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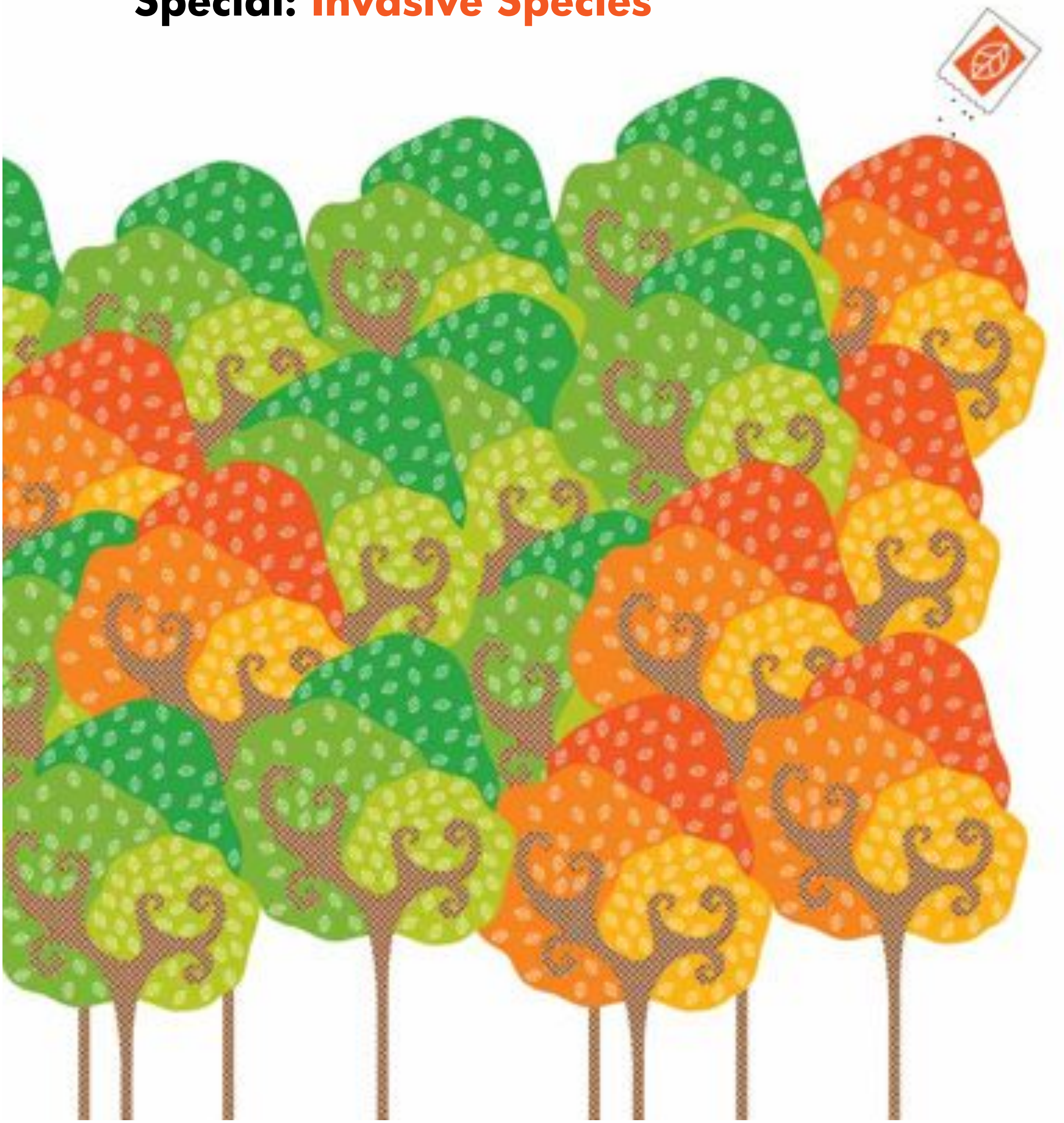
Special: Invasive Species



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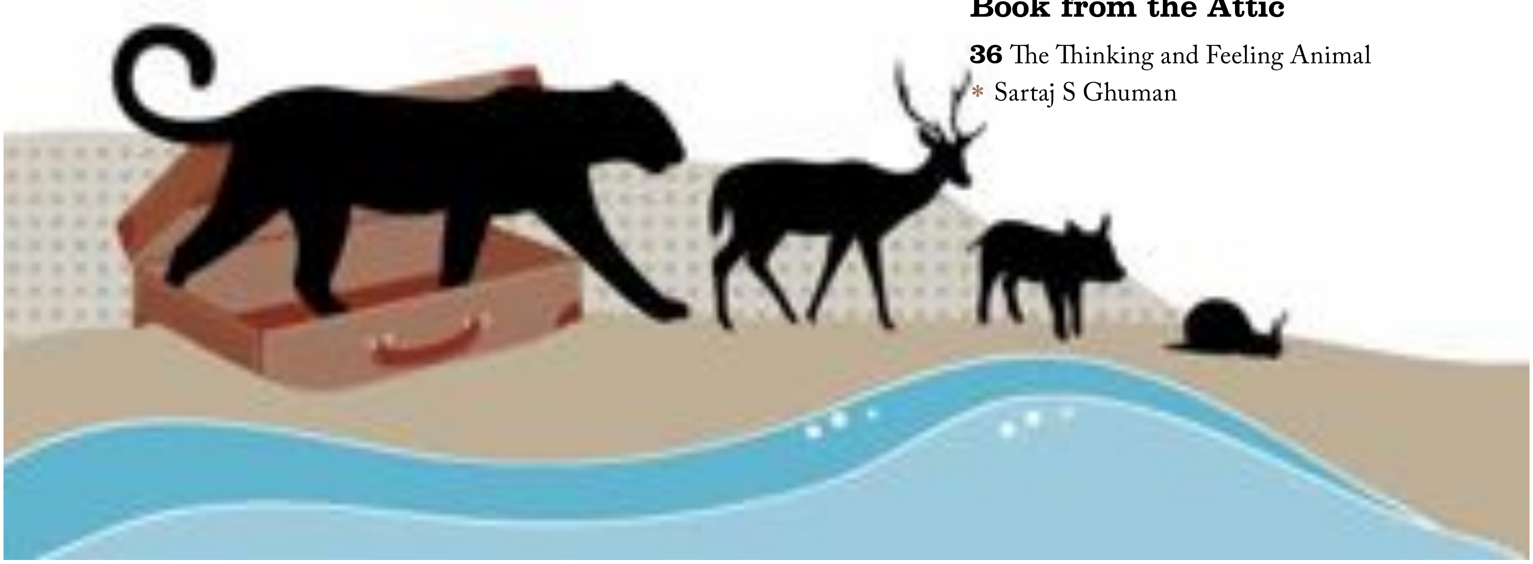
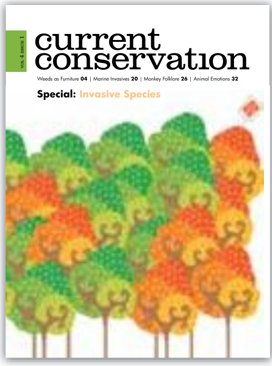
Kalyani Ganapathy



editor's note



Cover art by Kalyani Ganapathy

Invasive species are a part of our lives, so much so that we don't even notice that a number of the plants and animals around us are foreigners. More importantly, their impact on native biodiversity goes unnoticed. In this issue, we have contributions from distinguished scholars working on a diverse assemblage of invasive species, and within these pages you will find some unlikely invaders—elephants in the Andamans, mosquitoes in Hawaii, and domestic cats everywhere.

Over the past three years Current Conservation has been a source of research news and conservation stories, but from this volume onwards we are bringing about a change in our profile to include a broader variety of material, a new look, and a revamped website to engage those of you interested in conservation, science or simply just nature.

For instance, are books ever too old to be read? We introduce a new book review section—'Book from the Attic', where we solicit reviews of dated, but nonetheless pivotal, books that have changed the way we view the natural world around us. And what better book to inaugurate this section than one of Darwin's? Page 36 reviews Darwin and his thoughts on animal emotions.

As Current Conservation transforms into this new avatar, we solicit your participation, feedback and any input you may care to give us. We look forward to hearing from you.

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Photo: Kalyan Varma | Artwork: Pallavi Baasri

RED LIGHT AREAS PREVENT CLOSE ENCOUNTERS

A novel warning system to alert villagers to passing elephants could reduce human-elephant conflict on the Valparai plateau in Tamil Nadu, southern India, a mosaic of plantations (predominantly tea), woodlots and rainforest fragments.

Home to one of the largest populations of elephants in the region, the plateau sees frequent interactions between people and elephants that result in accidental human fatalities, usually late in the evening or at nighttime, when elephant movement is hard to see.

But a new initiative by M Ananda Kumar and colleagues at the Nature Conservation Foundation, Mysore, could change all that. In association with the corporations, running the plantations, the Forest Department, media, and women's self-help groups, Kumar and his team plan to install flashing red lights activated by GSM based technology mounted on poles near colonies and bus stops. These 'Elephant Alert Indicators,' seen from up to a kilometer away, will flash red when elephants are in the vicinity, allowing locals to use alternative routes or wait till the lights are turned off. Kumar and his team, who have documented elephant-human conflict in Valparai since 2002, hope to build on the success of earlier initiatives. The team previously introduced a system that allows villagers to learn of elephant herd movement across the plateau through cable TV. The movements of the elephant herds appeared on a news ticker across the screen of a local television channel through the evenings.

Technology offers promising solutions to conservation problems, says Kumar.

Selling Nests to Save Birds

The indiscriminate poaching of swiftlet nests could be ended while at the same time allowing simultaneous sustainable harvest of nests in the Andaman Islands, India, according to a bold initiative by scientists and forest officers.

Edible-nest swiftlets are widely distributed across south and southeast Asia, and their nests are the main ingredient in bird-nests soup, a popular dish in the Orient region. Valued at US$ 400/kg in the international market, poachers in India can earn up to Rs. 10,000/kg of nests harvested. Poaching of nests from caves prevents birds from raising young, and the subspecies of swiftlet on the Andaman Islands is under threat. Efforts to control this by including the species in Schedule I of the Indian Wildlife Protection Act (according it the highest degree of protection) failed, given the difficulty of monitoring caves in inhospitable terrain. The solution could lie in a unique program initiated by the late Ravi Sankaran and now executed by Shirish Manchi, Salim Ali Centre for Ornithology and Natural History, Coimbatore in association with the Andamans Forest Department. The program employs poachers to protect caves (numbering 181), and nests are harvested after the first breeding cycle.

Additionally, birds are translocated to abandoned buildings in order to establish breeding centres similar to those in Southeast Asia. Cross-fostering of chicks from caves to the buildings will eventually encourage more birds to breed in the buildings, given that the species is philopatric. Nests are kept in the custody of the forest department, and their sale will be monitored by a co-operative society (comprising of forest department, local communities and biologists). The team persuaded the Indian Government to deregister the species from Schedule I on a probation basis for 3 years, during which this controversial program will be monitored.

Shirish Manchi

Fast Facts

* Nests in caves in groups
* Build nest out of saliva
* Build nest for every brood
* Nest philopatry (return to breed in the cave they were born in)

Biological Invasions:
from ecology to human well-being

Kalyani Ganapathy

Every so often, an introduced species tends to become dominant in its de novo environment, competing with native species, altering the structure and functioning of native ecosystems, and doing untold ecological and economic damage.

People have moved species from one part of the globe to another throughout human history. For the most part species introductions have been deliberate—most of the food we eat, the fibres we use, the plants in our gardens, have their origins in distant parts of the world. Occasionally, species introductions have been inadvertent or accidental—as hitchhikers on deliberate introductions, or, increasingly, as a collateral to growing global travel and trade. Every so often, an introduced species tends to become dominant in its de novo environment, competing with native species, altering the structure and functioning of native ecosystems, and doing untold ecological and economic damage: the arrival of avian malaria in the Hawaiian islands led to the extinction of several bird species unique to the archipelago, and to the decline of many others; introduced grasses have altered fire regimes, thereby changing ecosystem structure, composition, and dynamics in the Americas; introduced trees are reducing water flow into aquifers and affecting water supply to Cape Town in South Africa. These are examples of what have come to be known as invasive alien species, 'invasive' a reference to the ecological damage they cause, and 'alien' a reference to their non-native biogeographical provenance. So great is the concern about invasive alien species today, that the international Convention on Biological Diversity has ranked them amongst the foremost threats to biodiversity and ecosystem functioning.

A British biologist, Charles Elton, was amongst the earliest to draw attention to the problem of invasive species in the late 1950s. He was concerned that with increasing human-aided movement of species around the planet, the uniqueness and distinctness of biodiversity in different parts of the world was in danger of being homogenised. He cautioned that though not all alien species were necessarily invasive, those that were could have devastating impacts. He also cautioned that the potential danger from invasive alien species was likely to be greatest on oceanic islands, with their unique but vulnerable biota, and in disturbed environments, where available resources could be readily preempted by invasive species.

