Seven decades of institutional learning: managing alien plant invasions in the Kruger National Park, South Africa

Llewellyn C. Foxcroft and Stefanie Freitag-Ronaldson

Abstract Long-term ecological and economic sustainability will ultimately determine the outcome of any conservation management programme. Invasive alien plants, first recorded in the Kruger National Park, South Africa, in 1937, are now recognized as one of the greatest threats to the biodiversity of this Park. Such plants have been managed in the Park since 1956, with control advancing mainly through a process of trial and error. Refinement of invasive plant management strategies has resulted in an understanding of the target plants' biology and ecology, herbicide use and herbicide-plant interactions, as well as the plant-insect interactions of biological control. Careful integration of different control methods has proved essential to ensure the most appropriate use of techniques to deliver the best possible results from the resources available and achieve long-term sustainability. We outline the development of control efforts and current control programmes and the process of their incorporation into the institutional memory of Kruger National Park over the last 7 decades.

Keywords Biological control, chemical control, institutional memory, invasive alien plants, Kruger National Park, mechanical control, South Africa.

Introduction

The Kruger National Park is situated in the eastern Limpopo and Mpumalanga Provinces of South Africa, bordered along its entire eastern side by Mozambique (Fig. 1). The Park extends 360 km from north to south and covers 20,000 km^2, making it one of the largest protected areas in the world. Kruger is bisected by seven major river systems, originating in the highlands to the west and draining a combined area of *c*. 88,600 km^2. The Park falls within the savannah biome of southern Africa (Scholes, 1997) and has been classified into 35 landscape types (Gertenbach, 1983).

Kruger National Park, although largely a roadless area under protection since its declaration as a National Park in 1898, has not escaped the increasing threats of biological invasions (Foxcroft & Richardson, 2003; Freitag-Ronaldson & Foxcroft, 2003). Invasive alien plants (naturalized alien plants that produce offspring, often in large numbers and at considerable distance from the parent plants and thus with the potential to spread over vast areas; Richardson *et al*., 2000), probably already present in the Kruger National Park region prior to its gazettement, have established and dispersed along all major rivers and vast areas of upland vegetation. Stevenson-Hamilton recognized invasive alien plants as a concern almost 7 decades ago (Stevenson-Hamilton, 1937) when management was not based on research and science but on a practical understanding of the environment (Rogers & Bestbier, 1997). Unfortunately, little was done to address the problem until the 1950s, and even then this was insufficient to curtail the invasions.

The first six alien plant species were recorded in 1937 as 'troublesome weeds' (Table 1A; Obermeijer, 1937), and this initial list has been periodically updated (Table 2). Currently, 372 alien plant taxa have been recorded in the Park (Foxcroft *et al*., 2003; Table 2). This includes two transformer species (transformer species are invasive plants that change the character, condition, form or nature of ecosystems over a substantial area; Richardson *et al*., 2000; Table 1B), 125 invasive species, and 223 species that are either naturalized (meaning alien plants that reproduce consistently and sustain populations over many life cycles but do not necessarily invade natural, semi-natural or human-made ecosystems) or casual aliens (alien plants that may flourish and even reproduce occasionally in an area, but that do not form self-replacing populations; Foxcroft *et al*., 2003). The most prevalent invasive species include two terrestrial invaders and three species of free-floating aquatic macrophytes (Table 1C; Foxcroft & Richardson, 2003).

History of control efforts

The first management efforts in the Park were aimed at the eradication of species such as Persian lilac *Melia*

