Introduction

Poverty, the welfare of the poor and related issues such as natural resource management, particularly in the poorest countries of the world, are now centre-stage concerns of the global community of nations. Even though poverty rates have been falling over recent decades, approximately 896 million people still lived on less than US$1.90 a day in 2012, with concomitant severe problems of undernourishment, high child mortality and lack of opportunities for education (World Bank, 2016). A series of ‘Earth Summits’ and assessments of progress, which started in the early 1990s, have enabled nations to gradually redefine and clarify the key issues driving poverty and environmental degradation, and the links between the two. Furthermore, the global community has drawn up a set of 17 ‘Sustainable Development Goals’ (https://sustainabledevelopment.un.org), which have provided some focus for the discussions on actions and the orientation of aid budgets for development for the foreseeable future. These points are particularly relevant for tropical Asia, where many of the countries are still developing.

There is of course a multitude of issues that the world’s poorest nations are trying to grapple with. In attempts to improve the livelihoods of the poor, most governments have identified, and are trying to address, key problems related to trade, access to land and credit, education, health and gender issues. However, the highest proportion of poor people in developing countries still lives in rural areas. Issues driving poverty in what are essentially agricultural communities are therefore of major concern. Consequently, there is an additional struggle for governments to bed solutions within the development of infrastructure in rural areas that are compatible with sustainable natural resource management and the conservation of biodiversity.

Thus, rural livelihoods and their sustainability require a multidimensional analysis. In order to understand more clearly ways in which interventions can be made to improve livelihoods, previous analyses (e.g. see Carney, 1998) have placed emphasis on the concept of ‘capital assets’ (natural, social, human, etc.) upon which individuals draw to build their livelihoods and what combinations of these lead (depending on the social group) to sustainability. Two main elements have been identified as facilitating change (both positive and negative): one is the structures and processes that define people’s livelihood options (e.g. government policies); the other is referred to as the ‘vulnerability context’ in which the assets exist.
– the trends, shocks and local cultural practices that affect livelihoods.

Such approaches to the livelihoods issue have allowed a clearer understanding of the parameters that affect the spectrum of assets on which particular social groups depend. There has been much discussion and debate on the 'macro-factors' effecting change (e.g. trade policies), but the topic of this chapter is the controversial issue of invasive alien species as a factor that is reported to undermine development and thereby make rural livelihoods more vulnerable to the poverty trap (e.g. see McWilliam, 2000; Rai and Scarborough, 2015).

Invasive alien pathogens, plants and arthropods have been a threat to agriculture since early colonial times; these species were introduced, either deliberately or accidentally, when the ranges of economically important crops and livestock were expanded into new lands to support the migration of human populations, and this tide of invasive alien species that affect agriculture continues (Bebber et al., 2014). Moreover, on a global basis, invasive alien species have come increasingly into the public domain over the last 40 years: (i) because of the increase in both the diversity of taxa that include invasive species and the number of species within these taxa reported as having become invasive; and (ii) as a consequence of the recognition and ensuing concern that economic sectors other than agriculture are now affected (Mooney et al., 2005).

There are published studies – albeit broad scale – that attempt to illustrate the enormity of the quantitative negative impact of invasive alien species in a few selected countries (e.g. Pimentel et al., 2002) but these studies are focused mostly on the developed world. There have also been a number of international responses to the issue of invasive species and requests for action from countries; an example is the Strategic Plan for Biodiversity, 2011–2020 under the Convention on Biological Diversity (CBD) (www.cbd.int/sp). None the less, there remains a wide spectrum of views on how much of a threat, if any, invasive alien species are to national economies, livelihoods and the environment; there is also a lack of clarity on what national and regional actions are needed. In addition, few countries have invasive alien species as a priority policy issue. Sustainable and cost-effective methods of managing many invasive alien species both exist in principle – for example, biological control through the introduction of host-specific natural enemies – and are available in practice, so technology per se is not a major limiting factor at this point in time.

As invasive alien species have now been reported to affect most developing countries, it is important to take stock of the current situation so as to be able to understand both the likely scale of the threats that they may pose to poor people who rely on agriculture and the environment, and the actions needed to address the threats should they prove real. This chapter examines the reality of the threat of invasive species, with a focus on invasive alien plants in the developing countries of tropical Asia to form a ‘case study’ of what type of information is available on invasive alien plants, the magnitude of the threats involved and whether or not these plants have any benefits. The extent to which country and other stakeholder responses and actions to the reported threats match this reality is then reviewed. This is followed by a discussion of what factors have led to the paucity of action that has been found and whether this is leading to a crisis of the impacts of invasive plants and other invasive alien species.

Tropical Asia is roughly defined for purposes of this chapter as the region stretching from Afghanistan eastward to Vietnam, and from Nepal southward to Indonesia. The focus is on invasive alien plants as these form a disproportionately large number of the world’s worst invasive alien species in terms of numbers and reported impact: Of the 100 of the world’s ‘most invasive alien species’ listed by the Invasive Species Specialist Group (ISSG) under the Species Survival Commission (SSC) of the World Conservation Union (IUCN), 36 species are plants (ISSG, 2000) and many of these are reported as a common problem in tropical Asia (e.g. Saxena, 1991; Waterhouse, 1994).
The Reality of Invasive Alien Plants: What Do We Know?

