Bioinvasions and Globalization

Ecology, Economics, Management, and Policy

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Preface

This volume is motivated by a concern expressed at the 8th Conference of the Parties to the Convention on Biological Diversity (CBD) over "gaps and inconsistencies" in the international regulatory framework (Decision VIII/27 of COP 8: Alien species that threaten ecosystems, habitats or species (Article 8 (h)). At least part of the problem identified by the CBD lies in the fact that there are similar "gaps and inconsistencies" in our knowledge of biological invasions. As with many anthropogenic environmental problems, the social and natural science of biological invasions are still poorly articulated. There is, for example, almost no research into interactive effects between the main social and environmental drivers of change in the global distribution of species. This volume explores the current state-of-the-art in the social and ecological science of invasive species, and draws out the implications for the national and international regulation of the problem. It is organized into three parts.

Part 1 identifies the major drivers behind the problem: globalization (the ever closer integration of the world system), climate change, and land use change—and explores the extent to which an understanding of these drivers can help us predict the introduction, establishment, and spread of species that have the potential to impose significant harm. While the individual chapters focus on distinct drivers—Thomas and Ohlemuller and New and McSweeny on climate, Perrings *et al*. on trade, and Williamson and Pyšek *et al*. on landscape and land use change—together they establish two of the key messages of the book. One is that invasive species risks are endogenous: they are the product of human decisions that determine the direction and volume of trade, the level of sanitary and phytosanitary effort, and the way in which landscapes are structured. This makes it important for policy and management to address the factors that determine those decisions. The other is that the risks associated with different species are interdependent. Many human and animal pathogens, for example, not only share the same origins but also the same pathways and vectors. Equally, vulnerability to one invasive species may be determined by the success of others. This matters precisely because it is ignored by the very fragmented regulatory and institutional environment within which the invasive species problem is addressed. Indeed, this is where many of the gaps and inconsistencies identified by the CBD come from. Aside from these two messages, Part 1 also underlines the limitations on our capacity to predict biological invasions from the data on drivers, and hence the importance of learning—a theme picked up in subsequent chapters.

Part 2 comprises a set of five chapters that explore the economics of the problem, focusing on the main elements of the decision problem facing environmental authorities at the national level. A dominant theme of these chapters is the treatment of uncertainty. Given the fundamental uncertainty associated with novelty in trade goods, trade routes, landscape change, and so on, several chapters ask what the right way to deal with the problem may be. Simpson argues forcefully that reversing global integration is not desirable even if it were feasible, and that a better option is to control the high-risk species introduced alongside trade goods. This raises a series of questions about the optimal control of such species. The question of how to identify problematic species at the port of entry is explored by Springborn *et al*. The question of whether to control an invasive species at the port of entry or beyond, and what resources to commit to control, is explored by Polasky. The question of whether control is better directed to the structure of the landscape is explored by Touza *et al*., and the question whether to target the current or steady-state abundance of invasive species is addressed by Finnoff *et al*.

One key message coming out of Part 2 is that the rate of growth and spread of an invasive species are critical parameters in the development of efficient (or cost effective) control strategies. Finnoff *et al*., for example, show that control at the steady-state abundance of the invasive species is a "good enough" strategy for fast growing species, whereas for slow-spreading species it is necessary to understand the transition dynamics. At the same time, as Perrings *et al*. show in Part 1, inspection and interception effort will be decreasing along an optimal trajectory wherever species are "slow-growing" relative to the economy. A second key message is that while prevention is almost always better than cure, there exist a range of possible strategies that, at least in Part 2, extends from inspection and interception all the way to control of the spatial structure of an invaded landscape. Just what strategy dominates depends on the costs and benefits of different forms of intervention.

Part 3 comprises a set of papers on different aspects of the management and policy problems. All are informed by just this point: that strategy choice depends on the costs and benefits of different forms of intervention. Indeed, as Pejchar-Goldstein and Mooney point out, identifying the costs and benefits of different options is an essential first step. As in Part 2, the range of options considered varies widely. Keller and Lodge, Uma Shaanker *et al*., and van Wilgen and Richardson all consider the options open to the nation state. Keller and Lodge focus on species introductions and take the cost-effectiveness of preventive measures as their starting point. Uma Shaanker *et al*. focus on established invasive species, and assume that the costs of eradication are prohibitive. Van Wilgen and Richardson are in between. They pose the following question: why should control measures be delayed until the costs become prohibitive? They identify the problem as lying in the perceived costs and benefits of control options, but connect the decisions made at each stage with the quality of information available to the decision-maker. At the point where rapid intervention and eradication might be efficient, decision-makers frequently do not have information on either the ultimate damage or control costs of invasive species and hence choose to do nothing. The authors observe that once a species has established and spread, control will not be selected unless the damage costs are understood to be extremely high—as with the problem being tackled by the Working for Water project in South Africa.

In the final chapter in Part 3 we return to the original motivation for this volume, the gaps and inconsistencies in the international regulatory regime identified by the CBD. Most chapters focus on national defensive measures. This is a default strategy. It is what is allowed under Article XX of the General Agreement on Tariffs and Trade (GATT) and the Sanitary and Phytosanitary (SPS) Agreement (1994). Both agreements authorize unilateral actions to address national risks associated with imports from individual countries, but ignore both the fact that many countries lack the information or capacity to take advantage of that authority, and also the effect of those actions on third countries. We contrast this position with the International Health Regulations (2005) (IHR) which directly focus on global public health risks. The IHR not only authorize collective action to mitigate such risks at the global level, they also provide for resource flows to low income countries to help build capacity to implement the regulations. The fact that the main authorizing agreement for action on trade-related invasive species risks ignores the global public good is the most fundamental gap in the international regulatory regime. Indeed, two key messages from Part 3 are that the SPS Agreement be brought into conformity with the IHR, and that a body be established to undertake the monitoring and risk assessment needed to enable all countries to take advantage of the provisions of the SPS Agreement.

Despite the growing focus on climate change, it is hard to believe that there is any other environmental problem of greater importance than the one addressed in this volume. It may not be as visible as many other problems, in part because expenditures on invasive species and their wider impacts are spread across a large number of sectors—health, agriculture, fisheries, forestry, and conservation to name but a few. But it is likely that the total impact of invasive pests and pathogens on human well-being is greater than the impact of almost any other environmental issue. There is certainly no greater global environmental threat than that posed by emerging zoonotic diseases. Nor is there another environmental issue where persistent failure to address the global dimensions of the problem carries a higher cost. This should be sufficient to trigger both the international coordination needed to resolve the problem, and the science needed to inform that effort.

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CHAPTER 14

Invasive Plants in Tropical Human-Dominated Landscapes: Need for an Inclusive Management Strategy

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14.1 Introduction

Invasive species have been regarded as one of the most important yet subtle threats to biological diversity (Cronk and Fuller 1995; Humphries *et al*. 1991; Luken and Thieret 1997; Schmitz *et al*. 1997; Simberloff 1998; Vitousek *et al*. 1997). In fact, according to the Convention on Biological Diversity (CBD), invasive species are defined as those that result in considerable damage to ecosystem processes (Secretariat of the Convention on Biological Diversity 2005). It is frequently claimed that the impact of invasive species on biological diversity is the second largest threat next only to that due to habitat destruction and climate change, especially in the Islands (D'Antonio and Kark 2002; Vitousek *et al*. 1997; Walker and Steffen 1997). Free from their native habitats, invasive species are no longer reined in by ecological forces that may have otherwise kept their population in check. Consequently, through their path of invasion, invasive species compete, marginalize, and frequently usurp native biological diversity (Mooney and Hobbs 2000). In extreme cases, invasive species can also lead to the extinction of native species (Atkinson *et al*. 1995, 2000; Gurevitch and Padilla 2004; Jenkins *et al*. 1989; Van Riper *et al*. 1986; Warner 1968; Wikelski *et al*. 2004; Williamson 1996 and references therein; Work *et al*. 2000).

Besides impacting on the native flora and fauna, invasive species are also reported to impair critical ecosystem services (Braithwaite and Lonsdale 1987; Braithwaite *et al*. 1989; Cronk and Fuller 1995; Hobbs and Mooney 1986; Vitousek and Walker 1989) such as disrupting pollinator and dispersal services to native species (Feinsinger 1987; Ghazoul 2001; see review in Levine *et al*. 2003) and altering the nutrient recycling and disturbance regime (see review in Levine *et al*. 2003). Parker *et al*. (1999) identified at least five distinct environmental consequences of invasive species ranging from their impacts on the phenotypic characteristics of native individuals to their impacts on the ecosystem services and processes.

While there are few estimates, it is well recognized that invasive species do have a significant economic impact (Perrings *et al*. 2000). It is speculated that the annual cost of invasive species in the US alone could be in the order of 137 billion US$, which amounts to nearly two per cent of the country's GDP (McNeely 2001; Pimentel *et al*. 2000; Pimentel *et al*. 2001). These costs are difficult to audit as often it is necessary to impute the indirect economic losses as well. Thus in South Africa, besides the direct cost of invasive species, the loss of agricultural productivity due to competition for scarce water by the invasive species is also being considered to evaluate the impact of invasive species (van Wilgen and van Wyk 1999).