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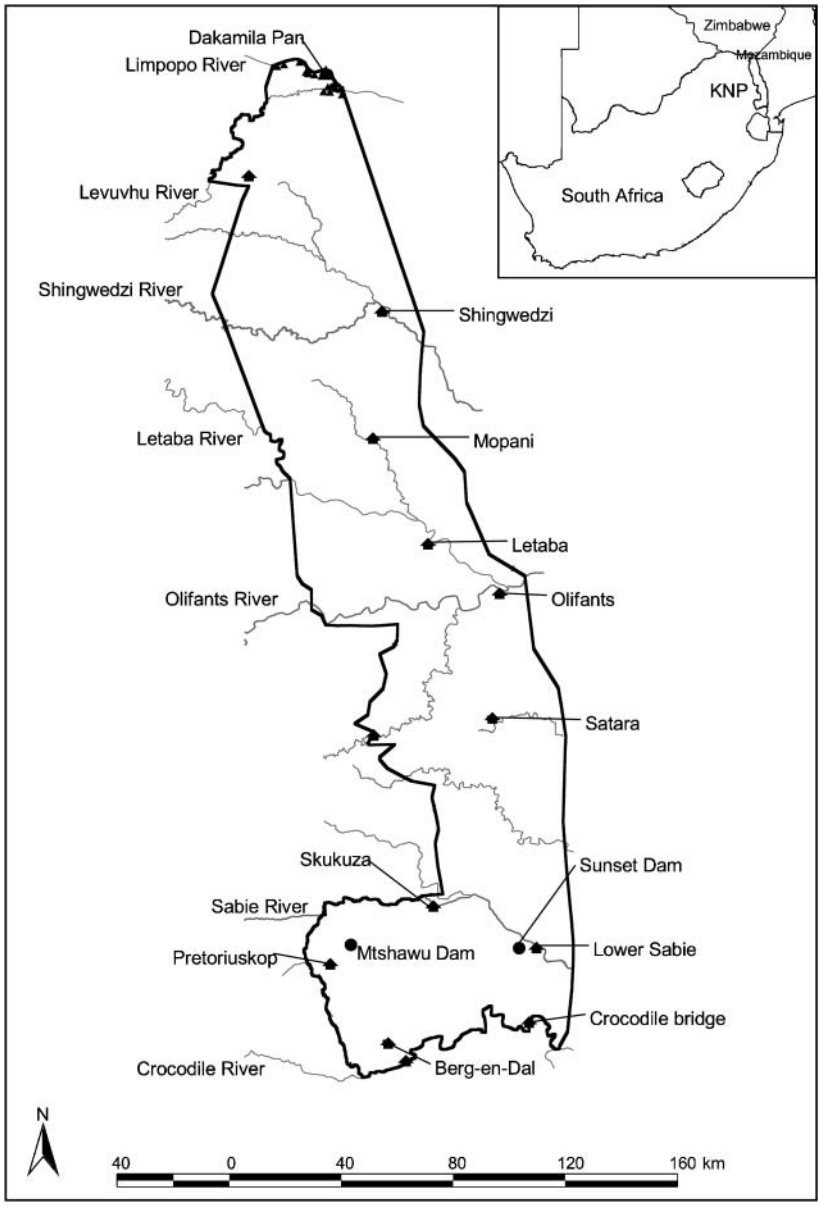

Fig. 1 Map of the Kruger National Park, indicating the main rivers and larger tourist camps. Also shown are specific dams and pans mentioned in the text. The inset shows the location of the Park (KNP) in South Africa.

azedarach L. on the Sabie, Crocodile and Nsikasi Rivers. This was done by boring holes into the trunks and filling these with paraffin (Joubert, 1986) and in 1957 through mechanical means (Macdonald & Gertenbach, 1988; Fig. 2). Chemical control of invasive alien plants in the Park initially developed slowly but later became the main control method and focus of research. During the 1960s the herbicide KOP 250 (2,4,5,-T) was tested and proved effective (Joubert, 1986), resulting in the formal introduction of herbicides into the control of alien plants. Numerous herbicide trials followed over the ensuing years, with herbicides also used to control woody shrubs, aquatic weeds, bush thickening and road verge encroachment. Nevertheless, these often failed to provide adequate control of the plants and in some areas resulted in erosion and other impacts, especially along firebreaks and fences (Joubert, 1986).

By 1985 10 species (Table 1D) were thought to have been successfully eradicated, with the eradication of a further 14 species considered possible (Macdonald & Gertenbach, 1988). However, of the 10 species considered eradicated, six still require ongoing control efforts today. Whether failure to eradicate these species was because of later reintroductions or, more likely, a lack of continuity in control efforts, is not specified in available reports (Foxcroft *et al.*, 2003). We believe the latter reason more plausible as eradication is extremely difficult under any scenario (Panetta & Timmons, 2004).

During 1982–1995 control operations were conducted by the Park's dedicated alien plant clearing team

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Table 1 Examples of invasive alien plant species in the Kruger National Park. Groups of species are also cross-referenced to specific discussion points in the text.

