Biological control options for invasive weeds of New Zealand protected areas

SCIENCE FOR CONSERVATION 199

Victoria Ann Froude

Published by
Department of Conservation
P.O. Box 10-420
Wellington, New Zealand

Science for Conservation is a scientific monograph series presenting research funded by New Zealand Department of Conservation (DOC). Manuscripts are internally and externally peer-reviewed; resulting publications are considered part of the formal international scientific literature.
Titles are listed in the DOC Science Publishing catalogue on the departmental website http://www.doc.govt.nz and printed copies can be purchased from science.publications@doc.govt.nz

ISSN 1173-2946
ISBN 0-478-22266-1

This report was prepared for publication by DOC Science Publishing, Science & Research Unit; editing by Geoff Gregory and layout by Ruth Munro. Publication was approved by the Manager, Science & Research Unit, Science Technology and Information Services, Department of Conservation, Wellington.

CONTENTS

Biological control options for invasive weeds of New Zealand protected areas

Victoria Ann Froude

Pacific Eco-Logic Ltd, 18 Seaview Road, Paremata, Porirua City, New Zealand

ABSTRACT

More than 240 invasive weed species adversely affect indigenous biota and ecosystems of lands and waterbodies managed by the New Zealand Department of Conservation. Potentially high establishment costs limit biological control programmes to a few species of concern, although there may be opportunities for joint programmes with other agencies.

Biological control may be most useful ecologically where relatively few invasive species proliferate and their removal would bring significant conservation gains (e.g. *Salix cinerea, S. fragilis, Pinus contorta*). It may, however, be difficult to pursue biological control programmes for species that are valued in other contexts such as soil conservation.

Programme outcomes cannot be reliably predicted and it may take many years before these are known. Biological control works best as part of a comprehensive weed management programme. If successful it may eventually reduce or remove the need for conventional control.

This review on the potential contribution of biological control to the Department's weed management strategy addresses: weed impacts; benefits, risks and measuring biological control outcomes; international programmes and their outcomes for biological control of weeds in natural areas; New Zealand investigations for each invasive weed species affecting New Zealand protected areas; and an assessment process for prioritising biological control investigations.

Keywords: biological control; invasive weeds; terrestrial weeds; aquatic weeds; weed impacts; natural areas; protected areas; biological control assessment; weed management strategy; *Anredera cordifolia*; *Cortaderia jubata*; *Cortaderia selloana*; *Lonicera japonica*; *Lagarosiphon major*; *Salix cinerea*; *Salix fragilis*; *Tradescantia fluminensis*

Froude, V.A. 2002: Biological control options for invasive weeds of New Zealand protected areas. *Science for Conservation 199*. 68 p.

1. Introduction

Department of Conservation (DOC) staff frequently suggest biological control as a possible control option for recalcitrant weed species of conservation concern. Biological control programmes require a large initial investment to research and test possible control agents. Once operational, ongoing maintenance costs are generally less than those incurred using only conventional control. The high initial costs mean that the Department could only invest in a few selected biological control programmes.

This investigation was established to provide the Department with guidance about the appropriateness of biological control for weed species affecting terrestrial and aquatic protected areas in New Zealand.

2. Background

2.1 OVERVIEW OF WEEDS IN NEW ZEALAND NATURAL AREAS

The 1997 DOC weed database listed over 240 species of introduced plants as actual or potential invasive weeds (Owen 1997). This number continues to increase as more species naturalise and more information is collected. The common and scientific names for these invasive weed species are listed in Appendices 1 and 2.

The 240 species of invasive weeds are a subset of the more than 19 000 introduced terrestrial and freshwater plant species currently in New Zealand. As at March 1998 there were 2068 named indigenous vascular plant species and 2068 naturalised introduced vascular species (E.R. Nicol, Landcare Research, pers.comm.).

The number of naturalised pests has been growing steadily since the 1860s. In the Auckland Region there are more than 615 naturalised introduced plant species (Esler & Astridge 1987) with four new species naturalising every year (Esler 1988). Owen (1998) states that for New Zealand as a whole, if historical trends continue, about 10% of the new naturalised plant species will eventually become significant ecological plant pests.

2.2 WHAT IS BIOLOGICAL CONTROL?

Biological control is defined as 'the actions of parasites, predators and pathogens in maintaining another organism's density at a lower average than would occur in their absence' (e.g. DeBach 1964; Nordlund 1996; McFayden 1998).

There are three different approaches for applied biological control (McFayden 1998):

Conservation. Protection or maintenance of existing, naturally-occurring populations of biocontrol agents.

Augmentation. Regular action to increase populations of biocontrol agents, either by periodic releases or by environmental manipulation. Most examples of augmentation using insects are when the introduced biocontrol agent has poor dispersal capacity and the weed occurs in discrete scattered areas. For example, the floating fern salvinia (*Salvinia molesta*) is controlled in ponds and other waterbodies in Australia by the regular release of the weevil *Cyrtobagous salviniae*.

Classical biocontrol. Importation and release of exotic biocontrol agents, with the expectation that the agents will become established and further releases will not be necessary.

Internationally, most weed biological control is of the classical type and the conservation approach is rarely used (Harris 1993). There is some augmentation using bioherbicides (primarily with fungi) or insects. While there is extensive literature on potential bioherbicides, problems with mass production, formulation and commercialisation continue to prevent the use of bioherbicides as economically viable alternatives to chemical and mechanical weed control (Morin 1996).

Generalist mammalian herbivores and herbivorous fish have been promoted by some as biocontrol agents. While these herbivores will reduce the biomass of plants in an area, their browsing is not host-specific as they reduce both undesirable and favoured plants. Examples include grass carp browsing aquatic plants and goats browsing terrestrial vegetation. Generalist herbivores may be appropriate in some locations, such as a lake with a suite of problem plant species and few, if any, remaining indigenous plants.

3. Review objectives

This review had the following objectives:

- To assess the effectiveness and ecological implications of biological control as a weed control method for use by DOC
- To develop criteria for assessing under what circumstances the Department should initiate or support biological control programmes for weed species affecting terrestrial, freshwater and marine natural areas
- To assist the Department to make logical and effective decisions on the funding of research into the biological control of weed species affecting natural areas.

4. Methodology

4.1 REVIEW OF INTERNATIONAL BIOLOGICAL CONTROL OUTCOMES

This consisted of: a review of international biocontrol literature; internet website searches; and correspondence with biocontrol experts in research and management organisations.

Information was sought on:

- The outcomes of biological control programmes both generally and in natural/protected areas
- Measuring the success of biological control programmes
- Factors affecting biological control project and programme successes and failures
- The benefits and risks of biological control.

4.2 ASSESSMENT AND MANAGEMENT OF WEED THREATS

The threats posed by the 240 species in the DOC weeds database were identified. The semi-quantitative rankings, *effect on system* and *biological success rating* scores, were collated from Owen (1997). Departmental staff identified both the 10 weed species that were most difficult to control in their conservancies; and the 10 weed species that had the greatest ecological impact in their conservancies.

The potential role of biological control as part of the Department's weed management strategy was identified.

4.3 IDENTIFICATION OF INTERNATIONAL AND NEW ZEALAND BIOLOGICAL CONTROL WORK FOR PROBLEM WEED SPECIES

Julien & Griffiths (1998) provided the primary source of information on international biological control programmes for the 240 species in the DOC weed database. This was supplemented with additional published and unpublished material (e.g. Landcare Research biocontrol feasibility studies for particular species).

4.4 SELECTING WEED SPECIES FOR BIOLOGICAL CONTROL INVESTIGATIONS

Draft criteria and questions were developed to assess the suitability of problem weed species for biological control assessments to be funded at least in part by the Department. These criteria were included as part of a background paper prepared for a Departmental biological control workshop held in March 2000. The criteria and questions were tested at the workshop, and subsequently refined into a three-stage assessment process:

- initial assessment criteria
- detailed questions to guide information collection
- comparative evaluation criteria.

4.5 PRELIMINARY BIOLOGICAL CONTROL ASSESSMENTS OF EIGHT INVASIVE WEED SPECIES

The Department selected the species for preliminary biological control assessment. This was based on feedback from 13 conservancies on what were: the 10 weed species with the greatest environmental impact in their conservancy; and the 10 species that were most difficult to control. A weed species scored one point for each conservancy that recorded the species in a 'top 10' list. Weed species that scored a total of four or more were assessed as potential candidates for biological control investigations. A variety of factors were used to reduce this list for preliminary assessment to eight species. This evaluation is documented in Appendix 3. Preliminary biological control assessments were undertaken for: *Anredera cordifolia*; *Cortaderia jubata*; *C. selloana*; *Lonicera japonica*; *Lagarosiphon major*; *Salix cinerea*; *S. fragilis*; *Tradescantia fluminensis*. Material for these assessments was contributed by Pauline Syrett (Landcare Research) and Adrian Spiers (Hort Research).

5. Review of international biological control outcomes

5.1 INTRODUCTION

The use of introduced insects and pathogens to control problem plants is the core of classical biological control. Up to the end of 1996 there had been at least 1150 deliberate releases of 365 species of invertebrates and fungi on to 133 weed species in 75 countries (Julien & Griffiths 1998). Most of these releases were made to address weeds affecting horticultural crop, pasture and forestry systems although some were also weeds of natural areas. An increasing number of programmes focus on weeds that are primarily or solely weeds of natural areas.

The USA and Australia are most active in classical biological control of weeds, followed by South Africa, Canada and New Zealand. Deliberate introductions of biological control agents have been made in another 70 countries (Waterhouse 1998).

5.2 BENEFITS OF BIOLOGICAL CONTROL

A successful biological control programme eventually reduces, or in some cases removes, the need for conventional (often chemical) methods of control for a weed species that is growing prolifically in the absence of its natural pests and pathogens. Waterhouse (1998) states that the benefit-to-cost ratio of successful control can be very high, especially when earlier successes in one country form the basis for repeating the introductions elsewhere. Crawley (1989a) observed that 'while the overall success rate for biological weed control may be relatively low, the successes are permanent and highly cost effective. An additional benefit of biological weed control lies in its target specificity …'

There are some weed biological control programmes where the results have been spectacular. The most famous example is that of prickly pear (*Opuntia stricta)* in Australia. Investigations for control agents began in 1912. While one of five agents initially affected *Opuntia vulgaris*, *O. stricta* continued to spread. Research continued with 12 agents being released. One moth, *Cactoblastis cactorum,* was a success. At the time the moth was released in 1926, 24 million ha were infected with prickly pear. By 1939 the infestation of prickly pear in Queensland had been reduced by more than 99%. The moth has largely kept the plant under control since then (Landcare Research 1996).

Biological control often works best as part of an integrated weed management programme (e.g. Rees & Hill in press).

5.3 RISKS OF BIOLOGICAL CONTROL PROGRAMMES

5.3.1 Little or no long-term beneficial effects on ecological values

Many of the summaries in Julien & Griffiths (1998) demonstrate that a biological control programme may have little or no long-term effect on the target weed. At the first level, agents may fail to establish, while at the second level the agents may establish but have little or no demonstrable effect on individual host plants. At the third level the agents may damage individual plants but this has little effect on the extent and vigour of target plant populations.

A target weed species may be controlled to some degree by biological control agents, but this may provide little long-term ecological benefits in some protected areas where the target weed is replaced by other weed species. For example, Coffey & Clayton (1988) found that the removal of the introduced aquatic macrophyte lagarosiphon (*Lagarosiphon major*) from a lake may result in its replacement by one or more other exotic weedy macrophytes. Froude & Richmond (1990) found that the relative abundance of four introduced macrophyte weed species (*Lagarosiphon major, Egeria densa, Elodea canadensis,* *Ceratophyllum demersum*) in each of the Rotorua lakes was strongly influenced by which of the four species had been introduced into each lake and how long each species had been there.

Standish (2001) stated that both reducing the biomass of the target weed and preventing re-invasion by other weed species were the biggest challenges for any New Zealand biocontrol programme for wandering Jew (*Tradescantia fluminensis*). Biological control may effectively manage *T. fluminensis* but not the problem of other weeds that are likely to invade with a reduction of *T. fluminensis* (e.g. *Hedychium gardnerianum, Selaginella kraussiana*).

5.3.2 Adverse effects on indigenous species

There is some disagreement as to the extent of the adverse effects of biological control agents on indigenous species. Waterhouse (1998) states that there have been only eight examples of damage to non-target plants, and most of these were predicted by routine testing prior to release of the agents. Simberloff & Stiling (1999) suggest that a number of unspectacular adverse effects may have gone unobserved because of a lack of comprehensive monitoring and the difficulty in demonstrating the cause of a species' decline or extinction. They suggest that other species in a community could also be affected.

There are documented examples of adverse effects on indigenous species. *Rhinocyllus conicus* was introduced into North America for the control of weedy thistles in the genera *Carduus* and *Silybum,* but now attacks many native thistles in the genus *Cirsium*, including rare endemic species (Turner & Herr 1996). This outcome was predicted in the host specificity trials (Pauline Syrett, pers. comm.).

A South American cactus moth *Cactoblastis cactorum* was introduced into the West Indies in 1957 to control the cactus *Opuntia triacantha.* Following its successful establishment it was sent to several other islands, after which it spread naturally to several Caribbean islands including Cuba. Its discovery in the Florida Keys in 1989 was the first record of its establishment in Continental USA. It poses a serious risk to endangered and other rare *Opuntia* species in Florida, and its eventual spread to Texas and Mexico appears inevitable (Bennett & Habeck 1995).

In Hawaii the native plant *Tribulus cistoides* has become rare because of herbivory by seed weevils introduced to control the puncture vine *Tribulus terrestris* (Howarth 1991).

The cinnabar moth (*Tyria jacobaeae*) was introduced into Oregon to control ragwort. It also feeds on a native herb *Senecio triangularis* and reduces seed viability (Diehl & McEvoy 1989).

Sometimes the conservation risks and benefits associated with biological control can be in dispute. For example, the proposed biological control progamme for saltcedars (*Tamarix* spp.) in North America is associated with concern about the wellbeing of an endangered species—the south-western willow flycatcher. Originally this bird species nested in indigenous riparian vegetation. Many western riparian areas are now dominated by introduced invasive saltcedars. The south-western willow flycatchers are now using the saltcedars for nesting, even though they provide inferior habitat compared to indigenous species. A lack of understanding as to why the birds are using the saltcedars has led to a reluctance by endangered-species workers to take action against the shrub, even though it is the main biotic change in the western riparian ecosystems and a primary suspect in the decline of the south-western willow flycatcher (DeLoach et al. 2000).

5.3.3 Potential high costs, unpredictable outcomes, and delays in results

The costs of biological control programmes that do not build on work by other countries can be high. A large programme with multiple agents may cost \$1–2 million, while a programme with a single well-known insect agent may be \$100,000 (Pauline Syrett, pers.comm.).

Because it is not possible to reliably predict the outcomes of a biological control project (Williamson 1999) a sizable initial expenditure may be made with no guarantee of a satisfactory outcome. In commenting on the extreme difficulty of predicting outcomes, Cullen (1992) observes that 'this is a continual source of frustration and a waste of resources, yet attempts to do better are notoriously difficult and make little progress, to the extent that many workers feel it is not worthwhile, preferring to rely on release of the agent as the only valid test of finding whether it will be successful.'

The Australian CSIRO website states that approximately 85% of introduced agents had failed to control the target weed. CSIRO has been undertaking a review of past programmes to identify factors that could improve success rates.

Even where a biological control agent is effective it may take many years for meaningful reductions in weed populations to be achieved. For example, in New Zealand the ragwort flea beetle is only just beginning to reduce ragwort populations, 17 years after the beetle's introduction (Richard Hill, pers. comm.).

5.4 MEASURING THE OUTCOMES OF BIOLOGICAL CONTROL PROGRAMMES

Syrett et al. (in press) describe the ultimate measure of a successful biological control programme as:

> 'following the establishment of control agents, the target weed no longer presents any economic or environmental threats and the weed is under complete and sustained control. It is also necessary that savings generated by the removal of the weed threats are greater than the costs of the biological control programme.'

They observed that the success of a biological control programme is rarely this clear.

It can be difficult to determine the true success of a biological control programme. The effects may be patchy in time and space. While a programme may prevent the target weed from reaching its full potential distribution, it may still allow some range expansion. Sometimes complementary weed management programmes are stopped, and so although the biological control programme constrains the spread of the target weed, there is still an increase in the weed's range.

It is important not to judge a biological control programme too soon after release of the agents and before they have had sufficient time to act. Sometimes, the control initially observed is not maintained. For example, the 'once promising outlook of biological control of gorse (in Oregon) with the spider mite *Tetranychus lintearius* has faded away' because heavy predation significantly reduced the gorse mite numbers (Coombs 1999). Alternatively, biological control agents can take many years to show a demonstrable effect (e.g. ragwort flea beetle in New Zealand).

Sometimes the effects or otherwise of a biological control agent can be masked by external factors such as weather. Myers (1995) reported that, had the areas not been subject to a long-term monitoring programme, an observed decrease in a population of diffuse knapweed (*Centaurea diffusa*) after the introduction of biological control agents may have been misinterpreted as successful biological control rather than a response to a decrease in spring rainfall.

The success of a biological control project can be measured at three levels: whether the agent establishes; whether the agent is damaging the target plant; and whether populations of the target plant are being decreased in extent and vigour.

Olchers & Hill (1999) defined four levels of control that an agent can exert on populations of the target plant:

Complete. No other control measures are needed to reduce the weed to acceptable levels at least in areas where agents are established.

Substantial. Other methods are needed to reduce the weed to acceptable levels, but less effort is required because the weed infestation is reduced in size and/or density.

Negligible. In spite of damage inflicted by agents, control of the weed remains entirely reliant on the implementation of other control measures.

Unknown. Either the release of the agents has been too recent for meaningful evaluation, or the programme has not been evaluated.

The levels of weed reduction needed to achieve 'complete control' may vary depending on the purpose of the control. A substantial reduction in target weed populations would probably be required if the purpose is to eliminate the weed from protected areas. Conversely, a lesser reduction in weed populations may be appropriate if the purpose is to reduce the effect of a weed on water supplies. Many South African biological control programmes seek to reduce woody invasive shrubs to increase water supplies (Zimmerman & Neser 1999).

5.5 FACTORS AFFECTING THE SUCCESS OF BIOLOGICAL CONTROL PROGRAMMES

Plant attributes associated with successful biological control include (Crawley 1989b; Palmer & Miller 1996):

- Genetic uniformity. High genetic uniformity of the weed is important for repeatable and predictable biological control using a single agent (e.g. the widespread successful control of the aquatic plant salvinia (*Salvinia molesta)* by *Cyrtobagous salvinae* (Crawley 1989b; Julien & Griffiths 1998).

- Lack of perennation or dormancy (e.g. salvinia)
- Susceptibility to secondary infection
- Phylogenetic distance from economic species and indigenous flora
- Asexual reproduction. Weeds that reproduce asexually have lower genetic diversity and may be more easily controlled than sexually reproducing weeds (Burdon & Marshall 1981).

Insect attributes associated with successful plant control include:

- Host specificity (Crawley 1989a)
- High intrinsic rates of growth (Crawley 1989a, b)
- They are subject to strong pressures from parasites, predators or competitors in their native habitats (Wapshere 1985).

Crawley (1989a) found that beetles were 'conspicuously more successful than any other insect groups'. Success is not dependent on the number of agents released and one agent can be as effective as several agents (Myers 1985).

