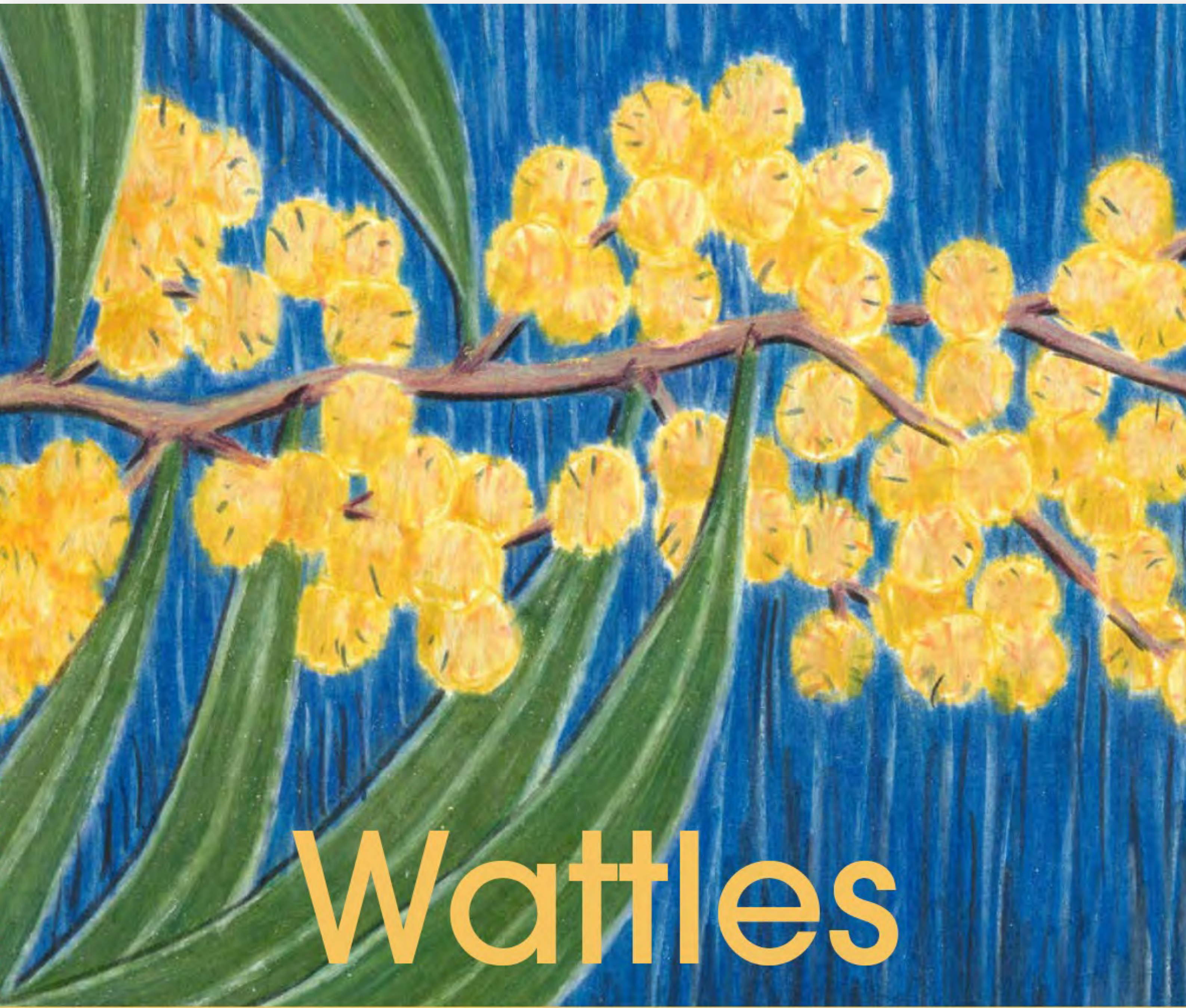

Wattles

Australian *Acacia* species around the world

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CABI

26 Controlling Invasive Australian *Acacia* Species: The South African Story

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Abstract

Australian *Acacia* species ('wattles') were introduced to South Africa for a range of purposes from the early 19th century onwards. Some wattle species continue to be grown and utilized for timber and bark products, but since the mid-20th century management has increasingly had a focus on reducing their impacts as invasive species. Wattles are thus 'conflict species' that generate both positive benefits and negative impacts, and management and legislation have had to accommodate the often opposing views and needs of various stakeholders. Proposals to introduce biological control agents in the 1970s were initially strongly resisted, and only ten seed-feeding and flower-galling insects and one gall-forming rust fungus have been released between 1982 and 2020, although several other agents are currently under consideration for future release. Released agents provide various levels of control against ten wattle species. Legislation was passed in 1983 that required landowners to manage wattles as invasive species, but also allowed for the continued growing of some species for commercial purposes. In 1995, the South African government initiated nationwide control campaigns against invasive alien plants, including wattles, to both reduce negative impacts and create employment. To date, ZAR 1.4 billion has been spent on physical and chemical control of wattles through this programme (2020 ZAR values), but this control has reached < 6% of the estimated invaded area. The effectiveness of control is not monitored, so the outcomes of this investment are largely unknown. Seven wattle species that have limited distributions have been systematically controlled with a view to achieving nationwide eradication, but extirpating even small populations could take decades given that many invasive wattles have large persistent seed banks. When cleared of wattles, ecosystems are largely left to self-recover, although active restoration of the historically displaced vegetation is clearly needed in many instances. Future management of wattles in South Africa will have to build on the lessons learnt over the past century, and will continue to be constrained by insufficient funds and competing interests. The development of national species-level policies, with clear and attainable goals, will be needed to guide integrated management into the future.

26.1 Introduction

Agricultural expansion, European colonization, industrialization and the concomitant increases in human population led to a dramatic increase in the demand for wood in South Africa in the 18th and 19th centuries (Lückhoff, 1973). Given that most native tree species tend to be

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slow-growing, there was significant interest in importing trees to increase the supply of timber, firewood and for other purposes. As a result, Australian trees and shrubs in the genus *Acacia*, commonly known as wattles, were introduced to South Africa as early as 1833 for a range of purposes, including timber production, sand stabilization and bark products (Poynton, 2009; Chapters 9 and 12, this volume). Wattles provide an interesting case study of the history of management because, while they were initially managed for beneficial uses, many wattle species have become invasive and interventions became necessary to reduce the negative impacts caused. These initiatives included the introduction of legislation, the implementation of biological control and government support to landowners to control wattles. Currently, more is spent on the management of wattles than on any other group of invasive alien plants in South Africa (Zengeya and Wilson, 2020). Many species in this genus are 'conflict species' with both useful and harmful effects, so the opposing views of various stakeholders had to be considered when setting goals for management (Zengeya *et al.*, 2017; also see Chapter 8, this volume). This chapter reviews the history of wattle management in South Africa against a backdrop of changing perceptions; it also evaluates how effective this management has been.

26.2 Wattles as Useful Plants

While this chapter has a focus on the management of wattles as invasive alien plants in South Africa, it is important to recognize that many species are still considered useful in the country. This introduces a set of dynamics regarding their management which must be understood to contextualize the development of management of such species (van Wilgen and Richardson, 2014).

