REPORT

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FAO EXPERT CONSULTATION ON WEED RISK ASESSMENT

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FAO EXPERT CONSULTATION ON WEED RISK ASSESSMENT

Edited by Ricardo Labrada

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The Need for Weed Risk Assessment

Ricardo Labrada
FAO Weed Officer
Email Ricardo.Labrada@FAO.org

Summary

Invasive plants and animals are often exotic species, entering new areas without bringing along their natural enemies; thus spreading widely at the level of farms or a through a particular territory, country or region of the world. Their presence and proliferation heavily affect the ecosystem, causing a shift in the existing vegetation and wildlife. Agriculture is one of the areas most affected by the invasion of new exotic plants. There are many examples of introduced plants, some of them intentional, which are serious weeds in the agriculture of various regions of the world. The problem will worsen as free trade becomes more active, and this will increase the risk of new pest introductions, including exotic plants with or without weedy characteristics. Concern about the introduction and spread of invasive plants has increased recently and is well reflected in the 1994 Convention on Biological Diversity and in various other national treaties. However, there is a need to create more awareness about the problem and to establish effective mechanisms for prevention. In this context, the development and publication of guidelines for weed risk assessment are proposed, which should be based on existing standards of pest risk analysis of the IPPC. The FAO expert consultation on weed risk aims at developing the use of such a methodology by national authorities and plant quarantine inspectors.

Introduction

The problem of introduced exotic plants has existed since time immemorial, but it intensified with the discovery of the western hemisphere in 1492. Many new plant species were introduced into Eurasia and Africa from this new hemisphere while the Americas also assimilated many species common to Eurasian habitats. However, only those plants possessing "weedy" characteristics became invasive, since these characteristics enabled them to spread rapidly and to compete effectively with native plants. Their persistence in new habitats has been mainly due to their prolific production of seeds or other vegetative organs.

More invasive plants are being introduced into new areas, and the situation is aggravated by the current situation of active free trade. Therefore, preventive measures will need to be implemented as well as risk assessments made of exotic plants with the potential to adapt and become established in new habitats.

FAO regularly conducts activities related to safe and effective prevention of the spread and introduction of pests of plants and plant products, and promotion of measures for their control. This work is normally conducted by the International Plant Protection Convention (IPPC), a multilateral treaty deposited with the Director-General of FAO and administered through the IPPC Secretariat located in FAO's Plant Protection Service. A total of 117 governments officially adhere to the IPPC.

Although IPPC has approved guidelines for pest risk analysis (IPPC, 1996), which provide the process for evaluation of any plant pest, some additional details are needed when evaluating risks associated with exotic plants.

Economic impact of introduced exotic plants

Invasive plants and animals are often exotic species, entering new areas without being accompanied by their natural enemies; thus they spread or reproduce prolifically. Invasive species have always been a very serious problem. They may significantly alter the ecosystems, seriously affect agricultural production and disturb recreational areas. Several invasive plants have the ability to compete with and replace native species in natural habitats, and the spread of exotic plants has had a tremendous impact in many countries.

It is considered that weedy plants introduced into the USA have caused annual losses to agriculture of no less than US$ 3.6 billion (US Congress, Office of Technology Assessment, 1993). In many countries, natural flora of different sites has been completely replaced by exotic invasive plants. Agriculture is also severely affected by these new species. Johnsongrass (table 1), which was introduced during the 19th Century into the USA, Mexico and Cuba, became the major weed problem in several arable crops; Itchgrass (*Rottboellia cochinchinensis*) from Southeast Asia was introduced into the Caribbean and Central America, where it became one of the main weeds in sugarcane and maize. FAO estimated that 3.5 million ha are heavily infested by this weed (FAO report, 1993). In Panama, the grass *Saccharum spontaneum* was introduced as cover for borders along the canal; now it has spread throughout Panama and parts of Costa Rica. The broadleaf Asteracea *Chromolaena odorata* (formerly *Eupatorium odoratum*) was introduced into Africa and Asia as a cover in many plantations, and it is now a very serious problems in areas where cocoa, oil palm and other perennials are grown. Another annual Asteracea *Parthenium hysterophorus* was introduced in food aid coming from North America into several countries of Asia and Africa. At present it poses a very serious problem to agriculture in India, Ethiopia and other countries and also to the health of the farmers themselves. This weed was also introduced into Australia where it has invaded large crop areas. Other species, such as water hyacinth (*Eichhornia crassipes*), were imported into several countries as ornamentals and are now a problem affecting irrigation networks, supply of hydroenergy, fishing and navigation, and creating habitats for the development of human disease vectors. In the recent past, in several countries of Africa and the Middle East, various species of *Prosopis* have been introduced; in some areas, such as Ethiopia, South Africa and Sudan, the plants have become weeds invading the most fertile areas. Some other plants have been introduced deliberately as food or medicines by immigrants. Exotic plants have also arrived in many places hidden as contaminants in the soil or in imports of plant origin.

This problem will worsen as free trade becomes more active, and this will increase the risk of introduction of new pests, including exotic plants with or without weedy characteristics.

Table 1

Some examples of introduced plants in various regions of the world

Species	**Area of Introduction**
Sorghum halepense	Americas
Rottboellia cochinchinensis	Americas
Mimosa pigra	Africa, Asia & Oceania
Chromolaena odorata	Africa, Asia & Oceania
Parthenium hysterophorus	Africa, Asia & Oceania
Lantana camara	Africa, Asia & Oceania
Eichhornia crassipes	Central America, Caribbean, Africa, Asia & Oceania
Prosopis spp.	Middle East & Africa
Striga asiatica	North America

What to do?

The introduction and spread of invasive plants have gained recognition over the recent past. This concern is well reflected in the 1994 Convention on Biological Diversity (CBD) and in various other national treaties. However, most developing countries still need assistance to deal with matters related to the prevention of invasive plants.

This prevention should consist of "the development and implementation of measures such as policies, plans, legislation and programmes to prevent alien and living modified organisms from adversely affecting biodiversity".

Public education and awareness are also required in order to keep the population informed on this issue. Society needs to be informed of the consequences of introducing materials potentially contaminated with exotic plant seeds from abroad. It is also important to widely inform on the impacts likely to occur after such introduction. Particular attention should be given to the education of farmers about problems associated with the planting of certain types of shelterbelt or forage crops that may become invasive species in nearby natural areas. Taxonomists should also need to be educated. In many cases, these scientists have introduced species without any thought for their potential weedy characteristics.

Risk assessment

As mentioned previously, there is a need to draw up additional guidelines to assess the risk of exotic plants. The method should help to predict which species have the capacity to become established in a new habitat and to invade new areas.

Only a few developing countries, and some developed ones, regularly carry out activities to evaluate the risk of new invasive plants. In many of these countries there is no list of quarantine weed species. Plant Protection Services and their quarantine sections should be able to determine the likelihood of introducing or spreading invasive species and also to determine adequate measures to minimize their potential harm. Therefore, the three steps indicated in IPPC pest risk analysis have to be followed:

a) Identification of the pathway that may allow the introduction and/or spread of the exotic plant (fig. 1).
b) Pest risk assessment, which consists of considering all aspects of each plant and, in particular, available current information about its geographical distribution, biology and economic importance. This information is then used to assess the establishment, spread and economic importance potential in the endangered area and, finally, characterization of the potential of introduction (fig. 2).
c) Pest risk management, i.e. determining phytosanitary measures to be applied to effectively protect the endangered area (fig. 3).

Recognizing invasive species and understanding the problems they cause are critical to minimize their impact. In this context, public awareness about problems caused by the introduction of exotic plants is important, and government officials should also be educated in order to obtain the necessary support for weed prevention and control.

The reason for an expert consultation on weed risk assessment

Plant Protection Services should be empowered in matters pertaining to the introduction of exotic plants and/or weeds, to help them to make appropriate decisions in order to prevent these problems and to minimize the impact free trade may have on agriculture in the years to come.

A guideline dealing specifically with weed risk assessment, based on existing standards of pest risk analysis of the IPPC, should be developed and published. The objectives of the expert consultation are to discuss the draft guidelines and improve them where necessary. Once the guidelines are approved FAO, with the support of the donor community, will be in a position to propose a programme for training technicians and quarantine inspectors of countries from developing regions of the world.

