INVASIVE PLANTS IN AGRO-ECOSYSTEMS IN NEW ZEALAND: ENVIRONMENTAL IMPACT AND RISK ASSESSMENT

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ABSTRACT

Introduced plants and animals have been vital to the welfare of societies throughout human history. There has been a significant downside to these introductions, however, as many of these species have become invasive. This Bulletin discusses the problem of invasive plants in a New Zealand context by providing the history of invasive plants in the country, the biosecurity systems in place and the implementation of these systems at both national and regional levels.

Weed risk assessment (WRA) is the best way of determining the invasive potential of introduced plants. This Bulletin outlines four WRA models developed and being used in New Zealand, including one specifically for aquatic plants. The final section of this Bulletin deals with potential sources of new weeds in New Zealand, and how in general the invasive plants would behave in the country.

INTRODUCTION

The huge increase in trade and international travel resulting from globalization brings with it the possibility of introducing a range of organisms. Some of these are deliberately moved round the world as crop plants or domesticated animals. Others are parasitic on global trade – they travel on or in containers, second-hand vehicles and luggage. Deliberately and accidentally introduced organisms can damage both agro-ecosystems and natural ecosystems, both of which are vital for the future of humankind. Goats, deliberately introduced to many of the world's islands, seriously damage natural and planted forests alike. Hitch-hiking rats, established everywhere, destroy crops and stored foods, native wildlife and human health.

We often think of invasive pests as animals – rats, fire ants or malaria-carrying mosquitoes. Invasive plants however cause as much as, or even more, damage. 'Weeds are a particular, not well defined, type of plant distinct from, but overlapping with, invasive and colonizing species' (Williamson 1996). In New Zealand and Australia, most weeds are invasive, and most threats of new weed species come from outside the region (Williamson 2001).

New weeds are spreading quickly round the world and no country is immune. 'Weed' trees invade natural and planted forests, reducing yields and damaging biodiversity. Weedy shrubs spread across pasture land. Water hyacinth blocks lakes, rivers and canals. While the invasive marine alga *Caulerpa taxifolia* changes marine environments worldwide into 'marine deserts'.

Islands, big or small, have ecosystems which are especially vulnerable to invasions by plants or animals. Islands often have unique endemic species found nowhere else, and these may be eradicated by invasive species. (Clout & Veitch 2002). In theory, islands should be easier to protect from invasive species.

Keywords: attributes, biosecurity, champion and clayton's model, Ester's model, invasive plants, plant biosecurity, New Zealand, Pheloung's model, risk assessment, weeds, weediness, Williams' model

However, human beings seem determined to transform ecosystems everywhere into 'natural' equivalents of multinational corporations.

HISTORY OF INVASIVE PLANTS IN NEW ZEALAND

The early history

New Zealand separated from the supercontinent Gondwanaland before mammals evolved. About 80 million years ago the Tasman Sea formed, separating New Zealand from Australia. The only mammals that succeeded in reaching New Zealand were several marine mammals and three species of bat. In due course, birds filled niches occupied elsewhere in the world by mammals. New Zealand's plant life was also unique, although related to flora in Tasmania and South America. New Zealand today has about 2,450 native plant species. About 80% of these are found nowhere else in the world.

New Zealand remained untouched by human beings until the Maori arrived in canoes between about 950 and 1130 AD. The Maori introduced six crop species – kumara, taro, gourd, paper mulberry, yam and ti pore (the tropical cabbage tree) – to New Zealand (Belich 1996), but apparently brought no weed species. Few native species have ever become weedy, the main exceptions being manuka (*Leptospermum scoparium*) and matagouri (*Discaria toumatou*). Both of these invade pasture land cleared from native bush. Another native plant which may become a weed is large-leaved muehlenbeckia (*Muehlenbeckia australis*), a vine which sometimes damages trees and shrubs.

European explorers brought the first seed of weeds to New Zealand, probably as contaminants of potato tubers or vegetable seeds. With the rapid expansion of agriculture following European settlement in the 1800s, many crop and pasture seeds were introduced, mostly from Europe. With them came the seeds of invasive species. Many of those early weeds are of European origin although some also arrived, directly or indirectly from America, Asia and Australia.

Although many weeds were introduced as contaminants of crop or pasture seed, some were deliberately introduced. In 1850, noxious weed legislation was thought necessary to help stem the spread of new weeds.

The recent decades

Since those early years, new plant species have continued to become established in New Zealand. Heenan *et al.* (1999, 2002) and Webb *et al.* (1995) list the recently naturalized species. More than half of the 5,000 plant species growing wild in New Zealand have been introduced. At least another 25,000 introduced plant species are present in gardens or under cultivation. Many of these could become naturalized, and some will certainly become weed problems in the future. The New Zealand Department of Conservation (DOC) estimates that over 70% of current invasive weeds in conservation areas were introduced as ornamental plants, 12% for agriculture, horticulture or forestry, and only 11% accidentally.