Poynton (2009) noted that '... few plant genera are of greater utility to man or have yielded a wider range of products than *Acacia*'. He noted further that 18 species were introduced to South Africa before 1900. Since then, many more wattle species have been introduced to South Africa; Magona *et al.* (2018) found records of 141 species reportedly introduced to the country, but could only confirm that 33 species were still present. The introduction of most wattle species to South Africa resulted in high propagule pressure (large numbers of seeds and repeated introductions; Le Roux *et al.*, 2011). Although many of these species failed to establish, by 2021 there were at least 21 species that had become naturalized or invasive in the country (Table 26.1). Wattles can be categorized into four main groups based on the uses to which they were put when introduced: (i) forestry; (ii) dune stabilization; (iii) ornamental; and (iv) those that were only ever planted at a few sites or in a few arboreta for trial purposes (Richardson *et al.*, 2015; Chapter 9, this volume). These groupings differ in terms of when they were introduced, and where and how widely they were planted. This in turn affects the complexity of their management as invasive species, with widespread and commercially important species being more difficult to control than species with restricted distributions or ornamental rather than commercial value (Donaldson *et al.*, 2014a).

Stabilization of open sand dunes around Cape Town involved the extensive planting of *A. cyclops* and *A. saligna* in the late 19th and early 20th centuries (Shaughnessy, 1986). These plantings continued until as late as 1947. Similar plantings took place along hundreds of kilometres of South Africa's west and south coasts (Lubke, 1985). All of these plantings were characterized by high propagule pressure (Le Roux *et al.*, 2011; Chapter 6, this volume).

Acacia melanoxylon was introduced for timber production in 1848. This species was extensively planted in the early 20th century to suppress weed growth where native trees had been felled, and to assist natural regeneration of indigenous trees (Geldenhuys, 2004). This practice was discontinued in 1930 due to concerns that *A. melanoxylon* was depleting soil moisture, suppressing indigenous tree seedlings and spreading throughout the forests. The species was also planted in pure or mixed stands, including other alien timber trees. Most plantings did not yield good timber (Donald, 1959), and many plantations were therefore replaced with other species. *Acacia melanoxylon* trees growing in indigenous forest settings were however considered a highly valuable asset (Von Breitenbach, 1967) and continued to be managed for high-quality timber. In 1981 the Department of Forestry stopped the planting of *A. melanoxylon* in forest gaps, and

Table 26.1. Information on the introduction status and salient features of naturalized Australian *Acacia* species in South Africa, with proposals for management. Introduction status is as per the Darwin Core term 'dwc:degreeOfEstablishment' (Groom *et al*., 2019). Number of grid cells occupied is from Henderson and Wilson (2017). Primary use (i.e. reason for introduction) as per introduction pathway classification as interpreted by Table 5 in Harrower *et al*. (2017), except that 'trial' can be considered as either 'botanical gardens and zoos' or 'forestry' as there is no clear category for arboreta (also see Chapter 9, this volume); in some cases the taxa were explicitly planted as forestry trials, but the distinction with forestry is that trials were never planted in large numbers. Negative impacts recorded in South Africa are from van Wilgen *et al*. (2022b; also see Chapters 22 and 23, this volume for impacts recorded in other parts of the world); net value for *Acacia mearnsii* is from De Wit *et al*. (2001). Biological control effectiveness scored as per Zachariades (2021). Regulatory listings are those that came into force March 2021 (Department of Environment, Forestry and Fisheries, 2020). The regulatory categories are: 1a = Species targeted for national eradication; 1b = Species to be controlled as part of a national management programme, no trade allowed; 2 = Species to be controlled as part of a national management programme, but permits can be issued for usage (e.g. forestry) provided that steps are taken to control spread; 3 = Species to be controlled as part of a national management programme, but existing trees may be kept without permits (this is for species that are being phased out, e.g. feature trees can be kept, but they may not be replaced). Risk analysis as per the process outlined in Kumschick *et al*. (2020). For taxa that have not yet been evaluated in South Africa (as of 1 August 2023), a recommendation is included here. Environmental Impact Classification for Alien Taxa (EICAT) categories are from global studies (see Chapter 23, this volume for details). The EICAT categories of impact are: DD = Data Deficient; MC = Minimal Concern; MN = Minor; MO = Moderate; MR = Major; MV = Massive. Note that several other species are known to occur in Table Mountain National Park (e.g. *A. schinoides* and *A. ulicifolia*) but are not included here as their current status is to be determined.

Acacia species	Introduction status (with number of quarter-degree grid cells occupied)	Primary use	Impacts and benefits	Biological control effectiveness	Regulatory listing category	Impact; Recommendations from risk analysis
A. adunca	Established (1)	Trial planting	No recorded benefits or impacts. Has potential to outcompete native plants, so net value could become negative	No biocontrol agents have been introduced	1a	Global EICAT category: DD; Retain as 1a and continue eradication attempt
A. baileyana	Widespread invasive (103)	Ornamental	Used as an ornamental plant, but many options for non-invasive alternatives exist. There are no documented impacts in South Africa, but has potential to outcompete native plants, so net value could become negative	Negligible effect on density, biomass, area occupied and rate of spread	3	Global EICAT category: MR; No risk analysis yet. Research might be needed to determine if exempting existing trees from control sufficiently reduces the risk (i.e. category 3 = category 1b with existing cultivated trees exempt OR category 1b with no exemptions)

A. cultriformis	Established (1)	Ornamental	No recorded benefits or impacts	No biocontrol agents have been introduced	Not listed	Global EICAT category: MN; List as 1b, eradication deemed unfeasible given its widespread presence in gardens.
A. cyclops	Widespread invasive (175)	Dune stabilization and barriers (historical); firewood	Recorded to have multiple impacts on ecosystems (increased fuel loads leading to increased fire intensity and erosion; disruption of sand movement leading to beach erosion; reductions in native bird species richness and abundance), but value unquantified. Beneficial in terms of firewood production. Overall net value probably negative	Substantial reductions in density and rate of spread, but not on biomass and area occupied	1b	Global EICAT category: MR; No risk analysis yet. The widespread trade in firewood harvested from invasive populations is technically illegal, but such trade is unlikely to contribute to spread. Amendments to regulations could exempt harvesting of firewood as part of an integrated control programme. Given the impact of biological control, the potential to remove the listing has been discussed, though continuing control is important in many areas.
A. dealbata	Widespread invasive (302)	Forestry	Recorded to reduce native invertebrate species richness and abundance. Is used for wood and bark products, but the value of this species is not quantified. Overall net value probably negative as it is not widely planted for commercial purposes	Negligible effect on density, biomass and area occupied; minor reductions in rate of spread	2 (exempted for an existing plantation)	Global EICAT category: MR; Change listing to 1b (with use for community livelihood purposes exempted), given the taxon is not widely commercially used.

Continued

Table 26.1. Continued.