While the successful biological control of a weed in one country greatly increases the probability of success in another (McFayden 1998), there are some situations where this does not occur. For example lantana (*Lantana camara* var. *aculeata*) has shown a highly variable response to numerous biological control projects in many countries (Julien & Griffiths 1998).

The risks of a biological control programme can be reduced where there is a good understanding of the target weed's ecology, including the impacts of the potential agents on the demography of the target weed in its country of origin (Kriticos et al. 1999).

Caution is needed when using a biological control agent that feeds on seeds. Several authors recommend confirming that the target weed's seed production is sufficiently limited that the potential agent would reduce target weed populations (e.g. Anderson 1989; Myers 1995; Myers & Risley 2000). Cloutier & Watson (1990) showed that more than 99.5% of the seed production of diffuse knapweed would need to be destroyed to cause the population to decline. Powell (1990) showed that diffuse knapweed was very resilient to biological control agents that decreased seed production and predicted an equilibrium density of 70 rosette plants per square metre with the existing agents.

The purple loosestrife (*Lythrum salicaria*) biocontrol programme in North America demonstrates the importance of comprehensive research investigations before and after agents are released. Purple loosestrife is a wetland perennial weed responsible for the degradation of many important wetlands throughout temperate North America. This programme included a wide variety of concurrent ecological investigations including studies to identify potential natural enemies of the introduced control agents, the importance of genetic inbreeding and founder colony size on insect establishment, patterns and rates of insect dispersal, herbivory effects on the target plant, and plant-insect relationships (Blossey et al. 1996). A standardised monitoring procedure is being used to compare results across the entire distribution of purple loosestrife.

Crawley (1989b) stated that certain plant attributes are associated with the failure of biological control projects. These attributes include rhizomatous perennial growth, low-quality food for insects, and high capacities for recovery after browsing. Crawley (1989a) observes that among perennial plants the most conspicuous failures have come from families such as Gramineae and Cyperaceae. Other reasons for failure include the incorrect identification of the weed and/or the agents and the introduction of agents to environmental conditions to which they are not suited (Crawley 1989b). Sands & Scholtz (1985) give an example of the importance of using the correct agent to control salvinia. The effective agent, *Cyrtobagous salviniae,* tunnels through plant rhizomes, nodes and leaves causing major plant damage, while the closely related weevil, *C. singularis*, feeds externally and has little impact.

Weed species can behave differently in different environments which can limit the transferability of biological control investigations. For example, the aquatic weed hydrilla (*Hydrilla verticillata*) does not form surface-reaching beds in New Zealand and so the terrestrial biological control agents used in Florida and elsewhere would not be successful if introduced here (John Clayton, pers. comm.).

The probability of developing a successful biological control programme may be reduced if the target weed species has close relatives of economic or conservation value. This is because the selected agents must not affect the valued species and so need to be highly host-specific. This can reduce the potential choice of agents.

Smith (2000) suggests using modelling to develop hypotheses about the reasons for the successes and failures of biological control projects. These models attempt to address questions such as:

- How effective will biocontrol be and when will we see some results?
- How many species of control agent should be used and in what order?
- How big should the release of the control agent be?
- Is there a nett benefit from biological control when the invasive species has economic value?
- How can we explain observed weed agent dynamics?
- What is the potential for plant pathogens in biological control?
- How can biocontrol be a component of an integrated pest management programme?
- How does biocontrol affect the spatial distribution of the target weed?

Rees & Hill (in press) provide a New Zealand example of the use of models to predict the outcome of seed-feeding biocontrol agents on gorse abundance for several environmental and management scenarios including fire. These show that to obtain the greatest impact, biological control should be used in association with management practices that prevent or substantially reduce recruitment.

5.6 INTERNATIONAL REVIEWS OF THE SUCCESS OF BIOLOGICAL CONTROL PROGRAMMES

Julien et al. (1984) estimated that for each weed biocontrol programme in a particular country, an average of three or four agents were introduced. Of these, two or three agents became established, but only a fraction of those that established actually controlled the problem weed.

Crawley (1989b) developed a semi-quantitative index to score 627 releases prior to 1980. His assessment suggested that the most successful releases were those that were effective over large areas. Eight of the eleven most successful projects involved the large-scale control of *Opuntia* species. The more recent and regularly successful control of salvinia since 1980 was not included in this review.

Crawley found that the most frequently controlled individual weed species were firstly lantana (*Lantana camara*) and secondly St John's wort (*Hypericum perforatum*). Collectively the *Opuntia* species were most frequently controlled. Ironically, many of the unsuccessful projects were attempting to control the same species as those projects that were most successful (e.g. lantana).

The problems of subjectivity in assessing the success of biocontrol can be reduced by single-country evaluations where the author has good information on all projects and can use the same criteria for assessing them.

Hoffman (1995) developed a set of criteria for evaluating the success of weed biological control programmes in South Africa. He determined that at least 23 of the 40 programmes undertaken before 1990 had been of sufficient duration to evaluate using his criteria. His evaluation showed that 26% (6) of the target weed species were under complete control; 57% (13) were under substantial control; but for 17% (4) of the target weed species control was negligible. Hoffman observed that the figure of 26% for species under complete control was misleading, because three of the species were only minor problems in South Africa, and were subject to biological control only because these weeds were a problem elsewhere and effective biological control agents were already available, while the other three weed species also relied on agents that had been successfully used elsewhere.

Olchers & Hill (1999) updated Hoffman's figures by summarising key attributes of 51 South African biological control programmes. They found that 8 species were completely controlled; 14 species were substantially controlled; 4 species had negligible control; and the outcomes for 21 species were unknown.

As of 1988, there had been 90 introductions of biological control agents into Hawaii to control 21 species of weeds (Gardner et al. 1995). It has been estimated that biological control had been effective in achieving complete control of seven species of weeds and significant partial control of three additional species (Lai 1988).

5.6.1 General trends

The literature review and correspondence with international biological control researchers and natural area managers found few assessments of the long-term effectiveness of biological control programmes for weeds in natural areas.

Email correspondence with practitioners in those countries most active in biological control activities (Australia, Canada, Great Britain, New Zealand, South Africa and United States of America) found that biological control for weeds primarily of natural areas is generally a recent phenomenon. It is too early to identify many of the outcomes.

5.6.2 South Africa

The most thorough assessments of the long-term ecological effects of biological control programmes for weeds of natural areas are for South Africa. Table 1 summarises the outcomes of biological control programmes for four weed species affecting natural areas there. It shows that biological control is not always successful even if substantial resources are committed, and that an integrated approach to weed management is essential.

5.6.3 Queensland, Australia

Terrestrial weeds that affect natural areas and are subject to biological control programmes include rubber vine (*Cryptostegia grandiflora)*, lantana and *Opuntia* species.

Julien & Griffiths (1998) record the 1988 introduction of one agent and a 1994 introduction of the second agent into Queensland for rubber vine. The first agent can cause total defoliation in localised outbreaks, while the second causes repeated defoliation in some locations resulting in variable amounts of damage depending on the weather. The nett effect of this damage on the weed is as yet unclear (Rachel McFayden, Department of Natural Resources, Queensland, pers. comm.).

Julien & Griffiths (1998) also list more than 20 different agents for *Lantana camara* that have been introduced into Australia (including Norfolk Island) from 1914 to 1995. Nine of the agents did not establish, the fate of two of the agents was unknown, 12 agents established and had no effect, and one agent had a partial effect in Norfolk Island. The nett effect of these projects on the weed in natural areas in Queensland is nil (Rachel McFayden, pers. comm.).

In addition, Julien & Griffiths (1998) identify a number of Australian biological control projects for four cactus species in the genus *Opuntia*. Before biological control, *Opuntia* species replaced indigenous understorey flora in brigalow scrubland and adversely affected lands used for economic purposes. The biological control agent *Cactoblastis cactorum* was introduced in 1926. By 1935 it was providing significant control of two varieties of *Opuntia stricta*. Subsequent outbreaks were controlled within a few years. At least 18 other agents have been introduced for *Opuntia* species. The effect of these has been variable including: providing good control until *Cactoblastis* assumed the dominant role; attacking either old or young plants; not located recently; minor or no effect; or did not establish. Ironically, little of the brigalow shrublands now remains in Queensland (Rachel McFayden, pers. comm.).

The aquatic weeds water hyacinth (*Eichhornia crassipes*), salvinia (*Salvinia molesta*) and water lettuce (*Pistia stratiotes*) are subject to biocontrol programmes and there is no chemical control for these species in conservation areas in Queensland. The magnitude of the biocontrol benefits are unknown as there was no measurement of pre-biocontrol impacts of these species.

TABLE 1. OUTCOMES OF BIOLOGICAL CONTROL PROGRAMMES FOR SELECTED WEED SPECIES AFFECTING NATURAL AREAS IN SOUTH AFRICA. (INFORMATION DERIVED FROM HOFFMAN 1995.)

WEED SPECIES AND PROBLEM CAUSED	BIOLOGICAL CONTROL AGENT OUTCOMES	WEED RESPONSE TO BIOLOGICAL CONTROL/SITE OUTCOMES	MANAGEMENT RESPONSE TO BIOLOGICAL CONTROL OUTCOMES
Lantana camara: this is one of the two most invasive weeds in Kruger National Park.	16 species of agents have been released. 6 species have established. Together these species cause substantial damage.	The effectiveness of biological control efforts has been limited because *L. camara* includes a large number of different cultivars, each of which is effectively a distinct weed species. Because the agents are highly specific and survive on one or at most several cultivars this means that susceptible cultivars are replaced by herbivore-resistant cultivars and the weed problem persists.	Agent investigation is continuing.
Opuntia stricta (cactaceous shrub): during the 1980s this was recognised as one of the two most important invasive weeds in Kruger National Park.	One agent which had been used successfully elsewhere was introduced in 1988. The agent established and spread over the *O. stricta* range in Kruger NP in 5 years. Populations of the agent, a moth, seldom reached levels required for larvae to destroy large plants.	Dense infestations of the weed persisted because *O. stricta* can compensate for damage caused by the agent.	In areas treated with herbicides the agent larvae were able to destroy the many seedlings and small plants preventing them from reaching maturity and producing fruit. This led to the curtailment of the long-range dispersal of *O. stricta*. Follow-up treatment of cleared areas is needed less frequently where the agents are present. The revised strategy was to treat well established, dense infestations of the weed with herbicides and to rely on the agent to restrict weed resurgence and spread.
Prosopis sp. (mesquite): was extensively planted in dry NW South Africa to provide shade, a rich source of nectar and pollen, and fodder for stock (seed pods). By the mid 1900s mesquite was invasive in the South African rangelands. Now there is a conflict of interest between farmers and conservationists.	A beetle agent was released in 1987. Within 3 years the beetle has dispersed through the range of the weed. The beetles lay their eggs in the seed pods with each larva feeding on and damaging a seed.	Without appropriate management the beetle has little effect on mesquite. This is because mammalian herbivores eat the pods before beetles can use them.	Beetle damage can be enhanced by fencing off weed infestations between January and September. This minimises livestock and wild herbivores. Seed pods can be fed to the livestock in October. This largely retains the nutritive value of the pods and minimises seed dispersal.
Sesbania punicea is a perennial leguminous shrub. It was introduced as an ornamental in 1850. It started to become a problem in river systems during the 1960s.	3 weevil species were introduced & readily established. 1 species (*Trichapion lativentre*) became widespread. The lower breeding rates and slower dispersal of the other 2 species restricted their distribution.	Each season *T. lativentre* destroys nearly all flower buds so reducing seed production by 98%. Agent *Rhyssomatus marginatus* then destroys 88% of the few seeds produced. Where both agents are present seed production is reduced >99%, i.e. plants are almost infertile. Where both agents are present for over 5 years, seedling recruitment almost ceases. The actions of these 2 agents enhances the effect of the third agent, a stem-boring weevil *Neodipiplogrammus quadrivittatus*. Five years after release, the agent's levels mean that most mature plants are destroyed by weevil larvae.	Where seedling recruitment almost ceases, mechanical removal becomes possible because the removed trees are not replaced. The damage caused by the stem-boring weevil resembles a mechanical control operation—to be effective it relies on a dearth of seeds in the soil.

Julien & Griffiths (1998) identify biological control programme outcomes for these aquatic species. One agent was introduced for water lettuce in 1982. This agent successfully decreased the area occupied by the plant and individual plant size and weight. Three agents were introduced for water hyacinth between 1975 and 1990. The first agent introduced provided good control where there were large infestations and less control where pesticides had been used and where temperatures were cooler. Two agents were introduced for salvinia. One agent provided successful control in coastal areas and elevated tropical and subtropical areas.

5.6.4 Oregon, USA

In natural areas in Oregon there are biological control programmes for leafy spurge (*Euphorbia esula*), ragwort (*Senecio jacobaea*), gorse (*Ulex europaeus*), Scotch broom (*Cytisus scoparius*) and Canada thistle (*Cirsium arvense*). Biocontrol programmes are combined with changed management practices, usually by encouraging plant competition by decreasing grazing rates and time. There has been some success in controlling leafy spurge and ragwort which are the main species that invade undisturbed areas (Eric Coombs, pers. comm.).

Julien & Griffiths (1998) record that 12 agents for leafy spurge were introduced into USA between 1975 and 1993, but several species were not introduced into Oregon. Most species did not establish or were slow to establish in Oregon, but two species were contributing to the decline of the weed. Three agents for ragwort were introduced into Oregon between 1959 and 1966. All agents have had some effect in decreasing ragwort populations, with one species resulting in a 93–99% reduction in the weed in some places.

6. Weeds in New Zealand protected areas

6.1 WEED IMPACTS IN PROTECTED AREAS

6.1.1 On native plants

Plants introduced into New Zealand: are a major threat to nine native plant species that are likely to become extinct in the wild in the immediate future; are one of the main risks to the survival of 61 threatened native plant species; and adversely affect another 16 species (Reid 1998). They also threaten the long-term viability of a number of other indigenous plant species by, for example, hybridisation and fragmenting native plant populations.

Threatened plants affected by weeds are most likely to occur in alpine seepages, wetlands, rivers and lakes, foreshore habitats, dune lakes and sand dune communities (Reid 1998).

6.1.2 On native animals

Introduced plants threaten indigenous fauna by changing and/or removing their habitat. For example, woody weeds such as gorse and broom invade braided riverbeds, destroy open feeding and nesting sites required by native wading birds, and provide cover for predators (Balneaves & Hughey 1990). Introduced plants also reduce indigenous food sources. For example, the spread of the introduced grass browntop (*Agrostis capillaris*) has so decreased the cover of indigenous herbs that few endemic grassland moths can survive (White 1991).

6.1.3 On indigenous biological communities

At least 575 000 hectares of high-priority protected natural areas are threatened in the next 5–15 years if weed invasions are not controlled (Owen 1998). This includes at least: 152 800 ha forest and scrub; 324 200 ha tussocklands, alpine herbfield, native grasslands; 35 700 ha coastal and duneland communities; 21 300 ha freshwater aquatic, wetlands and riparian areas; 11 400 ha coastal wetlands; 4400 ha geothermal areas, drylands, salt lakes, etc.; and 26 200 ha mixed communities.

Invasive plant species threaten the long-term survival of indigenous communities by replacing indigenous species, changing indigenous vegetation structure and composition, altering successional and other natural processes such as nutrient cycling, and changing the habitat for indigenous fauna.

The most vulnerable communities to weed invasion are coastal, freshwater and lowland terrestrial communities, as well as tussock grasslands and shrublands.

Freshwater ecosystems

Alien plants have spread throughout most of New Zealand's rivers and lakes (Howard-Williams et al. 1987) and modified most remaining freshwater wetlands.

The effects of introduced aquatic plants in lakes and rivers include:

- Elimination or displacement of native plant species including threatened species
- Limitation of the distribution of native species in lakes to those deeper sites where sufficient light exists, and shallower more exposed sites
- Removal of the indigenous habitat of many indigenous invertebrates, thereby resulting in the loss of many of these species from some lakes
- Formation of floating mats of invasive weed species that block out light, thereby displacing all indigenous aquatic life in small waterbodies and the indigenous turf communities on the margins of larger waterbodies.

In wetlands and margins of other freshwater bodies, the tall dense growth of some invasive species (e.g. Manchurian wild rice *Zizania latifolia*) can out-compete emergent indigenous species. Even lower-stature introduced plants such as parrots feather (*Myriophyllum aquaticum*) and yellow flag iris (*Iris pseudacorus*) can displace the emergent native plants. Crack and grey willow (*Salix fragilis* and *S. cinerea*) lower water tables, shade other species and choke waterways. For example, willows are destroying the Whangamarino Wetland indigenous sedgelands, which have been reduced from 2800 ha in 1940 to 26 ha in 1993 (West 1994). Strandings of uprooted material from extensive offshore weed beds can result in significant changes to inshore lake biota, including the regular loss of indigenous emergent shoreline species.

Estuarine ecosystems

Spartina (*Spartina* spp.) threatens more than 20 important estuaries and harbours. It destroys the habitat for many invertebrates and the feeding and roosting areas of wading birds, and can displace mangroves (Partridge 1987). In 1997, spartina partially covered or threatened three-quarters of the Manawatu Estuary mudflats (Owen 1998).

Coastal and duneland communities

Coastal communities have been extensively fragmented and weed invasions are an ongoing threat to coastal cliff, dunelands (including dune swales) and rocky supra-tidal areas.

Marram grass (*Ammophila arenaria*), although still planted to stabilise dunes, completely displaces native plant species (including threatened species) and facilitates the invasion of woody weeds such as gorse. There are a wide variety of other weed species that invade the naturally low-stature communities of dunelands.

Forests and scrub

Owen (1998) identifies more than 111 high-priority protected forest and shrubland areas that are threatened with weeds. Vines smother trees and understorey plants. For example, in parts of the Manawatu and Rangitikei, old man's beard (*Clematis vitalba*) has obliterated all but the largest trees; and in Taihape Scenic Reserve old man's beard has caused the local loss of at least four threatened plant species (West 1992). While many vine species start with canopy openings and edges, shade-tolerant vines (e.g. climbing asparagus *Asparagus scandens*) can invade intact forests.

Ground cover and sprawling plants, e.g. wandering Jew (*Tradescantia fluminensis*) and mist flower (*Ageratina riparia*), can form dense mats that prevent indigenous seedlings growing. Shade-tolerant introduced trees can grow rapidly after disturbance to out-compete native species. Many introduced understorey plant species can displace indigenous plant species, e.g. wild ginger (*Hedychium* spp.).

Introduced plant species frequently change scrub successional processes, and the scrub species' composition and structure.

Tussock grasslands

Wilding pines threaten more than 260 000 ha of tussock and alpine protected areas in the next 10–15 years if left uncontrolled (Owen 1998). This includes much of Tongariro National Park as well as a number of other locations. In the Red Hills in Marlborough, dense stands of wilding conifers currently cover about 450 hectares. If left, these stands could rapidly spread and dominate about 18 000 ha of indigenous tussocklands and shrublands.

Other trees and woody species that are major threats include heather (*Calluna vulgaris)*, broom and gorse. Heather is the most widespread and invasive weed in Tongariro National Park and is spreading at up to 7 km/year. It has greatly reduced the native plant cover in tussocklands, alpine herbfields and frost flats; and reduced the diversity of native insects, with some species in danger of becoming locally extinct (Chapman & Bannister 1990). Although primarily a problem in grazed South Island hill country, hawkweeds (*Hieracium* spp.) can adversely affect protected natural areas, particularly in the Central North Island and the hill country east of the Main Divide in the South Island.

