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OPINION ARTICLE

Plant invasions research in Latin America: fast track to a more focused agenda

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While many developed countries have invested heavily in research on plant invasions over the last 50 years, the immense region of Latin America has made little progress. Recognising this, a group of scientists working on plant invasions in Latin America met in Chile in late 2010 to develop a research agenda for the region based on lessons learned elsewhere. Our three main findings are as follows. (1) Globalisation is inevitable, but the resultant plant introductions can be slowed or prevented by effective quarantine and early intervention. Development of spatially explicit inventories, research on the invasion process and weed risk assessments can help prioritise and streamline action. (2) Eradication has limited application for plants and control is expensive and requires strict prioritisation and careful planning and evaluation. (3) Accepting the concept of novel ecosystems, new combinations of native and introduced species that no longer depend on human intervention, may help optimise invasive species management. Our vision of novel ecosystem management is through actions that: (a) maintain as much native biodiversity and ecosystem functionality as possible, (b) minimise management intervention to invasives with known impact, and (c) maximise the area of intervention. We propose the creation of a Latin American Invasive Plants Network to help focus the new research agenda for member countries. The network would coordinate research and training and establish funding priorities, develop and strengthen tools to share knowledge, and raise awareness at the community, governmental and intergovernmental levels about the social, economic and environmental costs of plant invasions.

Keywords: control; eradication; globalisation; inventories; novel ecosystems; plant invasions; quarantine; Weed Risk Assessment

Introduction

Plant invasions have been increasingly studied ever since the publication of the seminal work by Charles Elton (1958). After realising the huge economic and ecological impact of invasive species, governments in the USA, Europe, Australia, New Zealand and South Africa have invested heavily to develop and implement integrated and focused research policies on invasives (Pimentel 2002; Commonwealth of Australia 2009; Vilà et al. 2010). However, the immense developing Latin American region, comprising of 20 countries and 10 dependencies, has lagged behind these advances and work has been dispersed and uncoordinated (Nuñez and Pauchard 2010). Bringing this into a global context, Pyšek et al. (2008) showed that between 1980 and 2006 there were about tenfold more publications and four times more invasive species taxa studied in North America than in South America. It is only in the last decade that plant invasion research has

started to emerge as a focused field in Latin America (Pauchard et al. 2004). The scarcity of studies on plant invasions and the parallel paucity of supporting policy and investment in the region pose an opportunity to develop a focused Latin American invasive plant research agenda to provide knowledge to help identify priorities for both decision makers and managers. We propose that we can fast track the development of this research agenda by using the knowledge and experiences from developed countries elsewhere in the world. However, unlike other regions, the scarcity of resources in Latin America requires that research priorities are focused on applied issues and realities of a globalised world.

The scope of our paper is to discuss principal themes for a research agenda that will help mitigate the impacts of invasive plants on native biodiversity; we do not specifically address human or economic impacts (see the review by Ehrenfeld 2010). Since the main (but not exclusive) aim

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of protected areas is to safeguard biodiversity, many of the ideas presented here are applicable to their management. We pose three core ideas, each based on experience gained in developed countries and tuned to the reality of Latin America, which may help guide this new agenda:

- (1) Given the movement of people and goods associated with globalisation, the rate of plant invasion will only increase in Latin America. A focus on the prevention of new introductions through a well-informed public and government, rigorous legislation and efficient quarantine services should be a priority. Underpinning this is the need for regional introduced species inventories. These species inventories would form the basis of Weed Risk Assessment (WRA) models. Species identified as high risk should become the focus of parallel basic research into the invasion process and applied research into the development of new management options.
- (2) Eradication and control efforts for invasive plant management have often proven to be inefficient because of the intrinsic difficulties to extirpate prolific and naturalised species and the need for extensive resources to sustain action in the long-term. Ensuring optimal use of limited resources by focusing on management actions that will result in a positive impact is important. This can be achieved by only performing control and eradication programmes early in the invasion process when success is more likely to be achieved and/or when potential biodiversity losses are considered to be extremely high. Identifying these programmes is an active area of applied research.
- (3) The increasing human population and use of natural resources and presence of introduced species are transforming native ecosystems into ecosystems composed of new arrays of native and exotic species. Inevitably, we have to learn to coexist with exotic species because many are naturalised and here to stay. Independent of the efforts devoted to maintain protected areas, it will be necessary to study and learn how to manage these novel ecosystems, which are increasingly common, to conserve native biodiversity.

We expand on these three ideas below and then discuss the way forward in the Latin American context.

Globalisation is inevitable: mitigating impacts

Plant dispersal

Globalisation is inevitable: each year the flow of goods and people increases and its geographical network reaches further. Global economic and population growth facilitates an increase in the regional and international traffic of species needed for agriculture, timber and pasture production.

