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Environmental weeds in Australia and New Zealand: issues and approaches to management

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Abstract Environmental weeds are plants that invade natural ecosystems and are considered to be a serious threat to nature conservation. Australia and New Zealand, where biota with a high degree of endemism have evolved, are particularly susceptible to environmental weeds. Environmental weeds have been implicated in the extinction of several indigenous plant species, and they also threaten ecosystem stability and functional complexity. Historically, emphasis has been placed on the chemical or manual 'control' of weed infestations, often with little consideration of the long-term effectiveness or the ecological consequences of such an approach. As the threat from environmental weeds is becoming more fully recognized, an integrated, strategic and ecological approach to weed management is being recommended. In both countries, systems for screening new plants before allowing entry for cultivation have been developed. For already established plants, management is conducted within a legislative and policy framework such as the Regional Pest Management Strategies that operate through the *Biosecurity Act 1993* in New Zealand. Noxious weed legislation in Australia has historically focused on agricultural weeds, but some Acts are (or have recently been) undergoing revision to give greater emphasis to environmental weeds and the involvement of the community in weed management. Quarantine, legislation, research and on-ground management are complemented by education programmes about the impact and control of environmental weeds. This paper provides an overview of the 'tool-kit' needed to manage environmental weeds in Australia and New Zealand, comparing and contrasting the approaches taken in the two countries. It also provides a broad framework for the case studies that make up this special issue on the ecology and management of environmental weeds in both countries.

Key words: education, environmental weeds, policy, quarantine, research, weed management.

INTRODUCTION

Environmental weeds are plants that invade natural ecosystems and can cause major modifications to indigenous biodiversity and ecosystem function. They are considered to be one of the greatest threats to nature conservation in both Australia and New Zealand (Humphries *et al.* 1991; Owen 1998a; Commonwealth of Australia 1999; Low 1999). In Australia, environmental weeds have been implicated in the extinction of four plant species (Groves & Willis 1999) and are currently threatening several more. Environmental weeds are a subset of invasive plants. Many species of invasive plants do not present an obvious threat to ecosystem function and indigenous biodiversity. The problems caused by environmental weeds cannot be simply stated in economic or agronomic terms (such as the loss of produce yield caused by weeds) because the threat also concerns issues of ecosystem stability, functional complexity and biodiversity (Adair & Groves 1998). Thus, environmental weeds represent a particular challenge for natural resource managers.

Although Australia and New Zealand are geographically close, differences in their size, population, climate, vegetation, disturbance regimes and systems of government make an interesting contrast when addressing the management of environmental weeds. These and other issues are the subject of this review, which aims to encapsulate the different dimensions of managing environmental weeds in the two countries. This will serve as a framework for the other articles in this special issue, which focus on the ecology and management of environmental weeds in Australia and New Zealand.

The vegetation of Australia and New Zealand

Because of their geographical and evolutionary isolation, both Australia and New Zealand have evolved biota with a high degree of endemism, which is particularly susceptible to invasive plants (Thresher 1999). This is evident from the extent and impact of environmental weeds in these countries. In this section,

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brief descriptions are provided of the indigenous vegetation of Australia and New Zealand in order to familiarize readers with the range of communities found in the two countries, with the rest of the section focusing on the types, extent and impact of environmental weeds.

The indigenous flora of New Zealand is typical of an isolated island archipelago with a cool to warm temperate climate; there is a relatively low number of vascular plant species (Table 1) and a high degree of endemicity (Wardle 1991). Forests dominated by *Nothofagus,* or podocarps and associated hardwoods, are the dominant native vegetation. However, because the country is mountainous, tussock grasslands and associated high-alpine communities dominate above the treeline (altitude 200–1500 m, depending on latitude) and in lower altitude areas east of the main dividing ranges, where forest cover was destroyed by the fires of Polynesian and European settlers (Wardle 1991). The country is fringed with marine communities dominated by large, brown seaweeds. Other common vegetation communities that occupy smaller areas are subalpine herbfields and shrublands, successional shrublands, coastal shrublands and sandbinders, and wetlands (swamps, mires, lakes, ponds, and brackish and saline streams). Very small areas are dominated by specialized vegetation communities (geothermal shrublands, salt-tolerant herbs, coastal turfs, limestone cliff shrublands and arid nutrient-poor herbfields).

The ecosystems of Australia are very varied, owing to the range of climates – including cool temperate, arid and tropical – arising from the large range in latitudes, and because Australia is a large island continent. This diversity leads to a range of vegetation types (Groves 1994) including the spinifex-dominated arid interior, semiarid shrublands, tropical and temperate grasslands, rainforests and woodlands (including savannahs), temperate eucalypt-dominated forests and shrublands, chenopod shrublands, heathlands, mangrove forests, salt-marshes, alpine and subalpine vegetation, inland wetlands, and vegetation communities found in the aquatic and coastal zones. Unlike New Zealand, which has mainly temperature-limited ecosystems (Basher *et al.* 1998), Australia has mainly rainfall-limited ecosystems and fire is a major factor influencing vegetation dynamics (Keith 1996). Because of its size, age and geological and evolutionary isolation, Australia has high levels of endemism, with over 80% of mammal, reptile and flowering plant species being endemic (Dovers & Williams, unpublished data, 2000). Certain taxa in Australia contain a globally significant number of species (e.g. reptiles, ants, lichens), as do certain regions (e.g. Great Barrier Reef, wet tropics, south-west corner). As such, Australia is one of the 12 countries identified as mega-biologically diverse (Common & Norton 1992) and, because it is the only high-income country in this group, Australia has a very important stewardship role.

Table 1. Estimated numbers for the indigenous, naturalized and exotic flora of Australia and New Zealand

New Zealand	
Total indigenous plant species	2055
Naturalized exotics	2071
(240 of which are managed as recognized environmental weeds by the Department of Conservation)	
Exotics in cultivation only	18 480
Total number of exotics	20 551
Australia	
Indigenous vascular plant species (Burgman & Lindenmayer 1998)	25 000
Naturalized exotics (Hnatiuk 1990)	2200
Environmental weeds (Swarbrick & Skarrat 1994)	1060

Plant species known in New Zealand as at July 1998. Data from Herbarium CHR, Landcare Research. Total indigenous flora refers only to formally described taxa.

Environmental weeds in New Zealand and Australia

The introduction of many species into Australia and New Zealand has been deliberate. For example, all the important crop plants and farm animals are introduced species. Many of the plant species in the two countries have become naturalized, forming self-sustaining populations that developed without direct intervention by humans. In New Zealand, Polynesians introduced a small range of exotic species, which are part of the naturalized flora today, including food plants such as *Cordyline fruticosa* (L.) Goepp. and *Aleurites moluccana* (L.) Willd. (Sykes 1977). Indigenous peoples are thought to have inhabited Australia for at least 60 000 years, although none of the introduced plants in the country are thought to have been taken there by Aborigines (Groves *et al.* 1997). However, Aborigines have had other impacts on the Australian environment, particularly through their use of fire (Bowman 1998).

Europeans began colonizing New Zealand and Australia approximately 200 years ago and have introduced a far greater range of species than the indigenous peoples of either country. Acclimatisation Societies were set up so the early settlers could make the environment more like 'home' in Britain. For example, in 1861 an Acclimatization Society was formed in Victoria, Australia with the principal objective: 'the introduction, acclimatization and domestication of all innoxious [meaning "harmless"] animals, birds, fishes, insects and vegetables whether useful or ornamental'. Accidental introductions have also been relatively common in both countries. If urban Auckland can be

used as a representative example of the pattern of plant naturalization in New Zealand, Europeans introduced many more species accidentally than they did deliberately for agriculture or horticulture (Esler 1988).However, the trends in rates of naturalization indicate that the number of species naturalizing from those deliberately introduced for horticulture (including garden ornamentals) in New Zealand may now exceed those naturalizing from accidental introductions (Esler 1988).