Marine communities

About 20 naturalised marine macroalgae have been identified. To date, only undaria (*Undaria pinnatifida*) has been identified as posing a significant risk. It grows in waters from low intertidal to shallow subtidal and has spread to a number of sheltered waters including Wellington Harbour, Porirua Harbour, the Marlborough Sounds, and Big Glory Bay (Stewart Island).

Islands

A survey of 60% of New Zealand's islands found only 25% to be free of weed problems (Atkinson 1997). The number of weed species and their impact on offshore islands is steadily increasing in northern and central offshore islands and weeds are invading important wildlife refuges (e.g. Kapiti and Poor Knights Islands) and unique islands (e.g. Little Barrier and Rangitoto Islands).

Little Barrier Island contains endemic species and 21 forest types as well as being an extremely important wildlife refuge. Between 1978 and 1990, climbing asparagus has spread from a small infestation to be present in 100 hectares. It is capable of invading and killing the entire understorey in most, if not all, of the Island's lower forests (Veitch 1996). Other weeds such as moth plant (*Araujia sericifera*) have also reached the Island.

6.2 LIST OF WEED SPECIES THAT INVADE PROTECTED AREAS

Owen (1997) compiled a database of weeds on conservation land in New Zealand. This list is used for the tables in Appendices 1 and 2.

Appendix 1 provides an indicative assessment of the scale of the weed problem in New Zealand protected areas. For each of the more than 240 weed species listed, there is a series of weediness scores from Owen (1997), and year 2000 scores by DOC conservancies on weed impact and difficulty of control. The explanation for these scores is in Appendix 1.

6.3 CONTEXT FOR DOC'S WEED MANAGEMENT

DOC manages weeds in protected areas throughout New Zealand. This includes marine, freshwater and terrestrial environments covering the full latitudinal and altitudinal range of New Zealand, including its many offshore islands. As the Department manages approximately one third of New Zealand's land area, it needs to be concerned about a wider range of weed species than other New Zealand land and water managers.

The statutes under which the Department works under require it to protect indigenous flora and fauna and their habitats. Appendix 4 contains a selection of relevant legislative provisions. These legislative provisions place high requirements on the Department to control invasive weed species as part of protecting indigenous flora and fauna and their ecosystems. Other New Zealand agencies are responsible for biosecurity generally. The Ministry of Agriculture and Forestry administers the Biosecurity Act 1993 and prepares national pest management strategies. Regional councils prepare regional pest management strategies under the Biosecurity Act 1993.

The Department's strategic plan for managing invasive weed species (Owen 1998) contains the following objectives:

1. To minimise the risk of introductions of new plant taxa that are potentially invasive, or new genetic stock likely to significantly increase the adverse effects of established plants.
2. To minimise the numbers, or contain the distribution, of new invasive weeds where this is feasible.
3. To protect land, freshwater and marine sites that are important to New Zealand's natural heritage from the impacts of invasive weeds.
4. To sustain and improve the essential skills, control techniques, information and relationships that support DOC's management of invasive weeds in the long term.
5. To maintain and improve the quality of DOC's weed management systems.

The plan focuses on two strategic approaches to invasive weed management: weed-led management and site-led management.

6.3.1 Weed-led management

The purpose of weed-led control programmes is to prevent new invasive weed species invading a conservancy or spreading beyond a limited distribution. Weed-led programmes focus on species with a limited distribution and/or low numbers within the programme's defined area, but which have the potential to significantly increase their numbers, distribution and impact. This includes plant species that:

- are present in New Zealand but not yet naturalised
- have only recently become naturalised and are starting to spread
- have an isolated distribution, or one confined by environmental requirements
- are well established in some regions but are beginning to invade an adjacent conservancy.

Once a species has become well-established and relatively widespread, eradication or containment is rarely feasible. Examples of 1998 weed-led programmes are: eradicating hornwort (*Ceratophyllum demersum*) and cathedral bells (*Cobaea scandens*) from the Wairarapa Plains; eradicating boxthorn *(Lycium ferocissimum*) and spartina from Southland; preventing *Glyceria maxima* and *Lagarosiphon major* from establishing in Southland; and preventing marram grass from invading Fiordland National Park. Most of the Southland programmes involve the Southland Regional Council.

6.3.2 Site-led management

The purpose of site-led programmes is to protect the quality and integrity of the natural values within a particular place. The focus is a management unit with high natural values. A management unit may be an entire protected area, a collection of reserves close to each other, or a subset of a larger protected area. Site-led programmes usually involve widespread weed species, but can include species within, or about to invade, the management unit which have the potential to significantly alter the management unit values. In site-led programmes it is common for a number of weed species to be controlled, and for actions to be taken to prevent re-invasion by the weed species removed or by alternative weed species.

6.4 BIOLOGICAL CONTROL AND DOC

Sections 5.2 and 5.3 discussed the benefits and risks of biological control programmes, especially for weeds of natural areas. Section 5.4 discussed measuring outcomes of biological control programmes and section 5.5 discussed factors affecting the success of biological control programmes. These sections are all relevant in a consideration of the role of biological control in the Department's weed management strategy.

It is important to distinguish between weed-led and site-led management.

The 'prevention of invasion or spread beyond a limited distribution' purpose of weed-led management provides limited opportunities for biological control, unless the species is also being controlled for other purposes in other areas. This is because eradication and containment objectives usually seek the rapid removal of all material of the species concerned.

Biological control programmes are usually longer term (section 5.3.3), their outcomes are usually not predictable (section 5.3.3) and they do not usually remove all plant material as the agent would die out. It is, however, recognised that other management options can be used to supplement biological control, and this has been shown to improve outcomes (e.g. Hoffman 1995).

Protecting the quality of natural values for identified sites is the focus of site-led management. This involves many different species at many different types of sites from throughout New Zealand. It is also important to prevent re-invasion by both the species removed and other species that are able to grow on the site. Section 5.3.1 discusses the problem of reinvasion by other species after the successful control of the existing problem species. This is likely to limit the ecological effectiveness of biological control (or other) programmes targeted at single weed species in sites where such substitution is likely.

Biological control could contribute to some site-led weed management because of the long-term nature of some projects and the associated ongoing costs of conventional control.

The costs of biological control programmes (section 5.3.3) mean that they could contribute to the control of relatively few of the species of concern. This would not remove the need for conventional control for the other weed species affecting a site either at the same time or following the removal of the initial 'target weed'. The unpredictable nature of biological control programmes and the potentially long time before the target weed populations respond to the biological control agents (section 5.3.3) are other factors that need to be considered.

Where other agencies (e.g. regional councils) are interested in biological control of weed species of concern to the Department, this provides opportunities for cost sharing. This could improve the attractiveness of some potential biological control programmes.

There are some weed species of major concern to the Department, that others still find useful (e.g. marram grass). It is likely to be difficult to proceed with biological control programmes for such species at this time.

The probabilities of developing a successful biological control programme for weed species with close relatives of economic or conservation value in New Zealand may be reduced (section 5.5).

All applications to import and/or release a biological control agent into New Zealand require permission from the Environmental Risk Management Authority (ERMA) under the Hazardous Substances and New Organisms Act 1996. It would be the resonsibility of the funding agencies to obtain this approval. Applicants are required to provide a comprehensive risk assessment that addresses a wide range of ecological, social, cultural and public health matters.

The process for developing a classical biological control programme in New Zealand, especially where there are no international leads, could take 8–10 years (McGregor & Gourlay 2001). It includes: identifying and studying the ecology of potential biological agents; studying the ecology of the weed in its native range compared to New Zealand; determining the host range of potential biological control agents (done outside of New Zealand); obtaining approval from ERMA to import agents into quarantine for further host range testing; obtaining further approvals from ERMA once host range testing has been completed in order to release any suitable agents into New Zealand; and cage rearing of approved agents to ensure that the founding individuals contain no diseases or parasitoids.

6.5 SUMMARY OF NEW ZEALAND AND INTERNATIONAL BIOLOGICAL CONTROL PROJECTS

Appendix 2 summarises known biological control projects for species listed in the DOC ecological weed database (Owen 1997). It identifies the number, location and stage of biological control projects, and outcomes where these are known.

In this biological control summary, a project is defined as the investment, testing and introduction of a particular agent for a problem plant species in one country. Where there are multiple introductions over several years of the same agents in the same country this is also treated as one project. A biological control programme is a suite of projects collectively intended to address a problem plant. Many programmes use more than one agent, often addressing different parts of the plant or plant life cycle.

7. New Zealand biological control programmes and investigations

7.1 OUTCOMES

Fowler et al. (in press) considered that only six New Zealand weed biological control programmes were sufficiently advanced to be assessed for their effectiveness. Of these, one species was judged to be under complete control, four were under partial control, and control was negligible for one species.

7.2 WEED SPECIES

For each of the weed species listed below, one or more biological control agents have been introduced into New Zealand and one or more of these agents have become established (with one exception).

- alligator weed *Alternanthera philoxeroides*
- broom *Cytisus scoparius*
- Californian thistle *Cirsium arvense*
- gorse *Ulex europaeus*
- hawkweeds *Hieracium* spp.
- heather *Calluna vulgaris*
- Mexican devil *Ageratina adenophora*
- mist flower *Ageratina riparia*
- nodding thistle *Carduus nutans*
- old man's beard *Clematis vitalba*
- piripiri *Acaena anserinifolia* (agent not established)
- ragwort *Senecio jacobaea*
- Scotch thistle *Cirsium vulgare*
- St John's wort *Hypericum perforatum.*

New agents are being studied for some of these weeds.

Biological control feasibility studies have been completed for:

- boneseed (*Chrysanthemoides monilifera)*
- banana passionfruit *Passiflora mollissima*
- Chilean needle grass *Nassella neesiana*
- nassella tussock *N. trichotoma*
- climbing asparagus *Asparagus scandens* (with some information on *A. asparagoides)*
- wild ginger *Hedychium* spp.
- woolly nightshade *Solanum mauritianum*

- moth plant *Araujia sericifera*
- pampas grass and purple pampas *Cortaderia* spp.
- privet *Ligustrum* spp.
- variegated thistle *Silybum marianum*
- wilding pines *Pinus* spp.
- lagarosiphon *Lagarosiphon major.*

Reasons for selection of weeds of conservation concern for initial biological control feasibility studies are given in Appendix 3. Summaries of those feasibility studies that address some invasive weed species of protected areas are in Appendix 5.

Biological control feasibility studies/investigations are proceeding for buddleia (*Buddleja davidii*), blue morning glory (*Ipomoea indica*) and barberry (*Berberis* spp).

Surveys for insect fauna on, or affecting, the target weed in New Zealand have been/are being completed for:

- boneseed *Chrysanthemoides monilifera*
- Chilean needle grass *Nassella neesiana*
- nassella tussock *Nassella trichotoma*
- banana passionfruit *Passiflora mollissima.*

Investigations looking for new potential biocontrol agents overseas are beginning for (Pauline Syrett, pers. comm.):

- boneseed
- woolly nightshade
- blackberry (*Rubus fruticosus* agg.).

There are also several self-introduced biological control agents: e.g. hemlock moth and blackberry rust.

8. Prioritising weed species for DOC-sponsored biological control investigations

8.1 PROCESS FOR ASSESSMENT

As so many weed species are of concern, the Department needs to be able to systematically assess the suitability of particular weed species for biocontrol investigations.

A three-stage assessment process is proposed as follows:

- Initial assessment criteria. The flowchart (Fig. 1) was designed to quickly identify: whether major issues need to be addressed, especially with other agencies; and the first group of weed species for which biological control investigations should be a low priority.

- Detailed questions. These identify the information that should be collected for each weed species before a decision is made to commit resources to biological control investigations.
- Comparative evaluation. This uses selected information collected in the second stage of assessment to identify priority species for biological control investigations. The evaluation uses qualitative scores to allow comparisons using different types of information.

8.2 INITIAL ASSESSMENT CRITERIA

Use Fig. 1 for initial assessment criteria in stage 1.

8.3 DETAILED ASSESSMENT QUESTIONS

Table 2 lists the detailed questions that should be addressed in stage 2 of the assessment process. This is primarily an information collection phase designed to ensure that decisions are based on comprehensive information.

8.4 COMPARATIVE EVALUATION

Table 3 lists the stage 3 factors and scorings to assist in the determination of priorities for biological control investigations. This stage uses selected information collected in stage 2 of the assessment process.

It is recommended that an expert panel be used to fine-tune the relative weightings between the different factors and to score weed species of concern.

The expert panel should contain the appropriate expertise to ensure that currently widespread but less damaging weeds do not score more highly than more damaging species that currently have a limited distribution. It should also contain appropriate aquatic expertise and be familiar with the issues associated with biological control programmes in aquatic systems. For example, in lakes which are about to become eutrophic, the aquatic weed *Lagarosiphon major* (lagarosiphon) can stabilise lake sediments and absorb nutrients from the water, thereby reducing the nutrients available for algal blooms (John Clayton, pers. comm.). A decrease in lagarosiphon vigour in these situations would not be helpful.

The qualitative scores of Table 3 are summed to give a total for each species evaluated. Those species with the highest scores would generally be the highest priorities for the Department to investigate biocontrol options.

It is important to remain flexible. It may be useful to become involved in a project for a lower-scoring species if there is a lot of leverage provided by other parties. Alternatively, one factor (e.g. strong opposition from key sector groups) may mean that it would not be worthwhile to investigate biological control options for a high-scoring species.

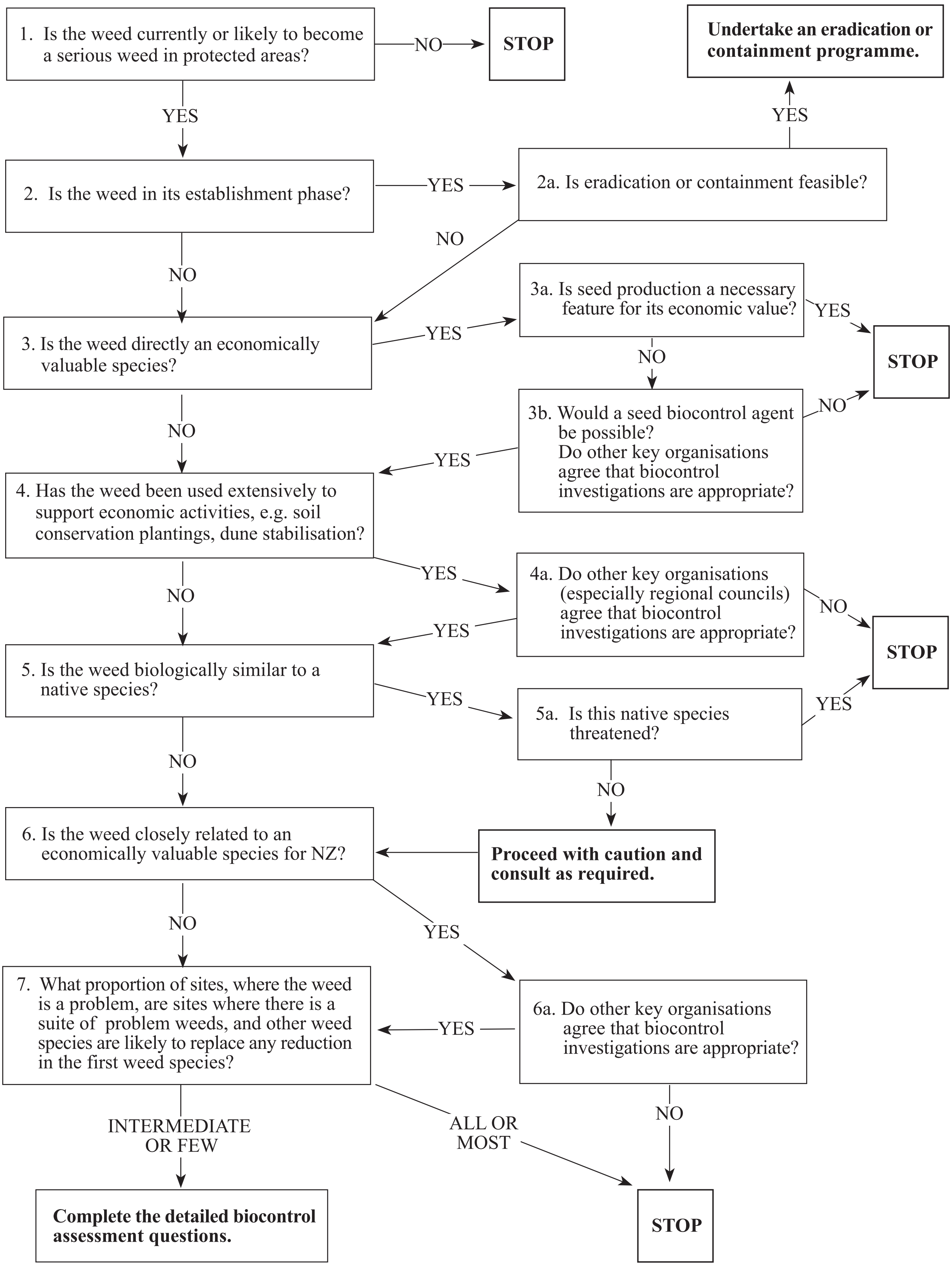

Figure 1. Initial assessment flowchart: Should DOC investigate biocontrol for a particular weed species?

TABLE 2. DETAILED QUESTIONS TO ASSIST DOC IN DECIDING WHETHER TO INVESTIGATE BICONTROL OPTIONS FOR PARTICULAR WEED SPECIES.

Weed population dynamics

- What is the *biological success rating* score (ex Owen 1997)?
- What is the current distribution and density of the weed?
- How does the weed's current distribution compare with its potential distribution in New Zealand?
- Are there significant areas of infestation outside of DOC protected areas?
- How does the weed spread?
- How fast is the weed spreading?
- What is the native environment of the weed and what is known about what limits the species in its native environment?
- What extent of genetic variation is there in this species?

Impacts of the weed

- What is the *effect on system* score (ex Owen 1997)?
- What ecological communities does the weed invade?
- What are the current impacts of the species and how serious are these impacts?
- What are the projected impacts of the species?

Controlling the weed

- What level of control would meet conservation management objectives for this species generally and/or for the sites on which it occurs (i.e. what density of weed would make difference)?
- What is the effectiveness and cost of non biological control methods for the weed including existing control methods?
- What are the characteristics of the weed that make it difficult to control?
- Are other agencies involved in controlling this weed?

Existing biological control knowledge/interest

- Are other agencies investigating or interested in investigating biological control for this species?
- Are there any agents for this species in New Zealand?
- Has the weed been a target of a biological control programme in another country? How successful was that programme?
- Has the weed been a target of biological control investigations in another country? How promising are those investigations?
- Are there biological control programmes or investigations for closely related species in another country?

Costs

- What are the likely costs of a biocontrol programme for this weed?
- Who may contribute to funding these costs?

Likelihood of success

- What are the attributes of the weed that will facilitate, or militate against, biocontrol success?
- How phylogenetically distinct is the plant from indigenous and economically valuable species?
- Is there likely to be opposition to a biocontrol programme for this species?

TABLE 3. RANKING FACTORS FOR COMPARATIVE EVALUATION OF THE SUITABILITY OF PARTICULAR WEED SPECIES FOR BIOLOGICAL CONTROL INVESTIGATIONS.