For example, in both Australia and Brazil, millions of hectares of savannah have been sown with African pasture grasses in order to increase livestock production; these have quickly naturalised and transformed the environment irreversibly (Pivello, Shida et al. 1999; Rossiter et al. 2003). Unfortunately, the traits that are used for selecting pasture persistence are the same traits used to characterise a species as invasive (Lonsdale 1999). A further pathway for the dispersion of potentially invasive plants is the trade of ornamental plants (Reichard and White 2001; Harrington et al. 2003). In Europe, Lambdon et al. (2008) found that 52.2% of naturalised invasive plants were originally brought in as ornamentals.

Plant invasions appear to be a relatively recent phenomenon in Latin America (Fuentes et al. 2008) and are not spatially homogeneous. The tropical biomes, across much of Latin America, are the least invaded (Vitousek et al. 1997). However, it appears that there is a time bomb ticking in Latin America: the invasion process seems to be at an early stage with much of the resident exotic flora not yet naturalised and/or invasive. Examples include ornamental species in Galapagos (Trueman et al. 2010) and production species such as *Pinus* currently invading southern Chile (Richardson et al. 2008; Langdon et al. 2010). This so-called time lag or minimum residence time in the naturalisation–invasion continuum is a much documented theme (Kowarik 1995; Castro et al. 2005). Furthermore, it is also possible that many exotic species are already invasive but have yet to be scientifically documented (e.g. *Pueraria lobata* (Willd.) Ohwi in Bolivia).

Quarantine

Quarantine has long been practiced as a measure to slow the movement of pests and diseases. Global instruments such as The International Plant Protection Convention have facilitated the development of tools that analyse risk and develop measures to prevent species movement. However, such measures will always meet some resistance as they may contravene trade agreements (Simberloff 2003b; Brunel et al. 2009) and appear to compromise the interests of industry. Australia and New Zealand, both island nations, are the world leaders in the use of a quarantine system at three levels (pre-border, border and post-border) to minimise the risk of invasion (Ministry of Agriculture and Forestry 2008; Commonwealth of Australia 2011). The principle that all species are potentially invasive until proven otherwise, combined with a permitted species list, is the cornerstone of their policies. Unfortunately, the application of this principle requires considerable investment in biosecurity, especially in a continental setting, which is unlikely to occur in most Latin American countries. In fact, most Latin American countries at best have limited legislation to prevent the movement of exotic species that threaten plant and animal production or human health. Notable exceptions are pre-border legislation and control for Chile and regional control in Ecuador for the Galapagos Archipelago.

Weed Risk Assessment

Considering that there are over 26,000 known exotic plants species in Australia (J. Hosking, pers. comm.) it is likely that the more geographically diverse Latin America has similarly high numbers (e.g. the Galapagos Islands alone has 870 registered exotic species). However, with the limited resources available, management should focus on highest priority species (based on potential or proven impact) and high biodiversity sites. WRA is a tool used to assess potential invasiveness of species at a bioregional level. Pheloung et al. (1999) carried out much of the pioneering work on WRA in Australia and New Zealand using a weighted scoring system with 49 variables based on a taxon's current weed status in other parts of the world, climate and environmental preferences, and biological attributes. After 8 years of use in Australia, Weber et al. (2009) used the data from 1844 species assessments to show that the model could be reduced to just four variables: broad climate suitability, ability to reproduce in the first year, self-fertilisation and benefits from disturbance. It has also been shown that a panel of experts composed of policy makers, practitioners and scientists can achieve the task of ranking priorities more rapidly and accurately than a desktop study (Pheloung et al. 1999; Daehler et al. 2004). However, it should be noted that not all potentially invasive species are captured using WRA (Gordon et al. 2008).

WRA has been used at the pre-border level to screen new import requests and is used to prioritise management activities on resident exotic flora. In addition to Australia, the WRA system has been adapted to other parts of the world including New Zealand and the archipelagos of Hawaii, Bonin and Galapagos (Gordon et al. 2010). WRA has also been used to help manage quarantine issues between countries that share a land border, such as Chile and Argentina (Fuentes et al. 2010), and guidance questions could easily be modified to suit the needs in Latin America.

Inventories

The use of WRA to prioritise management activities on exotic species has a basic requirement: good inventories. Few existing publications on invasive species in Latin America have focused on inventories (e.g. Ojasti et al. 2001; Guézou et al. 2010). Grey literature may exist, but many lists are not checked, are based on field observations or have poor geographical referencing. Noteworthy initiatives taken by some countries are the development and disclosure of draft databases of all flora including invasive species (e.g. Forzza et al. 2010). The '13 Nation Inter-American Biodiversity Information Network' integrates information from Western Hemisphere countries to support the detection and management of invasive alien species. Examples of nodes include Bolivia (IABIN Bolivia 2011) and Chile (IABIN Chile 2011). These are important first steps and should be strengthened. A good model to follow is the pan-European DAISIE (Delivering Alien Invasive Species Inventories for Europe) project developed between

2004 and 2008. Its aim was to create an inventory of invasive species that threaten European terrestrial, freshwater and marine environments including plant, vertebrate and invertebrate species. This extensive database has been used for meta-analyses including the identification of the most invasive alien plant groups (Lambdon et al. 2008) and the general impacts on ecosystem services (Vilà et al. 2010).

