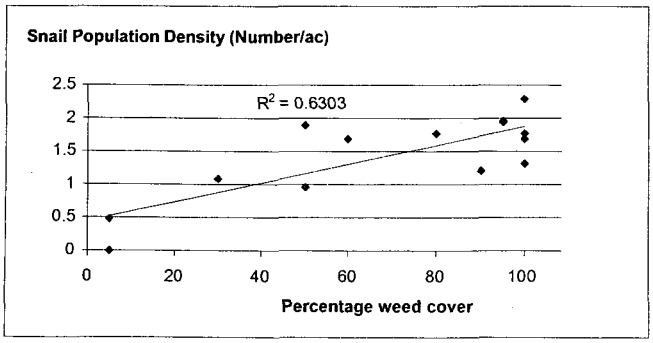


Figure 3. Positive linear relationship between weed cover and snail density.

Expenditure for molluscicide had been reduced by Rs. 1,897 per household per season. Many new crop varieties have been introduced by 40% of households. These include the some of the crops abandoned earlier as a result of snail damage. The area of cultivation has also been increased by the farmers. Before the snail management interventions about 15.6 acres (approx. 38.5 ha) were cultivated by the farmers in Kurudana, and after the interventions the area cultivated has been increased up to 25.5 ac (approx 63 ha). Considering the time spent for snail

management interventions in farmland, about 53% of the households spend 2-5 days per month, 13% spend one day per month, and 13% spend 2-3 hrs per month. The rest of the households (about 21%) do not collect snails at all.

The average income of a household per season after the management interventions was estimated at Rs. 48,978. Compared to the average income prior to the snail management interventions (Rs. 41,448), this is about an 18% increase of household income (Rs. 7,530) per season. The savings for pesticides was estimated at Rs. 4,064 per household per season, and the total minimum net benefits was estimated at Rs. 11,594 per household per season. The NPV of the minimum net gain with the project is estimated at Rs. 46,269 per household at 10% discount rate, over a 10-year time period, assuming that only one season is cultivated per year.

Discussion

Many IAS have caused considerable economic losses in agriculture and forestry systems, as well as resulting in negative impacts on ecological integrity (Pimentel *et al.,* 2001). The Giant African Snail (*Achatina fulica*) is one such species that has become a serious agricultural pest at high population densities as was observed in the Kurudana Village. The estimated cost of the losses from this species highlight that it could impose considerable economic losses to the rural agricultural communities (Lelwala *et al.,* 2008). The estimated cost reported, consisted of only a part of the direct cost. Excluding direct costs such as labor cost before the interventions, and indirect costs such as health and environmental costs, the total cost due to snails would be much higher than the current estimates. The total benefits calculated for the particular season was not fully taken into account for the analysis, as many crops cultivated during the season were still to be harvested. Therefore, the expected benefits from those crops were not included in the analysis. Hence, the actual benefits could be much higher than estimated in this paper. The minimum estimated benefits from the management of snail population show the economic significance on the livelihood of the farmers in Kurudana village. It was also evident that the positive results of snail management interventions have led to the cultivation of abandoned fallow lands in the village.

The results of the household survey and the snail population density assessments indicate that the mechanical control measures are most cost effective compared to chemical control in terms of both economic and environmental point of view (Lelwala *et al.,* 2008). Despite the benefits gained by the mechanical control measures, some farmers (53% of the sampled households) still rely on molluscicide to control the snail population. Further, a considerably high snail density was documented in the banana cultivated areas, where debris such as cut stumps and leaves create daytime hideouts for snails. Weed cover, too, provide daytime hideouts for snails. Litter and weed maintain moist microhabitats that prevent snails from dehydrating during the hot day-time, thus protecting them from predators and providing good breeding grounds. Maintaining the farmland free of litter and weed and regular collection of snails is equally important to reduce and prevent further proliferation of current snail populations.

This type of community based interventions to control the spread of IAS such as *A. fulica* which impose negative effects on rural livelihoods takes considerable time and effort to achieve the desired target. As commonly experienced by community workers, maintaining the momentum of community based initiatives for a long term is a challenging task. Therefore, continuous monitoring and regular community interactions and awareness on the benefits of the initiative is

mandatory. Pressurizing the farmers through regular follow-up as well as supporting the farmers could also help to maintain the momentum. Awareness among government line agencies on the magnitude of threat and economic losses caused by snail population is also vital for the success of the initiative as they can contribute actively to prevent further spread IAS, detection of the problem at early stages and take necessary measures to address the issue at very early stages, to prevent and minimize potential economic losses. Local government and institutional support could play a major role in the success of community based initiatives. This is an ongoing project and more interventions will be carried out in the future.