Cross ref.	Text reference	Species	Common name	Habitat
A	First alien plant species recorded	*Chenopodium ambrosioides* L.	Wormseed/goosefoot	Ruderal
		Cocculus hirsutus (L.) Diels	Cocculus	Ruderal
		Boerhavia diffusa L.	Erect boerhavia	Ruderal
		Gomphrena celosioides Mart.	Prostrate globe amaranth	Ruderal
		Argemone mexicana L.	Yellow-flowered Mexican poppy	Ruderal
		Tagetes minuta L.	Khaki bush	Ruderal
B	Species considered to be transformer species	*Lantana camara* L.	Lantana	Terrestrial
		Opuntia stricta Haworth Haworth.	Sour prickly pear	Terrestrial
C	Currently the most prevalent species	*Lantana camara* L.	Lantana	Riparian
		Opuntia stricta Haworth Haworth.	Sour prickly pear	Terrestrial
		Chromolaena odorata (L.) R.M. King & H. Rob.	Chromolaena	Riparian
		Azolla filiculoides Lam.	Red water fern	Free-floating aquatic macrophyte
		Eichhornia crassipes (Mart.) Solms	Water hyacinth	Free-floating aquatic macrophyte
		Pistia stratiotes L.	Water lettuce	Free-floating aquatic macrophyte
D	10 species considered to have been eradicated by 1985	*Salix babylonica* L.	Weeping willow	Riparian
		Acacia dealbata Link.	Silver wattle	Riparian
		Senna didymobotrya (Fresen.) Irwin & Barnaby	Peanut-butter cassia	Riparian
		Caesalpinia pulcherrima (L.) Schwartz	Pride of Barbados	Riparian
		Opuntia aurantiaca Lindl.	Jointed cactus	Terrestrial
		Ipomoea purpurea (L.) Roth	Morning glory	Riparian
		Nicotiana glauca R.C. Graham	Wild tobacco	Riparian
		Tecoma stans (L.) Kunth	Yellow bells	Riparian
		Bidens pilosa L.	Common blackjack	Ruderal
		Salvinia molesta D.S. Mittchell	Kariba weed	Free-floating aquatic macrophyte
E	Species for which approved biocontrol agents have been released	*Azolla filiculoides* Lam.	Red water fern	Free-floating aquatic macrophyte
		Eichhornia crassipes (Mart.) Solms	Water hyacinth	Free-floating aquatic macrophyte
		Lantana camara L.	Lantana	Riparian
		Opuntia stricta Haworth Haworth.	Sour prickly pear	Terrestrial
		Pistia stratiotes L.	Water lettuce	Free-floating aquatic macrophyte
		Salvinia molesta D.S. Mittchell	Kariba weed	Free-floating aquatic macrophyte
		Sesbania punicea (Cav. Benth)	Red sesbania	Riparian

consisting of 10 people, with occasional assistance from rangers' labour teams. Work performance was coarsely measured by recording the number of plant stems removed, focusing mainly on *Lantana camara* and *Opuntia stricta*. In this period, 6,889,515 stems were removed, and a further 8,579,314 stems were removed during 1996–1999 (Freitag-Ronaldson & Foxcroft, 2003). During the latter period a geographic information system was first used to capture the extent of clearing operations, which amounted to approximately 92,688 ha. This represents only 16% of the total area (590,295 ha) invaded by alien plants in the Park but is still essential to the long-term success of the control operations (Freitag-Ronaldson & Foxcroft, 2003) as these areas are regularly followed up.

In 1997 the National Working for Water (WFW) programme launched its first alien plant control project in the Park, with the sponsorship of ZAR 3 million from the Royal Netherlands Government and ZAR 6 million from the Poverty Relief fund of the South African Government. This enabled the employment of up to 1,000 unemployed people, focusing only on clearing invasive alien plants. The project has continued to the present, with a total of around ZAR 60 million (*c*. USD 8.5 million) being spent on control efforts in the Park to the end of the 2006/2007 financial year. These massive

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Table 2 Records of alien plant species in Kruger National Park, arranged chronologically (from Foxcroft & Richardson, 2003; Freitag-Ronaldson & Foxcroft, 2003).