Research on the invasion process

Studies on the detrimental effects of invasive plants on biodiversity are still scarce in Latin America. However, several growing areas of research are helping to provide important baseline information for management. Much of the recent research in Latin America has focused on describing the actual or potential impacts on biodiversity of transformer species: those that change the character, condition, form or nature of ecosystems over a substantial area (Pyšek et al. 2004). The identification of transformer species is important as it allows management interventions to be focused on those species which have a potential or measured impact on biodiversity and/or ecosystem processes. Examples of transformers include: *Rubus ulmifolius* Schott in Juan Fernandez Islands, Chile (Dirnböck et al. 2003); *Kalanchoe daigremontiana* Raym.-Hamet & H.Perrier in arid Venezuela (Herrera 2007); *Prosopis juliflora* (Sw.) DC. in north-eastern Brazil (Andrade et al. 2009); *Melinis minutiflora* P.Beauv and *Hyparrhenia rufa* (Nees) Stapf in the Venezuelan and Brazilian savannahs (Hoffmann et al. 2004; Baruch and Jackson 2005); *Urochloa decumbens* (Stapf) R.D.Webster and *Pinus elliottii* Engelm. in Brazilian savannahs (Pivello, Carvalho et al. 1999; Zanchetta and Diniz 2006); *P. radiata* D.Don in central Chile (Bustamante and Simonetti 2005); and *Artocarpus heterophyllus* Lam. in the Brazilian Atlantic forest (Abreu and Rodrigues 2010). Conversely, many invasive species, such as those that produce offspring, often in very large numbers, at considerable distances from the parent plants, and thus have the potential to spread over a large area (Pyšek et al. 2004), can integrate with native flora causing little obvious impact. Examples include *Coffea arabica* L., *Citrus sinensis* Osbeck in Brazil and *Stapelia gigantea* N.E.Rr. in Venezuela (Sevilha et al. 2001; Chacón et al. 2009).

Other publications have centred on understanding the invasive potential of plants by studying their reproductive and population biology, information useful in management (Cannas et al. 2003; Peña et al. 2008; Becerra and Bustamante 2009; Herrera and Nassar 2009). However, an additional problem often hampering effective management of invaded systems has been a lack of knowledge about the changes in ecosystem processes. Often profound biotic and abiotic ecosystem changes occur with invasions that result in the crossing of irreversible thresholds. These include changes in soil properties, precipitation, native flora, native plant recruitment, light and mutualisms (Chacón et al. 2009; Jäger et al. 2009; Heleno et al. 2010; Bueno and Baruch 2011).

Eradication is difficult and control is expensive*Eradication*

The word eradication is often evoked as the panacea of weed management and has many definitions. The extirpation of all individuals (including seeds) from a defined geographic area is the one we use here. Whilst this end is attractive to funding agencies and decision makers alike, there is an increasing body of literature that shows the goal of plant eradications, in all but small areas, is difficult if not impossible (Rejmánek and Pitcairn 2002; Simberloff 2003a; Panetta and Timmins 2004; Panetta 2009; Gardener, Atkinson et al. 2010; Gardener, Cordell et al. 2010). Without affirmative answers to the following criteria, outlined by Panetta and Timmins (2004), an eradication project will fail:

- (1) Can reintroduction (immigration) be prevented?
- (2) Is the distribution and search area delimited?
- (3) Is the project area easily accessible?
- (4) Does the rate of removal exceed the rate of increase?
- (5) Does the species in question have a short-lived seed bank?
- (6) Are the resources sufficient to fund the project to its conclusion?
- (7) Are there clear lines of authority to take all necessary actions?
- (8) Is there permission from land holders?

Given that the above conditions are difficult to fulfil even in countries with long experience in invasive species management, eradication may not be a universal tool in Latin America. For example, of 30 planned eradication projects in the Galapagos Islands, Ecuador, eight were not started because they did not meet the above criteria, 18 were unsuccessful and four were successful to date: these were all less than 1 ha in net area, on land with a single owner and did not have persistent seed banks. It is likely that three more projects will be successful in the near future: they are tree species which have long maturation times and are without persistent seed banks (Gardener, Atkinson et al. 2010). However, Simberloff (2009) argued that many successful eradication projects are not well reported in the literature which has generated an unjustified pessimism in scientists about the prospects of eradication. If eradication is to be considered, then they should be on small recently established populations where the full extent is delimited.

