A proposed conservation weed risk assessment system for the New Zealand border

SCIENCE FOR CONSERVATION 208

Peter A. Williams, Aaron Wilton and Nick Spencer

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 0-478-22331-5

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

CONTENTS

A proposed conservation weed risk assessment system for the New Zealand border

Peter A. Williams[1], Aaron Wilton[2] and Nick Spencer[2]

[1]Landcare Research, Private Bag 6, Nelson, New Zealand
[2]Landcare Research, P.O. Box 69, Lincoln, New Zealand

ABSTRACT

Existing border weed risk assessment models have deficiencies relating primarily to the low proportion of imports that become weeds and the lag times before they may do so. A new system was developed from data on the behaviour of 25 000 exotic plant species already in New Zealand, and the weediness of their close relatives. Species transition rates from one invasion stage to the next, i.e. present in New Zealand, to naturalised, to conservation weeds, are highly variable for different groupings of plants. This variation was used to develop a score based on the *chance,* or probability, that a new species will become a conservation weed. This was modified by consideration of the ease and time it would take to identify escaped populations in the wild, and estimates of how difficult the species would be to control. Because the potential effects of a new species are speculative, an impact score was calculated based only on the present New Zealand distribution and documented impacts of conservation weeds of similar life forms to the assessed species. Examples of the outputs from this system, compared with the results of others, indicate it has potential to assist in weed risk assessment at the border. Suggestions are made for testing the system, either by using historical New Zealand data, or by applying it in other regions outside New Zealand.

Keywords: Weed risk assessment, plant introductions, biosecurity, conservation.

Williams, P.A.; Wilton, A.; Spencer, N. 2002: A proposed conservation weed risk assessment system for the New Zealand border. *Science for Conservation 208.* 47 p.

1. Introduction

The Department of Conservation is required to provide policy advice to the Minister responsible for biosecurity on the risks posed by potential new organisms (including new weed species and new genomes of exotic taxa already present in New Zealand) to indigenous flora and fauna. In part, this is because the Hazardous Substances and New Organisms Act 1996 (HSNO Act) states that species not present in New Zealand be assessed by the Environmental Risk Management Authority (ERMA) for the risks, e.g. to native biodiversity, and benefits, e.g. to the economy, of allowing them into New Zealand. In essence, the legislation requires that a species would have a low probability of establishing in the wild and be unlikely to have significant effects on conservation values, before it will be allowed entry.

A scoping report identified the issues surrounding the importation of potential new weeds into New Zealand (Williams et al. 2000). The report concluded that New Zealand has been exposed to most of the range of weed impacts reported throughout the world, although novel impacts must be expected from any new invaders. In a broad sense, the report identified the ecosystems most vulnerable to impacts from weeds. The most likely reasons for plant importation were determined from importation records, along with the plant families these species were likely to belong to, their regions of origin, and entry pathways. In recent decades, new species have arrived directly from South East Asia and South America, with only a limited history of cultivation and naturalisation outside their native region. As a result, new species of weeds are appearing in New Zealand that have no history of weediness elsewhere.

Existing screening methods successfully detected, and deflected, many potential weeds from entry (Williams et al. 2000). However, these methods have difficulties in reliably detecting invasion events, which have low probability (Smith et al. 1999). They also give little indication of the likely effects of new weeds. The Department of Conservation therefore requested Landcare Research to develop a weed risk assessment system that addressed these deficiencies.

This report summarises the issues surrounding weed risk assessment, with particular reference to the problems of weed risk assessment systems for new plant species at the border. It proposes ways in which these might be improved.

2. Overview and aims

The increasing world-wide concern with weed invasions has generated growing international demand for weed risk assessment systems, both as quarantine protocols (Forcella & Wood 1984; Panetta 1993; Lonsdale 1994; Hughes 1995; Pheloung et al. 1999) and as prioritising tools for existing weeds.

Many studies have attempted to identify the characteristics of invaders, from the early studies of an 'ideal weed' (Baker 1974) to general studies of groups of plants within a country (Perrrins et al. 1992; Lonsdale 1994; Maillet & Lopez–Garcia 2000), a continent (Thompson et al.1995; Reichard & Hamilton 1997) or throughout the world (Crawley 1987; Mack 1995, 1996; Rejmanek & Richardson 1996; Williamson 1996; Rejmanek 1999, 2000). There are some predictive variables associated with weediness that are broadly applicable over whole plant families, e.g. pines. However, these rarely have predictive value when extended to larger groups, as from pines to non-pines amongst the conifers (Rejmanek & Richardson 1996). The consensus appears to be that no traits are universally important for all species in all habitats. The characteristics of the receiving environment are of equal importance in determining the likelihood of a new species surviving and in shaping the traits it must have to do so (Thompson et al. 1995; Williamson & Fitter 1996; Higgins & Richardson 1998, D'Antonio et al. 2000). Selection for traits also operates in natural environments on the native flora (Keddy 1992; Diaz et al. 1998). The corollary is that the importance of any particular plant trait in determining the success or failure of invasion will be discernable only after the species has either established or is known to have failed in a new habitat. The reliability of the prediction will therefore increase with time since first introduction. Even then, there may be no suite of endogenous plant characters that will reliably predict potential weediness, e.g. for fleshy-fruited woody species in Australia (Mulvaney 2001) and New Zealand (R.B. Allen; pers. comm.), grasses in Australia (Lonsdale 1994) or amongst pasture plants in general (Scott 1999). This is hardly surprising, for it would probably not be possible to predict, simply from flora descriptions, the relative success of our many *Coprosma* species were they, for example, to be introduced into South Australia. There is mounting evidence, however, that propagule pressure, either per individual plant, or through time, does enhance the chance of success for a species (Mulvaney 2001; Kowarik 1995; Mack 1996; Williamson & Fitter 1996; Crooks & Soule 1999; Richardson 1999; Rejmanek 2000).

Weed screening systems have been devised for woody plants in general (Reichard & Hamilton 1997), groups of woody plants (Tucker & Richardson 1995), and water plants (Champion & Clayton 2001), and a few have been developed by national risk assessment authorities such as the United States Department of Agriculture (Lehtonen 2001). The Australian weed risk assessment system (Australian WRA) (Pheloung et al. 1999) is applied at the border by the Australian Quarantine Inspection Service to detect potential weeds amongst all plant groups. The system assumes that if a species has had the opportunity to become a weed in another country, and it has done so, and if the climate and environment are compatible with Australia, then it is likely to become a weed in

Australia. Although this argument is essentially circular, a history of weediness elsewhere has been the most reliable predictor of weediness in several studies (Scott & Panetta 1993; Reichard & Hamilton 1997; Williamson 1998; Maillet & Lopez 2000). This system was modified slightly to suit New Zealand conditions—termed the NZWRA (Pheloung et al. 1999)—and it has been tested in Hawaii where it was the most successful of the systems compared (Daehler & Carino 2000).

There are two major failings to using history as the central argument in weed risk assessment, especially in New Zealand. The first is that an increasing proportion of exotic species growing in New Zealand that are becoming naturalised have no recorded history of becoming weeds in other countries (Williams et al. 2000). It follows that an increasing proportion of plants proposed for importation will be similarly unknown outside their native range. This trend is likely to increase, because only a small proportion of the world's flora and potential weeds have been exchanged between continents (Rapoport 1991), and many others have had insufficient time to exhibit weedy tendencies (Crooks & Soule 1999).

The second major criticism directed towards such models derives from the fact that amongst any group of organisms, those attaining pest status do so at a very low rate (Williamson 1996). Consequently, any screening system is likely to be wrong as often as it is right (Smith et al. 1999). This means many species that would not eventually become weeds would be excluded, and some that would be accepted would become weeds. Various ratios of weeds to non-weeds amongst imported plants have been proposed, ranging from ratios of about 1:1000 for angiosperms in Britain (Williamson & Fitter 1997) to 130:1000 for grasses in tropical Australia (Lonsdale 1994). This wide diversity of ratios, and the effects of lag times changing the ratios, means the search for any universal ratio is futile (Rejmanek 2000). Furthermore, there is no adequate ecological theory to underpin the future impact of those species that do establish in the wild (Parker et al. 1999).

Ratios encompassing all plant species for a region, e.g. Williamson (1996) underestimate the insight to be gained from the variability in weediness among taxonomic groups. On a world scale also, some families are significantly more likely to produce weed species than others. Prominent amongst these are Fabaceae (legumes), Hydrocharitaceae (water plants), Poaceae (grasses) and, particularly, the Myrtaceae (bottle-brush), Rosaceae (roses), Salicaceae (willows), and Tamaricaceae (tamarix). Families less likely to provide weed species are the Orchidaceae (orchids) or Rubiaceae (coffee) (Daehler 1998). An index of invasiveness for a selection of woody angiosperm families on a world scale has been developed by Rejmanek & Richardson (in press) based on the ratio of invasive species to the number of threatened species in a family. The proportion of invasive species in families ranged from 0 to 8%. Rejmanek & Richardson (in press) have developed an invasive index (range: 0 to 1.4) which indicates that the Aceraceae, Betulaceae, Elaeagnaceae, and Salicaeae produce the most invasive woody angiosperm species.

Potential solutions to the problem of predicting the response and impact of new species in new environments have been proposed, ranging from the establishment of international databases (Rejmanek 2000), desk-based screening procedures for very specific groups of plants (Tucker & Richardson 1995), including field trials (Aronson et al. 1992; Mack 1996), and the concentration of prediction efforts on species that have naturalised with varying degrees of success (Smith et al. 1999). The latter approach is appealing because the environment has effectively filtered out a high proportion of candidate exotic species: that is, those that have been able to grow have, and have become established locally; those that cannot, have not. This greatly reduces the chances of an error in estimating potential weediness. Emphasis on recently naturalised species should, therefore, become a much greater priority amongst control authorities in New Zealand. However, the horticulture industry is promoting hundreds of newly listed casual and naturalised species and by the time these are recognised as potential weeds, they will already have been widely grown and sold (Gaddum 1999). This makes it imperative to prevent potential new weeds entering New Zealand.

If a species is a well known pest in other countries, it is easy to review the literature and mount a case to prohibit its entry. However, increasingly this will not be the case, and the following scenario is likely: there is an application to import a plant species from, for example, Bolivia. An assessing officer is likely to have a plant identification which has been checked and verified, the plant family the species belongs to, a general botanical description, some idea of its distribution, and the reason proposed for its introduction. The officer does not have, however, a good regional model relating the characteristics of the plant group, perhaps to the genus level, to the receiving environment (e.g. Tucker & Richardson 1995). The paucity of information means that the model of Pheloung et al. (1999) merely tells the officer to seek more information before making a decision. But none is available. Is it possible to state, more precisely, the risk posed by this species to the conservation land of New Zealand?

The core issues in such an assessment are:

- The probability that it will naturalise, based on the history of its congeners (if there are any) overseas and in New Zealand.
- How difficult would it be to detect and remove at the earliest stage of invasion if it did naturalise in New Zealand, e.g. would it even be distinguishable from native species?
- If it was not controlled, what impacts would it have in New Zealand?

This study aims to develop methodologies to address these three core issues, and to use these to produce a revised border weed risk assessment system for detecting potential weeds of conservation land, and to suggest ways that the system might be tested.

3. Rationale and methods

This section explains the concepts and definitions central to the report, where the data were obtained to develop the new assessment system, and why certain calculations were undertaken.

3.1 DEFINITIONS AND DATA SOURCES

Confusion has arisen in the literature in recent years concerning the nomenclature used in discussion of weediness and invasions (Richardson et al. 2000). This arises because of poor understanding of processes, and because of the lack of distinction between weed population spread and the perceived impact of those weed populations on economic or non-economic values. In this study we were restricted in our terminology to that used in the Lincoln Landcare Research Herbarium (CHR) and that in common usage amongst New Zealand botanists. Species lists were updated for nomenclature and introduction status (e.g. naturalised) following Parson et al. (1995), except for grasses where Edgar & Connor (2000) was used. The following key describes how the status of any individual species was decided:

1. Presence in New Zealand
1a. Absent
1b. Present (go to 2)

2. Present
2a. In cultivation only (here we refer only to introduced exotic species)
2b. Present in the wild (go to 3)

3. Present in the wild
3a. Native (not further dealt with here)
3b. Exotic (= introduced species) (go to 4)

4. Exotic
4a. Casual (exotic) species: one that appears in the wild, but may not form self-sustaining populations. This applies to species which may become naturalised (see below) and those that may have once been naturalised, but no longer have self-sustaining wild populations. It derives principally from the definition of Webb et al. (1988), but has been broadened by Heenan et al. (1998) to include species which are reproducing, i.e. new individuals are growing or clonal material is spreading, but *only in the immediate vicinity* of planted (or discarded) individuals. The species may be doing this without direct human intervention. The essential point of this definition is that the species has not dispersed and established new loci *away from* the original plantings. It may appear in semi-natural or natural habitats, for periods determined by the longevity of the individuals, but those individuals are considered as having parents only at the site of the original plantings. In Webb et al. (1988) and Heenan et al. (1998) the distance involved in 'away' or 'immediate vicinity' were not defined. In effect, they mean the species is not reproducing in any other land use class, i.e. it reproduces *only* in the cemetery, derelict experimental farm (several grasses are in this category (Edgar & Connor 2000)),

or arboretum where the parents grow. In the case of discarded vegetative material, this may, in fact, be 'away' or 'some distance from' cultivated material, but it has not spread vegetatively or sexually from the site where it was carried to, such as a rubbish tip (Heenan et al. 1998). It would be of interest to know if there was anything unique about the site(s) that was allowing the population to spread, in order to predict its future direction, but such details are seldom recorded in herbaria.

4b. Naturalised (exotic) species: one that forms a minimum of one self-sustaining population in the wild 'away' from, or not merely 'in the vicinity of' the original plantings. This population(s) may be in conflict with human values for the area, in which case it would be termed a weed, or it may not.

It should be noted that we do not necessarily agree with all aspects of these definitions, but are constrained by the classifications used by the authors of the available data.

The species classed as casual in our lists include both 'casual' plants and also 'naturalised' plants in terms of the definitions suggested by Richardson et al. (2000). This is because the field observations and herbarium material that the species are classified from in our data do not always allow the distinction between these classes. Wherever possible, however, species used in our calculations are classified as either casual or naturalised.

It is important to realise that many naturalised species will have, at one stage, been casual species. We cannot, therefore, assume all species presently listed as casual in the floras will, in fact, remain so, and neither can we assume that they have previously been self-sustaining and are now declining as Esler (1988) has recorded for many species in Auckland City. Therefore, the future status of recently recorded casual species, especially, is speculative.

