Chapter 21
Manipulating Alien Plant Species Propagule Pressure as a Prevention Strategy for Protected Areas

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Abstract In this chapter we argue that preventing the introduction and spread of alien species in protected areas is still a highly relevant and critically important management strategy despite current and future global change. There has been a provocative and attention grabbing call of late in the conservation literature to accept alien species invasions as inevitable and perhaps even desirable. Such 'novel ecosystems', it has been argued, may function equivalently or better under future conditions. However, we suggest that it is the very uncertainty that global change and its associated impacts bring that makes prevention more necessary than ever for protected areas. Here we focus on the variables affecting protected areas that can and cannot be manipulated to strengthen prevention efforts. Because so much has been learned about alien species prevention, we also outline different approaches for existing protected areas and those that are planned in the future, with particular emphasis on the management of invasive alien plant pathways and propagule pressure.

Keywords Invasive plants • Protected areas • Prevention • Management • Climate change

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21.1 Introduction

Preventing the introduction and colonization of invasive alien plants is an integral component of the management plans of protected areas (PAs) around the world. However, absolute exclusion of unwanted species is recognised as an unrealistic goal in most cases (Rejmánek and Pitcairn 2002; Pluess et al. 2012a, b) and the porosity of PA borders has been well documented since the first global effort to survey invasions in PAs (Usher 1988). Global climate change, atmospheric N deposition, human population growth, land conversion and associated disturbances, and higher levels of trade are all factors contributing to accelerating rates of invasions in most ecosystems (e.g. Meyerson and Reaser 2002; Meyerson and Mooney 2007; Hulme et al. 2009; Chytrý et al. 2012), and present further challenges to the successful prevention of invasive plants incursion into PAs. Other challenges, such as the activities that foster plant introductions in the surrounding matrix (e.g. horticulture, erosion control) and global economic fluctuations that affect the ability to staff and manage PAs for prevention of invasive plants, further complicate management.

Given this rather grim view, it is appropriate to ask whether prevention attempts are still relevant, worthwhile, or even possible. Prevention is a key management option, generally considered as more effective than mitigation and restoration after invasion has taken place (Pyšek and Richardson 2010). Prevention has been identified by the Convention on Biological Diversity in 2002 as the priority management action, with early detection, rapid response, and possible eradication only to follow when prevention fails, and long-term management being the last option (Simberloff et al. 2013). Generally, prevention is applicable at different stages (e.g. Pyšek and Richardson 2010; Blackburn et al. 2011), starting with screening and constricting pathways and vectors, intercepting movements at national borders and assessing risks resulting from international trade; these approaches repeatedly proved successful in reducing the propagule pressures of potential invaders and saving substantial amounts of money to economies (see Simberloff et al. 2013 for examples).

In this chapter we focus on invasive alien plant species prevention as a critical component of PA management. Here, we define 'prevention' as the protection of a defined reserve from invasive alien plants which includes both (i) trying to prevent the arrival of new invasive species and (ii) eradicating or controlling those already present. Therefore, this definition includes limiting the spread of an invasive species already established in a PA, as prevention from on-going and potentially increasing impacts within the reserve. This perspective takes a page from the successful biosecurity approaches that have been employed by New Zealand (Hulme 2011a) and other countries at their borders to manage incursions of unwanted organisms (www.biosecurity.govt.nz/biosec).

Specifically, we highlight the variables controlling plant invasions in PAs with regard to whether or not they can be manipulated. This strategy may be both more effective for preventing the introduction and spread of invasive plants, and more efficient in terms of allocating scarce resources to invasive plants management in PAs.

21.2 Prevention from a Practical Perspective: The Relevance in the Face of Global Change

Over the last several decades, management approaches of PAs have necessarily evolved to recognise and incorporate global, regional and local changes and to consider uncertainty in future trajectories. This evolution holds also for management of invasive species in PAs where absolute exclusion may not only be impractical from an economic perspective but also simply impossible given new and evolving introduction pathways that facilitate high levels of propagule pressure.