With increasing domestic and international trade, and the greater movement of humans around the globe (both in numbers and speed), the rate of introduction of plant species has increased considerably. For example, more than 20 000 exotic vascular plant species have been introduced to New Zealand to date (Table 1). Of these, the number of naturalized vascular species is more or less equivalent to the number of indigenous species and represents approximately 10% of the total exotic vascular flora (Table 1). The Department of Conservation has so far identified approximately 240 introduced plants as actual or potential environmental weeds (Owen 1997) and this represents approximately 10% of the naturalized flora. Thus, the introduced flora of New Zealand conforms quite closely to the 'tens rule' described by Williamson and Fitter (1996); however, this conformity could simply be an artefact of time, as many species may not have been in the country long enough to naturalize and become invasive. The 'tens rule' does not apply as closely in Australia. Whereas the number of plants introduced into Australia is uncertain, around 2300 species are thought to have become naturalized and 50% of species are classified as environmental weeds (Table 1). The differences in the proportion of naturalized species that have become environmental weeds may be related to the different sizes and environments of the two countries, and the range of plant communities within them.

Virtually all of the vegetation communities listed for Australia and New Zealand are affected by environmental weeds, with both aquatic (marine and freshwater) and terrestrial ecosystems being affected (see papers in this special issue). Although most of the environmental weeds in New Zealand are from the Northern Hemisphere temperate zone, species from every continent, except Antarctica, have naturalized and become environmental weeds (Table 2). Of these, nearly 240 environmental weeds (approximately three-quarters) were deliberately introduced into New Zealand as ornamental plants, approximately 14% were imported for agriculture, horticulture or forestry and approximately 10% resulted from accidental introductions (Buddenhagen *et al.* 1998).

When considering weeds in both agricultural and natural systems, there has been a gradual shift over time in the countries of origin of Australian weeds since Europeans arrived. In the early days of settlement, weeds from Europe were dominant, but more recently, weeds of American origin have become more significant in Queensland, whereas those from the Mediterranean predominate in South Australia (Groves *et al.* 1997). Groves *et al*. found that, for Australia as a whole, the African continent and the Americas were each equally important as a source of plants naturalized since 1971. This is reflected in a recent study of weed species in urban bushland in Perth, Western Australia (Wills 1998), which found that the most common point of origin for weed species, including the ones that produce the most damage, was South Africa. In Victoria, new plant introductions since 1970 have mostly originated from South Africa and Europe, and have been deliberately introduced as ornamentals (Weiss 1999).

Patterns of invasion at the continental scale have also been documented, with terrestrial invasions in northern Australia tending to be widespread and dominated by one species, whereas in southern Australia the pattern seems to be one of multispecies invasions (Humphries *et al.* 1991), more like the situation in lowland New Zealand. Few natural systems in Australia appear immune from invasion by environmental weeds, but there are considerable differences in the level of invasion, both within and between vegetation types, with disturbance history and proximity to human development being key elements (Adair & Groves 1998). Most of the work in Australia on invasive marine species has focused on temperate systems, and the north-west Pacific has been documented as the main source of identified plant and animal pests including the algae *Undaria pinnatifida* (Harvey) Suringar (wakame) and *Codium fragile tomentosoides* (dead man's fingers or spaghetti weed) (Thresher 1999).

However, not all environmental weeds are introduced from overseas. They can be indigenous species that have been deliberately planted for horticulture beyond their natural range or where altered disturbance

Table 2. Origin of environmental weeds recorded for New Zealand

Origin	No. of species
Australia	12
South America	21
Central America	8
North America	7
South Africa	14
Africa	10
Pantropical	3
Asia	25
Eurasia	32
Europe	25
Mediterranean	4
Cosmopolitan	1
Southern Hemisphere	60
Northern Hemisphere	101

Data from Owen (1997).

regimes have encouraged their spread into areas where they did not grow previously. Despite being 'native' plants, weeds of indigenous origin can severely disrupt ecosystems. In Australia, examples are *Leptospermum laevigatum*, *Acacia baileyana* and *Pittosporum undulatum* (Mullett 1996). In New Zealand, examples are *Metrosideros excelsa* Sol. ex Gaertn. (Williams 1996), *Muehlenbeckia australis* (Forst.f.) Meissn. (Baars & Kelly 1996) and *Pittosporum crassifolium* Banks et Sol. ex A. Ln Cunn (Bellingham 1991).

Table 3. Characteristics of plants which indicate a potential for weediness in native ecosystems

High input of viable propagules.
Short (<2 years) development time to reproductive maturity.
Seed or other reproductive units with prolonged (>5 years) periods of dormancy.
High rate of aerial or subterranean biomass production, particularly under conditions of low light, water or nutrient availability.
Dense and spreading foliage canopy.
Efficient long distance (>1 km) dispersal capabilities.
Presence of interspecific allelopathic properties or absence of intraspecific allelopathic properties.
Successful colonizer of disturbed or bare ground.
Reproductive strategies that facilitate survival in fire prone environments.
Broad distribution over a range of distinct climatic types.
Low susceptibility to attack by phytophagous organisms.

After Adair (1995).

Types of environmental weeds

Although there have been several attempts to predict the attributes of species that are likely to be invasive, most efforts have been unsuccessful (Hobbs & Humphries 1995). A number of approaches have been taken, including characterizing reproductive traits, dispersal mechanisms, the ability to flourish in a given climate, genetic characters, taxonomic patterns and functional groups of plants. It should be noted that not all invasive species represent an obvious threat to nature conservation, and that environmental weeds are a subset of this larger group. A recent attempt by Adair (1995) listed key ecological attributes that indicate a potential for weediness in native ecosystems (Table 3). Some of these attributes were used to determine the biological success rating of the approximately 240 environmental weeds identified in New Zealand (Owen 1997). Possessing one or more of these attributes is thought to increase the probability that a species can successfully invade. For example, in New Zealand most naturalized species came from places that New Zealanders traded with directly, often regions with similar agricultural systems, climates and soils (Webb *et al.* 1988).

Table 4. The range of life forms that are environmental weeds with examples for Australia and New Zealand

Life form	Australia	New Zealand
Trees	*Pinus* spp. (Gill & Williams 1996), *Tamarix aphylla* (Griffin *et al.* 1989)	*Pinus contorta* Loudon, *Acer pseudoplatanus* L. (23%)
Shrubs	*Chrysanthemoides monilifera* ssp. *rotundata* (Vranjic & Groves 1999), *Mimosa pigra* (Braithwaite *et al.* 1989)	*Calluna vulgaris* (L.) Hull, *Berberis darwinii* Hook. (17%)
Vines and creepers	*Cryptostegia grandiflora* (Grice 1997), *Asparagus asparagoides* (Sorensen & Jusaitis 1995)	*Clematis vitalba*, *Anredera cordifolia* (Ten.) Steenis (14%)
Grasses	*Brachiaria mutica*, *Nassella trichotoma* (Campbell & Vere 1995)	*Ammophila arenaria* (L.) Link, *Spartina alterniflora* Loisel, *Spartina anglica* C.E.Hubb. (14%)
Plants with bulbs, tubers and rhizomes (geophytes)	*Watsonia* spp., *Allium triquetrum*	*Hedychium gardnerianum* Ker-Gawl., *Crocosmia* × *crocosmiiflora* (Nicholson) N.E. Brown. (11%)
Herbs and succulents	*Marrubium vulgare*	*Hieracium lepidulum* (Stenstroem) Omang. (Wiser *et al.* 1998), *Hieracium pilosella* L. (Rose & Frampton 1999), *Ageratina riparia* (Regel) R. King et H. Robinson. (16%)
Aquatic plants	*Salvinia molesta* (Room & Julien 1995), *Undaria pinnatifida*	*Lagarosiphon major* (Ridley) Moss ex Wager., *Hydrodictyon reticulatum*, *Undaria pinnatifida* (5%)

In brackets, the percentage of the total environmental weed flora found in each of these groups (information only available for New Zealand). See also Table 7 for selected species in New Zealand.

Several authors have concluded, however, that there are enough exceptions to suggest that there are no particular suites of characteristics that make a plant invasive. Although no one species possesses all the attributes that may lead to invasiveness, invasive species as a group do appear to have certain attributes in common (Groves & Burdon 1986). These attributes have been used to develop systems in Australia and New Zealand for assessing the potential weediness of species being introduced for a range of purposes (see section on Quarantine and Hygiene).