Today there is a great deal of interest, both in what makes certain species more invasive than others, and in what makes certain ecosystems more vulnerable to invasion than others—questions that can provide insights into how ecosystems are assembled. These questions also have tremendous practical significance for the conservation of biodiversity and the services that society derives from ecosystems, as they can provide us with tools to predict which species are most likely to become invasive, and can enable us to model invasive species spread and to prioritise management interventions. There is also growing interest in evaluating the economic consequences of invasive species for human well being, and in developing appropriate policies and capacities for invasive species prevention, control, or mitigation.

This special feature brings together a collection of articles that showcases a diversity of concerns related to invasive alien species. Perrings et al. examine the economic and policy aspects of the problem of biological invasions at a global scale, especially with respect to global trade. The authors include microorganisms in their definition of biological invasive species, thus encompassing issues of emergent and recurrent human diseases. Their assertion, that the problem of invasive species is the most significant environmental issue facing humanity, is therefore not surprising.

Volin reviews work on *Lygodium microphyllum*, a climbing fern native to the Old World and now widespread in the southeastern USA. This article illustrates the kinds of information, across scales, required to understand the ecological underpinnings of a species' invasiveness; such information can aid the search for appropriate control methods and enable predictive modeling of the species' spread, of value for managers and policy makers.

Three of the articles focus on *Lantana camara* in India, undoubtedly a reflection of lantana's status as amongst India's most widespread terrestrial invasive species. However, they examine very different aspects of lantana—Sharma and Raghubanshi focus on its ecological impacts, Babu et al. talk about mitigation and control, and Shaanker et al. propose adaptation and related livelihoods. The article by Sharma and Raghubanshi draws on their work on the impacts of lantana on biodiversity and ecosystem functioning. They also propose that lantana's invasive success may not be explained by any one characteristic of the species but rather, could be attributed to multiple mechanisms. Babu et al. describe a method they have designed to control lantana and restore native species and ecosystem functioning, which may have high benefits, particularly in protected areas.

The management of invasive species can have complex effects on livelihoods and ecology, as illustrated by both Shaanker et al. and by Shackleton and Gambiza. Shaanker et al. argue that once an invasive species has become widespread it may be best to live with it and enable local communities to draw a livelihood from it, thus reducing the costs of control. Shackleton and Gambiza draw our attention to *Euryops floribundus*, a native invasive species in South Africa; its eradication, though of benefit to livestock owners, would adversely affect women who depend on it for fuel.

Rauf Ali is dismissive of the focus on what he terms the 'page 3 species,' including lantana. Instead, he draws attention to the vulnerability of island ecosystems, in this case the Andaman islands, to invasions. His choice of invasive species—both elephants and chital are native to the Indian mainland—helps underscore an important point, that 'alien' is a biogeographical rather than a political concept. His choice of invasive species also underscores the cultural obstacles to our dealing with animal invasive species.

Namboothri and Shanker draw our attention to *Kappaphycus alvarezii*, a marine invasive species, and its relationship with industrial production of soft drinks. Cola production has created an economic interest in the species, to the extent that arguments are made contesting the species' invasiveness. Who bears the burden of proof? Should we adopt the precautionary principle? This collection of summaries informs us that there are a great diversity of biologically invasive species and contexts, with some fundamental uncertainties but possibly great implications for human welfare.

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feature | R Uma Shaanker, Gladwin Joseph, NA Aravind, R Kanan, KN Ganeshaiah

Making chairs for conservation

Ramesh Kannan

Women artisans at work at the Lantana Craft Centre, Ramagalli, MM Hills

Some say putting a weed to good use is the best way to control it. Can this novel strategy result in a win-win for multiple interest groups?

The management of invasives has focussed on preventing and containing invasive species and thereby mitigating their impacts on local biodiversity, ecosystem functioning, and human health. However, apart from a few examples, such management has been only partly successful while being very costly. The management of invasive species is especially challenging in tropical human-dominated landscapes. Invasive species can exacerbate the biodiversity crisis by reducing population densities of native species, many of which are important for livelihoods of the rural poor. Invasive species could potentially lead to further marginalisation of these impoverished people. But the reverse is also true. In tropical human-dominated landscapes invasive species are often viewed as resources that can provide potential economic benefits to the poor. Control of invasive species in these habitats may lead to loss of rural livelihoods. 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. In these countries, invasive species control may have to be weighed against the resulting loss. This challenges conventional wisdom about managing invasive species, at least for tropical landscapes. This also creates an interesting dilemma: to control or not to control. Mainstream research on management of invasive species has scarcely addressed this question.

Management decisions do not conform to a 'one size fits all', and a suite of different strategies-including exploitation of the invasive at some stage of its invasion -rather than a single strategy, could be regarded as an approach to minimizing the net costs. Optimising management strategies for invasive species requires evaluating the full range of costs and benefits of alternative control options. The following questions can be considered: a) 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, b) at what threshold (or when), should management effort be considered to have failed (i.e., when are benefits due to control actually less than the damage costs)?

Kalyani Ganapathy

We expect the ecological impact of an invasive species to be low at an early stage soon after introduction but before it has spread widely (the 'lag phase'). The impacts of the invasive species are likely to increase during the subsequent exponential growth ('logistic') and stabilisation ('equilibrium') phases (see figure). In the early stages of invasion, eradication is generally preferred, both because the marginal costs are low and because the potential benefits are large. Ironically, often no management effort is initiated at this stage, either because the ecological costs are small or because they are not yet perceived. As both the abundance and the impacts of the invasion increase, management investments start being made. Most management, though expensive, tends to be deployed during this phase. In the last, stable phase, management interventions are not only very expensive but tend also to be the least successful. regarded as futile. But should management options to control invasive species at this stage be abandoned? Could alternate management strategies be developed?

From a management perspective, the increasing ecological cost of invasive species should be weighed against any benefits that may accrue. In the range of options available for management, one can allow for the entire spectrum from complete eradication to adaptive management (wherein the species can actually be gainfully used; *http://tncweeds.ucdavis.htm*). Today, a number of species are notorious for being invasive across the world, and notable among them are *Eichhornia, Prosopis,* and *Opuntia*. Control tor management of these invasive species, especially in tropical human-dominated landscapes, with traditionally

Lantana toys and furniture at the Krishi Mela 2010, University of Agricultural Sciences, Bangalore

poor economies, has been nearly absent or woefully unsuccessful. Over time, though, at least some of these invasive species have blended into the local ecosystems and become integrated into the livelihoods of people for two reasons.

First, invasive species tend to be abundant and freely available for harvest. Second, invasive species can offer a suitable, if not a perfect, substitute for existing resources that are scarce or expensive. Abundance and substitutability result in low opportunity cost of collection and utilisation.

If you cannot break it, at least bend it!

The invasion and current spread of lantana across the world represents a typical case of a successful invasive species. Management options for lantana are few, expensive, and possibly futile. One potential management strategy, therefore, would be the utilisation of lantana. Could this lead to adaptive management of lantana in a manner that would reduce the net cost of the species by partially offsetting both control and damage costs? We present a case study of a recent initiative that encouraged the use of lantana among marginalised communities in southern India. A number of forest dwelling communities in India depend almost exclusively on forest resources for their livelihood. On such community, the Soligas, were hereditarily dependent on bamboo and cane resources. In recent years indiscriminate extraction has severely depleted the natural stocks of cane and bamboo, and has directly threatened their principal source of livelihood. An appropriate substitute for the declining wild bamboo and rattan resources could make a substantial difference to the Soligas.

We explored the possibility of using the locally abundant invasive species, lantana, as a substitute for bamboo and canes to maintain or even enhance the livelihoods of these communities, while alleviating the stress on beleaguered populations of bamboo and canes. Kannan and colleagues promoted the use of lantana as a substitute for bamboo and canes and 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 person-days of employment in lantana craft increased from about

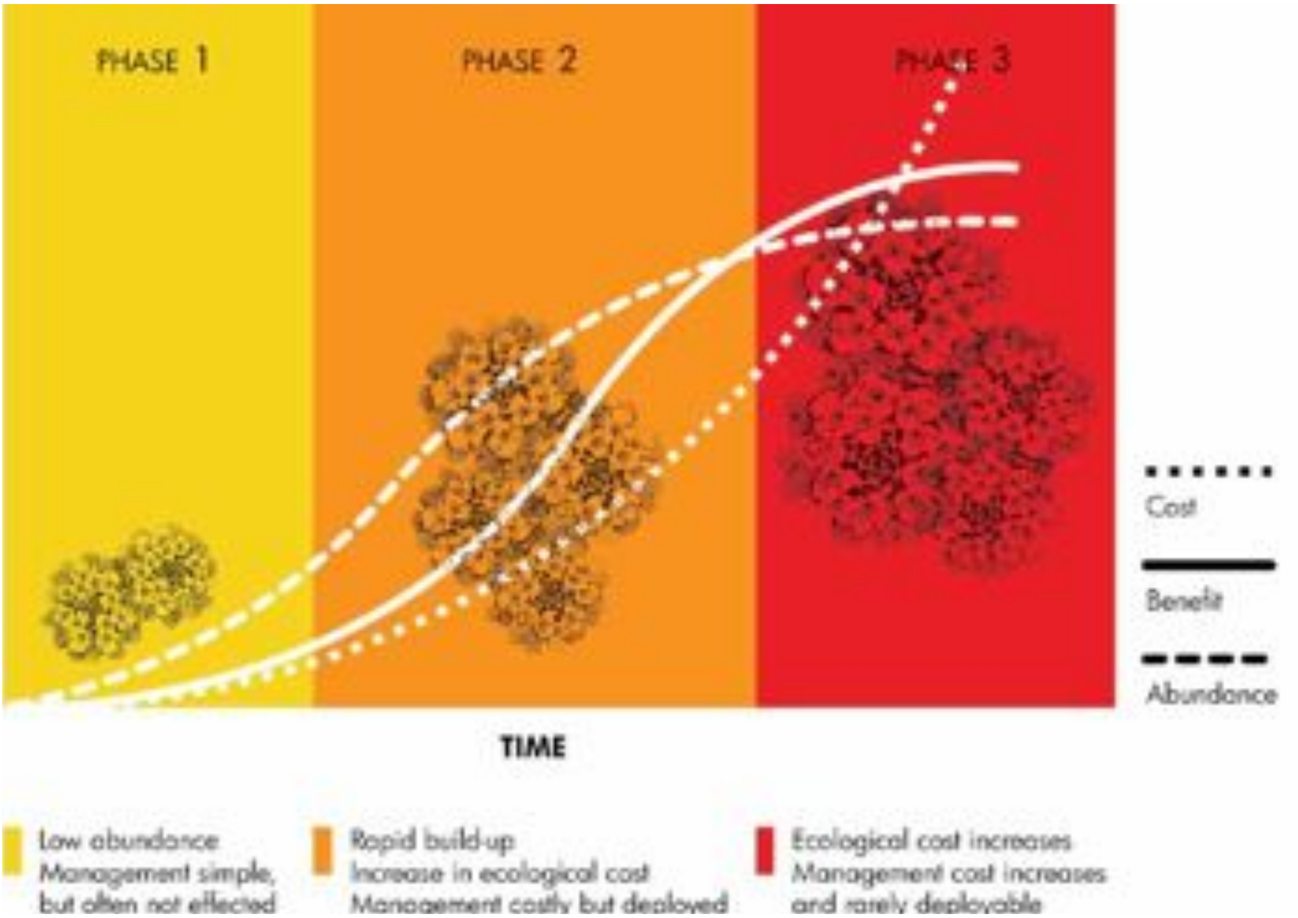

Photo: Ramesh Kannan | Infographic: Pallavi Baasri

Schematic representation of the temporal dymanics of an invasive species, showing the change in associated ecological costs over time; also shown is the pattern of benefits from the invasive species (in the event of its use)

30 in 2004 to more than 80 in 2006. Over the same period, the mean annual per capita income from lantana increased from US$ 17.90 to US$ 63.93, a significant jump.

Viewed in the context of managing invasive species, this initiative offers an unconventional approach to minimising the net cost: the use of lantana could allow for the regeneration and recruitment of native species and mitigate other ecosystem damages such as pollinator loss; the harvest of lantana could provide a window of opportunity for the regeneration of at least some native plants; and the extraction of the weed might help in reducing the incidence of forest fires, which otherwise are fanned by lantana and also offer greater accessibility for both animals as well as people. Of course, these mitigating effects would depend on the scale and the ways in which lantana is eventually used.