Control

Control, unlike eradication, is ongoing and, although it does not have a large initial cost, can become accumulatively expensive in the long-term. It is thus important to focus on control projects where the objective is likely to be achieved and/or where potential biodiversity or socio-economic losses are considered to be high if no management action

is taken. Decision makers rightly invest the majority of resources in the most obvious problem: controlling widespread transformer species. Unfortunately, realistic objectives, careful planning, targeted implementation and periodic evaluation are often overlooked resulting in costly projects with little strategic focus. In addition, objectives should focus on maintaining biodiversity and ecosystem processes rather than suppressing the target invasive species. This means that the target species should only be reduced in abundance to below a threshold of impact. This can be reached by using traditional chemical or manual control methods (Buddenhagen et al. 2004; Cuevas and Zalba 2010; Mazzolaria et al. 2011) and with the use of Integrated Weed Management (IWM) which incorporate all available tools such as chemical, manual, use of fire and biological control (Buckley et al. 2004). IWM uses modelling to match each tool with weaknesses in the plant's population biology to maximise efficiency. Another potential tool to help in the optimal allocation of resources to management interventions is quantitative bio-economic modelling (Leung et al. 2002). This mathematical approach combines both the risk that a species poses (ecological, economic and social) and the costs and benefits of various management interventions (such as prevention or control). Unfortunately, careful planning does not always lead to the desired result; in some cases the intervention can result in further degradation or facilitate the invasion of other species (Zavaleta et al. 2001; Jäger et al. 2009). An adaptive management process is essential to achieve positive results.

Biological control of widespread transformer invasive species has been used as an effective management tool for the last century, providing exceptional value for money. For example, a recent economic analysis has shown an overall benefit–cost ratio of 23:1 for biological weed control programmes in Australia, based on increased production, control cost savings and health benefits (Page and Lacey 2006). However, success is not always assured. Van Driesche et al. (2010) analysed 49 weed biological control projects for protection of natural ecosystems in different countries and found that 60% achieved complete or partial control.

Biological control was implemented as early as 1952 in Latin America, but adoption has been limited compared with that of developed countries. Ironically, there has been considerable research sponsored by the developed world to look for biological control agents of Latin American species that are invasive in their countries (Ellison and Barreto 2004). The reasons for the limited adoption of biological control in Latin America include the lack of trained personnel, inadequate infrastructure and insufficient funds for the large initial research investment that is required (Medal 2004). Furthermore, there are sometimes unreasonable bureaucratic barriers to the necessary movement of potential non-target species for testing or introduction of biological control agents (e.g. the movement of rare and threatened non-target species to a country with adequate testing facilities can be highly restricted).

We suggest that Latin American member countries should try to adopt already developed projects that have been successful elsewhere. For example, the fungus *Phragmidium violaceum* (Shultz) G. Winter was developed as a control for other *Rubus* spp. but was found to be effective against *Rubus constrictus* Lef. & M. and has been successfully released in Chile (Ellison and Barreto 2004; Barreto 2009).

Novel ecosystems

Eradication has limited application, control is expensive and requires strict prioritisation and to do nothing is unimaginable. Overall, it appears that the return of invaded ecosystems to their previous weed-free status is not possible in most cases and research towards that end would be wasted, resulting in a system that is only sustainable with huge human inputs. A change of paradigm was proposed by Hobbs et al. (2006) by introducing the concept of novel ecosystems. The key characteristics of these ecosystems include new combinations of species (native and introduced) with possible changes in ecosystem function. These ecosystems, while being the result of human action, no longer depend on human intervention for their maintenance. The concept of novel ecosystems is not an acceptance of plant invasions per se, but is more a change of management focus from the invasive species to maximising native species biodiversity and promoting a stable state. We should, however, continue efforts to maintain some ecosystems, notably protected areas, in their relatively pristine states.

As more of the Earth becomes transformed by human actions, novel ecosystems will increase in importance, but they have been studied relatively infrequently. An example is the new forests of Puerto Rico which developed from abandonment of agricultural and plantation lands. These forests are dominated by exotic trees such as *Spathodea campanulata* P.Beauv. that have the capacity to colonise highly degraded habitats. Although these novel forests have lower native tree species diversity, they facilitate the regeneration of native understory plants and have a similar ecosystem function to that of native forests (Lugo 2009; Abelleira-Martinez 2010). In some cases deliberately planted exotic species (e.g. *Acacia* spp.) may facilitate regeneration of a native understorey (e.g. *Castanopsis hystrix* Miq.) by making abiotic conditions more favourable to natives (Yang et al. 2009). However, this is not always the case (Mascaro et al. 2008).