Naturalised species may grow primarily in an urban environment, on agricultural/forestry land, or on land with a predominance of natural values, or equally well in all these land classes. They may be considered weeds (in that they conflict with human values) on one or more of these land classes. Whether they are 'weeds' or not varies according to the observer, both overseas (Perrins et al. 1992; Williamson 1993), and as shown by a range of New Zealand assessors (Pheloung et al. 1999). The term 'weed' is used here in the broad sense (but confined to non-native species), to mean any plant interfering with human values. All 'weeds' are either casual or naturalised species, but not all species in these categories are 'weeds'. The term 'invasive species' has often been used to describe species interfering with human values over a wide extent or with a perceived high impact, including conservation values (e.g. Cronk & Fuller 1995) as discussed by Richardson et al. (2000). However, we do not use the term 'invasive species' here because, in common parlance, a naturalised species (as defined above) may be perceived as 'invasive' if it conflicts with human values at any stage of its range expansion. This includes the beginning of its expansion in the wild, e.g. in the under-story of small bush reserves within Auckland city, or at later stages of its spread such as the heather (*Calluna vulgaris*) on the Tongariro Plateau.

The term used here is 'conservation weed': any species, at any stage of its expansion in the wild beyond casual (as we define it), which is perceived by persons working in the area of nature conservation in New Zealand to be impacting in any way on nature conservation objectives. 'Conservation weeds' may also be weeds of other land use classes such as farming. At the time of this study (1999) there were about 250 such species, but the number is dynamic. Species range from those that are widespread and long-established to those which have only recently naturalised and been listed in Owen (1997) or, even more recently, added to the unpublished lists held by DOC (Owen 1998). These are collectively referred to as 'DOC weeds'. Species are added to these lists either because their populations are expanding or because an increasing knowledge of their interaction with the native biota now suggests they are having deleterious effects (e.g. Reid 1998). Note that this later reclassification does not require a species to have recently spread. A combined list used in this study is provided in Appendix 1. This list identifies the several groups of species listed only at the generic level in Owen (1997, 1998).

Some conservation weeds are considered to be having a particularly high impact, usually related to the extent of their spread and local dominance, e.g. old man's beard (*Clematis vitalba*), Russell lupins (*Lupinus polyphyllus*) and heather (*Calluna vulgaris*). Such species would be classified as 'transformers' by Richardson et al. (2000), because they have major impacts on ecosystem processes such as vegetation succession or soil nitrogen status. We do not distinguish this group here.

Apart from the list of DOC weeds (Appendix 1), the major data source used in this study is the ALLWEEDS database held by Landcare Research at Lincoln. These data are a list of all the 24 700 exotic species believed to be in New Zealand, including those in cultivation. The data were originally classified into families ordered according to Hutchinson (1959), whereas we obtained the number of world species in families and genera from Mabberley (1996), who largely follows the slightly different classification system of Cronquist (1981). This necessitated a few adjustments in our subsequent calculations and data, as a few minor families in the database could not be utilised.

A history of weediness in other countries—provided the species has had the opportunity to become weedy—is a useful indicator of potential weediness in new habitats. For this reason, weed history has been incorporated into weed risk assessment models (Pheloung et al. 1999). The ALLWEEDS database records the number of weed lists the species appears on overseas, derived from world lists such as Index Kewensis (Jackson et al. 1895; Mabberley 1997), regional floras and the world (Holm et al. 1977) or regional weed lists (e.g. Lazarides et al. 1997). These lists cover both agricultural and environmental weeds, and poisonous plants, and no distinction was made between classes in our calculations.

Most species in the database have a life form descriptor, allocated by these numerous authors. A life form classification compatible with these descriptors was developed.

3.2 ASSESSING THE LIKELIHOOD OF A PROPOSED INTRODUCTION BECOMING A NEW CONSERVATION WEED

Assessing the probability of a proposed introduction *escaping* is often the first issue to be addressed for any potential pest. However, such events are seldom recorded so we are forced to use surrogates for 'escape', such as 'casual' and 'naturalised'.

We know that the *average* probability of a particular exotic species naturalising, and becoming a weed of any kind, is low, (i.e. < 0.1). However, this probability certainly varies between taxonomic groups (Section 2) and, possibly, other groupings such as life forms. One way of adding precision to an assessment of the likelihood of a particular species becoming a weed would be to calculate the probability of this happening based on the historic records of the class or classes to which the species belongs. This percentage of the particular group to become weeds (in this case) is termed the *base rate*. Obviously, as Rejmanek and others have pointed out, the rate will increase with time as more species of the group naturalise. In the future, databases held by Landcare Research would enable us to update these ratios for New Zealand with every newly recorded naturalisation. Such calculations will also be possible eventually on a world scale. However, at this point, the base rate can be seen as the *minimum* probability of a plant species becoming a weed. To do this it must pass a series of *transition stages,* from being merely present in New Zealand as an exotic (most commonly in cultivation), to a casual adventive, naturalised adventive, weed, conservation (DOC) weed etc.

Using historical records assumes that the existing assemblage of species of a particular group present in New Zealand has been drawn at random from the rest of the group not in the country, and that the next one, i.e. the newly proposed import, will also be drawn at random from the remainder of the group. However, this is unlikely to be the case for several reasons. Species already in cultivation have probably been selected from the pool of their congeners for their ability to establish and persist, e.g. in New Zealand. Furthermore, past selections may have been chosen for a different set of landuse purposes than those presently being selected for in proposed new imports. For example, grass species were mostly selected for pasture production in the early days of New Zealand settlement, but nowadays they are also likely to be selected for ornamental purposes. The environment into which these species are being introduced will also be changing, and may be quite different from that experienced by the earlier arrivals. This will also influence future survival of existing naturalised plant species—as Esler (1988) recorded for Auckland city—as well as the chance that future introductions will behave in a manner similar to their naturalised congeners. To illustrate this point, pampas grasses (*Cortaderia* spp.) would not be the problem they are in New Zealand today, were it not for the waste ground provided by large-scale exotic forestry plantations, a land use that did not exist 100 years ago. As a result of uncertainties like those just described, new species may have different abilities and, hence, probabilities of establishing in the wild in New Zealand than relatives already present here. However, the assumption is made that the transition rates of historical introductions and future introductions will be similar.

There are several ways plants can be categorised to provide information on the likelihood that a particular species will become a conservation weed. Of these, taxonomic groupings such as family and genus, and life form (e.g. perennial woody plant, vine, annual herb) are likely to be the most informative. This is because, on a world scale, conservation weeds are more likely to be aquatic or semi-aquatic (not dealt with in detail in this report), grasses, nitrogen-fixers, climbers and clonal trees (Daehler 1998). Trees are important invaders in New Zealand, but compared with the world as a whole, ferns, grasses, rushes, and woody vines are also likely to be important in New Zealand (Williams et al. 2000). Weed risk experts are aware that certain taxonomic categories of plants have a greater proportion of weeds than others. Woody legumes, grasses, and vines, for example, fall into this category, and species have sometimes been scored for weediness based partly on their life form/taxonomic attributes (Pheloung et al. 1999).

We calculated the various transition rates for all plant families, genera, and major plant life forms present in New Zealand, by comparing the number of species known to be only in cultivation in a grouping, with the number naturalised, and recorded as DOC weeds. Casual species were sometimes used in these calculations as indicated in the Tables.

These data give the probability of a species becoming a DOC weed, based on certain explicit assumptions, but they say nothing of its likely impact on plant communities or ecosystems. Given that we may know very little about new plant species, knowledge of the weediness of a species overseas may be useful. However, because overseas lists often do not pertain specifically to conservation weeds, the number of lists a species appears on may have less utility for detecting conservation weeds than for detecting potential weeds in general at the border. We therefore investigated the relationship between the number of overseas weed lists a species appears on and its perceived relative weediness in New Zealand. For this we used scores for both known weeds and non-weeds made by botanists and conservation workers in New Zealand obtained in a previous study made by one of us (P.A.W.) while testing the Australian WRA (Pheloung et al. 1999). We combined the scores for these two groups of respondents into a single index and compared them with the number of overseas weed lists a species appeared on. Comparisons were undertaken independently for the life form categories adopted for this study (4.1.1).

3.3 ASSESSING THE DIFFICULTY OF MANAGING A NEW CONSERVATION WEED

Risk is an estimate based on probability of an event multiplied by the impact of that event (Orr et al. 1993). However, the potential to manage or mitigate risk is an important adjunct to any assessment of it. Here we estimate the potential to manage the risk as the second component of the overall assessment. This assessment of what is required to manage the risk posed by a new weed is independent of the availability of resources to undertake such management, should the species become established. There are several levels of management including eradication or containment. The appropriate option would be decided only after the species had been detected in the wild as a casual or naturalised exotic. Those attributes of a particular plant species that make it hard to control are likely also to contribute to the impacts it has on the environment. But whereas assessments of the former are based mainly on autecological information about the plant itself, those of the latter make more assumptions about the receiving environment. For example, whether or not birds in the new environment—in this case New Zealand—will eat the fruit and disperse it. Management predictions are likely to be more accurate than those concerning more complex ecosystem interactions with the receiving environment. 'Can it be killed' is easier to answer than 'will it effect biodiversity'?

Of particular importance is ease of detection and removal from the wild. For example, a single nassella (*Stipa trichotoma*) plant (a grass) can be removed more easily than a lone pine tree, but identifying grass species is difficult and requires experience and there is a low chance of identifying a nassella plant at an early invasion stage. In the Australian WRA model (Pheloung et al. 1999) the potential for management action is included in the section on persistence attributes and contributes to the overall weediness score, and its influence on the final score can be seen on the spreadsheet when scoring the species.

An evaluation of the potential benefits of a proposed import is an entirely separate component of the decision process (Pheloung et al. 1999). Species that pose a risk to the environment vary in economic importance from great (e.g. *Pinus* spp.) to minor (e.g. some horticultural species). Methods of weighing the risk to the environment against the potential economic benefits of a new species are beyond the scope of this report. However, it should be noted that while exclusion of an agricultural species on the basis of a false positive assessment (excluding a species which was not actually a weed) may have a significant long-term effect on the New Zealand economy, there would be less effect if a minor ornamental species was excluded (as there will usually be a suitable substitute).

3.4 ASSESSING THE IMPACTS OF A NEW CONSERVATION WEED

Assessing the impacts of a potential new weed involves predicting the interaction between a species not in the country and the environment and biota of that country. Where the species has a history of weediness in other countries with similar climates, soils and biota, some predictions may be possible. Otherwise, predictions of possible interactions are likely to be highly speculative. For this assessment we relied on recent literature and impacts were related to a range of life forms (Williams 1997).

4. Results

The results are in five sections. The first three expand on the issues outlined in the introduction and describe their potential for building into a new weed risk assessment system (4.1–4.3). The fourth section (4.4) describes how these are incorporated into the new weed risk assessment system itself and some examples are presented. The fifth section (4.5) describes how this system might be tested.

4.1 ASSESSING THE LIKELIHOOD OF A NEW CONSERVATION WEED

The first issue to be addressed concerns the probability of a new species becoming a DOC weed, in terms of its taxonomic classes (family and genus) and the life form to which it belongs. An explanation of the life form classification developed is therefore required (4.1.1), and this is followed by an analysis of the transition rates (4.1.2). The usefulness of weed history is examined in section 4.1.3.

4.1.1 Life forms

Many life form classifications are available, beginning with Raunkiaer's scheme (Raunkiaer 1934) and including detailed systems such as that of Esler (1988); but a scheme classifying plants at the border must be able to easily accommodate all species. Terms used in the formal botanical literature to indicate a species' life form are extremely variable, and may or may not include an indication of height (e.g. shrub, or shrub to 2 m); leaf persistence (e.g. evergreen shrub); the presence of vegetative organs such as bulbs or corms (e.g. bulbous herb); the presence of spines (e.g. spiny shrub to 2 m) and so on. These terms can often be related to taxonomy, but this is not universally so. For example, 'herbaceous' is applied to both monocotyledonous and dicotyledonous herbs (annual and perennial). Terms frequently overlap, for example 'small tree' and 'tall shrub'. The total number of such terms taken from the literature on the ALLWEEDS database was 1418. Where no species-specific information is available, the only information for a species will be that describing the genus or family, e.g. woody shrub or tree. There are 31 such terms on the database.

The unambiguous categorisation of these life form terms resulted in a simple classification:

Herbs (except orchids, grasses, bamboos)
Orchids
Grasses (other than bamboo)
Bamboos
Vines (woody and herbaceous but excluding climbing orchids)
Trees and shrubs (except gymnosperms and palms)
Gymnosperms
Palms

Not all plant groups are included here; for example, many annual herbs are listed only as herbs, which is insufficient information to classify them on the basis of longevity as annual or perennial. It would also be desirable to divide vines into herbaceous and woody vines but this was not possible for many exotic species known only in cultivation.

We reclassified all 25 000 species on the ALLWEEDS database according to this system.

4.1.2 Transition rates

Life form is the largest grouping available other than plant families that can be used to examine transition rates of species from one category to another (e.g. naturalised to weed). Life forms vary from being only slightly related to taxonomic groupings at the family level, to being closely related; i.e. grasses are both a life form and a taxonomic unit (Gramineae).

Grasses, excepting bamboos, have the highest naturalisation rate of 42.8%, followed by bamboos at 28% (Table 1). Vines naturalise at three times the rate of trees and shrubs other than gymnosperms and palms (13.5% cf. 4.2%). Gymnosperm trees and shrubs naturalise twice as fast as their non-gymnosperm counterparts. Some large groups, namely palms, naturalise at less than 1%, while no orchids (not shown) have naturalised. These relationships are obviously highly dependent on the families contributing to the life forms. Two very large families—Asteraceae (daisies) and Fabaceae (legumes)—are shown broken into the three major life-form categories. Vines naturalise about twice as fast as trees and shrubs in both the Asteraceae and Fabaceae. There are only a few Asteraceae vines involved, but in the Fabaceae where there is a larger sample, the naturalisation rate of vines is similar to non-vine herbs. While there

TABLE 1. TRANSITION RATES FOR SELECTED LIFE FORMS ACROSS ALL FAMILIES AND WITHIN SEVERAL FAMILY GROUPINGS.
NAT'D = NATURALISED, CAS. = CASUAL.

FAMILY	SELECTED LIFE FORMS	TOTAL N.Z. SPP. (N)	CAS. IN N.Z. (N)	NAT'D IN N.Z. (N)	NAT'D/ TOTAL N.Z. SPP. (%)	DOC WEED SPP. IN GROUP* (N)	DOC WEED/ TOTAL N.Z. SPP. (%)	DOC WEED NAT'D PLUS CAS. SPP. (%)
Various	Vines	505	16	68	13.5	25	5.0	29.8
Various	Trees and shrubs except gymnosperms and palms	2829	42	118	4.2	134	4.7	83.8
Various	Gymnosperms, trees and shrubs	372	5	28	7.5	13	3.5	39.4
Various	Palm trees and shrubs	601	0	3	0.5	0	0.0	0.0
Various	Grasses except bamboos	505	43	216	42.8	32	6.3	12.3
Bambusa	Bamboos	57	0	16	28.0	0	0.0	0.0
Selected families								
Asteraceae	Herb	851	41	169	19.9	17	2.0	8.1
Asteraceae	Trees and shrubs	66	3	9	13.6	2	3.0	6.0
Asteraceae	Vines	6	1	2	33.3	2	33.3	66.0
Fabaceae	Herb	317	10	64	20.2	2	0.6	2.7
Fabaceae	Trees and shrubs	462	9	41	8.9	18	3.9	36.0
Fabaceae	Vines	43	1	8	18.6	1	2.3	1.1

* Includes casual and naturalised, which is why some DOC/naturalised are very high.

are important exceptions (e.g. *Clematis vitalba*), most vines are annual or perennial herbs with relatively short generation times, which probably accounts for their faster naturalisation rate compared with their woody close relatives.