From exclusion to inclusion

Any action (including promoting the use of the invasive) that can reduce the ecological cost of the invasive is a potentially useful strategy. A shift in our view of managing invasive species, from one of exclusion to that of inclusion may be pragmatic, particularly in tropical human-dominate landscapes where low income and the abundance of the invasive species constrain effective control, while the lack of rural options encourages utilisation. For example, Geesing and colleagues defend the use of *Prosopis* thus, "Notwithstanding the unquestionable ecological changes produced by *Prosopis* invasion, where the species has been introduced it is necessary to make the best of a situation that is hardly reversible."

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feature | Suresh Babu, Amit Love, Cherukuri Raghavendra Babu

Resolution to Restore

No half measures work in eradicating persistent invaders. Complete eradication with local participation is the only long-term solution. Weed infested landscapes, with drastically diminished ecosystem functions, offer unique challenges and opportunities for restoration. Weeds hinder the regeneration of a productive native community.

Protected areas (PAs) across India today are invaded by alien invasive species that include *Lantana camara*, *Mikania micrantha*, *Chromolaena odorata*, *Ageratum conyzoides*, *Parthenium hysterophorus* and *Hyptis suaveolens*. Although difficult, restoring landscapes colonized by invasive species is important for the conservation of biodiversity and for the sustenance of other ecosystem services.

Lantana (*Lantana camara*), one of the world's most troublesome weeds, has virtually invaded all the tropical and subtropical regions of India. Although attempts have been made to control lantana by physical, chemical and biological methods, there has been little success either in its control or in the prevention of its spread. The control methods in use at present remain inadquate and infeasible owing to the sheer magnitude of the infestations, low land values, and lack of incentives for control. The lack of understanding of the species' biology and lack of site-specific information of its ecology are major bottlenecks in developing effective tools for its management. It has yet to be recognised, for instance, that habitat degradation has triggered the invasion of lantana and that a final solution has to come in the form of habitat restoration. The methods that have been in practice for controlling lantana typically included chopping the main stem at the base, clipping aerial shoots and burning the clumps, and uprooting. Although these methods do bring about a short term reduction in the cover of lantana, with the onset of monsoons, profuse coppicing from multiple growing points occurs. Clipping is totally ineffective and only causes the clumps to spread and become hardier. Burning results in coppicing from the buried meristematic zone and also increases soil erosion. Burning on a large scale is normally not resorted to in PAs, besides the fact that this practice may actually be advantageous to the weed in the long run. Uprooting, besides being labor intensive, disturbs the soil, exposes the buried seeds of lantana, and leads to their rapid germination.

Building on past experience with lantana management, and on the basis of a systematic assessment of its biology (the magnitude of its spread, its phenology, the distribution of growth points from which the plant resprouts or coppices, its architecture-including root system-soil microbiology and seed dispersal strategies) we ventured to develop a new management strategy, the 'cut rootstock method'. This method involves the of lantana by cutting below the rootstock (see photograph), which we determined, experimentally, to be the most effective way of preventing it from coppicing. This is followed by ecological restoration using locally available legumes and grasses. Landscapes where lantana has been removed using this method need to be re-weeded, especially under trees where the bird dispersers of lantana perch. lantana removal must be followed by restoration of weed-free landscapes, preferably of grassland or forest communities depending on the needs of stakeholders, to prevent re invasion by lantana or secondary invasion by other alien species. The new strategy was developed using experimental plots at Laldhang and Jhirna at Corbett Tiger Reserve and has subsequently been

Pallavi Baasri

implemented successfully in other parts of Corbett (Uttarakhand), Kalesar National Park (Haryana) and Satpura Tiger Reserve (Madhya Pradesh).

The two experimental plots at Corbett have been the flagships of this control strategy that involved effective removal and ecological restoration of 'weed-free landscapes'. The plots were browsed by chital and there was some mortality, but it was not a serious impediment because herbivore numbers were small, since this area had been a settlement till quite recently. We were able to achieve high survival rates (measured on an annual basis) for tree saplings because of modification of soil conditions and the habitat by short grasses such as *Penisetum ciliaris*, *Eulaliopsis binata*, *Heteropogon contortus*, *Paspalidium scrobicularis*, *Cynodon dactylon*, and *Sporobolus indicus*, as well as leguminous species like *Desmodium gangeticum*, *D. triflorum*, *Flemingia bracteata*, *F. fruticosa*, *F. macrophylla*, *Indigofera astragalina*, and *I. hirsuta*). The experimental plots are now fully covered with a carpet of several grass species and legumes, with scattered trees. At Laldhang, the Corbett management has scaled up the restoration plot to 64 ha. The area was fenced off due to frequent instances of cattle grazing from nearby villages. This plot now harbours luxuriant grassland with few interspersed trees and diverse avifauna. The Jhirna plot was left unfenced because there was no cattle grazing. This plot is now frequented by large herds of such browsers as chital and sambar, which form the major prey base for carnivores. So far there have been several recorded tiger sightings at Jhirna in the vicinity of the restoration plot (including carcasses of kills within the plots). The two plots established at Jhirna and Laldhang, using the integrated control and restoration strategy outlined above, are now used for demonstration of the technique. At both sites the original relative density of lantana clumps varied from 80% to 100% and the areas were devoid of native species except for a few scattered trees that served as perches for bird dispersers of lantana. Within 2 years of the restoration program at Corbett (June 2005 to June

2007), both demonstration plots harbored grassland communities with annual and perennial native grasses and legumes. Several workshops and hands-on training programs were also held to enable foresters and park managers to scale up the lantana control and restoration measures, with field visits to the plots and demonstration of the technique employed. Various aspects of this model including the costs and benefits of clearing lantana and then converting the landscape into productive grasslands and woodlands, were highlighted to gain wider acceptance for the model. A simple manual was developed and widely circulated to aid foresters in removing lantana by the cut-rootstock method and to identify the grasses and legumes used in the Corbett model.

Subsequently, other forest managers of Uttarakhand State have adopted this technique. These forests include the Rajaji National Park, Landsdowne Forest Division, and Nainital Forest Division. In Corbett itself, lantana has been removed from over 2500 ha and restoration of these patches is in progress under the supervision of the park management. The advantages of the new management strategy over other control methods currently used are its cost effectiveness, its simplicity and ease of adoption and the successful control of lantana that the technique ensures, without the use of chemicals or exotic biological control agents, and with minimal disturbance of the soil. One of the major reasons for the popularity of the cut-rootstock method has been the fact that the restored patches do not require care after the first two years, since all the species used are native. Forest departments of other states, convinced by the effectiveness of the approach, have already removed lantana from several hundred hectares of forest land, particularly around Panchmarhi Biosphere Reserve in Madhya Pradesh and Kalesar National Park in Haryana. However, as we have learned from our experience in Corbett, the ultimate success of such a program relies heavily on the conviction and motivation of stakeholders. Landscapes degraded by invasive species are often extensive, and even as weeds are eradicated from one area, propagule pressure and thus, reinvasion, can persist due to the continuing presence of weeds in other areas.

A well-coordinated removal program followed by restoration at suitably large scales is necessary to tilt the scales in favor of native species. A strong determination by the park managers was crucial for the success of such a program. The benefits of lantana eradication and subsequent restoration to grasslands in Corbett have been many:

Suresh Babu

Top: *The Laldhang experimental plot as a lantana monoculture*
Above: *As luxuriant grassland with interspersed trees after restoration*

enhanced biological productivity, particularly in terms of palatable species of grasses and legumes; greater retention of soil moisture; prevention of soil erosion; enrichment of native biodiversity; the increased frequency of wildlife sightings; and enhanced recreational values, since Corbett is a favorite destination for eco-tourists and ornithologists.

We anticipate that our observations on lantana management in Corbett and the success of the Corbett model will help in developing similar management strategies for other PAs that are presently overrun by lantana and also other weeds such as *Mikania micrantha*, *Chromolaena odorata* and *Parthenium hysterophorus*. However, any restoration program for these other invasive species would also need to be informed by an understanding of the biology of the invader, the local soil and micro climatic conditions, the status of the ecosystem, the larger landscape matrix, and most importantly, the requirements of the stakeholders.

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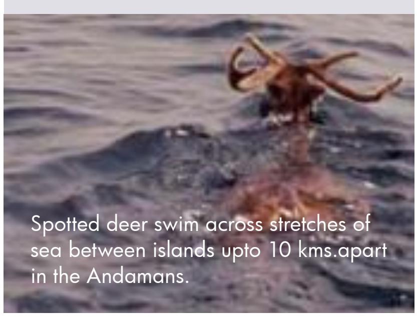
Controlling Invasives

The loud mating calls of introduced Coqui frogs cause sleepless nights for residents in Hawaii. The frog problem has become so acute that it has reduced the value of invaded properties. Locals spray citric acid or bleach to kill the frogs, and scientists are now experimenting with infecting the frogs with a nematode parasite found in their native Puerto Rico.

Populations of coconut rhinoceros beetle accidentally introduced to islands of the South Pacific are kept in check with bio-control measures. Researchers feed a virus from Malaysia to healthy beetles that are then released to infect the rest of the population. The virus destroys the stomach walls, causing beetles to stop eating.

The mile-a-minute weed (*Mikania micrantha*), a fast-growing creeper, was introduced to India by the British to camouflage airstrips during World War II. Native to Central and South America, is now found across South Asia and the Pacific.

The arrival of mosquitos in Hawaii with the first Europeans, and the avian malaria that followed, took a massive toll on the endemic bird diversity, even causing extinctions.



Spotted deer swim across stretches of sea between islands upto 10 kms.apart in the Andamans.

Carp: Robin Abraham | Chital: Manish Chandi | Cat: Invasive Animals Cooperative Research Centre

Killer Cats

The domestic cat is a widespread invader globally, and causes enormous and often undocumented damage to native fauna.

Feral as well as pet cats prey on native fauna, primarily birds and small to medium-sized mammals. Predation by cats is particularly critical on islands. In Britain alone, cats (9 million) are responsible for killing approximately 275 million animals a year. One domestic cat in New Zealand was documented to bring in 558 animals from a radius of 600 mt around its home over a 17-year lifetime.

Though listed as one of the 100 worst invaders worldwide by the IUCN, management and eradication of feral cats remains controversial. The most common methods of control are killing of cats and the 'trap-neuter-release' (TNR) method. While animal rights groups condemn cat killing, studies have shown that the TNR method is ineffective in controlling cat populations. Various organisations urge less agressive methods like not feeding stray cats and keeping domestic cats indoors. The solution to the cat problem might lie in a combination of methods, including accepting novel (and grisly?) alternatives like the cat-eating festival in Peru or the underground cat-fur trade in China.

FISHY BUSINESS

Native to Europe and northern Asia, Common carp (*Cyprinus carpio*) are one of the earliest widely-introduced fish. They are a problem species in their introduced range, causing damage to plant and animal communities in freshwater ecosystems. Carp are attracted to each other through smell, and scientists are using this to try and control them in Minnesotta, USA. The idea is to release carp pheromones in targeted areas of the rivers to lure the fish into concentrations, where they can be netted. A more long term-solution is being attempted in Australia, where carp are being genetically modified so they produce only male offspring.

Carp (left) are introduced in Indian rivers by the Fisheries Department to increase revenue of local fishers.

feature | Charles Perrings, Harold Mooney, Mark Williamson

The Economics *of* Invasives

The Nature Conservancy

If we take the expenditure to counter pests in agriculture, forestry and fisheries along with the output lost through invasive pests and pathogens in all sectors, and add to that the costs of both, emergent and recurrent diseases of international origin, the problem of invasive species makes all other environmental problems pale into insignificance.

Invasive species are defined by the Convention of Biological Diversity as ".. those alien species which threaten ecosystems, habitats or species". If we take the expenditure to counter pests in agriculture, forestry and fisheries along with the output lost through invasive pests and pathogens in all sectors, and add to that the costs of both emergent and recurrent human diseases of international origin, the problem of invasive species makes all other environmental problems pale into insignificance.

The ecological and economic dimensions of the problem of invasive species are connected at different levels. The ecological changes that lead ecosystems to be more vulnerable to the impacts of invasions, the fragmentation and disturbance of habitats, loss of biodiversity and increasing pollution burdens, are a direct consequence of economic behaviour. The ecological mechanism connecting invasive species, functional diversity and ecosystem resilience, the rate at which species are dispersed, is highly correlated with the growth of trade, transport and travel. The main consequence of a loss of resilience is a reduction in the capacity of ecosystems to maintain functionality and the production of ecosystem services over a range of environmental conditions. This has direct implications for the value of both output and the underlying ecological assets—the natural capital—of the system. At every level, the ecological impacts of the economic activities involved are incidental to and are ignored by the actors concerned.

They are said to be externalities of the market transactions involved, meaning that they are not taken into account by the people engaged in those transactions. The economic problem of biological invasions is first to understand the nature of invasive species externalities and why they occur, second to evaluate the consequences they have for human well-being, and third to develop policies and instruments for their internalisation.