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FIGURE 1

PEST RISK ANALYSIS

Stage 1: Initiation

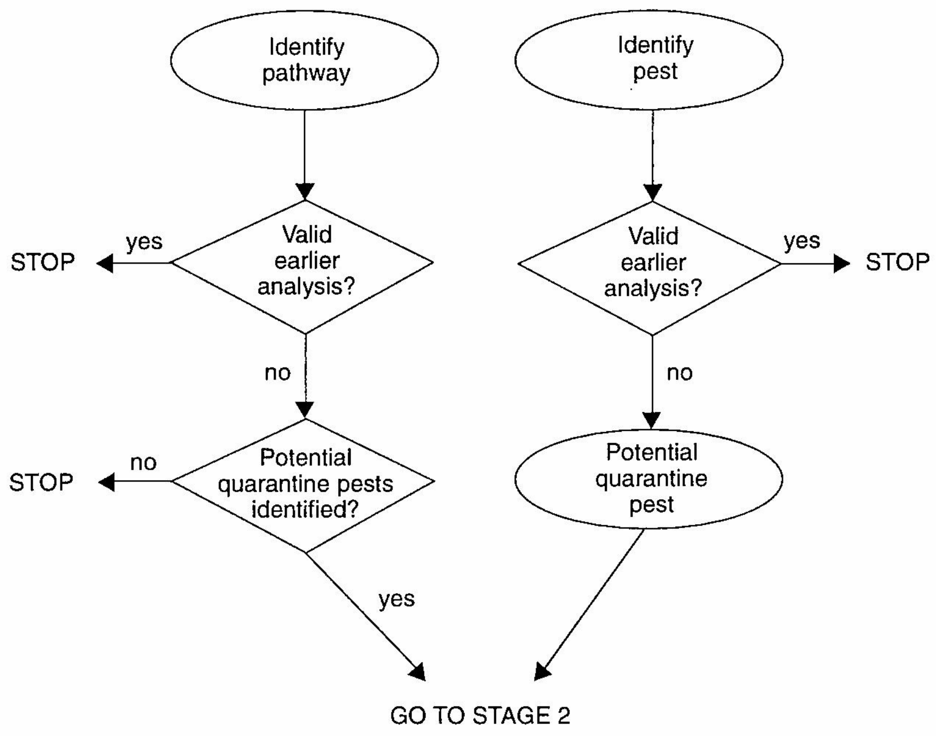


FIGURE 2

PEST RISK ANALYSIS

Stage 2: Assessment

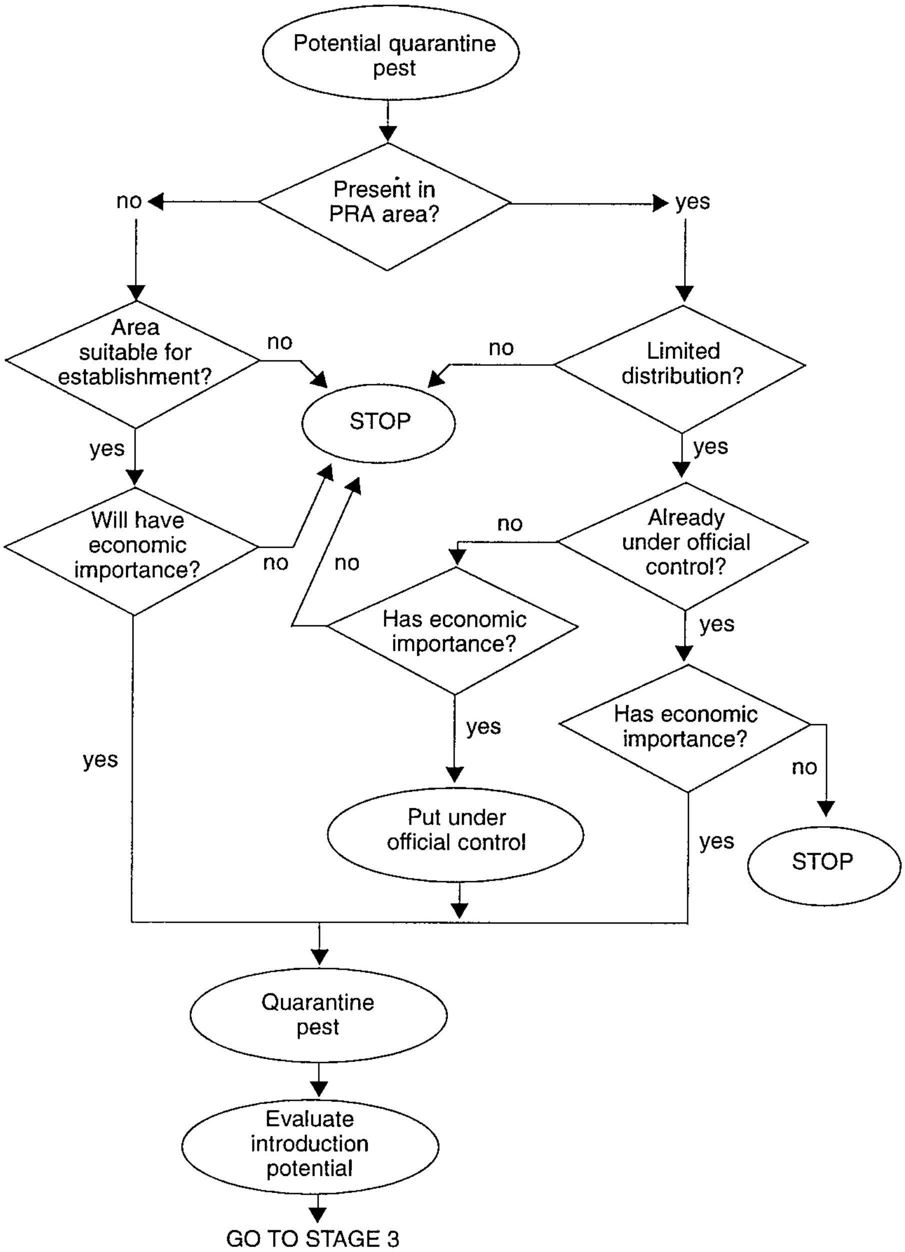
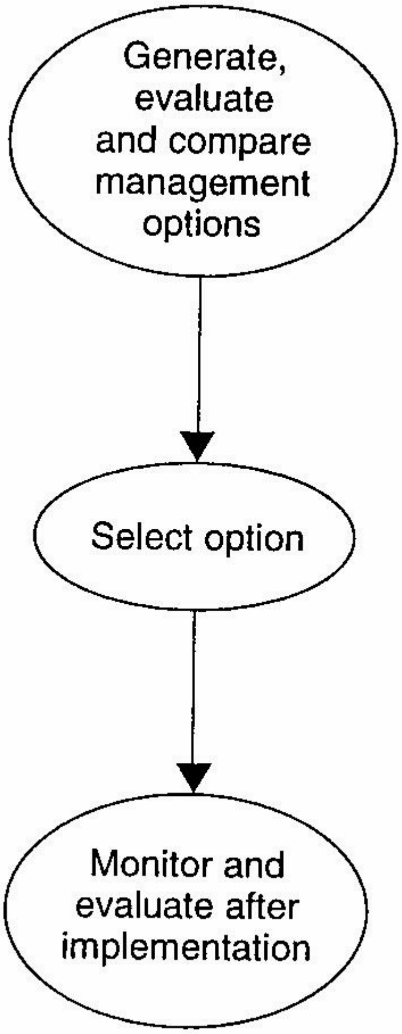


FIGURE 3

PEST RISK ANALYSIS

Stage 3: Management

from Stage 2



New Global Strategies for Weed Prevention through Mandatory Prescreening, Early Warning and Rapid Response, and a New Biological Protection Ethic

Randy G. Westbrooks
Invasive Plant Coordinator
United States Geological Survey
E-Mail: rwestbrooks@weblnk.net

Summary

Prior to the globalization of trade in the pas few decades, plant and animal regulatory programmes that existed in most countries were deemed more or less adequate to ensure food and fibre production through exclusion and rapid response to high profile crop pests such as foot-and-mouth disease, gypsy moth and Mediterranean fruitfly. While such programmes continue to fulfil their original purposes, increased trade and travel have created many new pathways for the spread of alien invasive species to distant regions of the planet. To counter this emerging threat to biodiversity, three new strategies need to be employed:

- *mandatory pre-screening of all imported plants and animals* to determine if they should be regulated (under current international rules);
- *early detection and rapid assessment of confirmed new species with free living populations* to determine how they should be addressed; and,
- development of *a biological protection ethic* to promote the use of native species when possible, and to discourage the use of harmful invasive species (both native and exotic) for utilitarian purposes.