Total no. of species	Additional number of species	Source
6	6	Obermeijer (1937)
32	26	Codd (1951)
43	11	Van der Schijff (1957)
76	33	Van der Schijff (1969)
150	74	Gertenbach (1985)
156	6	Macdonald & Gertenbach (1988)
202	46	Anon (1995)
214	12	Anon (1997b)
360	146	Foxcroft (1999)
362	2	Foxcroft (2000)
366	4	Foxcroft (2001a)
370	4	Foxcroft *et al.* (2003)
372	2	Foxcroft (2004)

management efforts, built upon the foundations of the Park's own alien plant clearing programmes, have led to the current situation in which invasive plant population abundances are nearing maintenance levels, with annual follow-up operations being implemented. However, should these follow-up operations lapse, experience has shown that the system will revert to its former densely invaded state (Freitag-Ronaldson & Foxcroft, 2003).

Biological control

Biological control is the intentional use of populations of upper trophic level organisms, commonly referred to as natural enemies, to suppress populations of target invasive alien plant species. The introduction of a new species from one country to another is not without inherent risks. However, South Africa's Agricultural Research Council Plant Protection Research Institute (ARC-PPRI) is regarded as one of the top biocontrol research organizations in the world (Klein, 2001) and permission for biocontrol agent release needs to be given by both the National Department of Agriculture and the Department of Environmental Affairs and Tourism prior to release anywhere in South Africa (Klein, 2001). The ARC-PPRI is the lead partner in biocontrol efforts in Kruger National Park and the use of any such agents is only considered after all necessary national research, testing, screening and permissions have been granted. These stringent pre-release processes have resulted in an absence of non-target effects on any indigenous species in either the Park or elsewhere in South Africa (Klein, 2001).

In Kruger the first biological control agent (*Neohydronomus affinis*; Coleoptera: Curculionidae) was introduced by ARC-PPRI for the control of *Pistia stratiotes* at Dakamila Pan in the far northern Pafuri region in 1985 (Cilliers *et al.*, 1996; Martin & Foxcroft, 2001). This marked another significant milestone for the management of invasive plants and led to the development of integrated control programmes in the Park. Since 1985, 16 biological control agents have been introduced into the Park for the control of seven alien plants (Table 1E; Martin & Foxcroft, 2001) with research predominantly focused on long-term post-release