Conclusions

The populations of *A. fulica* can be controlled effectively by regular collections in affected areas, through the active participation of local communities. Proper sanitation in farmlands is a vital practice in controlling *A. fulica* populations and preventing its further proliferation. Management of *A. fulica* populations contributes to increasing household income significantly, while reducing associated costs. Effective management of *A. fulica* population depends on control measures carried out on a regular basis and should be integrated to the daily routine of the farmers. The line agency support for enforcement and regular follow up is vital to maintain the farmers' commitment and motivation, which are key to the success of community based initiatives.

Acknowledgements

This case study was carried out under the project on "Promoting Sustainable Livelihoods and Addressing Underlying Causes of Poverty" in Hambantota district, Sri Lanka funded by OAK. The authors acknowledge the support and cooperation provided by Dr. Susil Liyanaarachchi (Director/Programmes, CARE International), Mr. Ali Raza Rizvi (Regional Group Head, ELG2-Asia), Mr. Ilangerathna, and M. Dissanayaka (Project Director/CARE International, Hambanthota). The technical input provided by Dr. Devaka Weerakoon (Consultant - Regional Species and Biodiversity Programme of ELG2-Asia) is very much appreciated. The villagers of Kurudana village are also acknowledged for their active support to implement this case study, and for providing us with relevant information for the assessment.

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APPENDIX 1

MANAGEMENT STRATEGY FOR *Achatina fulica* IN KURUDANA VILLAGE

SCOPE: This strategy and action plan is aimed at managing the populations of *A. fulica* in the Kurudana area, and preventing its further spread into other areas of the Hambantota district, as a serious agricultural pest.

Proposed activities

Activities proposed in the frame work are broadly categorized into three main topics, namely prevention of spread, early detection and warning and control of the population.

PREVENTION OF SPREAD: The prevention of entry is always the best option for invasive alien species, due to time and financial implications related to subsequent management. Therefore, the following measures could be taken to avoid the further spread of this species into other areas of the Hambantota district:

1. Raise awareness among general public and responsible authorities (ie. Agricultural Research and Development Officers / Production Assistants, Samurdhi Officers, Grama Niladharis, Public Health Inspectors and Midwives etc.),
    - Produce an awareness leaflet for distribution
    - Conduct a mobile campaign in villages
    - School awareness programmes
2. Identification of potential pathways of entry and spread, and manage the risks associated with each pathway
    - Transport of garden produce, waste, organic fertilizer (cow dung etc.), coconut leaves etc.
3. Regular monitoring in agricultural landscapes
    - Mobilize farmer organizations for vigilance (through Samurdhi, Grama Niladhari, Agricultural officers and CARE staff members)
    - Vigilance through school children
4. Conduct a rapid assessment of the occurrence of *A. fulica* in the Hambantota district
    - Prepare a map of the current distribution of Achatina in the district, and use it for awareness programmes on IAS (through CARE field staff members)

EARLY DETECTION AND WARNING: No matter how efficient is the preventive measures; there is always a risk of entry. When a particular IAS enters into a new habitat it takes some time to establish before causing harm to livelihoods and biodiversity. This is the best point in time to start eradication of IAS. Early detection involves the following activities:

1. When garden products (such as organic fertilizer, coconut leaves) and clay bricks etc, are brought to a house-hold from another area, check the material carefully for the presence of *A. fulica* and its growth stages.
    - If specimens are detected, immediately destroy them
    - Inform surrounding households in the village
2. Train relevant local government officers (Agriculture, Samurdhi and Environmental officers etc.) to identify and assess the risks of *Achatina*
3. Each household should conduct regular surveys of their lands to see whether *Achatina* is present,
    - In the event of detection, immediately inform others through the village farmer organizations and CBO's