Quite understandably, against the overarching negative effects of the invasive species on biodiversity and ecosystem services, the global agenda has been to prevent and contain the invasive species and thereby to mitigate their impacts on local biodiversity and the ecosystem function and human health (www.gisp.org). However, apart from a few prominent examples (such as the control of *Optunia* in Australia), management of invasive species has met with limited success (Cilliers 1983; see review in *Day et al.* 2003). The low degree of success is further compounded by the fact that preventing and controlling the spread of invasive species is often enormously expensive. Obviously, management of invasive species in low income countries of the tropics, which incidentally also happen to have some of the most invasive species ridden landscapes, is heavily constrained (Perrings 2005).

The management of invasive species is especially challenging in tropical human-dominated landscapes. First, in these habitats, invasive species can exacerbate biodiversity crises by reducing the population densities of indigenous species, many of which fulfil subsistence needs of the rural poor (Shackleton *et al*. 2007 and references therein; Uma Shaanker *et al*. 2004a). In many of these regions, non-timber and minor forest products (NTFPs) constitute an important source of livelihood for millions of people (Uma Shaanker *et al*. 2004a). In India alone, it is estimated that over 50 million people are dependent on NTFPs for their subsistence and cash income (National Centre for Human Settlements and Environment 1987; Hegde *et al*. 1996). Recent studies in India have shown that traditional income sources from forest based resources could be jeopardized by invasive species, both directly due to impact on resources and indirectly by rendering these resources less accessible for collection and harvest (Uma Shaanker *et al*. 2004a). Thus, under these circumstances, invasive species could potentially lead to further marginalization of the already impoverished livelihoods of the people in the tropical human dominated landscapes.

Second, in tropical human-dominated landscapes, invasive species have often been viewed as a resource that can accrue potential economic benefits that can aid rural livelihoods. Thus it is not uncommon that control of invasive species in these habitats may actually lead to loss of rural livelihoods (Perrings 2005). While the resolution of this interesting dilemma—to control or not—is admittedly a difficult one to address, it throws open serious challenges to the conventional wisdom and approach in managing invasive species, at least for the tropical landscapes.

Unfortunately, mainstream research on management of invasive species has scarcely addressed this question. In fact, as argued by Shackleton *et al*. (2007), the impact of invasive species on rural livelihoods has received little attention, despite the fact that rural land and waters are most affected by invasive species.

In summary, solutions to the management of invasive species need to be reworked to take into account the fact that invasive species can impact human livelihoods both negatively and positively. Besides the existing strategies for the management of invasive species, there is a need for alternative strategies in terms of the net benefit they yield, taking of course all benefits and costs into account.

Here we consider a specific case of control of invasive species in largely tropical landscape, with the attendant problems of human dependence on natural resources as well as lack of investment portfolios to control invasive species. We propose management strategies that promote use of the invasive as a way of minimizing the net costs of the invasive species.

While the above thesis seems to be at variance with conventional management strategies that always work to exclude the species, it could actually be viewed as one among the spectrum of management options, also trying to maximize the marginal returns of limiting the damage and control costs of the invasive species.

In the following section we first briefly review how the management of invasive species scales with the dynamics of the invasion; clearly management decisions do not necessarily conform to "one size fits all" and hence different strategies, including perhaps the exploitation of the invasive at some stage of its invasion, could be regarded as a rational approach to minimizing its net costs. Second, we review briefly three examples of invasive species, where exploitation of the species may help reduce the net costs imposed by the species. In the last section, we present a recent case study that has explored the use of *Lantana camara* as a substitute for bamboo and canes in India and discuss how such use could be viewed in the context of limiting the damage as well as control costs of the species and hence increasing the marginal benefits of managing the invasive species.

14.2 Dynamics of invasive species and management scenarios

Optimizing management strategies for invasive species requires an evaluation of the full range of costs and benefits of alternative control options on one hand and the reduction of the ecological impacts on the other. Accordingly, in managing invasive species, it might be useful to consider the following questions: a) how should management scale with the temporal dynamics of invasive species, b) what are the threshold levels of invasion that warrant management (when benefits due to investments in control exceed the damage costs) and, as a corollary, c) at what threshold (or when), should management effort be considered to have failed (that is, when benefits due to control are actually less than the damage costs)? Clearly, answers to these questions would not only put the current management strategies in perspective but also help raise interesting alternatives to existing management solutions. We address these questions briefly below.

14.2.1 How does management scale with the dynamics of invasive species?

The temporal dynamics of invasive species have been characteristically represented as a logistic function (Fig. 14.1; Hobbs and Humphries 1994; McGarry *et al*. 2005; http://tncweeds.ucdavis.edu) with 1) an initial lag phase where the invasion has set in and the species has been able to found single or multiple populations at the site of invasion; 2) a logistic growth phase where, upon successful establishment, the species reproduces rapidly and occupies a disproportionately large ecological space, and finally 3) a stable phase where the species is seen to have nearly saturated the available niche and possibly attained an equilibrium state

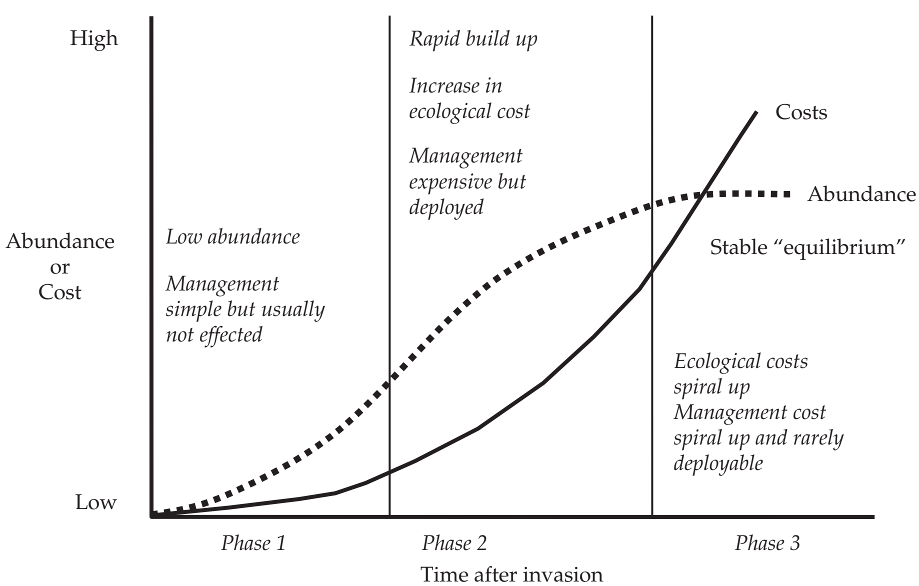

Figure 14.1 A schematic representation of the temporal dynamics of an invasive species and its associated ecological costs (please see text for explanation).

(McGarry *et al*. 2005; Williamson 1996). The time taken from invasion to attaining the stable phase varies with species, ranging from as low as 4 years to as high as 90 years (http://tncweeds.ucdavis.edu) and may be dependent upon a number of factors including the life history strategies of the species, extraneous drivers, and so on. Obviously, for invasive pathogens, the timescales would be even smaller (Jules *et al*. 2002; http://www.cbd.int/doc/submissions/ias/ias-diversitas-risk-2007-en.pdf).

Assuming that the ecological cost of an invasive species is a function of its spread and abundance, least impacts would be predicted when the species is still in its lag phase, but with higher impacts during the subsequent logistic and stable "equilibria" phases (Fig. 14.1). Thus across the time period of invasion, the ecological cost curve would tend to also increase at an increasing rate until perhaps the stable phase is attained. However, in the latter phase, the cost curve may still be expected to increase reflecting multiplier effects, such as the accumulated effects on local ecosystems including arrest of recruitment of native flora, allelopathic effects, and pollinator or seed dispersal disruptions (Achhireddy and Singh 1984; Dunbar and Facelli 1999; Feinsinger 1987; Fensham *et al*. 1994; Ghazoul 2001; Jain *et al*. 1989; Lamb 1991; Lyon and French 1991; Martin 1999; Mersie and Singh 1987; Sharma *et al*. 1988; Singh and Achhireddy 1987; Vivrette and Muller 1977; also see review in Levine *et al*. 2003).

It follows from the above, that the resources committed to control invasives would not be equal across the temporal dynamics of invasion. In the early stages of invasion, eradication is the generally preferred option, both because the marginal costs are low and the potential benefits are large. For example, when *Caulerapa*, a highly invasive algae from the Mediterranean, invaded California waters, immediate action was taken to eradicate the weed (Anderson 2003). Ironically, however, because the implied ecological costs are either too small or not yet perceived at this stage, often no management effort is initiated. In the logistic phase, with greater impacts and increased perception of the invasion, management investments are made, though they are expensive. Most management programs end up being deployed during this phase (logistic phase; Fig. 14.1).

In the last, stable phase, management interventions are not only going to be very expensive but tend to be least successful, and hence are rarely deployed. That is, in this stage, the marginal benefits due to control tend to be less than the marginal control costs. Thus for all practical purposes, management of invasive species in the third phase may be regarded to be a futile exercise. But should management options to control invasive species at this stage be abandoned? Could alternate management strategies be developed? We are particularly interested in addressing this question, because, at least in tropical landscapes, it is not uncommon to find invasive species that have swamped entire ecosystems (presumably reflecting the stable phase) and thus exhausted most management options that are economically viable.

While the answers to the questions raised above are as challenging as they are interesting, we believe that part of the problem lies in our current view of invasive species purely from the point of their negative impacts. We argue that incorporating a plurality of view, that invasive species across their temporal dynamics may also have some positive impacts and can probably be exploited for use, could drastically change the calculus of their management.