This section provides a review of the published literature on invasive alien plants in tropical Asia to help understand the real scale of the problem and also identify any situations where invasive plants provide benefits. However, let us first look at the history of the issue as this helps to set the context of the problem.

Where does the issue of invasive alien plants stem from and what size is the problem?

As in other parts of the world, alien floras in tropical Asia have developed as a result of trade and colonialism. Although herbaceous and woody plants have been introduced for centuries into new areas around the globe for economic, aesthetic and other purposes, the major movements of species began in the European mid-colonial times from the 1700s onward. It was then that plants began to be translocated in vast numbers to colonial regions, largely by European concerns such as the East India Companies, for agricultural and ornamental purposes (Heywood, 1989). Botanic gardens established in these regions played a central part in this by acting as ‘ports’ where new species could be propagated for wider distribution (Heywood, 1989; Hulme, 2011). The number of plants moved during this period was astronomical and resulted in many species becoming first naturalized and then notorious invaders (Cronk and Fuller, 1995).

Trade (e.g. by private seed companies) and other factors such as tourism and transport have developed since those times, particularly from the last part of the 20th century, and many authors identify this rise in human activities as a main driver of new species invasions (Burgiel et al., 2006). Thus, intentional introductions of plant species continue, resulting in the wider dispersal of existing invasive species as well as introductions of other species that are now becoming invasive. It has also long been recognized that accidental plant introductions have been taking place as well (Myers and Bazely, 2003). Once again, the evidence in the published literature as a whole suggests that these are largely because of the current growing volume of trade (Jenkins, 1999; Levine and D'Antonio, 2003); evidence on other invasive species taxa suggests that accidental introductions of those are likewise on the increase (Elmer, 2001). Common pathways of accidental introduction include imports of agricultural products such as crop grains. Nevertheless, up to the early 2000s, intentional introductions were still the most common set of pathways for the spread of invasive alien plant species (Kowarik, 2003; Mack, 2003).

Information on the proportion of alien plant species in national floras is very patchy as national audits are, unfortunately, lacking in many developing countries. Further, where data are available, figures are very variable, but sometimes high (Myers and Bazely, 2003). Knowledge about the proportion of invasive plant species is equally sketchy, although Waterhouse (1993) estimated that 44% of significant weeds in South-east Asia are non-native. Where national data have been reported, they often lack the definition needed to characterize alien plant species at different stages of naturalization and invasion as suggested by Pyšek et al. (2004). However, Khuoro et al. (2012) did adopt a systematic approach in assessing the alien and invasive flora for the whole of India for the period 1890–2010. They found that 1599 species are alien and that this constitutes 8.5% of the Indian vascular flora (lower figures than previously reported). Only a small proportion of this alien flora is classed as invasive but, of these species, many are now widespread in the country.

Much research has been aimed at elucidating the species characteristics that lead to invasiveness. Evidence suggests that biological factors are partially responsible, including propagule pressure, both natural and human-mediated (Dehnen-Schmutz et al., 2007), and polyploidy (e.g. through hybridization processes), as plants with this genetic make-up appear to be able to survive
in a wider range of ecological conditions than the original diploid plants. In Singapore, for example, where many invasive plant species now occur over wide areas, polyploidy has been recorded in all of the major alien plant taxa studied (Pandit et al., 2006). None the less, extraneous factors, largely anthropomorphically driven, are now exacerbating plant invasions. Dominant among these are land-use change, changes in land-management practices (e.g. increased use of fire in grassland ecosystems) and climate change (Chapin et al., 2000; Masters and Norgrove, 2010).

**Overview of the impacts of invasive alien plants**

On a global basis, the reported impacts of invasive alien plants are diverse (Weber, 2003; Mooney, 2005) and many agricultural, semi-natural and natural terrestrial and aquatic ecosystems are now affected in some way by them. There are many invasive alien plant species reported from tropical Asia and a large proportion of these are present in more than one country (Waterhouse, 1994; Weber, 2003); the list is also growing steadily. The main problem species are all dicotyledons; in contrast, alien grasses do not seem to be as problematic in Asia as they are in the Americas. It has been hypothesized that this is because the long history of human presence in Asia and Africa may have affected the evolution of the native grasses (D’Antonio and Vitousek, 1992): Old World grasses have evolved under intense grazing pressure from large ungulates and thus have developed adaptations that include features such as perennating organs at ground level, rapid growth in response to defoliation and adaptation to fire, while grasses from the Neotropics have not evolved these features and so are inferior competitors in Asia and Africa.