CONTROL METHODS CARRIED IN KURUDANA VILLAGE

Mechanical control

1. Initiate a village household level campaign to collect specimens of *Achatina* in home gardens, fallow land etc., and destroy them in a designated pit by burning;, adding a concentrated salt solution; adding a molluscicide
    - Have a designated pit/concrete barrel in a corner of the home garden to dispose *Achatina* specimens
    - Repeat this on a daily basis in home gardens during the evening hours (when the adults come out from hiding places)
2. Regular village campaigns to manually collect specimens and dispose them into designated pits.
3. Specimens encountered each day in an opportunistic manner should be immediately destroyed
4. Create barricade in eradicated plots (*i.e.* shallow ditches filled with salt etc.)
5. Placement of baits in home gardens to attract mollusks and dispose them
    - Place rotting fruits, vegetables and food residues in designated area
6. Create pitfall traps in the ground to trap specimens (*i.e.* plastic containers buried in soil and filled with a solution of salt/Metaldehyde)
    - Check pitfall traps on a daily basis and dispose collected specimens into the designated pit
7. Manipulate identified breeding grounds/hideouts such as clay brick piles and fuel wood piles and create hostile conditions to keep off the pest (*i.e.* spread salt, re-arrange piles)

Chemical control

Intensive chemical control should only be carried out during the initial period of management. Once the spread is under control, chemical control using pesticides should be considerably reduced.

1. Spread non persistent molluscicides/baits in regular intervals (e.g. Metaldehyde, Metheocarb baits), especially during the most active season of mollusks (eg. during rains)
2. Apply molluscicides dusts/sprays to base of fruit trees such as papaya
3. Apply molluscicides on built barriers such as ditches
4. Try to use plant extracts such as Neem on a trial basis, to see whether they are active against *Achatina*

Cultural control

1. Cultivate crops that are non palatable (resistant) to *Achatina* (*i.e.* Bittergaurd)
2. Practice rotation of crops in a seasonal manner
3. Adapt good tillage practices in home gardens and agricultural land
4. Clean the piles of rubble, debris, and clay bricks in home gardens.
5. Establishment of barriers
    - Create a shallow ditch around the home garden, and fill it with concentrated salt and/or sludge obtained from the Salt pans in Bundala and Hambantota
    - Create a shallow ditch around potential hide-outs of *Achatina* (*i.e.* garbage pits, clay brick piles etc.) and fill them with salt and/or sprinkle Metaldehyde powder
5. Fallow lands should be cleared, and subjected to controlled burning
6. Disposal of garbage should only be made in a designated place where the pest cannot use garbage as hideout or breeding ground
    - Burn the material in pit on a regular basis
7. Change behaviours of the community that support the Gastropod
    - Maintenance of clean home gardens

Biological control

1. Support the occurrence of natural predator populations such as Monitor lizard, Greater Coucal and Mongoose in home gardens

- Do not allow dogs to attack and chase such animals
- Collect specimens that have died as a result of chemical applications, and bury them in a designated pit (to avoid being consumed by natural predators)

INDICATORS FOR MONITORING

Indicator	Status
Snail population density in home gardens and agricultural lands	Increased considerably; no change; slightly decreased; considerably decreased
Damage to agricultural crops	What are the crops damaged?; Level of damage (Increased considerably; no change; slightly decreased; considerably decreased); Loss of production (kg/ number of fruits etc.)
Status of chemical pesticide used to manage Achatina	Frequency of applications: Number of times applied per week/month Types of pesticides used: Quantity of pesticides applied per week/month: Costs of pesticide use per month:
Status of control methods applied	Specific control methods used by each household and frequency; Time spent for applying control methods per household per month; number of village campaigns held for control
Spread of Achatina into other villages	Information on spread (specific village, status of spread and damage, etc.)
Replication of best practices in other villages/farms	Number of neighboring farmers who visited Kurudana to observe management actions, and adopted the management methods; Visitation by relevant government officials for observing management work in Kurudana; Awareness raising programmes held
Status of the management actions being practiced by households	Types of control methods used per household/farm; Status of control methods being practiced by selected households (Highly satisfied; satisfied; needs improvement; not satisfied);
Efficiency of control methods applied	The status of results related to different control methods (highly successful; ,moderately successful; not successful)
Crop diversification related to control of *Achatina* populations and its spread	New crops cultivated and/or re-introduced; Area of crops increased; Increase of income due to crop diversification