The economic forces that drive the problem of biological invasions include trends in land use that affect the vulnerability or susceptibility of ecosystems, trends in trade, transport and travel that affect the likelihood of species introductions, and trends in technology that affect species' impacts. While globalisation has implications for all three, it is especially important for the second, influencing both the species involved in exchanges and the likelihood of their becoming invasive. The development of new trade routes has led to the introduction of new species either deliberately or accidentally, while the growth in the volume of trade along those routes has increased the frequency with which introductions are repeated. Species introductions are an externality of trade whose cost depends heavily on the way that ecosystems are exploited, both because that influences the vulnerability of those systems to invasion, and because it determines the value at risk from invasions.

The introduction of any given species has very different consequences in landscapes exploited for distinct purposes.

A plant pathogen specific to a particular cultivated crop, for example, may have no implications outside of agricultural areas, but may be devastating within those areas. Indeed, agroecosystems are typically the most vulnerable to invasive species, though also the most likely to be protected through controls. For the agricultural sector, for example, invasive species cause damage costs equal to around 50% of agricultural GDP in the USA and Australia, 30% in the UK, but between 80% and 110% of agricultural GDP in South Africa, India and Brazil. To date, however, there are almost no studies of the implicit cost of habitat fragmentation, disturbance, or other landscape changes that affect the ease with which introduced species can establish and spread.

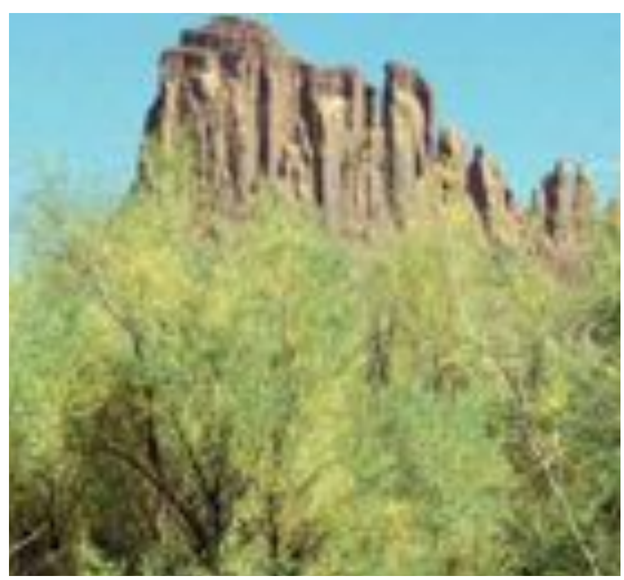
Where there is uncertainty about the likelihood of both introductions and the potential consequences of establishment and spread, the economic problem resolves into an evaluation of the relative net benefits of mitigation versus adaptation strategies: of preventive action versus control after the fact. What makes the problem particularly difficult is precisely the uncertainty attaching to several aspects of the invasion process. The historic likelihood that any given introduced species will establish, spread and inflict appreciable harm on the host system is low. However, the few species that do turn out to be damaging can be very harmful indeed—as was the case with the plague in Europe, smallpox, measles and typhus in the Americas, or the Spanish Flu world-wide.

Three related issues turn out to be important in the theory of invasive species control. The first is the relative costs and benefits of alternative strategies and, in particular, the relative costs and benefits of mitigation versus adaptation strategies. The second is the degree of uncertainty involved, and the third is the rapidity and spatial extent of the potential spread of the invasive species.

In the absence of reliable estimates of the net benefits of investment in the defensive capabilities of ecosystems themselves, the relative costs and benefits of alternative strategies generally involve a comparison of net benefits of

inspection and interception or detection and eradication versus the control of established invaders. Of the three strategies-inspection (to prevent introduction), detection (to identify and eradicate species that have got past the border but have not yet spread) and control (management of species that have established and spread - inspection and detection are generally substitutes. Reducing the cost of one of these two strategies will increase the optimal effort devoted to it and reduce the optimal effort devoted to the other. However, both are substitutes for the control of established populations. The optimal inspection strategy depends on the level of uncertainty attaching to commodity groups and trade routes. Where the risks associated with particular commodity groups or trade routes are known, then a targeted inspection strategy makes sense.

But where the risks are not known, it is optimal to adopt a random audit approach. In an evolutionary system where the capacity to predict the consequences of novel events is limited by the lack of historical precedents, building that capacity through both monitoring and experimentation is an essential part of the policy toolkit. Biological invasions are an externality of international trade, and the solution to the problem requires policies to address that fact directly. These imply international cooperation, which means collaborative action both in terms of the multilateral agreements governing trade (the General Agreement on Tariffs and Trade) and the effects of trade (the Sanitary and Phytosanitary Agreement, and the International Plant Protection Convention), and of the intergovernmental organisations established to address different dimensions of the invasive species problem. For virulent human or animal pathogens



Page 14: *Cheatgrass, Bromus tectorum, in Dinosaur National Monument, Utah. It has spread from Southern Eaurope to Russia, Asia, North America, Japan, South Africa, Australia, New Zealand, Iceland, and Greenland, and displaces many native species.*

Page 15: *The zebra mussel, Dreissena polymorpha, introduced to the Great Lakes in ships ballast, causes millions of dollars of damage every year.*

Facing Page; clockwise from top: *Fountain grass, Penisetum setaceum, is a major fire threat to many of Hawaii's natural areas. Tamarisk, Tamarix ramosissima, from southern Eurasia, has invaded riparian areas in many dryland environments. Water hyacinth, Eichhornia Crassipes, originally from South America, has spread widely through Africa, Asia, and North America. In India it has invaded large areas of the Kerala Backwaters.*

Above: *The red palm mite, Raoiella indica, moved by trade and travel between Caribbean islands.*

that are likely to spread globally the scale at which the problem needs to be addressed is clearly global. At the same time, however, many introduced species spread locally at fast enough rates to make them problematic at that scale, but have no implications beyond that. Application of the subsidiarity principle implies that problems of that sort be dealt with at a local scale. Between such polar cases, however, lie problems that occur over a wide range of scales. The challenge in this for the economic, epidemiological and ecological sciences is to determine the spatial and temporal scale of the problem-including its causes and effects-and to analyze both the problem and the policy and management options accordingly.

Global protection against many invasive species risks is a public good of a very special kind-a 'weakest link public good'. Because global protection is a weakest link public good, the lower the capacity of poor countries to deal with damaging and rapidly-spreading invasive species, the greater the exposure of all their trading partners. It follows that the more closely integrated is the global system, the greater the incentive to high income countries to build capacity in the weakest links in the chain. In the case of human, animal and plant pathogens, the risk of infection or re-infection can be reduced by direct support of the sanitary and phytosanitary capabilities of low-income trading partners.

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Further reading:

Perrings C, HA Mooney, & MH Williamson. 2010. Bioinvasions and globalization: Ecology, economics, management, and policy. Oxford: Oxford University Press.


Kalyani Ganapathy

Corals OR Cola

between the devil and the deep blue sea

Human-mediated marine invasions are increasingly perceived as ecologically and economically devastating. They have been identified as one of the top five threats to marine ecosystems globally; causing species extinctions and biotic homogenisation.

J K Patterson

Right: *Kaneohe Bay, Hawaii: alga growth rate of 260 metres per year; covers 50% of substrate in many areas*

Ocean-going vessels, which can account for the movement of 7,000-10,000 species at a time, are the single most important pathway for the dispersal of marine organisms. In addition, the intentional introduction of species for aquaculture is becoming an important mode of spread of potentially invasive species. One such species introduced to India is the seaweed *Kappaphycus alvarezii*.

Kappaphycus alvarezii in India

K. alvarezii was first introduced by the Central Salt and Marine Research Institute to Gujarat, in 1993, and later to Mandapam, in 1995, for large-scale commercial culture. *K. alvarezii* is used to produce the gelling agent, *kappa carrageenan*, which, in turn, is used in industrial gums, and in products such as soft drinks. The entrepreneurial venture of seaweed cultivation was undertaken by Pepsi Foods Limited (PFL) along with the Central Salt and Marine Chemicals Research Institute (CSMCRI) as a livelihood option for Self Help Groups (SHG) on an attractive buy-back arrangement. Large-scale culture of the species began in 2001 in the Palk Bay waters off Mandapam (which supports coral reefs and seagrass beds). By this time, the species had been classified as an invasive species and had wreaked havoc in the reefs of the Hawaiian and Caribbean islands. At the Kaneohe Bay, Hawaii, the alga is spreading at the rate of about 260 metres per year, and covers 50% of the benthic substrate in many areas. It can grow over, smother, and prevent fresh establishment by both coral larvae, and other benthic invertebrates and its invasive potential and ability to re-grow has aroused the concern of researchers.

Recent studies and our own in situ observations have shown that the species has spread to the marine protected areas within the Gulf of Mannar Biosphere Reserve. The alga is growing extensively on the branching coral colonies of *Acropora formosa* and *A. nobilis*, smothering the corals beneath. We found that all coral polyps below the algal mat were dead. The alga grows so densely and compactly on the coral colonies that, once well-established, it is impossible to separate the alga from the coral colony without causing severe damage or breaking. If left unchecked, and if no immediate remedial action is taken, the alga could well

Arguements supporting introduction of *K. alvarezii* to India & flaws therein

	In support	Why it won't work
cultivation	- Novel polythene bag technique: CSMCRI believed this would prevent escape of any fragments	- Did not work for large-scale culture due to fouling & stunted algal growth - Net bags were tried but discarded after reports of a strand of *K. alvarezii* from Andaman Islands. It was then considered a local variety and open unrestrained culture on rafts was begun
biology	- Reproduces through vegetative propagules, so will not spread far - Specific conditions for sexual reproduction do not occur in these waters	- Vegetative propagation methods are equally, if not more, successful modes of dispersion compared to sexual methods in invasive species. - In the Caribbean, it now reproduces sexually, more than 20 years after its introduction
occurrence	- A few strands were found off the Andaman islands. Therefore, it is native and not alien	- Andamans are biogeographically distinct from Indian mainland so strands could still be considered exotic - Initial strands from other countries, implying that stock under culture is alien
process	There is no reported natural stock anywhere in the world, and the alga has become available at a large scale only through cultivation.	- Alien species need not be invasive or dominant in their region of origin. - In its native Philippines, it is natural that there is no large wild stock. When introduced to a new coast with no natural pressures, it could possibly become invasive


Naveen Namboothri

spread to other parts of the marine protected area and lead to large-scale ecosystem phase shifts and undermine the functionality of coral reefs. Some scientists (including Dr. APJ Abdul Kalam, former President of India), have hailed *Kappaphycus* cultivation as an important alternate livelihood option for communities. The culture of the alga is a lucrative activity and comes with a promising buy-back package, and central and state government support.

The entire issue of *K. alvarezii* raises questions about the integrity and responsibilities of science, scientists and people in power. While the idea of introducing *K. alvarezii* to provide a livelihood alternative for resource-dependent communities is certainly well-intended, the scientific information and research to support and justify its introduction is weak and unsubstantiated. The most audacious justification so far provided for the introduction of *K. alvarezii* was the discovery of a few strands of the species in the Andaman and Nicobar islands, leading to its being declared a native species.

If immediate measures are not undertaken to check the spread of large-scale culture, at least till the species is conclusively proven to be harmless, it could lead to complications in future management. With more people depending on the seaweed for livelihoods, conflicts could evolve if management policies are to be put in place.