This review of information about the impacts of alien plants in tropical Asia is not exhaustive, but the aim has been to include a representative set of papers with quantitative information from the available literature. There are many published papers that describe the presence, spread and status (on the last, these are mostly negative, though some are positive) of invasive plants in agricultural and natural ecosystems. There are also studies, albeit not many, on the extent of awareness of local communities about invasive plants (e.g. Rai et al., 2012). Furthermore, experimental studies on impacts, such as actual crop losses in specific farming systems, impacts on rural livelihoods, costs of control and losses to native biota or ecosystem services are quite scarce and much information that is given tends to be anecdotal (Peh, 2010). None the less, some data are available, and an up-to-date review of the literature on all types of impact of invasive plants in the Indian sub-continent is given in Bhatt et al. (2012); the situation that these authors depict reflects that in other parts of the developing world.

Some species of invasive alien plants have been reported as particularly widespread and also problematic in tropical Asia through their various impacts on agriculture, natural ecosystems and human and animal health (e.g. Kohli et al., 2006; Peh, 2010), and thus are commonly cited in this review. Examples include *Ageratum conyzoides*, *Chromolaena odorata*, *Mikania micrantha*, *Mimosa pigra* and *Parthenium hysterophorus* in the Asteraceae, and *Lantana camara* in the Verbenaceae. These particular species all originate from the Neotropical region and were either introduced as ornamentals (e.g. *L. camara*) or for agricultural purposes (e.g. *M. micrantha*) or introduced accidentally (e.g. *P. hysterophorus*). The predominance of South American species in an alien Asian flora has been confirmed by Khuroo et al. (2012) for India.

The negative impacts of invasive alien plant species have been reported in the literature in the following systems: agriculture and plantation forestry; native biota (e.g. resulting from competition); ecosystems (with impacts on nutrient cycles, water tables, etc.); rural communities and human and livestock health; and industrial processes. Recent work (see Blackburn et al., 2014) has developed a system to categorize impacts on the basis of type; in this review,
however, we adhere to the traditional sector approach, as this is also how national governments in the developing world commonly make assessments of invasive species. Apart from a few brief comments, positive impacts are not covered here as studies tend to be anecdotal.

**Human and livestock health**

In many countries, beside invasions in crops and natural habitats, invasive alien plants are commonly reported occurring in fallows and wastelands, along roadsides and in other disturbed habitats. Globally, the highest proportion of invasive tree and woody shrub species, for example, is found in wastelands and disturbed habitats (Haysom and Murphy, 2003). In such situations, both positive and negative impacts have been reported. In the former case, some species have been reported as useful for soil stabilization and/or local fuelwood supply in degraded habitats (Parthasarathy et al., 2012), largely because the species concerned have a high rate of biomass production. Nevertheless, rural communities and their livestock experience high exposure to many of the invasive alien plant species through daily livelihood activities. Given the abundance of these species and the lack of advice on how to control them, rural communities have little choice but to incorporate invasive alien plants into their livelihood schedules (Rai et al., 2012). A number of these species are toxic to humans and animals. *L. camara* has been reported as being toxic to livestock and wild ungulates (Ambika et al., 2003). *P. hysterocephorus* is a major problem in the farmlands and wastelands of several countries in tropical Asia, and is still spreading. In India, where this plant has invaded over 14 million hectares of farmland alone, it is a major health concern to humans and livestock. In humans, symptoms include allergic eczematous contact dermatitis from prolonged contact, and allergic rhinitis (hay fever) and allergic bronchitis as a reaction to the pollen (Towers and Subba Rao, 1992; Kaur et al., 2014). Livestock tend to avoid the plant, but will feed on it in pure stands, and the death of animals has been reported (Kohli et al., 2006). Likewise, *M. micrantha* has a wide distribution in agricultural areas and wastelands in wetter regions (e.g. north-east India). In these regions, a significant proportion of rural communities allow goats to graze on the plant and they also use it as fodder for goats in winter months, although it is reported to affect animal health (Siwakoti, 2007).

**Agricultural, forestry and fisheries systems and rural livelihoods**

As part of a global assessment of the impacts of invasive species, the costs of these impacts by invasive alien plants in agroecosystems were estimated at a national level in India by Pimentel et al. (2002). Annual losses to crop production were estimated to be US$37.8 billion and losses to pastures at US$0.92 billion; this was 42.5% of the total loss (US$91.02 billion) to crops, pastures and forests from all invasive species, i.e. not only plants.

In annual field crops in the Indian sub-continent, *L. camara* is commonly reported invading wasteland and around agricultural fields (Kohli et al., 2006, 2009; Peh, 2010); it also invades pastures and reduces their productivity (Sharma et al., 2005; Love et al., 2009). *A. conyzoides* is found in arable land, competing with maize, wheat and rice (Batish et al., 2009; Kohli et al., 2009), and it is also found in pastures. This species is particularly widespread in the Himalayan hill ranges and the Western Ghats of India (Kaur et al., 2012a). In Nepal, *A. conyzoides* causes reductions in rice production, with grain yield reduced by 25–47% and straw yield 13–18% (Manandhar et al., 2007). *P. hysterocephorus* is reported as a common aggressive invader of wasteland, overgrazed pastures and the borders of agricultural land (Kohli et al., 2009), and in some older studies on crops it was shown to cause yield losses of up to 40% (Khosla and Sobti, 1981) and to reduce forage production by 90% (Nath, 1981). Likewise, in experimental fields of sorghum, the species has been estimated to cause losses in grain weight of up to 30% (Channappagounder et al., 1990).
L. camara and C. odorata have frequently been reported from across tropical Asia as affecting tree crops and forest plantation trees; L. camara affects coffee, coconut, oil palm, rubber, banana and sugarcane (Sharma and Raghubanshi, 2012), while C. odorata seems to be especially troublesome in plantations of coconut, rubber, coffee, cashew, bamboo, teak, Dalbergia and Eucalyptus (Kohli et al., 2009). In West Timor (Indonesia), C. odorata severely affects pastures and thus feed for the cattle that are important to the semi-subsistence farmers (McWilliam, 2000).