Research paper

Chapter 19

Research on Invasive Alien Plants in Sri Lanka: An Analysis of Past Work

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Abstract: Sri Lanka has a short history on invasive alien plants (IAP) as much of the work on invasive alien species (IAS) was initiated after organization of the first national symposium in 1999. During the past ten years, IAP in Sri Lanka received considerable attention by scientists and as a result several research publications were released. An analysis was done using 124 publications on IAP in Sri Lanka resulted over the past ten years in order to identify the aspects/subject areas that have been given priority in past research, species that have been addressed in detail, specific locations in which studies on IAP have been conducted and the degree of involvement of the government and non government sectors in IAP research. The total number of publications per year was also observed. Majority, (73%) of the publications on IAP of the last decade was based on field and laboratory studies and 27% were reviews. Impacts, control and management of IAP were well addressed, but not many publications were focused on economical impacts. Aspects such as genetics/germplasm studies, reproductive biology, germination, establishment and propagation methods, distribution and spread, potential uses, allelopathic compounds, legal issues and studies on public awareness were paid little attention while physiology and competitive ability of IAP and detection of new or potential IAP and their locations were fairly investigated. Only 22 IAP have been subjected to autecological studies. Plant species such as *Lantana camara, Mimosa pigra, Parthenium hysterophorus, Prosopis juliflora, Cuscuta chinensis* were popular examples. Eighty three per cent of the publications were focused on terrestrial species although aquatic species were considered as the most problematic group of IAP. Locations such as Udawattekele forest reserve and Hantana range were popular study sites among the 14 areas in which IAP work was based on. Authors of many of the publications were affiliated to government institutions and the involvement of the university community on IAP research was 60%. Frequency of publications on IAP were high in years 1999, 2000 and 2008 indicating that organization of national symposia has provided a better opportunity in disseminating findings of IAP work in Sri Lanka. However, it is evident that very limited aspects of IAP have been explored during the past few years and many windows of opportunities exist for IAP work in the future.

Jayarathne, B. and Ranwala, S. (2010): Research on invasive alien plants in Sri Lanka: An analysis of past work. In: Invasive Alien Species – Strengthening Capacity to Control Introduction and Spread in Sri Lanka (Eds: Marambe, B., Silva, P., Wijesundara, S. and Atapattu, N.), pp 179-184. Biodiversity Secretariat of the Ministry of Environment, Sri Lanka.

Introduction

In 1992, more than 191 nations of the world including Sri Lanka expressed their commitment to prevent introduction, spread and establishment of Invasive Alien species (IAS) and to adopt all possible effective measures for their control when the Convention on Biological Diversity (CBD) addressed IAS directly through its article 8(h). Further, IAS related issues were indirectly addressed through CBD articles 7 (Identification and monitoring), article 12 (research and training), article 13 (public education and awareness) and article 14 (impact assessment and minimizing adverse impacts), article 17 (exchange of information), article 18 (technical and scientific cooperation) and article 20 (financial resources) providing more opportunities and provisions to combat IAS at global, regional and national scales (CBD, 1994).

Becoming a signatory to CBD on 5th June 1992 and following ratification on 23rd March 1994, the Sri Lankan focal point to the CBD, the (then) Ministry of Transport, Environment and Women's affairs together with the World Conservation Union (IUCN) placed IAS as an important issue in the Biodiversity Conservation Action Plan (BCAP) of Sri Lanka. Subsequently, when environment portfolio became part of the Ministry of Forestry and Environment, management of IAS in Sri Lanka was given priority in the National Framework for Biodiversity Conservation Action Plan prepared in 1998 (MoFE,1998).

In October 1999, the first National Symposium on IAS in Sri Lanka was organized with the objectives of collecting available information, assessing awareness status, nature and magnitude of ecological and economic impacts and identifying possible solutions for IAS control in Sri Lanka (Marambe, 1999). This event opened up pathways and opportunities for IAP research in Sri Lanka and focused the attention of many responsible and concerned governmental and non governmental agencies, commercial sector, scientific research organizations and the general public on identification of IAS of national and regional significance, their abundance and impacts on ecosystems, species or habitats. The second National Symposium on IAS was held in September 2000 focusing much attention on impacts of IAS on ecosystems and suggestions on effective management of IAS in Sri Lanka (Marambe, 2000). Financial assistance from national and international agencies facilitated research on various aspects of IAP among relevant authorities and as a result, over the past ten years, several publications on IAS in Sri Lanka were released in the form of reports, dissertations, journal papers and abstracts, articles in newspapers and magazines which were made available to general public at libraries of many government and non government agencies.