In summary, the management options would not be expected to be consistent across the dynamics of invasion, but would tend to be a function of the species, habitats occupied, naturalization and establishment, spread process, and so on. In extreme cases, where the net benefits of control are negative, it might even pay to encourage the invasive, not restricting it. Under this overarching view, management of invasive species may not preclude any options as long as the marginal benefits of control are positive.

Some introduced species have the potential to yield benefits that may outweigh any negative impacts they have on the flow of ecosystem services in the affected habitats. For example, a few introduced species have been shown to provide direct and indirect benefits to the ecosystem, including prevention of soil erosion, pollinator services, soil enrichment, non-timber wood requirement,

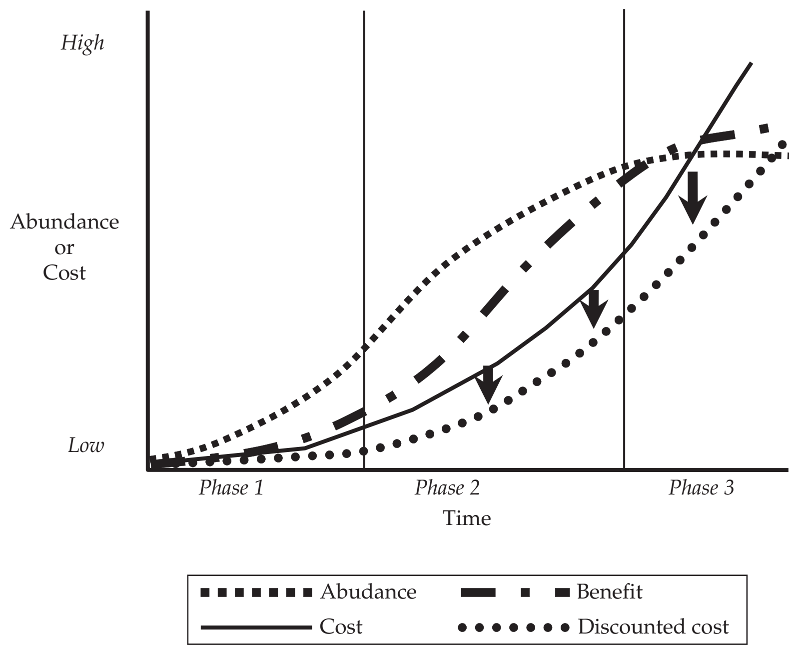

Figure 14.2 A schematic representation of the temporal dynamics of an invasive species showing the discounted ecological cost should the invasive accrue some benefit from its use (please see text for explanation).

bio-fuel, biofertilizers, and with the more recent recognition that they may contribute to carbon sequestration (Geesing *et al*. 2004; Kannan *et al*. *in press*). In fact, Zavaleta *et al*. (2001) argued that control of the invasive species during the third phase (stable phase) could be confounded by the fact that it may actually lead to loss of certain functions that the invasive species has been able to replace during the process of stabilization in its new habitat. Also, in several instances, invasive species could have both negative and positive impacts, and it might be necessary to adopt a holistic frame and not be eclectic in the choice of the impacts. For example, Wootton *et al*. (2005) reported that *Carex kobomugi*, an invasive species on the Florida coast has been recognized to be beneficial in stabilizing sand dunes while also imposing an ecological cost by displacing other species.

In tropical human-dominated landscapes, the introduced species can serve as an important resource to aid rural livelihoods. Siges *et al*. (2005) reported that the invasive shrub, *Piper aduncum*, could actually provide livelihoods to rural people in Papua New Guinea. As will be described in the next section, there are now a number of cases where the introduced species has been integrated into the livelihood requirement of local people. In an interesting treatment of biological invasions and poverty, Perrings (2005) acknowledged that in low income countries, because people might exploit invasive species for food, fiber, and fuel, there could be an ambivalent attitude to the control of invasive species. Indeed in these countries, control of invasive species may have to be weighed against the loss that may be incurred due to the loss of resources.

From a management perspective, the increasing ecological cost of invasive species should be weighed against any benefits that may accrue (Fig. 14.2). Accordingly, the strategy for management or otherwise will depend upon the boundary condition such as (a) opportunity cost of use of invasive and (b) the trade-off between potential ecological costs and benefits of use of invasive species.

Thus it appears that the management strategy, within the limits of temporal dynamics of the invasive species, would be a function of the relative marginal benefits and costs involved in controlling the invasive species. In the range of options available for management, one can allow for the entire spectrum from complete eradication to an adaptive management (wherein the species can actually be gainfully used; http://tncweeds.ucdavis.htm).

14.2.2 When control of invasive species fails: three examples

The history of management of invasive species, or perhaps the lack of successful management, has unleashed several notorious invasive species in the world, notable among them being *Eichhornia*, *Prosopis*, *Optunia*, and *Lantana* (See review in Day *et al*. 2003; Julien *et al*. 2001; Navarro and Phiri 2000; Matthews 2004). A combination of factors, including a rapid multiplication rate and the lack of successful control measures, has lead to a widespread colonization of those species across the face of earth, save those landscapes that are inherently unsuitable for the species. Control or management of these invasive species, especially in tropical human-dominated landscapes with traditionally poor economies, has been nearly absent or woefully unsuccessful. On the contrary, over their time of residence, at least some of these invasive species have blended into the local ecosystems and become integrated into the livelihoods of people (Shackleton *et al*. 2007).

One of the best illustrated examples of an invasive species is Water Hyacinth (*Eichhornia*). The plant was introduced from South America to many parts of the world between 1879 and 1890 for its ornamental value (www.gisp.org; http://www.invasivespeciesinfo.gov). A century and half later, the species has invaded nearly all parts of the tropical world (Navarro and Phiri 2000). The plant is known for its incredibly high rate of multiplication, producing about 3000 saplings in just 50 days and covering an area of 600 m^2 in a year. The plant is considered one of the worst aquatic invaders in the world (Holm *et al*. 1991). Efforts to control the plant, in the conventional sense of the term, have been not very successful (Navarro and Phiri 2000).

Confronted by the huge biomass of the plant, efforts have been made in many parts of the world to explore the possibility of using the invasive as a resource in a variety of scenarios. For example, in a number of countries including the Philippines, Indonesia, and India, Water Hyacinth is being used as a substrate in a small-scale cottage industry for making paper. In many African and South East Asian countries such as Kenya, Tanzania, Thailand, Philippines, Malaysia, and Bangladesh, Water Hyacinth is used to make furniture, carpets, mats, pillows, and ropes. Wicker items made from the stems have proved extremely popular in Germany and Japan. In Bangladesh, Water Hyacinth is being used to make fiber boards and paper (http://practicalaction.org/docs/technical_information_service/water_hyacinth_control.pdf). Water Hyacinth is also used to make low cost organic fertilizer for farms. In Sri Lanka, Water Hyacinth is mixed with organic municipal waste, ash, and soil, composted and sold to local farmers and market gardeners. In Malaysia, fresh water hyacinth is cooked with rice bran and fishmeal and mixed with copra meal as feed for pigs, ducks, and pond fish (Gopal 1987). Similar practices are used in Indonesia, the Philippines, and Thailand (National Academy of Sciences 1976). Water Hyacinth has also been used for bio-remediation especially in the removal or reduction of nutrients, heavy metals, organic compounds, and pathogens from water (Gopal 1987).

Another equally notable species is *Prosopis*. The species was introduced from south and central America to many parts of the world, to meet the fuel wood requirement and thus reduce the pressure on indigenous forests (Geesing *et al*. 2004; Mwangi and Swallow 2005). Unfortunately, and as has been the case with a number of such introduced species, *Prosopis* came to invade large swathes of landscape and be associated with a number of negative impacts. Control measures proved to be quite unsuccessful. However over time, with its naturalization in many parts of the world, *Prosopis* has come to be used as an important resource (Geesing *et al*. 2004; Mwangi and Swallow 2005). In Niger and Yemen, *Prosopis* has been exploited for fuelwood, free-grazing forage, construction materials, and pods are even used to make biscuits (Geesing *et al*. 2004).

The flowers of *Prosopis* species are regarded as a valuable source of bee forage, and honey has become the food product most often derived from *Prosopis* (Geesing *et al*. 2004). In Niger and Mauritania, *Prosopis* plantations have been established for sand dune stabilization (Jensen and Hajej 2001), restoration of degraded land in Cape Verde, and remediation of saline land in India. It has also been used as shelterbelts, with animal fodder and other uses as co-products (Geesing *et al*. 2004). It has been estimated that the annual income generated by selling *Prosopis* wood in the rural market would yield 3.25 million US dollars per annum (Boureima *et al*. 2001). In an interesting experiment, more than 500 women and farmers have been trained in making *Prosopis* flour for making food for human consumption and also to utilize this new bio-resource (Geesing *et al*. 2004).

Our final example is of *Optunia* cacti that were introduced into South Africa in 1700 (Larsson 2004). Over the next three centuries, *Optunia* invaded virtually all parts of South Africa with few effective control systems in place. Again, as in the case of Water Hyacinth and *Prosopis*, local ingenuity found that the fruits of the invasive *Opuntia ficus-indica*, could serve as an important food resource for humans, and the cladodes as fodder for the livestock (Larsson 2004). More recently, new products such as Prickly Pear wine and jam are being made from the fruit (Shackleton *et al*. 2007). However, in Australia, Opuntia was successfully contained by biological control agent *Cactoblastis cactorum* (Parsons and Cuthbertson 2001; Tu *et al*. 2001). At present, *Opuntia* spp. remains as isolated and scattered populations (Greenfield and Nicholson 2007).