The naturalisation rate of individual plant families ranges from 0 to 100% (Table 2). In the case of some families, most (> 80%) of the world's species have already been introduced into New Zealand, e.g. *Pinus* spp. At the other extreme are families where < 20% of the world's flora has been introduced. Some of the latter group show high (> 10%) rates of naturalisation, indicating a large pool of potential weed species.

The average naturalisation rate for all families with at least one DOC weed, together with all other families with five or more species that are weeds, is 2.3%. Some families are several times more likely to naturalise than the average, irrespective of their size: Salicaceae (willows), Juncaceae (rushes), and Poaceae (all grasses) have the highest naturalisation rates. Table 2 shows all the families represented as DOC weeds (in 1999). Many of these families are already represented throughout New Zealand by more than 20% of their total world flora, in part because of intense efforts to establish them here, e.g. the large number of willows (*Salix* spp.) of the family Salicaceae (Van Kraayenoord et al. 1995). But for many others, less than 10% of the world's flora has even arrived in New Zealand. Many of these have a naturalisation rate in excess of 10%, e.g. Hydrocharitaceae (water plants), Cyperaceae (sedges), and Haloragaceae (water plants and others). Were proposed imports drawn from families at random—which is probably not the case, as discussed—these families would pose the greatest threat because they show the greatest ability to naturalise and most species in the family have still to arrive here.

The mean transition rate from 'present in New Zealand' to 'DOC weed' for families with at least one weedy species is 7%. The distribution of the transition rate data is highly skewed, with many families having less than 5% weeds and a few greater than 20%. The mean transition rate from 'naturalised' to 'DOC weed' is 14.5% (Appendix 2). Overall, the greater the proportion of a family that has naturalised, the higher becomes the chance that species of that particular family will be a weed of conservation land (Appendix 2). Family naturalisation rate can therefore be used to indicate the likelihood of a species becoming a conservation weed.

The proportion of species in a family that have naturalised can be used to assess the probability of a new species naturalising and becoming a conservation weed. It must be emphasised that *because many species have had insufficient time either to naturalise or spread and become conservation weeds in New Zealand, these transition rates are likely to be minimum rates.* The present data on transition rates will be closest to long-term trends for families with short life cycles that have been present in New Zealand for the longest periods (> 100 years—these are mainly herbs). It will be least reliable for families of long-lived woody species, which have been present for shorter periods.

Families that have already shown potential to become conservation weeds, along with the proportion of the family present in New Zealand, either in cultivation or in the wild, are shown in Table 2. This ranking of families assumes that species are proposed for introduction on a random basis and that the families are all equal in other respects such as their native distributions in habitats similar to those in New Zealand.

TABLE 2. PLANT FAMILIES OF SPECIES REPRESENTED BY CONSERVATION WEEDS; THE PERCENTAGE OF THE WORLD SPECIES OF THE FAMILY IN NEW ZEALAND EITHER IN CULTIVATION OR IN THE WILD, AND THE PERCENTAGE NATURALISED IN NEW ZEALAND, RANKED FROM HIGHEST TO LOWEST WITHIN COLUMN.

All other factors being equal (but see text) families in the top right box, and ascending within that box, have a greater chance of contributing the next species to be introduced (but see text) and becoming naturalised than families in the lower left box. This is because those at the top right have shown the greatest ability to naturalise and there is a greater proportion of the family still not introduced into New Zealand.

Percentage naturalised in New Zealand	>10	Salicaceae Cannaceae Rosaceae	Juncaceae Poaceae Phytolaccaceae Polygonaceae Solanaceae Grossulariaceae Tropaeolaceae Brassicaceae Gunneraceae Oleaceae Lamiaceae	Hydrocharitaceae Cyperaceae Haloragaceae Polygalaceae Amaranthaceae Balsaminaceae Boraginaceae Convolvulaceae Curcubitaceae Lythraceae Asteraceae Malvaceae Verbenaceae Fabaceae
	10–5	Pinaceae Elaeagnaceae Caprifoliaceae Juglandaceae Crassulaceae Iridaceae	Scrophulariaceae Berberaceae Bignoniaceae	Myoporaceae Celastraceae Moraceae Euphorbaceae Zingiberaceae
	< 5	Asclepiadaceae Arecaceae Aceraceae Agavaceae Ranunculaceae Betulaceae Iridaceae Crassulaceae Liliaceae	Myrtaceae Rhamnaceae Ericaceae Passifloraceae	Araliaceae Araceae Apocynaceae Anacardiaceae Commelinaceae Clusiaceae
		> 20	20–10	< 10
	Percentage of world species present in New Zealand			

If even the most simple criteria were adopted for classing a species as an unacceptable risk, based solely on the probability of it becoming naturalised, thresholds are still required to define that level of risk. For some plant families the chance of naturalisation is greater than 1:10 (> 10% naturalised) and we would consider the chance of a new species in this family naturalising is *almost certain*; 1:10–1:20 (10–5% naturalised) is *very likely*; 1:20 to 1:50 (4–2%) is *likely*; < 1:50 to 1:100 (2–1%) is *unlikely*; and less than 1:100 (< 1%) *very unlikely*.

For individual families there needs to be sufficient data as a basis for calculating the proportions. This will vary with the size of the plant family and the number of species in the family introduced into New Zealand. The greater proportion of species in the family already introduced, and the larger the family, the greater the reliability of this figure. Species proposed for importation that have no other family members in New Zealand cannot be assessed in this way.

When naturalisation rate is examined at a *generic level* among conservation weed genera that are well represented in the weed flora, either numerically (*Pinus* spp.) or on the basis of their being widely distributed (e.g. *Cotoneaster*), there is still a wide range of naturalisation rates, from a minimum of 2.4% (*Acer*) to a maximum of 64.7% (*Racosperma*) (Table 3).

Genera with high transition rates (> 50%) from present to conservation weed are uncommon in New Zealand and generally contain only a few species (e.g. *Cortederia, Ulex*). However, many relatively species-rich genera have naturalisation rates of 15% or greater. Several of these are grasses (*Agrostis, Bromus*) or other genera that we might expect to have high naturalisation rates based on the naturalisation rate of the family (e.g. *Racosperma*, Fabaceae; *Cestrum*, Solanaceae). Others are from families where the naturalisation rate is about the national average of 10% (e.g. *Jasminum*, Oleaceae; *Prunus*, Rosaceae).

Many weedy genera consist of only a few species and therefore offer only a weak basis for computing ratios. Naturalisation rate of small genera should be treated with caution when computing likely weediness.

TABLE 3. TRANSITION RATES FOR SELECTED CONSERVATION WEED (DOC WEED) GENERA WITH MORE THAN ONE NATURALISED SPECIES. NAT'D = NATURALISED, CAS. = CASUAL.
Genera such as *Arundo, Dactylus, Larix, Pandorea, Tradescantia* are excluded on this basis.

GENUS	LIFE FORM	TOTAL N.Z. SPP. (N)	CAS. IN N.Z. (N)	NAT'D IN N.Z. (N)	NAT'D/ TOTAL N.Z. SPP. (%)	DOC WEED SPP. IN GROUP* (N)	DOC WEED/ TOTAL N.Z. SPP. (%)	DOC WEED/ NAT'D + CAS. SPP. (%)
Acer	Trees and shrubs	83	0	2	2.4	1	1.2	50.0
Agrostis	Grass	8	0	4	50.0	1	12.5	25.0
Bromus	Grass	31	0	13	41.9	1	3.2	7.7
Cestrum	Trees and shrubs	8	0	5	62.5	4	50.0	80.0
Clematis	Vines	62	1	5	8.1	3	4.8	50.0
Cortederia	Grass	4	0	2	50.0	2	50.0	100.0
Cotoneaster	Trees and shrubs	48	2	8	16.7	3	6.3	30.0
Hakea	Trees and shrubs	39	0	4	10.3	3	7.7	75.0
Jasminum	Vines	19	0	5	15.1	2	10.5	40.0
Lupinus	Herb	27	1	4	14.8	2	7.4	40.0
Pinus	Trees and shrubs	93	0	14	15.1	11	11.8	78.6
Plectranthus	Herb	24	1	3	12.5	3	12.5	75.0
Prunus	Trees and shrubs	53	2	10	18.9	4	7.5	33.0
Racosperma	Trees and shrubs	17	2	11	64.7	6	35.3	46.0
Sorbus	Trees and shrubs	57	0	2	3.5	1	1.8	50.0
Ulex	Trees and shrubs	2	0	2	100.0	1	50.0	50.0

* Includes casual and naturalised.

4.1.3 Weed history overseas

The proportion of species in a family present in New Zealand that appear on overseas weed lists ranges from 0 to 100%, with a mean of 27% (Appendix 1).

The positive significant correlation between trees, shrubs and vines with the number of weed lists, reflects the tendency for these life forms to invade a wide range of land use classes including conservation land. The absence of a correlation with herbs and grasses (Table 4) reflects the fact that many of these are weeds only

TABLE 4. CORRELATIONS BETWEEN THE NUMBER OF WEED LISTS SPECIES OF SEVERAL LIFE FORMS OR GROUPS APPEAR ON OVERSEAS, AND THE MEAN SCORE FOR WEEDINESS OF THESE SPECIES AS ASSESSED BY CONSERVATION WORKERS AND BOTANISTS (WEEDINESS SCORES FROM DATA COLLECTED BY PHELOUNG ET AL. 1999).

LIFE FORM	NUMBER OF SPECIES IN LIFE FORM OR GROUP	r^2	S.E.	SIGNIFICANCE
Trees, shrubs and woody vines	41	+0.340	1.137	$P = 0.05$
Dicot. herbs	64	+0.131	1.155	N.S.
Monocot herbs	37	+0.181	1.300	N.S.

of agricultural land, annual weeds, for example, and were given low scores by our respondents (Pheloung et al. 1999). A further complication of any such testing of expert opinion against assessment models, is the impossibility of determining to what extent the expert's opinion is influenced by their knowledge of the species overseas, as opposed to their analysis of the species in the new country.

To conclude, whereas there is little relationship between herbaceous life forms, overseas weed lists, and weediness on conservation land in New Zealand, it does appear that the greater the number of overseas weed lists a woody species appears on, the greater the likelihood is of it becoming a conservation weed in New Zealand.

This outcome can be used to address the first core issue of the study, that of using the history of a species' congeners in assessing its likely weediness in New Zealand. As an average of about 30% of species per family appear on overseas weed lists, we rated > 50% as *very high* (score 4), 50%–10% *medium* (score 3), 10%–1% *low* (score 2), < 1% *very low* (score 1), and no weeds scored 0. Because there was a significant positive relationship between woody weeds and the number of lists they appeared on, as described above, these scores are doubled for woody weeds in the new assessment system (Section 4.4.1).

These numbers obviously have greatest utility for species that either have a history of cultivation outside their country of origin, or are weeds within their home region.

4.2 ASSESSING THE DIFFICULTY OF MANAGING A NEW CONSERVATION WEED

This section addresses the second core issue, of how difficult would it be to detect and remove a new plant species at the earliest stage of invasion if it did naturalise in New Zealand. If a plant species already has a history of weediness elsewhere, then it is likely to have certain identifiable attributes which make it so (e.g. persistent seed bank), and to have been the subject of control attempts. Information about these would aid in assessing the difficulty of controlling the species in New Zealand. Where there is no information about controlling the plant, ease of control or eradication must be inferred from attributes of the species or its congeners. These attributes could be classified in a variety of ways, but four seem critically important as described below, along with their scores as used in the new assessment system (4.4.1).

1. *Reproductive capacity*. The amount of viable seed a species produces and its ability to reproduce and spread vegetatively (including suckering capacity) are critical components of invasion success; but the *relative* importance of these factors to invasion and ease of eradication are less clear. Species with persistent seed banks can be just as difficult to eradicate as those with vegetative reproduction. However, species with *both* attributes appear to be more invasive, on average, than those with only one of these attributes (Fitter & Peat 1994; Thompson et al. 1995). This is partly because they employ different strategies as their populations increase (e.g. *Mahonia aquifolium,* Auge & Brandle 1997).

Species which either set seed or spread via vegetative organs are therefore scored (1), and (2) if they do both. Those which are unlikely to set seed, and which have no vegetative organs, are ranked (0). Dispersability by wind or birds is commonly included as a factor, but it is unlikely that we could sufficiently judge the importance of this for species new to cultivation to include it in the scoring system. (In contrast, for a naturalised or even casual species that is spreading, dispersability as an indicator of invasion potential can often be ascertained.)

2. *Rate and pattern of spread by humans*. All new species proposed for importation will presumably be propagated and spread purposely at some point if they are permitted entry. A score of (1) is applied if a species is likely to spread widely through the country and/or be grown as a crop to produce a large propagule source. This would be the general case, but a species might be scored (0) if it is likely to be grown in a very restricted area in the foreseeable future.

3. *Time to detection*. Detection of new infestations within a very few generations is important if a species is to be eradicated or contained within a small area. This requires that the species is recognisable at this early stage. Species cryptic in the wild, such as a short grass or a vine with inconspicuous foliage, or likely to be confused with native species by the moderately informed observer (e.g. privet spp., ferns), are likely to pass through several generations before they are identified as weeds.

These hard-to-detect species are scored (1). Trees or shrubs with conspicuous architecture or leaf forms such as palms (Cameron 2000a), shrubs (e.g. *Banksia* spp., Cameron 2000b), or mega-herbs (e.g. wild ginger) are rated (0). These scores take into consideration the habitats a species might possibly invade. Species of habitats that are difficult to observe, for example, wetlands, are likely to be well established before they are noticed. Scores should be based on the most cryptic species/habitat combination likely to occur.

4. *Resistance to management*. The intensity of weed control can be thought of as the product of the difficulty of killing an individual at the first attempt, including such factors as non-target effects, and the frequency of visits to re-treat the infestation. A species' ability to resprout after damage can be an important factor contributing to its persistence. While information on seeding ability and specialised organs (such as underground tubers or resprouting ability) is relatively easily obtained, knowledge of response to management is seldom available for new species. Species rated (1) are those with persistent seed banks (> 1 year); specialised above- or below-ground organs which have the capacity to persist at the site when no above-ground vegetation is visible and/or are capable of dispersing to form new loci from these organs; or species

which are known to reproduce from pieces of the above-ground part of the plant (e.g. Salicaceae). Species lacking these features, and that can be readily killed with an appropriate combination of physical and chemical treatment would be rated (0). Control information to this level of certainty would probably only be available for an established weed species. In the absence of such information the default score would be (1).