Introduction

Over the past several thousand years, people have intentionally and accidentally moved many organisms far beyond their historical native range around the world. The majority of these species are either beneficial to human civilization or have been benign in free living populations. However, a small percentage of introduced species pose a serious threat to the biodiversity of natural areas and/or diminish the production capacity of managed or agricultural ecosystems. Unlike chemical pollutants that degrade in the environment over time, invasive species, now termed *biological pollutants*, have the ability to reproduce and spread. By moving plants and animals far beyond their native ranges, the major biogeographical realms are being blurred, and a biological Pangaea is being recreated that is having negative impacts on biodiversity.

Currently, about 3,800 species of known introduced plants (compared to a native flora of 18,000 species) have established free-living populations in North America (J. Kartesz, Biota of North America Program, UNC-Chapel Hill). These represent established exotics that have become invasive (1,450 species are recognized as agricultural weeds) or could become invasive in the future. Researchers at Cornell University have calculated the total cost of invasive species to the American economy to be in excess of $US 138 billion per year. Thus, preventing the spread and establishment of invasive species throughout the world is a critical strategy in protecting the sustainability of agriculture and biodiversity.

Invasive Species, coming to America. Since the break-up of the supercontinent Pangaea about 180 million years ago, North America has been geographically isolated from the rest of the world, and thus largely protected from biological invasions. However, that changed in a short time with the beginning of modern European colonization about 500 years ago, and became a serious problem with the onset of modern transportation and travel in the 20th century.

During colonial days, when global trade and travel were minimal, foreign pests, which threatened crop and livestock production, were the primary concern. Invasive species of natural areas had few pathways and opportunities to spread beyond their native ranges in other regions of the world. In those days, before natural areas were invaded by alien invasive species, there was little concern or even notice of the thousands of plant and animals that were being imported for utilitarian purposes such as game fishing [European carp (*Cyprinus carpio*)], soil erosion [kudzu (*Pueraria montana*)] (Figure 1), windbreaks [Russian olive (*Eleagnus angustifolia*)], medicinal herbs [purple loosestrife (*Lythrum salicaria*)]and for ornamental use [salt cedar (*Tamarix chinensis*)]. In fact, such introductions were widely encouraged. While many of these introductions remain beneficial today, some of them have become invasive and pose a threat to our remaining natural and conservation areas - areas that have been reduced to ‘islands’ in a sea of disturbance.

Figure 1. Kudzu (*Pueraria montana*) was imported from Japan in 1876 as an ornamental porch vine, and used later for erosion control throughout the South. Kudzu now infests several million acres and causes over US$ 500 million in control costs and timber losses per year.

Prohibited Lists – The Heart of the Current US Crop Protection System. The current US federal/state agricultural protection system was developed in the late 1800s and early 1900s in response to outbreaks of plants and animal pests such as foot-and-mouth disease, Mediterranean fruitfly (*Ceratitis capitata*) and gypsy moth (*Lymantria dispar*). The current system includes programmes that form two lines of defence against invasion through:

1. **Exclusion of foreign agricultural pests:**
   A. Production of pest free commodities in exporting countries (e.g. disease-free beef)
   B. Pre-clearance at ports of export
   C. Inspection and clearance at ports of entry

2. **Detection and eradication of domestic outbreaks:**
   A. Survey and detection
   B. Containment
   C. Eradication

On the surface, it would seem that this system could provide protection against invasion by all types of invasive species. However, in reality the system was set up to facilitate trade by protecting American agriculture from invasion by high profile plant and animals pests and diseases. For decades, alien pests of concern have been assessed for invasiveness and prohibited introduction into the USA under a menagerie of federal laws. In 2000, most of these laws were superseded by the omnibus Federal Plant Protection Act. *While the new Plant Protection Act provides equal authority for regulation of all types of invasive species*, including invasive plants, *the decision to assess a candidate species to determine whether it should be regulated is still optional in most cases*. As a result, most species that are imported into the United States are still not being assessed for invasiveness – in general, the system does not require it. (The exception to this is new fruits and vegetables, which must be assessed under Quarantine 56 for invasiveness prior to importation.)

The current system generally works fine to protect monocultural agricultural production systems from *known* foreign pests. However, in order for the nation to effectively meet the challenge it faces with invasive species in all types of environments, new approaches for preventing introduction, establishment, and spread of invasive species are needed.

Mandatory pre-screening – a regulatory yield sign to slow the global movement and spread of invasive species. Based on past experience in Hawaii and New Zealand, it is has been concluded that a very low percentage of all introduced plants will become invasive in a new area over time. However, intentionally introduced species represent a high percentage of all species that become invasive, and thus mandatory pre-screening of all imported plants and animals is the only sure way to identify potential invaders before they are introduced into a new country. The very successful Australian Weed Risk Assessment System has demonstrated the viability of this approach, and could serve as a model in developing a similar system in the United States.

For continuity with the current national plant regulatory systems, the proposed pre-screening system could continue to focus on 'prohibited' species. However, unlike most current systems that only assess a small percentage of proposed species for invasiveness, the new system would assess all proposed species to determine whether they should be prohibited entry[1], regulated entry[2], permitted entry[3] or placed on a National Invasive Plant Watch List[4].

Under this proposed system, as in the past, species found to be invasive that are absent from or occur in a limited percentage of their potential ecological range within the country would be formally listed under the country's plant regulatory laws. Following current international rules under the International Plant Protection Convention, proposed species found to be invasive that already occur in a large percentage of their potential ecological range in the country (either in trade or in free living populations) would not be formally listed. However, if appropriate, such species could be placed on a National Invasive Plant Watch List (non-regulatory) o *discourage* further artificial spread (see Diagram 1). Kudzu (*Pueraria montana*), which is a very serious invader in the southeastern United States, would not be officially prohibited entry from the US under this approach because it does not meet the official definition of a 'quarantine significant pest' – it is simply too widespread to regulate. However, it could definitely be placed on a National Watch List to discourage further importations and spread within the country. New introductions of kudzu from different parts of its native range could hybridize with established populations in the USA and create more invasive biotypes. At the state level, where enforcement is typically conducted at the point of sale, another approach would be to combine the traditional prohibited listing system with a formal permitted listing approach. Under this approach, all species proposed for importation into a state would fall into one of the following regulatory categories:

1) *Prohibited non-native species* (highly destructive species which may not be possessed, imported, purchased, sold, propagated, transported or introduced except under permit issued by an appropriate agency)
2) *Regulated non-native species* (species that have some beneficial commercial or recreational use, and would become invasive unless regulated);
3) *Unregulated (permitted) non-native species* (species which have been reviewed by an appropriate agency and have been determined to present a low risk of becoming invasive, or is an invasive species that is currently present and beyond control).
4) *Unlisted non-native species* (species that have not been reviewed and classified by an appropriate agency and thus may not be possessed, imported, purchased, sold, propagated, transported or introduced into the state).

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[1] **Prohibited species** would be officially listed, highly destructive species (absent from or occupying a small percentage of their potential ecological range in the US) with no commercial or recreational use that would cause great harm to native ecosystems or agriculture if released into the wild.

[2] **Regulated species** would be officially listed species (absent from or occupying a small percentage of their potential ecological range in the US) that have some beneficial commercial or recreational use, but would become invasive unless regulated.

[3] **Permitted (approved) species** would be placed on an informal list for future reference.

[4] **Species of ecological concern** that are not prohibited or regulated could be placed on a National Invasive Plant Watch List.