	SCORES 'WORST'	'BEST'
The weed		
What is the 'biological success rating' score?	Low = 1	High = 5
What is the current distribution/density?	Low = 1	High = 5
How does the weed distribution (and density) compare to the potential?	Low = 1	High = 5
What is the rate of spread?	Low = 1	High = 5
Impacts		
What is the 'effect on system' score?	Low = 1	High = 5
How serious are the impacts of the weed?	Low = 1	High = 10
To what extent would natural successional processes in protected areas address the impacts of this weed in the sites where it occurs?	Significantly = 0	Not = 5
Control		
How effective are existing and alternative non-biological control methods?	High = 0	Low = 5
How expensive are existing and alternative non-biological control methods?	Low = 0	High = 5
If biological control significantly reduces the extent/vigour of a target weed how likely is site reinvasion by other weed species?	High = 0	Low = 10
Biological control		
To what extent would other agencies be likely to support biological control investigations and implementation?	Not = 0	Active = 10
Have there been overseas successful biocontrol programmes or investigations for this species?	No = 0	Successful = 5
How phylogentically distinct is the weed from economically valuable species or (threatened) indigenous species?	Low = 0	High = 5
Total	6	80

Note: The score weightings would need to be refined by an expert panel.

9. Initial biological control feasibility assessments for selected weed species

9.1 *ANREDERA CORDIFOLIA* (MADEIRA VINE)

9.1.1 Background

Madeira vine is from South America and is established in the wild in coastal areas in New Zealand from North Auckland to Hawke's Bay, the Manawatu and the Canterbury Port Hills. It does not produce fruit in New Zealand, but spreads from pieces of rhizome and stem tubers. Madeira vine has an *effect on system* score of 8 and *biological success rating* of 9 with a total score of 25 (Owen 1997). The lack of seed production and the absence of seedbanks depresses its biological success rating. Two out of 13 conservancies identified it as one of their 10 highest environmental impact weeds and three conservancies ranked it as one of 10 most difficult species to control.

9.1.2 Potential agent specificity

There are no New Zealand native members of the family Basellaceae. This makes it easier to find agents that will not damage indigenous species.

9.1.3 Potential biological control agents and biological investigations by other agencies

There are no obvious insect or pathogen candidates for Madeira vine (Pauline Syrett and Adrian Spiers, pers. comm.). There have been no biological control programmes for this species and there appear to be no other agencies involved in related biological control investigations.

9.1.4 Analysis and recommendations

At this stage it appears that DOC may need to fund the entire investigation which, given the lack of leads, could be expensive. Chances of agent specificity are reasonable as there are no other family members in New Zealand.

This species should be assessed using the revised detailed assessment and evaluation criteria (sections 8.2 and 8.3). It is recommended that the Department investigate what weed species might replace Madeira vine, if it is reduced by biological control agents. If Madeira vine were to be frequently replaced by other invasive weeds this would lower its attractiveness for biological control investigations. It is also suggested that there be an assessment of range containment options if any still exist.

9.2 *CORTADERIA SELLOANA* (PAMPAS GRASS) AND *C. JUBATA* (PURPLE PAMPAS)

9.2.1 Background

These two *Cortaderia* species from South America are widespread and a problem for both plantation forestry and protected areas. McGregor (2000a) states that although *C. jubata* is currently less widespread it may have greater invasive potential because it is self-fertile. Both *C. selloana* and *C. jubata* have an *effect on system* score of 7 and a *biological success rating* score of 14, giving a total score of 28 (Owen 1997). These species were ranked as two of the top 10 weed species for impact on the environment by five conservancies, and as two of the top 10 weed species for being difficult to control by four conservancies. The score of nine in column 8 in Appendix 1 was the highest ranking, matched only by *Tradescantia fluminensis* (wandering Jew) and *Lonicera japonica* (Japanese honeysuckle).

9.2.2 Agent specificity

There are five endemic *Cortaderia* species in New Zealand. This means that any potential agents would need to be highly host-specific. Pathogens are the most likely source of any biological control agents, as few host-specific insects feed on grasses (Pauline Syrett, pers. comm.).

9.2.3 Potential biological control agents and biological control investigations by other agencies

A biological control feasibility study for *Cortaderia* spp. found that the prospects for a classical biological control programme for pampas grasses in New Zealand appeared poor (McGregor 2000a).

Both *Cortaderia jubata* and *C. selloana* are serious weeds in several countries, including Australia and the USA where there are no native *Cortaderia* species. McGregor (2000a) suggests that those countries might collaborate in a survey of pampas grass in its native environment to identify pathogens that are sufficiently host-specific. He considered that there was a small chance of finding a suitable South American rust or smut fungus.

Adrian Spiers (pers. comm.) identified 49 species records from the Fungus Host Distribution Database for *Cortaderia* species from New Zealand, South America and the USA. There are 17 fungal records specifically for *Cortaderia selloana*. Of the pathogens recorded on *C. selloana*, only *Fusarium graminearum* is pathogenic and potentially suitable for biological control. There are also fungal records for the New Zealand *Cortaderia* species as well as some fungi which affect *Cortaderia* species generally. This includes an unidentified species of *Fusarium* on an unidentified species of *Cortaderia*.

Adrian Spiers recommends that the most useful approach would be to request North American researchers to look out for dying plants of *C. selloana* in the hope of obtaining an aggressive strain of *Fusarium*.

9.2.4 Analysis and recommendations

There are no biological control programmes in other countries for pampas greass or purple pampas. Landcare Research has prepared a feasibility study for both species (McGregor 2000a). This study is pessimistic about the chances of finding a suitable biological control agent for either species and considered that such an agent would need to be a fungus.

It may be worthwhile to ask North American researchers to identify an aggressive strain of *Fusarium graminearum*. There would, however, need to be extensive host-specificity testing of this species to ensure that the fungus did not affect the five endemic *Cortaderia* species.

If the Department wishes to proceed with any investigations on introduced *Cortaderia* species, it should seek collaboration with other New Zealand and international organisations. The successful control of introduced *Cortaderia* species would provide benefits to a wide range of interests, including forestry companies. Such work should probably involve both introduced *Cortaderia* species.

9.3 *LAGAROSIPHON MAJOR* (LAGAROSIPHON)

9.3.1 Background

Lagarosiphon major is from southern Africa and now occurs in lakes, rivers and streams throughout all the North Island and much of the South Island. Southland Regional Council has a programme to prevent *Lagarosiphon major* from establishing in Southland (Owen 1998).

Lagarosiphon has an *effect on system* score of 8 and *biological success rating* score of 11 with a total score of 27 (Owen 1997). It reproduces asexually in New Zealand. The lack of seed production and the absence of seedbanks depresses its *biological success* score. Three out of 13 conservancies ranked this plant as one of 10 weed species that has the most environmental impact in their conservancy, and three conservancies ranked it as one of the 10 most difficult weed species to control.

In parts of the North Island, lagarosiphon often occurs in association with one or more other invasive aquatic weeds such as *Egeria densa* (egeria), *Elodea canadensis* and *Ceratophyllum demersum* (hornwort). Of these four species, egeria and hornwort have the most pronounced adverse environmental effect although they are much less widely distributed than lagarosiphon or *Elodea.*

Lagarosiphon scored highly with conservancies because it is now so widespread. In the South Island and parts of the North Island it is the main invasive weed species present in many lakes and rivers.

Where either egeria or hornwort is present, these species tend to replace lagarosiphon throughout much of its depth range (John Clayton, pers. comm.). Both of these species are increasing their range, although in the case of hornwort, there is a programme to prevent it from reaching the South Island.

In shallow lakes where there is a strong risk of algal blooms and ecological collapse caused by eutrophication, members of the Hydrocharitaceae (e.g.

lagarosiphon or egeria) can be beneficial (John Clayton, pers. comm.). In the absence of native plants these weed species stabilise the sediments and absorb nutrients from the water column. Examples of lake ecological collapses include Lakes Waikare and Omapere.

9.3.2 Agent specificity

There are no indigenous plant species in the family Hydrocharitaceae, which also includes *Egeria*.

9.3.3 Potential biological control agents and biological control investigations by other agencies

While Julien & Griffiths (1998) identify various grass carp projects for lagarosiphon and other invasive weeds, this is not host-specific classical biological control. This is because grass carp eat a variety of plant species including, and often especially, desirable indigenous plant species.

There are no true biological control programmes in other countries for lagarosiphon and there is no information in New Zealand about potential biocontrol agents.

9.3.4 Analysis and recommendations

Lagarosiphon in its native southern Africa is much smaller and less vigorous than in New Zealand.

While it has naturalised in other countries it appears to be a troublesome weed solely in New Zealand (Paul Champion, pers. comm.). This would mean that any biological control investigations would need to be fully funded by New Zealand. Given the lack of leads this could be expensive.

McGregor & Gourlay (2001) concluded that 'prospects for biological control of lagarosiphon are difficult to assess because so little is known about the plant in its native range. Natural enemies of the plant undoubtedly exist … There is doubt, however, over the desirability and consequences of such a programme.' They recommended that, 'In view of the more serious threats posed by other freshwater macrophytes such as *Ceratophyllum demersum,* the appropriateness of committing resources to a biological control programme for lagarosiphon be re-evaluated.'

9.4 *LONICERA JAPONICA* (JAPANESE HONEYSUCKLE)

9.4.1 Background

Japanese honeysuckle originates from eastern Asia and was first recorded in New Zealand in 1926. Today it is common in and around disturbed forest in much of New Zealand except in the southern South Island. As it is an attractive climber when flowering, many people do not attempt to control it on their properties. Japanese honeysuckle received a total *effect on system* score of 9, *biological success rating* score of 13 and a total score of 31 in Owen (1997). Seven out of 13 conservancies identified the species as one of the 10 weed species that have the most environmental impact in their conservancy and three conservancies ranked it as one of the 10 weed species that are the most difficult to control.

9.4.2 Agent specificity

It is likely that the introduction of biological control agents would result in some damage to cultivated species. A US study showed that indigenous insects caused more damage to the native *Lonicera* than to the weedy introduced *Lonicera*. (Pauline Syrett, pers. comm.).

In the family Caprifoliaceae, there is one New Zealand genus, *Alseuosmia*, with eight species.

9.4.3 Potential biological control agents and international biological control work

There are no known international biological control programmes for Japanese honeysuckle. Several pathogens of *Lonicera* are established in New Zealand but none of these appears to be causing serious damage to Japanese honeysuckle (Pauline Syrett, pers. comm.).

Adrian Spiers (pers. comm.) has identified 42 fungal species records for Japanese honeysuckle on the Fungus Host Distribution Database. He identified 10 as pathogens that could make good biological control candidates.

Japanese honeysuckle is a potential target for biological control in southern USA. Biological control investigations could become more viable if a field survey into the native range of the weed was jointly supported by New Zealand and US agencies (Pauline Syrett, pers. comm.).

9.4.1 Analysis and recommendations

Japanese honeysuckle is of major concern throughout much of New Zealand. As it often occurs in disturbed forests and forest remnants with other weedy species, it would be important to clarify that any decrease in its vigour resulting from biological control would provide sufficient ecological benefit to the Department's site-led weed management programmes.

A decrease in Japanese honeysuckle would benefit disturbed forests and forest remnants generally although many of these are not subject to a Departmental site-led weed management programme and/or are not on land administered by the Department. Accordingly, any biological control investigations should be done in association with other agencies (especially regional councils) in New Zealand and the USA should they decide to proceed with biocontrol investigations for Japanese honeysuckle.

If biological control investigations are pursued the pathogens identified by Adrian Spiers (pers.comm.) could be worth investigating. Host-specificity testing would be required to avoid any risks to the eight indigenous *Alseuosmia* species.

9.5 *SALIX CINEREA* (GREY WILLOW)

9.5.1 Background

Grey willow was first recorded in New Zealand in 1925. It is a shrub or small tree that grows to 7 m in height, although it is often 1–2 m. Grey willow occurs extensively in swamps, along river banks and in the wetter areas behind coastal dunes, where it is often the dominant plant species, forming a continuous canopy that replaces low-stature indigenous vegetation. It is widely distributed from North Auckland southwards, especially in the Waikato, Bay of Plenty and the eastern South Island. Grey willow has been planted extensively for water and soil conservation.

Grey willow received an *effect on system* score of 9 and *biological success rating* score of 14 with a total score of 32. This was one of the highest scores in Owen (1997). Seven of 13 conservancies identified it as one of the 10 weed species that have the most environmental impact in their conservancy.

9.5.2 Agent specificity

Eleven of the 300–500 species of *Salix* and five hybrids are naturalised in New Zealand. There are no known native species that are close relatives of grey willow. Many willow species in New Zealand are or have been used for commercial purposes including water and soil conservation.

9.5.3 Potential biological control agents and biological control investigations by other agencies

There are no known biological control programmes in other countries for grey willow. There are a number of generalist insects that have been recorded feeding on various willow species in New Zealand. The two specialised willow feeders established here are the willow gall sawfly and a recent introduction of another gall-making sawfly that is severely defoliating willow trees (Pauline Syrett, pers. comm.). There is extensive literature addressing pests and diseases of willow species.

Adrian Spiers (pers. comm.) has identified 40 fungal species records for grey willow in the Fungus Host Distribution Database. He suggests that five species could be considered for biological control. The fungus *Chondrostereum purpureum*, which can cause extensive stem die back when it is inoculated into willow stems, is already present in New Zealand.

9.5.4 Analysis and recommendations

Grey willow is widely recognised as an ecological problem for aquatic habitats and was viewed as one of the most serious weeds in terms of impact by many conservancies. As it often forms a continuous canopy replacing lower-stature indigenous vegetation, a reduction in its vigour could provide significant ecological benefits. Grey willow has been extensively planted for water and soil conservation and is still planted in some areas. It is suggested that the Department seek a general agreement from regional councils that biological control investigations for grey willow are appropriate (see initial assessment criteria in Fig.1).

There are a number of possibilities for biocontrol agents, especially fungal species. If regional councils support biological control investigations in principle for grey willow it would be worthwhile to carry out a literature search, and possibly a feasibility assessment for pathogens identified by Adrian Spiers. The Department would need to be prepared to be the sole funder for the programme.

9.6 *SALIX FRAGILIS* (CRACK WILLOW)

9.6.1 Background

This species was first recorded in New Zealand in 1880. It is now widely distributed on both main islands, Stewart Island and the Chatham Islands. Crack willow grows up to 25 m high and occurs along lake, river and stream margins, in ponds and other wet areas. Crack willow adversely affects ecological values by changing the natural character of waterbodies, displacing indigenous plant species, and changing habitats for indigenous fauna. It regenerates readily from brittle, easily broken shoots, thereby blocking streams and drains. Crack willow has been planted for soil and water conservation.

Crack willow received an *effect on system* score of 9 and *biological success rating* score of 10 with a total score of 28 (Owen 1997). Six out of 13 conservancies identified crack willow as one of 10 weed species that have the most environmental impact in their conservancy.

9.6.2 Agent specificity

See grey willow.

9.6.3 Potential biological control agents and biological control investigations by others

See grey willow.

Adrian Spiers (pers. comm.) has identified 89 fungal species records for crack willow in the Fungus Host Distribution Database. He suggests that eight fungal species and two genera could be considered for biological control. The fungus *Chondrostereum purpureum*, which can cause extensive stem die-back when it is inoculated into willow stems, is already present in New Zealand. Walls (1990) notes that this was the only biocontrol agent for willow that received permission for use in Canada.

9.6.4 Analysis and recommendations

Crack willow is widely recognised as an ecological problem for aquatic habitats and was viewed as one of the more serious weeds in terms of impact by many conservancies. A reduction in its vigour could provide significant ecological benefits. Like grey willow, crack willow has been extensively planted for water and soil conservation. It is unclear what council attitudes are to existing plantings. At present some plantings are removed by councils when they clog up waterways and cause flooding. As with grey willow, it is suggested that support from regional councils be sought before biological control investigations are undertaken.

There are a number of possibilities for biological control agents, especially fungal species. If a biocontrol investigation proceeds it should start with a literature search, and possibly a feasibility assessment for pathogens identified by Adrian Spiers. The Department may need to be prepared to be the sole funder for the programme.

9.7 *TRADESCANTIA FLUMINENSIS* (WANDERING JEW)

9.7.1 Background

Wandering Jew was first recorded in New Zealand in 1916 and is now widely established, especially in frost-free locations throughout the North Island and locally in the South Island. It has also naturalised in eastern Australia, Spain, Russia, south-eastern USA, and is considered an agricultural weed in its native South America (Standish 2001).

Once wandering Jew is introduced to a site, the available light is the main factor limiting its spread and distribution (Kelly & Skipworth 1984). Drought may also limit biomass accumulation (Standish et al. in press). Its greatest impact on forest regeneration occurs at forest edges and where canopy cover has been reduced. These impacts include: preventing seedling regeneration; and where there is a high biomass of wandering Jew, increasing litter decomposition and altering nutrient cycling (Rachel Standish, pers.comm.).

Standish has found that once wandering Jew has been removed it is likely to be replaced by other invasive species that also inhibit the regeneration of indigenous species.

Wandering Jew received an *effect on system* score of 8 and *biological success rating* score of 9 with a total score of 25 (Owen 1997). The lack of seed production and the absence of seedbanks contribute to the low *biological success* score. In New Zealand, wandering Jew regenerates from stem fragments only. Six out of 13 conservancies identified this species as one of the 10 weed species that has the most environmental impact in their conservancy and three conservancies ranked it as being one of the 10 species that are most difficult to control.

9.7.2 Agent specificity

There are no indigenous members of the family Commelinaceae. This provides more options for agent selection.

9.7.3 Potential biological control agents and international biological control work

There are no known biological control attempts for wandering Jew in other countries. There are no reports of insect agents in New Zealand or Australia (Standish 2001).

Fungal pathogens are the most likely candidates for wandering Jew biological control. Adrian Spiers (pers. comm.) has identified eight records in the Fungus Host Distribution Database, and four fungal species that are capable of causing extensive die-back of wandering Jew providing that an aggressive strain is involved.

Standish (2001) listed a number of plant pathogens of wandering Jew and suggested that several be further researched as either a classical biological control agent or, depending on the species, a mycoherbicide.

9.7.4 Analysis and recommendations

Standish (2001) states:

> 'There are two matters to consider regarding the prospects for the successful biological control of *T. fluminensis*. First, like chemical and manual control methods, biological control addresses the symptom rather than the cause of weed invasion. Therefore, biological control may effectively manage *T. fluminensis* but not the problem of other weeds that are likely to invade with a reduction of *T. fluminensis* (e.g. *Hedychium gardnerianum*, *Selaginella karussiana*).
>
> The second matter to consider is that a biological control agent needs to be able to reduce the standing biomass of *T. fluminensis* to less than 200 g/m^2 to allow regeneration of tolerant native species (e.g. *Dysoxylum spectabile*) and, ideally, to lower levels, as native seedling species richness and abundance increase with decreasing *T. fluminensis* biomass … This reduction of 75% of plant mass seems a realistic prospect for a biological control programme…'

As wandering Jew often occurs in disturbed forests and forest remnants, especially along forest and stream margins, it would be important to clarify that any decrease in vigour resulting from biological control would provide sufficient ecological benefit to the Department's site-led weed management programmes.

A decrease in wandering Jew would benefit disturbed forests and forest remnants generally, including many locations not subject to a DOC site-led weed management programme and/or not on land administered by the Department. Accordingly, any biological control investigations should be done in association with regional councils and territorial authorities that manage indigenous forest remnants. The forests managed by councils are often small and close to urban and/or developed landscapes where wandering Jew is frequently a problem. There should also be liaison with potential overseas collaborators.

Standish (2001) concluded that wandering Jew was a good candidate for biological control, but 'reducing both the weed's biomass and reinvasion by other weeds are the biggest challenges for a biocontrol programme to overcome'.