The three examples presented above are all symptomatic of invasive species that represent the far end of the temporal dynamics curve (Fig. 14.2). Having spread far and wide, they have either attained what one might refer to as a stable equilibrium condition or at best a stable phase in their invasion. Management options at this stage, as mentioned earlier, are very limited, basically because of the impracticability of management. In fact in all of the three examples listed above, the costs of containment may not be justified by the damage avoided. It is under these conditions that the species in question lend themselves to alternate management streams including using them as resource. While the latter approach does not classify itself as conventional in so far as controlling invasive species goes, it can, as argued earlier, be viewed as an alternative nevertheless that aims to use the resource and thereby lead to a reduction in the net cost of the species.

In fact, a number of invasive species the world over have been incorporated into the daily livelihoods of people (Table 14.1). Why would communities use alien invasive species? Kannan *et al*. (*in press*) conjectured that among other factors the following may be the common drivers that compel communities to use resources that they hitherto had no knowledge of: a) availability of the invasive species in abundance—towards the end of their logistic expansion and stable phase the invasive species become quite abundant and, in a typical ecosystem setting, perhaps constitute the predominant vegetation community; b) zero investment resource—invasive species are frequently a zero-investment resource, freely available for harvest, in fact, forest managers and farmers alike, in most circumstances, would be very willing to have their forest or field cleared of the invasive; c) substitutability of invasive species with some locally available but rare or otherwise expensive resource—invasive species could offer a suitable if not a perfect substitute for an existing resource, that is either scarce or is expensive; d) opportunity cost of collection and utilization—because of their abundance and substitutability, the opportunity cost of collection and utilization of many invasive species is very low.

14.3 The specific case of *Lantana* in India

14.3.1 Invasion, spread, and ecosystem impacts

Lantana camara (hereafter referred to as *Lantana*) is one of the most notable alien invasive plant species with a pan-continental distribution. Native to Central and South America, the plant is now reportedly distributed and established in over 60 countries around the world (Parsons and Cuthbertson 2001; Day *et al*. 2003). The plant has been considered one of the worst weeds recorded in

Table 14.1 Some examples of use of invasive species

Sl no	Invasive species	Uses	References
1	*Lantana camara*	Basket, furniture, charcoal, medicine, toys	Joshi 2002; Kannan *et al*. *In Press*
2	*Eichhornia crassipes*	Pillows, furniture and carpets	http://www.water-hyacinth.com/crafts.html http://ecosyn.us/ecocity/Links/My_Links_Pages/water_hyacinth01.html
		High quality paper and cattle feed	Nolan and Kirmse, 1974 http://itdg.org/docs/technical_information_service/water_hyacinth_control.pdf
		Bioconversion of water-hyacinth hemicellulose acid hydrolysate to motor fuel ethanol by xylose–fermenting yeast	Nigam 2002
		Used for fiber board, fertilizer, cooking wood and cultivation of mushrooms, briquettes, sewage treatment, animal feed production and mushroom cultivation and composting	http://library.thinkquest.org/C0126023/uses.htm Haider 1989
3	*Prosopis spp*.	Fuel wood, fencing poles, furniture, food, honey and charcoal, wood flooring	http://www.gardenorganic.org.uk/pdfs/international_programme/Prosopis-PolicyBrief-1.pdf http://www.vetiver.org/OT_prosopis.htm Geesing *et al*. 2007
4	*Opuntia ficus-indica*	Fruits	Shackleton *et al*. 2007
5	*Oreochromis mossambicus*	Food for humans and Zoo animals	Dahanukar *et al*. 2005 (Cited in McGarry *et al*. 2005)
6	*Mimosa pigra*	Fuel wood	http://www.worldagroforestrycentre.org/Sea/Products/AFDbases/AF/asp/SpeciesInfo.asp?SpID=672

human history (Cronk and Fuller 1995). *Lantana* has usurped numerous native plants of their niches as well as unsettling farm lands and forest gaps. Forest managers and farmers alike are at their wits end to control the weed (Ganeshaiah and Uma Shaanker 2001).

Lantana was introduced into India at the National Botanical Gardens, Calcutta in 1807, as an ornamental plant by the British (Thakur *et al*. 1992). Since then, the plant has successfully invaded virtually all parts of the country (Fig. 14.3). In India, it is distributed from the sub-montane regions of the outer Himalayas to the southernmost part of India, occurring in every forest type from about 400 m above sea level (ASL) and above (Thakur *et al*. 1992). Millions of hectares of grazing land as well as agricultural lands are infested by the weed. It forms the major undergrowth in forestry plantations (Singh 1976) and is generally found to be associated with anthropogenic disturbances (Ganeshaiah and Uma Shaanker 2001). An ecological niche model of the species indicated that among the possible sites of invasion, two of the country's megadiversity hotspots, namely, the Western Ghats and the Eastern Himalayas are also very suitable and thus prone for invasion by the plant (Fig. 14.3).

Innumerable studies have been conducted to assess the impacts of *Lantana* on ecosystems and ecosystem services. While most of them demonstrate an adverse effect, a few studies have shown a positive effect of the plant. A brief summary of the impacts of *Lantana* is presented in Table 14.2.

Several methods for controlling *Lantana*, including chemical, mechanical, fire, and biological controls have been used but with limited success (see review in Day *et al*. 2003; Davis *et al*. 1992). Fire is one of the cheapest methods for controlling *Lantana* and is often used in grazing areas. However, mature *Lantana* is fire tolerant and re-growth from seeds and basal shoots is common. Extensive efforts have been made to find effective biocontrol agents for

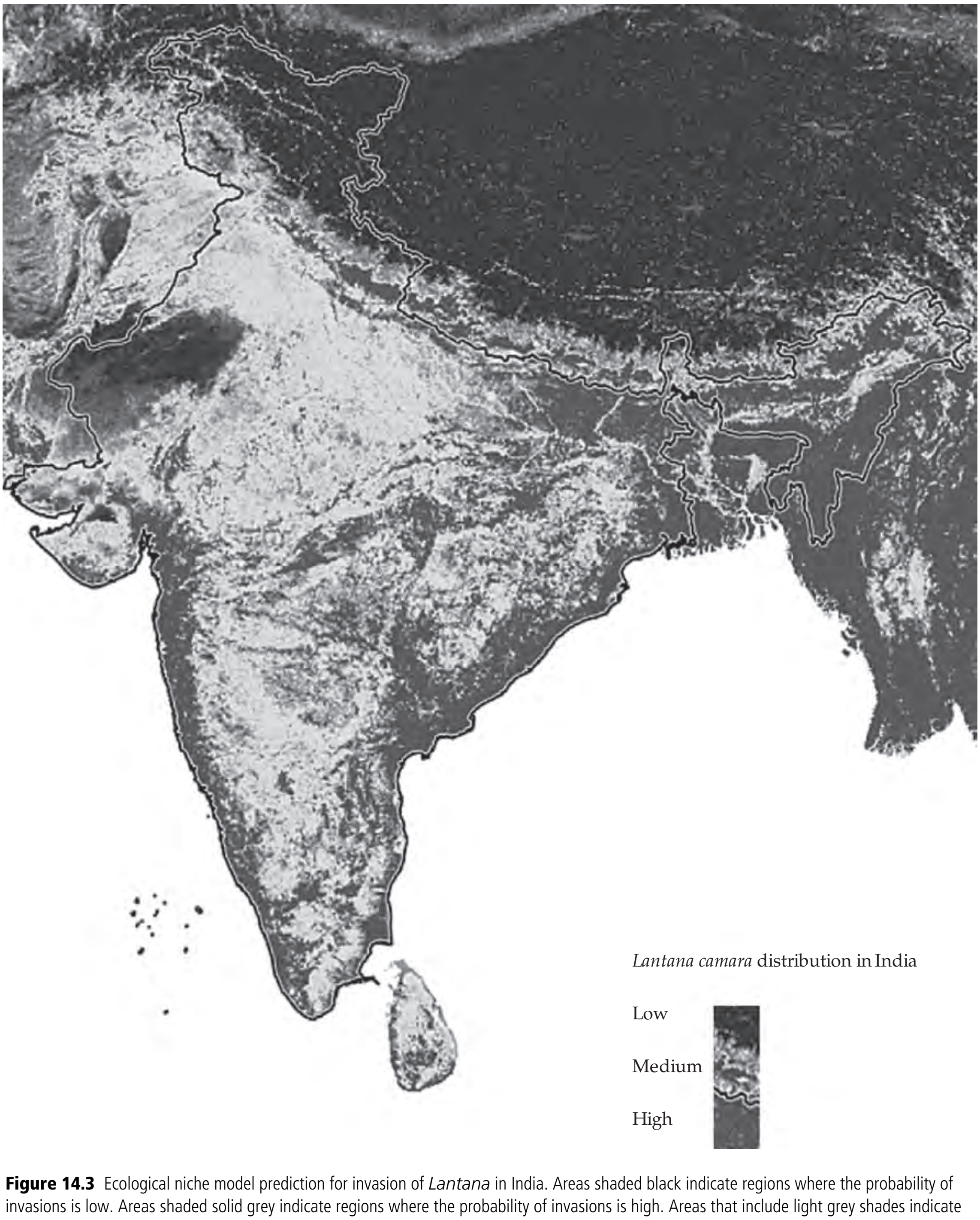

Figure 14.3 Ecological niche model prediction for invasion of *Lantana* in India. Areas shaded black indicate regions where the probability of invasions is low. Areas shaded solid grey indicate regions where the probability of invasions is high. Areas that include light grey shades indicate regions where the probability of invasions is intermediate. Note that both the biodiversity hotspots are highly prone for invasion. Inset: Cumulative increase in records of Lantana in published floras in India. (Courtsey: Map of the ecological niche model prediction from Mohammed Irfan, ATREE, Bangalore).