This paper emphasises work done on Invasive alien plants (IAP) in Sri Lanka during the past years and attempts to identify the aspects/subject areas that have been given priority in past work, IAP species that have been studied in detail, specific locations in which research studies on IAP have been conducted and the degree of involvement of the government and non government sectors in IAP research related work so as to recognize existing 'data gaps' with regard to invasive alien plants in Sri Lanka.

Methodology

Information available on IAP in Sri Lanka published in the form of full papers, abstracts and feature articles in journals, magazines, reports and newspapers were obtained from electronic search engines in scientific literature including the Science Citation Index and going through

library catalogs of various government and non government institutes and agencies. Details such as the title, authors and their affiliations, summary of the work and the year of publication were recorded for each document. The published information was categorized according to types of publication (e.g. full paper, abstract, feature article or a report), types of studies (whether the work has been focused on a specific plant species or particular plant group, whether laboratory and/or field experimentation was involved) and priority aspects/subject areas of studies in past work. The subject areas were chosen as; reproduction and seedling establishment, ecological and economical impacts, propagation, chemistry/allelochemicals, assessment of distribution using geographic information systems or any other mapping or survey techniques, reporting of occurrence, physiological aspects, usage, control and management, identification of potential/ new IAP, biology/invasive behavior, competitive ability/ ecology, history and introduction pathways, determination of invasiveness, genetics related studies, legislation on IAP, risk assessments, status of public awareness, impacts of tsunami on IAP etc. The year of publication was also taken into account. The number of publications for each of the categories mentioned above was identified. The study also included identification of IAP that were addressed or studied in detail in the past years, locations in Sri Lanka in which work on IAP were focused and the degree of involvement of the government and non government sectors in publishing findings of IAP research.

Results and Discussion

A total number of 124 publications on IAP in Sri Lanka were collected during the study. Nearly half of the publications were published as full papers (48.5%) whereas 35% of the publications were in the form of abstracts. Out of the total, 11.5% included reports while feature articles in newspapers and magazines were 5%.

As far as the types of studies were concerned 52% of the publications have addressed IAP issues generally whereas 48% of the publications were focused on specific plant(s). Out of the latter group, 73% were findings of field and/or laboratory work and the remainder (27%) consisted reviews on a particular species. Among the publications based on field/laboratory work 71.4% included studies on invasive alien terrestrial plants and only 14.3% were focused on invasive alien aquatic plants. A similar number (14.3%) of publications had addressed both groups.

Among the sixteen subject areas recognized in past IAP research-related work, impacts, control and management of IAP were the most popular aspects studied. The next popular subject areas in past research on IAP were reporting of occurrences, physiological/ biological/ ecological aspects which accounted for 5-10 publications from each subject area. Assessment of spread/distribution using geographic information systems or any other mapping/ survey techniques, uses of IAP, identification of potential/ new IAP, legislation related issues had 2-5 publications each in the past ten years whereas subjects such as reproduction and seedling establishment, genetics related studies, history and introduction pathways, determination of invasiveness, status of public awareness, impacts of tsunami on IAP had only one publication each indicating that these fields were poorly explored by the researchers (Figure 1). Focus on use of molecular tools, socio- economic and policy research including studies on livelihood support mechanisms have to be addressed in the future in order to strengthen the 'science of IAP' in Sri Lanka. Development of participatory projects and collaborative network among institutes would encourage interdisciplinary investigations.

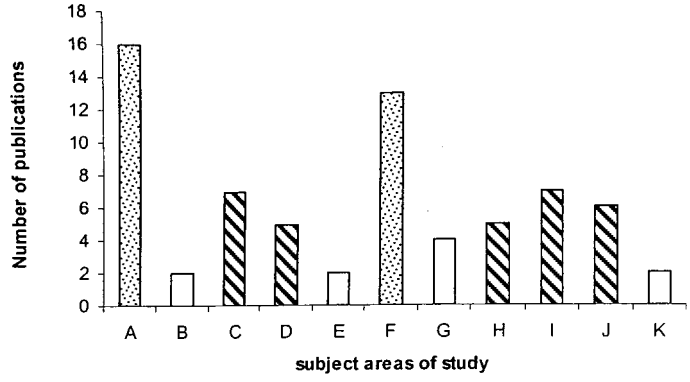


Figure 1. Priority aspects/subject areas of studies in IAP work during 1999-2008.
A-ecological and economical Impacts, **B**- assessment of distribution using geographic information systems or any other mapping/survey techniques, **C**-reporting of occurrence, **D**-physiological aspects, **E**-usage, **F**-control and management, **G**-identification of potential/new IAP, **H**- biology/invasive behavior, **I**-competitive ability/ecology, **J**- determination of invasiveness, **K**-legislation on IAP.