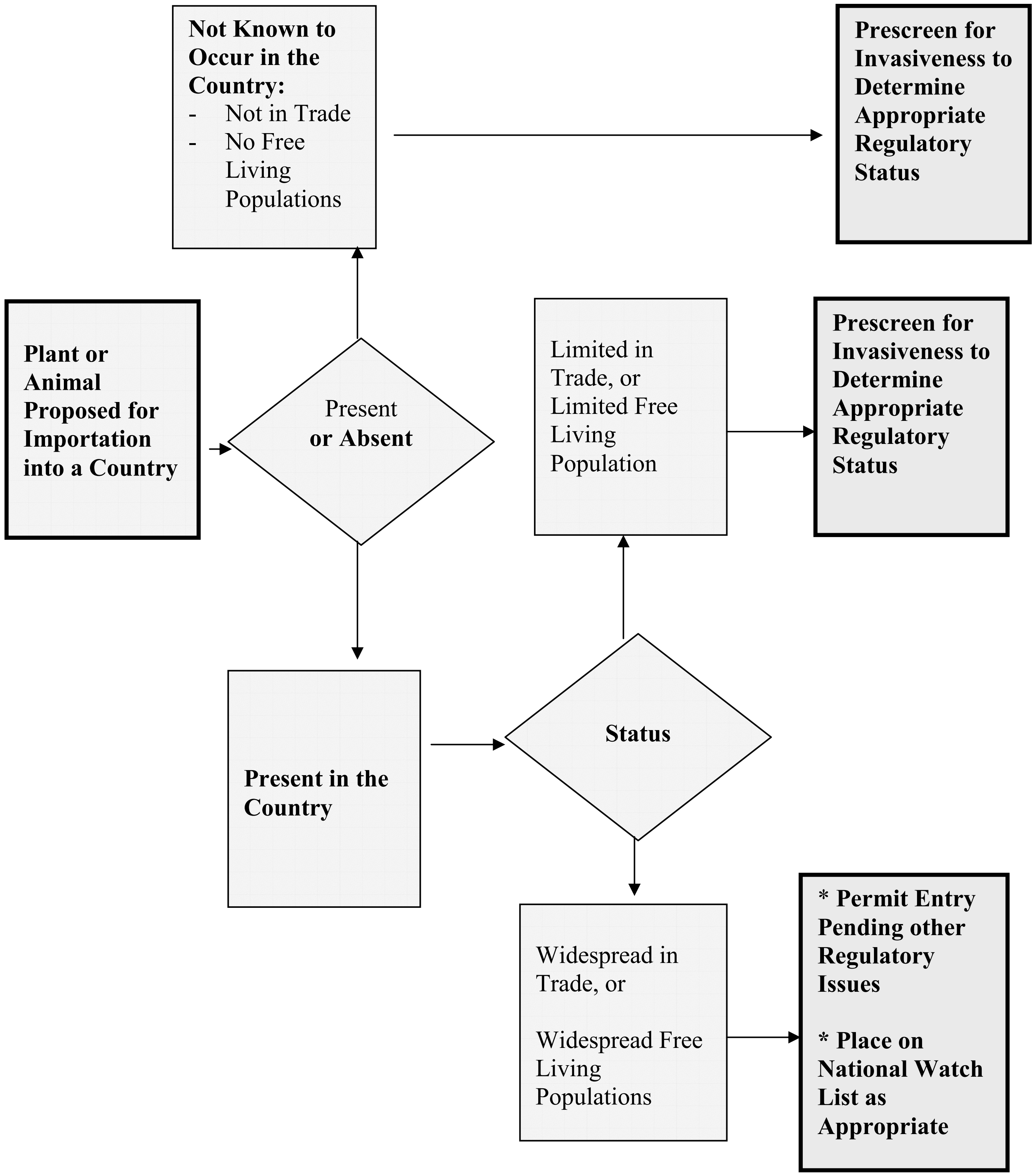

Diagram 1. Proposed system for mandatory pre-screening of imported plants and animals.

New approaches for early warning and rapid response to new invasive plants in the United States

As already stated, there is a growing awareness that introduced invasive species are having significant and increasing impacts on the US economy, ecosystems and native species, and pose increasing threats to human health. The United States, with the greatest biome-level diversity of any nation and a large inventory of relatively intact ecosystems, is particularly vulnerable to such biological invasions. Until recent times, this was not much of a threat due to the relative isolation of the North American continent. However, increased trade and travel have created many new pathways for intentional and incidental spread of exotic species, and have significantly increased the threat of new and recurring biological invasions. Increased international trade in ornamental plants (including seeds) is a special concern because many of the currently known exotic invasive plants in the USA were originally imported as ornamentals. Increased trade in ornamental plants with megadiversity countries, such as China and South Africa, will probably increase this problem. While the majority of introduced species are not harmful to the American economy or the environment, a small percentage of them are very damaging and need to be detected as soon as possible.

Once established, invasive species frequently have long lag times. Introduced species that initially escaped many decades ago are only now being recognized as invasives. Due to this lack of attention on free living exotic species, exotic plants now comprise a growing percentage of the flora of all states (e.g. HI 43%, NY 36%, MO 25%, CA 18%, TX 10%). With continual introductions over the past 100 years, it can be expected that some exotics that are not currently identified as invasive will become significant problems in the future. Thus, there is an urgent need to document and address species that were introduced in past years; as well as the potentially larger problem of the species that are being introduced today. Without a coordinated national system for early detection and rapid response which are integrated with general vegetation surveys, free living exotic plants will continue to incubate until they become the invasive plants of tomorrow – the major weeds of the 21st century and beyond.

Under the current US crop protection system, federal and state plant regulatory agencies work to protect the nation from economically important plant and animal pests and diseases. However, due to a lack of resources and organized constituencies, newly established invasive plants (both agricultural weeds and invasive plants of natural areas) are seldom detected and addressed on public or private land until populations become widespread and prevention/eradication becomes impractical. The recent appearance of the Brazilian floating fern giant salvinia (*Salvinia molesta* D.S. Mitchell) in 30+ water bodies in nine states is a notable example of the problem, and has highlighted the serious need for a new and systematic approach for addressing new invasive species and, in particular, invasive plants (Figure 2).

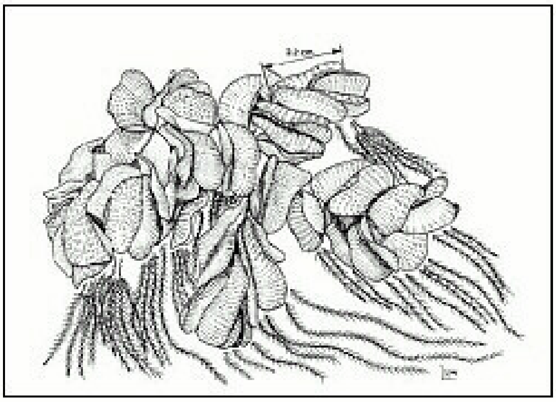

Figure 2. Giant Salvinia (*Salvinia molesta*), a floating fern from Brazil that is widely regarded as one of the worst aquatic weeds in the world, now occurs in at least 30 water bodies in nine states in the USA. (Illustration courtesy of the Center for Aquatic and Invasive Plants, University of Florida.)

The Story of Common Crupina – a New Invasive Plant in the Northwestern USA

Common crupina (*Crupina vulgaris* Cassini), a perennial composite from southern Europe, was first noticed in the northwestern USA in 1968 in Idaho County, Idaho, about six miles east of Grangeville along Highway 13 on the Sammy vonBargen Ranch (see Figure 3). The plant was first collected at the site on 26 July 1969. In 1970, a cursory survey of the area revealed that a vigorous stand of the plant dominated an area of about 40 acres[5]. By 1981, when common crupina was listed as a Federal Noxious Weed and an eradication feasibility study was undertaken by the University of Idaho, the infestation had increased to 23,000 acres. The study, which was completed in 1988, concluded that common crupina *could indeed be eradicated* from the United States. By September 1991, when a federal/state task force met in Lewiston, Idaho, to discuss the funding of a cooperative eradication project, common crupina had spread to 55,000 acres in Idaho, 8,000 acres in Oregon, 400 acres in Washington state and 20 acres in California. At that meeting, due to environmental concerns about the impact of pesticides on sockeye salmon in the Salmon River, no consensus was reached by involved agencies, and the crupina project was abandoned. Since that time, crupina has continued to spread, and efforts to find a suitable/effective biological control agent have been unsuccessful. Needless to say, if the original 40-acre infestation of crupina had been reported and summarily eradicated in 1968, the long-term impacts of this introduced invasive plant on biodiversity and rangeland productivity in the Northwest could have been avoided. The moral of the story is that invasive species need to be detected early, reported, assessed, contained and eliminated whenever possible...... *Weeds Won't Wait!*

[5]The first known population of common crupina in the USA, which was collected in Boston, MA, in 1877, did not survive (Pers. Comm., Cindy Rochet, USFS, Medford, OR).