Our vision of novel ecosystems in Latin America are those which: (a) maintain as much native biodiversity (genes, species and ecosystems) as possible and mirror original functionality (composition, structure, natural processes and ecosystems services); and (b) reduce management intervention to a minimum whilst maximising the total area of intervention. The intrinsic contradiction in the above vision is that some transformer species usually directly impact biodiversity and therefore without a drastic intervention there will be biodiversity loss. Without

some cost-effective way of reducing the competitive vigour of transformer species, such as biological control, we will not be able to maintain native biodiversity in priority conservation areas. For our above vision to be implemented, new knowledge and tools are needed including quantifying thresholds of impact, understanding interactions between the novel mix of organisms and their physical environment, and having adequate management capacity and stakeholder acceptance. Roura-Pascual et al. (2011) used scenario planning as a tool for learning about the future options for management in South Africa's Cape Floristic Region, a region suffering from substantial problems with invasive plants. Scenario planning is a tool that allows us to identify the driving forces of uncertainty that shape the current situation and potential trajectories of different interventions so that we can develop realistic strategies for future management.

The way forward

The authors of this paper represent five member countries and believe our agenda is broadly in line with that of others' (Pauchard et al. 2004). One way to accomplish this future collaboration is through a Latin American Invasive Plants Network. This network could contribute to the following key objectives:

- (1) Support the formation of research groups for studying plant invasions in Latin American countries. The network could help coordinate a campaign to direct national and international organisations to fund priority research and training, especially of early career scientists.
- (2) Develop a regional strategic and collaborative research focus incorporating the novel ecosystem approach and biodiversity protection as the two main guiding principles. Research should focus on providing supporting information for the development of effective quarantine, early intervention and strategic control. Information and tools that will be needed include: spatially explicit species inventories, prioritisation of species using WRA, basic research on priority species, management options and contacts of relevant experts. New and existing multimedia tools should be developed to share knowledge. Parallel research assessing the ecological/evolutionary impact of invasive plants should also be encouraged.
- (3) Raise public and government awareness of economic and environmental costs of plant invasions and communicate the message that prevention is far more cost effective than cure. The principle goal is to encourage a coherent quarantine network among Latin American countries.

According to the above objectives, the highest priority projects for the Latin American Invasive Plants Network

include: (a) an in-depth evaluation of the state of the knowledge of invasive plant research including the compilation of existing literature (both grey and peer reviewed); (b) a Latin America wide collation and analysis of inventory and ecological data; and (c) the development of a standard and readily usable protocol for WRA of all species in distinct ecological regions.

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References

- Abelleira-Martínez OJ. 2010. Invasion by native tree species prevents biotic homogenization in novel forests of Puerto Rico. *Plant Ecology* 211:49–64.
- Abreu RCR, Rodrigues PJFP. 2010. Exotic tree *Artocarpus heterophyllus* Lam. (Moraceae) invades the Brazilian Atlantic Rainforest. *Rodriguésia* 61:677–688.
- Andrade LA, Fabricante JR, Oliveira FX. 2009. Invasão biológica por *Prosopis juliflora* (Sw.) DC.: impactos sobre a diversidade e a estrutura do componente arbustivo-arbóreo da caatinga no Estado do Rio Grande do Norte, Brasil. *Acta Botanica Brasilica* 23:935–943.
- Barreto RW. 2009. Latin American weed biological control science at the crossroads. In: Julien MH, Sforza R, Bon C, Evans HC, Hatcher PE, Hinz HL, Rector BG, editors. *Proceedings of the XII International Symposium on Biological Control of Weeds*. Wallingford: CAB International. p. 109–121.
- Baruch Z, Jackson RB. 2005. Responses of tropical native and invader C4 grasses to water stress, clipping and increased atmospheric CO₂ concentration. *Oecologia* 145: 522–532.
- Becerra P, Bustamante RO. 2009. The effect of herbivory on seedling survival of the invasive exotic species *Pinus radiata* and *Eucalyptus globulus* in a Mediterranean ecosystem of Central Chile. *Forest Ecology and Management* 256:1573–1578.
- Brunel S, Petter F, Fernandez-Galiano E, Smith I. 2009. Approach of the European and Mediterranean Plant Protection Organization to the evaluation and management of risks presented by invasive alien plants. In: Inderjit, editor. *Management of invasive weeds*. Berlin: Springer. p. 319–343.
- Buckley YM, Rees M, Paynter Q, Lonsdale M. 2004. Modelling integrated weed management of an invasive shrub in tropical Australia. *Journal of Applied Ecology* 41:547–560.
- Buddenhagen CE, Rentería JL, Gardener MR, Wilkinson SR, Soria M, Yanez P, Tye A, Valle R. 2004. The control of a highly invasive tree *Cinchona pubescens* in Galapagos. *Weed Technology* 18:1194–1202.
- Bueno A, Baruch Z. 2011. Soil seed bank and the effect of the needle litter layer on seedling emergence in a tropical pine plantation. *Revista de Biología Tropical (International Journal of Tropical Biology)* 59:1071–1079.
- Bustamante RO, Simonetti JA. 2005. Is *Pinus radiata* invading the native vegetation in central Chile? Demographic responses in a fragmented forest. *Biological Invasions* 7:243–249.
- Cannas SA, Marco DE, Paez SA. 2003. Modelling biological invasions: species traits, species interactions, and habitat heterogeneity. *Mathematical Biosciences* 183:93–110.
- Castro SA, Figueroa JA, Muñoz-Schick M, Jaksic FM. 2005. Minimum residence time, biogeographical origin, and life cycle as determinants of the geographical extent