The results of the present study also revealed that the average rate of publications on IAP in Sri Lanka during 1999-2008 was 12 publications per year. Further, the total number of publications per year during the past ten years neither became consistent nor gradually increased. This could be partly related to the limited availability of financial resources for continuation of scientific research in Sri Lanka during the last decade. However, it was evident that number of publications per year was exceptionally increased in the years in which symposia on IAS were organized in Sri Lanka (Figure 2). Thus, it was evident that the three National symposia on IAS served as a roof for scientists, administrators, policy makers to disseminate and exchange knowledge, coordinate and corporate towards addressing issues related to IAP in Sri Lanka.

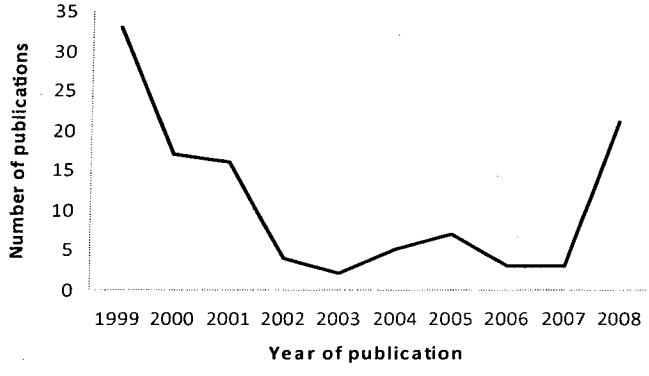


Figure 2. Number of publications on IAP during 1999-2008

The present study also identified that publications on IAP were limited to only 22 plant species (Table 1). The noxious weed *Lantana camara* was frequently subjected to investigations while *Parthenuim hysterophorus* was also a priority plant species for studies between the years 2000-

2005. Plant species such as *Cuscuta chinensis, Prosopis juliflora, Mimosa pigra* were paid adequate attention while other species received very limited attention.

Table 1. Invasive alien Plants species in Sri Lanka in which detail studies have been Conducted and published during 1999-2008.

Scientific name	Common name [Sinhala (S)/ English (E)]	Plant family
Cestrum aurantiacum	Cestrum (E)	Solanaceae
*Clidemia hirta**	Hairy clidemia, Koster's curse (E) Kata kalu bowitiya (S)	Melastomataceae
Clusia rosea	Pitch apple (E), Gal goraka (S)	Clusiaceae
Cuscta chinensis	Cuscuta, Dodder (E) Aga ula nethi wel (S)	Convolvulaceae
Cylindrospermopsis raciborskii	Cylindo (E)	Nostocaceae (Cyanobacteria)
*Eichhornia crassipes**	Water hyacinth (E) Japan jabara (S)	Pontederiaceae
*Lantana camara**	Prickly lantana (E) Gandapanna, Baloliya (S)	Verbenaceae
Mayaca fluviatilis	Mayaca (E)	Mayacaceae
*Miconia calvescens**	Velvet tree (E	Melastomataceae
*Mimosa pigra**	Yodha nidikumba (S)	Fabaceae
Myroxylon balsamum	Balsamum tree (E), Kattakumanjal (S)	Fabaceae
Ochlandra stridula	Bata (S)	
*Opuntia stricta**.	Cactus , prickly pear (E) Katu pathok (S)	Cactaceae
Panicum maximum	Guinea grass (E) Gini thana (S)	Poaceae
Panicum repens	Torpedo grass (E)	Poaceae
Parthenium hysterophorus	Congress weed, White top weed (E), Parthenium	Asteraceae
Prosopis juliflora	Mesquite (E) Kalapu andara (S)	Fabaceae
Pteridium aquilinum	Bracken (E) Werella (S)	Dennstaedtiaceae
Salvinia molesta	Salvinia(E), Diya pansi (S)	Salviniaceae
Tithonia diversifolia	Wild sunflower (E)	Asteraceae
Sphagneticola trilobata	Arunadevi, Kelanitissa (S)	Asteraceae

* Indicates species listed in the world's 100 worst IAS (IUCN, 2001).