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perspective | Gyan Prakash Sharma
AS Raghubanshi

How Lantana invaded India

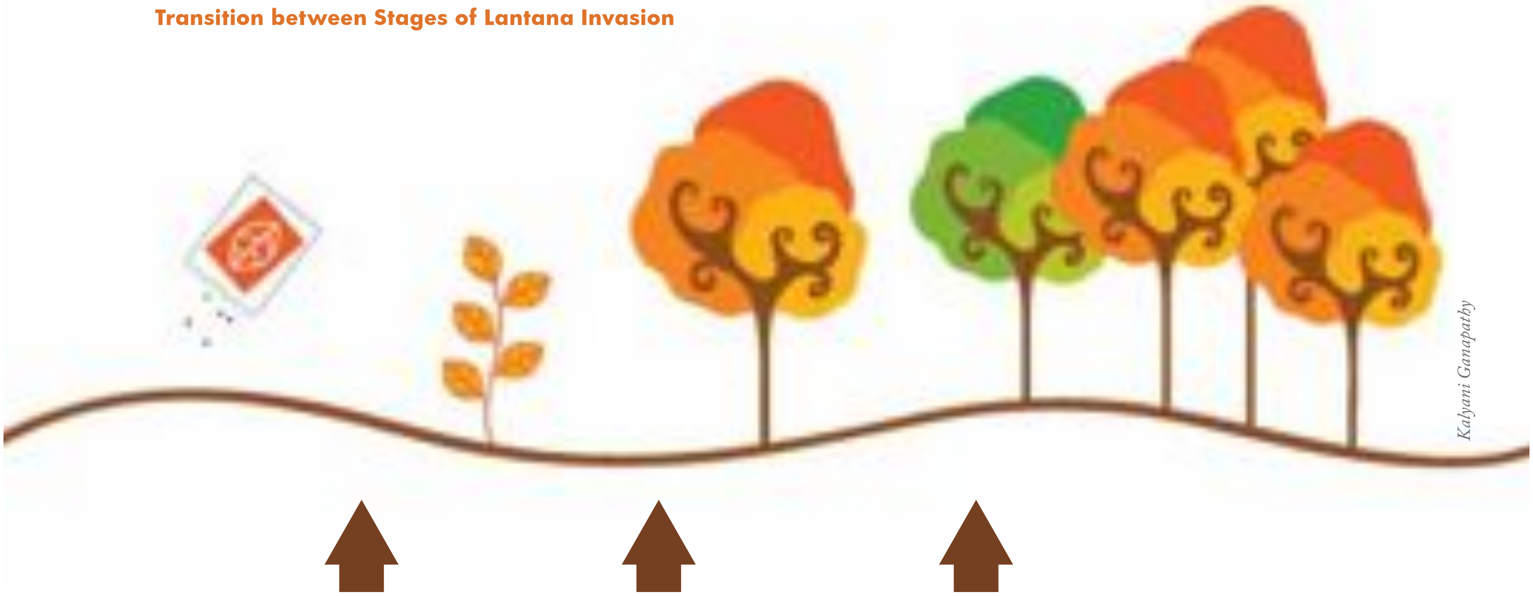
There are a growing number of invasive species in ecosystems around the world. One such invasive species is *Lantana camara.* Key biological attributes of lantana that make this species among the world's 100 worst invasive weeds include fitness homeostasis, phenotypic plasticity, widespread dispersal by birds that feed on its fruit, a broad geographic range, vegetative reproduction, fire tolerance, ability to compete effectively with the native flora, and allelopathy.

It is not clear how lantana arrived in India, although there are anecdotal references to the introduction of lantana as an ornamental in the early 19th century. lantana may have been introduced into India on multiple occasions—as an ornamental plant in Coorg and as a hedge plant in Calcutta. We can trace its spread in Nainital district of India: it was introduced around 1905; till 1911 it was confined to hedges and was sparsely distributed; by 1929 it had become widespread, forming dense thickets in farms, pastures, fallows, and forest areas. Lantana has invaded most Indian pasture lands (13.2 million ha) besides forest and fallow areas, and the cost of its control is estimated to be US$ 70 per hectare. Indian populations of lantana have been around for a long time (about 2 centuries). This would suggest that lantana has had time to evolve and become locally adapted. However, it is difficult to attribute the success of lantana to any one factor alone, and one could invoke different hypotheses to explain its success at different stages of the invasion process (see overleaf).

Consequences of lantana invasion, particularly on the native flora, are little understood and need to be studied. Our studies provide a qualitative and quantitative overview of the effects of lantana on ecosystem structure and function in tropical dry forests of northern India. Many species of tropical dry forests have small local populations, but several of them exhibit declining or even severely depleted populations in lantana-invaded locations. Such invasions create demographic instability among native tree species, reduce tree diversity, and could even change the structure of the forest in the near future (examples of species with declining populations include *Acacia auriculiformis*, *Adina cordifolia*, *Boswellia serrata*, *Briedelia retusa*, *Buchanania lanzan*,

Kalyani Ganapathy

Transition between Stages of Lantana Invasion



Biologists have invoked a number of potential explanations, or hypotheses, for the success of invasive species.
Fluctuating Resource Hypothesis: The ability of invasive species to preemptively take advantage of resources (light, soil nutrients, space) that become available following a disturbance.
Presence of Empty Niches: Some species-poor ecosystems, such as oceanic islands, are thought to be more vulnerable to invasions than species-rich ecosystems.
Enemy Release Hypothesis: Invasive species are often thought to be successful in their introduced environments due to the lack of natural enemies to keep them in check.
Evolution of Increased Competitive Ability: Freedom from enemies (herbivores or predators) might allow introduced species to allocate resources to growing larger, or faster.
Novel Weapons: Invasives may spread rapidly in new environments due to weapons like antimicrobial or allelopathic chemicals they exude from roots, which may inhibit other species in their new environments-the *Allelopathic Advantage Against Resident Species* of some invasive species is an example.

Cassia fistula, *Elaeodendron glaucum*, *Emblica offi-cinalis*, *Eriolena quinquelaris*, *Hardwickia binata*, *Miliusa tomentosa*, *Schrebera swietenioides*). Lantana can also have a devastating impact on the rich herbaceous understory.

We also observed that lantana litter inputs increase with increasing lantana cover and that the chemical composition of lantana litter is very different from the chemical composition of native forest species litter. The high nitrogen and low lignin content of lantana litter and the favorable microclimate beneath lantana canopies favour faster decomposition and release of nitrogen. This alteration in litter inputs and chemistry beneath lantana positively and significantly alter soil nitrogen availability, nitrogen mineralization, and total soil nitrogen, leading to a positive feedback: lantana increases soil nitrogen availability, and this, in turn, favours the growth of lantana. Our research suggests the need for prioritization of issues, designing of hierarchical management, and adaptive management strategies in response to lantana invasion. New research approaches warrant further investigation with more in situ experimentation. There is also an urgent need for information regarding the current and the potential distribution of lantana, for its monitoring, control, and possible eradication. All this can only be possible through increased public awareness of the harmful impacts of lantana on our landscapes. Amalgamation of all this will create a promising environment in which lantana research can be promoted, funded, and nurtured through a 'Lantana working group' for India.

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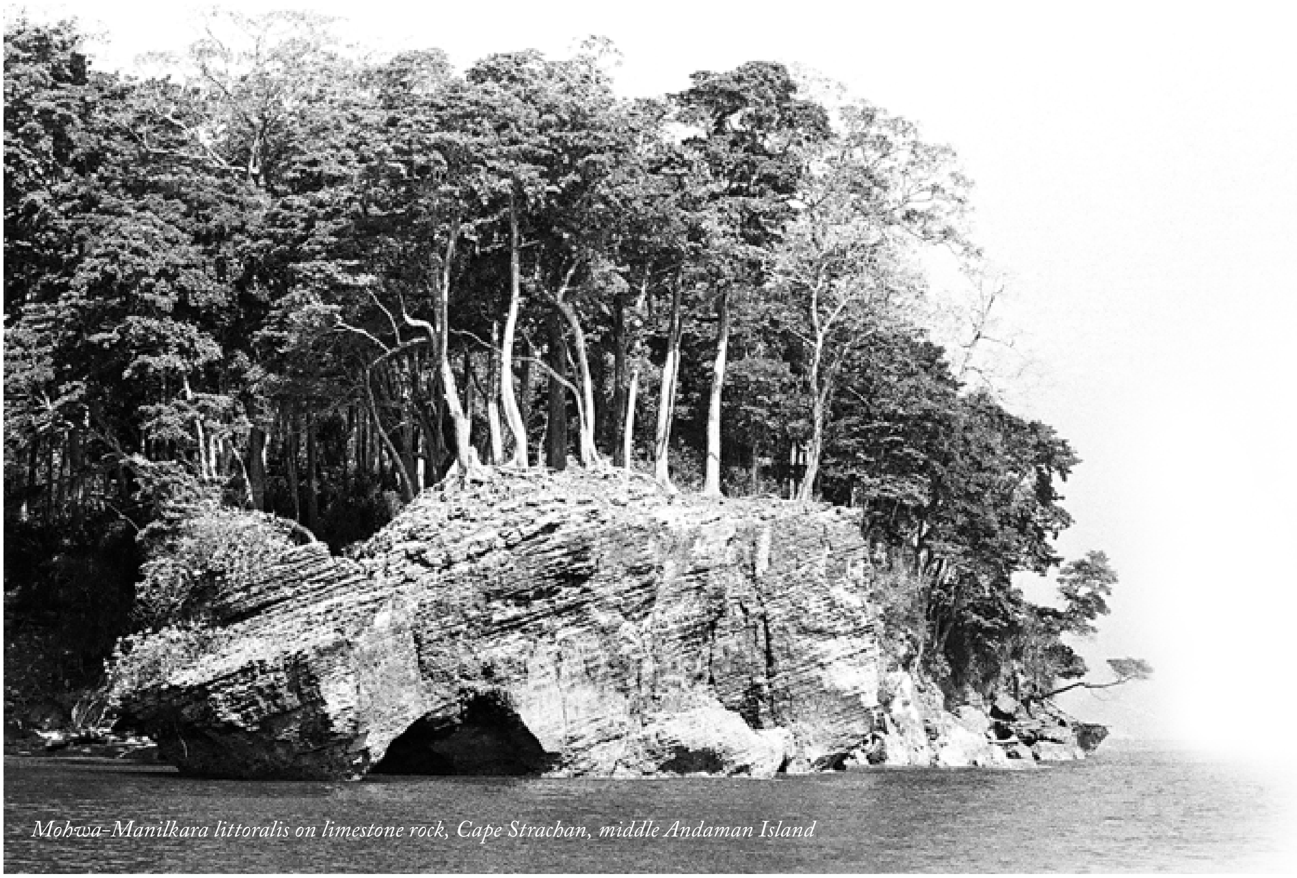
Invading the Andamans

From weeds to elephants, animals brought in by humans cause economic and environmental damage in the Andaman Islands

Manish Chandi



Mohwa-Manilkara littoralis on limestone rock, Cape Strachan, middle Andaman Island

Invasive species are especially problematic on islands. Islands tend to be depauperate of species, and this enables a lot of introduced species to take hold. Invasives arrive by various means. They are either deliberately introduced (as household pets or ornamental plants), or arrive as commensals (e.g., rats, mice), foodgrain contaminants (as weeds), or in ship-water ballast. Ship water ballast is estimated to carry up to 10,000 species daily to areas outside their native range, making this one of the main pathways of introduction. Islands also have a large number of range-restricted endemic species, that might face extinction when competition with invasives occurs. Even invasives that do not attract attention in mainland areas can become troublesome on islands. This is specially the case when there are no predators, and endemics have evolved in the absence of predators.

While some invasives spread by extending their ranges in the areas where they have been introduced, the most important factor is the availability of transport vectors. These could be domestic animals passing through with parasites on them. These could also be trucks and cars; the presence of road networks is a key factor in the spread of invasives. In the Indian subcontinent, knowledge of invasives is basically confined to 'page 3' plants. The well-known ones here are *Chromolaema odorata* (eupatorium), *Lantana camara* (lantana), *Eicchornia crassipes* (water hyacinth) and *Mikania micrantha* (mile-a-minute weed). Every protected area management plan gives a laundry list of these plants, with a recommendation that they 'be controlled'. How this is to be done is never specified. Animal invasives are largely ignored, because of the perception that these are common animals and cannot be called invasives. These include feral dogs and cats, which cause great damage to our natural ecosystems.

While hardly noticed on the Indian mainland, bird and animal invasives have begun to play a significant role in both the ecology and the economics of the Andaman Islands. A total of 12 bird species have been introduced into the Andamans, mainly at the end of the 19th century. Of these, 5 are still found there, 6 have disappeared, and the status of 1 is unknown. Of the five still found, two are invasive. The most ubiquitous of the bird invasives found in South Andaman is the common mynah (*Acridotheres tristis*). This species of the Indian mainland has spread all over Southeast Asia, parts of Australia and New Zealand, and the island groups of the South Pacific. They are known to prey on the eggs and nestlings of other bird species, and may compete in the Andamans with indigenous hole nesters such as the glossy starling and the black woodpecker. They are listed as being among the 100 most invasive species in the world.

A much more recent invader is the house crow. Seven individuals were seen flying off a boat in Port Blair in 2003. Timely action was not taken to eradicate them, and now they number several hundred.

In other island ecosystems where crows have become established they are agricultural pests as well as disease vectors. House crows were also introduced into the Nicobars in the past, though the exact date is not known. Of the 13 mammal species that were introduced here-including domestic animals-two, (leopard and hog deer) have died out, but most of the rest are problematic. The most ubiquitous of these is the chital (*Axis axis*). In the Andamans the regeneration of forests is severely affected wherever chital are common, since they browse on seedlings, even in evergreen forest. The only two species they appear to avoid are *Pongamia pinnata,* a coastal evergreen species, and *Lagerstromia hypoleuca,* a deciduous species. As a result, large areas that were originally semi-evergreen forest have become deciduous in character due to the pre-dominance of *Lagerstromia hypoleuca*.