Environmental weeds come in all shapes and sizes, and grow in all niches in an ecosystem. Woody species (trees, shrubs and vines) comprise just over half of the environmental weeds in New Zealand (Table 4), and aquatic species constitute the smallest component. The aquatic environmental weeds, however, have a disproportionate impact on native aquatic communities; they have spread throughout most of the rivers and lakes of New Zealand, and only a few isolated water bodies support wholly native vegetation. They have also been linked to the impacts of urbanization around northern Sydney (King & Buckney 2000). The proportions of different life forms of weeds has not been documented in Australia, but environmental weeds occur across a broad range of forms (Table 4). In particular, the threat imposed by invasive marine species has been appreciated only recently (Thresher 1999).

Environmental weeds are found in almost any family of plants, although particular families tend to dominate. For example, in temperate southern Australia the Asteraceae (e.g. *Chrysanthemoides monilifera*) contributes the most species to the weed flora (Groves & Burdon 1986), probably because this plant family contains more species than most. In contrast, in New Zealand only 7% of approximately 240 recorded environmental weeds are from the Asteraceae. Plant families most often represented in New Zealand are Poaceae (32 species), Fabaceae (20 species), Asteraceae (17 species) and Rosaceae (14 species). Between five and nine environmental weed species are from the following families in New Zealand: Bignoniaceae, Hydrocharitaceae, Iridaceae, Juncaceae, Liliaceae, Myrtaceae and Solanaceae. Almost half of the families (35) are represented by just one species and altogether 72 families make up the recognized environmental weeds (data from Owen 1997). Looking at the broader group of naturalized exotics, as opposed to environmental weeds, as many as 120 families are represented in the Australian state of Victoria, and most of the species belonging to the families Poaceae, Asteraceae and Fabaceae. Similar patterns are also found in Tasmania (Rozefelds *et al.* 1999). Consequently, while species that are terrestrial environmental weeds come from a large number of families in both New Zealand and Australia, the Poaceae, Asteraceae and Fabaceae are of particular concern (see also Carr *et al.* 1992 for a regional analysis).

The impact of environmental weeds

Environmental weeds can have a range of impacts on natural systems, as listed in Table 5. However, quantitative measures of the impacts of environmental weeds on these systems are still relatively rare (Adair & Groves 1998). This situation is gradually improving with a recent review describing the impacts of several terrestrial weeds at the species and ecosystem levels in Australia (Groves & Willis 1999). In addition, studies such as that of French and Eardley (1997) demonstrate some of the more subtle impacts weeds can have on less obvious elements of biodiversity, such as invertebrates. In this volume, there are several papers that begin to examine the more complex interactions between environmental weeds and other organisms, including those by Zancola *et al.* (2000) and Vranjic *et al.* (2000). Even so, the impacts of environmental weeds on ecosystem processes has not been well researched in Australia or New Zealand. It is likely, however, that major changes to ecosystem structure (Table 6) will lead to losses of biodiversity. This has been observed in New Zealand, where several species introduced deliberately for naturalization in the wild (Table 7) have dispersed effectively from the locations in which they were planted, reducing the diversity of both plant and animal species in all cases.

Table 5. Potential impacts of environmental weeds on indigenous ecosystems

Competition with indigenous plants for light, nutrients, moisture, pollinators, and they smother or crowd the soil.
Replacement of indigenous plant communities.
Prevention of natural regeneration.
Change in the movement of water in both soil and watercourses.
Increase of soil erosion by shading out ground plants which would normally hold the surface soil together.
Change in the shape of the land (e.g. different grass types on coastal sand dune systems may introduce poisons into the soil which prevent other plants growing around them, or they poison animals).
Provision of food and/or shelter for pest animals (and some indigenous animals).
Change in water quality or characteristics (e.g. willow species, *Salix*), and habitat for fish and other aquatic animals.
Introduction of foreign genes into local plant populations by cross breeding (hybridization and gene swamping).
Change in fire behaviour by altering characteristics such as the quantity and distribution of fuel.
Alteration of disturbance regimes.

It must be remembered that the impacts of environmental weeds are not always detrimental. They provide some indigenous (and pest) animals with additional food sources and shelter. In the case of indigenous animals sheltering in or feeding upon the weeds, management strategies should consider the supply of alternative shelter and food sources. Consideration of the control of indigenous dispersal agents such as birds and mammals also needs to be included in management options. Weeds can be spread quite widely by animals, as demonstrated for species such as the possum (Williams *et al.* 2000). Even though the possum is an introduced pest in New Zealand, the principles apply to both indigenous and introduced animals.

Legislative and policy framework

Several challenges have been associated with weed legislation in Australia (Commonwealth of Australia 1999), and legislation certainly should not be seen as an end in itself. However, legislation can be used strategically to support other measures. The nuts and bolts of the legislative and policy framework for New Zealand and Australia are outlined in Appendix 1, which includes details of the different legislative Acts, initiatives (such as the National Weeds Strategy in Australia, including the recent listing of the worst 20 weeds in the country; Table 8) and regional partnerships between Australia and New Zealand.

One of the major differences between Australia and New Zealand in terms of the policy and legislative environment is that Australia has three tiers of government (local, State and Commonwealth). Local governments, of which there are approximately 750 in Australia, are taking up an increasing role in environmental management (Binning *et al.* 1999; Cripps *et al.*1999), as the level of government closest to the community. However, because local governments are given their powers directly by the State governments, ultimately their responsibilities remain at the discretion of State legislation. The bulk of power over land and

Table 6. Direct structural modifications of Australian native plant communities resulting from weed invasions

Initial community type	Modified type	Invading species
Sedgeland	Tall shrubland	*Mimosa pigra*
Wet grassland	Closed forest	*Annona glabra*
Dry grassland	Tall shrubland	*Acacia nilotica*
Lowland rainforest	Vine thicket	*Thunbergia grandiflora*
Subtropical rainforest	Vine thicket	*Macfadyena unguis-cati, Anredera cordifolia*
Aquatic (shallow water)	Wet grassland	*Glyceria maxima, Brachiaria mutica*

After Panetta & Lane (1996).

Table 8. Twenty species identified as weeds of national significance in Australia

Common name	Scientific name
Alligator weed	*Alternanthera philoxeroides*
Athel pine	*Tamarix aphylla*
Bitou bush/boneseed	*Chrysanthemoides monilifera*
Blackberry	*Rubus fruticosus* agg.
Bridal creeper	*Asparagus asparagoides*
Cabomba	*Cabomba caroliniana*
Chilean needle grass	*Nassella neesiana*
Gorse	*Ulex europaeus*
Hymenachne	*Hymenachne amplexicaulis*
Lantana	*Lantana camara*
Mesquite	*Prosopis* spp.
Mimosa	*Mimosa pigra*
Parkinsonia	*Parkinsonia aculeata*
Parthenium weed	*Parthenium hysterophorus*
Pond apple	*Annona glabra*
Prickly acacia	*Acacia nilotica* ssp. *indica*
Rubber vine	*Cryptostegia grandiflora*
Salvinia	*Salvinia molesta*
Serrated tussock	*Nassella trichotoma*
Willows (except weeping willows, pussy willow and sterile pussy willow)	*Salix* spp. (except *S. babylonica*, *S.* × *calodendron* and *S.* × *reichardtii*)

Table 7. Examples of species in New Zealand introduced deliberately into the wild for naturalization

Species	Reason for introduction
Calluna vulgaris (L.) Hull	Planted in the tussock grasslands adjacent to Tongariro National Park as habitat for grouse which was unsuccessfully introduced (Bagnall 1982; Chapman & Bannister 1990).
Ammophila arenaria L.	Planted to stabilize sand dunes in many areas (Partridge 1991; McKelvey 1999); *Chrysanthemoides monilifera* ssp. *rotundata* was also planted in coastal areas of New South Wales, Australia to minimize soil erosion (Vranjic & Groves 1999).
Pinus contorta Loudon	Aerially sown in mountainous country onto eroding slopes above treeline or steep hillsides where the natural forest cover had been destroyed by fire (Richardson & Higgins 1998).
Spartina alterniflora Loisel. and *Spartina anglica* C. E. Hubbard	Planted in estuaries to hasten reclamation (Partridge 1987).

resource management in Australia resides with the eight States and Territories with their own sets of policies and legislation. These different mechanisms have led to complex and often inconsistent approaches, such as the various systems for classifying and listing noxious weeds, leading to a call for nationally consistent, transparent and simple regulatory controls to operate across the States and Territories (Thorp & Lynch 1999). The Commonwealth Government, which is a signatory to international conventions, nonetheless has significant constitutional powers of intervention, especially concerning corporations, trade and foreign affairs, and it can wield financial influence. Also, in recent years the Australian Commonwealth has adopted a greater role in coordinating and integrating environment and resource policy. However, it is still felt that many policies that are critical for the prevention of loss of biodiversity caused by invasive species are yet to be captured in legislation at the Commonwealth level (Sharp 1999).