Most of the research on IAP was published by authors affiliated to government organizations and 60% of this work was conducted at Universities. This may highlight the participation and involvements of academia in the field of IAS as well as the importance of conducting and publishing research by non governmental organizations and community based organizations involved in IAP related work. However, a mechanism is also needed to make available the results of research to general public in order to keep the lines of communication open to both directions. This is very important with regard to IAS as human being is responsible for 'spreading' as well as for the 'control' of biological invasions.

Conclusions

Limited aspects on IAP in Sri Lanka have been explored during last decade thus indicating that many windows of opportunities exist for future work in relation to IAP. Increased finances for research, participatory projects, public-private partnerships, better collaboration among institutes would no doubt encourage more research on IAP in Sri Lanka in future while development of a system to disseminate findings of research will be useful to bridge the gap between research and awareness.

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Research paper

Chapter 20

Commercial use of Invasive Alien Species as a Consummative to Control Their Distribution

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Abstract: Use of invasive alien species (IAS) as a means of their control has started receiving the attention of the scientists and practitioners, mainly due to the heavy costs involved in the conventional methods of their removal from ecosystems. An attempt was made to use *Clidemia hirta*, one of the invasive alien plants reported in Sri Lanka, to manufacture paper as means of reducing their population densities, as well as an economic activity for the communities. The paper produced using stems and leaves of *C. hirta* were highly suitable for producing visiting cards, letterheads and other stationeries. The process did not use heat treatments and bleaching techniques, and also promotes recycling of used-papers.

Introduction

Invasive alien species (IAS) is one of the major threats to native biota. Among many factors contributing to the spread of IAS, the 'negligence by human beings' is the key causal factors supporting the alien invasions. Lack of scientific knowledge in identifying IAS, and religious and cultural beliefs have supported the spread of IAS in different ecosystems of the country. People are reluctant to destroy a species that no longer in use (e.g. tank cleaner – *Pterygoplichthys multiradiatus*), but would prefer to dump the species in an environment suitable for its survival. This would lead to the collapse of the ecosystem as a result of invasion of several such introduced alien species. As costly management strategies proposed by the scientists have kept local communities away from action that save the environment, there is a need for low-cost and effective alternatives that community could embark on in overcoming the problems of IAS. The

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intention of this paper is to suggest actions to enable the participation of local communities in controlling of IAS.

The IAS control strategy used in this study was to manufacture stationary such as paper, file covers, letterheads, visiting cards, wrapping papers as well as photo frames and vases out of material obtained from *Clidemia hirta*, a known IAS in Sri Lanka (Marambe *et al.*, 2003). *Clidemia hirta* is found widely distributed by roadsides of Sinharaja Forest area where the natural canopy cover is absent. The plant also shows a patchy distribution on riverbanks and in places where landslides have occurred-removing normal forest undergrowth.

Materials and Methods

The young stems and leaves of *C. hirta* (only upper 70-80%) parts were taken for the pulp production, avoiding the hardest parts of stem and the roots. The young stem parts were cut in pieces of around 3-4 cm in length for easy blending, while keeping sufficient fiber content intact. These young stem parts of *C. hirta* were mixed with water (45-60% w/v) in a blender (2-3 min in all 3 speeds at 18,000 rpm).

Four kg of shredded, 80 gsm photocopy papers (used papers) was mixed in 8 liters of water by using a Hollander Beater for 5 min. Then the 250 g of young *Clidemia* parts was blended separately in a domestic blender for 5 min with 250 ml of water. This action was repeated until the total *Clidemia* used was 4 kg. Thereafter, the separately made two pulps were mixed in a Hollander Beater for about 4 min.

The final pulp was used for making handmade paper using a mold (frame size: 30 cm width x 45 cm length; mesh size 500 µm) and a decal (frame size: 30 cm width x 45 cm length x 45 cm height) (Figure 1), pieces of raw fabric (33.5 cm width x 51.8 cm length), a 400 ml glass beaker, and sponge.

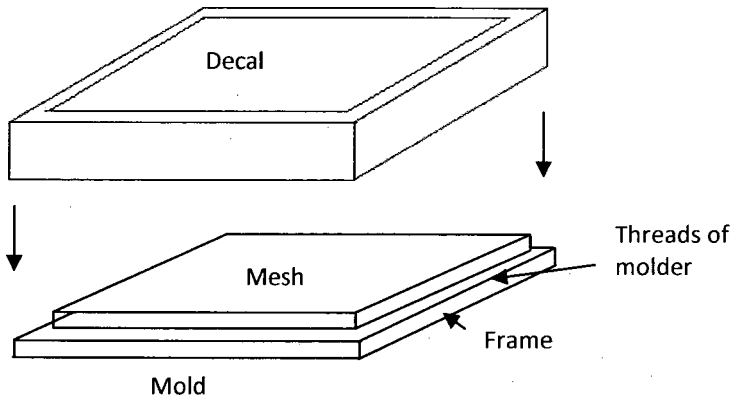


Figure 1. Mold and decal.