Elephants were used for timber operations on Interview Island, and in North Andaman. When the timber operator in that area went bankrupt in 1962, the elephants were released into the forest and became feral. On Interview Island these elephants have damaged the vegetation by debarking and knocking down trees. Moreover, the deer here will not allow any regeneration. The result is an annual rate of forest loss on Interview Island significant enough to be detected on satellite imagery. Cats, dogs, goats, and cattle have all become feral in different parts of the islands. Dogs form packs and have been known to attack humans. They also attack sea turtles that come ashore to lay eggs, in addition to digging up and eating the eggs. While no study has been done on cats, they probably cause serious mortality among the bird species found in the islands. Goats contribute to the degradation of Barren Island. This island is volcanic, and is not inhabited. British sailors released the goats there in the mid-1800s as insurance against any future shipwreck in the area. They were subsequently introduced on Narcondam Island in the 1970s, where they began spreading; luckily the Andaman and Nicobar Administration acted on a report by Ravi Sankaran detailing the damage they did, and has taken steps to eradicate them. The control of chital has been recommended for a while, but the permissions from MOEF are not forthcoming yet. The control of dogs has also not been undertaken yet; fear of animal rights activists seems to play a large role here.

I will not go into the various plant species that have become invasive here, save to state that even on Great Nicobar island, a short study found 12 invasive weed species. Most of these were contaminants of seed material that had been brought there. Escaped ornamental plants have also caused major problems around Port Blair. What is required urgently is a national policy to deal with invasives, especially in these island areas that are particularly vulnerable. This policy would have to consider invasion pathways, vectors of spread, and legal and cost-effective mechanisms for control and eradication.

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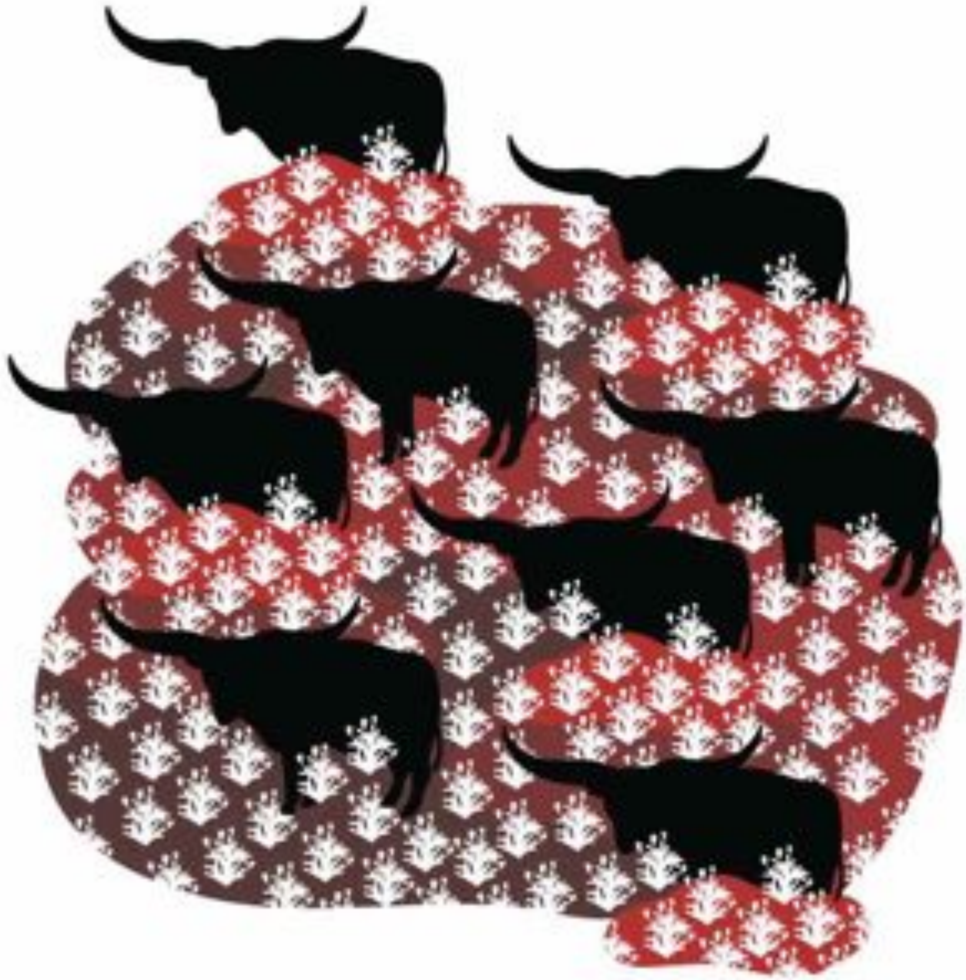
Kalyani Ganapathy

Tackling Invasive Species:
the story of a shrub in South Africa



Kalyani Ganapathy

Sometime native plants run rampant under changing circumstances, becoming ecological disasters. But how does one control this when the plant nowenhances local livelihoods?

Invasive plant species are a considerable threat to productive land use and economic returns in many areas of the world. Thus they are frequently viewed within a degradation paradigm, having been facilitated by inappropriate land use practices resulting in reduced useful productivity. For example, the economic cost of alien invasive species has been estimated at being close to 5% of world GDP. However, not all invasives are alien. For example, at least 10% of South Africa is encroached by indigenous species that form almost monospecific stands over large areas, and this encroachment is increasing through perceived injudicious land use practices. Therefore the economic costs of invasive species in general are likely to be far higher. Given the overwhelmingly negative narratives pertaining to the economic impacts of invasive species, the social and sometimes ecological dimensions of these processes receive considerably less attention. Consequently, eradication programmes are designed on economic imperatives with insufficient consideration of the social and ecological implications. Frequently, the alien species are cleared by manual, biological or chemical means, but without altering the original land use practices that encouraged the invasion in the first place. Thus, in the long run, the species reinvades. Management is addressing the symptoms rather than the cause.

We recently examined the case of invasion by an indigenous perennial shrub, *Euryops floribundus* NEBR, in the inland mountains of the Eastern Cape province, South Africa. This mountainous area is covered largely by semi-arid, sub-montane grasslands. A few trees and shrubs can be found in valley bottoms, but most were removed by local communities long ago for fuelwood and fencing poles. The species has a wide distribution, but is usually relatively sparse and confined to rocky outcrops. However, in the Macubeni area it has invaded large tracts of land, and is believed to be promoted by heavy grazing pressure by domestic livestock. In protected outcrops it grows up to 2.5 mt tall, but in open environments it is usually less than 0.75 metre tall.

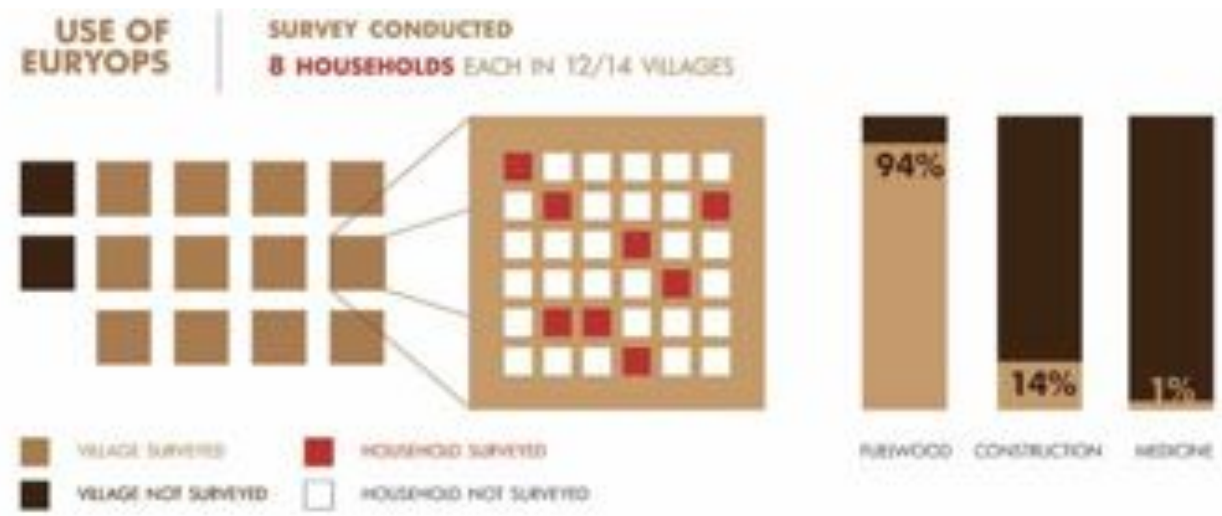
The Macubeni area is one of the poorest in South Africa. It consists of 14 villages with approximately 1,700 households. Livestock stocking rates in the Macubeni area are over three times what is recommended by government extension officers. The significant signs of gully and sheet erosion obvious throughout the area are blamed on the high stocking rates (although the relative contributions of the absence of contours in arable fields on hilly slopes, and weak control of runoff from roads has not been investigated). Consequently, in 2004, the central government sought to involve local households in a land rehabilitation and poverty relief programme. After basic consultations they agreed to hire local labour to manually remove approximately 1,500 ha of *Euryops* as a means to create more grazing for the livestock and so reduce the grazing impact per unit area. Almost US$1 million was allocated to the programme, comprising 35,350 person days of labour. However, there was no scientific investigation of the causes of the *Euryops* invasion, nor of how the broader population viewed or used it.

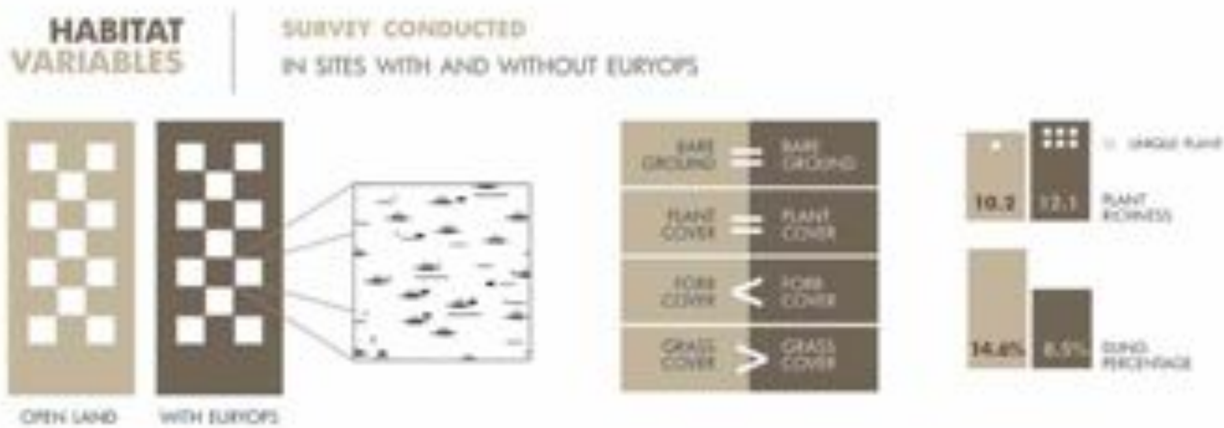
Through a household survey, we found that most households interviewed used *Euryops* as a source of biomass fuel for cooking, with most households collecting it daily or every second day. A few households also used it as packing to build livestock enclosures, and almost none used it for medicinal purposes. Many stressed that without *Euryops* they would have to purchase paraffin for cooking fuel, which was expensive and not always available. Hence, their energy security was vested in being able to collect *Euryops* within an accessible distance.

The results of an ecological survey comparing sites, with and without *Euryops* reflected certain differences in habitat variables. Overall, there was no statistical difference in the proportion of bare ground or total plant cover between invaded and paired non-invaded areas. However, there was significantly less grass cover, but a higher forb cover, in invaded sites. Interestingly, however, was the fact that there was a significantly higher plant species richness in the invaded sites than the paired non-invaded ones, largely due to the increased richness of forb species. The invaded areas had six species exclusive to it not found outside the *Euryops* patches, whereas the open grasslands had only one species that was not found in invaded areas. The frequency of livestock dung in open grasslands (14.6 + 3.4 %) was almost double that recorded in the invaded areas (8.5 + 2.5 %). Cluster analysis of the species composition indicated that none of the designated groupings were exclusive to invaded or non-invaded areas, and that 75 % of the paired sites were faithfully placed within a matching cluster. This suggests that overall plant species composition is similar between the two, and the composition of groupings in the cluster analysis reflected underlying abiotic site characteristics rather than differential land use pressure.

The situation regarding the occurrence, use and management of *Euryops* at the site is clearly complex, with contrasting needs and understandings. Local households clearly make extensive use of it as a resource, and are highly dependent upon it as their primary source of fuel. Its removal therefore represents a potential cause of hardship and reduction in energy security. Another benefit of its presence seems to be the higher plant species richness associated with patches of *Euryops* relative to the surrounding grasslands.