10. Summary and conclusions

10.1 BENEFITS AND RISKS

A successful biological control programme eventually reduces, or in some cases removes the need for conventional methods of control for a weed species. It is targeted to a particular species or group of closely related species and, once established, the agents continue to provide benefits.

The main risks of biological control programmes are: they may have little or no long-term effect on the target weed populations; where a weed is controlled to some degree a reduction in that species may be followed by the invasion of other weed species; there may be adverse effects on indigenous species although a rigorous pre-release investigation should address this; the costs of establishing a biological control programme can be high (up to $1–2 million) for a large programme with multiple agents (Pauline Syrett, pers. comm.); it is not possible to reliably predict the outcome of a biological control project; internationally, most agents introduced for biological control fail to control the target weed; and even where a biological control agent is effective it may take many years before there are meaningful decreases in weed populations.

10.2 ASSESSING THE OUTCOMES OF BIOLOGICAL CONTROL PROGRAMMES

It can be difficult to determine the true success of a biological control programme as the effects may be patchy in space and time. Short-term effects may not be sustained. Alternatively, it can take many years for agents to have a demonstrable effect.

Although it is not possible to predict the outcomes of biological control, a number of authors have identified factors associated with successes and failures in biological control programmes.

Uncertainties can be reduced with a good understanding of the target weed's ecology including the impacts of the potential agents on the demography of the target weed in its native range. Considerable work is also required to ensure host specificity of the agents. A comprehensive monitoring programme is required to reliably assess the effects of a biological control programme.

10.3 OUTCOMES OF BIOLOGICAL CONTROL

By the end of 1996 there had been at least 1150 deliberate releases of 365 species of insects and fungi on to 133 weed species in 75 countries (Julien & Griffiths 1998). While many releases were made to address weeds in human production systems, some of the species concerned were also weeds of natural areas. An increasing number of biological control programmes are now focusing on weeds primarily or solely of natural areas.

Julien et al. (1984) estimate that for each weed programme in a particular country an average of three to four agents were introduced. Of these, two or three agents became established, but only a fraction of those established actually controlled the target weed. It is too soon to identify the outcomes of many more recent biological control programmes.

Outcomes can be improved if biological control is part of a comprehensive approach to weed management.

10.4 WEEDS AND NEW ZEALAND PROTECTED AREAS

Weeds are a major threat for a number of threatened indigenous plants. They threaten indigenous fauna by changes to, or the removal of, habitat and they decrease indigenous food sources. At least 575 000 ha of high-priority natural areas are threatened in the next 5–15 years if weed invasions are not controlled (Owen 1998). Alien plants have spread throughout most of New Zealand's rivers and lakes, and modified most remaining freshwater wetlands.

The 1997 DOC database of weeds on conservation land in New Zealand (Owen 1997) contains more than 240 species. The report includes an indicative assessment of the scale of the problem posed by each species.

The Department needs to manage weeds in terrestrial, freshwater and marine protected areas throughout New Zealand's entire latitudinal and altitudinal range including its many offshore islands.

The statutes under which the Department works in effect place high requirements on it to control invasive weed species as part of protecting indigenous flora and fauna and the ecosystems of which they are a part. The Department manages approximately one-third of New Zealand's land area.

The Department's strategic plan for managing weeds focuses on two strategic approaches to invasive weed management: weed-led (species) management and site-led management. The purpose of weed-led management is to prevent new invasive weed species spreading and so management is generally eradication or strict containment. This provides limited opportunity for biological control unless the species is also being controlled for other purposes in other areas.

The purpose of site-led management is to protect the quality and integrity of natural values of identified sites. This involves many different species at many different sites throughout New Zealand. It is also important to prevent re-invasion by the weed species removed or by alternative weed species. The risk of re-invasion by other weed species is likely to decrease the ecological effectiveness of biological control or other programmes targeted at single weed species in sites where such substitution is likely.

The potential costs of biological control programmes mean that it could probably only contribute to the control of relatively few of the species of concern. This would not remove the need for conventional control for other weed species affecting a site.

There are oportunities for cost sharing of biological control programmes where the weed species are a problem for other agencies. For example, regional councils prepare and implement regional pest management strategies under the Biosecurity Act 1993 and manage land under the Local Government Act 1974. There are some weed species of major concern to the Department that others still find useful (e.g. marram grass). It may be difficult to proceed with biological control programmes for such species at this time.

This report summarises New Zealand and international biological control programmes and investigations for each of 240 weed species on the DOC weeds database. There is no international work for most of the weed species of major concern to the Department, although New Zealand feasibility studies have been undertaken for some of these species.

10.5 ASSESSING PRIORITIES FOR BIOLOGICAL CONTROL

A three-stage process is suggested for use by the Department to help identify priorities for biological control investigations.

The initial assessment criteria flowchart is designed to quickly identify whether major issues need to be addressed, especially with other agencies. A set of detailed questions identifies the information that should be collected for each weed species prior to making a decision to commit resources to biological control investigations. A comparative evaluation between species would use qualitative scores for selected factors and would most appropriately be undertaken by an expert panel.

10.6 PRELIMINARY EVALUATION OF EIGHT SPECIES OF PARTICULAR CONCERN TO DOC

Preliminary biological control feasibility assessments were undertaken for eight species: *Anredera cordifolia*; *Cortaderia jubata*; *C. selloana*; *Lonicera japonica*; *Lagarosiphon major*; *Salix cinerea*; *S. fragilis*; *Tradescantia fluminensis.*

10.7 CONCLUSIONS

It is suggested that the biocontrol strategy for the Department primarily address weeds that are part of site-led programmes. Ecological gains resulting from biological control would be most likely for species that occur in habitats where there is a relatively low risk of replacement by other weed species once the original target weed species are controlled. Examples of such species include grey willow (*Salix cinerea*), crack willow (*S. fragilis*), marram grass (*Ammophila arenaria*), *Pinus contorta*, and wilding pines. There is a risk of opposition to biological control investigations for some of these species because of their use for water and soil conservation. Close liaison is needed with regional councils and others about biological control options for these species.

Biological control could only be part of a suite of tools addressing weed management at sites where there is a strong risk of invasion by a variety of other weed species once an initial problem weed species is reduced in extent and density. Costs and benefits of biological control would need to be evaluated accordingly.

The potential of biological control for aquatic weeds needs to be carefully assessed, based on the relative impacts and benefits of different weed species and the specific characteristics of New Zealand aquatic systems.

A successful biological control programme will provide benefits beyond the identified site-led weed management programmes. This especially applies to species such as wandering Jew (*Tradescantia fluminensis*) and Japanese honeysuckle (*Lonicera japonica*). Many weeds of concern to the Department are also weeds on lands not managed by it. There is a need to liaise closely with regional councils and other land and water managers to achieve a co-ordinated approach to biological control investigations for weeds that damage natural areas.

There needs to be strict host-specificity testing for all potential biological control agents. This particularly applies if the target weed species is in the same genus or family as an indigenous or economically valuable species.

All biological control projects should be accompanied by a comprehensive monitoring programme to assess the effect of the agents on the target weed and other components of the environment.

11. Acknowledgements

This review was prepared for New Zealand Department of Conservation Investigation 3248. Many people were consulted as part of the review process.

I acknowledge the contribution of the following people from New Zealand: Adrian Spiers, Chris Buddenhagen, Chris Richmond, Graeme Lacock, Hugh Gourlay, Jason Roxburgh, John Clayton, Karen Cronin, Lynley Hayes, Lisa Forester, Melanie Newfield, Murray McClea, Paul Champion, Pauline Syrett, Peter McGregor, Richard Hill, Simon Fowler, Susan-Jane Owen and Susan Timmins.

I acknowledge the following international contributions: Kate Blood, Department of Natural Resources and Environment, Victoria; Richard Groves, CSIRO; Rachel McFayden, Department of Natural Resources, Queensland; Dane Panetta, Department of Natural Resources, Queensland; Merrilyn Paskins, Department of Primary Industry and Fisheries, Darwin; Quentin Paynter, CSIRO, Northern Territories; Richard Roush, University of Adelaide; Cory Lindgren, Ducks Unlimited, Stonewall, Canada; Alec McClay, Alberta Research Council, Vegreville, Canada; Judith Myers, University of British Columbia, Vancouver, Canada; Bernd Blossey, Cornell University, USA; Gary Buckingham, Florida Biocontrol Laboratory, USA; Eric Coombs, Oregon Department of Agriculture, USA; Jack DeLoach, US Department of Agriculture, Temple, Texas, USA; Svata Louda, University of Nebraska, USA; Margaret Smith, University of Greenwich, Kent, England; Mark Williamson, University of York, England; Cliff Moran, University of Cape Town, Rondebosch, South Africa.

Pauline Syrett (Landcare Research) and Adrian Spiers (HortResearch) contributed material used in the preliminary biological control assessments in chapter 9.

Susan Timmins, Pauline Syrett and two anonymous referees provided critical comments on drafts of this report.

12. References

Ainsworth, N. 1999. Current research on environmental weeds. *Plant Protection Quarterly 14(3)*: 108–111.

Anderson, A. 1989. How important is seed predation to recruitment in stable populations of long lived perennials. *Oecologia 81*: 310–315.

Atkinson, I.A.E.; Cameron, E.K. 1993. Human influence on the terrestrial biota and biotic communities of New Zealand. *TREE 8*: 447–451.

Atkinson, I.A.E. 1997. Problem weeds on New Zealand islands. *Science for Conservation 45*.

Balneaves, J.M.; Hughey, K.F.D. 1990. The need for control of exotic weeds in braided river beds for conservation of wildlife. Proceedings of 9th Australian Weeds Conference, Adelaide. Pp. 103–108.

Bennett, F.D.; Habeck, D.H. 1995. *Cactoblastis cactorum*: A successful weed control agent in the Caribbean, now a pest in Florida? Proceedings of the Eighth International Symposium on Biological Control of Weed, 2–7 February 1992, Lincoln University, Canterbury, New Zealand. Delfosse, E.S.; Scott, R.R. (eds). DSIR/CSIRO, Melbourne. Pp. 21–26.

Blossey, B.; Malecki, R.A.; Schroeder, D.; Skinner, L. 1996. A biological weed control programme using insects against purple loosestrife (*Lythrum salicaria*) in North America. Proceedings of IX International Symposium on Biological Control of Weeds, pp. 351–355. Moran, V.C.; Hoffman, J.H. (eds), 19–26 January 1996. Stellenbosch, South Africa.

Brockerhoff, E.G.; Kay, M. 1998. Prospects and risks of biological control of wilding *Pinus contorta* in New Zealand. *Proceedings of 51st NZ Plant Protection Conference*: 216–223.

Brockerhoff, E.G.; Withers, T.M.; Kay, M.; Faulds, W. 1999. Impact of the defoliator *Cleopus japanicus* (Coleoptera : Curculionidae) on *Buddleja davidii* in the laboratory. *Proceedings of 52nd NZ Plant Protection Conference*: 113–118.

Burdon, J.J.; Marshall, D. R. 1981. Biological control and the reproductive mode of weeds. *Journal of Applied Ecology 18*: 649–58.

Chapman, H.M.; Bannister, P. 1990. The spread of heather, *Calluna vulgaris* (L.) Hull, into native plant communities of Tongariro National Park, New Zealand. *Journal of Ecology 14*: 7–16.

Cloutier, D.; Watson, A.K. 1990. Application of modelling to biological weed control. Proceedings of the VIII International Symposium on Biological Control of Weeds, 6–11 March, 1988, Rome, Italy. Delfosse, E.S. (ed). Ministero dell' Agricoltura e delle Foreste, Rome/CSIRO, Melbourne. Pp. 5–12.

Coffey, B.T.; Clayton, J.S 1988. Changes in the submerged macrophyte vegetation of Lake Rotoiti, central North Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research 22*: 215–223.

Coombs, E.M. 1999. Biological Control of Weeds annual report 1999. Oregon Department of Agriculture Noxious Weed Control Program. 21 p. and appendices.

Crawley, M.J. 1989a. The successes and failures of weed biocontrol using insects. *Biocontrol News and Information 10*: 3. CAB International.

Crawley, M.J. 1989b. Plant life—history and the success of weed biological control projects. Proceedings of the VII International Symposium on the Biological Control of Weeds, 6–11 March 1988, Rome, Italy. Delfosse, E.S. (ed). Ministero dell'Agricoltura e delle Foreste, Rome/CSIRO, Melbourne. Pp. 17–26.

Cullen, J.M. 1992. Prediction and practice in biological control. Pp 137–140 in Richardson, R.G. (ed) Proceedings of the first international weed control congress. Vol 2, Monash University, Melbourne.

De Bach, P. 1964. The scope of biological control. Pp. 3–20 in De Bach (ed) Biological control of insect pests and weeds. Chapman & Hall, London, UK.

DeLoach, C.J.; Carruthers, R.I.; Lovich, J.E.; Dudley, T.L.; Smith, S.D. 2000. Ecological interactions in the biological control of saltcedar (*Tamarix* spp.) in the United States: Toward a new understanding. Proceedings of X International Symposium on Biological Control of Weeds, 4–14 July, 1999. Montana State University, Bozeman, Montana, USA.

Diehl, J.W.; McEvoy, P.E. 1989. Impact of the cinnabar moth (*Tyria jacobaeae*) on *Senecio triangularis*, a non-target native plant in Oregon. Proceedings of VII International Symposium on the BioControl of Weeds, 6–11 March 1988, Rome, Italy. Delfosse, E.S. (ed). Ministero dell'Agricoltura e delle Foreste, Rome/CSIRO, Melbourne. Pp. 119–126.

Esler, A.E. 1988. Naturalisation of plants in urban Auckland, New Zealand. 5: Success of the alien species. *New Zealand Journal of Botany 26*: 565–584.

Esler, A.E.; Astridge, S.J. 1987. Naturalisation of plants in urban Auckland, New Zealand. 2: Records of introduction and naturalisation. *New Zealand Journal of Botany* 25: 523–537.

Fowler, S.V.; Syrett, P.; Hill, R.L. in press. Success and safety in the biological control of environmental weeds in New Zealand. *Australian Journal of Ecology*.

Fowler, S. 1999. Feasibility study of the biological control of banana passionfruit (*Passiflora mollissima* and *P. mirta*) in New Zealand. Landcare Research Contract Report LC 9900/32 (unpublished).

Froude, V.A.; Richmond, C.J. 1990. Aquatic weed control in the Rotorua Lakes—a discussion paper on management issues and options. Department of Conservation, Rotorua. 46 p.

Gardner, D.E.; Smith, W.C.; Markin, G.P. 1995. Biological control of alien plants in natural areas of Hawaii. Proceedings of the Eighth International Symposium on Biological Control of Weeds, 2–7 February 1992, Lincoln University, Canterbury, New Zealand. Delfosse, E.S.; Scott, R.R. (eds). DSIR/CSIRO, Melbourne. Pp. 35–40.

Groves, R.H. 1999. Environmental weeds—past, present and future. *Plant Protection Quarterly 14(3)*: 92–95.

Harman, H.M.; Syrett, P.; Hill, R.L.; Jessep, C.T. 1996. Anthropod introductions for biological control of weeds in New Zealand 1929–1995. *New Zealand Entomologist 19*: 71–80.

Harns, P. 1993. Effects, constraints and the future of weed biocontrol. *Agriculture, Ecosystems and Environment 46*: 289–303.

Harris, R.; Stewart, C.; Syrett, P. 1999. Wild ginger (*Hedychium* spp.): prospects for biological control. Unpublished Landcare Research Report.

Hill, R.L.; Gourlay, A.H.; Fowler, S.V. 2000. The biological control programme against gorse in New Zealand. Proceedings X International Symposium on Biological Control of Weeds, 4–14 July, 1999. Montana State University, Bozeman, Montana, USA.

Hoffman, J.H. 1995. Biological Control of Weeds: the way forward, a South African perspective. 1995 BCPS Symposium Proceedings No 64: Weeds in a changing world.

Howard-Williams, C.; Clayton, J.S.; Coffey, B.T.; Johnstone, I.M. 1987. Macrophyte invasions. Pp. 307–331 in Viner, A.B. (ed). Inland Waters of New Zealand. Bulletin of the DSIR, Taupo.

Howarth, F.G. 1991. Environmental impacts of classical biological control. *Annual Review of Entomology 36*: 485–509.

Julien, M.H. (ed) 1992. Biological Control of Weeds: a world catalogue of agents and their target weeds. Third edition. CAB International, Wallingford, UK. 186 p.

Julien, M.H.; Griffiths, M.W. 1998 (eds). Biological Control of Weeds—a world catalogue of agents and their target weeds. 4th edition. CAB Publishing, Wallingford, UK.

Julien, M.H.; Kerr, J.D.; Chan, R.R. 1984. Biological Control of Weeds: an evaluation. *Protection Ecology 7*: 3–25.

Kelly, D.; Skipworth, J.P. 1984. *Tradescantia fluminensis* in a Manawatu (New Zealand) forest: I. Growth and effects on regeneration. *New Zealand Journal of Botany 22*: 393-397.

Kriticos, D.; Brown, J.; Radford, I.; Nicholas, M. 1999. Plant population ecology and biological control: *Acacia nilotica* as a case study. *Biological Control 16*: 230–239.

Lai, P.Y. 1988. Biological control: a positive point of view. *Proceedings of the Hawaiian Entomological Society 24*: 239–44.

Landcare Research 1996. The Biological Control of Weeds book—a New Zealand guide. Te Whakapau Taru.

McClay, A.S. 1995. Beyond 'before and after': experimental design and evaluation in classical weed biological control. Proceedings of the Eighth International Symposium on Biological Control of Weeds, 2–7 February 1992, Lincoln University, Canterbury, New Zealand. Delfosse, E.S.; Scott, R.R. (eds). DSIR/CSIRO, Melbourne. Pp. 213–19.

McFayden, R.E.C. 1998. Biological Control of Weeds. *Annual Review of Entomology 43*: 369–393.

McGregor, P.G. 1999a. Prospects for biological control of woolly nightshade, *Solanum mauritianum* (Solanaceae: Solanoiteae). Landcare Research Contract Report LC 9900/035 (unpublished).

McGregor, P.G. 1999b. Prospects for biological control of nassella tussock, *Nassella trichotoma* (Poaceae: Stipeae). Landcare Research Contract Report LC 9899/116 (unpublished).

McGregor, P.G. 1999c. Prospects for biological control of Chilean needle grass, *Nassella neesiana* (Poaceae: Stipeae). Landcare Research Contract Report LC 9899/128 (unpublished).

McGregor, P.G. 2000a. Prospects for biological control of pampas grass (*Cortaderia* spp.) (Poaceae). Draft Landcare Research Contract Report LC9900/82 (unpublished). 13 p.

McGregor, P.G. 2000b. Prospects for biological control of privet (*Ligustrum* spp.) (Oleaceae). Landcare Research Contract Report LC 9900/127 (unpublished). 18 p.

McGregor, P.G. 2001 Prospects for biological control of wilding conifers. Landcare Research Contract Report LC 0001/154 (unpublished). 17 p. Prepared for Hawke's Bay Regional Council and Environment Canterbury.

McGregor, P.G.; Gourlay, H. 2001. Prospects for the biological control of lagarosiphon (*Lagarosiphon major (*Hydrocharitaceae)). Landcare Research Contract Report LC 0102/030. Prepared for the Department of Conservation, Wellington. 11 p.

Moran, V.C.; Hoffman, J.H.; Donnelly, D.; Van Wilgen, B.W.; Zimmerman, H.G. 2000. Biological control of alien, invasive pine trees (*Pinus* species) in South Africa. Proceedings of the X International Symposium on the Biological Control of Weeds, 4–14 July, 1999. Montana State University, Bozeman, Montana, USA. Pp. 941–953.