[5]Stickney, P. 1972. *Crupina vulgaris* (Compositae: Cynareae), new to Idaho and North America. Madrono 21:402.

Figure 3. Common Crupina (*Crupina vulgaris*), an annual rangeland weed from eastern Europe that now occurs in Idaho, Oregon, Washington and California. (Background Photo: *Crupina* Habitat; Inset Photo: *Crupina* in flower).

Development of a national early warning and rapid response system for invasive plants in the United States. The US Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICMNEW) identified development of an early warning and rapid response system as one of its long range strategic goals at the FICMNEW Planning Retreat, which was held in October 1998, in Shepardstown, West

Virginia. To begin this process, the US Geological Survey and the USDA Forest Service hosted an Early Warning and Rapid Response Workshop in Ft. Collins, Colorado, in June 2000. Attendees included Federal, state, industry, environmental and private landowner representatives who had been active in noxious weed or invasive plant issues. Subsequently, the proceedings of the workshop were posted on the FICMNEW Home Page. The Plan described here was first drawn from the major recommendations that were developed at that workshop, as well as relevant recommendations under the National Invasive Species Management Plan. The first draft of the plan was released for limited informal review in November 2001. In mid-March 2002, a revised draft of the plan was released for wide distribution and review by 150 or more agencies and non-governmental organizations. In the near future, the plan will be posted on a number of websites, including the FICMNEW Home Page (http://bluegoose.arw.r9.fws.gov/FICMNEWFiles/FICMNEWHomePage.html).

Following analysis of comments received, the plan will be provided to the National Invasive Species Council staff and the National Council Invasive Species Advisory Committee (ISAC). FICMNEW will then be looking for opportunities for demonstration projects to field test the proposed Early Warning and Rapid Response System. Currently, the Invasive Species Council staff is organizing an All Taxa Subcommittee on Early Warning and Rapid Response. As this occurs, FICMNEW will work with them on integrating this plan into an overall national early warning and rapid response plan for invasive species.

Early warning system overview. The overall purpose of the National Early Warning and Rapid Response System will be to provide a coordinated framework of public and private partners at the local, state, regional and national levels to more effectively address new invasive plants through:

- Early detection and reporting of suspected new plants to appropriate officials
- Identification and vouchering of submitted specimens by designated botanists
- Verification of suspected new state, regional, and national plant records
- Archival of new records in designated regional and plant databases
- Rapid assessment of confirmed new records
- Rapid response to new records that are determined to be invasive.

Once fully implemented across the United States, the proposed early warning and rapid response system will provide an important second line of defence against invasive plants that will work in concert with Federal efforts to prevent unwanted introductions at the ports of entry. With both systems in place, the nation will be better able to defend against future economic and environmental losses due to “plants out of place”. Refer to Diagram 2 for an outline of system elements and how information is expected to flow in the system.

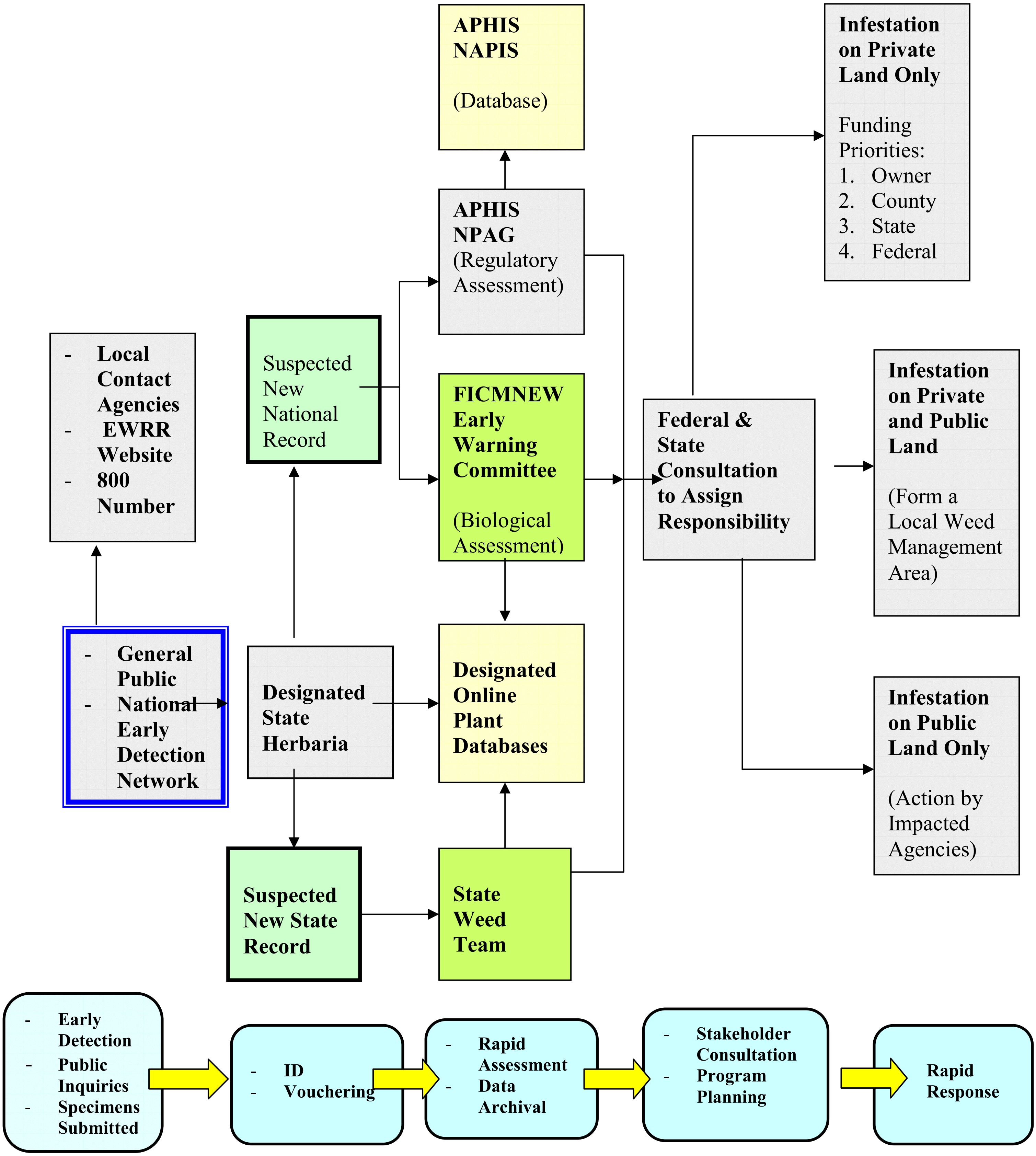

Diagram 2. Proposed National Early Warning and Rapid Response System for Invasive Plants in the United States. (**NPAG:** New Pest Advisory Group. **NAPIS:** National Agricultural Pest Information System; **FICMNEW:** Federal Interagency Committee for the Management of Noxious and Exotic Weeds)

Functional elements of the proposed National Early Warning System. Ultimately the US National Early Warning System for Invasive Plants will contain a number of elements that are implemented by different groups, organizations or agencies.

Functional elements and potential activity areas of the proposed system include:

A. **Early detection, reporting, identification, vouchering and information management**

- A volunteer network of people who observe study, and collect plants in the USA.
- Established local points of contact (local offices that could promote detection and collection of new plants).
- Designated State Botanists to assist in developing the National Early Detection Networks, and to identify plant specimens submitted through the detection network.
- Identification aids and training for network participants.
- Voucher specimens of confirmed new state and national records.
- Web-based distributive information management system comprised of new and existing online plant databases that can be simultaneously queried by one or more centralized search engines.

B. **Interagency partnering and operations**

- Designation of a National Early Warning Coordinator to coordinate the development and operation of the system.
- Establishment of a National Early Warning Committee to provide oversight and direction in the development and operation of the system.
- Establishment of State Interagency Partnerships (State Invasive Species Councils, Weed Management Areas) to develop State Early Warning Systems, to coordinate on-site assessments and rapid response to new invasions.
- Development of a State Management Plan for Invasive plants, which includes elements for early warning and rapid response.