In the face of inevitable global change, why is prevention of plant invasions into PAs still relevant? Much literature in the last decade has focused on changing temperature and precipitation patterns that could favour invasive species and negatively impact habitats for native species (e.g. Thuiller 2007; Lambdon et al. 2008; Palmer et al. 2008; Potts et al. 2010). This, of course, includes PAs where many unique biotic and abiotic features and interactions are regulated by temperature and precipitation (Baron et al. 2009). Recent work by Diez et al. (2012) analysed three regional North American datasets of flowering phenology over time. They found that predicting general patterns of phenological response to climate change may be possible at the community level once regional climate drivers (i.e. in addition to temperature) are accounted for (Diez et al. 2012). Such predictions may help to inform the timing and types of management efforts, particularly when interbreeding and hybridization are of concern.

Research has also predicted that both native and introduced species will migrate towards the poles as the climate changes (Walther et al. 2002; Parmesan 2006; Hellmann et al. 2008; Baron et al. 2009), as is already occurring for several species (Parmesan and Yohe 2003). This implies that at least some of the native species that reside within PA boundaries will migrate out of the reserve and new species (both native and alien) will expand their range, migrate in, and colonise the PA resulting in novel biotic assemblages (Baron et al. 2009). Some plants already present in the PA will likely increase in abundance and perhaps also in their distributional range. How individual PA management will respond to the immigration of natives not previously present and to the proliferation of other species already within the reserve should depend on the particular management goals of each site, including how those native immigrants interact with important extant fauna and flora. A further challenge to the relevance of preventing plant invasions is the recent high-profile species translocation conservation strategy (assisted migration) and the controversies that this has generated (Hoegh-Guldberg et al. 2008; Ricciardi and Simberloff 2009; Richardson et al. 2009; IUCN 2012; Schwartz et al. 2012).

However, as has been well documented, invasive species cause significant and lasting changes in natural landscapes over time through ecosystem engineering (e.g. hydrology, accretion, erosion), allelopathy and nutrient cycling (e.g. N-fixation, resource acquisition), and altering light and temperature regimes, that result in profound changes in faunal and floral communities (habitat loss, extirpation, decrease in species diversity, community structure and trophic relationships, etc.); these various types of impacts have received much attention recently (Farnsworth and Meyerson 2003; Liao et al. 2008; Gaertner et al. 2009; Pyšek and Richardson 2010; Vilà et al. 2011; Pyšek et al. 2012; Strayer 2012; Simberloff et al. 2013). Many PAs contain endangered species or rare ecosystem types that could be permanently altered or driven to local extinction by an unchecked invasion. In many countries, PAs are not only considered national treasures because of their historical significance and the species they harbour (e.g. Yellowstone National Park, USA), but are also critical for providing ecosystem goods and services, such as water (van Wilgen et al. 2011, 2012) and an income source for those who live nearby. The potential loss of some or all of these native species, ecosystems and eco-services due to biological invasions keeps the prevention strategy both relevant and crucial.

21.3 Proactive Prevention: To Manipulate or Not

In all PAs, there are variables that can be changed and other variables that are beyond the control of PA management (Table 21.1). While each PA is unique in terms of its location and placement in the larger landscape matrix, some general factors can be applied across most PAs. Detailing these factors for each PA is an important starting point for a PA management plan to better understand where effort and resources can result in positive change and where they cannot. However, the first and perhaps most important distinction in proactive prevention in PAs is whether manipulations to prevent plant invasions are intended for established reserves or for those still in the planning stages.

Globally, the percentage of terrestrial area dedicated to protection of nature has grown over the last two decades. Figure 21.1 presents data on the percentage change in PAs for different regions of the world. Developed regions are grouped while developing regions, arguably hot spots of biodiversity, are distinguished. All regions show at least some increase in the percentage of protected area since 1990 and some (both developed and developing) show additional gains since 2000. If this increasing trend in protected area creation continues, a bifurcated approach for prevention in established PAs versus prevention planned PAs is needed. This dual prevention protocol would allow best practices to be implemented at the earliest stages in newly established PAs, and lessons to be learned from existing PAs where prevention has been successfully applied. However, major knowledge gaps persist. We still do not have satisfactory answers to questions such as:

- Do prevention opportunities differ between established and planned protected areas?
- Is it possible to design new parks that aid in prevention?
- Are prevention strategies 'built in' to reserve design more effective than retroactive prevention?