We suggest this is because the shrub offers a physical refuge to certain species. This is supported by the lower-grazing pressure in the invaded areas (as indexed by the lower frequency of livestock dung). Thus, on the one hand there is widespread soil erosion and invasion by *Euryops*, which prompted external authorities to take action. As livestock grazing regimes were implicated (although never examined) in





Pallavi Baasri

both of these negative manifestations the reasoning of authorities was either reduce the livestock numbers or increase the area available for grazing. Local owners of livestock argued for the latter, proposing that funds be provided to manually remove *Euryops*. If successful this would benefit households who own livestock and also provide some temporary employment to poorer households. However, livestock owning households are in the minority, and are generally more wealthy than average. Moreover, livestock ownership is the domain of men, and in a patriarchal society they have greater power in community meetings and household affairs. On the other hand, our results have show that the removal of *Euryops* will deprive most households of their primary source of biomass fuel. Interestingly, the collection of biomass fuel is the purview of women, who typically lack a voice in community meetings and household affairs. It will also open up the invaded areas to increased grazing again, and potential loss of the refuge sites for several plant species. However, if the excessive grazing was the cause of the invasion in the first place, what will prevent the shrub from reinvading in time? The bottom line is that until a thorough ecological study is undertaken to understand the causes and consequences of the invasion, any interventions and relief efforts are likely to be temporary, whilst removing the respite the invasion offers to heavy grazing and its presumed attendant ill-effects of soil erosion and reduction in plant species richness.

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** James Gambiza is a Senior Lecturer in Environmental Science, Rhodes University, Grahamnstown, South Africa.*

Further reading: Shackleton CM & J Gambiza. 2008. Social and ecological trade-offs in combating land degradation: The case of invasion of a woody shrub (Euryops floribundus) at Macubeni, South Africa. Land Degradation & Development 19: 464-46

Anatomy of an Invader

This climbing fern has plastic sex, lives in crowded communes and likes it wet. Strangely, its not these aberrant quirks but its secret underground life that makes it a good invader.

In the continental United States, the Florida Everglades ranks among the top locations in regard to the number and coverage of introduced invasive species. Among Florida's non-indigenous invasive flora, a relatively recently introduced species, *Lygodium microphyllum*, also known as Old World climbing fern, is quickly becoming one of its most widespread. *L. microphyllum* first drew attention for escaping cultivation and spreading into natural lands in the late 1960s. However, little was done with this observation until the late 1990s, when active scientific research on its ecology and management, including biological, chemical, and mechanical control activities began in earnest.

L. microphyllum, a vine-like fern native to the pantropics of the Old World, is typically considered a benign constituent of its native plant communities. However, in its Florida introduced habitat it can develop a near monoculture, smothering the native understory under a mat of vegetation that can be thicker than 1 metre. The fern also climbs into the native overstory, eventually shading and killing the canopy trees and resulting in their collapse. In some cases, the fronds act as a 'fire ladder,' allowing fire into the canopy and resulting in the death of the host trees.

After an invasive species has been studied for a time, a Gestalt of that species usually begins to emerge. Unfortunately, this has been slow to develop in the case of *L. microphyllum.*

After more than a decade of study, the reasons for its success as an invader only now begin to become apparent. To truly understand why an invasive plant is successful often requires examining the species across a range of scales and in both its native and introduced habitats. This has been the strategy my colleagues and I have used to discover why *L. microphyllum* is such a successful invader in its de novo environment. We began by studying its reprodution, including its mode of reproduction, the seasonality of sporulation and its spore production. Our subsequent studies examined the fern's community ecology and its growth, both in situ and under controlled conditions, with various environmental treatments, including the influence of different light and different hydrological environments on its growth.

Several of these field and controlled studies were linked with landscape-scale studies to develop a spatial model of the fern's potential spread across its introduced environment. Finally, cross-continental controlled and common garden studies were carried out to compare the growth of the fern in its native versus its introduced environment. We learned much from our studies of *L.microphyllum*'s reproductive biology. The fern is homosporous-it produces bisexual gametophytes and, consequently, it can reproduce by three different reproductive strategies: intragametophytic selfing, intergametophytic selfing and outcrossing. Intragametophytic selfing allows for long distance dispersal because it only requires one gametophyte to establish new colonies, since sporelings (i.e., young plants) result from the union of an egg and sperm on the same gametophyte. The second and third strategies require two spores to land close together and to germinate into gametophytes, such that a sperm can swim from one gametophyte to the

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other. In the case of intergametophytic selfing, the two gametophytes are from the same parent plant, while with outcrossing the two gametophytes are from different parent plants. Typically, homosporous ferns are conservative in their reproductive strategy, in that they only reproduce by one of the three modes. We found that this is not the case for *L. microphyllum*, which we determined was able to reproduce by all three mating strategies. However, we also discovered an interesting invasive twist to its reproductive strategy.

When a gametophyte first germinates from a spore, it is almost always female and this female produces a pheromone that makes all younger nearby gameotphytes to become male, thus assuring outcrossing. On the other hand, if after a few weeks there are no nearby spores or gametophytes, the female will become bisexual by producing male organs thus assuring fertilisation. Collectively, these highly plastic reproductive strategies help explain the fern's long distance dispersal. We followed this initial work with studies related to the fern's seasonal spore patterns, spore production and community ecology. In its introduced environment, we found that dense sites of *L. microphyllum* produce spores year round, with a peak production in the wet season. We estimated a density of 15,000 spores per cm^2 of fertile leaf area, resulting in approximately three billion spores present at each invaded site at any given time. Our community-level studies showed that the presence of the fern coincided with a wet but not permanently inundated environment, and the coverage of the fern was greatest in a low-light understory environment, which likely facilitates its early establishment and growth. Anecdotally, *L. microphyllum* can be found in the various light conditions that exist in Florida's native ecosystems, from low to high irradiances. Later evidence in controlled studies showed that small plants of *L. microphyllum* have the same relative growth rate after 3 months whether growing in 20, 50 or 70% full sun light. The ability of the fern to maintain high growth under different light environments appears to be related to its ability to allocate carbon to stems in a highly plastic and favorable manner. For instance, in the highest light environment, the plants grow on average 2.9 m for every gram of carbon invested, while in the lowest light conditions the plants grew 4.2 m per gram of carbon. These findings were supported by 2 years of field observations where under high light conditions the height of the actual climbing mat (i.e., not individual stems) increased 1.43 m per year on host canopy trees.

We were able to combine the attributes of the fern from our studies of its reproduction biology and ecology with a series of aerial transects to develop a spatial model predicting the future spread of this highly invasive fern across the landscape. In 1978, a survey of known individual *L. microphyllum* sites was published. In 1993, the South Florida Water Management District began conducting aerial surveys every 2 years to monitor invasive species, including *L. microphyllum*, locations across the Southern Florida region. Combined with our earlier data, we were able to construct a cellular automaton landscape model by calibrating the model from the 1978 survey data stepped through to 1993. Then we validated the model independently from 1993 to 1999 using the aerial data. Finally, by initializing our model with the 1999 aerial survey data, we predicted the spread of the fern to 2014, showing that 37% of the 40,000 km^2-grid cells covering Southern Florida would have *L. microphyllum* present by 2014. In the absence of aggressive control measures, this model predicted that the coverage of *L. microphyllum* could exceed the coverage of the top five invasive species in Florida by 2014. Fortunately, aggressive biological, chemical and mechanical control for this species has been ongoing.

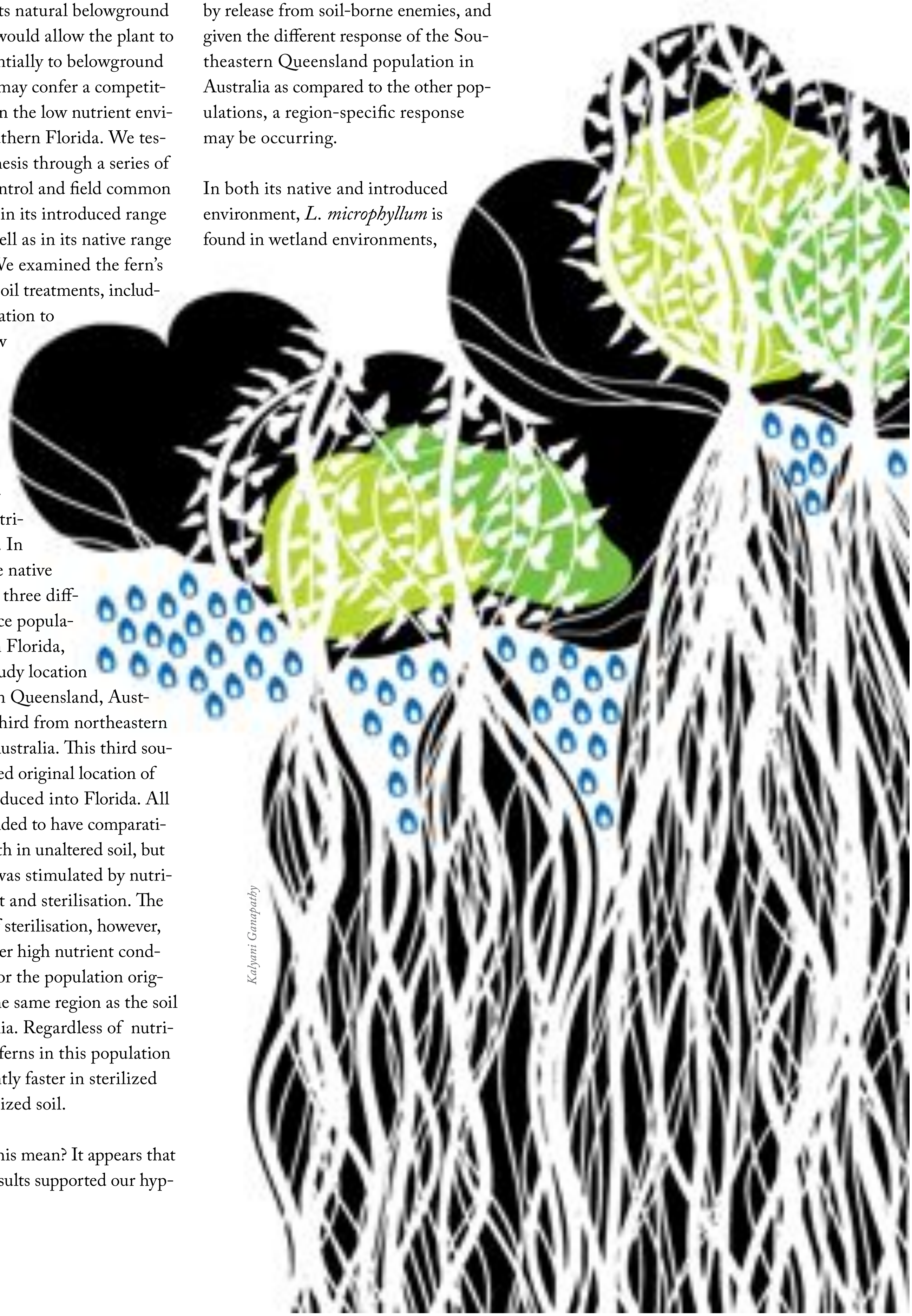
These early studies highlighted some of the attributes that help explain *L. microphyllum*'s ability to be invasive in its introduced environment. The same studies, combined with intensive monitoring efforts, allowed us to develop a spatially explicit predictive model that assisted in sounding the alarm, particularly to policy makers, since most land managers had already understood the dire consequences that ignoring this species would have on natural lands.

However, this series of studies was not sufficient to fully understand why this species is so successful in its new environment, while being apparently so benign in its native range. Moreover, to optimise management of this species, further studies were needed to provide additional information that could be used in both biological control and land management efforts.

Interestingly, from our earlier controlled studies under different light conditions, we found that *L. microphyllum* allocated 48% of its carbon to belowground tissues, while a native vine in the same study averaged only 27%. The latter is a typical investment for a vine belowground, given that vines characteristically maximise their allocation to above ground tissues in order to reach greater heights to optimise light interception. *L. microphyllum*, on the other hand, is able to grow to great heights, but it does it with relatively little investment in carbon. It was this observation that first led us to consider that, perhaps, *L. microphyllum* is such a successful invasive because it may be released from its natural belowground enemies. This would allow the plant to allocate substantially to belowground tissues, which may confer a competitive advantage in the low nutrient environment of southern Florida. We tested this hypothesis through a series of coordinated control and field common garden studies in its introduced range in Florida as well as in its native range in Australia. We examined the fern's growth across soil treatments, including soil sterilization to eliminate below ground natural enemies, and nutrient amendments to examine the possible interaction of soil nutrient availability. In addition, in the native range, we used three different fern source populations; one from Florida, one fromthe study location in Southeastern Queensland, Australia, and the third from northeastern Queensland, Australia. This third source is the reputed original location of the plants introduced into Florida. All populations tended to have comparatively poor growth in unaltered soil, but growth for all was stimulated by nutrient amendment and sterilisation. The overall effect of sterilisation, however, was muted under high nutrient conditions, except for the population originating from the same region as the soil used in Australia. Regardless of nutrient treatment, ferns in this population grew significantly faster in sterilized than non-sterilized soil.