- of naturalized plants in continental Chile. *Diversity and Distributions* 11:183–191.
- Chacón N, Herrera I, Flores S, González JA, Nassar JM. 2009. Chemical, physical, and biochemical soil properties and plant roots as affected by native and exotic plants in Neotropical arid zones. *Biology and Fertility of Soils* 45:321–328.
- Commonwealth of Australia. 2009. Weeds in Australia; [cited 2011 January 27]. Available from: <http://www.weeds.gov.au/>
- Commonwealth of Australia. 2011. Australian Quarantine and Inspection Service; [cited 2011 Jan 27]. Available from: <http://www.daff.gov.au/aqis>
- Cuevas YA, Zalba SM. 2010. Recovery of native grasslands after removing invasive pines. *Restoration Ecology* 18:711–719.
- Daehler CC, Denslow JS, Ansari S, Kuo H. 2004. A risk-assessment system for screening out invasive pest plants from Hawaii and other Pacific Islands. *Conservation Biology* 18:360–368.
- Dirnböck T, Grimler J, Lopez PS, Stuessy TF. 2003. Predicting future threats to the native vegetation of Robinson Crusoe Island, Juan Fernandez Archipelago, Chile. *Conservation Biology* 17:1650–1659.
- Ehrenfeld JG. 2010. Ecosystem consequences of biological invasions. *Annual Review of Ecology Evolution and Systematics* 41:59–80.
- Ellison CA, Barreto RW. 2004. Prospects for the management of invasive alien weeds using co-evolved fungal pathogens: a Latin American perspective. *Biological Invasions* 6:23–45.
- Elton CS. 1958. *The ecology of invasions by animals and plants*. London: Methuen.
- Forzza RC, Leitman PM, Costa AF, Carvalho Jr AA, Peixoto AL, Walter BMT, Bicudo C, Zappi D, Costa DP, Lleras E, et al. 2010. Lista de Espécies da Flora do Brasil. Rio de Janeiro: Jardim Botânico do Rio de Janeiro. [cited 2011 July 4]. Available from: <http://floradobrasil.jbrj.gov.br/2010/>
- Fuentes N, Ugarte E, Kuhn I, Klotz S. 2008. Alien plants in Chile: inferring invasion periods from herbarium records. *Biological Invasions* 10:649–657.
- Fuentes N, Ugarte E, Kuhn I, Klotz S. 2010. Alien plants in southern South America. A framework for evaluation and management of mutual risk of invasion between Chile and Argentina. *Biological Invasions* 12:3227–3236.
- Gardener MR, Atkinson R, Renteria JL. 2010. Eradications and people: lessons from the plant eradication program in Galapagos. *Restoration Ecology* 18:20–29.
- Gardener MR, Cordell S, Anderson M, Tunnicliffe RD. 2010. Evaluating the long-term project to eradicate the rangeland weed *Martynia annua* L.: linking community with conservation. *The Rangeland Journal* 32:407–417.
- Gordon DR, Mitterdorfer B, Pheloung PC, Ansari S, Buddenhagen C, Chimera C, Daehler CC, Dawson W, Denslow JS, LaRosa A, et al. 2010. Guidance for addressing the Australian Weed Risk Assessment questions. *Plant Protection Quarterly* 25:56–74.
- Gordon DR, Onderdonk DA, Fox AM, Stocker RK. 2008. Consistent accuracy of the Australian weed risk assessment system across varied geographies. *Diversity and Distributions* 14:234–242.
- Guézou A, Trueman M, Buddenhagen CE, Chamorro S, AM, Pozo P, Atkinson R. 2010. An extensive alien plant inventory from the inhabited areas of Galapagos. *PLoS ONE*. [cited 2011 Jan 27]; 5:e10276. Available from: <http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0010276>
- Harrington RA, Kujawski R, Ryan HDP. 2003. Invasive plants and the green industry. *Journal of Arboriculture* 29:42–48.
- Heleno R, Lacerda I, Ramos JA, Memmott J. 2010. Evaluation of restoration effectiveness: community response to the removal of alien plants. *Ecological Applications* 20:1191–1203.