In contrast, New Zealand has two levels of government (national and regional) and one principal agency responsible for the management of environmental weeds. The Department of Conservation, as the agency responsible for one-third of the land mass and all of the marine reserves in New Zealand, has a major role in establishing policy and coordinating environmental weed management nationally, and is also actively involved in research on environmental weeds. The application of this model, and because New Zealand has a much smaller area and a higher population density than Australia, means that environmental weeds are potentially more manageable there.

Quarantine and hygiene

New Zealand and Australia are unusual in that they are island states and thus do not have borders with other countries, on sea or land. This relative isolation means that up until recently it has been difficult for species to reach these islands without human intervention, but even more recently the frequency and intensity of human intervention has increased significantly. This also means that quarantine and hygiene are especially critical elements in the 'tool-kit' for managing environmental weeds.

In New Zealand, the Ministry of Agriculture and Forestry is primarily responsible for quarantine and hygiene, whereas in Australia the Australian Quarantine Inspection Service regulates the importing of all terrestrial or aquatic plant seeds, stock or tissue culture, regardless of use. The North Australian Quarantine Strategy specifically aims to protect northern Australia from diseases, pests and weeds. It maintains, and periodically reviews, lists of exotic insect pests, plant diseases, animal diseases and weeds, which could enter through the northern border of Australia, and are serious threats to the productivity, export markets and the environment. With such an extensive border, the maintenance of quarantine is a particularly difficult issue in Australia.

Both countries have recently introduced new weed risk assessment systems, with the system in New Zealand modelled on the Australian approach (Pheloung *et al.* 1999). In New Zealand, this tool is intended for use by the Environmental Risk Management Authority (ERMA) when evaluating proposed plant introductions. The assessment system is designed to detect weeds of environmental and agricultural concern. Key characteristics considered in the assessment process are: domestication/cultivation, climate requirements and distribution, weedy behaviour, undesirable traits, plant type, reproduction requirements, dispersal mechanisms, and persistence attributes. The scores obtained when using the system fall into three categories: accept, reject and evaluate. As this approach has only recently been introduced, it is difficult to judge its effectiveness. For more information on weed risk assessment, see Steinke & Walton (1999) for Australia and Pheloung *et al.* (1999) for New Zealand.

One tool that the Ministry of Agriculture and Forestry uses to reduce the risks of contaminants being introduced with imported goods is Import Health Standards (IHS). Other Government departments may also use IHS to manage risks within their areas of responsibility. All goods considered to present a risk must have an IHS before they can be imported. The Ministry of Fisheries intend to develop an IHS for ballast water to complement existing voluntary guidelines (Owen 1998a). All boats and aeroplanes entering New Zealand are checked by Ministry of Agriculture and Forestry officials, sometimes using dogs as detection tools. New Zealand Customs is currently using X-ray systems to detect undeclared seeds being brought in by travellers. Passengers travelling to New Zealand are required to declare any activities which are likely to lead to increased risk of accidental introduction of unwanted organisms. These activities include visiting a farm or camping. Sniffer dogs are regularly used to check airmail for plant material. Similar checks are carried out in Australia, including use of the RapiScan system in some States to detect quarantine risk material in postal items (Sandy Lloyd, personal communication). Discussions are also being held at the international level to enable management of the increasing volume of plant material coming through the mail system and being ordered over the Internet.

Other quarantine and hygiene issues arise when considering offshore and outlying islands. This is of particular concern for New Zealand, as many of these islands represent the last remaining habitats for some indigenous plants and animals. Consequently, visitors to the subantarctic islands are required to have clean

footwear, clothing and luggage before going ashore on any of the islands (Department of Conservation 1997). All gear taken ashore for expeditions must be packed in a quarantine store, which the Department of Conservation maintains specifically to ensure that hygiene is of the highest standard. Similar quarantine and hygiene codes exist for the Poor Knights, Three Kings and Kermadec Islands. Raoul Island, the northernmost island in the Kermadec group, has approximately 300 plant species, but almost two-thirds of these are introduced. A weed eradication programme has been running there for almost 30 years (West 1996) but, despite strict quarantine, *Selaginella kraussiana* (Kunze) A. Braun was recorded there for the first time in 1998 (R. Dudfield, personal communication). However, because of the high degree of weed awareness among the staff on the island, this environmental weed was quickly identified and appropriate eradication techniques were implemented.

Education and communication

Raising awareness about environmental weeds and how they can be managed is another key element in the management tool-kit. Indeed, communication has been identified as a critical success factor for the future of weed management (Thorp & Lynch 1999).

With increased emphasis on education and the provision of information, the range of stakeholders with an interest in environmental weeds is growing. For example, many garden plants that can become environmental weeds are still sold by nurseries, at least in Australia. To try and minimise this practice, the current emphasis is on an education and awareness campaign, with the government, nursery industry and horticultural media working together to find solutions (Blood 1999). However, this process is made more difficult by the complex and inconsistent approach to noxious weed legislation in Australia, making it virtually

Table 9. Key events in New Zealand leading to greater awareness of environmental weeds

Time period	Events
Early to mid 1980s	An extensive publicity campaign to raise public awareness of *Clematis vitalba* L., as an environmental weed, with support from David Bellamy to raise the profile of the campaign.
1986	*Clematis vitalba* L., gazetted as a class B target noxious plant (West 1986).
1987	Department of Conservation established, with responsibility for managing environmental weeds on public land and for raising public awareness (advocacy) about the threats that environmental weeds pose to native plant and animal communities, irrespective of their tenure.
1993	*Biosecurity Act 1993* established with responsibility for weed awareness and management coming much more into the public domain. This replaced the *Noxious Plants Act 1978*.
1994	The Royal Forest and Bird Protection Society of New Zealand and the Institute of Noxious Plants Officers obtained a voluntary agreement with the New Zealand Nurserymen's Association to halt sales of the worst environmental weeds. A list of these weeds was drawn up and agreed to (Craw 1994).
1995–1996	National Surveillance list created for inclusion in Regional Pest Management Strategies by Regional Councils. Subsequently, a booklet that provides a photograph, brief description, common names and species names and indications of ecosystems at risk for 110 species was published (Vervoort & Hennessy 1997). This is distributed extensively by Council staff at field days, agricultural shows and other events organized for public participation.
1996	*The Good Plant Guide* published on species that could be grown without having an adverse effect on the environment (Craw 1996).
1997	Development of an environmental training module on weed management (Lynch & West 1999) for Department of Conservation staff. Will be available to the wider community in the future.
1999	*Pests and Weeds: A Blueprint for Action* (Hackwell & Bertram 1999) published by the New Zealand Conservation Authority, outlines the economic costs and dangers that pests, weeds and pathogens now pose in New Zealand, and provides a blueprint for action to save sensitive environments and vulnerable industries.
Ongoing	Landcare Research produces two public awareness newsletters about weeds, *Weed Identification News* (on environmental weeds), and *What's New in Biological Control?* (on the biological control of weeds).
Being developed	Partnerships between the Department of Conservation and a wide range of groups with an interest in weed management. Part of the policy involves developing public awareness activities to improve public recognition of weed threats and support for management undertaken by the Department (Owen 1998a: pp. 43–6). Partnerships will be crucial to the success of surveillance, many weed-led programmes and some site-led programmes.

impossible for potential sellers of nursery stock or seed to comply with the legislation, particularly when shipping to interstate customers (Thorp & Lynch 1999). In New Zealand, a regulatory approach is taken and all Regional Pest Management Strategies list plants in various categories ranging from Total Control Plants to Regional Surveillance Plants, which are not to be sold, propagated or knowingly distributed.