4.3 ASSESSING THE IMPACTS OF A NEW CONSERVATION WEED

What impacts a new species might have is the third core issue to be incorporated into the new weed risk assessment system. The impacts of invasive weeds throughout the world have been summarised by Cronk & Fuller (1995), and particularly for biodiversity by Adair & Groves (1998). This later group could be described as conservation weeds and their impact on New Zealand ecosystems, and other anecdotal observations, were summarised by Williams et al. (2000).

Changes in vegetation architecture and composition are an obvious example of the way adventive vegetation differs from native vegetation, as summarised for woody plants by McQueen (1993). Such changes as do occur also vary through time (McQueen 1993; Wiser et al. 1998) and their ultimate impact will not be known for decades.

Weeds impact on native biodiversity and ecosystem processes at all trophic levels, although such impacts have been measured only rarely in New Zealand (e.g. Ogle et al. 2000). Soil microfauna diversity and abundance is influenced by ginger (*Hedychium gardnerianum*), wandering Jew (*Tradescantia fluminensis*) and gorse (*Ulex europaeus*) (G. Yeates pers. comm.). Heather (*Calluna vulgaris*) reduces insect biodiversity (Keesing 1994), as does wandering Jew (R. Toft, pers. comm.). Tussock grassland moths have declined in the last 50 years and this is associated with the spread of the grass brown top (*Agrostis capillaries*) into tussock grassland (White 1991). Indigenous insects are more common on forest edges than in the interior so the substitution of native forest edge species with adventive species is likely to reduce native insect diversity (J. Dugdale, pers. comm.), although the extent of this has not been quantified.

Endangered plant species (Cameron et al. 1995) are threatened by weeds in New Zealand, as summarised by Reid (1998), and described in detail for the effects of Old Man's beard (*Clematis vitalba*) by Ogle et al. (2000). As most endangered plant species in New Zealand tend to be of low stature, they are threatened by any plant species that can overtop them, which is likely to include most weeds. All weed life forms may impact endangered plants, but herbaceous species less than 0.5 m tall are the most significant because they affect threatened plant populations at their regeneration stage, especially seedling establishment. Grasses are the most important weeds in this category, ranging from short species such as brown top to tall species such as pampas grasses. Sedges are important in damp areas. Several shrubs and species of pines also commonly have this effect. Vines less commonly threaten endangered plant species in New Zealand (Reid 1998), but if they do, their impacts can be severe (Ogle et al. 2000). Several vine species that are invasive in New Zealand have also been implicated in declines in native species other countries (e.g. Australia, Groves & Willis 1999).

The importance of herbaceous or short woody life forms amongst the DOC weeds reflects the habitats of threatened species, which are concentrated in wetland and associated communities, coastal habitats, open land, tussock grasslands and short grasslands, and scrub (Reid 1998). Fewer threatened species are from forest and montane and alpine areas. The former group of communities also has the greatest number of invasive plant species (Table 5).

TABLE 5. THE PROBABILITY OF A WEED SPECIES BELONGING TO ONE OF THREE LIFE FORMS INVADING THREE DIFFERENT VEGETATION TYPES. BASED ON THE OCCURRENCE OF ALL DOC WEED SPECIES IN THE THREE VEGETATION TYPES.

LIFE FORM	OCCURRENCE OF INDIVIDUAL LIFE FORMS IN ONE OR MORE OF 3 VEGETATION TYPES (%)		
	FOREST	SCRUBLAND AND GRASSLANDS	OPEN (< 10% COVER)
Herbs	17	64	27
Vines	36	58	6
Trees and shrubs	14	73	13

Weeds may have impacts on animal and bird behaviour. A clear New Zealand example of this is the invasion of braided riverbeds by willows (*Salix* spp.) and nitrogen-fixing herbs or shrubs such as lupins (*Lupinus* spp.). The nesting habitat for waders is reduced by lupins (Hughey & Warren 1997) and willows (Maloney et al. 1999) although the overall impact on bird numbers caused by these weeds is not known. Likewise, although it appears that the habitat for endemic birds is depleted when indigenous fruiting plants are replaced by weed species (Williams & Karl 1996), this hypothesis has not been tested.

Changes to soil nutrient regimes are commonly claimed as an effect of invasive legumes, and nitrogen status of sand dune soils is undoubtedly raised by lupins (Gadgill 1982). The same claim is made for gorse, based largely on the evidence of Eugunjobi (1969), but there is no evidence that this nitrogen has any lasting effect on vegetation processes (P.A. Williams, unpubl. data). Hawkweeds (*Hieracium* spp.) do effect soil conditions in the immediate vicinity of individual patches (McIntosh et al. 1995), but whether they change the composition of the vegetation is debatable (Scott et al. 1990; Scott 1999).

Weeds are known to change the frequency of erosion and deposition in riparian zones, and while willows obviously do this, we have no clear idea of how these (mostly lowland) systems functioned prior to their modification by humans, and therefore no datum against which to measure the effects of the introduced species.

Weeds may also hybridise with New Zealand native species. Because of this, incorporating congeners with native species in the scoring system was considered. However, the hybridisation risk is very slight and would need to be assessed on an individual species basis (Williams et al. 2000). Furthermore, for hybridisation to occur, the weed species would have to be well distributed and established amongst the native species, meaning that the effects of hybridisation are likely to be no greater or more likely to occur than other effects associated with the weed becoming well established.

Overall, the evidence available for predicting the likely impact of a new species in New Zealand is meagre. For example, we do not know if a short-lived species which is clearly causing the reduction of a rare plant on a local scale has a greater or lesser impact than a long-lived species which is spreading but, as yet, has no apparent impact on species diversity. The situation is no better when examined at a world scale because our limited understanding of weed impacts in natural systems prevents us placing relative scores on different kinds of impacts (Parker et al. 1999), although attempts have been made (Stephens et al. 2000).

Various assessment systems have attempted to incorporate estimates or surrogates of impact into systems scoring naturalised species (Esler et al. 1988; Owen 1997; Champion & Clayton 2001) or exotic species proposed for importation (Pheloung et al. 1999). However, reliable information on a species-by-species basis will be available only for well-established weeds, and Parker et al. (1999), have proposed how this information might be used.

It therefore seems premature to attempt to quantify, at the border, a new species' likely impacts in New Zealand. Even so, some impacts are probably more readily predictable for some life forms in certain ecosystems than in others. The best we can probably do is try and indicate the relative degree of invasibility of different vegetation/community types by a range of life forms, and combine this with the kinds of effects we suspect may occur based on life form a new species belongs to. These estimations must also be couched within certain time frames, and for the purposes of this study a term of 100 years is considered. For example, there is evidence that herbs and grasses prevent tree seedling regeneration (Kelly & Skipworth 1984; Reid 1998); therefore, the woody vegetation formed in their presence is likely to be different from that which would occur in their absence. This example also illustrates that different life forms, such as forbs and grasses, are likely to have similar impacts. In terms of their impacts, these life forms can be combined, especially given the paucity of information available for a new species. The following life form combinations were used in the scoring system:

- Herbaceous species, including grasses and rushes (and ferns)
- Vines
- Trees and shrubs

These three groupings include both monocotyledonous and dicotyledonous families, and trees and shrubs includes gymnosperms, so the classification derived from the ALLWEEDS database relates to this classification as shown in Table 6. The impacts associated with these three groupings are not exclusive to them. For example, some tussock grasses and bamboos probably have impacts more similar to shrubs than to other herbaceous species, so that potential plant height must always be considered.

TABLE 6. A SIMPLE THREE-PART CLASSIFICATION OF PLANT LIFE FORMS FOR ASSESSING WEED IMPACTS AND THEIR RELATIONSHIP TO THE MORE COMPLEX LIFE FORM/TAXONOMIC CLASSIFICATION USED IN SECTION 4.1.1.

SCORING CLASSIFICATION	COMPLEX CLASSIFICATION
Herbaceous species	Herbaceous perennial herbs Orchids Grasses (other than bamboo) Bamboos
Vines	Vines
Trees and shrubs	Trees and shrubs (excluding gymnosperms) Gymnosperms Palms

It is similarly possible to combine the vegetation types that these weed species impact (Owen 1997; Williams 2000) into three groups:

- Forest
- Scrub, shrub land, tall tussock land, short tussock land, herb field, and fern land
- Bare land (all land with < c.10% cover), i.e. riverbeds, bluffs, salt flats

The very meagre reports of weed impacts in New Zealand combined with those observed overseas (see summary in Cronk & Fuller 1995; Adair & Groves 1998; Buddenhagen et al. 1998; Parker et al. 1999) suggest that the possible impacts of a species of a known life form invading New Zealand are likely to be similar to those summarised by Williams (1997) (Table 7).

All three weed life forms are known to affect the biological aspects of ecosystems. There are, at present, no records of vines impacting on the several ecosystem processes that the other two groups are known to change; although these impacts probably do occur, especially with nitrogen-fixing vines. Overall, while the mechanism of the interaction may vary—for example, shading and suppression may occur via a canopy tree or ground herb—the kinds of interactions are not weed life-form specific and most interactions cannot be excluded simply on the basis of life form. The particular interaction will be dependent on many aspects of the new weed species' biology and ecology.

Not all life forms are equally likely to invade all ecosystems, however, and this is indicated by New Zealand data showing that different weed life forms are more likely to occur in some vegetation types than in others (Table 5).

Based on the history, to date, of weed invasions in New Zealand, herbaceous species are most likely to invade scrub and grassland, followed by open land and then forest. Vines are most likely to invade scrub and then forests. Their frequency of occurrence in grasslands (not shown separately) is low, as it is for open land, most likely because these vegetation types lack climbing support. Shrubs and trees are most likely to invade shrub and grassland, followed by forests and open land with equal proportions.

In reality, it is critical when assessing the impact of a potential weed species that we recognise the very limited knowledge we have of ecosystem processes in the presence of adventive species. This ranges from processes such as litter decomposition and nitrogen fixation which can occur quite rapidly, to longer-

TABLE 7. THE MAJOR IMPACTS OF TERRESTRIAL WEED LIFE FORMS FROM THE WORLD LITERATURE.

WEED LIFE FORM GROUPS	CHANGES VEGETATION SRUCTURE	CHANGES VEGETATION COMPOSITION	SUPPRESSES REGENERATION	FACILITATES OTHER WEEDS	DECREASES PLANT DIVERSITY	DECREASES ANIMAL DIVERSITY	CHANGES ANIMAL BEHAVIOUR	CHANGES HYDROLOGICAL REGIME	CHANGES FIRE REGIME	CHANGES NUTRIENT REGIME	CHANGES EROSION/DEPOSITION
Herbaceous perennials	•	•	•	•	•	•	•	•	•	•	•
Vines	•	•	•	•	•	•	•				
Trees and shrubs	•	•	•	•	•	•	•	•	•	•	•

term changes to species diversity and abundance, and to very long term effects such as changes in vegetation succession that can potentially last for hundreds of years (e.g. the changes arising from the spread of conifers in the high country). If a weed species is spreading into areas of conservation value, we must assume it is changing 'natural' processes. These changes will always be species- and ecosystem-specific and, on close inspection, will not always conform to current understanding. While very specific species interactions may be quite damaging, such as weeds occupying bird nesting habitat (Russell lupin) or preventing the regeneration of an endangered plant species, none of these interactions can be accurately predicted for new species.

4.4 A CONSERVATION WEED RISK ASSESSMENT (CWR) SYSTEM

This section describes some of the steps DOC would need to take to assess the conservation weed potential of a new species, and then details a new weed risk assessment system based on the rationale and scores presented in sections 4.1–4.3.

The first step, after having obtained an accurate identification and taxonomic position for a new species, is to determine whether it has a history of weediness elsewhere. If it has, then the species is quite likely to become a weed in New Zealand, including a conservation weed. Furthermore, even if it is a weed primarily of agriculture systems, if the climate where it is a weed or of its home range is similar to the climate in any region of New Zealand, then the precautionary principle should be applied. The recommendation would be made that the species should not be introduced into New Zealand for the reason that it may impact on either conservation values or agricultural systems. Conversely, even if a species has been in cultivation for a long period and has not shown weedy tendencies, it cannot be assumed it will not do so in New Zealand unless its relatives at all taxonomic levels have no weedy tendencies, e.g. orchids. Should there be no history of the proposed new species being a weed elsewhere, an assessment could proceed using the system outlined below. This could also be used as part of the case against the importation of species which do have a weed history elsewhere.

4.4.1 Scoring system

The following scoring system derives from the discussions and scores presented in sections 4.1 to 4.3, and is in two parts. These are:

(A) the likelihood of the species establishing (Table 8) and how easily it might be controlled (Table 9) (sections 4.1–4.2).

(B) if it does establish, which ecosystems it would be most likely to impact on (Table 10) (section 4.3).

The outcome is a total score termed the conservation weed risk (CWR) assessment.

(A.1) What is the chance of the species becoming a weed in New Zealand, based on the history of other species in the same family and genus in New Zealand and overseas? Note that this does not ask about the species itself for, as explained, the scoring system (Table 8) must take into account species new to cultivation. A higher score is given to a species if members of its taxonomic group are already naturalised in New Zealand, because this means that at least one close relation has demonstrated the ability to cross the environmental thresholds associated with New Zealand environments. Genera could be scored higher than families on the basis of closer behavioural similarity, but many genera contain few species. Individual sub-scores from 0 to 5 are based on the historical behaviour (%) of the species in that class, e.g. > 10% of the species in the family have naturalised in N.Z. (score = 5). The scores for woody species and vines are multiplied by two, because these life forms are perceived as having high impact (Williams 1997). The potential total CWR score ranges from 0 to 18.

TABLE 8. WORKSHEET FOR ASSESSMENT OF THE CHANCE A SPECIES WILL BECOME A CONSERVATION WEED BASED ON THE NATURALISATION AND WEED HISTORY OF ITS RELATIVES.

History		**Score**	**Class: yes/no, or score from 0 to 5 based on the historical behaviour (%) of the species in that class.** e.g. if > 10% of the species in the family have naturalised in N.Z., the score = 5 (see appendix 1)
Family naturalises	N.Z. Elsewhere		> 10% (5) 10–5% (4) 4–2% (3) 2–1% (2) < 1% (1) 0 (0) Yes (1) No (0)
Genus naturalises	N.Z. Elsewhere		> 10% (2) < 10% (1) 0 (0) Yes (1) No (0)
Family weedy	N.Z. Elsewhere		> 50% (4) 50–10% (3) 9–1% (2) < 1 (1) 0 (0) Yes (1) No (0)
Genus weedy	N.Z. Elsewhere		> 10% (2) < 10% (1) 0 (0) Yes (1) No (0) multiply by 2 if woody or vine
Sum = CWR A.1			

(A.2) Would this species reproduce in New Zealand (1), would it be spread extensively by humans (2), and if it escaped into the wild, would it be readily identified (3) and controlled? (4). In contrast to A.1, which is based solely on evidence from the relatives of the species being assessed, this question requires knowledge of the species' attributes. This question is only a modifier of A.1. The potential score range is 0 to 5 (Table 9). The highest score should be used in each section in the rare situation where no information is available.