Table 14.2 Summary of the studies of impacts of *Lantana* on ecosystem and ecosystem services

Effect	References
Positive effects	
Increases regeneration of native species*	Murali and Setty 2001
Increased soil nutrient pools and nutrient mobility	Lamb 1982
Increases soil nutrients	Wilson 1968; Lamb 1982
Increases regeneration of non timber forest products	Ganesan *Pers. Comm*
Antifungal potential in soil	Shaukat and Siddiqui *et al*. 2001
Antimicrobial, fungicidal, insecticidal, and nematicidal activity, but not antiviral activity	Chavan and Nikam 1982; Sharma and Sharma 1989
Lantana pulp is used for writing and printing paper	Gujral and Vasudevan 1983
Used as a cover crop in deforested areas and also used to enrich the soil and protect against erosion	Anon. 1962; Greathead 1968; Willson 1968; Ghisalberti 2000
Negative effects	
Decrease in regeneration of native species*	Jain *et al*. 1989
Decrease in biodiversity	Lamb 1991; Lyon and French 1991
Decrease in species richness	Fensham *et al*. 1994
Contamination of gene pool of native *Lantana* species	Sanders 1987; Anon. 1999
Threat to native species of *Lantana* from competition	Sanders 1987, 2001
Reduces the pollinator loads of native plants	Feinsinger 1987
Extinction of the shrub *Linum cratericola*	Mauchamp *et al*. 1998
Alters fire regime	Humphries and Stanton 1992
Affects human health by harboring malarial mosquitoes and tsetse flies	Gujral and Vasudevan 1983; Greathead 1968; Katabazi 1983; Okoth and Kapaata 1987; Mbulamberi 1990
Allelopathic effects, resulting in either no growth or reduced growth	Achhireddy and Singh 1984; Achhireddy *et al*. 1985; Mersie and Singh 1987; Sharma *et al*. 1988; Jain *et al*. 1989; Singh and Achhireddy 1987
Decrease in community biomass and a proportional increase in the foliage component in the vegetation	Bhatt *et al*. 1994
Loss of pasture land	Culvenor 1985
Threat to agriculture	Holm *et al*. 1991
Poisoning of cattle, buffalo, sheep, goats horses and dogs, guinea pigs and captive red kangaroos	Sharma *et al*. 1988
Unripe fruit are mildly poisonous	Morton 1994; Sharma 1994

Lantana (Cilliers 1983; Greathead 1968; Harley 1973; Neser and Cilliers 1989; Perkins and Swezey 1924). Unfortunately most of these attempts have been unsuccessful in India and elsewhere in the world (Julien and Griffiths 1998).

The invasion and current spread of *Lantana* across the world represents a typical case of a successful invasive species through its temporal dynamics of initial establishment, logistic spread and, finally, successful colonization and establishment (the stable phase). Management options at this stage (as mentioned above) are few and even if deployed would be expensive and futile. Save for the discovery of a silver bullet, the species has come to stay in most places of its invasion. Managers have their backs to the wall, just as for the cases of Water Hyacinth, *Optunia*, and *Prosopis*. The cost of containing *Lantana* may not justify the damage avoided.

Under these circumstances, as we have argued earlier, one of the strategies could be to look at the possible utilization of the invasive and explore whether this can lead to an adaptive management of the invasive in a manner that would reduce the net cost of the species, by partially offsetting both control and damage costs. Here we present a case

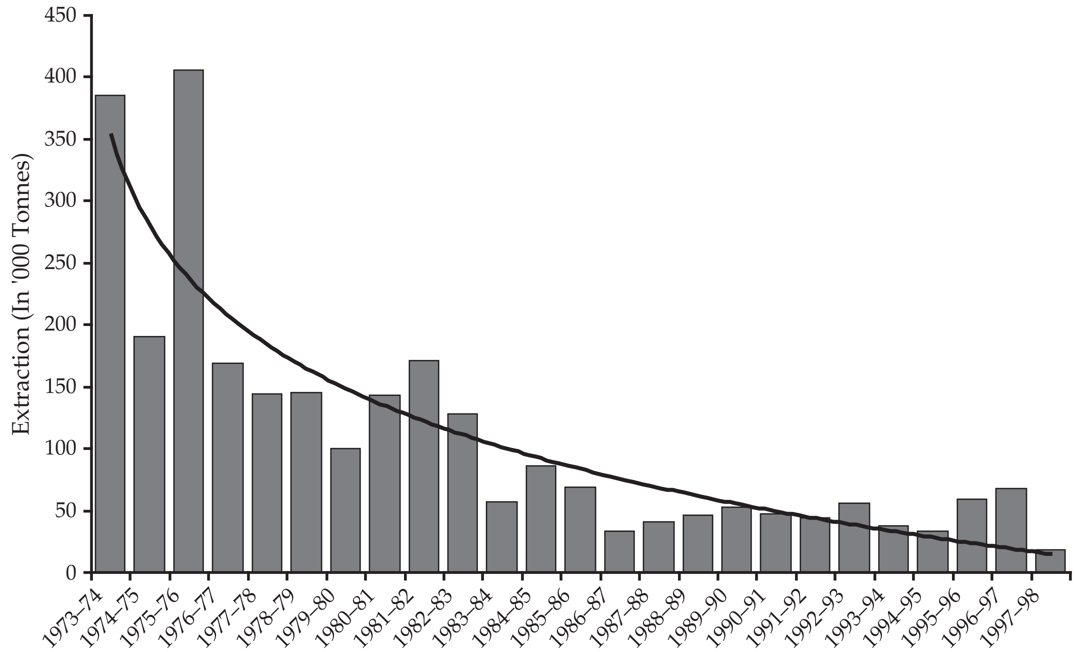

Figure 14.4 Decline of bamboo yields in Karnataka, India (From Uma Shaanker *et al*. 2004b).

study of a recent initiative that encouraged the use of *Lantana* among the marginalized communities in southern India.

14.3.2 When you cannot break it, at least bend it!

In India, a number of forest dwelling communities depend almost exclusively on forest resources for their livelihood (Murali *et al*. 1996). Among these communities are the *Medars* and *Koravas* and a number of scheduled castes and tribal communities, such as the *Soligas* (Uma Shaanker *et al*. 2004b). These traditional weaving communities are often hereditarily dependent on bamboo and cane resources, with most of them having no other means of livelihood (Uma Shaanker *et al*. 2004b). In recent years, indiscriminate extraction of bamboo and canes (the two materials most preferred for weaving) has severely depleted the natural stocks and in many places has directly threatened the livelihoods and further marginalized these communities (Uma Shaanker *et al*. 2004b; Fig. 14.4). Lack of alternative sources of income and land tenure has further aggravated these marginalized communities (Uma Shaanker *et al*. 2004b). Any effort that can offer an appropriate substitute for the declining wild bamboo and rattan resources could make a substantial difference to their livelihood.

Kannan *et al*. (2008) explored the possibility of using the locally abundant invasive species, *Lantana*, as a substitute for bamboo and canes such that a) it could maintain or even enhance the livelihoods of the traditional weaving communities dependent upon scarce bamboo resources and b) alleviate the stress on natural population of bamboo and canes and therefore help in conserving native biological diversity.

Lantana forms one of the most dominant plant communities in the open forest, roadsides, wastelands, and fallows. Typically with dry to moist deciduous vegetation, most forest sites have been invaded by *Lantana*. At one site, namely MM Hills, Karnataka State, nearly 80 per cent of the 290 km^2 of the forest has been invaded by *Lantana* (Ganeshaiah and Uma Shaanker 2001). The density of the weed ranged from 932 stems ha^{-1} in moist

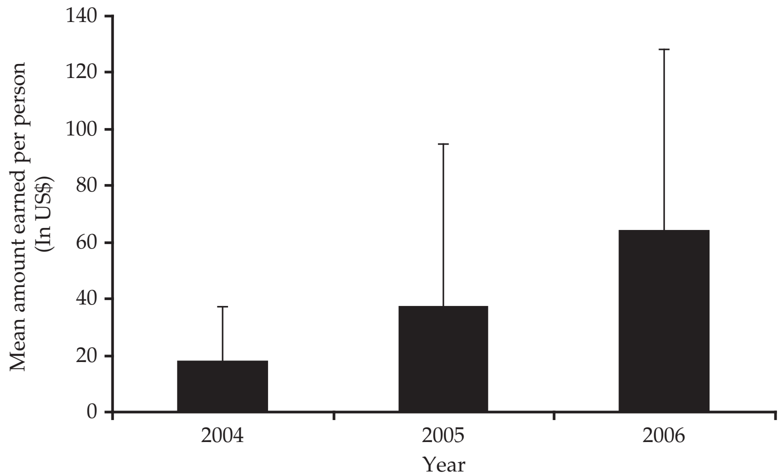

Figure 14.5 Mean per capita increase in cash income of artisans using *Lantana* as a substitute for bamboo and canes (From Kannan *et al. In press*).

deciduous forest to 1941 stems ha^{-1} in dry deciduous forest (Ganeshaiah and Uma Shaanker 2001). At none of the sites was *Lantana* ever used as a resource with cash value; its only use was as a hedge plant around fields to protect crops from cattle and wild animals.