Esler (1988) has provided an excellent summary of the history of introduction of new invasive species into New Zealand. Although his study focused on the North Island city of Auckland, much of this information is relevant to New Zealand as a whole. He estimated that, on average, one plant species became naturalised in Auckland every 88 days, or 4.12 species per year, between 1870 and 1970 (Fig. 1). There is no evidence that this rate has slowed since then (Jon Sullivan, *personal communication*).

An interesting aspect of the 'deliberate' introduction of weed species is the role of agricultural introductions. Halloy (1999) analysed such introductions into New Zealand. He observed that most introductions of agricultural species contributed little to the economy, and that even those that became important had effective life spans of about ten years. Lonsdale (1994) reported that of the hundreds of grasses and legumes intentionally introduced into northern Australia, only 5% gave an increase in pasture production, while over 60% of the remaining species became weeds.

INCREASING PRESSURE FROM TRADE AND TOURISM

New Zealand's forage production is based on exotic plant species. Most of these have been introduced without their natural range of pests

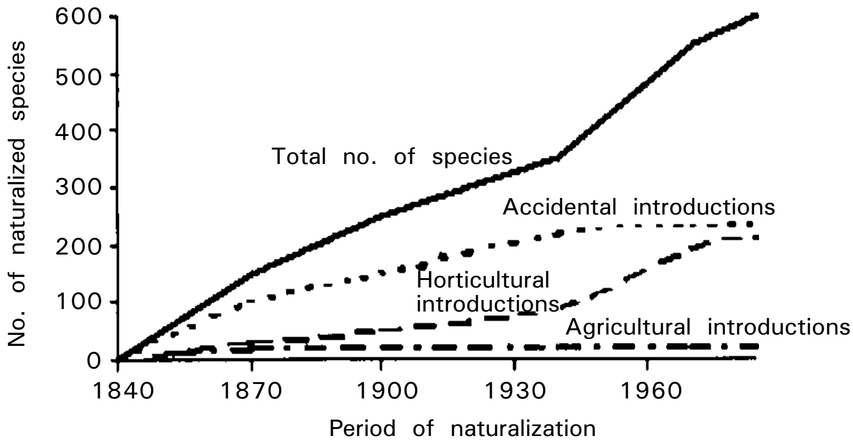

Fig. 1. Rate of naturalization of accidental, horticultural and agricultural introductions

Source: Esler1988

and diseases. This partial transfer of ecosystems makes New Zealand agriculture particularly vulnerable to invasions by weeds and pests. These may either arrive naturally, by air and ocean currents, or more commonly, through unintentional introduction by ship, plane and post. The potential for accidental introduction is very high. Currently, records of the Ministry of Agriculture and Forestry (MAF) show approximately 400,000 containers a year are unloaded each year in New Zealand. Of these, around 39% are contaminated. Fourteen per cent of cargo is inspected because of risk factors such as the point of origin, and another 10% is randomly chosen for inspection. Thus, there is no doubt that contaminated containers are entering New Zealand even if interception rates are perfect (Goldson *et al.* 2002). A further study of the external surfaces of shipping containers also showed considerable potential for entry by unwanted organisms (Gadgill *et al.* 2000). In addition, there are about 3.8 million passenger arrivals each year. MAF intercepts 86,000 prohibited items at the border each year, which have been found to carry more than 4,600 unwanted organisms. From this, it has been estimated that about 50 unwanted species enter New Zealand every year. However, not all of these are able to establish, or their presence may not be noted for some time. This already major threat will increase with growing tourism and trade. In addition, genetically engineered plants are now being developed in New Zealand, as well as introduced from overseas. Keeping out any plants that may become naturalised and weedy is vital. It is much easier and more effective to make such decisions at a national level than at a regional level.

BIOSECURITY IN NEW ZEALAND

It is obvious that biosecurity is extremely important to New Zealand, an island nation heavily reliant on agriculture, forestry and fisheries. New Zealand has one of the highest percentages of introduced plants in the world (Williamson 1996). It also has unique flora, fauna and environments, found nowhere else in the world. National biosecurity is under intense scrutiny, and a new national Biosecurity Strategy was launched in July 2003.

At present four government departments – the Ministry of Agriculture and Forestry (MAF), the Department of Conservation (DOC), the Ministry of Fisheries (MFish) and the Ministry of Health (MHealth) are lead agencies for biosecurity. MAF is responsible for border control. Inspection at the border has been improved in recent years by the introduction of X-ray machines and sniffer dogs to detect undeclared vegetable matter. The responsibility for evaluating proposed introductions as potential weeds has passed from MAF to the Environmental Risk Management Authority. DOC has the responsibility of protecting the New Zealand environment, and including large conservation areas.