Acacia species	Introduction status (with number of quarter-degree grid cells occupied)	Primary use	Impacts and benefits	Biological control effectiveness	Regulatory listing category	Impact; Recommendations from risk analysis
A. decurrens	Widespread invasive (126)	Forestry (historical)	There are no documented impacts, but almost certainly has similar impacts to those associated with *A. dealbata* and *A. mearnsii*. Is used for wood and bark products, but the value of this species is not quantified. Overall net value probably negative as it is not widely planted for commercial purposes	Negligible effect on density, biomass and area occupied; minor reductions in rate of spread	2 (exempted for an existing plantation)	Global EICAT category: MR; Change listing to 1b on the basis that the taxon is no longer commonly utilized
A. elata	Widespread invasive (51)	Ornamental	No recorded benefits or impacts, but has potential to outcompete native plants, so net value could become negative	No biocontrol agents have been introduced	1b	Global EICAT category: MC; No risk analysis yet. Suggestion is to retain as 1b
A. falciformis	Status undetermined, but assumed to be invasive (1)	Trial planting	No recorded benefits or impacts	No biocontrol agents have been introduced	Not listed	Global EICAT category: DD; No risk analysis yet, pending an eradication feasibility assessment suggestion is to list as 1a or 1b.
A. fimbriata	Invasive (2)	Trial planting	No recorded benefits or impacts, but has potential to outcompete native plants, so net value could become negative	No biocontrol agents have been introduced	1a	Global EICAT category: DD; Retain as 1a
A. implexa	Widespread invasive (3)	Trial planting	No recorded benefits or impacts, but has potential to outcompete native plants, so net value could become negative	None (some incidental damage from agents released on other wattles noted)	1a	Global EICAT category: DD; Retain as 1a (to be re-evaluated pending an eradication feasibility assessment)

A. longifolia	Widespread invasive (96)	Dune stabilization and barriers (historical)	Recorded to have multiple impacts on ecosystems (reductions in native plant species richness and cover, and native invertebrate richness and abundance) and has no recorded benefits. Net value almost certainly negative, but remains unquantified	Substantial reductions in density, biomass, area occupied and rate of spread, especially on drier sites	1b	Global EICAT category: MR; Retain as 1b
A. mearnsii	Widespread invasive (463)	Forestry	Multiple negative impacts have been recorded, including reductions in livestock-carrying capacity, excessive water use, decreases in soil carbon, reductions in native bird and invertebrate species richness and abundance, and disruption of pollination networks. Has commercial value for tannins and wood products, and from firewood harvested from invasive populations. Net value of the species remains positive provided that commercial activities are accompanied by effective control operations	Substantial reductions in rate of spread in winter-rainfall areas, negligible elsewhere	2 (exempted for an existing plantation)	Global EICAT category: MR; Retain as 2 (with use for community livelihood purposes exempted)
A. melanoxylon	Widespread invasive (171)	Forestry	No recorded impacts, but can outcompete native plants. The species is a source of high-grade furniture timber, but the overall value of this remains unquantified. Overall net value may well be positive	Moderate reductions in rate of spread	2 (exempted for an existing plantation)	Global EICAT category: MR; No risk analysis yet. Suggestion is to retain as category 2, with permits granted for cultivation and harvesting outside priority areas

Continued

Table 26.1. Continued.

Acacia species	Introduction status (with number of quarter-degree grid cells occupied)	Primary use	Impacts and benefits	Biological control effectiveness	Regulatory listing category	Impact; Recommendations from risk analysis
A. paradoxa	Invasive (1)	Trial planting	No recorded benefits or impacts. Has potential to outcompete native plants, so net value could become negative	No biocontrol agents have been introduced	1a	Global EICAT category: DD; Retain as 1a
A. piligera	Established (1)	Trial planting	No recorded benefits or impacts	No biocontrol agents have been introduced	Not listed	Global EICAT category: DD; No risk analysis yet. Ongoing control suggests eradication is feasible (i.e. category 1a
A. podalyriifolia	Widespread invasive (82)	Ornamental	Used as an ornamental plant, but many options for non-invasive alternatives exist. There are no documented impacts, but has potential to outcompete native plants, so net value could become negative	Negligible effect on density, biomass, area occupied and rate of spread	1b	Global EICAT category: DD; No risk analysis yet. Suggestion is to retain as category 1b
A. pycnantha	Widespread invasive (38)	Dune stabilization and barriers (historical)	No recorded benefits or impacts in South Africa, but is not utilized for any products and almost certainly has similar impacts to other species (e.g. *A. longifolia* and *A. saligna*). Net value almost certainly negative	Substantial reductions in density, area occupied and rate of spread	1b	Global EICAT category: MR; No risk analysis yet. Suggestion is to retain as category 1b
A. provincialis	Established (1)	Trial planting	No recorded benefits or impacts. Has potential to outcompete native plants, so net value could become negative	No biocontrol agents have been introduced	Not listed	Global EICAT category: DD; No risk analysis yet. Ongoing control suggests eradication is feasible (i.e. category 1a)

A. saligna	Widespread invasive (168)	Dune stabilization and barriers (historical)	Recorded to have multiple impacts on ecosystems (reductions in native plant species richness and cover, and native invertebrate richness and abundance; increased fuel loads potentially increasing fire intensity). Is used as a source of low-grade firewood and fodder, but the value has not been quantified. Net value probably negative	Substantial reductions in density and biomass, and some reduction in area occupied and rate of spread	1b	Global EICAT category: MR; No risk analysis yet. Suggestion is to retain as 1b
A. stricta	Widespread invasive (7)	Trial planting	No recorded benefits or impacts. Has potential to outcompete native plants, so net value could become negative	None (some incidental damage from agents released on other wattles noted)	1a	Global EICAT category: DD Retain as 1a (to be re-evaluated pending an eradication feasibility assessment)
A. viscidula	Invasive (1)	Trial planting	No recorded benefits or impacts. Has potential to outcompete native plants, so net value could become negative	No biocontrol agents have been introduced	Not listed	Global EICAT category: DD; No risk analysis yet. Ongoing control suggests eradication is feasible (i.e. category 1a)

reinstituted plantations on suitable sites outside forests where spread could supposedly be more easily contained (Geldenhuys, 2004).

Planting of wattles (primarily *A. mearnsii*, but also *A. dealbata* and *A. decurrens*) for bark and tannin products in South Africa began in around 1880, and the planted area grew steadily, reaching a peak of around 325,000 ha in 1960 (Sherry, 1971). The primary use of these species was for tannins extracted from the bark, which were used in the leather tanning industry (also see Chapter 8, this volume). Currently, the formal planted area is around 135,000 ha, and these species continue to be used for bark products (tannins, resins, flocculants, thinners, adhesives and dust suppressants), timber, wood chips, pulp, charcoal and firewood (De Wit *et al.*, 2001; also see Chapter 15, this volume).

During the mid-20th century, several *Acacia* species were introduced as ornamentals and planted in private gardens and on public land (e.g. *A. elata* was commonly planted in graveyards). Unlike the species introduced for forestry or dune stabilization, these species have only ever been planted in small numbers, generally in urban and peri-urban settings (although arguably the plantings of ornamental species took place at many more sites; Donaldson *et al.*, 2014b).

Concomitant to these introductions and spread around the country, many other wattle species were introduced to arboreta often specifically so they could be tested to see how they grew and to evaluate options for more widespread planting (Poynton, 2009; Magona *et al.*, 2018). Examples of this were as recent as 1998 when 33 wattle species were planted as part of a dry-land agroforestry trial in the Western Cape (Magona *et al.*, 2018). Although almost all of these species have since died out, in a few cases (e.g. at Tokai Arboretum and Makhanda Botanical Gardens) such trial plantings still exist with some species naturalizing and beginning to spread (Magona *et al.*, 2018).