C. **Rapid assessments**

- Online and distance technical support for assessing species invasiveness, potential impacts and available response strategies.
- Development of a classification system based on invasiveness and regulatory categories that permits land managers to assess the threat of specific taxa in a specific ecosystem to determine a proper course of action.

D. **Rapid response to confirmed outbreaks of invasive species**

- Development of protocols and contingency plans for rapid response to new infestations.
- Mechanisms for funding rapid response initiatives.

E. **Public outreach and access to information**

In order to detect, assess and rapidly respond to new incursions of invasive plants in the United States, it is critical that the amazing power of the Internet be harnessed. Ultimately, the goal is to provide one-stop shopping on the Internet for information on invasive species/issues:

- A national outreach and awareness campaign to raise awareness of the problem, and to engage the general public in early detection of new plants.

- Development of a distributive national information management system consisting of web-based databases that collect and maintain information relevant to documenting and assessing invasive plants in North America.

Creation of a new biological protection ethic for the 21st Century. Over the past 50 years, environmentalists have succeeded in raising public awareness and concern about the impacts of human civilization on the natural world. In the United States, public welfare laws and regulations such as the **Clean Air Act** {42 [U.S.C. s/s 7401 *et seq.* (1970)]} and the **Federal Insecticide, Fungicide, and Rodenticide Act** (FIFRA) [7 U.S.C. s/s 136 *et seq.* (1972)] were enacted in response to a public commitment to deal with this problem. Through the years, the success of national campaigns to prevent forest fires (USDA Forest Service – Smokey the Bear), to reduce chemical pollution and litter (Woodsy Owl – 'Give a hoot, don't pollute) and to promote recycling, resulted in an a new environmental protection ethic that has effectively changed public perception and concern about the environment.

In order to effectively address the little known challenges facing humanity and the environment relative to biological invasions, it will be necessary to find new ways to engage more people in the invasive species dialogue. In the 21st century, biologists will need to not only develop science-based approaches to address invasive species, but will need to gain public understanding and support of efforts to address the issue. Once biological pollution becomes just as unacceptable as chemical pollution did during the second half of the 20th century, local, state and federal agencies around the world will be better able to address the problem at its sources – something that is often politically sensitive or difficult today.

A biological protection ethic should:

- Promote the use of native (indigenous) species when possible and practical;
- Promote the use of non-invasive exotic species in landscape plantings when necessary;
- Discourage the use of harmful non-indigenous species for any purpose;
- Promote a 'good neighbour' policy in which land owners and managers assume residual accountability for infestations that spread from their own lands.

Just as it has become unthinkable to most people to pollute our lands and waters with harmful chemicals and hazardous waste, it should also be unthinkable to sell, plant or otherwise use harmful non-indigenous species.

Conclusions

In order to effectively address invasive species that pose a threat to natural and managed ecosystems, we need to develop new approaches to biological protection through **mandatory pre-screening of imported plants and animals** to determine if they should be officially regulated; develop **national level early warning and rapid response systems** to ensure that new species are promptly detected and assessed to determine an appropriate response; and finally create **a new biological protection ethic** to promote responsible use of harmful non-indigenous species that serve the common good.

Some considerations about weed risk assessment in France and Spain

J. Maillet*, C. Zaragoza**
*UMR BGPI, ENSA M., Pl. Viala, 34060 Montpellier Cedex, France
**** Servicio de Investigación Agroalimentaria,**
Gobierno de Aragón, Apartado 727. 50080 Zaragoza

Introduction

Every year thousands of seeds from exotic species are accidentally introduced into new regions (Crawley, 1986; Jauzein, 1998). A few of them will be able to develop populations that may then naturalize. Invasive plants are those species that colonize and proliferate in any ecosystem, whether naturally, semi-naturally or through the actions of man. From a survey, Weber (1997) estimated that exotic species represent five percent of all European flora. In France, most exotic species are found in "disturbed" areas such as crop fields, roadsides, sand dunes and riverbanks (Maillet, 1997), which seem more prone to invasion, while only a few establish in stable natural vegetation that may be more resistant to invasion (Fox & Fox, 1986). Although a few species are a major threat to natural areas, we do nothing to stop sudden infestations taking place in agricultural crops or various environments, with the consequent build-up of problems for farmers, stockbreeders, gardeners or nurserymen, or invasions occur in valuable natural environments (parks, wetlands and islands) that pose a threat to the native biodiversity. In the face of such problems, we cannot talk about official prevention or management and they only become a public concern when the problem is already irreversible (Jauzein, 1998).

With regard to the method of their introduction, various "points of entry" of invasive plants can be distinguished:

- Intentional introductions for agricultural, horticultural, forestry, revegetalization or soil conservation purposes, and also for research.
- Accidental introductions.
- As contaminants of seeds, grain feed, wood or soil deliberately introduced by man.
- As "stowaways" on various means of transport (boat, car, man or animals).

In order to develop adequate and efficient measures against invasive processes, it is necessary to distinguish between the above situations that would involve different methods of preventing or limiting such invasions.

I - Existing regulations in France and Spain

1.1 - Intentional introductions

Numerous requests for introduction, especially from horticulturists, are made every year in France as well as in other European countries. They concern grasses, vegetables, flowers, trees, etc. In France, it is considered that 54% of naturalized species of American origin are the result of intentional introduction (Maillet, 1997). Intentional introductions of plants should be subjected to risk assessment procedures by quarantine authorities to determine their weed potential.

However, in Spain as well as in France, officially the problem of invasive weeds is almost non-existent. In Spain, no specific regulation exists except for Royal Decree 2071/1993 (BOE, 1995), based on EU Directive 77/93/EEC (DOCE,1977) and subsequent amendments relating to protective measures against the introduction and spread of noxious organisms within the national territory or the European Union, and export to third countries. In the EPPO book of quarantine organisms (OEPP, 1996) only non-European species of the parasite dwarf mistletoe *Arceuthobium* are listed among many insects, acarians, nematodes, fungi, bacteria and viruses.

In France, the most recent official list of prohibited plants was published in 1998 and concerns cultivated plants likely to introduce pathogens. The only restriction relates to grasses from countries outside Europe. The introduction of any taxon from this family is prohibited, except ornamental species belonging to the Bambusoideae and Panicoideae sub-families and species of *Buchloe, Bouteloua, Calamagrostis, Cortaderia, Glyceria, Hakonechloa, Hystrix, Molinia, Phalaris, Shibalaea, Spartina, Stipa* and *Uniola* genera. However, the reasons for this list are not clear; presumably the tropical behaviour of these latter species is considered a limiting factor for their naturalization. A decree issued in 1993 also prohibits the transport and commercialization of *Caulerpa taxifolia.*

Apart from the fact that there are no official lists of species, it is important to note that even if there were lists they would probably not be sufficient. In particular, risks that are extremely difficult to evaluate are those related to the possibility of outcrossing between introduced and native species, which may result in introgression of genes. An example demonstrated by Lumaret (Toumi & Lumaret, 2001, and personal communication, 2002) is the relationship between *Quercus ilex*, a native species, and the American *Quercus* introduced into Mediterranean islands. The introduction of sub-species or ecotypes of native species can also create problems by producing invasion of new alleles, which should also be considered in order to conserve local biodiversity. This occurs with the introduction of species for restoration of ecosystems. The problem is even more important when herbicide-resistant populations are introduced, as is the case with *Lolium rigidum* “Wimmera”, resistant to some “fop” and “dim” herbicides (ALS inhibitors), which is imported as grass seed cover along roadsides.

1.2 - Accidental introductions by contaminant propagules

Many invasive species were probably accidentally introduced with imported crop-seed lots. For example, many tropical hydrophilous weeds soon adapted to Spanish or French summer rice conditions (e.g. *Heteranthera* spp., *Leptochloa fascicularis, Cyperus eragrostis , Lindernia dubia, Eclipta alba).* A particularly difficult problem to solve is red rice (*Oryza sativa* var. *sylvatica*) as contaminant of rice seed.

In France it is well known that many Panicoideae were introduced with maize seeds (*Panicum dichotomoflorum, P. gattingeri, P. capillare*). Soybean is considered as a means of introduction for several *Ambrosia* species.