So what does this mean? It appears that overall these results supported our hypothesis that the invasiveness of *L. microphyllum* in Florida is in part mediated by release from soil-borne enemies, and given the different response of the Southeastern Queensland population in Australia as compared to the other populations, a region-specific response may be occurring.

In both its native and introduced environment, *L. microphyllum* is found in wetland environments,



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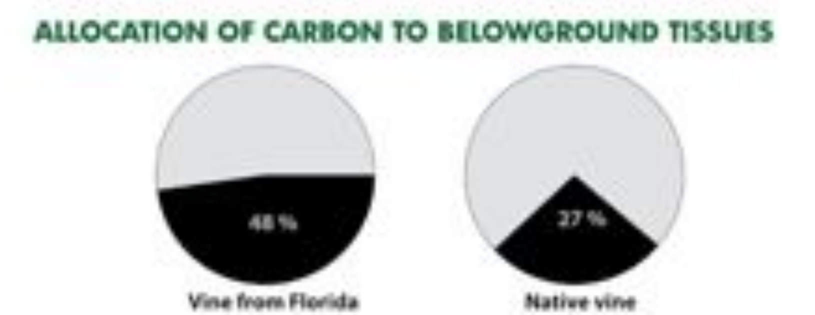
but appears to be able to tolerate a range of hydrological conditions. Therefore, we conducted another study to examine *L. microphyllum* growth response to three hydrological treatments; flood, drought and field capacity. Field capacity and drought showed no differences in growth, while flooded plants had significantly slower growth. However, it should be noted that, even after more than 2 months of continuous inundation, the flooded ferns demonstrated positive relative growth rate.

This apparent hydrological plasticity is likely another contributing factor to the fern's widespread establishment across a range of plant communities within the greater Everglades ecosystem. The fern's growth response to differences in hydrological conditions was largely explained by changes in its specific pinnae (i.e., leaf) area and photosynthesis: in other words, morphological and physiological determinants of growth, respectively.

From these numerous studies conducted at various scales under different environmental conditions, as well as from comparisons between introduced and native habitats, we eventually developed an understanding of why *L. microhpyllum* is such a successful invader, while at the same time a relatively benign presence in its native environment. In essence, *L. microhpyllum* possesses several life-history characteristics that may enhance its competitive ability in Florida, including plastic reproductive strategies, and prolific and continuous spore production. This fern appears to optimise its morphological and physiological characteristics to maximise photosynthetic area and minimise carbon costs in tissue construction, thereby gaining the ability to grow rapidly across gradients in light and hydrology. On the other hand, in its native range, this ability to grow across environmental gradients and reproductive output may be constrained by natural enemies. Our cross-continental comparisons appear to support our hypothesis that release from natural enemies belowground may also help explain the success of the fern in its introduced environment and, provocatively, given the different source population responses, it appears that a regional-scale version of the enemy release hypothesis might play a role in *L. microphyllum*'s invasive success.



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Our findings demonstrate the importance of a biogeographical approach to invasive species studies and have implications for the identification of potential biocontrol agents. Moreover, the numerous studies at different scales in the fern's introduced environment allowed us to make specific management recommendations, provided clues to its invasiveness that could then be corroborated by comparative studies of its native versus introduced ranges, and allowed us to develop a landscape-level model that could inform scientists, land managers, policy makers and the public, of the imminent danger of this particular invasive plant.

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Adult male Tonkean Macaque, Indonasia

Culture & Conservation

* Hari Sridhar

Social taboos might help protect the Tonkean Macaque.

Folklore about the Tonkean Macaque (*Macaca tonkeana*) might be the reason behind an indigenous group in Indonesia tolerating this crop-raiding species, reports a new study in the journal Oryx.

Erin P Riley, a primatologist at the San Diego state university, conducted semi-structured interviews among the To Lindu, an ethnic group indigenous to highlands in Lore Lindu National Park in Indonesia to understand how these people conceptualize the Tonkean Macaque, a species which frequently raids their crops. Through a qualitative analysis of the data, she identified three main themes which characterized the To Lindu's folklore about the macaques. 01 Macaques were biologically similar and related to humans; 02 Macaques should be treated well even when they raid crops because otherwise they will do much worse things 03 Macaques act as guardians of Lindu adat or customary law.

These biological, cultural and ecological links to the Tonkean Macaque envisioned by the To Lindu has resulted in a taboo that prevents them from harming this crop-raiding species. Riley, uses this case study, to highlight the importance of including traditional knowledge and beliefs in conservation efforts but also adds the caveat that cultural reasons for conservation are probably context-specific and might not apply for a different species or even for the same species in another area. Moreover, people's beliefs are not fixed and might change in response to external influences. For example, even among the To Lindu, another taboo against the felling of strangler figs is slowly vanishing seemingly in response to the rise of Christianity among its people. Given the tenuous nature of cultural reasons for conservation, it is therefore important that a suite of values, including ecological and economic benefits are used in justifying the conservation of a particular species.

Riley EP. 2010. The importance of human–macaque folklore for conservation in Lore Lindu National Park, Sulawesi, Indonesia. Oryx 44(2): 235–240.

Joining the Dots

* Hari Sridhar

Ecological networks might be the next big tool in conservation research

Conservation research has traditionally focused on understanding how human-induced disturbances such as pollution and hunting directly affect wild species, leading to their extinctions. Little is known about how these extinctions might in turn influence other species living in the area. One would guess that these influences will be important because species are connected to other species in myriad ways - as food, as predators, as competitors for the same resource and as partners in mutually beneficial relationships. Ulrich Brose, in this conceptual paper, argues that visualizing species as nodes in a network might help us understand these secondary effects of species extinctions.

Take for example a simple food chain involving an eagle, a snake and a frog. The snake feeds on the frog and in turn is fed on by the eagle. Now suppose these snakes are hunted for their skin and over time become extinct, what might happen to the eagles and the frogs? What might also happen to the insects which the frogs eat and the other creatures that the eagles eat? Building ecological networks of these relationships will help us predict the answers to these questions.

Ecological networks are representations of the pair wise relationships between species in an area. While initially, these networks were almost entirely used in the context of food webs such as in the example describe above, more recently, other kinds of relationships such as competition and positive interactions (for e.g. between plants and their pollinators) have also been investigated. This paper highlights two particularly important uses of network building in the context of conservation:

01 To identify and prioritise for conservation, species whose extinction will have strong secondary effects on other members of the community.
02 To understand what features of communities make them vulnerable or resilient to disturbance. For example, it has been shown in numerous studies that the greater the number of ties between species in a community, the less susceptible it is to disturbance.

In spite of a great deal of research into the impacts of humans on species and biodiversity over the last few decades, global extinction rates are currently at an all-time high. This paper makes the case that this is due to a lack of attention to species interactions and that the next big step in conservation research will be to understand these interactions using ecological networks.

Brose U. 2010. Improving nature conservancy strategies by ecological network theory. Basic and Applied Ecology 11(1): p. 1-5.

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Lessons from History

* R Nandini

Can historical records be used to determine population sizes and spread?

Historical records from museums specimens, reports, and field notes are a valuable source of information, and can provide perspective on long-term trends in species occurrence, and in specific cases can allow us to assess rates of population change. However, there are inherent biases in using this kind of data, such as no records of species absence, changes in sampling effort, spatial coverage, collection method or species focus that need to be accounted for before conclusions can be drawn.

Tobbias Jeppson and colleagues at the Swedish University of Agricultural Sciences examined over 42,000 historical records of 108 species of longhorn beetles in Sweden collected between 1908-2000 in order to determine if changes in species range coincided with changes in population abundance over time. They also factored rarity of species into this analysis; for instance, they predicted that rare species would decline in range if they declined in abundance.

The results showed that a number of species changed in abundance over time, with most species exhibiting increasing or stable trends while a few species showed declining trends in population sizes.

Changes in species range did not reflect changes in population size, and several species showed conflicting local and global trends. Rare species with increasing populations showed range expansions (unlike common species), and rare species with decreasing populations did not have larger range contractions. The authors suggest that merely using range of species in threat assessments might not suffice, and suggest using population sizes as well.

Jeppsson T, A Lindhe, U Gärdenfors & P Forslund. 2010. The use of historical collections to estimate population trends: A case study using Swedish longhorn beetles (Coleoptera: Cerambycidae). Biological Conservation 143: 1940 – 1950.

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Removing Rats with Care

* R Nandini

Eradication of invasives species involves monitoring of sympatric species

Invasive species cause much damage to native biota, and eradicating these invasives is often a difficult time-consuming and expensive process that involves careful planning and monitoring of sympatric species. Gregg Howald of Island Conservation, Canada, and colleagues at the University of California, Santa Cruz, eradicated black rats (*Rattus rattus*) on Anacapa island, off the coast of California, while simultaneously monitoring the impact of these efforts on native fauna between 2001 and 2008.

Pellets containing the poison Brodifacoum were air-dropped during the dry season, in a staggered fashion, between 2001-2002, to cover Anacapa Island. The island has a native population of deer mice, and care was taken not to eradicate this species. Before air-dropping pellets, specific species, like deer-mice and raptors, that were thought to be potentially at risk from the poison were captured, and a certain part of the local population was held in captivity. Several environmental variables (soil, ocean samples) and animal populations, including the target species, were monitored closely before and after the application of the poison. Rats were completely eradicated by the procedure and monitoring in the year found no more rats.

However, while most other native species were not adversely affected, the poison decimated populations of deer-mice, raptors and small birds. Rufus-crowned sparrows were most affected, and were not sighted by the authors even 6-7 years after application. The captive-held populations of deermice and raptors were released one year after application, and numbers are now seen to be similar to pre-application levels. Following successful eradication of black rats from the island, positive effects were seen on murrulets and other seabirds, including reduced predation on eggs and sightings of a one additional species of seabird. The authors stress the importance of holding captive populations of natives species during large-scale eradication efforts.

Howald G, Donlan CJ , Faulkner KR, Gellerman SOH, Croll DA and Tershy BR. 2009. Eradication of black rats Rattus rattus from Anacapa Island. Oryx 44(1): 30–40.

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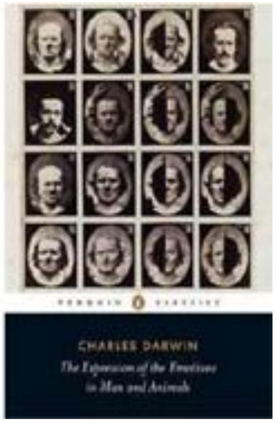

The Thinking & Feeling Animal

The behaviours of animals are easily seen and widely acknowledged, but do animals feel? In a book that was much ahead of its time, Charles Darwin illustrates the profusion of emotions in the animal kingdom.

'The Expression of the Emotions in Man and Animals', first published in 1872, followed in the wake of 'The Origin of Species' and 'The Descent of Man'. Although an important landmark in early behavioural studies, it was probably overshadowed by Darwin's earlier works of great importance and is thus not as well known as his other writings.

This book is not, as is sometimes made out to be, an explicitly comparative study of emotions in man and animals to establish the continuity of emotions. It is actually an investigation into the nature and origin of the expression of emotions. The questions Darwin intended to answer were more on the lines of how far particular movements of the features and gestures are really expressive of certain states of the mind and why certain muscles, and not others, contract under the influence of certain emotions. To this end he took an evolutionary approach, for he believed that the creationist assumption of immutability of species, adopted by most authors of the time, hindered a thorough investigation into the causes of emotions.

Darwin presents six lines of evidence to try and answer the questions he posed; of these, he gives most importance to the close observation of expression of several 'passions' in the 'commoner' animals. The other evidence stem from, for reasons that he explains in the introduction to the book, the observation of babies, impressions of observers about the emotion best expressed by photographs of the face of an old man when certain muscles were galvanized, study of emotions in paintings and sculpture, notes from observations of the insane, and notes on the expression of emotions in various races of human beings. The book thus brings together vast amounts of evidence from diverse fields like physiology, psychology, psychiatry, the arts and animal behaviour. As is characteristic of Darwin, there are no hand-waving arguments or enthusiastic, but unwarranted, interpretations; instead he conducts a patient appraisal of the available evidence and puts forward arguments supported by extremely insightful observations replete with detailed descriptions of behaviour.

What makes the book special, though, is how effortlessly and without hesitation Darwin bestows upon animals all that Descartes had denied them: feelings, emotions, volition. There is thus an important extension here of the doctrine of evolution of species, one that implies morphological, behavioural and mental continuity not just over evolutionary time as species evolve, but within the extant species as well. Although not explicitly sketched out in the text, the psychological continuity emerges as we are led to closely examine the emotions and behaviour of animals and man. 'The Expression' is thus a remarkable treatise, far ahead of its time, and an immensely significant forerunner to the development of fields like comparative psychology, which were eventually to give rise to disciplines like animal cognition and cognitive ethology that today delve into animal minds.

Charles Darwin. 1872. The Expression of the Emotions in Man & Animals. London: John Murray.

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Arjun Shankar

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