Below we discuss the major factors affecting invasions in nature reserves and begin to address these questions.

Table 21.1 Overview of factors aimed at preventing or minimizing alien species incursions into extant and future PAs

Factor type	Established PAs	Planned PAs
Manipulatable	Establish buffer zones	Location in landscape matrix (with respect to IAS propagule drivers and socioeconomic fabric of region)
	Restrict/regulate access to fragile areas	Planning buffer zones
	Input of propagules (intensity and timing of park visits, boundary control, biosecurity in PAs)	Education and implementation of codes of conduct
	Human behaviour, education, and codes of conduct	Location of visitor centres, entrance gates, roads and hiking trails
	Water regime	
	Regulated fires	
	Managing/eradicating invasive species already present	
	Allocation of funds into preventive measures of IAS management	
Non-manipulatable	Location in landscape matrix	Climate change
	Climate change	Natural fires
	N-deposition	N-deposition
	Natural fires	Human population development and activities
	Human population development and activities	Stochastic events
	Stochastic events	

Factors are divided according to whether or not they can be manipulated, completely or partially, with the aim to reduce invasive plant species and their impacts, and presented separately for PAs already existing and those to be established in the future. See text for discussion and examples of how the management can be accomplished or mitigation implemented to address those factors that could not be changed or managed

21.4 Vulnerability to Invasion

21.4.1 Location in the Extant Matrix: Managing Natural and Human-Induced Drivers of Propagule Pressure

For planned reserves, drivers of propagule pressure can, to a certain extent, be managed according to the PA location in the landscape matrix. In the Czech Republic and elsewhere in Europe, there are different types of PAs that differ in their levels of protection. In large-scale PAs that include extensive sections of inhabited landscapes such as national parks or so-called ‘protected landscape areas’, human activities, including commercial activities, are regulated but not excluded. Within these PAs, the most biologically valuable parts are declared as nature reserves and strict protection measures imposed, with the aim to completely

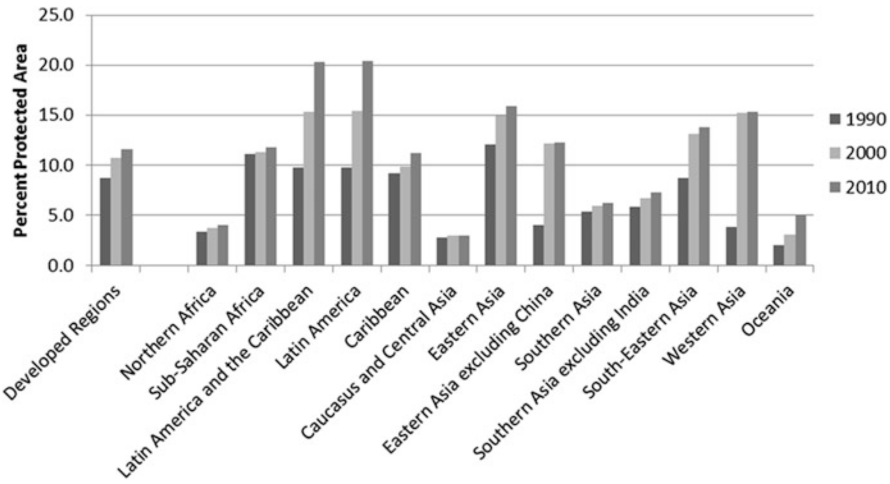

Fig. 21.1 Proportion of terrestrial area protected in developed and developing regions in 1990, 2000, 2010. The differently *shaded bars* represent pooled data for both categories for each of three decades. Pooled data are shown for developed regions in the *left* set of bars, developing regions are shown by individual regions. Data Source: IUCN and UNEP-WCMC (2012) The World Database on Protected Areas (WDPA): Accessed March 2012. Cambridge, UK: UNEP-WCMC

remove them from human influence and allow only natural processes to act. Data from the Czech Republic indicate that small-scale nature reserves located within larger PAs resulted in lower levels of invasion than in reserves established in the non-protected area landscapes.