Finally, although no longer related to the original reason for introduction, invasive stands of wattle species have become an important source of energy in the form of firewood. Many rural families depend heavily on this wood as their primary source of energy (de Neergaard *et al.*, 2005; Ngorima and Shackleton, 2019), and *A. cyclops* is an important source of firewood for 'braais' (barbecues) in the Western and Eastern Cape provinces.

26.3 Emerging Management of Wattles as Problem Plants

Concerns about the impacts of invasive alien plants in South Africa began to be raised in the late 19th century, with early botanists pointing out that these plants could displace natural vegetation (Stirton, 1978). However, very little was done with respect to invasive *Acacia* species until the early 1940s. Concerns about (inter alia) *A. cyclops*, *A. longifolia* and *A. saligna* in the Cape of Good Hope Nature Reserve were raised in 1941, leading to control efforts that were '... almost totally ineffective for at least the first 35 years' due to the lack of a systematic control strategy (Macdonald *et al.*, 1989). In 1945, the Royal Society of South Africa published a report on the future of the Cape fynbos, in which it was stated that '...one of the greatest, if not the greatest, threats to which the Cape vegetation is exposed, is suppression through the spread of vigorous exotic plant species' (Wicht, 1945). This was followed by the publication in 1959 of *The Green Cancer of South Africa: The Threat of Alien Vegetation to Our South African Veld and Forest*, which had an exclusive focus on the Cape fynbos (and mainly on the Kirstenbosch Botanical Garden) despite the national-level title (Anonymous, 1959). Subsequent publications (e.g. Taylor, 1969) described the worsening of the situation, particularly in the Cape. A book intended to raise awareness of the problem was published in 1978 (Stirton, 1978) and listed 26 invasive alien plant species from the (then) Cape Province, six of which were wattles. The fact that these publications were separated in each case by more than a decade indicates that while the threat of invasions was recognized, their control was not a priority (see also Chapter 8, this volume).

In 1986, the first wide-ranging attempt to synthesize information on biological invasions in South Africa was published (Macdonald *et al.*, 1986). That book included a section with five chapters that addressed the management of invasive alien plants, but there was little to report in the way of physical and chemical control measures. These had '...infrequently been the subject of sound, investigative research...', resulting in localized and patchy understanding that had '...arisen through a process of trial and error...' and that was specific to particular sites or species (Macdonald *et al*., 1986). One of the five chapters was devoted to *A. melanoxylon* (Geldenhuys, 1986), while another described, inter alia, the release of seed-attacking biological control agents on *A. longifolia* (Neser and Kluge, 1986).

By the early 1980s, the Department of Forestry had embarked on an ambitious programme aimed at clearing the Cape's mountain catchment areas of invasive trees, including wattles. However, much of the Department's early research focused on species in the genera *Hakea* (Fugler, 1983; Richardson, 1985) and *Pinus* (Richardson, 1989), while the work on controlling wattles was confined to biological control (Dennill and Donnelly, 1991; Chapter 21, this volume).

26.4 History of Legal Requirements for Controlling Invasive Wattles

South Africa has, since 1861, enacted at least 50 pieces of legislation to govern and regulate invasive alien plants (Lukey and Hall, 2020). Many of these laws targeted individual species, but in 1970 the government passed the Mountain Catchment Areas Act (Act 63 of 1970). This Act empowered the relevant Minister to issue directives to clear invasive alien plants, including wattles, from declared mountain catchment areas, as well as on land within 5 km of such declared areas. In 1983, the Conservation of Agricultural Resources Act (CARA, Act 43 of 1983) was promulgated. CARA placed an obligation on all landowners to control about 50 declared invasive species on their land, including 13 wattle species (*A. baileyana*, *A. cyclops*, *A. dealbata*, *A. decurrens*, *A. elata*, *A. implexa*, *A. longifolia*, *A. mearnsii*, *A. melanoxylon*, *A. paradoxa*, *A. podalyriifolia*, *A. pycnantha* and *A. saligna*). An amendment to CARA in 2001 expanded the list of invaders to 198 species and placed them into one of three categories, namely: Category 1 – harmful species that had to be controlled; Category 2 – harmful species that also had commercial value, and that could be cultivated under permits on demarcated areas; and Category 3 – invasive species with ornamental value that could be retained, but not replaced (Lukey and Hall, 2020). For more than four decades, these two acts provided the legal framework for managing wattles in South Africa.

In 2014, regulations were published under the National Environmental Management: Biodiversity Act (NEM:BA, Act 10 of 2004), replacing the CARA regulations. In terms of the revised NEM:BA Regulations of 2020, 560 alien taxa including animals, plants, fungi, and microbes were placed into categories similar to those created under the CARA regulations, including 16 wattle species (Table 26.1).

Whether or not 50 years of regulation has been effective in preventing or slowing the spread of invasive wattles is difficult to judge. As of December 2022, 76 permits had been granted for commercial activities involving at least one of the four wattle species listed under Category 2 in the NEM:BA regulations, with most permits issued for *A. mearnsii* (SANBI, 2023; note that some permits were issued for more than one species). However, whether or not permit holders are adhering to permit conditions is not known (Zengeya and Wilson, 2020). In addition, the government does not have sufficient capacity to enforce the requirement to control listed invasive species on both private and state land (regarded by many landowners as a 'faultless liability', i.e. being held liable for species which they themselves did not introduce; Lukey and Hall, 2020). Despite the regulations, and ongoing control efforts, the most widespread wattle species increased in range by between 5 and 25% from 2000 to 2016, although the spread of these species was not as marked as for other non-wattle species, where increases were around 50% (Henderson and Wilson, 2017). The slower spread of wattles was attributed to biological control rather than to compliance with regulations (Henderson and Wilson, 2017).

26.5 Biological Control

Most of the earlier management of invasive wattles was in the form of biological control (also see Chapter 21, this volume). Biological control agents were first released against wattles in South Africa in 1982, and since then ten agents have established on ten wattle species. All of these agents are specific to wattles, with some of them damaging more than one wattle species as predicted in host-specificity testing (this is not surprising as many wattles arise from relatively recent speciation and all are phylogenetically distinct from other acacias, *Acacia sensu lato*; Chapter 2, this volume). Except for the rust fungus *Uromycladium morrisii* Doungsa-ard, McTaggart, Geering & R.G.Shivas, all of these agents aimed only to reduce seed production of the target plants.

The biological control programme initially faced stiff resistance, notably from those with interests in growing *A. mearnsii* for bark tannin production and *A. melanoxylon* for timber. Stubbings (1977) argued that *A. mearnsii* was too valuable as a timber tree to be subjected to biological control, a view that was countered by Lückhoff (1977), who pointed to the serious problems that the species caused by invading natural ecosystems. As a result of these concerns, biological control was (and to a large extent still is) restricted to the use of seed-attacking agents (Chapter 21, this volume).