TABLE 9. WORKSHEET FOR ASSESSMENT OF THE POTENTIAL FOR SPREAD AND DIFFICULTY OF CONTROL OF A NEW SPECIES.

Attribute	**Actual score**	**Criteria with potential scores 2, 1 or 0**		
1. Reproductive capacity		(2) Viable seed and specialised vegetative organs[1]	(1) Viable seed or specialised vegetative organs[1]	(0) Not known to set seed and lacks vegetative organs[1]
2. Dispersal by humans			(1) Likely to be spread around	(0) Unlikely to be spread around
3. Visibility			(1) Cryptic	(0) Conspicuous
4. Resistance to management			(1) Resistant features	(0) No resistant features
Sum = CWR A.2				

[1] Defined in section 4.1.1.

(B.1) If the species established in the wild, and assuming it behaved in a similar way to other species of the same life form in New Zealand, what is the chance of it establishing in a range of different vegetation types? Choose one row. The figures in Table 10 are rounded to the nearest 5% from Table 5.

TABLE 10. WORKSHEET FOR ASSESSMENT OF THE CHANCE A NEW SPECIES WILL ESTABLISH IN A RANGE OF VEGETATION TYPES.

Life form	**Chance of invading the vegetation type (%)**		
	Forest	**Scrub and grassland**	**Open (< 10% cover)**
Herbs (excluding vines)	15	65	25
Vines	35	60	05
Trees and shrubs	15	75	15

(B.2) What general categories of impact might the species have in a range of different vegetation types, if it established in the wild, and assuming it behaved in a similar way to other species of the same life form in New Zealand and overseas? For reasons discussed in section 4.3 we are unlikely to be able to predict what the particular species/environment interactions will be, so these are likely to be some, or all, of those shown in Table 7; i.e. a summary of expected impacts from the available information.

The significance of the resulting scores, and the thresholds for recommendations, are made from the examples of the CWR scores generated by the system and their comparison with other systems.

4.4.2 Assessment examples

Several species covering a range of life forms, histories, weediness and usefulness were scored for Conservation Weed Risk (CWR). They were treated as if they were not in New Zealand; that is, the proportions of the genus or family in the various categories (Table 8) were recalculated with the species absent. Table 11 compares CWR scores with a published scoring system, the NZWRA (Pheloung et al. 1999, section 2); the mean weediness scores from New Zealand botanical experts generated during the study of Pheloung et al. (1999) (section 3.1); the presence of the species on overseas weed lists of any kind; presence on the composite DOC weed list (Owen 1998 in part); status in New Zealand from the Floras (Webb et al. 1988; Edgar & Connor 2000). Score sheets for individual species are in Appendix 5.

The species scores for the CWR A.1 in Table 11 range from 5 to 16, only 2 points short of the possible maximum of 18. Box elder (*Acer negundo*), butterfly bush (*Buddleja davidii*), and potato (*Solanum tuberosum*) illustrate the wide variation of outcomes between the various assessment systems. Box elder has a relatively high score (16) for CWR A.1, and has a 'reject' category for NZWRA system, yet New Zealand experts rank it a minor weed, and it is not a DOC weed. The high scores for CWR A.1 (16) and the outcome of 'reject' for the NZWRA system are because it has weedy relatives overseas and in New Zealand. New Zealand experts rank it as a minor weed because it has not yet become a conservation weed in New Zealand. The relatively high score (16) for butterfly bush by CWR A.1 reflects its weedy relatives, while the outcome of 'accept' for the NZWRA system reflects its apparently innocuous reproductive system and

TABLE 11. SCORES OBTAINED FOR VARIOUS SPECIES FROM QUESTIONS A.1 AND A.2 IN THE CWR SYSTEM COMPARED WITH OTHER SCORING SYSTEMS (SEE FOOTNOTES) AND THE SPECIES' STATUS IN NEW ZEALAND.

TAXON	FAMILY	CWR SYSTEM SCORES A1	CWR SYSTEM SCORES A2	NZWRA SYSTEM OUTCOME[1]	N.Z. EXPERTS WEED RANK[2]	WEED OVERSEAS (Y/N)[3]	DOC LIST[4]	N.Z. NATURALISATION STATUS AND COMMENT
Acer negundo (box elder)	Aceraceae	16	4	reject	minor	Y	N	Naturalised recently/ horticulture
Buddleja davidii (butterfly bush)	Buddlejaceae	16	4	accept	major	Y	Y	Widespread/horticulture
Clematis vitalba (old man's beard)	Ranunculaceae	12	4	reject	major	Y	Y	Widespread/weed only
Festuca rubra (red fescue)	Poaceae	10	4	reject	minor	Y	N	Widespread/agricultural plant
Pisum sativum (pea)	Fabaceae	6	3	accept	non weed	N	N	Casual/food plant
Reseda luteola (wild mignonette)	Resedaceae	11	4	accept	minor	Y	N	Widespread/wasteland weed
Solanum tuberosum (potato)	Solanaceae	16	4	reject	minor	N	N	Casual/food plant
Xanthorrhoea johnsonii (grass tree)	Lilliaceae	5	3	accept	Not determined	N	N	Absent/recently approved for importation

[1] see Section 2. [2] see Section 3.2, last paragraph. [3] from ALLWEEDS database, see Section 3.1.
[4] see Section 3.2.

lack of persistence features. In this case, simply the history of its relatives (CWR A.1) has proved to be a more accurate indicator of its behaviour in New Zealand as indicated by the 'major weed' category of the New Zealand experts, and it is also a DOC weed. The high score obtained for potato in CWR A.1, and the 'reject' outcome of the NZWRA, both reflect the large number of weeds in the family Solanaceae (i.e. any member of this family has a high chance of being a weed) and the plant's apparent weedy characteristic of vegetative organs. Both CWR A.1 scores and the NZWRA system failed to predict that potato would not become troublesome. Garden pea, which is equally innocuous, has only a low (6) score for CWR A.1, and is not ranked as a weed by any other system/opinion because although the family Fabaceae is weedy, the genus *Pisum* is not.

It would be possible to undertake scorings for a wide range of species using the CWR A.1 questions and define categorical levels of likelihood of a species becoming a weed in New Zealand along the score range (5–16 of those scored). In the meantime, it can be tentatively suggested that species with a score of A.1 6 or less would be unlikely to become a conservation weed, whereas those with a score of A.1 7 or more would be likely to become conservation weeds. Checking the A.1 score sheet for each species would show what taxonomic level the score was derived from.

The CWR A.2 scores range only from 2 to 4 for the species in Table 11. All have some reproductive capacity, but not all have the maximum scores for the questions relating to dispersal by humans, visibility, and resistance to management (see Table 9). Garden pea scores 3 because it has no persistent seed bank, whereas grass tree scores 3 because it has a life form novel in New Zealand that would make it easy to detect and control. Plant species with scores of more than 3 are considered likely to spread, and/or be difficult to control.

Species scores for CWR B.1 and B.2 are not shown because they are used only as qualifiers to the CWR A.1 and A.2 scores. They are obtained from the life-form group a species belongs to (Table 7) and the probability of that life-form establishing in particular vegetation types (Table 10). For example, if old man's beard were a new species, as a vine it would be likely to have the impacts listed under 'Vines' in Table 7, would have the probabilities of invading the vegetation types in the row 'Vines' (forest 35%, scrub and grassland 60%, open 5%) (Table 10).

To summarise, the following provides examples in words for the outcomes for two species assessed by CWR A.1, A.2, and B.1, B.2, were these species new to New Zealand:

Old man's beard would have a high chance of becoming a conservation weed and it would be likely to spread and be difficult to control. If it did become a conservation weed the kinds of impacts expected would be those listed above.

Garden pea would have a low chance of becoming a conservation weed, but if it did, it would be likely to spread and be difficult to control. However, because it is an annual herb, a life form not recorded as a DOC weed (Williams 1997), it would be likely to have only very low impacts on conservation values.

4.5 TESTING THE CONSERVATION WEED RISK ASSESSMENT (CWR) SYSTEM

Existing weed risk assessment systems are claimed to have low reliability because the base rate—the average probability of a newly introduced plant species becoming a weed—is very low (Smith et al. 1999). These authors reported base rates for plants introduced into Australia becoming weeds as ranging from 2% to 17% for tropical pasture grasses. In New Zealand, the mean of the base rate from introduction to conservation weed for families with at least one weed is 7% and often greater than 10%. According to Smith et al. (1999), such base rates are still too low for reliable predictions, despite the fact that any event which was likely to occur with this probability would be considered 'almost certain' in the arena of environmental safety. Thus Smith et al. (1999) have made a value judgment that gives a higher weighting to the projected benefits than to the odds of a false prediction that the species will be a weed. In fact, the chance that a new species will prove of significant economic benefit is also very low, as evidenced by the example of grasses imported into Australia, where very few were useful (Lonsdale 1994), and the relatively few plant species of any kind that support New Zealand agriculture (Halloy 1999).

The further issue surrounding the utility of these assessment systems is that they have largely been tested, and reportedly returned high levels of accuracy, on species that have been previously released into the country. One possibility of testing the proposed system in New Zealand to assist in overcoming this problem would be to 'reconstruct' the flora of New Zealand at previous times, say 1870, 1940 and 1980, to determine the variability in transition rates over these times. This task would be difficult for New Zealand as a whole, but it could be undertaken for Auckland City based on the data in Esler (1988), and the historical nursery catalogue records for all fleshy-fruited trees and shrubs held by Landcare Research. The outcomes of such historical analyses are, nevertheless, of limited value because of the 'lag' component of most plant invasions, and because the land use environment into which the species are invading has changed (Smith et al. 1999) since the 1840s.

Another possibility for testing the system would be to apply it in another weed-rich temperate region with much the same weed flora—southern Australia, for example—so as to determine whether invasion base rates were a characteristic of particular species over wider areas. For some large groups such as Pinaceae, this appears to be the case, for they are as invasive in New Zealand as anywhere else in the world (Richardson et al. 1994).

5. Conclusions

Transition rates of exotic plant taxa, from introduced, to casual or fully naturalised, and then to conservation weeds (listed in DOC weed databases), can be calculated from the data held on Landcare Research databases (ALLWEEDS database). These rates indicate that some groups of plants are many times more likely to be invasive than others. These ratios can be combined into a screening system, along with questions relating to an estimate of how difficult it would be to manage an escaped population, and what kinds of effects the species might have on conservation values. Conservation weed risk (CWR) scores generated by this new system are comparable with existing systems, but the new system needs to be tested. Possible ways of doing this are proposed.

6. Acknowledgements

This report was prepared by Landcare Research for the Department of Conservation as Investigation No. 3318.

The Landcare Research databases that this report uses were originally prepared by Euan Nicol. Thanks to Bill Lee, Dane Panetta, Rod Randall and Susan Timmins for helpful comments on an earlier draft, Anne Austin and Lynette Clelland for editorial assistence, and Jemma Callaghan for typing.

7. References

Adair, R.J.; Groves, R.H. 1998: Impact of environmental weeds on biodiversity. National Parks and Wildlife, Canberra. 51 p.

Auge, H.; Brandle, R. 1997: Seedling recruitment in the invasive clonal shrub, *Mahonia aquifolium* Pursh (Nutt.) *Oecologia 110*: 205–211.

Aronson, J.; Ovalle, C.; Avendano, J.; Avendano, R.J.; Ovalle, M.C. 1992: Early growth rate and nitrogen fixation potential in forty-four legume species grown in an acid and a neutral soil from central Chile. *Forest Ecology and Management 47*: 225–244.

Baker, H.G. 1974: The evolution of weeds. *Annual Review of Ecology and Systematics 5*: 1–24.

Buddenhagen, C.E.; Timmins, S.M.; Owen, S.J.; Champion, P.D.; Nelson, W.; Reid, V.A. 1998: An overview of weed impacts and trends. Pp. 11–21 in Owen, S.J. (Ed.): Department of Conservation Strategic Plan for managing invasive weeds. Department of Conservation, Wellington.

Cameron, E.K.; de Lange, P.J.; Given, D.R.; Johnson, P.N.; Ogle, C.C. 1995: New Zealand Botanical Society threatened and local plant list (1995 revision). *New Zealand Botanical Society Newsletter 39*: 15–28.

Cameron, E.K. 2000a: The naturalisation of *Banksia integrifolia* in New Zealand; time for action *New Zealand Botanical Society Newsletter 59*: 12–16.

Cameron, E.K. 2000b: Bangalow palm (*Archontophoenix cunninghamiana*) begins to naturalise. *New Zealand Botanical Society Newsletter 60*: 12–16.

Champion, P.D.; Clayton, J.S.2001: Update of adventive aquatic plant distribution in New Zealand and ranking model to determine priorities. Pp. 194–202 in Groves, R.H.; Panetta, J.G.; Virtue, J.G. (Eds): Weed Risk Assessment. CSIRO Plant Industry, Canberra.

Crawley, M.J. 1987: What makes a community invasible? Pp. 429–453 in Gray, A.J.; Crawley, M.J.; Edwards, P.J. (Eds): Colonisation, succession and stability. Blackwells Scientific Publications, Oxford.

Cronk, C.B.; Fuller, J.L. 1995: Plant invaders: the threat to natural ecosystems. Chapman Hall, London. 241 p.

Cronquist, A. 1981: An integrated system of classification of flowering plants. Cambridge University Press.

Crooks, J.A.; Soule, M. 1999: Lag times in population explosions of invasive species: causes and implications. Pp. 103–125 in Sandlund, O.T.; Schei, P.J.; Viken, A. (Eds): Invasive species and biodiversity management. Kluwer Academic Publishers, Netherlands.

D'Antonio, C.M.; Tunison, J.T.; Loh, R.K. 2000: Variation in the impact of exotic grasses on native plant composition in relation to fire across an elevation gradient in Hawaii. *Austral Ecology 25*: 507–522.

Daehler, C.C. 1998: The taxonomic distribution of invasive angiosperm plants: ecological insights and comparison to agricultural weeds. *Biological Conservation 84*: 167–180.

Daehler, C.C.; Carrino, D.A. 2000: Predicting invasive plants: prospects for a general screening system based on current regional models. *Biological Invasions 2*: 93–102.

Diaz, S.; Carbido, M.; Casanoves, F. 1998: Plant functional traits and environmental filters at a regional scale. *Journal of Vegetation Science 9*: 113–122.

Edgar, E.; Connor, H.E. 2000: Flora of New Zealand Volume V, Gramineae. Manaaki Whenua Press, Lincoln.

Esler, A.E. 1988: Naturalisation of plants in urban Auckland: a series of articles from the New Zealand Journal of Botany. Department of Scientific and Industrial Research, Wellington. 618 p.