If a new organism is found in New Zealand, emergency regulations can be used to eradicate it. In recent years, eradication of several insect pests has been attempted through such emergency procedures. Only four plant species have been given national pest status and are currently being actively eradicated by MAF. These are water hyacinth (*Eichornia crassipes*), Cape tulip (*Homeria collina*), Johnson grass (*Sorghum halepense*) and salvinia or Kariba weed (*Salvinia molesta*). Water lettuce (*Pistia stratiotes*) was in this category until recently, but is now believed to have been eradicated.

INTERNAL BIOSECURITY – THE ROLE OF REGIONAL COUNCILS

Plants that have become naturalized, but are regarded as less dangerous than the four species controlled by MAF, or that are too widespread for easy eradication, become the responsibility of Regional Councils. Weeds listed as pest plants by Regional Councils may include those that:

- Have been serious weeds for a long time (e.g. *Rubus fruticosus, Ulex europaeus* and *Senecio jacobaea*) and have probably more or less reached the limits of their distribution, but whose populations wax and wane with the prosperity of farming and with the kind of livestock being farmed,
- Have long been considered noxious and which may or may not still be expanding their ranges (e.g. *Berberis glaucocarpa, Lycium ferocissimum*, some thistle species),
- Are of limited distribution at present but could spread (e.g. *Pennisetum alopecuroides, Cyperus esculentus, Actinidia deliciosa, Nasella trichotoma*),
- Are established in the wild, and may yet become serious weeds. These plants are described as being in the 'lag' phase, or 'sleepers' (Panetta *et al.* 2001).

Plant species that can clearly be identified as potential weeds should be controlled while still in the 'lag' phase. Guthrie-Smith (1953) described the difficulties of spotting potential weeds early enough. He points out that it is impossible to:

> *"… catch up with a weed that has obtained a start. No action is ever taken in time; to begin with, the new plant is not noticed in its unit stage; when it numbers hundreds, a few of the more observant settlers become interested; when thousands appear it is talked of as a newcomer; only when the hundred thousand phase is past, when the plant has been carried or blown abroad to every corner of every province in New Zealand, is legislation attempted."*

Harris (2000) has developed a model for the cost/benefit assessment of pest plant control. Many Regional Councils in New Zealand use this to support their pest plant strategies. The model includes current and potential distribution, time to reach that potential, landowner efforts at control, value of land use, and potential impact due to lost production and control costs. The model provides Regional Councils with a uniform and partially objective means of comparing the importance of weeds. It certainly goes some of the way towards addressing weed risk assessments, and could easily be developed further. Two aspects of 'guesswork' involved in the model are the potential area infested, and the time taken for the weed to achieve its full potential. Both these are difficult or impossible to estimate accurately.

OFFICIAL IMPORTATION OF PLANT MATERIAL INTO NEW ZEALAND

Under the Hazardous Substances and New Organisms Act of 1996, any new organisms intended for introduction into New Zealand must be assessed for any risk they may offer to species already in New Zealand, to the environment, or to health. The term 'new organism' means a species coming into New Zealand for the first time. Cultivars of existing species do not need to undergo such risk assessment. However, a plant or animal developed through genetic modification (a GMO), for example a tree genetically modified to be resistant to an insect pest, is also classified as a new organism. The Environment Risk Management Authority (ERMA) is responsible for looking at the potential health and environmental impacts, as well as benefits, of new organisms before allowing their release in New Zealand.

ENVIRONMENTAL AND OTHER IMPACTS OF INVASIVE PLANTS

Invasive plant species have many different impacts. These can be classified either by their effect, or by how they are measured. As discussed by Virtue *et al.* (2001), such plants can have negative economic, environmental, ecological and/or social impacts. The magnitude of these impacts is an important determinant of the seriousness of an invasive species. At a simple level, the national impact can be calculated by multiplying localized impact (e.g. $/ha) and the current or potential distribution (e.g., ha). There is considerable difficulty, however, in defining all types of impacts (such as a loss of biodiversity or a reduction in aesthetic value) in monetary terms at a national level. The approach taken in previous assessment systems has been to list and score the range of mainly physical impacts of invasive species (Hiebert & Stubbendieck 1993; Owen *et al.* 1996), many of which also have environmental implications. These include:

Reduction in growth of desirable plants

Invasive species interfere with the growth of desirable plants through competition and allelopathy (Wardle *et al.* 1994). The reduction in growth is typically described as the percentage reduction in the biomass of desirable plants, relative to growth without the invasive species. The impact can also be measured, by the effect of an invader on other species at the genetic, individual, population, community or ecosystem level (Parker *et al.* 1999).