Kannan *et al*. (2008) promoted the use of *Lantana* as a substitute for bamboo and canes and helped designed appropriate *Lantana* products for rural and urban markets. Over 350 men and women were trained in the use of Lantana at several field sites in south India. More than 50 different products, from baskets to furniture were developed. The average number of man-days employed in *Lantana* craft increased from about 30 in 2004 to above 80 man-days in 2006 (Kannan *et al. in press*). For the same period, the mean annual income per capita from *Lantana* increased from US$ 17.90 to US$ 63.93 (Fig. 14.5). There was a significant increase in the annual income of families after adoption of *Lantana* craft compared to that before adoption ($p < 0.035$; $df = 8$).

In summary, the use of *Lantana* as a substitute for bamboo and canes significantly enhanced the income profile of the forest-based communities at several field sites in south India. Having been sensitized to the income generating potential of a resource that they had not regarded as convertible to cash income, use of *Lantana* provides a safety net for the very poor and marginalized tribal communities.

While this initiative was prompted by the immediate need to alleviate the livelihoods of the forest dwelling communities, viewed in the context of managing invasive species it offers an unconventional approach to contributing to minimizing the net cost of the invasive species. For instance, the use of *Lantana* could allow for the regeneration and recruitment of native plant species and mitigate other ecosystem damages such as pollinator loss. The stems, when harvested, provide a window of time during which regeneration of at least some native plants might be facilitated. The extraction of the weed might also help in reducing the spread of forest fires, which otherwise are fanned by *Lantana* stems, and also offer greater accessibility for both animals as well as men.

In other words, the use of the weed by the local communities provides for both reducing the control as well as damage costs of the species. However, it is obvious that these mitigating effects would be dependent upon the scale at which *Lantana* is being used as also in the manifold ways through which the invasive species could be used. For instance, in a more recent initiative, there has been an attempt at biorefining abundant biomass (typical of invasive species) for chemical prospecting (Uma Shaanker and Ganeshaiah 2006).

Clearly such innovative exploitation of "uncontrollable invasive species" would tend to substantially reduce the control and damage costs and hence allow for a net minimization of the cost of invasive species.

The use of *Lantana* as a substitute for the dwindling wild bamboo and cane resources by poor rural communities in India provides a new perspective on the use of invasives (Shackleton *et al*. 2007). The approach is easily replicable elsewhere in the world and could have important implications for much of the human-dominated forested landscapes in the world. The idea has already found favor in Madagascar and Sri Lanka, both to address problems with local livelihoods and to prevent the spread of this invasive weed (Kannan *et al. in press*).

Careful management of the use of invasive species should lead to interesting outcomes in its ecological and livelihood impacts. Can the use of the invasive be sustainable (and should this be of interest?). What are the potential conflicts in the use of the invasive species on one hand (by the poor) and the control of the invasive (by the forest managers)? Can the managed use of the invasive lead to a win-win situation for both the ecological services and functions that are otherwise impaired by the invasive species and the livelihood gains it might accrue to the communities? Ralph Waldo Emerson (1803–82) once quipped *"What is a weed? A plant whose virtues have not been discovered"* (1878). The work reported on the use of *Lantana* by Kannan *et al*. (2008) quite well exemplifies this quip.

14.4 The management of uncontrollable invasive species: from exclusion to inclusion

The current views on managing invasive species stem from the fact that these species frequently have high ecological and economic costs. While the weight of evidence does justify this view, management, or the lack of it, has often resulted in invasive species occupying a predominant ecological space that is simply beyond any control measures. Under these circumstances, our currently held view has often constrained the development of alternate management regimes to address the issue of invasive species. One of these alternate strategies that we have argued for in this chapter is to promote the utilization of the invasive species as one of the means to manage it. This approach might appear unconventional and at times defeat the entire purpose of controlling the invasive species. However, as argued earlier, viewed from the point of minimizing the net cost of the invasive, exploitation of the invasive could represent one possible approach towards this end. Thus, when conventional management options are no longer cost effective and the invasive species has come to a state of stabilization in the ecosystem, it might be worthwhile to reach out to alternative strategies even if it means exploiting the species. Under these circumstances we argue that any action (including promoting the use of the invasive) that can reduce the ecological cost of the invasive should be a potentially useful strategy. In short, this calls for a shift in our view of managing invasive species, from one of exclusion to that of inclusion. This may not only be pragmatic but also realistic, especially in tropical human-dominated landscapes where low income and the abundance of the invasive species constrain effective control, while the lack of rural options encourages utilization of invasive species. In this context, invasive species, especially those that have escaped effective control, could be viewed from a potential utilization point of view, as a specific case of management. This view is aptly summarized by Geesing *et al*. 2004, who mention in their defense of the use of *Prosopis*:

> Notwithstanding the unquestionable ecological changes produced by *Prosopis* invasion, where the species have been introduced it is necessary to make the best of a situation that is hardly reversible.

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References

Achhireddy, N.R. and Singh, M. (1984). Allelopathic effects of *Lantana* (*Lantana camara*) on milkweed vine (*Morrenia odorata*). *Weed Science*, 32, 757–61.

Achhireddy, N.R., Singh, M., Achhireddy, L.L., Nigg, H.N. and Nagy, S. (1985). Isolation and partial characterization of phytotoxic compounds from *Lantana* (*Lantana camara* L.). *Journal of Chemical Ecology*, 11, 979–88.

Anderson, L.W. (2003). California's Reaction to *Caulerpa taxifolia*: A model for invasive species rapid response actions. In Abstracts: Third International Conference on Marine Bioinvasions, March 16–19, 2003. Scripps Institution of Oceanography La Jolla, California. http://massbay.mit.edu/resources/pdf/MarinePDF/2003/MBI2003abs1.pdf.

Anon. (1962). *Lantana* Linn. (Verbenaceae), In B.N. Sastri, ed. *The Wealth of India: A Dictionary of Raw Materials and Industrial Products*, vol VI, Council of Scientific and Industrial Research, New Delhi, pp. 31–34.

Atkinson, C.T., Dusek, R.J., Woods, K.L. and Iko, W.M. (2000). Pathogenicity of avian malaria in experimentally-infected Hawaii Amakihi. *Journal of Wildlife Diseases*, 36, 197–204.

Atkinson, C.T., Woods, K.L., Dusek, R.J., Sileo, L.S. and Iko, K.W. (1995). Wildlife disease and conservation in Hawaii: pathogenicity of avian malaria (*Plasmodium relictum*) in experimentally infected I'iwi (*Vestiaria coccinea*). *Parasitology*, 111 Suppl., S59–S69.

Bhatt, Y.D., Rawat, Y.S. and Singh, S.P. (1994). Changes in ecosystem functioning after replacement of forest by *Lantana* shrubland in Kumaun Himalaya. *Journal of Vegetation Science*, 5, 67–70.

Boureima, M., Mayaki, A. and Issa, M. (2001). *Etudes socioeconomiques sur la commercialization des produits et sous-produits de la foret de* Prosopis *et sur la mise en place des marches ruraux dans l' arrondissement N'Guigmi*. Niamey, the Niger Institut national de recherches agronomiques du niger (INRAN) and FAO.

Braithwaite R.W., Lonsdale, W.M. and Estbergs, J.A. (1989). Alien vegetation and native biota in tropical Australia: the impact of *Mimosa pigra*. *Biological Conservation*, 48, 189–210.

Braithwaite, R.W. and Lonsdale, W.M. (1987). The rarity of *Sminthopsis virginiae* in relation to natural and unnatural habitats. *Conservation Biology*, 1, 341–43.

Chavan, S.R. and Nikam, S.T. (1982). Investigation of *Lantana camara* L. (Verbenaceae) leaves for larvicidal activity. *Bulletin of Haffkine Institute*, 10, 21–22.

Cilliers, C.J. (1983). The weed, *Lantana camara* L., and the insect natural enemies imported for its biological control in South Africa. *Journal of the Entomological Society of Southern Africa*, 46, 131–38.

Cronk, Q.C.B. and Fuller, J.L. (1995). *Plant Invaders*. Chapman and Hall, London, pp. 82–87.

Culvenor, C.C.J. (1985). Economic loss due to poisonous plants in Australia. In A.A. Seawright, M.P. Hegarty, L.F. James and R.F. Keeler, eds. *Proceedings of the Australia-U.S.A. Poisonous Plants Symposium*, Brisbane, Australia, pp. 3–13.

D'Antonio, C.M. and Kark, S. (2002). Impacts and Extent of Biotic Invasions in Terrestrial Ecosystems. *Trends in Ecology and Evolution*, 17, 202–04.

Davis, C.J., Yoshioka, E. and Kageler, D. (1992). Biological control of Lantana, prickly pear, and Hamakua Pamakani in Hawaii: a review and update. In C.P. Stone, C.W. Smith and J.T. Tunison, eds. *Alien Plant Invasions in Native Ecosystems of Hawaii: Management and Research*, Cooperative National Park Resources Studies Unit, Hawaii, pp. 411–31.