Eugunjobi, J.K. 1969: Dry matter and nitrogen accumulation in secondary successions involving gorse (*Ulex europaeus* L.) and associated shrubs and trees. *New Zealand Journal of Science 12*: 175–193.

Forcella, F.; Wood, T.J. 1984: Colonisation potentials of alien weeds are related to their native distributions—implications for plant quarantine. *Journal of Australian Institute of Agricultural Science 50*: 35–41.

Gaddum, M.1999: Gaddum's Plant Finder 2000. New Zealand Plant Finder, Gisborne, New Zealand.

Gadgil, R.L. 1982: Biological nitrogen inputs into exotic forests. Pp. 123–130 in Gandar, P.W. (Ed.): Nitrogen balances in New Zealand ecosytems. Department of Scientific and Industrial Research, Palmerston North.

Groves, R.H.; Willis, A.J. 1999: Environmental weeds and loss of native plant biodiversity: some Australian examples. *Australian Journal of Environmental Management 6*: 164–171.

Halloy, S.R.P. 1999: The dynamic contribution of new crops to the agricultural economy: is it predictable? Pp. 53–59 in Janick, J. (Ed.), Perspectives on new crops and new uses. ASHS Press, Alexandria, USA.

Healy, A.J.; Edgar, E. 1980: Flora of New Zealand, Vol III. Government Printer, Wellington.

Heenan, P.B.; Breitwieser, I.; Glenny, D.S.; de lange, P.J.; Brownsey, P.J. 1998: Checklist of dicotyledons and pteridophytes naturalised or casual in New Zealand: additional records 1994–96. *New Zealand Journal of Botany 36*: 155–162.

Higgins, S.; Richardson, D.M. 1998: Pine invasions in the southern hemisphere: modelling interactions between organisms, environment and disturbance. *Plant Ecology 135*: 79–93.

Holm, L.G.; Plucknett, D.L.; Pancho, J.V.; Herberger, J.P. 1977: The World's Worst Weeds: Distribution and Biology. University Press of Hawaii, Honolulu.

Hughes, C.E. 1995: Protocols for plant introductions with particular reference to forestry: hanging perspectives on risk to biodiversity and economic development. Pp. 15–32 in Stirton, C.H. (Ed.): Weeds in a changing world. British Crop Protection Council, England.

Hughey, K.; Warren, A. 1997: Habitat restoration for wildlife nesting on degraded braided riverbeds in New Zealand. Pp. 334–343 in Hale, P.; Lamb, D. (Eds): Conservation Outside Nature Reserves, Centre for Conservation Biology, University of Queensland, Brisbane, Australia.

Hutchinson, J. 1959: The families of flowering plants. Clarendon Press, London.

Jackson, B.D. 1895: Index Kewensis Plantarum Phanerogamarum. Clarendon, Oxford.

Keddy, P.A. 1992: Assembly and response rules: two goals for predictive community ecology. *Journal of Vegetation Science 3*: 157–164.

Keesing, V. 1994: The impact of *Calluna vulgaris* on native invertebrate communities in Tongariro National Park. In Williams, K.; Keys, H. (Eds): Proceedings of the second heather control workshop. Department of Conservation, Turangi.

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.

Kowarik, I. 1995: The lag phase in biological invasions with regard to the success and failure of alien species. Pp 15–38 in Pysek, P.; Prach, K.; Rejmanek, M.; Wade, M. (Eds): Plant invasions—general aspects and special problems, Academic Publishing, Amsterdam.

Lazarides, M.; Cowley, K.; Hohnen, P. 1997: CSIRO handbook of Australian weeds. CSIRO Publishing: Collingwood, Australia.

Lehtonen, P.P. 2001: Weed initiated pest risk assessment in the United States: guidelines for qualitative assessments. Pp. 117–123 in Groves, R.H.; Panetta, J.G.; Virtue, J.G. (Eds): Weed Risk Assessment. CSIRO Plant Industry, Canberra.

Lonsdale, W.M. 1994: Inviting trouble: Introduced pasture sepcies in northern Australia. *Australian Journal of Ecology 19*: 345–354.

Mabberley, D.J. 1997: The Plant Book. Cambridge University Press.

Mack, R.N.1995: Understanding the process of weed invasions: the influence of environmental stochasticity. Pp. 65–76 in Stirton, C.H. (Ed.): Weeds in a changing world. British Crop Protection Council, England.

Mack, R.N. 1996: Predicting the identity and fate of plant invaders: emergent and emerging approaches. *Biological Conservation 78*: 107–121.

Maillet, J.; Lopez-Gacia, C. 2000: What criteria are relevant for predicting the invasive capacity of new agricultural weeds? the case of invasive American species in France. *Weed Research 40*: 11–26.

Maloney, R.F.; Keedwell, R.J.; Wells, N.J.; Rebergen, A.L.; Nilsson, R.J. 1999: Effects of willow removal on habitat use by five birds of braided rivers, Mackenzie Basin, New Zealand. *NewZealand Journal of Ecology 23*: 53–60.

McIntosh, P.D.; Loeseke, M.; Bechler, K. 1995: Soil changes under mouse-ear hawkeweed (*Hieracium pilosella). New Zealand Journal of Ecology 19*: 29–34.

McQueen, D.R. 1993: A review of the interaction between naturalised woody plants and indigenous vegetation in New Zealand. *Tuatara 32*: 32–56.

Mulvaney, M. 2001: The effect of introduction pressure on the naturalisation of ornamental woody plants in south-east Australia. Pp. 186–194 in Groves, R.H.; Panetta, J.G.; Virtue, J.G. (Eds): Weed Risk Assessment. CSIRO Plant Industry, Canberra.

Ogle, C.C.; La Cock, G.D.; Arnold, G.; Mickleson, N. 2000: Impact of an exotic vine *Clematis vitalba* (F. Ranunculaceae) and of control measures on plant biodiversity in indigenous forest, taihape, New Zealand. *Austral Ecology 25*: 539–551.

Orr, R.L.; Cohen, S.D.; Griffin, R.L. 1993: Generic non-indigenous pest risk assessment process. Animal and Plant Health Inspection Service, USDA.

Owen, S.J. 1997: Ecological Weeds on Conservation Land in New Zealand: a database. Department of Conservation, Wellington.

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

Panetta, F.D. 1993: An assessment of the colonising ability of *Emex australis. Australian Journal of Ecology 19*: 76–82.

Parker, I.M.; Simberloff, D.; Lonsdale, W.M.; Goodell, K.; Wonham, M.; Kareiva, P.M.; Williamson, M.H.; Von Holle, B.; Moyle, P.B.; Byers, J.E.; Goldwasser, L. 1999: Impact: toward a framework for understanding the ecological effects of invaders. *Biological Invasions 1*: 3–19.

Parson, M.J.; Douglas, P.; MacMillan, B.H. 1995: Current names list for wild Gymnosperms, Dicotyledons, and Monocotyledons (except grasses) in New Zealand. Landcare Research, Lincoln.

Pheloung, P.C.; Williams, P.A.; Halloy S.R. 1999: A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management 57*: 239–251.

Perrins, J.; Williamson, M.; Fitter, A. 1992: A survey of differing views of weed classification: implications for regulating introductions. *Biological Conservation 60*: 47–76.

Rapoport, E.H. 1991: Tropical versus temperate weeds: a glance into the present and future. Pp. 11–51 in Ramakrishnan, P.S. (Ed.): Ecology of biological invasions in the tropics.

Raunkiaer, C. 1934: The life forms of plants and statistical plant geography; being the collected papers of Raunkiaer. Oxford, Clarendon Press. 632 p.

Reid, V.A. 1998: The impact of weeds on threatened plants. *Science & Research Internal Report No 164*. Department of Conservation, Wellington. 67 p.

Reichard, S.E.; Hamilton, C.W. 1997: Predicting invasions of woody plants introduced into North America. *Conservation Biology 11*: 193–203.

Rejmanek, M. 1999: Invasive plant species and invasible ecosystems. Pp. 79–102 in Sandlund, O.T.; Schei, P.J.; Viken, A. (Eds.): Invasive species and biodiversity management. Kluwer Academic Publishers, Netherlands.

Rejmanek, M. 2000: Invasive plants: approaches and predictions. *Austral Ecology 25*: 497–506.

Rejmanek, M.; Richardson, D.M. 1996: What attributes make some plant species more invasive? *Ecology* 77: 1655–1661.

Rejmanek, M.; Richardson, D.M. In Press. Invasiveness of conifers, its extent and possible mechanisms. 4th International Conifer Conference, Wye College, Kent, UK,

Richardson, D.M. 1999: Commercial forestry and agroforestry as sources of invasive alien trees and shrubs. Pp. 237–257 in Sandlund, O.T.; Schei, P.J.; Viken, A. (Eds): Invasive species and biodiversity management. Kluwer Academic Publishers, Netherlands.

Richardson, D.M.; Pysek, P.; Rejmanek, M.; Barbour, M.G.; Panetta, F.D.; West, C. 2000: Naturalisation and invasion of alien plants: concepts and definitions. *Diversity and Distributions 6*: 93–107.

Richardson, D.M.; Williams, P.A.; Hobbs, R.J. 1994: Pine invasion in the Southern Hemisphere: determinants of spread and invasibility. *Journal of Biogeography 21*: 511–527.

Scott, D. 1999: Ecological considerations in plant invasions, with some New Zealand examples. Pp. 109–121 in Yano, E.; Matsuo, K.; Shiuomi, M.; Andow, D.A. (Eds) Biological invasions of ecosystems by pests and beneficial organisms. National Institute of Agro-Environmental Sciences.

Scott, D.; Robertson, J.S.; Archie, W.J. 1990: Plant dynamics of New Zealand tussock grassland infested with *Hieracium pilosella*: *1*. Effects of seasonal grazing, fertilizer and overdrilling; II Transition matrices of vegetation changes. *Journal of Applied Ecology 27*: 224–241.

Scott, J.K.; Panetta, F.D. 1993. Predicting the Australian weed status of Southern African plants. *Journal of Biogeography 20*: 87–93.

Smith, C.S.; Lonsdale, W.M.; Fortune, J. 1999: When to ignore advice: invasion predictions and decision theory. *Biological Invasions 1*: 89–96.

Stephens, T.; Brown, D.; Thornley, N. 2002: Measuring Conservation achievement: applications of the concept over the Twizel area. *Science for Conservation 200*, Department of Conservation, Wellington.

Thompson, K.; Hodgson, J.G.; Rich, T.C.G. 1995: Native and alien invasive plants: more of the same? *Ecography 18*: 390–402.

Tucker, K.C.; Richardson, D.M. 1995: An expert system for screening potentially invasive alien plants in South African fynbos. *Journal of Environmental Management 44*: 309–338.

Van Kraayenoord, C.W.S.; Slui, B.; Knowles, F.B. 1995: Introduced forest trees in New Zealand 15. The willows. *New Zealand Forest Research Institute Report No.124*, Rotorua.

Webb, C.J.; Sykes, W.R.; Garnock-Jones, P.J. 1988: Flora of New Zealand; Vol. IV: Naturalised pteridophytes, gymnosperms, dicotyledons. Botany Division, Department of Scientific and Industrial Research, Christchurch, New Zealand. 1365 p.

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 51*: 5–22.

Williams, P.A. 1997: Ecology and management of invasive weeds. *Conservation Sciences Publication No.7*. Department of Conservation, Wellington. 67 p.

Williams, P.A.; Karl, B.J. 1996: Fleshy fruits of indigenous and adventive plants in the diet of birds in forest remnants, Nelson, New Zealand. *New Zealand Journal of Ecology 20*: 127–145.

Williams, P.A.; Nicol, E.; Newfield, M. 2000: Assessing the risk to indigenous biota from new exotic plant taxa and genetic material. *Science for Conservation 143*, Wellington, Department of Conservation. 42 p.

Williamson, M. 1993: Invaders, weeds and the risk from genetically manipulated organisms. *Experientia 49*: 219–224.

Williamson, M. 1996: Biological Invasions. Chapman and Hall, London.

Williamson, M. 1998: Measuring the impact of plant invaders in Britian. Pp. 57–68 in Starfinger, U.; Edwards, K.; Kowarik, I.; Williamson, M. (Eds): Plant invasions: ecological mechanisms and human responses. Backhuys Publishers, Leiden.

Williamson, M.; Fitter, A. 1996: The characters of successful invaders. *Biological Conservation 78*: 163–170.

Williamson, M.; Fitter, A. 1997: The varying success of invaders. *Ecology 77*: 1661–1666.

Wiser, S.K.; Allen, R.B.; Clinton, P.W.; Platt, K.H. 1998: Community structure and forest invasion by an exotic herb over 23 years. *Ecology 79*: 2071–2081.