Morin, L. 1996. Different countries, several potential biohorbicides, but always the same hurdles. Proceedings of the IX International Symposium on Biological Control of Weeds. 19–26 January 1996. Stellenbosch, South Africa, University of Cape Town. Moran, V.C.; Hoffman, J.H. (eds).

Myers, J.H. 1985. How many insect species are necessary for successful biocontrol of weeds? Proceedings VI International Symposium on the Biological Control of Weeds. Pp. 77–82.

Myers, J.H.; Risley, C.; Eng, R. 1989. The ability of plants to compensate for insect attack: why biological control of weeds with insects is so difficult. Proceedings of VII International Symposium on the Biological Control of Weed, 6–11 March, 1988, Rome, Italy. Defosse, E.S. (ed). Ministero dell'Agricoltura e delle Foreste, Rome/CSIRO, Melbourne. Pp. 67–73.

Myers, J.H. 1995. Long term studies and predictive models in the biological control of diffuse knapweed. Proceedings of the Eighth International Symposium on Biological Control of Weeds, 2–7 February 1992, Lincoln University, Canterbury, New Zealand. Delfosse, E.S.; Scott, R.R. (eds). DSIR / CSIRO, Melbourne. Pp. 221–224.

Myers, J.H.; Risley C. 2000. Why reduced seed production is not necessarily translated into successful biological weed control. Proceedings of the X International Symposium on Biological Control of Weeds, 4–14 July 1999. Montana State University, Bozeman, Montana, USA.

Myers, J.H. 2000. What can we learn from biological control failures? Proceedings of the X International Symposium on Biological Control of Weeds, 4–14 July, 1999. Montana State University, Bozeman, Montana, USA.

Myers, J.H.; Ware, J. in press. Setting priorities for the biological control of weeds: What to do and how to do it. Proceedings of the Hawaii Conservation Forum on Biological Control of Invasive Plants in Hawaiian Natural Ecosystems, USDA Forest Service.

Nordlund, D.A. 1996. Biological control, integrated pest management and conceptual models. *Biocontrol News Information 17*: 35–44.

Olckers, T.; Hill, M.P. (eds) 1999. Biological control of weeds in South Africa 1990–1998. *African Entomology Memoir No. 1.*

Owen, S.J. (compiler) 1997. Ecological weeds on conservation land in New Zealand: a database (January 1997—working draft). Department of Conservation, Wellington.

Owen, S.J. 1998. Department of Conservation strategic plan for managing invasive weeds. Department of Conservation, Wellington. 86 p.

Palmer, W.A.; Miller, E.N. 1996. A method for prioritizing biological control projects with reference to those of Queensland. Proceedings of the IX International Symposium on Biological Control of Weeds, 19–26 January 1996. Stellenbosch, South Africa, University of Cape Town. Moran, V.C.; Hoffman, J.H. (eds). Pp. 19–26.

Partridge, T.R. 1987. Spartina in New Zealand. *New Zealand Journal of Botany 25*: 567–575.

Powell, R.D. 1990. The functional forms of density-dependent birth and death rates in diffuse knapweed (*Centaurea diffusa*) explain why it has not been controlled by *Urophara affinis, U. quadrifasciata* and *Sphenoptera jugoslavica*. Proceedings of the Eighth International Symposium on Biological Control of Weeds, 2–7 February 1992. Lincoln University, Canterbury, New Zealand. Delfosse, E.S.; Scott, R.R. (eds). DSIR/CSIRO, Melbourne. Pp. 195–202.

Rees, M.; Hill, R.L. in press. Large scale disturbances, biological control and the dynamics of gorse populations. *Journal of Applied Ecology*.

Reid, V.A. 1998. The weeds of New Zealand threatened plants. *Science and Research Report 164*. Department of Conservation, Wellington.

Sands, D.; Scholtz, M. 1985. Control or no control: a comparison of feeding strategies of two Salvinia weevils. Proceedings of VI International Symposium on Biological Control of Weeds. Delfosse, E. (ed). 19–25 August 1984, Vancouver, Canada. Pp. 551–556.

Shearer, J.F. 1996. Development of a fungal pathogen for biocontrol of the submersed aquatic macrophyte *Hydrilla verticillata*. Proceedings of the IX International Symposium on Biological Control of Weeds, 19–26 January 1996. Stellenbosch, South Africa, University of Cape Town. Moran, V.C.; Hoffman, J.H. (eds).

Simberloff, D.; Stiling, P. 1999. Risks of species introduced for biological control. *Biological Conservation 78*: 185–192.

Smith, M.C. 2000. Models and problem solving in the biological control of weeds. Proceedings of the III International Weed Science Congress, Iguassu Falls, Brazil, 6–11 June 2000.

Standish, R.J. 2001. Prospects for biological control of *Tradescantia fluminensis* Vell. (Commelinaceae). *DOC Science Internal Series 9*. Department of Conservation, Wellington. 25 p.

Standish, R.J.; Robertson, A.W.; Williams, P.A. In press. The impact of an invasive weed (*Tradescantia fluminensis*) on native forest regeneration. *Journal of Applied Ecology.*

Stewart, C.A.; Emberson, R.M.; Syrett, P. 1996. Temperature effects on alligator weed flea-beetle *Agasicles hygrophila* (Coleoptera: Chrysomelidae) implications for biological control in New Zealand. Proceedings of the IX International Symposium on Biological Control of Weeds. 19–26 January 1996. Stellenbosch, South Africa, University of Cape Town. Moran, V.C.; Hoffman, J.H. (eds).

Syrett, P. 1999a. Prospects of biological control of bone-seed, *Chrysanthemoides monilifera* ssp. *monilifera*, Asteraceae: Calenduleae. Landcare Research Contract Report LC 9899/80 (unpublished).

Syrett, P. 1999b. Prospects for biological control of climbing asparagus *Asparagus scandens* Thunberg (Asparagaceae). Landcare Research Contract Report LC 9899/104 (unpublished).

Syrett, P.; Briese, D.T.; Hoffman, J.H. in press. Measures of success in biological control of terrestrial weeds by arthropods. Pp. 189–230 in Gurr, G.; Wratten, S.D. (eds) Measures of success in biological control. Kluwer, The Netherlands.

Turner, C.E.; Herr, J.C. 1996. Impact of *Rhinocyllus conicus* on a non-target, rare native thistle (*Cirsium fontinale*) in California. Proceedings of the IX International Symposium on Biological Control of Weeds. 19–26 January 1996. Stellenbosch, South Africa, University of Cape Town. Moran, V.C.; Hoffman, J.H. (eds).

Veitch, C.R. 1996. Plan for the control of exotic plants on Little Barrier Island (Hauturu). Unpublished report. Department of Conservation, Auckland.

Waage, J. 1992. Classical biological control of weeds. Pp. 240–247 in Proceedings of the First International Weed Control Congress, Melbourne.

Wall, R.E. 1990. The fungus purpureum as a silvicide to control stump sprouting in hardwoods. *Northern Journal of Applied Forestry* 7: 17–19.

Wapshere, A.J. 1985. Effectiveness of biological control agents for weeds: present quandaries. *Agriculture, Ecosystems and Environment 13*: 261–280.

Waterhouse, D.F. 1998. Foreword in Julien, M.H.; Griffiths, M.W. (eds). Biological control of weeds—a world catalogue of agents and their target weeds. 4^{th} edition. CAB International, Wallingford, UK.

West, C.J. 1992. Ecological studies of *Clematis vitalba* (old man's beard) in New Zealand. Vegetation report 736. DSIR Land Resources, Wellington.

West, C.J. 1994. Wild willows in New Zealand: proceedings of a willow control workshop hosted by Waikato Conservancy, Hamilton, 24–26 November 1993. Department of Conservation, Wellington.

White, E.G. 1991. The changing abundance of moths in a tussock grassland, 1962–1989 and 50 to 70 year trends. *New Zealand Journal of Ecology 15*: 5–22.

Williamson, M. 1999. Invasions. *Ecography 22*: 5–12.

Winks, C.J.; Fowler, S.V. 2000. Prospects for the biological control of moth plant *Araujia sericifera* (Ascleplacaceae). Landcare Research Contract Report LC 9900/100 (unpublished).

Zimmerman, H.G.; Neser, S. 1999. Trends and prospects for biological control of weeds in South Africa. Pp. 165–175 in Olckers, T.; Hill, M.P. (eds) Biological control of weeds in South Africa (1990–1998). *African Entomology Memoir 1.*

Glossary

Biocontrol agent (for plants) An organism that provides, or is intended to provide, some control of a problem plant by damaging some aspect of plant vegetative growth or reproductive systems. To date most agents have been insects, with most of the remainder being fungal pathogens

Biocontrol programme The suite of biocontrol agent projects collectively intended to control a problem plant species

Biocontrol project The investigation and testing associated with a particular agent for a problem plant species

Bioherbicides Highly concentrated inoculums of pathogens that are used against weeds in a similar manner to chemical herbicides

Biological control The actions of parasites, predators and pathogens in maintaining another organism's density at a lower average than would occur in their absence

Biological success rating This represents the biological capacity of the weed species. Characteristics associated with weediness (e.g. fast establishment and growth, high seed production and effective asexual spread) are given high scores. Used in Owen (1997)

Classical biocontrol Importation and release of exotic biocontrol agents, with the expectation that the agents will become established and further releases will not be necessary

Effect on system rating An assessment of the behaviour of the weed species in the community type and geographical location in New Zealand where it has the greatest impact. The features which are most detrimental to native communities are given the highest scores, e.g. major disturbance to ecological processes. Used in Owen (1997)

Established (agent) Agent becomes a permanent part of the biota

Host-specific (agent) Agent is restricted to one host or a small range of host plants

Monophagous agent Restricted to a single host

Mycoherbicides Highly concentrated inoculums of fungal pathogens that are used against weeds in a similar manner to chemical herbicides

Recovered (agent) Agent has been found since its initial release on plants of the target weed

Target weed This is a weed that is the focus of a biocontrol programme

Appendix 1

ASSESSMENTS OF WEEDS IN NEW ZEALAND PROTECTED AREAS

Explanation

The *effect on system* rating (column 3) is an assessment of the behaviour of the weed species in the community type and geographical location in New Zealand where it has the greatest impact. Features which are most detrimental to native communities are given the highest scores, e.g. major disturbance to ecological processes, community structure and composition (N/A = not available).

The *biological success rating* (column 4) represents the biological capacity of the weed species. Characteristics associated with weediness (e.g. fast establishment and growth, high seed production and effective asexual spread) are given high scores.

The *total weediness score* (column 5) = 2× (effect on system score) plus the biological success rating.

Columns 3–5 are from Owen (1997).

Top 10 threat (column 6) is the number of DOC conservancies (out of 13) that consider the weed to be one of the top 10 problem weeds (i.e. poses the greatest risk) in their conservancy.

The *Top 10 control difficult* (column 7) is the number of DOC conservancies that consider the weed is one of the top 10 weeds in their conservancy that are the most difficult to control.

Total top 10 (Column 8) sums the figures from columns 6 and 7. No weightings or multipliers are used.

There are some significant differences between the outcomes of the two scoring systems, e.g. Mysore thorn (*Caesalpinia decapetala*) receives one of the highest rankings using the methodology in Owen (1997), but does not score as being one of the top 10 weeds for either impact or difficulty of control for any conservancy.

The methodology in Owen (1997) is more systematic, but in both systems certain types of situations are 'disadvantaged'. For example, the ecological seriousness of plants that only reproduce asexually in New Zealand is underscored in Owen (1997) because a number of criteria used to determine biological success rating relate to seed production. Conversely, the conservancy rankings underscore weed species that are a serious problem in only one or two conservancies because the weed species may not have had sufficient time to spread.

The relative rankings of species can change over time as more information becomes available and the long-term effects of weed species become more apparent.

BOTANICAL NAME	COMMON NAME	TOTAL EOS EFFECT SCORE COL 3	TOTAL BSR SUCCESS SCORE COL 4	TOTAL 2×EOS+ BSR SCORE COL 5	TOP10 THREAT NO. CONS COL 6	TOP10 CONTROL DIFICULT NO. CONS COL 7	TOTAL TOP 10– COLUMNS 6 + 7 COL 8
Acer pseudoplatanus	sycamore	8	11	27	1	0	1
Acmena smithii	monkey apple	5	10	20	0	0	0
Actinidia chinensis	kiwifruit	N/A	N/A	N/A	0	1	1
Agapanthus praecox	agapanthus	3	11	17	1	1	2
Ageratina adenophora	Mexican devil	7	15	29	2	1	3
Ageratina riparia	mist flower	8	15	31	1	0	1
Agrostis capillaris	browntop	6	13	25	0	1	1
Allium triquetrum	onion weed	4	12	20	0	0	0
Alnus glutinosa	alder	7	12	26	0	0	0
Alocasia brisbanensis	elephant's ear	6	11	23	0	0	0
Alternanthera philoxeroides	alligator weed	9	10	28	0	0	0
Ammophila arenaria	marram	9	14	32	3	3	6
Anredera cordifolia	Madeira vine	8	9	25	2	3	5
Araujia sericifera	moth plant	8	11	27	4	3	7
Aristea ecklonii	aristea	7	13	27	0	0	0
Arrhenatherum elatius	tall oatgrass	6	11	23	0	0	0
Arum italicum	Italian lily	6	12	24	0	0	0
Arundo donax	giant reed	8	13	29	0	0	0
Asparagus asparagoides	smilax	9	12	30	3	3	6
Asparagus scandens	climbing asparagus	8	12	28	2	3	5
Berberis darwinii	Darwin's barberry	7	12	26	2	1	3
Berberis glaucocarpa	barberry	7	12	26	0	1	1
Bromus tectorum	cheatgrass	2	10	14	0	0	0
Bryonia cretica	white bryony	N/A	N/A	N/A	0	1	1
Buddleja davidii	buddleia	7	12	26	2	1	3
Caesalpinia decapetala	Mysore thorn	9	16	34	0	0	0
Calluna vulgaris	heather	7	13	27	2	3	5
Carduus nutans	nodding thistle	4	12	20	0	0	0
Carex longebrachiata	Australian sedge	5	12	22	0	0	0
Celastrus orbiculatus	climbing spindleberry	6	9	21	0	0	0
Ceratophyllum demersum	hornwort	N/A	N/A	N/A	2	2	4
Cestrum aurantiacum	orange cestrum	6	13	25	0	0	0
Cestrum elegans	red cestrum	6	16	28	0	0	0
Chrysanthemoides monilifera	boneseed	8	12	28	3	1	4
Cirsium spp.	thistles	4	13	21	0	0	0
Clematis flammula	clematis	4	11	19	0	0	0
Clematis vitalba	old man's beard	9	15	33	5	2	7
Cobaea scandens	cathedral bells	9	12	30	0	*	0
Convolvulus arvensis	convolvulus, field bindweed	6	13	25	0	0	0
Cortaderia jubata	purple pampas	7	14	28	5	4	9
Cortaderia selloana	pampas	7	14	28	5	4	9
Cotoneaster glaucophyllus	cotoneaster	6	13	25	2	0	2
Cotoneaster simonsii	Khasia berry	7	12	26	1	0	1
Crataegus monogyna	hawthorn	9	13	31	0	0	0
Crocosmia × crocosmiiflora	montbretia	5	12	22	1	2	3
Cytisus scoparius	broom	6	13	25	5	1	6
Dactylis glomerata	cocksfoot	5	12	22	0	0	0
Dipogon lignosus	mile-a-minute	6	11	23	0	0	0
Echium vulgare	viper's bugloss	5	11	21	0	0	0

BOTANICAL NAME	COMMON NAME	TOTAL EOS EFFECT SCORE COL 3	TOTAL BSR SUCCESS SCORE COL 4	TOTAL 2×EOS+ BSR SCORE COL 5	TOP10 THREAT NO. CONS COL 6	TOP10 CONTROL DIFICULT NO. CONS COL 7	TOTAL TOP 10– COLUMNS 6 + 7 COL 8
Egeria densa	egeria	7	10	24	*	1	1
Ehrharta erecta	veld grass	2	17	21	0	0	0
Ehrharta villosa	pyp grass	6	17	29	0	0	0
Elaeagnus × reflexa	elaeagnus	9	13	31	1	4	5
Equisetum arvense	horsetail	6	9	21	0	4	4
Erica lusitanica	Spanish heath	6	11	23	0	0	0
Erigeron karvinskianus	Mexican daisy	6	13	25	1	2	3
Eriobotrya japonica	loquat	5	9	19	0	0	0
Euonymus europaeus	spindleberry	4	11	19	0	0	0
Euonymus japonicus	Japanese spindleberry	4	11	19	0	0	0
Eupatorium cannabinum	hemp agrimony	N/A	N/A	N/A	1	1	2
Festuca arundinacea	tall fescue	7	15	29	0	0	0
Glyceria fluitans	floating sweetgrass	6	16	28	0	0	0
Gymnocoronis spilanthoides	Senegal tea	8	13	29	0	0	0
Gunnera tinctorea	Chilean rhubarb	N/A	N/A	N/A	1	1	2
Hakea gibbosa	hakea, downy	6	12	24	0	1	1
Hakea salicifolia	hakea, willow-leaved	6	11	23	0	1	1
Hakea sericea	hakea, prickly	6	11	23	0	1	1
Hedera helix	ivy	7	11	25	1	0	0
Hedychium flavescens	yellow ginger	8	8	24	2	0	2
Hedychium gardnerianum	kahili ginger	8	15	31	2	1	3
Hieracium spp.	hawkweed	7	15	29	2	3	5
Humulus lupulus	hops	5	11	21	0	0	0
Hydrilla verticillata	hydrilla	8	10	26	1	0	1
Hydrodictyon reticulatum	water net	8	12	28	0	0	0
Hypericum androsaemum	tutsan	7	13	27	0	0	0
Hypericum perforatum	St John's wort	3	11	17	0	0	0
Ipomoea indica	blue morning glory	9	12	30	1	0	1
Iris foetidissima	stinking iris	6	13	25	0	0	0
Iris pseudacorus	yellow flag iris	4	13	21	0	0	0
Jasminium humile	yellow jasmine	7	13	27	0	0	0
Jasminum polyanthum	jasmine	8	14	30	1	0	1
Juglans ailantifolia	Japanese walnut	N/A	N/A	N/A	0	0	0
Juncus acutus	sharp rush	4	14	22	0	*	0
Juncus articulatus	jointed rush	6	15	27	*	0	0
Juncus bulbosus	bulbous rush	6	15	27	0	0	0
Juncus effusus	soft rush	5	13	23	0	0	0
Juncus squarrosus	heath rush	7	13	23	0	0	0
Lagarosiphon major	lagarosiphon	8	11	27	3	3	6
Lantana camara var. *aculeata*	lantana	7	14	28	0	0	0
Larix decidua	larch	N/A	N/A	N/A	1	0	1
Leycesteria formosa	Himalayan honeysuckle	5	12	22	1	0	1
Ligustrum lucidum	tree privet	9	14	32	0	0	0
Ligustrum sinense	Chinese privet	6	13	25	0	0	0
Lolium perenne	perennial ryegrass	7	12	26	0	0	0
Lonicera japonica	Japanese honeysuckle	9	13	31	7	2	9
Lotus pedunculatus	lotus	5	14	24	0	0	0
Lupinus arboreus	tree lupin	7	13	27	0	0	0
Lupinus polyphyllus	Russell lupin	7	13	27	1	0	1
Lycium ferocissimum	boxthorn	7	13	27	1	1	2