Physical limits on movement

Examples of these physical limits are the presence of thorny thickets which prevent access by livestock to water (e.g. barberry, *Berberis glaucocarpa*), cause blockage of machinery at crop sowing or harvest (e.g. sand rocket, *Diplotaxis tenuifolia*), slow water flow in irrigation systems (e.g. water hyacinth, *Eichhornia crassipes*) or interfere with boat access (e.g. salvinia, *Salvinia molesta*).

Reduction in quality of land use product or usage

Agricultural examples of this impact are contamination of sheeps' wool with burrs or cleavers (*Galium aparine*); tainting of meat or milk (e.g. from twin cress, *Coronopus didymus*) and/or toxic chemicals; and contamination of grain with weed seeds (e.g. wild oats, *Avena fatua*). In natural ecosystems, this type of impact may be seen as damage to the beauty of the landscape, although this is difficult to quantify.

Direct effects on human and animal health

This relates both to external injuries in humans and animals from spines (e.g. Californian thistle, *Cirsium arvense*) and to internal injuries from ingestion of poisonous plants (e.g. St John's wort, *Hypericum perforatum*). There are also allergic reactions from physical contact with plants (e.g. giant hogweed, *Heracleum mantegazzianum*) and pollen (e.g. privet, *Ligustrum ovalifolium*).

Reduction in biodiversity

Invasive plant species can reduce the number and abundance of native plant and animal species. Aquatic environs are particularly sensitive to reduction in biodiversity, because control measures are so difficult. The simplest and most common measure of the impact on biodiversity is the effect on species richness, i.e., the number of species per unit area.

Negative effects on ecosystems

In addition to a loss of biodiversity, weeds can cause long-term, often irreversible, changes to the ecosystem. Humphries *et al.* (1991) stress the importance of introduced grasses in changing fire regimes throughout many climatic zones in Australia. Coastal paperbark, *Melaleuca quinquenervia*, is said to lower water tables in Florida wetlands (Randall 1996). Decaying infestations of salvinia may reduce the oxygen levels and pH of water (Parsons and Cuthbertson 1992). Such specific negative effects on ecosystems are not readily recognized by land managers, and are confirmed only by scientific studies. So far, there have been few such studies done for invasive plants (Adair and Groves 1998; Wardle *et al.* 1994, 1996).

Alternate hosts for plant pests and diseases

Many invasive species can act as alternate hosts for pests and diseases of economically important plant species. For example, Johnson grass is the alternate host of insect pests and a viral disease of maize and sorghum (Parsons and Cuthbertson 1992). Weeds such as blackberry, *Rubus* spp., can also provide a habitat and food resources for pest animals such as wild rabbits.

In order to predict the impacts of a new species with any accuracy, it is necessary to specify what kind of impact is most important. This is equivalent to the hazard identification stage of a risk assessment. There are numerous difficulties in getting good predictions. It is particularly dangerous to assume that a good explanation will lead automatically to a good prediction.

New Zealand as a country has examples of most kinds of weed impact. Impacts from new species are likely, therefore, to be similar to those already experienced. Nevertheless, some life forms, for example shade-tolerant shrubs, are under-represented in New Zealand. Unpredictable and unique combinations of new taxa and habitats are also possible. Communities most likely to be affected are shrub lands, open land, and disturbed forest (Williams *et al.* 2001).

RISK ASSESSMENT FOR WEEDS

A general discussion

To counter the threat from new plant species, all governments have the responsibility to ensure that all new plant species proposed to be imported must be evaluated for their potential to damage the productive capacity or environment of these countries. There are many approaches to predicting the weed potential of a new species (Mack 1996). The weed risk assessment (WRA) is one tool used to evaluate the possible adverse effects of importing new plant species.

Such an assessment is a 'new and developing discipline' (Groves *et al*. 2001), but WRA is rapidly developing. It is already helping us identify the interventions that we can undertake to reduce the impacts of weed invasions. If we know in advance which plants are going to become weeds, we can stop them entering the country in the first place. If they have already entered, we can eradicate them while they are still few in number, or make determined efforts to stop them spreading further. WRA has a place both in preventing new biological invasions, through the advance identification of potentially damaging species, and in reducing the impacts of newly invaded species, by identifying those species that are potentially most damaging. At present, however, WRA is being developed and implemented mainly in developed countries.