M. micrantha is an invasive plant of high rainfall regions in tropical Asia, where it is reported as a major problem in agricultural systems. In India, Abraham et al. (2002) showed through experimental studies that M. micrantha significantly decreases the growth and dry-matter production of pineapple, banana, cocoa, coconut and rubber. In addition, Kaur et al. (2012b) studied the effects of M. micrantha on plant richness and rice seedling growth in the Western Ghats. Average plant species richness in sites with M. micrantha was significantly lower (by 30%) than in sites without M. micrantha. In non-sterile soils treated with M. micrantha leaf leachate, these authors also demonstrated that rice seedling germination and growth was retarded by increasing dose levels of the leachate. The plant has been also reported as a problem in home gardens in Kerala, India (Murphy, 2001) and orchards in China (Zhang et al., 2004) where it smothers crops and retards growth. Shen et al. (2013) report that in south-western China, dense M. micrantha infestations cause 60% reductions in crop yields and make cultivation and harvesting difficult. In a socio-economic study of agroforestry farming systems in Kerala, Muraleedharan and Anitha (2000) found that farmers ranging from marginal (cultivating less than 1.5 ha) to large (with more than 5 ha) landholders all ranked weeding as the major constraint to cultivation; in this region, M. micrantha is a predominant weed. The cost of weeding varied between 24 and 35% of the total cost of cultivation, with costs higher in marginal and smallholder farms. On average, farms of all sizes infested with M. micrantha were earning Rs. 4000 (= approx. US$75)/ha p.a. less than equivalent farms where the species was absent. Clearly, this is a serious impact on marginal and smallholder farmers who are already poor. In earlier studies in Malaysia, M. micrantha was described as a problem in tree crop plantations such as rubber, oil palm and cocoa (Teoh et al., 1985), where yield reductions of 20–27.5% were reported. Traditional manual control of weeds in these crops proved to be unsustainable and so herbicides were used to reduce the M. micrantha infestations (Anwar and Sivapragasam, 2001).

Invasive alien plants also cause problems in tribal communities. In the Western Ghats, harvesting of non-wood forest products has become difficult for tribal communities because of the invasion by M. micrantha into the forests. The collection of reed bundles has been reduced by almost half in areas with thick M. micrantha infestations (Kerala Forest Research Institute – KFRI, unpublished data). Similarly, in the buffer zone of Chitwan National Park in Nepal, M. micrantha and other invasive plant species have invaded the community forests and grasslands and are having a major negative effect on community livelihood activities in buffer zones so that, for example, communities are driven to use more resources from the national park (Rai and Scarborough, 2015). Farming households have tried to adapt to the invaded landscape and accommodate the plants into their livelihoods, but they provide few uses (Rai et al., 2012).

Some classic earlier studies showed how invasive plants contribute significantly to the declining productivity of shifting agricultural (slash-and-burn or ‘jhum’) regimes in the high-rainfall hilly ranges of north-eastern India (Saxena and Ramakrishnan, 1984; Swamy and Ramakrishnan, 1987) (see Chapter 7, this volume). In this region, traditional shifting agricultural cycles of greater than 25 years have become shortened because of human population pressure. This, in turn, has allowed invasive alien plant species – predominantly M. micrantha and C. odorata – to dominate the flora in
shortened regimes because of their superior ability to survive fire (which is used to clear the land for cultivation) and to rapidly utilize soil nutrients, which are abundant after fire (Ramakrishnan, 2001). Even though the invasive plants do play a role in reducing losses of nutrients from runoff, under these conditions, farmers of the region were no longer able to operate sustainably. However, these studies also showed that natural forest succession occurred when farmed plots were left uncultivated as in the traditional longer term cycles of >25 years; in this scenario, the invasive plants are outcompeted by native species because light and nutrients become limiting under the developing forest canopy.

The tropical American shrub *Mimosa pigra* has invaded wetter areas in South-east Asia. The species affects both rice and oil palm cultivation in Thailand (Peh, 2010), and impacts have also been reported in oil palm and fruit orchards in Malaysia (Anwar and Sivapragasam, 2001). In aquatic systems, water hyacinth (*Eichhornia crassipes*) is one of the most widespread invasive plant species in tropical Asia and has been reported choking lakes and rivers and thereby disrupting boat transport and local fishing (MacKinnon, 2002).