This finding resulted in the formulation of the "several small inside single large" principle (SSISL) and was suggested as a biodiversity maintenance tool to help prevent plant invasions in nature reserves (Pyšek et al. 2002). This is because of the higher propagule pressure resulting from more intense human activities in landscapes that are not subject to any protection (Chytrý et al. 2008). Similarly, small dry rainforest reserves in Queensland, Australia that do not contain extensive areas of surrounding habitat are unlikely to be secure in the long term (Fensham 1996), pointing to the importance of the surrounding zones in management of small-scale reserves (see also Chown et al. 2003; Jarošík et al. 2011a). Establishment of future small-scale PAs, where this option is available or it is being decided among several possible areas of comparable quality to preserve, should take into account the character of surrounding landscape and connectivity of its more natural parts in the matrix. The above examples suggest that the most convenient strategy from the prevention point of view is to place, whenever possible, new PAs in regions of low human activity, ideally in partially protected landscapes.

Generally, managing pathways and propagule pressure is the key concept behind prevention. A recent study of alien plants incursion into Kruger National Park (KNP), South Africa (Foxcroft et al. 2011), indicated that understanding how drivers of propagule pressure operate can be potentially applied to the management of not only planned but also existing PAs. In this study, the number of alien invasive plants colonizing the park by crossing its border was primarily determined by the amount of water runoff and density of roads outside the park in its close surroundings. Of these two major vectors of propagules, the water runoff had a stronger effect, but both were complementary – where there was no river outside the park, roads acted as an effective driver for propagule pressure. Although the specific effects of factors likely differ among individual PAs, the role of the two major propagule drivers, representing natural and human-induced dispersal, seems to be generally applicable to PAs (Foxcroft et al. 2011). Interestingly, if the general KNP model is applied to individual invasive species, predictors from inside the park, such as the presence of main rivers and species-specific effect of vegetation types, also become important. Landscape characteristics outside the park, such as location of rivers, may serve as guidelines for management to enact proactive interventions to manipulate landscape features near the KNP to prevent further incursions. Predictors from the inside the KNP can be used to identify high-risk areas to improve the cost-effectiveness of management, to locate invasive plants and target them for eradication (Jarošík et al. 2011b).

However, the fact that rivers are the most powerful drivers of alien species propagules (Richardson et al. 2007; Pyšek et al. 2010) creates a conflict of interest because rivers increase habitat heterogeneity and maintain biodiversity and are therefore important landscape elements of many PAs. At present, park managers have little control over the upper reaches of the rivers that flow through KNP. Nevertheless, quantifying the threshold value of water runoff from surrounding areas below which invasion is less likely opens the way to prioritise control measures such as targeting particular riparian areas outside the PA for removal of invasive plants more urgently than others. Or, further spread of alien plants into KNP may be limited by relocating entrance gates to areas where water runoff is low, or follow the same principle if there is a need to create additional entrance gates (Foxcroft et al. 2011).

21.4.2 Buffer Zones: Making Use of Natural Vegetation Resistance to Invasions

Globally, there are twice as many alien species outside of nature reserves than are present within PAs (Lonsdale 1999), suggesting that there are some mechanisms conferring resistance to invasion on PAs. There is some rigorous evidence in the literature that natural vegetation in PAs acts as a buffer against invasion by aliens species. Vegetation of temperate reserves in the Czech Republic was shown to act as an effective barrier against the establishment of alien plants; old reserves had initially fewer aliens than young reserves, and over time it was more difficult for an alien species to invade a nature reserve than a corresponding section of non-protected landscape (Pyšek et al. 2003). The Kruger National park study revealed that in addition to the drivers of propagule pressure, the presence of natural vegetation decreased the abundance of invasive species inside the park. The number of records of invasive plants declined rapidly beyond 1,500 m inside the park, indicating that the park boundary limited their spread (Foxcroft et al. 2011). This phenomenon, of natural vegetation creating a buffer zone, can be potentially used as a prevention tool, if such zones are planned for future reserves, or established around existing PAs. Using vegetation buffer zones as a long term prevention strategy could help minimise the costs, disturbances, and risks associated with on-going active management in core protected areas. For existing parks, such as the KNP example, by focusing only on a subset of vegetation types identified as high-risk for invasion along the park boundary, and fine-tuning the target areas by using information on the presence of rivers and vegetative buffers, management can be made more cost effective (Jarošík et al. 2011b).