Initially, WRA was developed to counter potential weed threats to agriculture. Panetta *et al*. (2001) pointed out that predicting problem weeds in much easier for agricultural weeds than it is for environmental ones. Weeds that become problems in pastures are likely to be poisonous, prickly or otherwise unpalatable to livestock, and invasive. Environmental weeds have a much wider range of characteristics. Panetta (2001) concluded 'Screening systems designed solely to prevent importation of agricultural weeds are thus unlikely to limit the introduction of many invaders of natural areas', but screening systems for detecting invaders of natural areas will probably account for many potential agricultural weeds. More recently, however, WRAs have been developed for environmental risks as well as agricultural ones (Williams *et al.* 2002).

How WRA is carried out depends on the size of the area in question. Hopefully, we can use this type of assessment to make management decisions about weeds on a national, state, regional or local level (Panetta *et al.* 2001). At the national level, the answer that WRA is expected to give is relatively simple – "Will this plant have an impact as a weed if it becomes naturalized?" If the answer is 'Yes', the action may be the government decision to ban its import. If 'No', import may be allowed. The assessment there is acting as a barrier to potentially invasive species. Within a country, WRA may also be used at state level as a barrier, but since it is considerably more difficult to control interstate than international traffic, the objective and practice of WRA will change. As the distribution of the weed becomes greater, so are we less likely to be able to reverse its impacts. WRA at this stage is needed as a basis for prioritizing actions against known weedy species.

CURRENT WEED RISK ASSESSMENT SYSTEMS IN NEW ZEALAND

Esler's system

This model was devised by Esler *et al.* (1993) in response to a request from the Regional Councils for an objective and transparent method of assessing the relative importance of pest plants (formerly called 'noxious plants') already present in New Zealand. It results in two separate scores (Table 1), one for biological success, and one for weediness. Biological success ratings are associated with the ability of the species to establish and spread. These ratings range from 0 to 21. Weed status ratings refer to the nuisance value of the species, and range from 0 to 24. The authors gave Johnson grass (*Sorghum halepense*) ratings of 21 and 18 respectively, the highest rating of any existing weed in New Zealand.

Pheloung's system

The New Zealand Weed Risk Assessment model developed by Pheloung *et al.* (1999) is based on the Australian model devised by Pheloung (1996). Its aim is to test species not yet present in the country for their likely impact if they were introduced. It is probably the best effort yet available as an 'objective, credible, and publicly accepted risk assessment system to predict the weediness, or invasive potential, of the thousands of potential new entries' (Pheloung *et al.* 1999).

The technique involves answering 49 questions covering a range of weedy attributes (Table 2). The questions are essentially in three sections.

Biogeography

This covers aspects such as distribution, climatic preference, history of cultivation and weediness elsewhere.

Table 1. Weed evaluation scores

Attribute	Range of scores
Biological success rating	
Versatility	0-3
Maturation rate	0-3
Seedling ability	0-3
Dispersal and establishment	0-3
Cloning ability	0-3
Recovery	0-3
Competitive ability	0-3
Total biological success rating score	**0-21**
Weed status assessment	
Obstruction	0-3
Suppression	0-3
Health impairment	0-3
Quality impairment	0-3
Damage	0-3
Other	0-3
Opportunity	
Extent of suitable habitat	0-3
Resistance to management practices	0-3
Total weed status score	**0-24**

Source: Esler *et al.* 1993

Table 2. Risk assessment system question sheet
(Answer yes (y) or no (n), or don't know (leave blank), unless otherwise indicated)

Botanical name:		Outcome:
Common name:		Score:
Family name:		Your name:
1. Domestication/ cultivation	1.01	Is the species highly domesticated? If answer is 'no' go to question 2.01
	1.02	Has the species become naturalized where grown?
	1.03	Does the species have weedy races?
2. Climate and distribution	2.01	Species suited to climates (0-low; 1-intermediate; 2-high)
	2.02	Quality of climate match data (0-low; 1-intermediate; 2-high)
	2.03	Broad climate suitability (environmental versatility)
	2.04	Native or naturalized in regions with extended dry period
	2.05	Does the species have a history of repeated introductions outside its natural range?
3. Weed elsewhere	3.01	Naturalized beyond native range
	3.02	Garden/amenity weed of agi/disturbance weed
	3.03	Weed of agriculture/horticulture/forestry
	3.04	Environmental weed
	3.05	Congeneric weed
4. Undesirable traits	4.01	Produces spines, thorns or burrs
	4.02	Allelopathic
	4.03	Parasitic
	4.04	Unpalatable to grazing animals
	4.05	Toxic to animals
	4.06	Host for recognized pests and pathogens
	4.07	Causes allergies or is otherwise toxic to humans
	4.08	Creates a fire hazard in natural ecosystems
	4.09	Is a shade tolerant plant at some stage of its life cycle
	4.10	Grows on infertile soils
	4.11	Climbing or smothering growth habit
	4.12	Forms dense thickets
5. Plant type	5.01	Aquatic
	5.02	Grass
	5.03	Nitrogen fixing woody plant
	5.04	Geophyte
6. Reproduction	6.01	Evidence of substantial reproductive failure in native habitat
	6.02	Produces viable seed
	6.03	Hybridizes naturally
	6.04	Self-fertilization
	6.05	Requires specialist pollinators
	6.06	Reproduction by vegetative propagation
	6.07	Minimum generative time (years)
7. Dispersal mechanisms	7.01	Propagules likely to be dispersed unintentionally
	7.02	Propagules dispersed intentionally by people
	7.03	Propagules likely to disperse as a produce contaminant
	7.04	Propagules adapted to wind dispersal
	7.05	Propagules buoyant
	7.06	Propagules bird dispersed
	7.07	Propagules dispersed by other animals (externally)
	7.08	Propagules dispersed by other animals (internally)
8. Persistence attributes	8.01	Prolific seed production
	8.02	Evidence that a persistent propagule bank is formed (>1 yr)
	8.03	Well controlled by herbicides
	8.04	Tolerates or benefits from mutilation, cultivation or fire
	8.05	Effective natural enemies present in Australia/New Zealand