Conversely, in agroforestry systems in drier areas of the region, there have been a number of reports of positive impacts by trees and woody shrubs that have become invasive. Most species introduced for agroforestry have been selected for a number of traits, including their suitability for fodder and fuelwood. In many areas of the developing world, the very high demand for these and other forest products has meant that local communities have exhausted natural supplies. In some cases, the aggressive, spreading nature of introduced trees has resulted in reforestation, albeit with an introduced species. This, in turn, has provided rural communities with a ‘free’ and continuous supply of forest products. For example, in India, the South American tree *Prosopis juliflora* provides an important fuelwood supply for some local communities in arid and semi-arid areas (Sharma, 1981; Pandey et al., 2012), but it is also highly invasive in many areas, where it grows on waste ground, along roadsides and in pastures, and also threatens the environment (Pandey et al., 2012).

In forest plantations, *M. micrantha* was reported as a problem in the 1980s although this only became apparent when regular weeding was stopped because of labour shortages (Palit, 1981). In studies on the impact of the plant on teak plantation production, Muraleedharan and Anitha (2000) showed that the net profit per hectare over an 8-year production period in an infested plantation was reduced by Rs. 6274 (approx. US$118) compared with an *M. micrantha*-free plantation.

One significant feature common to several of the major invasive plant species in tropical Asia is their allelopathic properties, whereby combinations of root and shoot leachates and/or root exudates can reduce the growth of crop or other wild species. *P. hysterophorus*, for example, is a well-known allelopathic plant (Kohli et al., 2009). It releases inhibitors into the soil through leaching from the leaves, shoots and roots, and also through the further decomposition of the leachates in the soil. Likewise, the allelopathic effects of *L. camara* on a wide range of plant species have been well documented (Ambika et al., 2003).

**Natural ecosystems and biota**

There are several studies in the literature that report the negative impacts of invasive alien plants on natural ecosystems and their constituent biota. The most common impacts include ecosystem-level processes; for example, changes in fire regimes, water tables and nutrient cycles, and the displacement of native species. Very little information exists for tropical Asia on the impacts of hybridization on the genetic diversity of native plant species.

In northern India, *L. camara* has replaced or invaded large areas of natural stands of oak (*Quercus leucotrichophora*) and pine (*Pinus roxburghii*) (Bhatt et al., 1994). In a comparison of ecosystem functioning between *L. camara*-dominated shrubland and oak and pine woodlands, these authors
showed that the total net primary production (measured in tonnes/hectare p.a.) of \textit{L. camara} ecosystems was similar to that of both the oak and pine woodlands, but that the soil nitrogen and phosphorus levels in the \textit{L. camara} ecosystem were significantly lower than in either type of woodland. Rawat and Singh (1988) showed that \textit{L. camara} thickets have a high litter turnover rate and nutrient cycling, and they suggest that \textit{L. camara}, which is fast growing, can utilize nutrients more efficiently than slow-growing native species; this, in turn, contributes to the further spread of \textit{L. camara} (Sharma and Raghubanshi, 2012).

The effects of invasive plant can be directly or indirectly exacerbated by fire, which is common in grass or grass–forest ecosystems. For example, Murphy et al. (2013) suggest that a major factor driving the expansion of \textit{M. micrantha} in the Chitwan area of southern Nepal is the increase in frequency and area of burning of the grasslands every year, because \textit{M. micrantha} is a fire-adapted species. Likewise, Witkowski and Wilson (2001) point to the increased risk of fire in \textit{C. odorata}-invaded areas with a pronounced dry season; this is because the plants become highly flammable owing to the high oil content that develops during dieback after flowering.

Invasive plants can even disrupt tree pollination. \textit{C. odorata} is a major invasive species in the tropical dry forests of Thailand in areas where \textit{Shorea siamensis} is logged on a regular basis. In these areas, the butterfly pollinators of the tree \textit{Dipterocarpus obtusifolius} change their foraging location to \textit{C. odorata} (Ghazoul, 2004).

Studies on the displacement of native species tend to be mostly descriptive, although a few quantitative assessments have been made. Evidence to date suggests that disturbed forests with an open canopy are more prone to invasion than forest fragments with a closed canopy (Teo et al., 2003). Gaps in the forests of the Western Ghats created by selective logging operations are dominated by \textit{C. odorata}, which is absent in undisturbed forests (Chandrashekara and Ramakrishnan, 1994). In the tropical forests of Peninsular Malaysia, the invasive shrub \textit{Clidemia hirta} has been inferred to be a major agent driving changes in the regeneration of forest tree species in tree fall gaps by suppressing the normal growth of new native canopy trees in these gaps (Peters, 2001). Dogra et al. (2009) have reported that at lower elevations of the Shivalik Hills of the Himalayas (in Himachal Pradesh, India), \textit{A. conyzoides} and other major invasive plant species occupy approximately 20% of the natural ecosystem areas, but that \textit{A. conyzoides} accounts for approximately 30% of the alien plant species.

Other invasive plant species have invaded riparian systems. \textit{M. pigra} has invaded the Mekong River delta in Southeast Asia, where it has been reported to replace native vegetation (Peh, 2010) and form large monocultural stands. The shrub has a prolific seed capacity and this has been suggested as one of the reasons for its rapid spread in the region. It has been shown to cause local reductions in the abundance of native plants and tree seedlings and, thus, bird species diversity in Australia (Braithwaite et al., 1989); these effects are also likely to be happening in the Mekong Delta.