BOTANICAL NAME	COMMON NAME	TOTAL EOS EFFECT SCORE COL 3	TOTAL BSR SUCCESS SCORE COL 4	TOTAL 2×EOS+ BSR SCORE COL 5	TOP10 THREAT NO. CONS COL 6	TOP10 CONTROL DIFICULT NO. CONS COL 7	TOTAL TOP 10– COLUMNS 6 + 7 COL 8
Melianthus major	Cape honey flower	7	11	25	0	0	0
Mimulus guttatus	monkey musk	4	13	21	0	0	0
Myriophyllum aquaticum	parrot's feather	8	10	26	1	1	2
Nephrolepis cordifolia	tuber sword fern	5	10	20	0	0	0
Olea europaea subsp. *cuspidata*	African olive	6	14	26	0	0	0
Osmunda regalis	royal fern	NA/	N/A	N/A	0	0	0
Oxylobium lanceolatum	oxylobium	6	9	21	0	0	0
Pandorea pandorana	wonga wonga vine	N/A	N/A	N/A	0	0	0
Paraserianthes lophantha	brush wattle	6	12	24	0	0	0
Paspalum distichum	Mercer grass	5	13	23	0	0	0
Passiflora edulis	black passionfruit	6	11	23	0	0	0
Passiflora mixta	northern banana passionfruit	7	13	27	1	0	1
Passiflora mollissima	banana passionfruit	7	13	27	2	1	3
Pennisetum clandestinum	Kikuyu grass	8	13	29	0	0	0
Pennisetum macrourum	African feather grass	8	13	29	0	0	0
Pennisetum setaceum	African fountain grass	7	17	31	0	0	0
Phytolacca octandra	inkweed	3	14	20	0	0	0
Pinus contorta	lodgepole pine	8	12	28	7	1	8
Pinus pinaster	maritime pine	8	11	27	2	0	2
Pinus spp.	wilding pine	8	11	27	4	2	6
Plantago coronopus	buck's horn plantain	N/A	N/A	N/A	1	0	1
Poaceae	exotic pasture grasses	N/A	N/A	N/A	3	0	3
Polygala myrtifolia	sweet pea bush	5	10	20	1	0	1
Populus alba	white poplar	7	8	22	0	0	0
Prunus avium	sweet cherry	4	12	20	0	0	0
Pseudotsuga menziesii	Douglas fir	7	10	24	1	0	1
Psoralea pinnata	dally pine	7	10	24	0	0	0
Pyracantha angustifolia	orange firethorn	5	11	21	0	0	0
Racosperma dealbatum	silver wattle	7	13	27	0	0	0
Racosperma longifolium	Sydney golden wattle	7	12	26	0	0	0
Racosperma paradoxum	kangaroo acacia	7	12	26	0	0	0
Racospermum sophorae	sand wattle	N/A	NA/	N/A	1	0	1
Reynoutria japonica	Japanese knotweed	N/A	13	N/A	1	1	2
Reynoutria sachalinensis	giant knotweed	N/A	N/A	N/A	1	1	2
Rhamnus alaternus	evergreen buckthorn	7	15	29	3	1	4
Rosa rubiginosa	sweet briar	7	14	28	0	0	0
Rubus fruticosus agg.	blackberry	8	15	31	0	0	0
Rumex sagittatus	climbing dock	5	14	24	0	1	1
Salix cinerea	grey willow	9	14	32	7	0	7
Salix fragilis	crack willow	9	10	28	6	0	6
Salvinia molesta	salvinia, water fern	8	10	26	0	0	0
Sambucus nigra	elderberry	6	10	22	0	0	0
Sedum acre	stonecrop	7	14	28	1	2	3
Selaginella kraussiana	selaginella	5	13	23	0	0	0
Senecio glastifolius	pink ragwort	N/A	N/A	N/A	0	1	1
Senecio angulatus	Cape ivy	7	15	29	1	0	1
Senecio jacobaea	ragwort	5	13	23	0	0	0
Senecio mikanioides	German ivy	7	12	26	1	0	1
Senna septentrionalis	buttercup bush	6	13	25	0	0	0

BOTANICAL NAME	COMMON NAME	TOTAL EOS EFFECT SCORE COL 3	TOTAL BSR SUCCESS SCORE COL 4	TOTAL 2×EOS+ BSR SCORE COL 5	TOP10 THREAT NO. CONS COL 6	TOP10 CONTROL DIFICULT NO. CONS COL 7	TOTAL TOP 10– COLUMNS 6 + 7 COL 8
Setaria palmifolia	palmgrass	N/A	N/A	N/A	0	0	0
Solanum jasminoides	potato vine	9	14	32	0	0	0
Solanum linnaeanum	apple of Sodom	3	12	18	0	1	1
Solanum mauritianum	woolly nightshade	5	14	24	1	0	1
Solanum pseudocapsicum	Jerusalem cherry	4	11	19	0	0	0
Sorbus aucuparia	rowan	7	11	25	0	0	0
Spartina alterniflora	American spartina	7	8	22	1	0	1
Spartina anglica	spartina	7	11	25	0	2	2
Spartina × townsendii	spartina hybrid	7	11	25	0	0	0
Stipa neesiana	Chilean needlegrass	4	10	18	0	0	0
Stipa trichotoma	nassella tussock	7	13	27	0	0	0
Syzygium australe	brush cherry	N/A	N/A	N/A	0	0	0
Teline monspessulana	Montpellier broom	6	13	25	0	0	0
Thymus vulgare	thyme	N/A	N/A	N/A	1	1	2
Tradescantia fluminensis	wandering Jew	8	9	25	6	3	9
Tropaeolum majus	nasturtium	4	11	19	0	0	0
Tropaeolum speciosum	Chilean flame creeper	5	13	23	2	4	6
Tussilago farfara	coltsfoot	5	16	26	0	0	0
Ulex europaeus	gorse	7	14	28	3	0	3
Undaria pinnatifida	undaria	N/A	N/A	N/A	2	2	4
Vaccinium corymbosa	blueberry	N/A	N/A	N/A	0	0	0
Vinca major	periwinkle	5	12	22	0	1	1
Vitis vinifera	grape	N/A	N/A	N/A	0	1	1
Watsonia bulbillifera	watsonia	4	9	17	0	0	0
Zantedeschia aethiopica	arum lily	5	12	22	0	0	0
Zizania latifolia	Manchurian rice grass	N/A	N/A	N/A	0	0	0

Appendix 2

WEEDS IN NEW ZEALAND PROTECTED AREAS: SUMMARY OF INTERNATIONAL AND NEW ZEALAND BIOLOGICAL CONTROL PROJECTS

Explanation

The weeds database (botanical and common names) is from Owen (1997). Information on biological control projects is from Julien & Griffiths (1998) unless specified otherwise (N/A = not available).

BOTANICAL NAME	SPECIES COMMON NAME	INTERNATIONAL AND NEW ZEALAND BIOCONTROL PROJECTS (NUMBER, LOCATION AND STAGE)	OUTCOMES OF BIOCONTROL PROGRAMMES WHERE KNOWN
Acer pseudoplatanus	sycamore	None known	N/A
Acmena smithii	monkey apple	None known	N/A
Actinidia chinensis	kiwifruit	None known	N/A
Agapanthus praecox	agapanthus	None known	N/A
Ageratina adenophora	Mexican devil	9 projects with agent (2 spp.) releases 1945–91 in S. Africa, Australia, Hawaii, India, NZ (1958), China, Thailand	Project outcomes mixed: agents not established (2); initial damage then efficiency reduced by parasitism (2 including NZ); overall no control (3); partial control (2)
Ageratina riparia	mist flower	6 projects with agent (4 spp.) releases 1960–89 in Hawaii, S. Africa & Australia. NZ: White smut fungus introduced on behalf of ARC in 1998 (Landcare Research). Application lodged by ARC with NZ ERMA to release mist flower gall fly: no decision as at 30/06/00 (ERMA web site)	Project outcomes mixed: agents not established (1); little control (1), agent spreading (1), control (3 different agents in Hawaii). NZ: white smut fungus is established and causing damage (Pauline Syrett, pers. comm.)
Agrostis capillaris	browntop	None known	N/A
Allium triquetrum	onion weed	None known	N/A
Alnus glutinosa	alder	None known	N/A
Alocasia brisbanensis	elephant's ear	None known	N/A
Alternanthera philoxeroides	alligator weed	11 projects. Agent (4 spp.) releases 1964–82 in Australia, NZ (2 spp. in 1982 and 1 sp. 1984–87), China, Thailand, USA	Project outcomes mixed: agents not established (2 incl. NZ), unknown effects (1–NZ); variable with little effect in colder areas (3), control aquatic plants seasonally (4). Only 1 sp. (in USA) affects terrestrial plants. In all cases control in colder areas is a problem. NZ: 2 agents established with some damage in some situations (Pauline Syrett, pers. comm.). Substantial damage not widely observed in NZ (Stewart et al. 1996)
Ammophila arenaria	marram	None known	N/A
Anredera cordifolia	Madeira vine	None known	N/A
Araujia sericifera	moth plant	NZ Landcare Research feasibility study (Winks & Fowler 2000)	
Aristea ecklonii	aristea	None known	N/A

BOTANICAL NAME	SPECIES COMMON NAME	INTERNATIONAL AND NEW ZEALAND BIOCONTROL PROJECTS (NUMBER, LOCATION AND STAGE)	OUTCOMES OF BIOCONTROL PROGRAMMES WHERE KNOWN
Arrhenatherum elatius	tall oatgrass	None known	N/A
Arum italicum	Italian lily	None known	N/A
Arundo donax	giant reed	None known	N/A
Asparagus asparagoides	smilax	Included in NZ Landcare Research feasibility study on *A. scandens*. 1st agent (leaf hopper) introduced into Australia 1999/2000. Specificity testing currently for 3 other agents (Ainsworth 1999)	Too early to tell
Asparagus scandens	climbing asparagus	NZ Landcare Research feasibility study (Syrett 1999b)	
Berberis darwinii	Darwin's barberry	This may be subject to a future Landcare Research feasibility study	N/A
Berberis glaucocarpa	barberry	Ditto	
Bromus tectorum	cheatgrass, downy brome	None known	N/A
Bryonia cretica ssp.	white bryony	None known	N/A
Buddleja davidii	buddleia	Laboratory trials by NZ Forest Research. Application to ERMA being prepared for 1st agent; trials proceeding with 2nd agent (Brockerhoff et al. 1999)	Trials have shown significant reduction in stem length and biomass with 1st agent (Brockerhoff et al. 1999)
Caesalpinia decapetala	Mysore thorn	None known	N/A
Calluna vulgaris	heather	1 agent introduced into NZ Tongariro National Park in 1996.	Agent recently recovered (P. Syrett, pers. comm.)
Carduus nutans evaluation	nodding thistle	11 projects with agent releases (5 spp.) in USA, Canada, Argentina for the *C. nutans* group and 6 projects (3 agents) for *C. nutans* ssp. *nutans* in Australia and NZ	Of 3 spp. in Australia: under (2); early season seed reduction but not sufficient (1). Of 3 NZ spp.: reduction in seed (2) and reduction in thistle density (1).
Carex longebrachiata	Australian sedge	None known	N/A
Celastrus orbiculatus	Climbing spindleberry	None known	N/A
Ceratophyllum demersum	hornwort	One of a suite of aquatic plants for which various carp and non-selective fish species have been used. Not true biocontrol	N/A
Cestrum aurantiacum	orange cestrum	None known	N/A
Cestrum elegans	red cestrum	None known	N/A
Chrysanthemoides monilifera	boneseed	6 species introduced to Australia between 1989 and 1996. Australia: application to release a defoliating moth has been prepared and testing is proceeding for a mite, rust fungus and beetle (Ainsworth 1999). NZ: overseas agent investigations beginning (Pauline Syrett, pers. comm.); feasibility study (Syrett 1999a)	Establishment has not been confirmed for 5 agents. 1 agent has established at some release sites with reductions in flowers and fruit. Overall impact limited by poor rate of establishment in cooler, drier and more protected sites
Cirsium spp.	thistles	13 projects (5 spp.) for *C. arvense* in Australia, NZ, Canada, USA, 1963–94. Including 3 spp. for NZ. 1 agent introduced for *C. palustre* in NZ in 1984. 11 projects (3 spp.) including multiple releases for *C. vulgare* in Australia, Canada, S. Africa, NZ, USA	Projects for *C. arvense* have had minimal impact with agents failing to establish, or having a minimal or unknown impact. The NZ projects reflected the international trends. The agent for *C. palustre* established with redistribution continuing.

BOTANICAL NAME	SPECIES COMMON NAME	INTERNATIONAL AND NEW ZEALAND BIOCONTROL PROJECTS (NUMBER, LOCATION AND STAGE)	OUTCOMES OF BIOCONTROL PROGRAMMES WHERE KNOWN
			Projects for *C. vulgare* have so far had a minimal impact, with most agents failing to establish, or establishment is uncertain, or the impact is unknown
Clematis flammula	clematis	None known	N/A
Clematis vitalba	old man's beard	3 agents have been introduced into NZ (fungus, leaf miner, saw fly)	2 agents have established (Pauline Syrett, pers. comm.). NZ 1st country to use agents; too soon to tell effects. Agents attack foliage (Landcare Research)
Cobaea scandens	cathedral bells	None known	N/a
Convolvulus arvensis	convolvulus, field bindweed	2 agents each introduced to USA and Canada in 1987–89. 2 agents for *C. sepium* introduced into USA	Agent not established (2) or establishment not confirmed (2) for *C. arvensis*. Establishment of agents for *C. sepium* not confirmed
Cortaderia jubata	purple pampas grass	NZ Landcare Research feasibility study (McGregor 2000a)	
Cortaderia selloana	pampas grass	Ditto	
Cotoneaster glaucophyllus	cotoneaster	None known	N/A
Cotoneaster simonsii	Khasia berry	None known	N/A
Crataegus monogyna	hawthorn	None known	N/A
Crocosmia × crocosmiiflora	montbretia	None known	N/A
Cytisus scoparius	broom	7 projects (deliberate introductions) (4 spp.) in USA, NZ, Australia. 3 accidental introductions: 1–NZ; 2–USA. NZ: 2 agents released as at 08/99. 1 agent self-introduced. Further investigations proceeding (Landcare Research)	Of the deliberate introductions establishment has not been confirmed (3); impact is unknown (1–NZ), seed production is reduced (2 including 1–NZ); and overall effect is negligible (1). The 1 NZ accidental introduction kills twigs and sometimes branches and bushes
Dactylis glomerata	cocksfoot	None known	N/A
Dipogon lignosus	mile-a-minute	None known	N/A
Echium vulgare	viper's bugloss	NZ: Accidentally introduced agent for *E.candicans* is present on *E. vulgare.* Australia: 7 agents introduced for *Echium plantagineum*	N/A
Egeria densa	egeria	One of a suite of plants for which various carp and other non-selective fish species have been used. Not true biocontrol	N/A
Ehrharta erecta	veld grass	None known	N/A
Ehrharta villosa	pyp grass	None known	N/A
Elaeagnus × reflexa	elaeagnus	None known	N/A
Equisetum arvense	horsetail	None known	N/A
Erica lusitanica	Spanish heath	None known	N/A
Erigeron karvinskianus	Mexican daisy	None known	N/A
Eriobotrya japonica	loquat	None known	N/A
Euonymus europaeus	spindleberry	None known	N/A
Euonymus japonicus	Japanese spindleberry	None known	N/A
Eupatorium cannabinum	hemp agrimony	None known	N/A
Festuca arundinacea	tall fescue	None known	N/A

BOTANICAL NAME	SPECIES COMMON NAME	INTERNATIONAL AND NEW ZEALAND BIOCONTROL PROJECTS (NUMBER, LOCATION AND STAGE)	OUTCOMES OF BIOCONTROL PROGRAMMES WHERE KNOWN
Glyceria fluitans	floating sweetgrass	One of a suite of plants for which various carp and other non-selective fish species have been used. Not true biocontrol	N/A
Gymnocoronis spilanthoides	Senegal tea	None known	N/A
Gunnera tinctorea	Chilean rhubarb	None known	N/A
Hakea gibbosa	hakea, downy	1 agent to S. Africa in 1972	Established but large-scale fruit destruction not achieved
Hakea salicifolia	willow-leaved hakea	None known for this species.	N/A
Hakea sericea	prickly hakea	3 agents introduced to S.Africa 1972–79. A native fungus is used to a limited extent	1 agent limits regeneration after fire, 1 agent is causing significant seed damage and 1 agent causing insignificant damage. Native agent causing gummosis and plant death
Hedera helix	ivy	None known	N/A
Hedychium flavescens	yellow ginger	A feasibility study has been completed for NZ by Landcaare Research (Harris et al. 1999)	
Hedychium gardnerianum	kahili ginger	As above	
Hieracium spp.	hawkweed	Two agents have been introduced into New Zealand.	1 agent has been recovered (Pauline Syrett, pers. comm.)
Humulus lupulus	hops	None known	N/A
Hydrilla verticillata	hydrilla	5 projects involving 4 agents in USA and Mexico from 1987 to 1995. NZ: 1 grass carp project in at least 1 lake (not classical biocontrol). Lab and field trials with a fungal pathogen in USA (Shearer 1996)	2 agents established in Florida (USA) with 1 of these agents established in several other states. 1 agent impacting on plant density in waterbodies where it is established
Hydrodictyon reticulatum	water net	None known	
Hypericum androsaemum	tutsan	1 agent deliberately introduced to NZ (1947). 1 agent accidentally introduced to both NZ (pre 1952) and Australia	Deliberate introduction has not persisted. Accidental introduction is present at a number of sites in NZ and can cause severe damage and death over wide areas. Overall impact unknown. In Australia weed levels reduced to insignificant levels within 5 years of 1st record
Hypericum perforatum	St John's wort	Many introductions internationally involving 9 agents to 6 countries. NZ introductions of 3 spp: 1943,1961, 1963	Internationally variable response. NZ: 1943 agent established throughout weed distribution, significant impact in some areas but overall level of control varies temporally and spatially. High densities of 1961 agent can prevent flowering and kill seedlings but overall effect unknown
Ipomoea indica	blue morning glory	None known	N/A
Iris foetidissima	stinking iris	None known	N/A
Iris pseudacorus	yellow flag iris	None known	N/A
Jasminium humile	yellow jasmine	None known	N/A
Jasminum polyanthum	jasmine	None known	N/A
Juglans ailantifolia	Japanese walnut	None known	N/A
Juncus acutus	sharp rush	None known	N/A
Juncus articulatus	jointed rush	None known	N/A