Source: Pheloung *et al.* 1999

Undesirable attributes

These include toxicity, unpalatability to livestock and invasive behaviour.

Biology/ecology

This refers to the attributes that enable a plant to reproduce, spread and persist.

Pheloung's WRA system differentiates between plants that may become agricultural or environmental weeds. The final score can range from -14 for a totally benign species, to 29, for the maximum weediness score. A score of 0 or less means that the species can be accepted into the country. A score of 1 to 6 means that further evaluation of the species is necessary. A score of 7 or more indicates that importing the species should be prohibited.

Champion and Clayton's model for aquatic plants

The model of Champion and Clayton (2001) is an adaptation of the systems used in Esler *et al*. (1993) and Champion (1995), but is specifically designed for aquatic plants. Attributes of a plant's ecology, biology and weediness are assessed, based on observations of its behavior in New Zealand, and any information from other countries. The attributes of greatest importance are ranked on a scale of 0-10. The lower the score, the less important the attribute. These attributes are briefly listed in Table 3.

Champioin and Clayton (2001) claim that the two WRA models, viz. Esler *et al.* and Pheloung *et al.*, fail to discriminate adequately between aquatic plant species with different levels of impact. Many of the attributes scored by the above two models are not relevant to the assessment of aquatic plants, including fire risk and several dispersal characteristics. Aquatic habitats are also less likely to suffer the extremes of temperature found in terrestrial habitats. Champion and Clayton model recognizes the tendency of many introduced aquatic species to become weedy. The adaptive characteristics that enable them to survive in the aquatic environment include their ability to spread rapidly through the water and their general lack of woody structural tissue, since support is provided by the water.

Williams' model

Williams *et al*. (2002) devised a weed risk assessment system to assess the risk to the natural environment of candidates for importation. This model relies heavily on the weedy behavior of relatives of the species under test, both in New Zealand and overseas. This information is drawn from scientific publications. The first part of the assessment involves determining the likelihood of the species becoming established (score A.1, based

Table 3. Attributes and range of scores for aquatic plants

Attribute	Range of possible scores
Versatility	2-10
Competitive ability	0-10
Propagule dispersal	0-10
Degree of obstruction	0-10
Damage to natural ecosystems	0-10
Extent of suitable habitat not occupied within New Zealand	0-10
Resistance to management	0-10
Weed history in different habitats	1-9
Seeding ability	0-5
Cloning ability	0-5
Behavior in other countries	0-5
Maturation rate	1-3
Other undesirable traits	0-3

Source: Champion and Clayton 2001

Table 4. Contributing factors and ragne of scores

		A.1 scores	
Naturalization and weed history of the species' relatives		Range of scores	Class: yes/no, or score from 0 to 5 based on the historical behavior of species in that class, e.g. if >10% of the species in the family have naturalized in N.Z., the score = 5
Family is naturalized	In New Zealand	0-5	>10% (5), 10-5% (4), 4-2% (3), 2-1% (2), <1% (1), 0(0)
	Elsewhere	0-1	Yes (I), No (0)
Genus is naturalized	In New Zealand	0-2	>10% (2), <10% (1), 0(0)
	Elsewhere	0-1	Yes (1), No (0)
Family weedy	In New Zealand	0-4	>50% (4), 50-10% (3), 9-1% (2), <1% (1), 0(0)
	Elsewhere	0-1	Yes (1), No (0)
Genus weedy	In New Zealand	0-2	>10% (2), <10% (1), 0(0)
	Elsewhere	0-2	Yes (1), No (0) - multiply by 2 if woody or vine
Sum = A.1 score		0-18	
		A.2 scores	
Attribute	Range of scores		Criteria with potential scores 2, 1 or 0
1.	Reproductive capacity	0-2	(2) Viabale seed and specialized vegetative organs; (1) Viable seed or specialized vegetative organs; (0) no seed set, no specialized vegetative organs
2.	Dispersal by humans	0-1	(1) Likely to be spread around, (0) Unlikely to be spread around
3.	Visibility	0-1	(1) Not noticeable, (0) Conspicuous
4.	Resistance to management	0-1	(1) Resistant features, (0) No resistant features
Sum = A.2 score		0-5	