More specific studies include work in the Chitwan National Park, situated in the grass–forest region of southern Nepal, where it has been shown that \textit{M. micrantha} is outcompeting native grasses and other plant species (Sapkota, 2007). Here, the mortality of some dominant grasses (\textit{Saccharum spontaneum} and \textit{Imperata cylindrica}) was high in highly invaded grass–riverine habitat, with little or no regeneration of new plants; likewise, in subtropical hardwood forests, saplings of \textit{Bombax ceiba}, \textit{Dalbergia sissoo} and \textit{Acacia catechu} had died and no regeneration was observed. \textit{S. spontaneum}, \textit{I. cylindrica} and other grasses and shrubs are important fodder and browse species for herbivorous mammals of conservation importance – in particular the one-horned rhinoceros (\textit{Rhinoceros unicornis}) (Laurie, 1982; Hazarika and Saikia, 2012) and deer species. Indeed, recent in-depth studies have confirmed that in \textit{M. micrantha}-infested grass–riverine forest habitats, a number of demographic parameters (e.g. home-range size) of the
Invasive Alien Plants as a Constraint to Development in Tropical Asia

One-horned rhinoceros are negatively affected and this has been shown to be a direct consequence of the presence of *M. micrantha* (Naresh Subedi, National Trust for Nature Conservation, Nepal, unpublished data). By implication, it is likely that deer populations will also be negatively affected, and this will have serious effects on Bengal tiger (*Panthera tigris tigris*) numbers, as it has been established that these are directly proportional to the abundance of the tiger prey (Karanth and Nichols, 2002).

*I. cylindrica* is important for thatching in some communities in South-east Asia (FAO, 2016). However, the grass is also reported as being seriously invasive in this and other regions, where it affects crops and the environment (CABI, 2015).

Studies in the tropical dry deciduous forests of the Vindhyan hill ranges of west-central India that are invaded by *L. camara* suggest that the presence of the shrub reduces the recruitment of new native tree seedlings, with up to 60% reduction in species number recorded in these forests (Sharma and Raghubanshi, 2007). In the Western Ghats region of southern India, studies by Ramaswami and Sukumar (2011) on *L. camara* invasion in the seasonally dry and dry–moist forests of Mudumalai have shown that the frequency of occurrence and abundance of several key mammal-dispersed and mechanically dispersed native tree seedlings were significantly less under *L. camara* thickets compared with forest free of the shrub, whereas bird-dispersed species were not affected. The authors infer that lantana thickets create barriers to tree species dispersed by mammals or mechanical means and that, in time, the community composition of these forests will change. Work by Prasad (2010) in the dry deciduous forests of Bandipur Tiger Reserve in Karnataka in India has indicated that *L. camara* contributes significantly to tree species death on the borders of wide clearings in the forests.

In South-east Asia, Osunkoya *et al.* (2005) report that the Australian agroforestry trees *Acacia auriculiformis* and *A. cincinnata* have extensively replaced native shrubs (e.g. *Alphitonia* spp., *Commersonia* spp.) in heath forests in Brunei because the introduced trees are nitrogen-fixing species and the soils of the heaths are nutrient poor.

**Inferences from the existing data**

Taken as a whole, the inescapable conclusion from the studies reviewed in this section is that invasive alien plants have a dramatic negative impact on crops, pastures, human and livestock health, and ecosystem function and biodiversity in tropical Asia. The positive impacts are few; the main one reported is that some woody invasive plants now form an important supply of fuelwood for local communities, but several of those communities are now deeply concerned about the invasive nature of these species because they have invaded croplands. Although there is a paucity of quantitative information on the total losses to crop yields in specific farming systems, it seems likely that this will be a significant proportion of the total production in any one year. The findings of studies on the impacts on ecosystem function and biodiversity are likewise alarming. However, even though there is clear evidence that invasive plants can cause the local extinction of native plant species, there is no evidence from the literature that any specific native species in tropical Asia is under threat of extinction purely through the action of invasive plants. Peh (2010) reaches the same conclusion in a review of the impacts of invasive species in South-east Asia.

**Organizations and Frameworks that Address Invasive Plants at the Regional and National Levels in Tropical Asia**

Most of the world’s most serious invasive plant species are still spreading unchecked...
and this is also true in tropical Asia. This region faces new threats as well, with trade and transport opening up new areas to the import and export of agricultural products. Regional and national responses and actions to biological invasions have been varied, but no country in the region has a comprehensive response and management framework in place. Historically, the main frameworks and organizations were developed to protect agricultural interests, and this is still the main concern of these bodies; moreover, they cover invasive species of agricultural importance – with the emphasis tending to be on invasive alien pathogens, insects and mites, rather than plants, and the threats to other sectors still largely neglected.