Many weed species are listed as seed contaminants among other noxious organisms of the quality in the Technical Regulations for Seed and Plant Control and Certification. (BOE, 1986-2000, taken from the EU Directive 66/402 and modifications), but no particular mention is made of invasive exotic species.

1.3 - Accidental introductions by other means

There is no way to exclude accidental introduction of species, and generally invasion is only discovered once a plant has already become naturalized. Land managers need to assess the potential risk of range expansion and learn to predict early on whether the species will become a weed.

II - Means of prevention and control

2.1 - Prevention tasks

The best approach to future weed problems places the emphasis on prevention (Panetta *et al*., 1995). For new intentional plant introductions, it should be possible at least to develop a weed risk assessment procedure based on the **consultation of lists** of species considered invasive elsewhere. In Europe, Klemm (1996) drew up proposals for restriction based on the concept of biosecurity developed in New Zealand with the establishment of reference lists: **black list** for species well-known to be invasive elsewhere, **grey lists** for potential invasive species. However, such lists have not yet been established.

Commercialization of invasive species occurs not only without any regulation, but also without any information available for the consumer or for horticulturists. So it is possible to find in catalogues of plants for marketing, species such as *Arctotheca calendula*, *Senecio inaequidens*, *Jussiaea* sp., etc. Problematic plants such as *Myriophyllum brasiliense* or *Heracleum mantegazzianum* are recommended in gardening magazines. Few scientists defend the globalization concept for plants, and claim that preventing introduction (except for plants dangerous to man) is a conservative approach (Clement, 2002). However, local initiatives exist in France to inform the public, particularly regarding species presenting risks for human health *(Ambrosia artemisifolia, Heracleum mantegazzianum*) or for natural habitats *(Senecio inaequidens, Reynoutria japonica*). However, these actions are on a regional basis and very often small-scale in comparison with what is being done in the USA or Australia.

The Spanish Weed Science Society and other Institutions on many occasions have expressed their concerns about the need to draw up a list of quarantine species (Gómez de Barreda, 1997; Sobrino *et al.*, 1999). In France the national Botanical Academies, which are recognized by the Ministry of the Environment, have already submitted preliminary lists.

In the future, **weed risk assessment** (WRA) processes might be proposed, such as those developed in Australia (Pheloung, 1995) and the USA (Westbrooks & Eplee, 1996), in order to reject, accept or retain new introductions for evaluation. According to Reichard, Pheloung's WRA gives better results than the Hierarchical Tree Decisional System (HTD) (Reichard & Hamilton, 1997) and the Alien Plant Expert System (APES) (Tucker and Richardson, 1995). This WRA system has been adopted in various countries such as Hawaii, New Zealand, the Galapagos Islands and Australia.

These schemes generally use five criteria: history of invasiveness elsewhere; relatedness to species that show invasive behaviour; climatic match between original range and proposed area of introduction; noxious and undesirable traits; biological attributes of the species. However, even with risk assessment, Westbrooks (1991) considers that these procedures are inefficient. Although the quarantine system and risk assessment process in Australia are more elaborate, Smith *et al*. (1998) showed that they are not completely effective. This relative lack of success (Perrins *et al,* 1992; Smith *et al,* 1998) may be due to the fact that the most general and basic form of the assessment focuses on the biological characteristics of the plant. The ability of a species to become a weed, however, is a combined function of the attributes of the plant, the ecological properties of the recipient land, the natural disturbances or the management practices the land undergoes (MacIntyre *et al.*, 1995) and the way the plant is introduced into the new environment (Smith *et al.,* 1998).

2.2 - Surveys and control

For invasive weeds introduced accidentally, the main objective should be early detection. Controlling a weed infestation early will minimize the damage and significantly reduce control costs. Money spent on surveys is less than the resultant savings in control costs.

Some areas must be explored as a priority. Valuable sites (those with high biodiversity values) and vulnerable sites (those where weeds are most likely to invade: harbours, silos, along roadsides, railways and channels, places with "disturbed" vegetation, summer irrigated crops, tree nurseries, garden dumps) are often the first sites to be colonized by new weeds (Braithwaite & Timmins, 1999). The survey must be performed in an orderly fashion and programmed by specialists or trained staff, but fortuitous observations are also of great value. The advantage of early detection is only maximized if the new weed incursion is managed promptly. A network of botanists participate in this research in France, but not as part of an official body.

The weed risk assessment system already mentioned may also be used to determine whether new introduced species, or species that are already naturalized but not yet invasive, are potential invaders.

Timely integrated weed management strategies might be developed against species identified as potential invaders in order to prevent their spread. Unfortunately, control is usually only promoted once the species is already problematic and difficult to eradicate.

III - Criteria to define a plant as a possible invasive weed

There are two ways to examine plants for possible invasiveness: the first concerns species present in Spain and is based on expert opinion integrating several characteristics of the species. The second compares the characteristics of invasive American species, present (or not) in crops in France, in order to find common features that might explain their success in agroecosystems and how to use the eventual characteristics to predict risks of new introductions.

3.1 - Drawing up a list for Spain

What are the reasons for including a species in a quarantine list? Key elements of risk analysis include: (1) the probability of an adverse event, (2) the magnitude of the consequences of the adverse event, and (3) the uncertainty associated with the information used for assessment (Griffin, 2000). In a globalized world, where many useful plant species are the subject of intense free trade for food, fibre, forage, pharmacy, aromatic and ornamental purposes and can become invasive weeds depending on circumstances, it is a basic to define the risks involved.

The simplest criteria established for parasites and pests in a number of countries are as follows:

a) Not widespread in the country or area to be protected;
b) Dangerous due to its growth rate, spreading capability or its noxiousness in a particular crop or environment, its toxicity for humans or cattle, the likelihood of its causing ecological damage, and these effects demonstrated elsewhere in the world;
c) Problematic to manage or control.

A preliminary Spanish list

With the aim of presenting a draft according to the classification of the Directive 77/93/CEE of the European Commission for pests and diseases, the more frequent exotic species quoted in the bibliography are included (García Torres, 1993; Jauzein, 1998; Recasens & Conesa, 1998; Del Monte & Martinez, 1999; Weber & Gut, 1999; Sanz *et al*., 2001) in different sections. Alien species naturalized for more than 100 years and others not fitting criteria b) or c) have been eliminated from the lists. Some invasive native species are included in Section II. The great climatic and ecosystemic diversity of Spain, together with the changes in climate, must be taken into account to explain why some tropical plants could be considered a threat in irrigated lands, especially near the Mediterranean and the South of the Iberian Peninsula.

Part A: Noxious species whose introduction and spread must be controlled in Spain.

<u>Section I</u>: Noxious species whose presence has not been registered but whose effects are important (* mainly agricultural weeds)

**Ambrosia gigantea*
Amorpha fruticosa
**Asclepias syriaca*
Cyclachaena xanthiifolia
Heracleum mantegazzianum
**Hypericum calycinum*
**Impatiens glandulifera*
**Impatiens parviflora*
Orobanche minor
Parthenium histerophorus
**Reynoutria sachalinensis*
**Rottboellia cochinchinensis*
**Salvinia molesta*
**Sicyos angulatus*
**Solanum eleagnifolium*
Solanum viarum
Solidago gigantea
**Striga asiatica*
**Verbesina encelioides*
**Zantedeschia aethiopica*

<u>Section II:</u> Noxious species whose presence is already registered and whose effects are important (should be controlled on a regional scale).