- Herrera I. 2007. Diagnóstico del potencial invasor de dos plantas exóticas, *Kalanchoe daigremontiana* (Crassulaceae) y *Stapelia gigantea* (Apocynaceae) en una zona árida tropical Caracas: Instituto Venezolano de Investigaciones Científicas.
- Herrera I, Nassar JM. 2009. Reproductive and recruitment traits as indicators of the invasive potential of *Kalanchoe daigremontiana* (Crassulaceae) and *Stapelia gigantea* (Apocynaceae) in a Neotropical arid zone. *Journal of Arid Environments* 73:978–986.
- Hobbs RJ, Arico S, Aronson J, Baron JS, Bridgewater P, Cramer VA, Epstein PR, Ewel JJ, Klink CA, Lugo AE, et al. 2006. Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography* 15:1–7.
- Hoffmann WA, Lucatelli VMPC, Silva J, Azevedo INC, Marinho MD, Albuquerque AMS, Lopes AD, Moreira SP. 2004. Impact of the invasive alien grass *Melinis minutiflora* at the savanna-forest ecotone in the Brazilian Cerrado. *Diversity and Distributions* 2:99–103.
- IABIN Bolivia. 2011. Red de información sobre especies invasoras; [cited 2011 Jan 27]. Available from: <http://www.invasorasbolivia.com/>
- IABIN Chile. 2011. Red de información sobre especies invasoras; [cited 2011 Jan 27]. Available from: <http://i3n.usach.cl/>
- Jäger H, Kowarik I, Tye A. 2009. Destruction without extinction: long-term impacts of an invasive tree species on Galápagos highland vegetation. *Journal of Ecology* 97:1252–1263.
- Kowarik I. 1995. Time lags in biological invasions with regard to the success and failure of alien species. In: Pyšek P, Prach K, Rejmánek M, Wade M, editors. *Plant invasions: general aspects and special problems*. Amsterdam: SPB Academic Publishing. p. 15–38.
- Lambdon PW, Pyšek P, Basnou C, Hejda M, Arianoutsou M, Essl F, Jarošík V, Pergl J, Winter M, Anastasiu P, et al. 2008. Alien flora of Europe: species diversity, temporal trends, geographical patterns and research needs. *Preslia* 80:101–149.
- Langdon B, Pauchard A, Aguayo M. 2010. *Pinus contorta* invasion in the Chilean Patagonia: local patterns in a global context. *Biological Invasions* 12:3961–3971.
- Leung B, Lodge DM, Finnoff D, Shogren JF, Lewis MA, Lamberti G. 2002. An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. *Proceedings of the Royal Society London B* 269:2407–2413.
- Lonsdale WM. 1999. Inviting trouble: Introduced pasture species in northern Australia. *Australian Journal of Ecology* 19:345–354.
- Lugo AE. 2009. The emerging era of novel tropical forests. *Biotropica* 41:589–591.
- Mascaro J, Becklund KK, Hughes RF, Schnitzer SA. 2008. Limited native plant regeneration in novel, exotic-dominated forests on Hawai'i. *Forest Ecology and Management* 256:593–606.
- Mazzolaria AC, Comparatore VM, Bedmar F. 2011. Control of elmleaf blackberry invasion in a natural reserve in Argentina. *Journal for Nature Conservation* 19:185–191.
- Medal JC. 2004. Perspectives on biological control of invasive plants in Latin America. In Cullen JM, Briese DT, Kriticos DJ, Lonsdale WM, Morin L, Scott JK, editors. *Proceedings of the XI International Symposium on Biological Control of Weeds*. Canberra: CSIRO Entomology. p. 425–427.
- Ministry of Agriculture and Forestry. 2008. Biosecurity New Zealand; [cited 2011 April 18]. Available from: <http://www.biosecurity.govt.nz/>
- Núñez MA, Pauchard A. 2010. Biological invasions in developing and developed countries: does one model fit all? *Biological Invasions* 12:707–714.