There are several regional organizations in tropical Asia that partly deal with threats from invasive alien species, but not all cover invasive plants. The two principal organizations cover plant and animal health respectively: the Asia and Pacific Plant Protection Commission (APPPC) and the World Organisation for Animal Health (OIE).

The APPPC is the regional plant protection organization (RPPO), and it takes guidance from the International Plant Protection Convention (IPPC). The IPPC is the international standard-setting body for International Standards for Phytosanitary Measures (ISPMs), and the APPPC, like other RPPOs, uses these ISPMs to set phytosanitary standards for the Asia–Pacific region. The APPPC utilizes the IPPC ISPMs and has developed a number of standards for specific invasive species threats in the region; for example Guidelines for Protection Against South American Leaf Blight of Rubber (APPPC, 2009).

Currently, there are no specific regional standards that cover procedures for addressing the risks from invasive plants, but the IPPC ISPMs do include relevant guidance, e.g., Pest Risk Analysis for Quarantine Pests (IPPC, 2013). In the early 2000s, the IPPC and the CBD recognized the relevance of the IPPC to the CBD’s Article 8(h), which calls on all parties to the CBD to ‘prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species’, and since 2005 both conventions have been collaborating within the framework of a Memorandum of Cooperation. In 2014, the IPPC joined the Liaison Group of Biodiversity-related Conventions to enhance regional and national capacities to protect agricultural and wild plants, including threats from invasive alien species. It remains to be seen how far these international initiatives will be taken advantage of by RPPOs.

Livestock are central to the livelihoods of most rural communities in tropical Asia. In a similar vein to agricultural plant protection, the OIE sets international standards for animal welfare and has representation in the Asia–Pacific region. The OIE forms collaborations with appropriate bodies in the region. For example, in 2008, the OIE and the Association of Southeast Asian Nations (ASEAN) entered into a Memorandum of Understanding on technical cooperation for the protection of livestock against major animal diseases and zoonoses. The OIE is concerned with alien animal diseases and threats from invasive alien animals, although it does not cover threats to livestock or wild animals from invasive alien plants.

On the environmental side, the South Asia Co-operative Environment Programme (SACEP), established in 1982, does cover some aspects of the invasive alien species issue; this is mainly through the inclusion of invasive alien species threats in awareness raising and advocacy for environmental legislation.

The only truly regional framework to be set up in response to the increasing tide and threat of invasive alien species is the Asia-Pacific Forest Invasive Species Network (APFISN), which was established in 2004 by the Asia-Pacific Forestry Commission (APFC). The APFISN is a cooperative alliance of 33 member countries and its main aim is to help member states detect, prevent, monitor and eradicate or control invasive alien species in forest systems. The APFISN stock-takes national activities to identify gaps and needs in capacity building, and also raises awareness; it has developed an information-sharing forum as well.

Current national situations in some countries are reviewed in detail by other
authors in this book, so only some general points are made here. At the national level, accountability for plant protection and livestock welfare has historically lain within ministries of agriculture. This responsibility includes prevention, under the remit of quarantine departments, and early detection and control, which are generally within the remits of agricultural research and extension departments. In India, the responsibility for pest management lies jointly with central and state governments, and involves several organizations; this makes actions against invasive species difficult to coordinate (Mandal, 2011). Signatory countries under the CBD have produced National Biodiversity Strategy and Action Plans (NBSAPs) and these have to include plans to address invasive alien species. These plans have, in most cases, been devised by ministries of environment, however, and in most countries in the region they are not well linked into the existing frameworks under the ministries of agriculture.

In some countries, actions have been and continue to be taken against some major invasive alien plants and other pests of agricultural importance, but the efforts remain focused on species already familiar to agricultural sectors. Little effort has been made to address plants and other species that now threaten other sectors, such as forests, and that have become, or are becoming, a threat to agriculture. The exception is India, which does have a strong record in the use of classical biological control against invasive plant species.

**Why Have National Responses to Biological Invasions Been Patchy?**

It is clear from the existing published data on impacts that, while many gaps remain in our understanding of the nature of their impacts in farming and natural environments, taken as a whole, invasive alien plants do represent a major and growing threat across the agricultural, trade and environmental sectors in tropical Asia. So, why is there a paucity of investment and action in the region? This question has been raised in the past by other authors (e.g. MacKinnon, 2002).

Part of the problem lies in the nature of the invasive species issue. Overall, the issue is complex for various reasons, as the case study presented in this chapter on invasive alien plants in tropical Asia has illustrated:

- Some invasive species have developed from introductions in colonial times and have been spreading slowly in natural areas throughout countries and regions for well over a 100 years in some cases, so they remain ‘unnoticed’ because they have become part of the background flora and fauna. Hence, their long-term negative impacts are not recognized.
- A rapid expansion in the range of these species is taking place because of dramatic land-use changes and climate change, and many species are now affecting agricultural areas and forests.
- The development of trade has brought an increasing number of new invasive species, and not all trade pathways are monitored for plants or pests of quarantine significance.