Day, M.D., Wiley, C.J., Playford, J. and Zalucki, M.P. (2003). *Lantana Current Management Status and Future Prospects*. ACIAR Monograph 102, Canberra.

Dunbar, K.R. and Facelli, J.M. (1999). The impact of a novel invasive species, *Orbea variegata* (African carrion flower), on the chenopod shrublands of South Australia. *Journal of Arid Environment*, 41, 37–48.

Emerson, R.W. (1878). Fortune of the Republic. In The *Complete Works of Ralph Waldo Emerson*. Ams Pr Inc.

Feinsinger, P. (1987). Effects of plant species on each others pollination: Is community structure influenced? *Trends in Ecology and Evolution*, 2, 123–26.

Fensham, R.J., Fairfax, R.J. and Cannell, R.J. (1994). The invasion of *Lantara camara* L. in Forty Mile Scrub National Park, north Queensland. *Australian Journal of Ecology*, 19, 297–305.

Ganeshaiah, K.N. and Uma Shaanker, R. (2001). Impact of invasive species on the diversity, health and productivity of ecosystems: A study in the tropical forests of south India. Report submitted to CIFOR, Indonesia.

Geesing, D., Al-Khawlani, M. and Abba, M.L. (2004). Management of introduced Prosopis species: can economic exploitation control an invasive species? *Unasylva*, 217, 36–44.

Ghazoul, J. (2001). Direct and indirect effect of human disturbance on the reproductive ecology of tropical forest trees. In K.N. Ganeshaiah, R. Uma Shaanker and K.S. Bawa, eds. *Tropical Ecosystems: Structure, Diversity and Human Welfare*, Oxford-IBH Publications, New Delhi, pp. 97–100.

Ghisalberti, E.L. (2000). *Lantana camara* L. (Verbenaceae). *Fitoterapia* 71, 467–86.

Gopal, B. (1987). *Water Hyacinth*. Aquatic Plant Studies, 1. Elsevier Science Publishing Co., New York.

Greathead, D.J. (1968). Biological control of *Lantana*. A review and discussion of recent developments in East Africa. *Proceedings of National Academy of Science*, 14, 167–75.

Greenfield, B. and Nicholson, H. (2007). SA Arid Lands *Opuntia* species management plan, DRAFT. South Australian Arid Lands Natural Resource Management Board.

Gujral, G.S. and Vasudevan, P. (1983). *Lantana camara* L., a problem weed. *Journal of Scientific and Industrial Research*, 42, 281–86.

Gurevitch, J. and Padilla, D. (2004). Are invasive species a major cause of extinctions? *Trends in Ecology and Evolution*, 19, 470–74.

Haider, S.Z. (1989). *Recent Work in Bangladesh on the Utilization of Water Hyacinth*, Commonwealth Science Council/ Dhaka University, Dhaka.

Harley, K.L.S. (1973). Biological control of *Lantana* in Australia. In A.J. Wapshere, ed. *Proceedings of the III International Symposium on Biological Control of Weeds*, Montpellier, France, pp. 23–29.

Hegde, R., Suryaprakash, S., Achoth, L. and Bawa, K.S. (1996). Extraction of NTFPs in the forests of BR Hills 1. Contribution to rural income. *Economic Botany*, 50, 243–50.

Hobbs, R.J. and Humphries, S.E. (1994). An integrated approach to the ecology and management of plant invasion. *Conservation Biology*, 9, 761–70.

Hobbs, R.J. and Mooney, H.A. (1986). Community changes following shrub invasion of grassland. *Oecologia*, 70, 508–13.

Holm, L.G., Plucknett, D.L., Pancho, J.V. and Herberger, J.P. (1991). *The World's Worst Weeds: Distribution and Biology*. Krieger Publishing Company, Florida.

Humphries, S.E. and Stanton, J.P. (1992). *Weed Assessment in the Wet Tropics World Heritage Area of north Queensland*. Report to The Wet Tropics Management Agency.

Humphries, S.E., Groves, R.H. and Mitchell, D.S. (1991). Plant invasions of Australian ecosystems: a status review and management directions. *Kowari*, 2, 1–134.

Jain, R., M. Singh and Dezman, D.J. (1989). Qualitative and quantitative characterization of phenolic compounds from *Lantana* (*Lantana camara*) leaves. *Weed Science*, 37, 302–07.

Jenkins, C.D., Temple, S.A., Van Riper, C. and Hansen, W.R. (1989). Disease-related aspects of conserving the endangered Hawaiian crow. In J.E. Cooper, ed. *Disease and Threatened Birds. ICBP Technical Publication Number 10*. International Council for Bird Preservation, Cambridge, U.K., pp. 77–87.

Jensen, A. M. and Hajej, M.S. (2001). The road of hope: control of moving sand dunes in Mauritania. *Unasylva*, 207, 31–36.

Joshi, A.P. (2002). *Lantana*. Himalayan Environment Studies and Conservation Organisation (HESCO), Dehra Dun.

Jules, E.S., Kauffman, M.J., Ritts, W.D. and Carroll, A.l. (2002). Spread of an invasive pathogen over a variable landscape: A nonnative root rot on port orford cedar. *Ecology*, 83, 3167–81.

Julien, M.H. and Griffiths, M.W. (1998). *Biological Control of Weeds: A World Catalogue of Agents and their Target Weeds*. Fourth Edition, CAB International, Wallingford.

Julien, M.H., Hill, M.P., Center T.D. and Jianquig, D. (eds). (2001). *Biological and Integrated Control of Water Hyacinth Eichhornia crassipes*. Proceedings PR102 2001.

Kannan, R., Aravind N.A., Joseph, G., Uma Shaanker, R. and Ganeshaiah, K.N. Invasive weed aids livelihoods: *Lantana* as a substitute for bamboo in South India. *Conservation and Society*, In *Press*.

Kannan, R., Aravind, N.A., Joseph, G., Ganeshaiah, K.N. and Uma Shaanker, R. (2008). Lantana Craft: A Weed for a Need. *Biotech News*, 3, 9–11.

Katabazi, B.K. (1983). The tsetse fly *Glossina fuscipes* in the sleeping sickness epidemic area of Busoga, Uganda. *East African Medical Journal*, 60, 397–01.

Lamb, D. (1991). Forest regeneration research for reserve management: some questions deserving answers. In N. Goudberg, M. Bonell and D. Benzaken, eds. *Tropical Rainforest Research in Australia: present status and future directions for the Institute for Tropical Rainforest Studies*, pp. 177–81. Institute for Tropical Rainforest Studies.

Lamb, R. (1982). Some effects of *Lantana camara* on community dynamics of eucalypt woodland, pp. 304. *Proceedings of the 52nd ANZAAS Congress*, Townsville.

Larsson, P. (2004). *Introduced Opuntia spp. in Madagascar, problems and opportunities*. SLU External Relations, SLU. Minor field studies/Swedish University of Agricultural Sciences, SLU External Relations. Vol. 285.

Levine, J.M., Vila, M., D'Antonio, C.M., Dukes, J.S., Grigulis, K. and Lavorel, S. (2003). Mechanisms underlying the impacts of exotic plant invasions. *Proceedings of Royal Society of London, B*, 270, 775–81.

Loyn, R.H. and French, K. (1991). Birds and environmental weeds in south-eastern Australia. *Plant Protection Quarterly*, 6, 137–49.

Luken, J.O. and Thieret, J.W. (eds). (1997). *Assessment and management of plant invas*ions. Springer-Verlag, Inc., New York.

Martin, P.H. (1999). Norway maple (*Acer platanoides*) invasion of a natural forest stand: understorey consequences and regeneration pattern. *Biological Invasions*, 1, 215–22.

Matthews, S. (2004). *Tropical Asia invaded: the growing danger of invasive alien species*. The Global Invasive Species Programme (GISP) Secretariat, Cape Town, South Africa. Available at: www.gisp.org/downloadpubs/gispAsia.pdf

Mauchamp, A., Aldaz, I., Ortiz, E. and Valdebenito, H. (1998). Threatened species, a re-evaluation of the status of eight endemic plants of the Galápagos. *Biodiversity and Conservation*, 7, 97–107.

Mbulamberi, D.B. (1990). Recent outbreaks of human trypanosomiasis in Uganda. *Insect Science and its Application*, 11, 289–92.

McGarry, D., Shackleton, C.M., Fourie, S. *et al*. (eds). (2005). *A Rapid Assessment of the Effects of Invasive Species on Human Livelihoods, Especially of the Rural Poor*. pp. 210. South African National Biodiversity Institute, Kirstenbosch.

McNeely, J. (2000). Invasive species: a costly catastrophe for native biodiversity. *Land Use and Water Resources Research*, 2, 1–10.

Mersie, W. and Singh, M. (1987). Allelopathic effect of *Lantana* on some agronomic crops and weeds. *Plant Soil*, 98, 25–30.

Mooney, H.A. and Hobbs, R.J. (2000). *Invasive Species in a Changing World*. Island Press, Washington, DC.

Morton, O. (1994). *Marine algae of Northern Ireland*. Ulster Museum, Belfast.

Murali, K.S. and Siddapa Setty, R. (2001). Effect of weeds *Lantana camara* and *Chromelina odorata* growth on the species diversity, regeneration and stem density of tree and shrub layer in BRT sanctuary. *Current Science*, 80, 675–78.

Murali, K.S., Uma Shankar, Uma Shaanker, R., Ganeshaiah, K.N. and Bawa, K.S. (1996). Extraction of NTFPs in the forests of BR Hills 2. Impact of NTFPs extraction on regeneration, population structure and species composition. *Economic Botany*, 50, 251–69.