Source: Williams 2002

on the naturalization and weed history of its relatives), and how easy it might be to control (score A.2). The second part assumes that the species does become established, and considers which ecosystems are most likely to be affected. (score B). In practice, scores for the second part are used only as qualifiers to the A.1 and A.2 scores, and are not shown here.

Comparison of the four models

The four WRA models discussed above all have their strengths and weaknesses. None of them take into account, however, the fact that a species invading New Zealand is likely to enter the country without its natural enemies. Weediness in its country of origin also does not consider this point. Such considerations would need to involve scientists from several other disciplines (e.g. entomology, microbiology, plant pathology), apart from plant biologists.

The Champion and Clayton (2001) model is specially designed for aquatic plants. However, it is not suitable for determining the risk of new species compared with those already present, or for determining the relative importance of existing weeds. The Williams (2002) model offers some scope for evaluating the potential environmental as well as agricultural risk of new invaders. All these models could be improved by further experience and fine tuning. As they are, they do allow us a means both of evaluation, and of comparing the likelihood and potential magnitude of threats. The challenge still remains to predict the behavior of a species that has never been introduced anywhere else.

PRACTICAL USE OF WRA

The seeds of exotic weed species are sometimes introduced into New Zealand attached to fresh fruit. If they become established, these weed species may become a serious problem. In a recent study (Popay *et al.* 2003) different WRA systems were used to evaluate dangers to New Zealand agriculture and natural ecosystems from weed seeds accidentally imported into the country on the surface of fresh fruit. This information will be used by the MAF Biosecurity Authority to help set maximum pest levels: i.e. the number of seeds per fruit that are acceptable for imported fruits.

As part of the project, an assessment was made of the threat that nine such species could pose, if introduced and successfully established. The nine species are those whose seeds are most frequently found on imported pineapples, grapes, and other fresh fruit. All are warm-zone weeds, largely restricted to the tropics or sub-tropics. However, many sub-tropical weed species already flourish in New Zealand, and global warming is likely to allow these species to spread and become more important.

Information was collected on the form, ecology and weed status of each of the nine species. This information was then used for weed risk assessment according to the system devised by Pheloung *et al.* (1999). It was assumed that all these species could become established in New Zealand, at least in the northern areas, and that future climate change would enable them to thrive. For comparison, the technique devised by Esler *et al.* (1993) for assessing biological success and weediness for weeds already present in New Zealand was applied to the same nine species. The scores are shown in Table 5. For comparison, Table 6 provides weed risk assessment scores for some weeds already present in New Zealand.

POTENTIAL SOURCES OF NEW WEEDS IN NEW ZEALAND

New invasive plants could be newly imported species, or could be species already found cultivated in New Zealand. According to the Department of Conservation (updated from Owen 1998), more than 25,000 exotic species grow in gardens, plantations and farms in New Zealand, in addition to 2500 or more exotic species that have become naturalized. Four thousand of these exotic species have already been listed as weeds elsewhere in the world (Williams *et al.* 2001). New plants are

Table 5. Weed risk assessment scores for nine weed species whose seeds were found on imported fresh produce

Species	Pheloung *et al.* (1999)		Esler *et al.* (1993)	
	New Zealand weed score	Accept/ evaluate/ reject[1]	Biological success rating	Weed status assessment
Siam weed (*Chromolaena odorata*)	23	R	16	21
Sourgrass (*Paspalum conjugatum*)	22	R	19	15
Para grass (*Brachiaria mutica*)	21	R	14	12
Wild sugarcane (*Saccharum spontaneum*)	17	R	15	10
Ruby grass (*Rhynchelytrum roseum*)	14	R	11	4
Spider flower (*Cleome rutidosperma*)	12	R	11	6
Chickweed, sneezewort (*Ageratum conyzoides*)	12	R	16	9
Ivygourd (*Coccinia grandis*)	8	R	12	13
Cotton Panic (*Digitaria brownii*)	4	E	11	4