An extensive range of educational material has been developed in the last 15 years in both Australia and New Zealand, to the extent that it is impossible to cover it all in detail. Consequently, summaries identifying key events are provided for New Zealand (Table 9) and at the national level for Australia (Table 10). Similar information at the State level has never been collated, although there are numerous publications and other material relevant at the regional level. Two examples are the newsletter *Under Control* (which examines the management of pest plants and animals) published by the Keith Turnbull Research Institute in Victoria and *Weeds of Natural Ecosystems. A Field Guide to the Environmental Weeds of the Northern Territory, Australia* (Smith 1995), which identifies environmental weeds in the Northern Territory.

One critical question is how much of an impact these measures are having. A qualitative example can be given for *Clematis vitalba* L. in New Zealand, where there was an extensive publicity campaign in the early to mid-1980s to raise public awareness (see Table 9). More than 10 years later, many members of the public remain aware of the risks posed by this environmental weed. A recent example illustrating the impact of this publicity concerns the planted native forest exhibition in Bush City, part of the new Te Papa (Museum of New Zealand) in Wellington. Several times in 1998, the native clematis *Clematis paniculata* Gmelin was mistaken for *C. vitalba* and this was drawn to the attention of the museum staff, either by letter or in person. On one occasion plants were uprooted when in fruit, because they were thought to be *C. vitalba*. The members of the public responsible for this vandalism thought they were doing the right thing. The museum staff have now installed signs reminding people of the differences between the two species (P. J. Brownsey, personal communication). Another indication of the success of educational measures is the increasing involvement of the community in managing environmental weeds (AACM International 1997) and the growing interest in Weedbuster Week in Australia (Table 10). Even if community events are the only times that people become motivated about the management of environmental weeds, it is still better than no action at all.

Research

As with other areas addressed in this paper, it is easier to describe the research infrastructure in New Zealand

Table 10. Key events in Australia leading to greater awareness of environmental weeds at the national level

The Education Program of the Cooperative Research Centre (CRC) for Weed Management (established in 1995) and the National Weeds Strategy have been the two main foci for education on the ecology and management of weeds of agricultural and natural areas. Weedbuster Week, which is now held nationally each year in the latter half of October, has also been a particularly successful event in terms of raising broad community awareness about weeds in the landscape.

At a broad level, the Education Program of the CRC for Weed Management Systems has funded many honours and postgraduate scholarships, including several that examine environmental weeds. It has also funded a tertiary level textbook on integrated weed management that includes several chapters on environmental weeds. The Environmental Weed Education Coordinator for the CRC has been particularly active and has initiated or been actively involved in several major education campaigns including the following:

1. A weed activity calendar, incorporating information on environmental, agricultural and related weed activities around Australia and the world.
2. The Enviroweeds listserver, an active and informative email discussion group in Australia with 500 subscribers. To send a message to the discussion group, use: ENVIROWEEDS@majordomo.nre.vic.gov.au
3. The Weed Navigator, a comprehensive resource guide and contact directory in two volumes covering Australia and New Zealand (Taylor *et al.* 1999).

The National Weeds Strategy (NWS) has supported a number of publications on environmental weeds (see Adair & Groves 1998), including an annotated bibliography of publications on environmental weeds in Australia and New Zealand (Swarbrick & Timmins 1997). The Executive Committee for the NWS also has an Internet site that includes information on key weed policies, regulations, current issues, national initiatives, research, extension, training and personnel in Australia.

Weedbuster Week serves as a focus to raise weed awareness around Australia and includes activities such as cleaning up weeds, displays and competitions. These are held by voluntary groups including 'Friends of' groups, Landcare and gardening groups. Woody Weed, the Weedbuster Week icon, helps promote activities. The campaign started as Weed Awareness Week in Queensland in 1994. It grew into Weedbuster Day which was run in 1995 and 1996 with great success. New South Wales also held Weed Awareness Weeks in 1986, 1990 and 1996. In 1997 the event went national and in 1998 over 600 events were held around the country. The level of participation is growing. For further information see www.weedbusterweek.info.au or Vitelli *et al.* (1999).

because of the size and type of governance of the country. Research on environmental weeds in New Zealand is undertaken mainly by three groups: Crown Research Institute scientists (generally from Landcare Research and the National Institute of Water and Atmospheric Research), university scientists and Department of Conservation scientists. Research is funded largely by the tax payer through Science funds, disbursed through the Public Good Science Fund (PGSF) and administered by the Foundation for Research, Science and Technology; Education funds disbursed through universities; and Conservation funds disbursed through Department of Conservation. In addition there is some research funded by ratepayers, disbursed by Regional Councils. Smaller sums are available from the Lotteries Commission and from trust funds established by environmental non-government organizations. Regional Councils tend to support research that is focused on the control of environmental weeds by chemical or biological means. The Department of Conservation supports research on weed autecology, methods of control including biological control, impacts on native species and communities, public perceptions and actions, and information transfer (Timmins 1997). The PGSF supports fundamental research on the nature of invasive species and their impacts, as well as biological control.

In Australia, a broad range of government agencies and universities undertake research on environmental weeds. As in New Zealand, most of this research is funded by the tax payer. An indication of the nature of the research can be gained through the annotated bibliography of environmental weeds (Swarbrick & Timmins 1997). At the national level, however, the main focus of research has been through two Cooperative Research Centres (CRC): the CRC for Tropical Pest Management in northern Australia and the CRC for Weed Management Systems in southern Australia (www.waite.adelaide.edu.au/CRCWMS). The former CRC for Tropical Pest Management ceased operation in 1998, but individual organizations are still working on the ecology of environmental weeds in the north. The CRC for Weed Management Systems was set up in 1995 as a collaborative venture between research institutions, management agencies and industry. The aim of Program 3 of the CRC for Weed Management Systems is the development of integrated strategies for the sustainable management of weeds invading natural ecosystems in temperate Australia, and it has supported several studentships and honours,

Table 11. Types of research on environmental weeds with examples from New Zealand and Australia

Type of research	New Zealand	Australia
Autecological studies undertaken to define and understand the biology and ecology of individual species	Chapman & Bannister (1990), Hay & Villouta (1993), Hume *et al.* (1995), Williams & Buxton (1995), Bungaard *et al.* (1998), Timmins & Reid (2000)	Fensham *et al.* (1994), Vranjic & Groves (1999), Grice (1997), Downey & Smith (2000)
Impact that environmental weeds have on ecosystems	Kelly & Skipworth (1984), Scott *et al.* (1990), Tanner *et al.* (1990), Ogle *et al.* (2000)	Griffin *et al.* (1989), Braithwaite *et al.* (1989), Groves & Willis (1999)
Summarizing the scale of environmental weeds nationally	Howard-Williams *et al.* (1987), Williams & Timmins (1990), Lynch (1995), Buddenhagen *et al.* (1998), Nelson (1999)	Humphries *et al.* (1991), Groves *et al.* (1997) (covers weeds of both agricultural and natural ecosystems)
Summarizing the scale of environmental weeds locally (includes environmental weeds)	Johnson (1982), Esler (1988), West (1996)	Carr *et al.* (1992), Smith (1995), Grice & Brown (1996), Rozefelds *et al.* (1999)
The role of native and introduced animals as dispersers of environmental weed seeds	Allen & Lee (1992), Williams & Karl (1996), Williams *et al.* (2000)	
Indigenous plants that have become environmental weeds	Williams (1996), Baars & Kelly (1996), Bellingham (1991)	Mullett (1996), McMahon *et al.* (1996), Buist *et al.* (2000)
Physical or chemical control methods for environmental weeds	Williams & Buxton (1989), West (1994), Timmins (1995), Turner & Hewitt (1997)	Bruzzese & Lane (1996), Anderson *et al.* (1997)
Biological control studies which focus on identifying the agents likely to be most debilitating to the host weed and examining risks to valuable non-target species.	Syrett *et al.* (1995), Fowler *et al.* (2000)	Stahle (1997), Holtkamp *et al.* (1999)

postgraduate and postdoctoral positions on environmental weed management. For example, work conducted by the CRC for Weed Management Systems has shown that a combination of fire and herbicide, in addition to biological control methods, at the appropriate time can be an effective management tool to help combat bitou bush (*Chrysanthemoides monilifera* ssp. *rotundata*) infestations (Holtkamp *et al.* 1999). The use of fire as a management tool may not hold as much potential in New Zealand, as fire has not played a major role in vegetation dynamics and the indigenous vegetation may be less tolerant of the impact of fire.