Mwangi, E. and Swallow, B. (2005). Invasion of *Prosopis juliflora* and local livelihoods: Case study from the lake Baringo area of Kenya. ICRAF Working Paper– no. 3. World Agroforestry Centre, Nairobi.

National Academy of Sciences. (1976). *Making Aquatic Weeds Useful: Some Perspectives for Developing Countries*, National Academy of Sciences, Washington DC.

National Centre for Human Settlements and Environment. (1987). *Documentation of Forest and Rights. Volume* 1. National Centre for Human Settlements and Environment, New Delhi.

Navarro, L.A. and Phiri, G. (eds). (2000). Water hyacinth in africa and the middle east. A Survey of Problems and Solutions, International Development Research Centre (IDRC), Ottawa.

Neser, S. and Cilliers, C.J. (1989). Work towards biological control of *Lantana camara*: perspectives. In E.S. Delfosse, ed. *Proceedings of the VII International Symposium on Biological Control of Weeds*, Rome, Italy, pp. 363–69.

Nigam, J.N. (2002). Bioconversion of water-hyacinth (*Eichhornia crassipes*) hemicellulose acid hydrolysate to motor fuel ethanol by xylose–fermenting yeast. *Journal of Biotechnology*, 97, 107–16.

Nolan, W.J. and Kirmse, D.W. (1974). The Papermaking Properties of Water Hyacinth, *Hyacinth Control Journal*, 12, 90.

Okoth, J.O. and Kapaata, R. (1987). A study of the resting sites of *Glossina fuscipes fuscipes* (Newstead) in relation to *Lantana camara* thickets and coffee and banana plantations in the sleeping sickness epidemic focus, Busoga, Uganda. *Insect Science and its Application*, 8, 57–60.

Parker I.M., Simberloff, D., Lonsdale, W.M. *et al*. (1999). Impact: toward a framework for understanding the ecological effects of invaders. *Biological Invasions*, 1, 3–19.

Parsons, W.T. and Cuthbertson, E.G. (2001). *Noxious Weeds of Australia*, 2nd edition, CSIRO Publishing, Collingwood.

Perkins, R.C.L. and Swezey, O.H. (1924). The introduction into Hawaii of insects that attack *Lantana*. *Bulletin of the Experiment Station of the Hawaiian Sugar Planters' Association* 16, 1–83.

Perrings, C. (2005). *Biological Invasions and Poverty*. [online] URL: http: www.gisp.org/publications/brochures/invasivesandpoverty.pdf

Perrings, C., Williamson, M., and Dalmazzone, S. (2000). *The Economics of Biological Invasions*. Edward Elgar, Cheltenham, UK/Northampton, USA.

Pimentel, D., Lach, L., Zuniga, R. and Morrison, D. (2000). Environmental and Economic Costs of Nonindigenous Species in the United States. *BioScience*, 50, 53–65.

Pimentel, D., McNair, S., Janecka, J. *et al*. (2001). Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment*, 84, 1–20.

Sanders, R.W. (1987). Taxonomic significance of chromosome observations in Caribbean species of *Lantana* (Verbenaceae). *American Journal of Botany*, 74, 914–20.

Sanders, R.W. (2001). The genera of Verbenaceae in the southeastern United States. *Harvard Papers in Botany*, 5, 303–58.

Schmitz D.C., Simberloff, D., Hofstetter, R.H., Haller, W. and Sutton, D. (1997). The ecological impact of non-indigenous plants. In D. Simberloff, D.C. Schmitz and T.C. Brown, eds. *Strangers in Paradise: Impact and Management of Nonindigenous Species in Florida*, Island Press, Washington, D.C., pp. 39–61.

Secretariat of the Convention on Biological Diversity. (2005). *Handbook of the Convention on Biological Diversity Including its Cartagena Protocol on Biosafety*, 3rd edition. Montreal, Canada.

Shackleton, C.M., McGarry, D., Fourie, S., Gambiza, J., Shackleton, S.E. and Fabricius, C. (2007). Assessing the Effects of Invasive Alien Species on Rural Livelihoods: Case Examples and a Framework from South Africa. *Human Ecology*, 35, 113–27.

Sharma, O.P. (1994). Plant toxicosis in north–western India. In M.S. Colgate and P.R. Dorling, ed. *Plant associated Toxins: Agricultural, Phytochemical and Ecological Aspects*, pp. 19–24. CAB International, Wallingford.

Sharma, O.P. and Sharma, P.D. (1989). Natural products of the *Lantana* plant- the present and prospects. *Journal of Scientific and Industrial Research*, 48, 471–78.

Sharma, O.P., Makkar, H.P.S. and Dawra, R.K. (1988). A review of the noxious plant *Lantana camara. Toxicon*, 26, 975–87.

Shaukat, S.S., Siddiqui, I.A., Ali, N.I. and Zaki, M.J. (2001). Biological and chemical control of soilborne fungi and effect of these on growth of mungbean. *Pakistan Journal of Biological Sciences*, 4, 1240–3.

Siges, T.H., Hartemink, A.E., Hebinck P., and Allen, B.J. (2005). The Invasive shrub *Piper aduncum* and rural livelihoods in the Finschhafen area of Papua New Guinea. Human *Ecology*, 33, 875–92.

Simberloff, D., (1998). A Global Threat to Biodiversity and Stability. In P.H. Raven, ed. *Nature and Human Society*, National Research Council (U.S.), Board on Biology, Tania Williams, pp. 325–34.

Singh, M. and Achhireddy, N.R. (1987). Influence of *Lantana* on growth of various citrus rootstocks. *HortScience*, 22, 385–86.

Singh, P. (1976). *Lantana* weed and the *Lantana* lacebug. *Indian Forester*, 102, 474–76.

Thakur, M.L., Ahmad, M., and Thakur, R.K. (1992). *Lantana* weed (*Lantana camara* var. *aculeata* Linn.) and its possible management through natural insect pests in India. *Indian Forester*, 118, 466–86.

Tu, M., Hurd, C., and Randall, J.M. (2001). *Weed Control Methods Handbook: Tools and Techniques for Use in Natural Areas*. Wildland Invasive Species Program, The Nature Conservancy.

Uma Shaanker, R. and Ganeshaiah, K.N. (2006). Bioresources for Human Well-Being: Promises and Challenges. Abstract. Renewable Resources and Biofefineries Conference, 6th–8th September, 2006, University of York, UK.

Uma Shaanker, R., Ganeshaiah, K.N., Smitha Krishnan, *et al*. (2004a). Livelihood gains and ecological costs of non timber forest product dependence: assessing the roles of dependence, ecological knowledge and market structure in three contrasting human and ecological settings in south India. *Environmental Conservation*, 31, 242–53.

Uma Shaanker, R., Ganeshaiah, K.N., Srinivasan, K., Ramanatha Rao, V. and Hong, L.T. (2004b). *Bamboos and Rattans of the Western Ghats: Population biology, Socio-economics and Conservation strategies*. ATREE, IPGRI and UAS, Bangalore.

Van Riper III, C.S., Van Riper, S.G., Goff, M.L. and Laird, M. (1986). The epizootiology and ecological significance of malaria in the Hawaiian land birds. *Ecological Monographs*, 56, 327–44.

Van Wilgen, B.W. and Van Wyk, E. (1999). Invading alien plants in South Africa: Impacts and solutions. In, D. Eldridge and D. Freudenberger, eds., *People and Rangelands: Building the Future*. Proceedings of the VI International Rangeland Congress, Townsville, Australia, pp. 566–71.

Vitousek P.M. and Walker L.R. (1989). Biological invasions by *Myrica faya* in Hawaii: plant demography, nitrogen fixation, ecosystem effects. *Ecological Monographs*, 59, 247–65.

Vitousek, P. M., Walker, L.R., Whiteaker, L.D., Mueller-Dombois D., and Matson, P.A. (1997). Biological invasion by *Myrica faya* alters ecosystems development in Hawaii. *Science*, 238, 802–04.

Vivrette, N.J. and Muller, C.H. (1977). Mechanism of invasion and dominance of coastal grassland by *Mesembryanthemum crystallinum*. *Ecological Monographs*, 47, 301–18.

Walker, B.H. and Steffen, W. (1997). An overview of the implications of global change for natural and managed terrestrial ecosystems. *Conservation Ecology*, 1, 2. Available from the Internet. [online] URL:http://www.consecol.org/voll/iss2/art2.

Warner, R.E. (1968). The role of introduced diseases in the extinction of the endemic Hawaiian avifauna. *Condor*, 70, 101–20.

Wikelski, M., Foufopoulos, J., Vargas, H. and Snell, H. (2004). Galápagos Birds and Diseases: Invasive Pathogens as Threats for Island Species. *Ecology and Society* 9, 5. [online] URL: http://www.ecologyandsociety.org/vol9/iss1/art5/

Williamson, M. (1996). *Biological Invasions*. Chapman and Hall, London

Willson, B.W. (1968). Insects on trial in fight against *Lantana*. *Queensland Agricultural Journal*, (December), 748–51.

Wootton, L.S., Halsey, S.D., Bevaart, K., McGough, A., Ondreicka, J. and Patel, P. (2005). When invasive species have benefits as well as costs: managing Carex kobomugi (Asiatic sand sedge) in New Jersey's coastal dunes. *Biological Invasions*, 7, 1017–1027.