21.4.3 Visitors: A Goldmine for Prevention?

It has been repeatedly documented that the number of alien species that occur in a PA is closely related to that of human visitors, this pathway being one of the commonly used surrogates for propagule pressure in invasion studies (Macdonald et al. 1988; Usher 1988; Lonsdale 1999; McKinney 2002; Pyšek et al. 2002; Lee and Chown 2009a, b). In general, horticulture is considered as the most important pathway of introduction of invasive plants (e.g. Mack 2000; Hulme 2011b), but unintentional introductions, such as by visitors to PAs, also generate potentially invasive species. In the Czech flora, unintentionally introduced plant species are less likely to become invasive, but those that do represent a threat to natural areas because they invade a wider range of semi-natural habitats than species escaped from horticulture (Pyšek et al. 2011). The accidental introduction of invasive plant propagules by visitors interacts with the different land-uses within the PA. This can increase the spread of alien plants from areas within the PA such as tourist camps and staff villages, which serve as source areas of propagules (Foxcroft 2001; Foxcroft and Downey 2008).

In many parts of the world, measures to prevent the introduction and spread of invasive plant propagules by visitors to established reserves are already in place. For example, some parks regulate pathways by controlling the number of visitors and the seasons during which people can visit the park, or the accessible areas (e.g. Galapagos, Ecuador [www.galapagospark.org]). Many parks ask visitors to clean their shoes, clothes, tires and vehicles, equipment and pets before entering (e.g. Olympic National Park, Washington, USA and Yosemite National Park, California [www.nps.gov/yose/naturescience/invasive-plants.htm], USA) and some even provide cleaning stations for sanitizing hiking and hunting gear prior to entering the PA (e.g. Fiordland National Park, NZ, www.doc.govt.nz). However, additional prevention measures are possible and desirable, particularly for PAs that are still in the planning stages. For example, informed by scientific knowledge, strategic placements of entrance gates, visitor centres, or staff villages could be considered to reduce threats from plant invasions (Jarošík et al. 2011b; Foxcroft et al. 2011). Finally, an important part of preventive measures aimed at reducing propagule pressure and disturbances caused by visitors is education. Human behaviour is key to preventing biological invasions and it can be assumed that the majority of people visiting PAs are open to being educated about how to contribute to solving problems rather than creating them. Educated visitors can become a part of the on-going monitoring system for new introductions to PAs and all visitors should be educated on appropriate biosecurity precautions and their importance for the PA's preservation. In addition to directly changing behaviour, educated visitors can create culture change in which peer pressure helps to maintain biosecurity standards. In Europe, 'codes of conduct' relating to invasive plants exist for both the horticulture industry (e.g. Heywood and Brunel 2009) and for botanical gardens (Heywood and Sharrock 2012). They are aimed at educating those industries and the people that work in them. Developing and implementing a similar code of conduct for protected areas might be an effective way to formalise and encourage behaviour that strengthens prevention and results in a culture change by PA visitors. This is important because many PAs in Europe, such as large-scale national parks and protected landscape areas host gardening-related and other commercial activities, and as shown recently by Hulme (2011b), botanical gardens can represent serious threat in terms of alien plant invasions.