1 Reject means reject for importation, Accept means allow importation, and Evaluate means more information is needed.

Table 6. Weed risk assessment scores for some weeds already present in New Zealand

Species	Pheloung *et al.* (1999)		Esler *et al.* (1993)	
	New Zealand weed score	Accept/ evaluate/ reject[1]	Biological success rating	Weed status assessment
Bramble (*Rubus fruticosus*)	29	R	17	15
Johnson grass (*Sorghum halepense*)	25	R	21	18
Ragwort (*Senecio jacobaea*)	22	R	15	14
Milk thistle (*Silybum marianum*)	19	R	13	10
Spiny cockleburr (*Xanthium spinosum*)	15	R	10	8
Gorse (*Ulex europaeus*)	13	R	15	19

1 Reject means reject for importation, Accept means allow importation, and Evaluate means more information is needed.

regularly brought into New Zealand, whether accidentally, deliberately or illegally.

According to Smith *et al*. (1999), the reported proportion of introduced organisms that become pests ranges from 0.007% in the United Kingdom to 17% of the plants introduced into Australia as pasture plants. The authors settle on a 'possible central tendency' of 2%. If this is applied to the plant species already present in New Zealand, we might expect at least another 500 species to become agricultural pests or species which damage the natural environment. Williams *et al*. (2002) stress that some plant families are more dangerous than others. More than 10% of naturalized species from the Asteraceae (daisies) and Solanaceae (potatoes and tomatoes) have become weeds of agriculture or the environment. In contrast, species of Orchidaceae (orchids) and Bromeliaceae (bromeliads) have proved relatively harmless.

Once a plant species has escaped from a garden through discarded cuttings or by means of animals (mostly birds or humans), wind or water carrying its seeds or other propagules, it may form self-sustaining populations in the wild. In this case, it is said to have become naturalized, forming part of the New Zealand flora. From this point it might remain present only in small areas and quite harmless, or it may spread and become invasive.

INVASIVE PLANTS AND THEIR BEHAVIOR IN NEW ZEALAND

Newly introduced plants often follow the population growth pattern shown in Fig. 2 (Rahman and Popay 2001). The length of the lag phase is variable. It depends on how long it takes for the plant species to become acclimatized to local conditions, or to build up numbers to the point where it can expand rapidly. In some cases, the lag phase may end when external conditions change in such a way that the plant population can rapidly expand.

Many of the plant species introduced into New Zealand have been valuable for their economic value or the pleasure they bring to people. New species continue to be introduced. Some are useful and unlikely to adversely affect the environment, whilst others could be damaging. Some introduced species, such as gorse (*Ulex europaeus*) have become major weeds occupying thousands of hectares. Other introduced plant species have stayed where they were planted, in gardens or on farms.

EFFECT OF CHANGES IN CLIMATE ON WEED DISTRIBUTION

Further changes in New Zealand's climate and land use will offer a wider range of invasive plant species the opportunity to become naturalized and to spread further. Global warming is likely to bring a temperature increase of between 0.7°C and 3.1°C over the next 100 years in Australia and New Zealand. Rainfall patterns will also change. There are likely to be more adverse events – cyclones, floods, droughts and heatwaves. All of these factors could affect the species of weeds able to invade New Zealand.

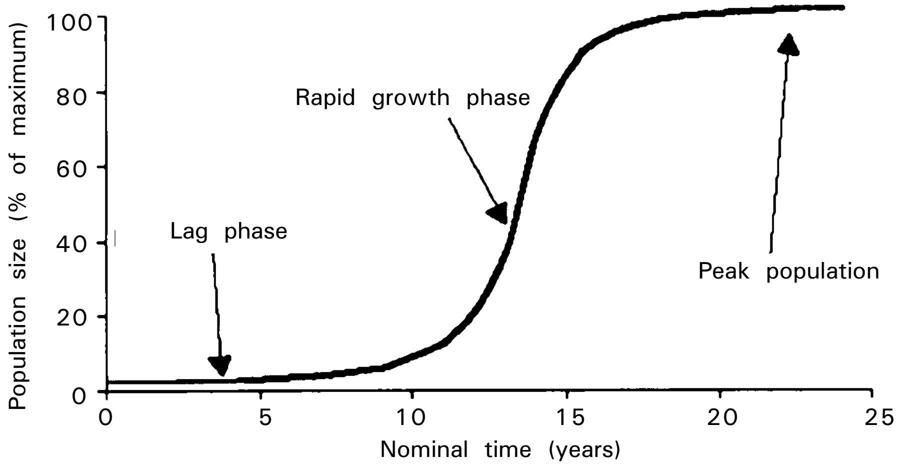

Fig. 2. Population growth pattern of a newly introduced species

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