BOTANICAL NAME	SPECIES COMMON NAME	INTERNATIONAL AND NEW ZEALAND BIOCONTROL PROJECTS (NUMBER, LOCATION AND STAGE)	OUTCOMES OF BIOCONTROL PROGRAMMES WHERE KNOWN
Juncus bulbosus	bulbous rush	None known	N/A
Juncus effusus	soft rush	None known	N/A
Juncus squarrosus	heath rush	None known	N/A
Lagarosiphon major	lagarosiphon	One of a suite of aquatic plants for which various carp and other non-selective fish species have been used. Not true biocontrol	N/A
Lantana camara var. *aculeata*	lantana	There have been at least 216 deliberate projects involving 36 agents and many countries. There are at least 34 (1–NZ in 1982) recorded cases of agents found in exotic locations where there is no information indicating a deliberate release	Many of the agents deliberately introduced have not established or if they have established they have had minimal effect. About 11 projects provided good control, about 16 projects provided some control. Some agents preferred drier locations while others preferred high humidity. Several projects restricted lantana spread. NZ 1982 record had unknown effect
Larix decidua	larch	None known	N/A
Leycesteria formosa	Himalayan honeysuckle	None known	N/A
Ligustrum lucidum	tree privet	NZ Landcare Research feasibility study (McGregor 2000b)	
Ligustrum sinense	Chinese privet	Ditto	
Lolium perenne	perennial ryegrass	None known	N/A
Lonicera japonica	Japanese honeysuckle	None known	N/A
Lotus pedunculatus	lotus	None known	N/A
Lupinus arboreus	tree lupin	None known. Naturally introduced disease late 1980s	Introduced disease killed extensive areas of lupins (V. Froude)
Lupinus polyphyllus	Russell lupin	None known	N/A
Lycium ferocissimum	boxthorn	None known	N/A
Melianthus major	Cape honey flower	None known	N/A
Mimulus guttatus	monkey musk	None known	N/A
Myriophyllum aquaticum	parrot's feather	1 agent introduced into S. Africa 1994	Agent established but effect unknown
Nephrolepis cordifolia	tuber sword fern	None known	N/A
Olea europaea subsp. *cuspidata*	African olive	None known	N/A
Osmunda regalis	royal fern	None known	N/A
Oxylobium lanceolatum	oxylobium	None known	N/A
Pandorea pandorana	wonga wonga vine	None known	N/A
Paraserianthes lophantha	brush wattle	1 agent introduced into S. Africa 1989	Agent established and under evaluation
Paspalum distichum	Mercer grass	One of a suite of aquatic plants for which various carp and other non-selective fish species have been used. Not true biocontrol	N/A
Passiflora edulis	black passionfruit	None known	N/A
Passiflora mixta	northern banana passionfruit	NZ Landcare Research feasibility study (Fowler 1999)	N/A
Passiflora mollissima	banana passionfruit	3 agents introduced into Hawaii 1988–96. NZ Landcare Research feasibility study (Fowler 1999)	1 agent not established, 2 agents established with 1 under assessment
Pennisetum clandestinum	Kikuyu grass	None known	N/A
Pennisetum macrourum	African feather grass	None known	N/A

BOTANICAL NAME	SPECIES COMMON NAME	INTERNATIONAL AND NEW ZEALAND BIOCONTROL PROJECTS (NUMBER, LOCATION AND STAGE)	OUTCOMES OF BIOCONTROL PROGRAMMES WHERE KNOWN
Pennisetum setaceum	African fountain grass	None known	N/A
Phytolacca octandra	inkweed	None known	N/A
Pinus contorta	lodgepole pine	NZ Forest Research have identified 2 promising cone-feeding agents (Brockerhoff & Kay 1998)	Further work is required to identify level of damage to seed production that is required and host specificity (Brockerhoff & Kay 1998)
Pinus pinaster	cluster/maritime pine	3 prospective agents (seed and cone feeders) from Europe have been identified for S. Africa. Further work is required on host specificity to avoid damage to key commercial species and transfer of pitch canker from *P. radiata* (Moran et al. 2000)	
Pinus spp.	wilding pine	*P. halepensis* – S.Africa: identified some host specific seed/cone feeding agents. *P. radiata* – S. Africa: not pursued biocontrol because of risk of fungus pitch canker being transferred by insect vectors to other pines (Moran et al. 2000)	
Plantago coronopus	buck's horn plantain	None known	N/A
Poaceae	exotic pasture grasses	None known. Many in this family are economically important species and so biocontol has not been pursued	N/A
Polygala myrtifolia	sweet pea bush	None known	N/A
Populus alba	white poplar	None known	N/A
Prunus avium	sweet cherry	None known	N/A
Pseudotsuga menziesii	Douglas fir	None known	N/A
Psoralea pinnata	dally pine	None known	N/A
Pyracantha angustifolia	orange firethorn	None known	N/A
Racosperma dealbatum	silver wattle	None known for this species. Some other species are effectively controlled	N/A
Racosperma longifolium (Acacia longifolia)	Sydney golden wattle	2 agents have been introduced into S.Africa (1982–85)	Collectively these agents have reduced seed production to 1% levels formerly found in S. Africa
Racosperma paradoxum	kangaroo acacia	None known for this species. Some other species are effectively controlled	N/A
Racospermum sophorae	sand wattle	As above	N/A
Reynoutria japonica	Japanese knotweed	None known	N/A
Reynoutria sachalinensis	giant knotweed	None known	N/A
Rhamnus alaternus	evergreen buckthorn	None known	N/A
Rosa rubiginosa	sweet briar	None known	N/A
Rubus fruticosus agg. (8 closely related species)	blackberry	No records of deliberate introduction for each of 2 agents in Australia & NZ. 1 deliberate introduction of 1 agent into Australia in 1991. Current Australian research to clarify *Rubus* taxonomy and identify strains of rust in field (Ainsworth 1999). NZ: Overseas agent investigations beginning (Pauline Syrett, Landcare Research, pers. comm.)	Australia: 1 agent (fungus) sucessfully attacks several species, with average 10% biomass reduction per year for *R. polyanthemus* in Victoria (deliberate introduction of new strain in 1991 increased decline) Impact other agent is unknown. Impact of blackberry rust in NZ patchy and limited (Landcare Research)
Rumex sagittatus	climbing dock	1 agent introduced for 4 Rumex spp. in Australia in 1989	Establishment not confirmed

BOTANICAL NAME	SPECIES COMMON NAME	INTERNATIONAL AND NEW ZEALAND BIOCONTROL PROJECTS (NUMBER, LOCATION AND STAGE)	OUTCOMES OF BIOCONTROL PROGRAMMES WHERE KNOWN
Salix cinerea	grey willow	None known	N/A
Salix fragilis	crack willow	None known	N/A
Salvinia molesta	salvinia, water fern	26 projects in 14 countries from 1971 to 1996. With 4 agents	1 agent (12 projects) was highly effective. The other agents either did not establish, had no effect, or the observed decline in the weed was due to other factors
Sambucus nigra	elder/elderberry	None known	N/A
Sedum acre	stone crop	None known	N/A
Selaginella kraussiana	selaginella	None known	N/A
Senecio glastifolius	pink ragwort	None known	N/A
Senecio angulatus	Cape ivy	None known	N/A
Senecio jacobaea	ragwort	17 projects in Australia, Canada, USA, NZ (4), 1929–90	NZ: 1 sp. not established; 2 spp. minimal effect overall; 1 sp. well established with plant reduction at some sites. Redistribution of several spp. continues
Senecio mikanioides	German ivy	None known	N/A
Senna septemtrionalis	buttercup bush	None known	N/A
Setaria palmifolia	palmgrass	None known	N/A
Solanum jasminoides	potato vine	None known	N/A
Solanum linnaeanum	apple of Sodom	None known	N/A
Solanum mauritianum	woolly nightshade	NZ Landcare Research feasibility study (McGregor 1999a). Agent investigations beginning (P. Syrett, pers. comm.)	N/A
Solanum pseudocapsicum	Jerusalem cherry	Ditto	
Sorbus aucuparia	rowan	None known	N/A
Spartina alterniflora	American spartina	Investigations in Australia (Paul Hedges, DPIWE, Tasmania, pers. comm.)	N/A
Spartina anglica	spartina	Ditto	N/A
Spartina × *townsendii*	spartina hybrid	Ditto	N/A
Stipa neesiana	Chilean needlegrass	Landcare Research Feasibility study (McGregor 1999c)	
Stipa trichotoma	nassella tussock	Ditto	
Syzygium australe	brush cherry	None known	N/A
Teline monspessulana	Montpellier broom	None known	N/A
Thymus vulgare	thyme	None known	N/A
Tradescantia fluminensis	wandering Jew	None known	N/A
Tropaeolum majus	nasturtium	None known	N/A
Tropaeolum speciosum	Chilean flame creeper	None known	N/A
Tussilago farfara	coltsfoot	None known	N/A
Ulex europaeus	gorse	6 agents have been introduced into New Zealand 1930–91. 12 other projects involving 9 agents in Australia, USA esp. Hawaii, Chile 1926–95	NZ results are not promising. The foliage feeders are not doing much damage although thrips can decrease growth by 10–20% and gorse spider mite can damage occasional plants. Seed feeders have not been eating enough seed, especially in autumn (Pauline Syrett, Landcare Research, pers. comm.). International: 2 agents have had some effect in Hawaii
Undaria pinnatifida	undaria	None known	N/A
Vaccinium corymbosa	blueberry	None known	N/A

BOTANICAL NAME	SPECIES COMMON NAME	INTERNATIONAL AND NEW ZEALAND BIOCONTROL PROJECTS (NUMBER, LOCATION AND STAGE)	OUTCOMES OF BIOCONTROL PROGRAMMES WHERE KNOWN
Vinca major	periwinkle	None known	N/A
Vitis vinifera	grape	None known	N/A
Watsonia bulbillifera	watsonia	None known	N/A
Zantedeschia aethiopica	arum lily	CSIRO (Aust) has carried out a preliminary survey for agents in S. Africa. No seed predators found. Currently identifying pathogens on plant in Australia (CSIRO website)	N/A
Zizania latifolia	Manchurian rice grass	None known	N/A

For summary of recent New Zealand Landcare Research biocontrol feasibility studies, see Appendix 5.

Appendix 3

SELECTION CRITERIA FOR WEED SPECIES FOR AN INITIAL BIOCONTROL FEASIBILITY ASSESSMENT

Explanation

*Combined conservancy scores (this is column 8 from Appendix 1). A weed species scored one point for each conservancy that recorded the species as:

- A top-ten weed species for impact
- A top-ten weed species in terms of difficulty to control.

BOTANICAL NAME	SPECIES COMMON NAME	*COMBINED CONSERVANCY SCORES	WHETHER SELECTED FOR INITIAL ASSESSMENT	MAIN REASONS FOR SELECTION OR NON-SELECTION
Ammophila arenaria	marram grass	6	No	Still being planted in some areas for soil conservation purposes in dunelands. Biocontrol likely to be opposed at this time.
Anredera cordifolia	Madeira vine	5	Yes	Reduction of biomass useful, especially as this is a non-fruiting species in NZ
Araujia sericifera	moth plant	7	No	Landcare Research feasibility study completed (Winks & Fowler 2000)
Asparagus asparagoides	smilax	6	No	Feasibility study completed by Landcare Research (Syrett 1999b)
Asparagus scandens	climbing asparagus	5	No	Ditto
Calluna vulgaris	heather	5	No	Biocontrol programme under way
Ceratophyllum demersum	hornwort	4	No	This species is highly damaging to freshwater habitats, although its 'score' is depressed given its limited distribution to date. There is a containment programme to exclude the species from the South Island (Owen 1998). There is a lot of genetic variation internationally—the origin of the NZ material is unknown (P. Champion, NIWA, pers. comm.)
Chrysanthemoides monilifera	boneseed	4	No	Feasibility study has been completed by Landcare Research (Syrett 1999a)
Clematis vitalba	old man's beard	7	No	Biocontrol programme under way
Cortaderia jubata	purple pampas grass	9	Yes	Serious weed—biomass reduction would be useful. Landcare feasibility study completed (McGregor 2000 a)
Cortaderia selloana	pampas grass	9	Yes	Ditto
Cytisus scoparius	broom	6	No	Biocontrol programme under way
Elaeagnus × reflexa	elaeagnus	5	No	This scored relatively highly because it is hard to control, but it is not widespread nor a major threat
Equisetum arvense	horsetail	4	No	This is hard to control rather than a threat
Hieracium spp.	hawkweed	5	No	Biocontrol programme under way

BOTANICAL NAME	SPECIES COMMON NAME	*COMBINED CONSERVANCY SCORES	WHETHER SELECTED FOR INITIAL ASSESSMENT	MAIN REASONS FOR SELECTION OR NON-SELECTION
Lagarosiphon major	lagarosiphon	6	Yes	This is now a widespread plant in aquatic systems and is difficult to control effectively on a long-term basis. It can be beneficial in shallow lakes that are highly eutrophic
Lonicera japonica	Japanese honeysuckle	9	Yes	Reduction of biomass would be worthwhile. This is a widespread plant especially outside reserves. A reduction outside reserves is likely to help inside reserves
Pinus contorta	lodgepole pine	8	No	Current Forest Research investigations (Brockerhoff & Kay 1998)
Pinus spp.	wilding pines	6	No	A suite of species, including economically valuable species, which could be adversely affected. Landcare Research feasibility study completed (McGregor 2001)
Rhamnus alaeternus	evergreen buckthorn	4	No	This is difficult to control rather than widespread
Salix cinerea	grey willow	7	Yes	Biomass reduction would be worthwhile. Adversely affects many wetlands/ aquatic habitats
Salix fragilis	crack willow	6	Yes	Ditto
Tradescantia fluminensis	wandering Jew	9	Yes	Reduction of biomass would be worthwhile
Tropaeolum speciosum	Chilean flame creeper	6	No	Difficult to control rather than widespread. Priority is to eradicate at particular sites
Undaria pinnatifida	undaria	4	No	Marine biocontrol not yet developed. Problem species in Australia too

Appendix 4

RELEVANT LEGISLATIVE PROVISIONS

Conservation Act 1987

The Department's functions (section 6) include:

- Managing all land and other resources held under the Act for conservation purposes (s6(a))
- Preserving indigenous fisheries and protecting freshwater fish habitats (s6(ab)).

The Director-General (section 53):

"Shall advocate the conservation of aquatic life and freshwater fisheries generally" (s53(3) (g))

"Shall acquire by means of purchase or otherwise and protect habitats" (s53 (3) (f))

"May control any introduced species causing damage to any indigenous species or habitat" (s53 (3) (g)).

Reserves Act 1977

This Act shall be administered in the Department of Conservation for the purpose of:

"(a) Providing for the preservation and management for the benefit and enjoyment of the public, areas of New Zealand…

(b) Ensuring, as far as possible, the survival of all indigenous species of flora and fauna, both rare and commonplace, and the preservation of representative samples of all classes of natural ecosystems and landscapes…" (section 3).

National Parks Act 1980

"[National parks] shall be preserved as far as possible in their natural state" (section 4(2)).

Marine Reserves Act 1971

The purpose of marine reserves is to preserve:

"for the scientific study of marine life, areas of New Zealand that contain underwater scenery, natural features, or marine life, of such distinctive quality, or so typical, or beautiful, or unique, that their continued preservation is in the national interest (s3(1)).

(a) They shall be preserved as far as possible in their natural state.

(b) The marine life of the reserves shall as far as possible be protected and preserved.

(c) The value of the marine reserve as the natural habitat of marine life shall as far as possible be maintained."

Appendix 5

RECENT LANDCARE RESEARCH FEASIBILITY STUDIES ON BIOLOGICAL CONTROL OF WEEDS

WEED	AUTHOR	MAIN FINDINGS/RECOMMENDATIONS
moth plant: *Araujia sericifera*	Winks & Fowler 2000	• No biocontrol investigations elsewhere in world. • Some potential agents have been identified in its native range of South America. • Recommended: survey of insects and pathogens on moth plant in NZ. • Recommended collaboration with research organisations in countries where moth plant is a problem.
climbing asparagus: *Asparagus scandens*	Syrett 1999b	• Any biocontrol programme will be limited by need to find control agents that do not damage cultivated asparagus. • No known biocontrol agents available. • Most biocontrol agents identified for closely related *A. asparagoides* are unlikely to be effective. • The Australian biocontrol programme for *A. asparagoides* has identified one insect that has potential if attacks on cultivated asparagus can be tolerated. • Recommended: survey of insects and pathogens on plant in NZ; test insects identified for Australian biocontrol programme for *A. asparagoides*; conduct a survey in S. Africa for insects and pathogens attacking the plant.
boneseed: *Chrysanthemoides monilifera*	Syrett 1999a	• In NZ boneseed occurs in stable habitats that are favourable to the establishment of biocontrol agents and in areas climatically similar to those from which biological control agents would be sourced. • Agents have been introduced into Australia for the control of boneseed and bitou bush. This experience can be used to assist NZ. • There are no closely related species of economic or conservation importance. • At least 3 insect species and a rust fungus are potential biological control agents for boneseed in NZ. • Estimate for the screening and introduction of 2 insect control agents is $200,000 over 3 years.
pampas grass: *Cortaderia* spp.	McGregor 2000a	• Prospects for classical biocontrol are poor. • The best prospect would be a mycoherbicide if a suitable fungus could be identified. • Possibility of collaboration with other countries (especially USA, Australia) where pampas is a problem. • NZ has five endemic species of *Cortaderia* so any biocontrol agent would need to be highly host-specific.
wild ginger: *Hedychium* spp.	Harris et al. 1999	• There are no endemic members of the family Zingiberaceae in NZ. • Several pathogens have been identified as potential agents. Specificity testing is needed. • Initial steps include a collection trip to India, monitoring wild ginger response to a bacterium in Hawaii, surveying NZ wild ginger for pathogens and invertebrates.

WEED	AUTHOR	MAIN FINDINGS/RECOMMENDATIONS
privet: *Ligustrum* spp.	McGregor 2000b	• Four species in NZ, with 2 being weeds. • Other NZ members of Oleaceae include 4 species of *Nestegis* (maire) and cultivated species including olive, lilac and ash. • *Ligustrum* spp. has been poorly surveyed in area of origin (SE Asia) and so prospects of discovering natural enemies that could be biocontrol agents look good. • CABI Bioscience has begun an investigation of *L. robustum* subsp. *walker*. This offers opportunities for collaboration. It is recommended that NZ species be included in agent host-specificity testing.
Chilean needle grass: *Nassella neesiana*	McGregor 1999c	• Chilean needle grass is less closely related to NZ native stipoid grasses than previously through. This improves prospect of finding a safe agent. • Prime biocontrol candidates are fungal pathogens. • Prospects are difficult to assess as Chilean needle grass has a more complex reproductive system than nassella tussock which may reduce impact of types of agent that work well for nassella tussock. • Recommendations: incorporating this programme into a similar programme for nassella tussock, with modifications; collaboration with Australian researchers to reduce costs. • Estimated cost to test 2 fungi in quarantine is $200,000 over 3 years.
nassella tussock: *Nassella trichotoma*	McGregor 1999b	• An Australian programme to attempt biocontrol of nassella tussock is under way. Collaboration is recommended to reduce costs. • As nassella tussock is a grass, a large number of plants would need to be included in host-specificity trials. • Estimated cost to test 2 fungi in quarantine is $200,000 over 3 years.
banana passionfruit: *Passiflora mollissima, P. mixta*	Fowler 1999	• *P. mollissima* has been the target of a biocontrol programme in Hawaii since 1981. Two moth species and one fungal pathogen released in the 1990s. Only one insect has established, but it has not had a significant impact to date. • A fungal pathogen was released in 1996 but more time is needed to assess its impact. More agents are being investigated. • Recommendations: collecting further information on current and future weed status in NZ; survey of insects and pathogens attacking banana passionfruit in NZ; maintain links with Hawaiian researchers to keep informed of progress there. • Review situation in 3–5 years and reassess Hawaiian situation.
woolly nightshade: *Solanum mauritianum*	McGregor 1999a	• A South African programme has released one agent. • Several other insects are candidates for the S. African programme but their host specificity has not been determined. There are problems with commercial species such as eggplant. • Recommendations: monitor S. African programme; review invertebrates and diseases on NZ woolly nightshade and native *Solanum* spp.; collaborate with S. African researchers to test S. African agents on NZ native and commercial *Solanum* species.