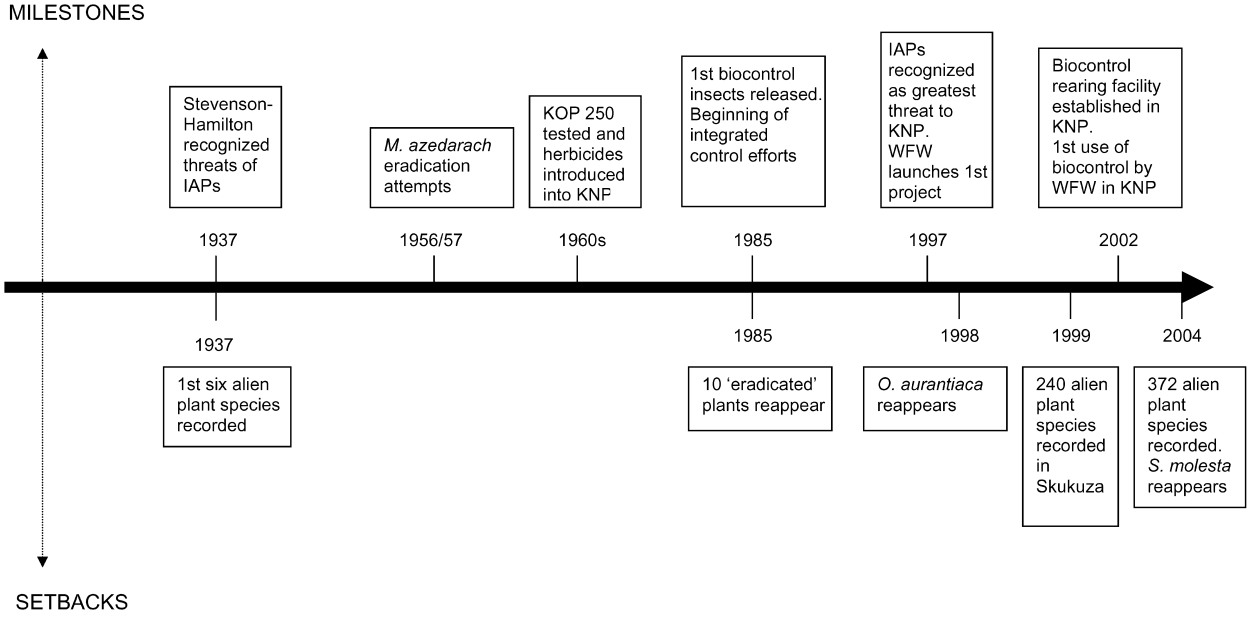

Fig. 2 Time line indicating milestones and setbacks during the management of alien plants in Kruger National Park (KNP) over the last 7 decades. IAPs, Invasive Alien Plants; WFW, Working for Water.

evaluation of plants under biological control, allowing a greater understanding of the insect-host interactions (Cilliers *et al*., 1996; Lotter, 1997; Hoffmann *et al*., 1998a,b). Although no specific studies were undertaken on whether or not there have been non-target effects, the long-term monitoring programmes provided opportunities to make the types of observations that would have detected any such effects. To date, none have been apparent. This was largely facilitated through a partnership between the Park, ARC-PPRI and the University of Cape Town.

The introduction of biological control has not been without problems. The often slow increase of insects, as well as the cyclic seasonal fluctuations, has received criticism from those not conversant with the functioning of biocontrol. The Park has been on the brink of abandoning certain biocontrol efforts when pressures to provide a quick chemical solution have been overwhelming, e.g. at the favoured tourist site of Sunset Dam near Lower Sabie (L.C. Foxcroft, S. MacFadyen & C.J. Cilliers, unpubl. data). Nevertheless, biological control has and will continue to play a major role in the control of aquatic weeds (e.g. *P. stratiotes*, *Azolla filiculoides* and *Salvinia molesta*) that are inherently aggressive and difficult to control. Biological control has provided long-term management options that effectively save the Park substantial resources and is also now recognized as one of the most cost-effective ways of managing invasions of alien plants (van Wilgen *et al*., 2001) with self-perpetuating populations of the control agent maintaining the abundance of the host weed plant at acceptable levels.

Role of staff in importing and distributing alien plants

Park staff played a major role in facilitating alien plant invasions in Kruger National Park (Foxcroft, 2001b; Foxcroft & Richardson, unpubl. data). In the past, Park staff unwittingly introduced exotic species into cultivation in tourist camps and staff villages for ornamental and other uses. Their subsequent escape into the surrounding indigenous vegetation highlights the role of intentional introductions as foci of future invasion, a situation not unique to the Park. For example, Foxcroft *et al*. (2006) documented how tourist lodges in the Ngorongoro Conservation Area, Tanzania, are landscaped with ornamental alien plant species that pose a significant future threat to the surrounding areas.

Current control efforts

Kruger National Park's 1997 biodiversity conservation management review, using a SWOT-type analysis (Strengths, Weaknesses, Opportunities and Threats), identified invasive alien species as one of the greatest ecosystem threats (Anon, 1997a) ahead of other traditionally recognized concerns such as poaching, fire and large mammal control. This was backed by widespread evidence from across the Park and a developing knowledge of invasion biology (Rejmánek *et al*., 2006). In essence, little institutional learning and management adaptation to invasive alien plant threats had taken place in the Park since Stevenson-Hamilton first raised his concerns in 1937. Nevertheless, the 1997 review also marked the time when the organization acknowledged and internalized the fact that given time and limited resources, invasive alien plants will establish to the detriment of indigenous biodiversity. Foxcroft & Richardson (2003) and Freitag-Ronaldson & Foxcroft (2003) partly ascribed the failure of the Park to manage early plant invasions to the lack of integration of alien plant control into overall management structures, which failed to recognize the long-term threats at the time.

Alien plants are currently controlled by a combined effort involving the Park (through its Invasive Alien Biota section and rangers) and the nationally funded WFW programme. WFW is particularly instrumental in management of riverine invasions, focusing on chemical and mechanical control of species such as *L. camara*, *Chromolaena odorata* and others. Collaboration with provincial WFW structures remains essential in coordinating operations at the catchment and landscape levels.