The wide range of research topics studied in New Zealand and Australia is summarized in Table 11, with examples of published papers given. The amount of research on environmental weeds is increasing as the respective governments become more aware of the threats posed to native ecosystems and contribute resources towards developing solutions. However, given the magnitude of the problems, there is room for considerably more work on weed issues. The way in which future research is conducted will require careful planning as past research models have been questioned and learning-based approaches advocated (Bullen & Woods 1999). It is also critical that the results of research are communicated in a manner that can be used by on-ground managers, or it will be of limited effectiveness. This means that researchers must adopt a range of communication tools in addition to publishing papers in refereed journals. To encourage this, research scientists should be rewarded for targeting their research results to the most appropriate audience.

Management of environmental weeds

Historically, the emphasis of most environmental weed management programs in New Zealand and Australia has been on the chemical or manual 'control' of weed infestations, often with little consideration of the long-term effectiveness or the ecological consequences of such approaches. The reluctance of the scientific community in New Zealand, to accept that native communities not directly disturbed by humans were vulnerable to invasive weeds, probably delayed management of environmental weeds for several decades. This is illustrated by the prolonged debate about the vulnerability of intact native plant communities in New Zealand to invasion by exotic species. Allan (1940), writing of the work of Thomson (1922) and Cockayne (1928), states:

> Both authors have sought to present the facts in true perspective and to combat the all still too prevalent views as to the relative vigour and aggressiveness of the introduced and the indigenous species . . . it is only the presence of man and his animals that has given the aliens the opportunity and power to occupy the land in the imposing manner we see to-day.

However, this is certainly not the case now, with scientists commonly advising regulatory authorities on environmental weeds and approaches to management (e.g. Department of Lands & Survey 1984). In Table 12, the approach taken by the Department of Conservation is used as a case study to highlight the main issues associated with the management of

Table 12. Management of environmental weeds by the Department of Conservation in New Zealand

The stated goal for managing approximately 240 environmental weeds by the Department of Conservation is: 'The integrity and sustainability of all natural areas that are important for nature heritage conservation, and the long-term survival of native species, are maintained or improved' (Owen 1998a). In order to achieve this goal there are five objectives (Table 10). The Department of Conservation works with the Ministry of Agriculture and Forestry, the Ministry of Fisheries and the Environmental Risk Management Authority to achieve effective border control (Objective 1).

Two different approaches to weed management are taken: weed-led (Objective 2) and site-led (Objective 3) (Table 11). The purpose of the weed-led approach is to prevent new environmental weeds from invading a Department of Conservation conservancy or spreading beyond a limited distribution. The desired outcome of this approach is eradication or containment of the target weed. Weed-led programmes have strict guidelines (Owen 1998a) and there is a series of steps which must be followed to determine whether a weed-led programme is warranted and technically and politically feasible (Owen 1998a). Feasible programmes are then prioritized by evaluating and scoring the weediness of the target species and the practicality of eradicating or containing it at the proposed scale (Owen 1998a).

Embedded within Objective 4 of the Department of Conservation strategic plan (Owen 1998a) is weed surveillance. The purpose of weed surveillance is to detect weeds as soon as they invade a conservancy, or as soon as they invade a relatively weed-free place, so that appropriate action can be taken at an early stage (weed-led or site-led control, respectively). Two approaches to weed surveillance are recommended: (i) active surveillance involving programmed staff time, targeting areas most likely to be invaded (vulnerable places) and areas most at risk from weeds (valuable places), and (ii) incidental observations made by anyone, anywhere (e.g. trampers, environmental non-government organizations, botanists on holiday), but with reports passed on to Department of Conservation staff who will follow them up. Both types of surveillance require a high degree of awareness by observers, and training to ensure that sufficient details are recorded (Braithwaite 1999).

Objective 5 is to ensure that the detection and control of weeds is carried out to the highest possible standard and following designated procedures and protocols.

Table 13. The New Zealand Department of Conservation's five objectives for managing invasive weeds

1. Border control.
2. Minimizing future problems.
3. Protecting specific high value sites.
4. Developing and maintaining capacity.
5. Quality management.

environmental weeds, applicable to both New Zealand and Australia. The Department of Conservation has five objectives for managing environmental weeds (Table 13), which include weed-led and site-led programmes (Table 14 and Table 15). On a regional scale in New Zealand, environmental weeds are identified in Regional Pest Management Strategies, and the whole community has a responsibility to manage the species listed according to the instructions given in the strategy. Regional Councils have an enforcement role, if required. Not all regions have developed Regional Pest Management Strategies yet (e.g. West Coast of the South Island), and adjacent regions can have quite different species and requirements listed. This is useful because regional differences in the establishment and behaviour of environmental weeds can be accommodated, but it can also lead to inconsistencies and problems for effective weed management.

Effective and efficient management of environmental weeds requires an understanding of the plant and the area in which it grows. Environmental weeds must be treated as a symptom of a problem, not just the cause. Increasingly however, the preferred approach to environmental weed management (as described in Table 14) is strategic, integrated and ecological. This means that weeds are examined in the context of adjoining areas or along with other issues within the area being managed: (i) using a combination of treatment techniques and proper and persistent follow-up procedures to ensure that weeds remain in check and the development of native species is encouraged, (ii) integrating weed management with other management programmes such as those for pest animals, fire and recreation, and (iii) integrating the input of various management bodies and using appropriate treatments

Table 14. Summary of the characteristics of weed-led and site-led programmes in New Zealand

Weed-led	Site-led
To prevent new species invading a conservancy, or prevent a new species becoming established nationally.	To protect the natural values of a particular place.
Focus on newly naturalized species in a region, or newly invading species or very confined species.	Focus on those species to be managed for protection of the place (often widespread).
Scale is usually a whole conservancy. May be national.	Scale is that of the defined place (management unit).
Sites of any quality, any tenure and anywhere.	Sites where infestations occur within the management unit, plus buffers and seed sources outside the management unit.
Success is considered to be when the species is eradicated or contained within the conservancy.	Success is considered to be when the natural community in the management unit responds in a desired way (e.g. regeneration) to the desired degree.
Non-control activities include species specific public awareness and weed hygiene, controls on sale and distribution, and surveillance.	Non-control activities include place-specific public awareness and weed hygiene, and integrated control with other threat management.

Table 15. Examples of site-led weed programmes in New Zealand

The Department of Conservation is carrying out approximately 200 site-led weed control programmes with sites ranging in size from <10 ha to approximately 20 000 ha (Owen 1999). Three examples of sites from throughout New Zealand with the maximum scores for botanical/wildlife values and urgency of control are (Owen 1998b):

1. Waipoua Forest, Northland. The largest remaining remnant of mature kauri (*Agathis australis* D. Don) forest with *Pennisetum macrourum*, *Elaeagnus* × *reflexa* Morren et Decne., *Hedychium gardnerianum*, *Cortaderia selloana* (Schultes et Schultes f.) Asch. et Graebner, and *Ageratina riparia* (Regel) R. King et H. Robinson as environmental weeds.
2. Mt Burnett, Kahurangi National Park, north-west Nelson. Plant species endemic to the area and unique shrubland/herbfield on dolomite with *Clematis vitalba*, *Ulex europaeus*, *Passiflora mollissima* (Kunth) L. Bailey, *Buddleja davidii*, *Cytisus scoparius* (L.) Link, *Cotoneaster glaucophyllus* Franchet, and *Erigeron karvinskianus* DC. as environmental weeds.
3. Waituna Wetland and Fortrose Spit, Southland. Wetland of international importance and unique dune/stonefield associations with *Sedum acre* L., *Angelica pachycarpa* Lange, *Erica lusitanica* Rudolphi, *Ulex europaeus*, and *Ammophila arenaria* as environmental weeds.

that are combined with an understanding of ecosystem dynamics, including all of the introduced and indigenous plants and animals. As the cost-effectiveness of weed control efforts is maximal during the earliest stages of weed invasion, actions for control of the most serious environmental weeds need to be triggered at low densities (Panetta 1999 and see Table 14).