- Ojasti J, González-Jiménez E, Szeplaki E, García LB. 2001. Informe sobre especies exóticas en Venezuela. Caracas, Venezuela.
- Page AR, Lacey KL. 2006. Economic Impact Assessment of Australian Weed Biological Control; [cited 2011 June 16]. Available from http://www.weedsrc.org.au/publications/technical_series.html
- Panetta FD. 2009. Weed eradication - An economic perspective. *Invasive Plant Science and Management* 2:360–368.
- Panetta FD, Timmins SM. 2004. Evaluating the feasibility of eradication for terrestrial weed incursions. *Plant Protection Quarterly* 19:5–11.
- Pauchard A, Cavieres L, Bustamante R, Becerra P, Rapoport E. 2004. Increasing the understanding of plant invasions in southern South America: first symposium on alien plant invasions in Chile. *Biological Invasions* 6:255–257.
- Peña E, Hidalgo M, Langdon B, Pauchard A. 2008. Spatial patterns of *Pinus contorta* invasion in a natural reserve in southern South America. *Forest Ecology and Management* 256:1049–1054.
- Pheloung PC, Williams PA, Halloy SR. 1999. A weed-risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management* 57:239–251.
- Pimentel D, editor. 2002. *Biological invasions: economic and environmental costs of alien plant, animal, and microbe species*. Boca Raton, FL: CRC Press.
- Pivello VR, Carvalho VMC, Lopes PF, Peccinini AA, Rosso S. 1999. Abundance and distribution of native and alien grasses in a “cerrado” (Brazilian savanna) biological reserve. *Biotropica* 31:71–82.
- Pivello VR, Shida CN, Meirelles ST. 1999. Alien grasses in Brazilian savannas: a threat to the biodiversity. *Biodiversity and Conservation* 8:1281–1294.
- Pyšek P, Richardson DM, Pergl J, Jarošík V, Sixtová Z, Weber E. 2008. Geographical and taxonomic biases in invasion ecology. *Trends in Ecology and Evolution* 23:237–244.
- Pyšek P, Richardson DM, Rejmánek M, Webster GL, Williamson M., Kirschner J. 2004. Alien plants in checklists and floras: towards better communication between taxonomists and ecologists. *Taxon* 53:131–143.
- Reichard SH, White P. 2001. Horticulture as a pathway of invasive plant introductions in the United States. *BioScience* 51:103–113.
- Rejmánek M, Pitcairn MJ. 2002. When is eradication of pest plants a realistic goal. In: Veitch D, Clout M, editors. *Turning the tide: the eradication of invasive species*. Auckland: Invasive Species Specialty Group of the World Conservation Union (IUCN). p. 249–253.
- Richardson BW, van Wilgen BM, Nuñez MA. 2008. Alien conifer invasions in South America: short fuse burning? *Biological Invasions* 10:573–577.
- Rossiter NA, Setterfield SA, Douglas MM, Hutley LB. 2003. Testing the grass-fire cycle: alien grass invasions in the tropical savannas of Northern Australia. *Diversity and Distributions* 9:169–176.
- Roura-Pascual N, Richardson DM, Chapman RA, Hichert T, Krug RM. 2011. Managing biological invasions: charting courses to desirable futures in the Cape Floristic Region. *Regional Environmental Change* 11:311–320.
- Sevilha AC, Paula A, Lopes WP, Silva AF. 2001. Fitossociologia de um trecho de floresta estacional no Jardim Botânico da Universidade federal de Viçosa (face sudoeste), Viçosa, Minas Gerais. *Revista Árvore* 25:431–443.
- Simberloff D. 2003a. Eradication—preventing invasions at the onset. *Weed Science* 51:247–253.
- Simberloff D. 2003b. How much information on population biology is needed to manage introduced species? *Conservation Biology* 17:83–92.
- Simberloff D. 2009. We can eliminate invasions or live with them. Successful management projects. *Biological Invasions* 11:149–157.
- Trueman M, Atkinson R, Guézou AP, Wurm P. 2010. Residence time and human-induced propagule pressure at work in the alien flora of Galapagos. *Biological Invasions* 12:3949–3960.
- Van Driesche RG, Carruthers RI, Center T, Hoddle MS, Hough-Goldstein J, Morin L, Smith L, Wagner DL, Blossey B, Brancatini V, et al. 2010. Classical biological control for the protection of natural ecosystems. *Biological Control* 54:S2–S33.
- Vilà M, Basnou C, Pysvek P, Josefsson M, Genovesi P, Gollasch S, Nentwig W, Olenin S, Roques A, Roy D, et al. 2010. How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. *Frontiers in Ecology and the Environment* 8:135–144.
- Vitousek PM, D’Antonio CM, Loope LL, Rejmánek M, Westbrook R. 1997. Introduced species: A significant component of human-caused global change. *New Zealand Journal of Ecology* 21:1–16.
- Weber J, Panetta FD, Virtue J, Pheloung P. 2009. An analysis of assessment outcomes from eight years’ operation of the Australian border weed risk assessment system. *Journal of Environmental Management* 90:798–807.
- Yang L, Liu N, Rain H, Wang J. 2009. Facilitation by exotic *Acacia*: *Acacia auriculiformis*, *Acacia mangium* as nurse plants in South China. *Forest Ecology and Management* 257:1786–1793.
- Zanchetta D, Diniz FV. 2006. Estudo da contaminação biológica por *Pinus* spp. em três diferentes áreas na Estação Ecológica de Itirapina (SP, Brasil). *Revista do Instituto Florestal* 18:1–14.
- Zavaleta ES, Hobbs RJ, Mooney HA. 2001. Viewing invasive species removal in a whole-ecosystem context. *Trends in Ecology and Evolution* 16:454–459.