Appendix 1

SPECIES CONSIDERED TO BE DOC WEEDS FOR THE PURPOSE OF THIS STUDY

GENUS	SPECIES	FAMILY	GENUS	SPECIES	FAMILY
Acer	*pseudoplatanus*	Aceraceae	*Leycesteria*	*formosa*	Caprifoliaceae
Acmena	*smithii*	Myrtaceae	*Ligustrum*	*lucidum*	Oleaceae
Agapanthus	*praecox*	Liliaceae	*Ligustrum*	*sinense*	Oleaceae
Agave	*americana*	Agavaceae	*Lolium*	*perenne*	Poaceae
Ageratina	*riparia*	Asteraceae	*Lonicera*	*japonica*	Caprifoliaceae
Ageratina	*adenophora*	Asteraceae	*Lotus*	*pedunculatus*	Fabaceae
Agrostis	*capillaris*	Poaceae	*Lupinus*	*arboreus*	Fabaceae
Allium	*triquetrum*	Liliaceae	*Lupinus*	*polyphyllus*	Fabaceae
Alnus	*glutinosa*	Betulaceae	*Lycium*	*ferocissimum*	Solanaceae
Alocasia	*brisbanensis*	Araceae	*Lythrum*	*salicaria*	Lythraceae
Alternanthera	*philoxeroides*	Amaranthaceae	*Malvaviscus*	*arboreus*	Malvaceae
Ammophila	*arenaria*	Poaceae	*Melianthus*	*major*	Melianthaceae
Andropogon	*virginicus*	Poaceae	*Mimulus*	*guttatus*	Scrophulariaceae
Anredera	*cordifolia*	Basellaceae	*Miscanthus*	*nepalensis*	Poaceae
Araujia	*sericifera*	Asclepiadaceae	*Myoporum*	*insulare*	Myoporaceae
Arctotheca	*calendula*	Asteraceae	*Myriophyllum*	*aquaticum*	Haloragaceae
Aristea	*ecklonii*	Iridaceae	*Nassella*	*neesiana*	Poaceae
Arrhenatherum	*elatius*	Poaceae	*Nassella*	*trichotoma*	Poaceae
Arum	*italicum*	Araceae	*Nymphoides*	*geminata*	Menyanthaceae
Arundo	*donax*	Poaceae	*Olea*	*europaea*	Oleaceae
Asparagus	*asparagoides*	Liliaceae	*Osmunda*	*regalis*	Osmundaceae
Asparagus	*scandens*	Liliaceae	*Ottelia*	*ovalifolia*	Hydrocharitaceae
Asparagus	*setaceus*	Liliaceae	*Oxylobium*	*lanceolatum*	Fabaceae
Azolla	*pinnata*	Salviniaceae	*Pandorea*	*jasminoides*	Bignoniaceae
Banksia	*integrifolia*	Proteaceae	*Pandorea*	*pandorana*	Bignoniaceae
Bartlettina	*sordida*	Asteraceae	*Paraserianthes*	*lophantha*	Fabaceae
Berberis	*darwinii*	Berberidaceae	*Paspalum*	*distichum*	Poaceae
Berberis	*glaucocarpa*	Berberidaceae	*Passiflora*	*edulis*	Passifloraceae
Bromus	*tectorum*	Poaceae	*Passiflora*	*mixta*	Passifloraceae
Bryonia	*cretica*	Cucurbitaceae	*Passiflora*	*mollissima*	Passifloraceae
Buddleja	*davidii*	Buddlejaceae	*Pennisetum*	*clandestinum*	Poaceae
Caesalpinia	*decapetala*	Fabaceae	*Pennisetum*	*macrourum*	Poaceae
Calluna	*vulgaris*	Ericaceae	*Pennisetum*	*purpureum*	Poaceae
Canna	*indica*	Cannaceae	*Pennisetum*	*setaceum*	Poaceae
Carduus	*nutans*	Asteraceae	*Phoenix*	*canariensis*	Arecaceae
Carex	*longebrachiata*	Cyperaceae	*Phytolacca*	*octandra*	Phytolaccaceae
Carex	*flacca*	Cyperaceae	*Pinus*	*banksiana*	Pinaceae
Celastrus	*orbiculatus*	Celastraceae	*Pinus*	*contorta*	Pinaceae
Ceratophyllum	*demersum*	Ceratophyllaceae	*Pinus*	*halepensis*	Pinaceae
Cestrum	*aurantiacum*	Solanaceae	*Pinus*	*nigra*	Pinaceae
Cestrum	*elegans*	Solanaceae	*Pinus*	*patula*	Pinaceae
Cestrum	*nocturnum*	Solanaceae	*Pinus*	*pinaster*	Pinaceae
Cestrum	*parqui*	Solanaceae	*Pinus*	*ponderosa*	Pinaceae
Chrysanthemoides	*monilifera*	Asteraceae	*Pinus*	*radiata*	Pinaceae
Cirsium	*arvense*	Asteraceae	*Pinus*	*strobus*	Pinaceae
Cirsium	*palustre*	Asteraceae	*Pinus*	*sylvestris*	Pinaceae
Cirsium	*vulgare*	Asteraceae	*Plectranthus*	*ciliatus*	Lamiaceae

GENUS	SPECIES	FAMILY
Clematis	*flammula*	Ranunculaceae
Clematis	*tangutica*	Ranunculaceae
Clematis	*vitalba*	Ranunculaceae
Cobaea	*scandens*	Cobaeaceae
Convolvulus	*arvensis*	Convolvulaceae
Cortaderia	*selloana*	Poaceae
Cortaderia	*jubata*	Poaceae
Cotoneaster	*glaucophyllus*	Rosaceae
Cotoneaster	*simonsii*	Rosaceae
Crassula	*multicava*	Crassulaceae
Crataegus	*monogyna*	Rosaceae
Crocosmia	*+crocosmiiflora*	Iridaceae
Cynodon	*dactylon*	Poaceae
Cytisus	*scoparius*	Fabaceae
Dactylis	*glomerata*	Poaceae
Dipogon	*lignosus*	Fabaceae
Echium	*plantagineum*	Boraginaceae
Echium	*vulgare*	Boraginaceae
Egeria	*densa*	Hydrocharitaceae
Ehrharta	*erecta*	Poaceae
Ehrharta	*villosa*	Poaceae
Elaeagnus	*+reflexa*	Elaeagnaceae
Elodea	*canadensis*	Hydrocharitaceae
Equisetum	*arvense*	Equisetaeae
Eragrostis	*curvula*	Poaceae
Erica	*lusitanica*	Ericaceae
Erigeron	*karvinskianus*	Asteraceae
Eriobotrya	*japonica*	Rosaceae
Erythrina	*+sykesii*	Fabaceae
Eucalyptus	*botryoides*	Myrtaceae
Eucalyptus	*globulus*	Myrtaceae
Eucalyptus	*saligna*	Myrtaceae
Euonymus	*europaeus*	Celastraceae
Euonymus	*japonicus*	Celastraceae
Festuca	*arundinacea*	Poaceae
Ficus	*carica*	Moraceae
Ficus	*macrophylla*	Moraceae
Ficus	*pumila*	Moraceae
Ficus	*rubiginosa*	Moraceae
Furcraea	*foetida*	Agavaceae
Galeobdolon	*luteum*	Lamiaceae
Glyceria	*fluitans*	Poaceae
Glyceria	*maxima*	Poaceae
Gunnera	*tinctoria*	Gunneraceae
Gymnocoronis	*spilanthoides*	Asteraceae
Hakea	*gibbosa*	Proteaceae
Hakea	*salicifolia*	Proteaceae
Hakea	*sericea*	Proteaceae
Hedera	*helix*	Araliaceae
Hedychium	*flavescens*	Zingiberaceae
Hedychium	*gardnerianum*	Zingiberaceae
Hieracium	*aurantiacum*	Asteraceae
Hieracium	*caespitosum*	Asteraceae
Hieracium	*lepidulum*	Asteraceae
Hieracium	*murorum*	Asteraceae
Hieracium	*pilosella*	Asteraceae
Hieracium	*praealtum*	Asteraceae

GENUS	SPECIES	FAMILY
Plectranthus	*ecklonii*	Lamiaceae
Plectranthus	*grandis*	Lamiaceae
Podranea	*ricasoliana*	Bignoniaceae
Polygala	*myrtifolia*	Polygalaceae
Populus	*alba*	Salicaceae
Potamogeton	*crispus*	Potamogetonaceae
Prunus	*avium*	Rosaceae
Prunus	*campanulata*	Rosaceae
Prunus	*laurocerasus*	Rosaceae
Prunus	*lusitanica*	Rosaceae
Prunus	*serrulata*	Rosaceae
Pseudotsuga	*menziesii*	Pinaceae
Psidium	*cattleianum*	Myrtaceae
Psidium	*guajava*	Myrtaceae
Psoralea	*pinnata*	Fabaceae
Pyracantha	*angustifolia*	Rosaceae
Racosperma	*dealbatum*	Fabaceae
Racosperma	*longifolium*	Fabaceae
Racosperma	*melanoxylon*	Fabaceae
Racosperma	*paradoxum*	Fabaceae
Reynoutria	*japonica*	Polygonaceae
Reynoutria	*sachalinensis*	Polygonaceae
Rhamnus	*alaternus*	Rhamnaceae
Rhaphiolepis	*umbellata*	Rosaceae
Rhododendron	*ponticum*	Ericaceae
Ribes	*sanguineum*	Grossulariaceae
Robinia	*pseudoacacia*	Fabaceae
Rorippa	*nasturtium-aquaticum*	Brassicaceae
Rosa	*rubiginosa*	Rosaceae
Rubus	*argutus*	Rosaceae
Rubus	*cardiophyllus*	Rosaceae
Rubus	*cissburiensis*	Rosaceae
Rubus	*cissburiensis + R. ulmifolius Schott*	Rosaceae
Rubus	*echinatus*	Rosaceae
Rubus	*flagellaris*	Rosaceae
Rubus	*fruticosus*	Rosaceae
Rubus	*laciniatus*	Rosaceae
Rubus	*leptothyrsos*	Rosaceae
Rubus	*nemoralis*	Rosaceae
Rubus	*ostryifolius*	Rosaceae
Rubus	*procerus*	Rosaceae
Rubus	*ulmifolius*	Rosaceae
Rumex	*sagittatus*	Polygonaceae
Salix	*cinerea*	Salicaceae
Salix	*fragilis*	Salicaceae
Salvinia	*molesta*	Salviniaceae
Sambucus	*nigra*	Caprifoliaceae
Schinus	*terebinthifolius*	Anacardiaceae
Sedum	*acre*	Crassulaceae
Senecio	*angulatus*	Asteraceae
Senecio	*jacobaea*	Asteraceae
Senecio	*mikanioides*	Asteraceae
Senna	*septemtrionalis*	Fabaceae
Setaria	*palmifolia*	Poaceae
Solanum	*jasminoides*	Solanaceae

Appendix 1 *continued.*

GENUS	SPECIES	FAMILY	GENUS	SPECIES	FAMILY
Homalanthus	*populifolius*	Euphorbiaceae	*Solanum*	*linnaeanum*	Solanaceae
Homeria	*collina*	Iridaceae	*Solanum*	*mauritianum*	Solanaceae
Humulus	*lupulus*	Cannabaceae	*Solanum*	*pseudocapsicum*	Solanaceae
Hydrilla	*verticillata*	Hydrocharitaceae	*Sorbus*	*aucuparia*	Rosaceae
Hypericum	*androsaemum*	Clusiaceae	*Spartina*	*alterniflora*	Poaceae
Hypericum	*perforatum*	Clusiaceae	*Spartina*	*anglica*	Poaceae
Impatiens	*sodenii*	Balsaminaceae	*Spartina*	*+townsendii*	Poaceae
Imperata	*cylindrica*	Poaceae	*Spartium*	*junceum*	Fabaceae
Ipomoea	*indica*	Convolvulaceae	*Stenotaphrum*	*secundatum*	Poaceae
Iris	*foetidissima*	Iridaceae	*Syzygium*	*australe*	Myrtaceae
Iris	*pseudacorus*	Iridaceae	*Tecomaria*	*capensis*	Bignoniaceae
Jasminum	*humile*	Oleaceae	*Teline*	*monspessulana*	Fabaceae
Jasminum	*polyanthum*	Oleaceae	*Trachycarpus*	*fortunei*	Arecaceae
Juglans	*ailantifolia*	Juglandaceae	*Tradescantia*	*fluminensis*	Commelinaceae
Juncus	*acutus*	Juncaceae	*Tropaeolum*	*majus*	Tropaeolaceae
Juncus	*articulatus*	Juncaceae	*Tropaeolum*	*speciosum*	Tropaeolaceae
Juncus	*bulbosus*	Juncaceae	*Tussilago*	*farfara*	Asteraceae
Juncus	*effusus*	Juncaceae	*Ulex*	*europaeus*	Fabaceae
Juncus	*squarrosus*	Juncaceae	*Utricularia*	*gibba*	Lentibulariaceae
Lagarosiphon	*major*	Hydrocharitaceae	*Vaccinium*	*corymbosum*	Ericaceae
Lantana	*camara*	Verbenaceae	*Vinca*	*major*	Apocynaceae
Lantana	*montevidensis*	Verbenaceae	*Watsonia*	*bulbillifera*	Iridaceae
Larix	*decidua*	Pinaceae	*Zantedeschia*	*aethiopica*	Araceae
			Zizania	*latifolia*	Poaceae

Appendix 2

PLANT FAMILIES FOR WHICH DATA ARE AVAILABLE (minimum 5 spp. in N.Z. unless a DOC weed)

FAMILY	TOTAL N.Z. SPP. (N)	TOTAL N.Z./WORLD SSP. (%)	NATURALISED/ TOTAL N.Z. SPP. (%)	DOC WEED SPP. IN FAMILY (N)	DOC WEED/ TOTAL N.Z. SPP. (%)	DOC WEED/ NATURALISED SPP. (%)
Acanthaceae	102	2.4	2.0	0	0.0	0.0
Aceraceae	84	74.3	2.4	1	1.2	50.0
Actinidiaceae	24	4.3	8.3	0	0.0	0.0
Adiantaceae	27	2.3	7.4	0	0.0	0.0
Agavaceae	165	40.2	2.4	2	1.2	50.0
Aizoaceae	384	16.0	2.1	0	0.0	0.0
Alismataceae	28	29.5	10.7	0	0.0	0.0
Amaranthaceae	45	5.6	30.0	1	2.2	7.4
Anacardiaceae	55	6.5	3.6	1	1.8	50.0
Annonaceae	22	1.1	10.6	0	0.0	0.0
Apiaceae	161	5.2	18.6	0	0.0	0.0
Apocynaceae	91	4.3	4.4	1	1.1	25.0
Aponogetonaceae	7	15.9	14.3	0	0.0	0.0
Aquifoliaceae	38	9.0	2.6	0	0.0	0.0
Araceae	181	6.1	4.4	3	1.7	37.5
Araliaceae	65	8.1	4.6	1	1.5	33.3
Araucariaceae	31	96.9	3.2	0	0.0	0.0
Arecaceae	601	22.7	0.5	1	0.2	33.3
Asclepiadaceae	484	17.0	0.4	1	0.2	50.0
Aspleniaceae	21	0.8	4.8	0	0.0	0.0
Asteraceae	1334	6.4	13.4	21	1.6	11.7
Balsaminaceae	14	1.6	21.4	1	7.1	33.3
Basellaceae	3.0	20.0	33.0	1	33.3	100.0
Begoniaceae	70	7.8	1.4	0	0.0	0.0
Berberidaceae	86	15.1	8.1	2	2.3	28.6
Betulaceae	75	50.0	4.0	1	1.3	33.3
Bignoniaceae	88	12.1	8.0	4	4.5	57.1
Blechnaceae	26	10.0	0.0	0	0.0	0.0
Bombacaceae	21	8.4	0.0	0	0.0	0.0
Boraginaceae	132	5.3	16.7	2	1.5	9.1
Brassicaceae	383	12.8	17.5	1	0.3	1.5
Bromeliaceae	812	38.5	0.0	0	0	0
Bruniaceae	10	14.5	0.0	0	0	0
Burseraceae	12	2.2	0.0	0	0	0
Buxaceae	11	18.3	9.1	0	0	0
Cactaceae	1523	92.3	0.1	0	0	0
Calycanthaceae	10	100.0	0.0	0	0	0
Campanulaceae	252	12.9	3.2	0	0	0
Canabaceae	3	100.0	33.0	1	33.3	100.0
Cannaceae	5	20.0	20.0	1	20.0	100.0
Capparaceae	12	1.8	8.3	0	0	0
Caprifoliaceae	146	40.0	8.9	3	2.1	23.1
Caricaceae	12	38.7	8.3	0	0	0