21.4.4 Factors that Cannot Be Manipulated

Some factors cannot be manipulated for a single PA, regardless of whether PAs are established or still being planned (Table 21.1). These include global climatic factors that change over time (e.g. 2 °C temperature increase per decade is projected by the IPCC 2007), the amount of N-deposition, natural fires beyond control and other stochastic events such as hurricanes or earthquakes, and the multiple pressures associated with human population development and growth. The United Nations is projecting that by 2100 the global population will exceed 10 billion with Africa and Asia as the most populous regions globally (www.un.org/esa/population). Population growth includes demographic and socioeconomic factors such as trade, but also political turmoil, changes in human life style, increases in consumption, behaviour potentially associated with increasingly scarce resources. International treaties and regulations to manage these global changes are notoriously difficult to enforce, particularly when they negatively affect trade and when they involve both developed and developing nations. While these larger global forces paint a somewhat gloomy picture, the take away message is that in terms of managing invasive plants in PAs, it is critical to dedicate energy and resources to the factors that can be controlled, but also to be prepared to adapt when outside forces influence prevention efforts.

21.5 Never Too Late: Eradication Can Reduce Propagule Pressure

Eradicating existing invasions is another dimension of prevention where the aim is to prevent propagules from spreading further within the target area, particularly when eradication is part of an early detection and rapid response strategy to manage 'offensively' rather than 'defensively' (sensu Rejmánek and Pitcairn 2002). As such, it is grouped with factors that can and should be manipulated to strengthen prevention. Both inside reserves and in the landscape outside of reserves the goal is to remove invasive populations. However, within reserves, eliminating or reducing propagules from which other invasive populations could establish is particularly crucial because most habitats in a PA are valuable and subject to protection. Indeed, most eradication campaigns against invasive plants have been conducted in some kind of PAs (23 of the 27 analysed in Pluess et al. 2012b; see also Genovesi 2011; Simberloff 2014 for an overview of successful eradications). The analysis in Pluess et al. (2012b) of factors affecting whether eradication will be successful or not indicated that event-specific factors, such as the extent of the infested area, reaction time and measures of sanitary control can be taken into account and even be manipulated to some degree by authorities dealing with invasive species management. Specifically, initiating the campaign before the extent of infestation reaches a critical threshold, starting to eradicate within the first 4 years since the problem was detected, paying special attention to plant invaders escaped from cultivation, and applying sanitary measures can substantially increase the probability of eradication success (Pluess et al. 2012b).

21.6 Game Over or Game on?

Is prevention of plant invasions in PAs still a relevant strategy? Our conclusion is emphatically yes. A policy shift away from invasive species prevention could in fact be disastrous, perhaps most especially in highly diverse developing countries where the stakes are especially high (Nuñez and Pauchard 2010; Lovei and Lewinsohn 2012). In addition to managing PAs under the uncertainty of climate change, an increased uncertainty would be added in terms of the effects and interactions of invasive plants with resident flora and fauna and abiotic processes, further complicating management and likely increasing costs. For these and other reasons, we strongly argue that prevention remains relevant and is perhaps more important than ever as the ability of ecosystems and native species to adapt to a changing future comes to the forefront of management and research agendas.

Despite the recent flurry of articles in high impact journals touting the inevitability of novel ecosystems and the benefits of invasive species, there have been spectacular successes associated with the eradication of invasive species and preventing their spread to new areas (e.g. Simberloff et al. 2011). We concede that in the face of overwhelming global change and dynamic international trade many of the old ecological rules no longer apply and those hard and fast solutions for completely preventing biological invasions are not feasible. However, we argue that we need to develop innovative approaches for preventing new introductions and invasions and must continue working to eradicate existing invasions, particularly in PAs that serve as the repositories for our global biological wealth. These approaches would include different strategies for existing versus planned reserves, managing pathways both spatially and temporally, managing propagule pressure through the creation and management of buffer zones to reduce propagule pressure, and redoubling our efforts to educate the millions of annual visitors to PAs worldwide and harness their enthusiasm to reinforce prevention efforts.

Given the uncertainty of how the future climate will affect the introduction and spread of invasive plants and the ecosystems where they are introduced, we would be wise to invest our energies in scenario-based planning which allows for an array of alternative futures (Baron et al. 2009). By employing strategies informed by adaptive management and research that distinguishes management approaches that do and do not accomplish prevention, we can begin to close the gap between theory and practice in preventing invasions in protected areas.

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