The principles of integrated management of environmental weeds (Groves *et al*. 1998) do not differ substantially from those applying to any weedy plant community. What differs sometimes for the case of environmental weeds is the application of those principles to particular situations. Natural ecosystems are more complex and species-rich than agricultural or pastoral ecosystems. Additionally, the recognition of the role of fire may be more important, especially in Australia, as may the relevance of biological control to limit the growth and development of the major environmental weeds. We still know very little about the biology and ecology of some of our major environmental weeds, which is an important basis for more effective weed control. Only with this knowledge can an integrated strategy for the control of environmental weeds in natural ecosystems be devised and progressively refined. It is an urgent task if the biodiversity in Australia and New Zealand is to be retained along with representative samples of their natural ecosystems.

As indicated earlier, most naturalized plants are not environmental weeds; however some will become so, given sufficient time or a change in conditions (disturbance, introduction of a pollinator, climate change etc.). So called 'sleeper weeds' (species that have naturalized but not yet expanded their populations exponentially) are a major concern in both countries. Groves (1999) identified two ecological factors that were useful in predicting sleeper weeds: time from naturalization and re-location to a more favourable site. As a first step, all introduced species already within Australia and New Zealand could be scored for these attributes (not just species which might be imported into either country). Applying these weed risk assessment models could be a second step, but this would be much more time consuming. Alternatively, Csurches and Edwards (1998) asked approximately 100 experts in Australia to nominate non-indigenous plant species that they considered to be 'potential environmental weeds' and that appeared to be in a very early stage of naturalization. By focusing on species with histories of occurring as weeds overseas, and that were amenable to eradication in Australia (because they have a localized distribution), around 35 species were listed as candidates for eradication.

CONCLUSIONS

The threat to indigenous biodiversity posed by environmental weeds has gained increasing recognition, particularly in the past decade. There are numerous aspects to the management of environmental weeds, and while progress is being made on most fronts, there is always room for improvement. In both Australia and New Zealand, new legislation, policy and planning documents form part of the tool-kit developed to address the issue of environmental weeds. The key measure is the successful implementation of these policies and plans, which would be assisted by greater coordination and cooperation between agencies and the different levels of government, especially in Australia. Increased knowledge of the ecology and biology of environmental weeds is required for their improved management in natural ecosystems, although the model used for conducting and communicating research also needs refining. Encouragingly, the number of education and training programmes on environmental weeds, and community involvement in weed management is growing. One of the biggest challenges that weed managers still face is convincing the public of the need to act early when an environmental weed is detected. Many people will not believe that a weed will cause problems until it is so widespread that it is difficult and expensive to manage. With the management of already established environmental weeds drawing heavily on resources in both countries, it is critical that new introductions, and sleeper weeds, are controlled before they become a major problem.

As noted at the start of this review, both Australia and New Zealand have evolved biota with a high degree of endemism, and which is particularly susceptible to environmental weeds. Overall, however, environmental weeds may be more manageable in New Zealand than Australia because it has (i) two levels of government instead of three, (ii) one department responsible for managing 30% of the country as well as marine reserves, (iii) a much smaller geographical area, and (iv) more people per unit area to help manage weeds. These characteristics lend themselves to a more coordinated and integrated approach to the management of environmental weeds on the ground, but does not discount the numerous and important initiatives underway in Australia.

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APPENDIX 1

The legislative and policy framework in New Zealand and Australia for the management of environmental weeds.

International

The principal international obligation in relation to restrictions at the borders of Australia and New Zealand derives from the World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures. This agreement requires all decisions on restriction to be substantiated by scientific risk assessments (Owen 1998a). Other relevant international agreements to which New Zealand and Australia are signatories to are the *International Plant Protection Convention 1951*, the *United Nations Convention on the Law of the Sea 1982* and the *Convention on Biological Diversity 1992*.

New Zealand

National

In New Zealand, the *Biosecurity Act 1993* and the *Hazardous Substances & New Organisms Act 1996* (HSNO Act) together provide the legislative framework for managing organisms, including potential environmental weeds, entering the country. The Biosecurity Act deals with organisms that may be unintentionally introduced with imported goods, including primary produce. The HSNO Act deals with organisms that people apply to import into the country (Owen 1998a). Border control activities are carried out by the Ministry of Agriculture and Forestry under the Biosecurity Act. The Ministry of Fisheries is responsible for detecting marine organisms that may enter the country via ballast water or fouled hulls (Owen 1998a).

The HSNO Act decreed the establishment of the Environmental Risk Management Authority, and the role of this agency is to evaluate all applications for importation of new organisms. The Environmental Risk Management Authority is an independent decision-making body and operates to prescribed guidelines. In addition to these agencies, the Biosecurity Council has been established to coordinate responses to biosecurity issues (Owen 1998a). Members of this council are drawn from a range of organizations with biosecurity responsibilities and include members from the Ministry of Agriculture and Forestry, the Ministry of Fisheries and the Department of Conservation.

Nationally applicable New Zealand government strategies include: Environment 2010 and the Government Strategic Result Area 9 Protecting and Enhancing the Environment. The Department of Conservation has also developed a Strategic Plan for Managing Invasive Weeds to guide the weed management activities of the Department (Owen 1998a). Many Acts that relate to the conservation or protection of land, water and organisms have specific sections relating to introduced plants or environmental weeds. Examples are the *Conservation Act 1987*, *Reserves Act 1977*, *National Parks Act 1980*, *Wildlife Act 1953*, *Marine Reserves Act 1971*, *Foreshore & Seabed Endowment Revesting Act 1991* and the *Resource Management Act 1991* (Owen 1998a).

Regional

Internally, Regional Councils are responsible for approving Regional Plant Pest Management Strategies under the Biosecurity Act (Owen 1998a). Regional Pest Management Strategies can be prepared by any individual or group, and depend on consultation and agreement between all major community groups to be effective. In Regional Pest Management Strategies, species and their management tend to be listed in four main categories: (i) total control, (ii) boundary control, (iii) national surveillance, and (iv) regional surveillance. The first two categories require the removal of all or some of an identified weed infestation and all categories ban the propagation, sale and distribution of listed species and apply nationally or regionally. National surveillance pest plants were identified and listed after consultation with a wide range of local and national organizations. For an example of a Regional Pest Management Strategy, see Southland Regional Council (1996).

National Pest Management Strategies can be prepared for any species of significant national concern. These are approved by the Governor General by Order-in-Council on the recommendation of a Minister. Since the introduction of the Biosecurity Act in 1993 no National Pest Management Strategies have been implemented for weeds but the Ministry of Fisheries is currently preparing one for *Undaria pinnatifida* (an invasive brown seaweed that is currently being eradicated from Big Glory Bay in Paterson Inlet on Stewart Island) and the Ministry of Agriculture and Forestry is developing one that will include Cape tulip (*Homeria collina* (Thunb.) Vent.), Johnson grass (*Sorghum halepense* (L.) Pers.), water hyacinth (*Eichhornia crassipes* (Mart.) Solms-Laub.), and salvinia (*Salvinia molesta* D. Mitch.).

Australia

National

Legislation A number of Commonwealth Acts are relevant to the management of environmental weeds in Australia. The following information has been summarized from Sharp (1999).

- *Quarantine Act 1908*.
  Provides the basis for restricting imports into Australia.
- *Wildlife Protection (Regulation of Imports and Exports) Act 1982*.
  Helps ensure that Australia complies with its obligations under the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). Also aims to protect native animals and plants of Australia by regulating the import of alien species which could have an adverse effect.
- *Biological Control Act 1984*.
  Establishes an authority to oversee biological control or eradication of alien species.
- *Natural Heritage Trust Act 1997*.
  Provides the framework under which policies for alien-species research and coordinated control or eradication can be launched. Under the Trust, this is done through a number of programmes, namely the National Feral Animals Control Program, the National Weeds Program and the Coasts and Clean Seas: Introduced Marine Pests Program (Commonwealth of Australia 1997).
- *Environment Protection & Biodiversity Conservation Act 1999* (enacted in July 2000).
  This new legislation will take the place of five Acts when it is enacted, and will offer a more direct approach to the control of alien species that could be described as being of national environmental significance.