Appendix 2. *continued*

FAMILY	TOTAL N.Z. SPP. (N)	TOTAL N.Z./WORLD SSP. (%)	NATURALISED/ TOTAL N.Z. SPP. (%)	DOC WEED SPP. IN FAMILY (N)	DOC WEED/ TOTAL N.Z. SPP. (%)	DOC WEED/ NATURALISED SPP. (%)
Caryophyllaceae	293	14.2	0.0	0	0	0
Casuarinaceae	17	24.3	11.8	0	0	0
Celastraceae	35	2.7	8.6	3	8.6	100.0
Ceratophyllaceae	30	3.3	100.0	1	3.3	3.3
Chenopodiaceae	62	4.8	30.6	0	0	0
Cistaceae	35	20.0	8.6	0	0	0
Clethraceae	10	15.6	0.0	0	0	0
Clusiaceae	78	5.8	2.6	2	2.6	100.0
Combretaceae	16	3.2	0.0	0	0	0
Commelinaceae	29	4.7	3.4	1	3.4	100.0
Convolvulaceae	60	3.6	16.7	2	3.3	20.0
Cornaceae	36	40.0	2.8	0	0	0
Crassulaceae	418	27.9	6.2	2	0.5	7.7
Cucurbitaceae	51	6.7	15.7	1	2.0	12.5
Cunoniaceae	7	2.1	0.0	0	0	0
Cupressaceae	116	100.0	4.3	0	0	0
Cyatheaceae	8	1.3	0.0	0	0	0
Cycadaceae	18	90.0	0.0	0	0	0
Cyperaceae	105	2.9	40.0	2	1.9	4.8
Davalliaceae	13	5.9	0.0	0	0	0
Dennstaedtiaceae	8	2.0	0.0	0	0	0
Diapensiaceae	7	53.8	0.0	0	0	0
Dilleniaceae	9	3.0	0.0	0	0	0
Dioscoreaceae	21	3.3	0.0	0	0	0
Dipsacaceae	41	16.4	4.9	0	0	0
Droseraceae	13	15.3	0.0	0	0	0
Ebenaceae	15	3.1	0.0	0	0	0
Elaeagnaceae	11	24.4	9.1	0	0	0
Elaeocarpaceae	9	1.7	0.0	0	0	0
Epacridaceae	21	5.3	4.8	0	0	0
Equisetaceae	3	10.0	33.3	1	33.3	100.1
Ericaceae	655	19.6	1.8	4	0.6	33.3
Eucryphiaceae	5	100.0	0.0	0	0	0
Euphorbiaceae	370	4.7	5.1	1	0.3	5.2
Fabaceae	1107	6.8	10.2	19	1.7	16.8
Fagaceae	161	15.3	2.5	0	0	0
Flacourtiaceae	18	2.1	11.1	0	0	0
Fourquieriaceae	6	54.5	0.0	0	0	0
Fumariaceae	48	10.7	12.5	0	0	0
Garryaceae	6	46.2	0.0	0	0	0
Gentianaceae	137	11.4	2.2	0	0	0
Geraniaceae	252	34.5	7.5	0	0	0
Gesneriaceae	124	5.2	0.0	0	0	0
Globulariaceae	19	7.6	0.0	0	0	0
Goodeniaceae	26	6.0	0.0	0	0	0
Grossulariaceae	23	6.8	21.7	1	4.3	20.0
Gunneraceae	7	17.5	14.3	1	14.3	100.0
Haemodoraceae	17	20.0	5.9	0	0	0
Haloragaceae	8	6.7	37.5	1	12.5	33.3
Hamamelidaceae	28	31.1	0.0	0	0	0

FAMILY	TOTAL N.Z. SPP. (N)	TOTAL N.Z./WORLD SSP. (%)	NATURALISED/ TOTAL N.Z. SPP. (%)	DOC WEED SPP. IN FAMILY (N)	DOC WEED/ TOTAL N.Z. SPP. (%)	DOC WEED/ NATURALISED SPP. (%)
Heliconiaceae	14	14.0	0.0	0	0	0
Hippocastanaceae	13	86.7	7.7	0	0	0
Hydrangeaceae	78	45.9	2.6	0	0	0
Hydrocharitaceae	7	7.8	85.7	5	71.4	83.3
Hydrophyllaceae	23	8.4	4.3	0	0	0
Illiciaceae	6	14.3	0.0	0	0	0
Iridaceae	739	41.1	5.3	6	0.8	15.4
Juglandaceae	25	42.4	8.0	1	4.0	50.0
Juncaceae	44	13.5	75.0	5	11.4	15.2
Lamiaceae	566	10.1	10.1	4	0.7	7.0
Lardizabalaceae	9	42.9	11.1	0	0	0
Lauraceae	50	2.3	6.0	0	0	0
Lentibulariaceae	14	5.7	7.1	0	0	0
Linaceae	22	7.3	18.2	0	0	0
Loasaceae	16	6.2	0.0	0	0	0
Loganiaceae	6	1.0	15.0	1	16.7	100.0
Lythraceae	34	5.9	0.0	0	0	0
Malpighiaceae	8	0.7	0.0	0	0	0
Malvaceae	32	2.1	12.5	1	3.1	25.0
Marantaceae	29	5.3	0.0	0	0	0
Melastomataceae	36	0.8	2.8	0	0	0
Meliaceae	35	6.1	0.0	0	0	0
Melianthaceae	14	7.1	1.0	0	0	0
Meliosmaceae	8	16.7	0.0	0	0	0
Menyanthaceae	4	10.0	25.0	1	25.0	100.0
Monimiaceae	6	1.3	0.0	0	0	0
Moraceae	56	4.7	7.1	4	7.1	100.0
Moringaceae	6	42.9	0.0	0	0	0
Musaceae	11	26.2	0.0	0	0	0
Myoporaceae	10	4.5	10.0	1	10.0	100.0
Myricaceae	8	16.0	0.0	0	0	0
Myrsinaceae	17	1.4	0.0	0	0	0
Myrtaceae	553	14.4	4.5	7	1.3	28.0
Nepenthaceae	70	100.0	0.0	0	0	0
Nyctaginaceae	14	4.0	14.3	0	0	0
Nymphaeaceae	15	25.0	20.0	0	0	0
Oleaceae	123	13.7	10.6	5	4.1	38.5
Onagraceae	86	13.2	20.9	0	0	0
Orchidaceae	1758	10.0	0.0	0	0	0
Oxalidaceae	59	10.3	22.0	0	0	0
Paeoniaceae	31	91.2	0.0	0	0	0
Pandanaceae	6	0.9	0.0	0	0	0
Papaveraceae	91	43.3	12.1	0	0	0
Passifloraceae	56	10.6	1.8	3	5.3	66.0
Pedaliaceae	13	13.7	0.0	0	0	0
Phytolaccaceae	8	12.3	37.5	1	12.5	33.3
Pinaceae	201	100.0	9.5	12	6.0	63.2
Poaceae	562	6.2	47.7	32	5.7	11.9
Podocarpaceae	24	15.5	0.0	0	0	0
Polemoniaceae	66	24.0	7.6	0	0	0
Polygalaceae	14	1.5	35.7	0	0	0

Appendix 2. *continued*

FAMILY	TOTAL N.Z. SPP. (N)	TOTAL N.Z./WORLD SSP. (%)	NATURALISED/ TOTAL N.Z. SPP. (%)	DOC WEED SPP. IN FAMILY (N)	DOC WEED/ TOTAL N.Z. SPP. (%)	DOC WEED/ NATURALISED SPP. (%)
Polygonaceae	122	10.6	23.8	1	0.8	3.4
Polypodiaceae	18	3.3	5.6	0	0	0
Portulacaceae	69	17.3	8.7	0	0	0
Primulaceae	270	33.8	2.2	0	0	0
Proteaceae	419	3.1	2.6	1	0.2	9.2
Pyrolaceae	6	14.3	0.0	0	0	0
Ranunculaceae	649	37.1	3.5	3	0.5	13.0
Restionaceae	27	6.8	0.0	0	0	0
Rhamnaceae	90	10.3	3.3	1	1.1	33.3
Rosaceae	670	21.6	12.1	26	3.9	32.1
Rubiaceae	119	1.1	8.4	0	0	0
Rutaceae	144	8.5	0.7	0	0	0
Salicaceae	106	24.4	23.6	3	2.8	12.0
Santalaceae	6	1.2	0.0	0	0	0
Sapindaceae	50	3.8	0.0	0	0	0
Sapotaceae	19	1.9	0.0	0	0	0
Sarraceniaceae	13	86.7	0.0	0	0	0
Saxifragaceae	175	36.8	0.6	0	0	0
Schisandraceae	6	12.8	0.0	0	0	0
Schizaeaceae	5	3.3	0.0	0	0	0
Scrophulariaceae	466	10.5	9.2	2	0.4	4.7
Selaginellaceae	7	1.2	14.3	0	0	0
Simaroubaceae	9	5.3	11.1	0	0	0
Smilacaceae	7	3.1	0.0	0	0	0
Solanaceae	188	7.2	25.5	9	4.8	18.8
Staphyleaceae	8	29.6	0.0	0	0	0
Sterculiaceae	42	2.8	0.0	0	0	0
Styracaceae	22	13.3	0.0	0	0	0
Taccaceae	8	80.0	0.0	0	0	0
Tamaricaceae	10	12.8	10.0	0	0	0
Taxaceae	10	50.0	10.0	0	0	0
Taxodiaceae	14	100.0	14.3	0	0	0
Theaceae	65	12.5	0.0	0	0	0
Thymelaeaceae	65	9.0	1.5	0	0	0
Tiliaceae	29	4.0	3.4	0	0	0
Tropaeolaceae	15	17.0	20.0	2	13.3	66.7
Ulmaceae	34	24.3	2.9	0	0	0
Urticaceae	24	2.3	20.8	0	0	0
Valerianaceae	22	5.5	9.1	2	9.1	100.0
Verbenaceae	85	4.5	10.6	2	2.4	22.2
Violaceae	90	10.8	6.7	0	0.0	0.0
Vitaceae	54	6.8	3.7	0	0.0	0.0
Xanthorrhoeaceae	16	26.7	0.0	0	0.0	0.0
Zamiaceae	115.0	100.0	0.0	0	0.0	0.0
Zingiberaceae	39	3.0	5.1	2	5.1	100.0
Zygophyllaceae	14	5.6	0.0	0	0.0	0.0

Appendix 3

TRANSITION RATES FOR SELECTED LIFE FORMS, FAMILIES, AND GENERA

		TOTAL N.Z. SPP. (N)	CASUAL SPP. IN N.Z. (N)	NATURALISED SPP. IN N.Z. (N)	NATURALISED/ TOTAL N.Z. SPP. (%)	DOC WEED SPP. IN GROUP[1] (N)	DOC WEED/ TOTAL N.Z. SPP. (%)	DOC WEED/ NATURALISED SPP. (%)
Selected life forms								
Vines		505	16	68	13.5	25	5.0	36.8
Trees and shrubs except gymnosperms and palms		2829	42	118	4.2	134	4.7	113.0
Gymnopserm trees and shrubs		372	5	28	7.5	13	3.5	46.4
Palm trees and shrubs		601	0	3	0.5	0	0.0	0.0
Grasses except bamboos		505	43	216	42.8	32	6.3	14.8
Bamboos		57	0	16	28.0	0	0.0	0.0
Selected families								
Asteraceae	Herb	851	41	169	19.9	17	2.0	10.1
Asteraceae	Trees and shrubs	66	3	9	13.6	2	3.0	22.2
Asteraceae	Vines	6	1	2	33.3	2	33.3	100.0
Fabaceae	Herb	317	10	64	20.2	2	0.6	3.1
Fabaceae	Trees and shrubs	462	9	41	8.9	18	3.9	43.9
Fabaceae	Vines	43	1	8	18.6	1	2.3	12.5
Poaceae	Non-bamboo	505	43	216	42.8	32	6.3	14.8
Selected genera								
Acer	Trees and shrubs	83	0	2	2.4	1	1.2	50.0
Agrostis	Grass	8	0	4	50.0	1	12.5	25.0
Arundo	Grass	1	0	1	100.0	1	100.0	100.0
Bromus	Grass	31	0	13	41.9	1	3.2	7.7
Cestrum	Trees and shrubs	8	0	5	62.5	4	50.0	80.0
Clematis	Vines	62	1	5	8.1	3	4.8	60.0
Cortederia	Grass	4	0	2	50.0	2	50.0	100.0
Cotoneaster	Trees and shrubs	48	2	8	16.7	3	6.3	37.5
Dactylus	Grass	1	0	1	100.0	1	100.0	100.0
Hakea	Trees and shrubs	39	0	4	10.3	3	7.7	75.0
Jasminum	Vines	19	0	5	15.1	2	10.5	40.0
Larix	Trees and shrubs	12	0	1	8.3	1	8.3	100.0
Lupinus	Herb	27	1	4	14.8	2	7.4	50.0
Pandorea	Vines	4	1	1	25.0	2*	50.0	200.0

[1] Includes fully naturalised and casual, which is why some DOC/naturalised ratios are high.

Appendix 3. *continued*

		TOTAL N.Z. SPP. (N)	CASUAL SPP. IN N.Z. (N)	NATURALISED SPP. IN N.Z. (N)	NATURALISED/ TOTAL N.Z. SPP. (%)	DOC WEED SPP. IN GROUP[1] (N)	DOC WEED/ TOTAL N.Z. SPP. (%)	DOC WEED/ NATURALISED SPP. (%)
Pinus	Trees and shrubs	93	0	14	15.1	11	11.8	78.6
Plectranthus	Herb	24	1	3	12.5	3	12.5	100.0
Prunus	Trees and shrubs	53	2	10	18.9	4	7.5	40.0
Racosperma	Trees and shrubs	17	2	11	64.7	6	35.3	54.5
Sorbus	Trees and shrubs	57	0	2	3.5	1	1.8	50.0
Tradescantia	Herb	12	1	1	8.3	1	8.3	100.0
Ulex	Trees and shrubs	2	0	2	100.0	1	50.0	50.0

[1] Includes fully naturalised and casual, which is why some DOC/naturalised ratios are high.

Appendix 4

SPECIES SCORES SHEETS FOR CWR A.1 AND A.2

See text section 4.4.1 for the classes and potential scores from which these are derived.

	ACER NEGUNDO	*BUDDLEJA DAVIDII*	*CLEMATIS VITALBA*	*FESTUCA RUBRA*	*PISUM SATIVUM*	*RESEDA ODORATA*	*SOLANUM TUBEROSUM*	*XANTHORROEA JOHNSONII*
Section A1								
Family naturalises N.Z.	2	5	2	2	1	1	1	1
Family naturalises elsewhere	1	1	1	1	1	1	1	1
Genus naturalises N.Z.	1	1	1	1	0	1	2	0
Genus naturalises elsewhere	1	1	1	1	1	1	1	0
Family weedy N.Z.	6	3	3	3	2	4	4	2
Family weedy elsewhere	1	1	1	1	1	1	1	1
Genus weedy N.Z.	2	2	1	2	0	2	4	0
Genus weedy elsewhere	2	2	2	1	0	1	4	0
A1 score	16	16	12	10	6	11	16	5
Section A2								
Reproductive capacity	1	1	1	1	1	1	2	1
Dispersal by humans	1	1	1	1	1	1	1	1
Visibility	0	1	1	1	1	1	0	0
Resistance	1	1	1	1	0	1	1	1
A2 score	3	4	4	4	3	4	4	3