Invasive wattle species in South Africa are not seed-limited and the widespread formation of large, long-lived seed banks is likely to replenish populations of wattles for many years to come, with few prospects for short- to medium-term reductions in density if biological control alone is relied upon (Richardson and Kluge, 2008; Strydom *et al.*, 2017; Chapters 17 and 31, this volume). The success of biological control is often measured by a reduction in the original population density of the invasive plant due to the activity of biological control agents. In the case of wattles, however, seed-reducing agents are unlikely to achieve this goal (Impson *et al.*, 2009, 2021a; Chapter 21, this volume). Even with high levels of seed destruction, the large seed loads allow sufficient seed to remain viable and germinate (Strydom *et al.*, 2017). Nevertheless, over several fire cycles, combined with physical control, a reduction in seed production will likely have substantial impacts on the number of seedlings at a site and so the follow-up control costs should decline (Impson *et al.*, 2021b). It would also be more appropriate to assess whether or not seed-reducing biological control agents are able to reduce the spread, or the rates of spread, of the target species (as opposed to assessing their ability to maintain populations on a site). In this sense, biological control of wattle species in South Africa constitutes an integral part of their overall management, which includes biological, chemical and physical control operations (Chapter 21, this volume). A reduction in seed numbers can contribute substantially to a corresponding reduction in costs and effort in follow-up clearing treatments when removing seedlings or young plants from previously cleared areas (Moran *et al.*, 2004).

26.6 Integrated Control

Attempts to control invasive wattle species in South Africa have used a number of approaches, and it has become clear that successful control will have to rely on using these approaches in combination, i.e. it will be necessary to practise integrated control. Integrated control combines the use of physical removal (felling larger plants and hand-pulling smaller seedlings and saplings), herbicides (to prevent resprouting after felling or to kill dense stands of germinating seedlings), biological control agents (to reduce vigour in adult plants and to reduce seed production) and fire (to kill standing plants and stimulate regeneration of soil-stored seeds) (van Wilgen *et al.*, 2001). Two issues are particularly important here. First, biological control has emerged as a vital component of integrated control because it reduces the rate of spread of wattle invasions by reducing seed output, enabling managers to more easily contain invasive populations (Impson *et al.*, 2021b). Richardson and Kluge (2008) noted that '...preventing the accumulation of seed banks by limiting seed production through biological control is by far the most effective means, and in almost all cases the only practical means, of reducing seed numbers'. Second, most wattle invasions are in fire-prone vegetation types (fynbos shrublands or grasslands) where frequent unplanned fires result in mass germination of soil-stored seeds. While fires can be used deliberately to assist with the control of wattles, for example by burning after felling to stimulate germination, such use needs to be followed by effective removal of seedlings by hand-pulling or the application of herbicides. In the event of an unplanned fire, management effort needs to be rapidly redirected to the burnt area to remove seedlings before they grow to a size where removal becomes difficult.

26.7 Government Support to Control Efforts

In 1995, the South African government established the 'Working for Water' programme (hereafter 'WfW'), which provides both private and state landowners with assistance in the form of teams of workers to clear invasive alien plants. This programme has the dual goals of controlling invasive alien plants and providing employment and development opportunities (Koenig, 2009; van Wilgen and Wannenburgh, 2016). However, while not responsible for managing invasive species in South Africa, it helps the state and private landowners who are legally responsible for control. Wattles have featured prominently in WfW's activities. The total amount spent on the control of invasive alien plants by WfW between 1999 and 2018 was ZAR 7.1 billion (control costs plus overheads, adjusted to 2020 values of ZAR; van Wilgen *et al.*, 2022a; 1 USD = approximately 17 ZAR). Control efforts were directed at 178 invasive alien plant taxa, but the effort was highly skewed towards the most widespread taxa, with 15 taxa receiving two-thirds of expenditure (van Wilgen *et al.*, 2022a). ZAR 1.2 billion (20.6% of the total spend) was used to target just three species (*A. dealbata*, *A. decurrens* and *A. mearnsii*). A further ZAR 181 million (3.3% of the total spend) targeted wattles in the fynbos biome (*A. cyclops*, *A. longifolia* and *A. saligna*; Figs 26.1 and 26.2). The total effort expended on controlling these six species over 20 years amounted to 4.6 million person-days worked in the field. Thus, almost a quarter of WfW's efforts were directed at wattles, but they only reached a small proportion (around 5%) of invaded area as estimated by Kotzé *et al.* (2020). Clearing of wattles requires repeated follow-up to remove emerging seedlings, so cleared sites have been visited repeatedly for that purpose, up to 16 or more times in some cases (Fig. 26.3).

WfW's contributions are routinely reported in terms of inputs (e.g. the amounts of money spent on control) and outputs (e.g. the area treated and the number of jobs created), but outcomes (changes in the invaded area or the restoration of biodiversity and ecosystem services to previously invaded areas) are not monitored

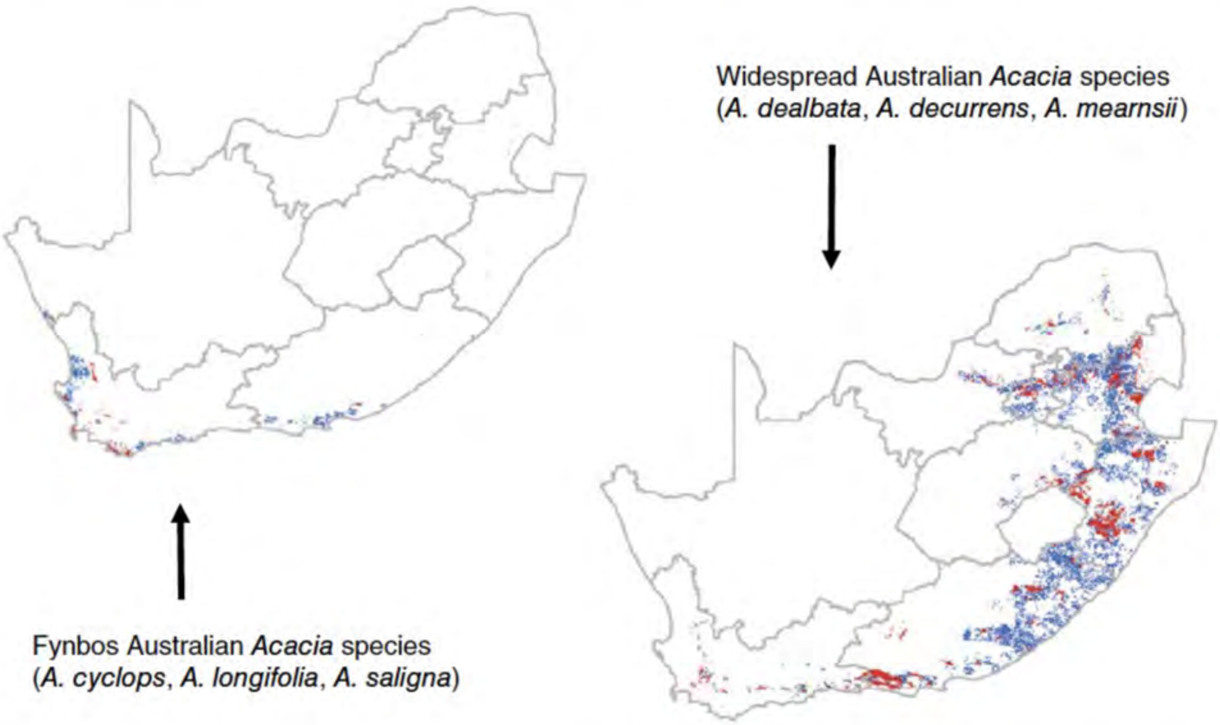

Fig. 26.1. The extent (shaded in red) of areas targeted for the control of Australian *Acacia* species by the Working for Water programme in South Africa between 1998 and 2020. Blue shading shows the estimated invaded area by the same species.