Then the prepared paper was kept under room temperature (31-32 °C) for about 24 hrs. Finally, the paper was removed from the raw fabric, ironed using domestic iron with the maximum output of 750W. The process was repeated several times by changing the mixed pulp content, starting at 100 ml to 900 ml. The thickness of the paper was measured by digital venire caliper at

the Materials Technology Section (MTS) of the Industrial Technology Institute (ITI), Sri Lanka. The paper thickness (GSM - Grams per Square Meter) was measured by weighing 10 cm x 10 cm piece of each paper using an analytical balance at the MTS of ITI and expressed after multiplying the value by 100. The strength of the paper was checked by inserting force by hands. Manufactured papers were finally tested for printing in a laser printer (HP Laser Jet 1020).

Results and Discussion

The pulp volume used and the resultant paper thickness is shown in Table 1. Both the thickness of paper and the GSM values increased with increasing pulp volumes. The strength differs from one sample to another according to the increasing of its pulp volume/GSM to the tension.

Table 1. The paper pulp used and the thickness of resulting paper.

Pulp volume (ml)	Pulp volume category	Paper thickness (mm)	Grams per Square Meter (GSM)
200	1	0.04 (±0.003)*	160
300	2	0.06 (±0.003)	238
400	3	0.08 (±0.003)	302
500	4	0.11 (±0.003)	380
600	5	0.13 (±0.003)	453
700	6	0.14 (±0.003)	532
800	7	0.15 (±0.003)	612
900	8	0.16 (±0.003)	701

*Values within parenthesis indicate standard error

Thin papers were used to print visiting cards successfully by selecting print settings-as rough paper (Figure 2). The thick papers couldn't be used for printing, but used on photo frames as they had sufficient strength to hold a considerable amount of weight.



Figure 2. Paper made out of *Clidemia hirta*.

Handmade paper using the mixture of normal paper pulp and *Clidemia hirta* pulp is an excellent product to produce visiting cards, letterheads and other stationeries. This pulp was made without heat treatment and bleaching agents, and also promotes the usage of 'used' papers. The pulp from used-paper was taken as a complex to provide supplementary strength to the

Clidemia pulp. Hence, the pulp mixture could be used for other purposes such as producing packaging material. The natural qualities such as colour and fiber appearance were durable for more than 2 years, if the products do contact with water. After use, they are totally bio-degradable.

The hard paper produced from *Clidemia hirta* were also used as materials for wall hangers. All these products were made using IAS as the main source, and they always came with an eco-friendly logo (tag) that has the idea behind the production. The unpublished consumer surveys have shown a higher interest for making such products on their own. Consumer use of products made out of the species tested would not only be a management strategy for IAS but also encourage self employment.

The researchers have continuously claimed the difficulty in controlling IAS using conventional methods, and many invasive plant species have shown a wider distribution over the years (Ranwala, 2008). What would it be in another five years to come? and would the solutions proposed or implemented to-date would be sufficient? The alternative strategies as proposed in this paper would be an effective starting point that would lead to an end to the spread of IAS.

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P. polystachion (http://www.anbg.gov.au/weeds/weeds.html)
M. pigra (http://www.redzlan.blogspot.com/2009/10/catclaw-mimosa.html)
C. hirta (http://pt. wikipedia.org/wiki/Ficheiro:Starr_030729-0107_Clidemia_hirta.jpg)
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M. musculus (http://www.mus-musculus.com/)
O. mossambicus (http://www.baixaki.com.br/papel-de-parede/12147-tilapia.htm)
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P. multiradiatus (http://forum.lowyat.net/topic/1249677)



M. pigra *C. hirta* *L. camara* *P. maximum* *D. suffruticosa*



S. molesta *O. dillenii* *P. polystachion* *E. crassipes* *P. juliflora*



C. ornata *C. batrachus* *M. musculus* *O. mossambicus* *P. diffusa*



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