The Park has developed a biocontrol rearing facility in Skukuza, primarily for rearing the cochineal biocontrol insect *Dactylopius opuntiae* (Homoptera: Dactylopiidae) that is mass-released throughout the 66,000 ha *O. stricta* invasion within the Park and neighbouring areas. WFW operational teams have adopted this new control option as an alternative to manually spraying herbicides. This marks a significant development in the long-term effective management of *O. stricta* in the Park and in the expanding scope of WFW operating procedures.

Control of invasive species also requires the management, mitigation and, where possible, prevention of propagule distribution. Thus recognition of the main vectors and pathways of dispersal are critical. In Kruger the invasion of riparian habitats far exceeds that of any other habitat and is directly linked to the extensive invasions in the upper catchments to the west of the Park (Foxcroft *et al*., 2007). Until satisfactory and sustained efforts are made in managing the plant invasions in the state-owned and private upper watershed areas, long-term control efforts will, at best, only provide temporary relief.

Impacts of invasive species

Within the Park indigenous species may be eliminated or extensively replaced with invasive plant species or associated complexes (Holmes & Cowling, 1997) but the direct negative impacts on biodiversity have not been investigated. However, it is implicitly assumed that such impacts are happening, and are therefore undesirable in the National Park context (IUCN, 2000; Freitag-Ronaldson & Foxcroft, 2003). The lack of research to quantify the negative impacts of invasive plants has been a shortcoming of the Kruger National Park programme (Foxcroft & Freitag-Ronaldson, 2005).

Structural ecosystem diversity includes landscape, habitat, population and genetic structure (Noss, 1990) and invasive species have effects at all these levels. The Park is structurally an island amidst vast and varying landscape uses and has been invaded to varying extents by numerous alien plant species (Foxcroft & Richardson, unpubl., data). Alien plant species are hypothesized to cause alternative landscape patterns to emerge, frequently with severe follow-on effects. Although not rigorously tested in the Park, Lotter & Hoffmann (1998) give an account of the impact of *O. stricta* on the vegetation structure. They showed that in an area densely invaded by *O. stricta* the vegetation was significantly altered, with *O. stricta* substantially outnumbering the indigenous plants. In a similar manner, species with allelopathic properties, such as parthenium *Parthenium hysterophorus*, which has invaded the southern region of the Park, may inhibit or prevent the establishment of indigenous species in its close proximity (Reinhardt *et al*., 2004).

Institutional learning: internalizing the experience

It appears that little of the experience gained through the management of invasive species was internalized in Kruger National Park for at least the first 6 decades. The slow response to increasing invasions over time have resulted and will continue to result in a costly and continuous management programme. Clearly, slow, insidious ecosystem impacts are not as obvious and do not generate the immediate and large response that sizeable infrequent disturbances do (Parsons *et al*., 2005), a reality that managers must now explicitly take into account. In Kruger this gradual increase in awareness, support and planning has only occurred in the last 10 years.

Efforts have been made to record and document the invasion history in the Park, providing an institutional memory and record of learning for future managers. However, the learning taking place both within the Park and internationally needs to be further internalized in the future, and we contend that: (1) Management must fully embrace the inherent risks and challenges associated with biological invasions by providing appropriate resources; an issue that has already received attention. (2) A well documented and annotated database and reference system must be maintained, including all invasive species distribution records, management history, research, monitoring and the myriad other activities that are taking place. (3) Setting of objectives (both short- and long-term), drafting of implementation plans, long-term monitoring programmes and research are key issues that require integration and adaptive feedback loops to develop an overall, institutional approach to biological invasions.

Kruger National Park has made substantial advances in integrating the science and management of invasive species into a learning framework (Foxcroft & Richardson, 2003; Freitag-Ronaldson & Foxcroft, 2003). Termed Strategic Adaptive Management, the process is embraced as a framework of managed learning, which steers strategic action to achieve desired endpoints in a complex ecosystem (Salafsky *et al*., 2001; Biggs & Rogers, 2003). Adaptive management has been successfully used in natural resource management in general (Salafsky *et al*., 2001; Biggs & Rogers, 2003; Smit, 2003) and invasive species management specifically (Tu, 2001; Towns, 2003). In Kruger this approach has helped articulate and elevate the threats, catalyze a broader understanding, and implement appropriate structured responses to invasions of alien plants. We suggest that reviewing and capturing previous management attempts, successes, and probably more importantly, failures, are important steps in improving future operations.

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