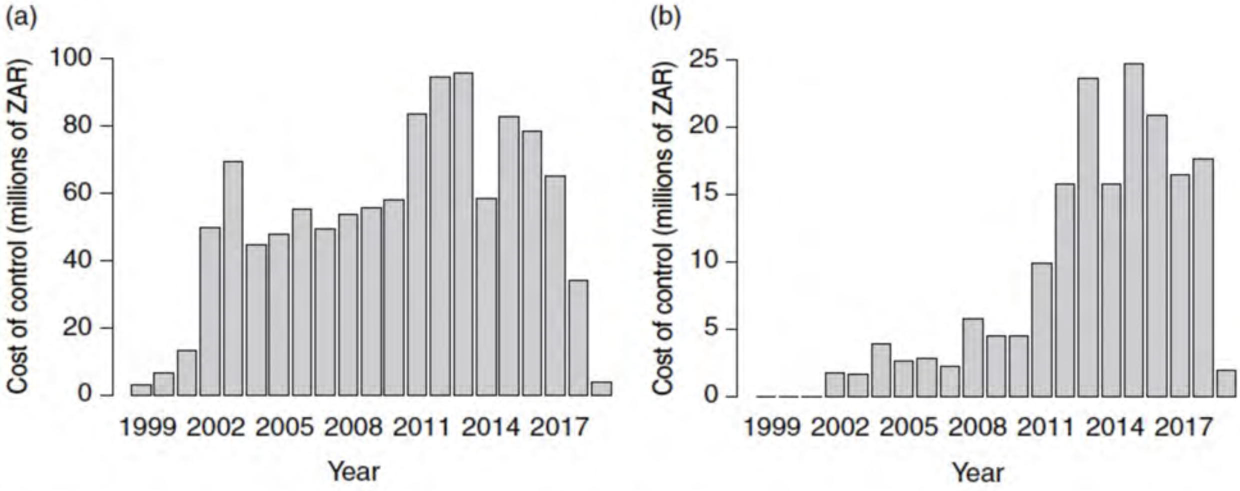

Fig. 26.2. Amount spent per year (adjusted to 2020 ZAR values) on control operations focusing on invasive Australian *Acacia* species by the Working for Water programme in South Africa between 1998 and 2018: (a) shows widespread wattle species (*A. dealbata*, *A. decurrens* and *A. mearnsii*) and (b) shows wattle species typical of the fynbos biome (*A. cyclops*, *A. longifolia* and *A. saligna*).

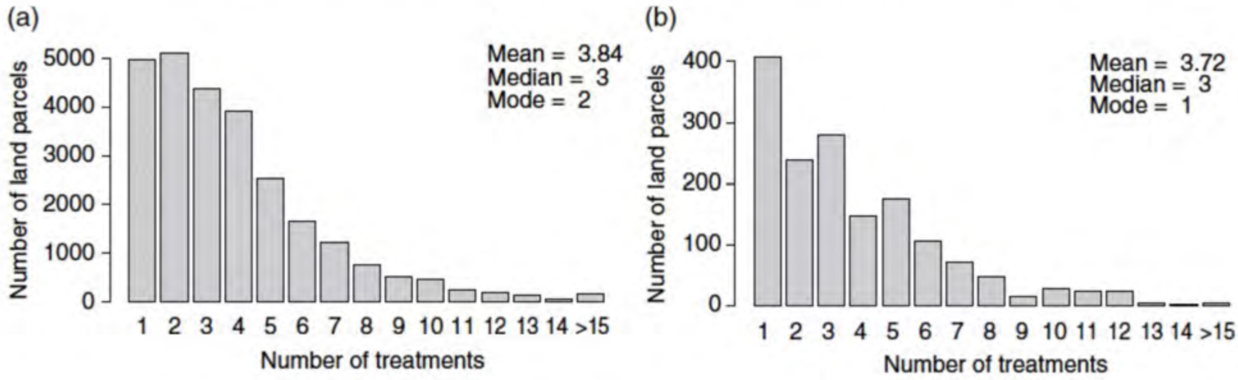

Fig. 26.3. The number of treatments carried out at a particular site between 1998 and 2018 (initial clearing, i.e. one treatment, and subsequent follow-up treatments to remove emerging seedlings, i.e. two or more treatments) for (a) widespread Australian *Acacia* species (*Acacia dealbata*, *A. decurrens* and *A. mearnsii*) and (b) wattle species typical of the fynbos biome (*A. cyclops*, *A. longifolia* and *A. saligna*).

by either WfW or most of its implementing agents. Consequently, the only information in this regard comes from studies that examined control effectiveness on a limited number of sites. Marais *et al.* (2004) estimated that it would take 31 years, at the levels of clearing achieved by then, to bring wattle invasions under control in South Africa. They also recognized that this was an underestimate given the many uncertainties at the time, including the lack of an accurate estimate of invaded area, the rate at which invasions would spread, the likelihood of continued funding and the efficiency of control. A study of the prognosis for gaining control of alien plant invasions in the fynbos protected area network (van Wilgen *et al.*, 2016) concluded that substantially more funding would be needed to reduce invasions to a manageable level, and that unless effectiveness was improved, the invaded area would continue to increase. Cheney *et al.* (2019) used data sets spanning 20 years of management in the Table Mountain National Park to model long-term outcomes of clearing wattles at different levels of management clearing efficacy. The efficiency was assessed in terms of achieving a goal of reducing wattle density to below one plant per hectare. They estimated that if the current clearing resources were used at maximum efficacy, it would take between 32 and 42 years to attain this goal. They concluded that less-efficient management would lead to the goal never being attained, and that increases in efficiency, rather than increases in funding or time spent on the problem, would be needed to achieve the goals of management. Attempts to clear wattle species from the Berg River catchment over 13 years succeeded in reducing overall cover (Fill *et al.*, 2017; Fig. 26.4), but not to the desired maintenance level, and at an eightfold greater cost than originally estimated (van Wilgen *et al.*, 2020). Other studies (e.g. McConnachie *et al.*, 2012; Kraaij *et al.*, 2017) have identified substantial inefficiencies in clearing projects that targeted invasive wattles. Thus, although WfW has been very successful in raising substantial funding to support control efforts and in meeting its targets for creating employment, it needs to increase efficiency if it is to reduce wattle invasions in priority areas. Effectiveness could be improved by better planning, focusing on priority areas and species, accepting trade-offs and practising triage, and improving the training and equipping of workers (van Wilgen *et al.*, 2016; Fill *et al.*, 2017; Cheney *et al.*, 2018). Some of this would require changes to the operating rules of WfW, for example by employing fewer but better trained and equipped workers, investing in planning and monitoring, and working on fewer areas to ensure adequate resources for priority areas.