Policy The overarching policy framework at the national level in Australia is the National Weeds Strategy (NWS) of 1997. This was endorsed by the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Ministerial Council on Forestry, Fisheries and Aquaculture (MCFFA) in 1997 and a revised edition was published in 1999 (Commonwealth of Australia 1999). The NWS takes a strategic approach to weed management problems of national significance, addressing environmental and agricultural weeds equally, and describes the nature of the problem, discusses why existing weed management measures are not adequate, and lists the roles and responsibilities of government, community, landowners and land users. It has three primary goals with underpinning objectives and strategies, which are to be addressed by an Executive Committee and government at all levels in tackling this form of land degradation.

The NWS has provided a focus for weed management at the national level (Thorp & Lynch 1999). The Commonwealth, together with the States and Territories, has provided money to implement the key elements of the NWS. This is being coordinated through the National Weeds Program (a programme of the Natural Heritage Trust), which has supported various initiatives such as the Australian Quarantine Inspection Service Weed Risk Assessment System (Steinke & Walton 1999). An important element of the NWS has been the development of a list of Australia's weeds of national significance (Table 8; see also www.weeds.org.au/natsig.htm) using a scientifically based approach. The next step is to develop cost-effective, strategic management plans for these weeds. Considerable progress has been made in the development of these plans, with project officers appointed and a number of national workshops held. The goal of the plans will be to reduce the impact of the weeds of

national significance to an extent where management is possible by the appropriate State and Territory governments.

The National Weeds Strategy Executive Committee has developed a low-tech, but informative web site to promote access to key weed policies, regulations, current issues, national initiatives, research, extension, training and personnel in Australia. This site (www.weeds.org.au) is recommended for people interested in finding out more about the National Weed Strategy and its many facets.

State level

Legislation

Weed legislation in Australia has principally focused on agricultural weeds, but some Acts are currently, or have recently, undergone revision to give greater emphasis to environmental weeds and the involvement of the community in weed management. When a plant has been declared under legislation, it can be called 'noxious'. In the past, most of the noxious weeds were weeds of agricultural systems (see Parsons & Cuthbertson 1992). In Victoria, recent changes to the legislation expanded the definition so that environmental weeds were better covered, with the definition of noxious weeds updated to 'a plant that has or may have the potential to become a serious threat to primary production, Crown land, the environment or community health in Victoria (refer to the *Catchment & Land Protection Act 1994* [Vic.])'.

It should be noted, however, that weeds of agricultural areas still have the highest profile in legislation at the State and Territory level. The list of the main legislation relevant to weed management (both environmental and agricultural) has been adopted from the web site of the National Weed Strategy Executive Committee, with some modifications. Further details, including contacts for legislation in each State and Territory, can be found at this site. However, it must also be noted that a range of other Acts in each of these jurisdictions can be relevant to weed management. For example, in Tasmania the *Living Marine Resources Management Act 1995* (Tas.) contains provisions to control the movement of particular marine plants, including weeds such as *Undaria pinnatifida* (DPIF n.d.). However, the purpose of this section is to illustrate the range of legislation and diversity of agencies that administer the Acts in the States and Territories of Australia.

Australian Capital Territory Amendments to the *Land (Planning and Environment) Act 1991* (ACT) in 1996 provide for a plant to be declared a pest plant, either generally or in a specific area.

New South Wales The *Noxious Weeds Act 1993* (NSW) is administered by NSW Agriculture, and is being reviewed as required under national competition policy. Consolidation of essential provisions is likely to be favoured. The *Native Vegetation Conservation Act 1997* (NSW) requires landholders wishing to clear or control invasive native plants to make applications to the Department of Land and Water Conservation, unless the activity is covered by an exemption.

Northern Territory No Regulations currently exist under the *Noxious Weeds Act 1980* (NT). A new Act is being drafted.

Queensland The *Rural Lands Protection Act 1985* (Qld) is administered by the Department of Natural Resources (formerly Lands) in Queensland, and mainly focuses on weeds specific to agriculture. A revised Act, which is currently being drafted, will be broadened to formally include environmental weeds. The *Agricultural Standards Act 1994* (Qld) is administered by the Department of Primary Industry and tends to focus on protection of crops.

South Australia The *Animal and Plant Control (Agricultural Protection and Other Purposes) Act 1986* (SA) is administered by the Animal and Plant Control Commission, which acts as an agency of the Crown. It has been reviewed recently, but the changes are yet to be passed. Weeds are listed under nine classes according to which schedules of the Act apply to them. South Australia has a system of local Animal and Plant Control Boards, and the classes are subdivided according to the Board areas in which particular weeds are proclaimed.

Tasmania The *Weed Management Act 1999* (Tas.) directly underpins a strategic approach to integrated and coordinated weed management at the State level. It provides a statutory requirement for a scientifically based weed risk assessment as part of the declaration process for nominated plant species as weeds, and identifies the need for (i) a comprehensive on-ground weed management plan to be attached to every declaration, (ii) an improved approach to providing the community with statutory powers to implement weed control, and (iii) the updating of compliance requirements and penalties in line with the seriousness of declared weed control.

Victoria *The Catchment & Land Protection Act* 1994 is administered by the Department of Natural Resources and Environment.

Western Australia The *Agriculture & Related Resources Act 1976* (WA) is administered by the Agricultural Protection Board, which has recently been incorporated into Agriculture WA. The Board has broad quarantine responsibilities and updates the species list by declaration. The *Plant Diseases Act 1989* (WA) is concerned primarily with pests and diseases, however, weeds are regarded as a form of plant disease under the Act. Species described in both Acts are similar and recent events with imported seeds have led to Agriculture WA compiling a list which would be adopted under both Acts.

Policy

All States and Territories have developed, or are developing, weed strategies to provide a framework for weed management. Many build on the NWS and address existing and potential weed problems, as well as providing a mechanism for cost-effective action. Encouragingly, environmental weeds are given a high profile in these plans (such as the Tasmanian WeedPlan: *A Tasmanian Weed Management Strategy* (Department of Primary Industries and Fisheries 1996)) as they are increasingly acknowledged as one of the most serious threats to natural environments. Indeed, Western Australia has recently released an *Environmental Weed Strategy for Western Australia*, which will have an accompanying database called *WeedBase*. Some of these weed strategies have their own web sites and links can be found through the Agriculture WA web site at www.agric.wa.gov.au/progserv/Plants/weeds/links.htm. This site also has a lot of other information that is likely to be of interest to readers.

Regional partnerships

Strong links have been formed at the government level between New Zealand and Australia, with two ministerial Councils, ANZECC and ARMCANZ, of relevance to this review. ANZECC was formed in 1991 to provide a forum for member governments to exchange information and experience and develop coordinated policies in relation to national and international environment and conservation issues. Until recently only Australia and New Zealand were full members, but Papua New Guinea was given this standing in December 1998. ARMCANZ consists of the Australian Federal, State/Territory and New Zealand Ministers responsible for agriculture, soil, water (both rural and urban) and rural adjustment policy. The objective of the Council, which had its first meeting in 1993, is to develop integrated and sustainable agricultural and land and water management policies, strategies and practices.

An official list of 20 weeds of national significance for Australia (Table 8) has recently been developed on behalf of ARMCANZ, ANZECC and MCFFA. The list was agreed with the States and Territories of Australia after extensive consultation. Weeds have been selected according to their invasiveness, economic, environmental and social impacts, current distribution, potential for spread, and effect in reducing the growth of desirable plants. The hope is that research organisations, commercial partners, industry and community groups will use the list to determine their priorities. Management plans will also have to be written for each of the weeds on the list. While endorsement of the list is not accompanied by any specific form of guaranteed funding, it will assist the Commonwealth, States and Territories in determining funding priorities.