Thus, the invasive alien species issue is multidimensional and difficult to address unless a national and regional approach is taken. As we have seen, invasive species have been an issue in agriculture for centuries, even though they were not always termed ‘invasive species’. However, concerns about invasive alien species and their impacts did not become manifest in environmental sectors until about the 1980s, first in North America and then, increasingly, in the developing world (e.g. see Mooney et al., 2005). Out of this realization developed much scientific review of the current ecological knowledge of invasive species in particular regions or countries, the process of invasion and the human dimensions of the problem, and the collation of information about experiences with management. Interestingly, some of the knowledge that emerged was new to the agricultural sector, for example the variety of pathways for the movement of invasive species.
None the less, three core and interrelated issues are at the heart of the problem:

- Within and between countries, there is a lack of national and regional awareness of the scale of the problems associated with invasive alien species, especially their economic and ecological impacts. This is largely a result of two factors: historically, developing countries have not had a sufficient skill base to collect these types of data; furthermore, and as already alluded to, the activities of government ministries, research bodies, public extension organizations, non-governmental organizations (NGOs), farmer groups and the private sector are disconnected, resulting in weak linkages and poor communication about the problems. For example, several authors (see Griffin, 2003) have noted the weak links that exist between national plant and animal protection agencies, which focus on agricultural issues, and other ministries or agencies that represent other stakeholders also severely affected by invasive species. Overall, this has led to a lack of coordinated responses to implement effective management with appropriate policy development, and insufficient response to international calls and guidelines for action (Butchart et al., 2010).

- Some capacity exists for managing invasive species within countries but, in general, this has lain in and remains within agricultural sectors (and so is not available to other sectors for the reasons discussed above), and focuses narrowly on traditional agricultural pests. As a consequence, it is inadequate for the wide range of invasive species that now exist, especially invasive alien plants.

- Although there is much knowledge about invasive species globally, some in web-based databases and tools, this knowledge is not available in forms usable by all the stakeholders that most need it. Also, most web-based tools lack detail on up-to-date best management practices for prevention, early detection and sustainable control.

In addition, and as already discussed, many of the reported impacts of invasive alien species in environmental sectors are qualitative, and this is particularly true of older reports. This has resulted in mixed perceptions about the true impact of invasive plants. For instance, there are situations where the impacts of invasions will ‘fade way’ over time, but these are few.

As a result of the above points, many involved in natural resource strategies have concluded that invasive species are a secondary problem, and the discussion about this issue still lies mainly within scientific circles.

Conclusions: Does a Lack of Response Matter, Is There a Crisis in the Making and Can Issues Be Resolved?

Invasive alien plants pose a major challenge for most of the countries in tropical Asia and across the rest of the developing world. They are a cross-cutting issue and thereby affect all major economic sectors of countries – agriculture, environment and trade. Most significantly, humans are both ‘drivers’ and victims of invasive plants.

A lack of comprehensive management responses to the issue has created and is perpetuating the unprecedented introduction of new invasive plant species into countries and the rapid expansion of existing invasive species. What is more, the problems continue to escalate in rural areas, with serious negative impacts on the livelihoods of the people. So it is clear that there is a crisis in the making. In some countries, communities try to control or utilize invasive species, including some invasive plants, but this rarely works and has yet to be demonstrated to be sustainable (Rai et al., 2012). In some instances, invasive species drive communities to abandon land and even villages. To take a case from another region, in East Africa, invasive plants have caused conflict between communities (Mwangi and
Invasive Alien Plants as a Constraint to Development in Tropical Asia

Swallow, 2008). Moreover, the worst affected are always the poorest people who have little in the way of resources.

What can we learn from experiences to date? Crop losses and threats to livestock and natural resources will continue and are likely to escalate in the absence of national and regional actions. This will threaten food security directly. Invasives species are also threatening local biodiversity, and through this, rural livelihoods too. In badly invaded areas though, invasive plants contribute a large proportion of the total biomass and so they play a significant role in reducing losses of nutrient from runoff; they can also provide supplies of local firewood. Notwithstanding, these positive impacts are at the expense of the almost complete monopolization of the environment by the invasive alien plant and, consequently, a severe reduction in local biodiversity, which may not be able to recover. None the less, sustainable solutions do exist. Globally, much is known about many of the serious invasive species and their impacts on crops, livestock and natural resources. For example, a key ‘action’ for consideration at national and regional levels is to regulate all pathways of trade in plant movement and, although this may be unwelcome to some trade sectors, it must be remembered that the outcome of unregulated trade in plant material can cause loss of livelihood and severe impacts on other sectors. There are existing control technologies – biological control and integrated pest management (IPM) – that are suitable for invasive plant species, are cost effective and environmentally compatible, and can achieve large-scale geographical impact (Murphy and Evans, 2009). When successful, such interventions against biological invasions are almost always overwhelmingly beneficial, with biological control, for instance, frequently giving benefit–cost figures of well into the hundreds, e.g. the control of water hyacinth in southern Benin resulted in a benefit–cost ratio of 124:1 (De Groote et al., 2003).

Thus, for tropical Asia, as for other parts of the globe, the opportunities are there to address the ongoing crisis of invasions of alien plant species. However, a core urgent need is for coordinated regional and national actions that involve all principal stakeholders in new partnerships to catalyse actions.

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