26.8 Eradication Attempts

In 2008, a unit was established within the South African National Biodiversity Institute for invasive species detection, assessment and eradication planning (Wilson *et al.*, 2013). The unit makes recommendations to government regarding the likelihood of success and possible cost of eradication, and the wattle species introduced as trial plantings were among the first taxa assessed under this initiative (with initial research by Zenni *et al.*, 2009 predating the formation of the unit). These recommendations have relied on extensive investigations regarding the introduction history of these wattles and on destructive sampling in the field to establish current distributions and population dynamics (e.g. Kaplan *et al.*, 2012, 2014). Most of these investigations have concluded that eradication of the species examined was potentially feasible, with the notable exception of *A. cultriformis* which has been found cultivated on several private properties across the country (Magona *et al.*, 2018). Given the persistence of long-lived and dense wattle seed banks (also see Chapter 31, this volume), proclaiming eradication would require repeated visits to sites to establish the absence of germination for a long time after the adult plants have been removed (Wilson *et al.*, 2011). Research is ongoing to determine the criteria for declaring that a population has been successfully extirpated and that nationwide eradication has been achieved (cf. Wilson *et al.*, 2016). One of the emerging lessons from this work in South Africa is the contention that if *any* wattle species is planted in a climatically suitable region in high enough numbers (i.e. high propagule pressure), it will become invasive (Wilson *et al.*,

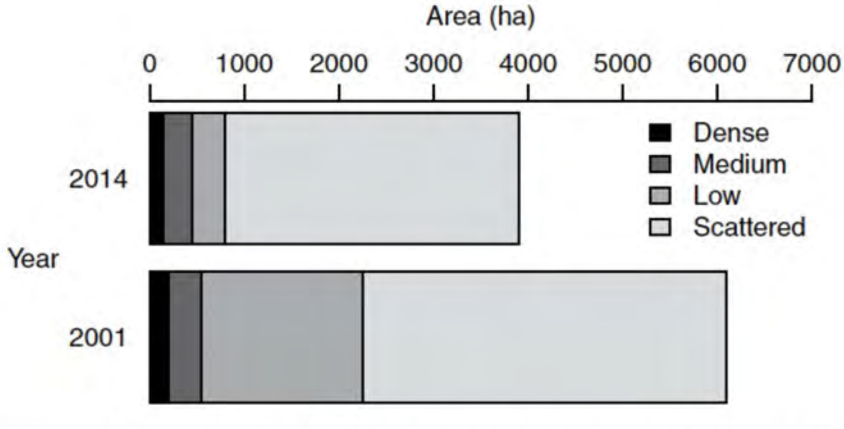

Fig. 26.4. Area occupied by invasive alien *Acacia* species at different levels of cover in South Africa's upper Berg River catchment at the initiation of a control project in 2001, and after 13 years of treatments in 2014. Cover levels are dense (> 50% cover), medium (26–50% cover), low (6–25% cover) and scattered (0.5–5.0% cover). Figure redrawn from Fill *et al.* (2017).

2011; Motloung *et al.*, 2014; Richardson *et al.*, 2015; Chapters 9 and 31, this volume).

26.9 Non-Government Control Efforts

Besides government funding, considerable contributions to invasive alien plant control have come from volunteer groups, non-government organizations (NGOs), and private companies and individuals (also see Chapter 28, this volume). These are poorly documented, so an assessment of the value of their contributions is challenging. Macdonald *et al.* (1985) provided outlines of ten volunteer groups in the fynbos biome, nine of which listed wattles among the species that they targeted. *Acacia cyclops* and *A. saligna* were targeted by almost all groups, while some also sought to control *A. elata*, *A. longifolia*, *A. mearnsii* and *A. melanoxylon*. In a more recent study, Jubase *et al.* (2021) identified 52 volunteer groups in the fynbos biome, who jointly cleared nearly 5300 ha of land per year with estimated labour contributions of ZAR 5.1 million annually. Volunteer groups were made up largely by older (average age 56 years) and well-educated people (82% had university degrees). Jubase *et al.*'s (2021) study addressed the factors that motivated people to become involved (e.g. many felt a moral obligation to deal with an obvious problem that was clearly a significant threat to nature) and the challenges that the groups faced (e.g. to attract new members and to have a real impact in difficult terrain with limited funding), but did not address the species that they targeted or how effective they were. There is anecdotal evidence, however, that such groups have made valuable contributions in the past (also see Chapter 28, this volume).

Private-sector investment into wattle control is equally not well documented. An Anglo-American company spent over ZAR 40 million controlling invasive alien plants (including wattles) on its 3200 ha Vergelegen property in the Western Cape between 2004 and 2015 (van Rensburg *et al.*, 2017). This reduced the extent and density of invasions, but cost almost four times the original cost estimate, and is still ongoing. Gaining control of invasions on this property may well be achievable because the operations will have the backing of a wealthy private company, but it is doubtful whether average private landowners would be able to sustain similar operations on their properties. More recently, NGOs have become active in raising funds to support ongoing control operations in some areas. For example, both The Nature Conservancy (an American NGO; Turpie *et al.*, 2018) and WWF (South Africa) have raised considerable sums to support the clearing of invasive plants (including wattles) from the water-catchment areas that supply the City of Cape Town (CoCT). To date, the funds have been used to clear 10,000 ha in seven mountain water-catchment areas and in the Atlantis Aquifer in the Western Cape (DEA&DP, 2021). It would be premature to speculate on the success of these interventions, but the additional funding could make a large difference by addressing some of the shortcomings of current approaches.

26.10 Ecosystem Restoration

Ecological restoration has not been a goal in most wattle control projects and active restoration interventions have typically not been implemented. Instead, control projects have relied on spontaneous recovery of the vegetation (i.e. passive restoration; Holmes *et al.*, 2020). In certain circumstances, however, active restoration is needed for ecosystem structure and functioning to recover (Hall *et al.*, 2021a). In the case of wattles, their negative impacts on native ecosystems (Chapter 22, this volume) exceed those of many other invasive species owing to their legacy effects such as large, long-lived seed banks, soil nutrient enrichment (Nsikani *et al.*, 2017, 2018a) and altered soil microbial communities (Le Roux *et al.*, 2018; Chapters 18 and 24, this volume). While necessary in some cases, active restoration adds significantly to the control costs (Gaertner *et al.*, 2012). Such additional costs may be justifiable in some cases, such as in highly threatened ecosystems, but resources are limited; therefore control should first target sites more likely to recover spontaneously (i.e. sites with lower cover of alien species or that have become densely invaded only recently).

There have been some attempts to identify priorities for ecosystem restoration in South

Africa. The CoCT applied the Analytical Hierarchy Process to prioritize sites for active restoration in nature reserves (Mostert *et al.*, 2018). Criteria used included ecosystem conservation status and connectivity function, functional importance and delivery of ecosystem services. The outputs of this exercise are currently guiding the implementation of restoration projects. For example, active restoration following wattle control is being conducted in critically endangered Cape Flats Sand Fynbos at the Blaauwberg Nature Reserve. Here a decade-long management–research collaboration is documenting the efficacy of various passive and active restoration treatments following clearing of dense stands of *A. saligna* (Krupek *et al.*, 2016; Hall *et al.*, 2021a,b). Five other CoCT reserves have small active restoration projects underway, and responses to these interventions are being monitored (L. Mossop, Cape Town, January 2022, personal communication). CoCT's focus on restoration is in marked contrast to most other wattle control operations, which do not explicitly state restoration as a goal and that typically rely on passive recovery of the vegetation.

Several lessons have been learnt with respect to restoration following wattle control, which is complicated because many wattle species are fire-adapted and the ecosystems they invade are fire-prone (e.g. fynbos and grassland; see van Wilgen and Scholes, 1997). Native fynbos and grassland species respond well to fire, but fire simultaneously stimulates the germination of wattle seeds, overwhelming any regeneration of native vegetation (P.M. Holmes, January 2022, personal observation). Nitrogen enrichment by wattles also leads to the establishment of nitrophilic secondary invaders such as grasses establishing after clearing, which complicates the restoration of the original vegetation (Fill *et al.*, 2018; Nsikani *et al.*, 2018b). Furthermore, resprouting species eliminated by dense stands of wattles may be difficult to restore in grassland (Zaloumis and Bond, 2011) and fynbos (Hall *et al.*, 2021a). Such species can be ecologically important, but have smaller seed banks than obligate reseeding species (Holmes, 2002). If these species have been lost from the above-ground vegetation, reintroduction by rootstock would be required.

An assessment of restoration potential (based on wattle invasion history and persistence of native species) is important for making informed decisions. At long-invaded fynbos sites with low restoration potential, it may be prudent either to use fire to stimulate wattle germination prior to active restoration, or to clear without burning in the first active restoration cycle to minimize competition from the wattle seedlings (Hall *et al.*, 2021b). In grasslands, post-clearance use of fire and rotational grazing by cattle have been used to restore rangeland function and water infiltration (Matela and McLeod, 2018), and engaging people in the planning and restoration process was key to success. Areas with high recovery potential were identified, and clear objectives were agreed upon in terms of wages, improved grazing and ongoing use of wattle products. Integrating the clearing plan with the grazing plan resulted in more grass cover, lower wattle cover and improved animal condition (Matela and McLeod, 2018). However, restoration attempts can be set back by unplanned fires, which in at least one case has led to poor grass recovery, a resurgence of wattles and severe erosion (A. Starke, Pietermaritzburg, January 2022, personal communication). This case highlights the legacies of dense wattle invasions (long-lived seed banks, flammable fuel loads, loss of key vegetation structural components; Nsikani *et al.*, 2018b) and their negative impacts on vegetation recovery.

In fire-free ecosystems such as strandveld (invaded primarily by *A. cyclops*) and forest (invaded by *A. melanoxylon*), many of the native species, like these two wattles, are bird-dispersed (also see Chapter 17, this volume) and do not require fire to optimize germination. Here spontaneous recovery of native species can follow wattle clearance alone, except in densely invaded sites where a gradual opening of the alien stand, in combination with some native rootstock planting, may be needed.

In riparian ecosystems, the majority of headwater fynbos riparian scrub communities were found to spontaneously regenerate following wattle control (Blanchard and Holmes, 2008). However lower-lying riparian stretches are embedded in modified landscapes, where additional negative impacts operate owing to changes in river geomorphology and hydrology, and spontaneous succession is unlikely and reinvasion after wattle control is highly probable (P.M. Holmes, 2021, personal observations). In response to this situation, restoration projects have initiated active planting of native riparian scrub species in foothill and lowland river segments (van Biljon, 2021). These projects require collaboration and buy-in from the local stakeholders, particularly the adjacent farming communities, in order to achieve long-term success.

26.11 Conclusions

Much useful experience has been gained in the control of invasive wattles over the past century, and most of the progress towards achieving control has come about because of biological control (Chapter 21, this volume). Although seed production is very unlikely to be reduced to below replacement levels (Strydom *et al.*, 2019), biological control has helped to reduce the dominance and spread of invasive wattles by reducing new inputs to the seed bank (Moran and Hoffmann, 2012; Henderson and Wilson, 2017). Over multiple fire cycles, an integrated approach to control that includes clearing and follow-ups is likely to be a highly successful strategy at invaded sites (Impson *et al.*, 2021b). However, in the short to medium term, significant investments in control are still essential if the impacts of wattle invasions are to be brought down. Current funding is insufficient to cover the entire invaded area in South Africa (van Wilgen *et al.*, 2016). In essence, this means that interventions need to be prioritized and scarce funds focused on priority areas, such as strategic water source areas, protected areas and threatened ecosystems. Further progress could be brought about by increases in efficiency (e.g. by improving planning and monitoring outcomes against set goals and by practising adaptive management) and focusing on areas with restoration potential. Several potentially damaging wattle species are being targeted for eradication, but this will require a sustained focus over several decades which may prove challenging.

Currently, government is funding formal risk analyses on all regulated alien species, in order to inform their appropriate placement into regulatory categories and for setting targets for their management (Table 26.1). These assessments are challenging, because in many cases there has been little or no research into the impacts that the species have (van Wilgen *et al.*, 2022b; see Chapters 22 and 23, this volume for impacts by wattles). In addition to their ecological impacts, it would also be very useful to examine the net impact, i.e. the economic value of benefits minus costs; this would be especially important in the case of wattles and other species that have useful attributes but are also harmful invaders (also see Chapters 22 and 23, this volume). Studies of the net value of invasive wattles are currently limited to a single species (*A. mearnsii*; De Wit *et al.*, 2001). As things stand at present, 16 out of the 21 wattle species recorded as naturalised in the country have been assigned to regulatory categories, the other five species are likely to also be regulated once completed risk analyses are considered by the relevant decision-making bodies (Table 26.1). Currently, for four species (*A. dealbata*, *A. decurrens*, *A. mearnsii* and *A. melanoxylon*) permits may be granted for commercial cultivation. However, neither *A. dealbata* nor *A. decurrens* are still widely used and risk analyses have suggested that permits are no longer appropriate. Regulatory recommendations should be updated as new information becomes available (e.g. formal cost–benefit analyses).

Attempts to control invasive wattles in South Africa would also benefit from the development of invasive species management plans, as envisaged in law (the NEM:BA, Act 10 of 2004), but to date no such plans have been developed and the responsibility for developing them remains unclear. Several guidelines are available in this respect. Van Wilgen *et al.* (2011) provide a framework for a national strategy for managing wattles in South Africa, which includes different approaches for areas where invasions are absent, or at the initial (sparse) or later (more dominant) stages of invasion. Wattles are also present either in planted stands or invasive populations, and special approaches are needed for these different situations – two of these are riparian ecosystems and urban areas. Holmes *et al.* (2008) derived a set of guidelines for managing woody invaders (largely wattles) in riparian areas. For urban areas, Gaertner *et al.* (2016) provide a framework for the CoCT, where management needs to consider public perceptions as to the benefits and impacts of invasive species. Finally, it is clear that the management of wattles cannot be considered in isolation from other invasive species when it comes to the allocation of funding (van Wilgen *et al.*, 2016), and exercises to prioritize wattles without considering other species will not be effective.

Managing wattles on privately owned land is a special challenge. Invasions of alien wattles occur at various densities across large parts of South Africa, a substantial (but as yet unquantified) proportion of which is on privately owned land. Sustainably controlling this vast infestation faces huge challenges. First, landowners need to formulate and agree on realistic goals for such management, which in itself is difficult because of different views and perceptions around the problem (van Wilgen, 2012). Some private landowners manage wattles for commercial profit, or they derive benefits in the form of firewood or fodder for livestock. Others would like to remove them for reasons of conservation or fire protection. Reaching consensus on goals at a landscape scale is thus often extremely difficult, although some local landowners have formed conservancies to address these issues. Even if objectives could be agreed on, a lack of funding remains a serious constraint, and even very wealthy landowners struggle to gain control (van Rensburg *et al.*, 2017). In addition, the application of effective control requires an in-depth understanding of best-practice methods, which few private landowners possess. Governments are also seriously under-resourced to be able to enforce compliance with regulations, and even local 'hack' groups (e.g. Jubase *et al.*, 2021; Chapter 28, this volume) often experience problems in gaining access to private land. While biological control has eased the task of manual and chemical interventions, private landowners will continue to struggle to gain control of wattle invasions over large areas.

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