**Abutilon theophrasti*
Achillea filipendulina
Achiranthes sicula
Albizia distachia (Canary Isl.)
**Amaranthus albus*
**Amaranthus powellii*
**Ambrosia artemisifolia*
Ammannia aegyptiaca
Ammannia coccinea
**Amsinckia calycina*
**Amsinckia lycopsoides*
Apium leptophyllum
**Apium nodiflorum*
**Araujia sericifera*
Asclepias curassavica
Baldellia ranunculoides

**Bergia capensis*
**Bidens aurea*
**Bidens subalternans*
**Centaurea diluta*
**Conyza blackei*
Cortaderia selloana
**Cyperus eragrostis*
Chamaesyce humifusa
Chamaesyce maculata
Chamaesyce nutans
Chamaesyce polygonifolia
**Chamaesyce prostrata*
**Chamaesyce serpens*
**Chloris gayana*
**Cuscuta campestris*
**Cuscuta epithymum*
**Datura inoxia*
**Datura stramonium*
Echinochloa oryzicola (E. phyllopogon)
Eclipta prostrata
Eichornia crassipes
**Eleusine indica*
Eschscholzia californica (Canary Isl.)
**Euphorbia polygalifolia*
Fallopia baldshuanica
Glyceria fluitans
Heliotropium curassavicum
**Heteranthera limosa*
**Heteranthera reniformis*
**Heteranthera rotundifolia*
Imperata cylindrica
**Ipomea purpurea*
**Leersia oryzoides*
**Leptochloa fascicularis*
**Leptochloa uninervia*
**Lindernia dubia*
**Najas gracilisima*
**Nicotiana glauca*
Oenothera biennis
**Orobanche cernua*
**Orobanche crenata*
**Orobanche ramosa*
**Oxalis latifolia*
**Paspalum dilatatum*
**Panicum capillare*
**Panicum dichotomiflorum*
**Pennisetum clandestinum*
Pennisetum setaceum (Canary Isl.)
Phytolaca americana
**Pelargonium capitatum (Canary Isl.)*
**Potamogeton pusillus*
Reynoutria japonica
**Senecio inaequidens*
**Sesbania exaltata*
**Sida spinosa*
**Solanum physalifolium*
**Solanum sarrachoides*
**Solanum sisymbrifolium*
Tropaeolum majus

Part B: Noxious species whose introduction and spread must be controlled in determined protected areas (wetlands, coastal and disturbed habitats, etc.)

Agerantina adenophora
Arctotheca calendula
Artemisia velotiorum
Azolla caroliniana
Azolla filiculoides
Carpobrotus acinaciformis
Carpobrotus edulis
Cortaderia selloana
Heterotheca subaxillaris
Opuntia dillanii
Paspalum vaginatum
Pennisetum setaceum (islands)
Spartina densiflora

3.2 - Analysis of exotic American agricultural weeds of France

At least 479 exotic species have naturalized in France (Fournier, 1961), of which less than 100 have been described as agricultural weeds (Maillet, 1992). Do other species represent a potential risk? According to Weber (1997), most of the exotic plant species naturalized in Europe originate from North American, followed by Asia and South America.

The objectives of the study conducted in 1999 were :

- To find general criteria that allow the prediction of American invasive species which present a risk to agriculture.
- To determine whether history, intrinsic biological characteristics or extrinsic properties of the recipient land explain the success of agricultural invasive weeds.

The main conclusions of the work are summarized below (for details see Maillet & Lopez-García, 2000).

Invasive species from North and South America which have become naturalized in France (274 species) were listed and divided into two groups according to their range: agricultural weeds (AWF) and environmental weeds (non-agricultural weeds = EWF) according to literature (Maillet, 1997). Eighty-seven species are found in fields and were therefore classed as AWF. Some of these may also be present in natural habitats, while by definition EWF are totally absent from cultivated areas. Data on six characteristics were obtained from the literature (Maillet, 1997) for the 274 species: original range, status as AW or not in the native range, life form, photosynthetic pathway, level of ploidy (when available) and main habitat invaded in France.

For 78 of the AWF, 14 traits were selected on the basis of previous attempts to predict invasiveness (Baker, 1974; Newsome & Noble, 1986; Grime *et al.*, 1988; Perrins *et al.*, 1992; Maillet, 1992; Scott & Panetta, 1993). Most of the criteria are biological and ecological features, although historical data (period of introduction) have been included since many invasive species have a time-lag between introduction and commencement of invasion. The status of the invasive species in its native range (AW or not) was also considered as it is often found to be a reliable predictor of ability to invade crops in the invaded area (Scott & Panetta, 1993). Due to lack of information, the native range was only roughly estimated, although it might be an important determinant of invasive ability (Rejmanek, 1995). The main results are as follows:

- The exotic American flora of France is highly diverse, consisting of many families and genera, with most families represented by a small number of species. Weber (1997) observed the same pattern for the exotic flora of Europe as a whole. Families which had the highest number of American exotic species in France (Asteraceae and Poaceae) are also recognized in Europe or at the global level as the most important families for invasion. There are many dicotyledon families amongst the American exotics, whilst monocotyledon families are poorly represented. Cyperaceae, Liliaceae and Iridaceae, naturalized in France, were mainly introduced from South Africa or Asia. Families well represented in America, such as Solanaceae, Oenotheraceae or Amaranthaceae, make a high contribution to the American weed flora of France.

- Most agricultural exotic weeds in France belong to Asteraceae and Poaceae, which are the largest families worldwide. However, the relative contribution by each family - a better indicator of invasiveness ability - shows a large contribution by minor families (Amaranthaceae, Euphorbiaceae, Oxalidaceae). However, by comparison, Rosaceae and Oenotheraceae are under-represented. Aquatic families are under-represented among American exotic weeds. The recent development of rice cultivation in France and the relatively small area covered by weeds might explain this fact (Maillet, 1997).

- The most successful families as agricultural weeds possess some features that might explain their presence in man-made habitats. Asteraceae are favoured by their great diversity of life-form, wind and human dispersal and their diversity of native habitats, but their high number among agricultural weeds seems to be more related to the large number of species within the family (Heywood, 1989). Poaceae, like Amaranthaceae and to a lesser extent Euphorbiaceae, are characterized by nitrophilia and the C4 photosynthesis pathway of a large number of American species. These physiological traits are advantageous in man-made habitats, under conditions of fertilization and/or irrigation. According to Daehler (1998), families with predominant abiotic dispersal (such as Amaranthaceae or Euphorbiaceae) have higher proportions of agricultural weeds. Their agricultural importance may be related to human dispersal. Furthermore, all the above-mentioned families possess a large number of herbaceous, short-lived species, well adapted to disturbance (ruderal species *sensu* Grime *et al*., 1988). Conversely, representatives of families which are unsuccessful as agricultural weeds are mainly woody taxa (e.g. Rosaceae or Fabaceae) or herbaceous hemicrytophytes (e.g. Oenotheraceae), with a life-cycle poorly suited to heavily distrubed habitats.

- Multifactorial analysis and hierarchical clustering clearly distinguish two groups of species linked by different sets of variables. The groups of EWF and AWF can be described by the small number of physiological and ecological attributes used in this analysis. The best discriminatory classification tree separates these groups only on the basis of weed status in America, which is also the variable with the main contribution to the AFC. This single variable was also the best predictor of weedy behaviour in the case of South African invasive species in Australia (Scott & Panetta, 1993). Weeds in one country are likely to become weeds when introduced into another country. So weed risk assessment procedures include this variable (Westbrooks, 1991; Pheloung, 1995).

Agricultural weeds

Agricultural weed status in America indicates that the species is already pre-adapted to agrosystem properties such as: periodic disturbance, high fertility and short growing season. This appears to be a way of discriminating between environmental and agricultural weeds, and also of predicting level of abundance when the exotic species, though not weedy in its original range, succeeds in growing as a weed in its new site.

The importance of time as a factor determining whether exotic plants have succeeded in becoming weeds or not has also been demonstrated in Australia (Scott & Panetta, 1993) and the USA (Forcella & Harvey, 1988). Our results tend to show that some weeds in

France may be rare because their introduction is too recent and insufficient time has passed to reach sufficient propagule pressure. Attempts to identify intrinsic attributes of species should give better results when comparing only species introduced during more or less the same period. Rice weeds are an exception. The recent development of this crop (post-1950) in France and the absence of native rice weeds may explain the rapid spread of recently arrived species (Maillet, 1992).

The life-cycle of American weeds in France seems to be important regardless of the date of introduction. Most important American weeds have a late spring emergence and a summer growing period, with a late flowering period which can end in November. They are adapted to annual crops such as maize, soybean and sorghum, or perennial crops such as fruit trees or vines. The long flowering and fruiting period increases the chance of producing a large number of seeds and forming a copious seedbank (Baker, 1974).

The characteristics of the groups of species present in each kind of crop are clearly related to management practices, such as the period of sowing which represents the start of growth, or period of harvesting which determines the time at which weed seeds need to be mature. A good knowledge of the phenology of exotic species is thus important. Different forms of seed dispersal may also be favoured by the structure of the vegetation. For example, in maize the height prevents wind dispersal of seeds, while in vineyards seeds may be blown more easily along the inter-rows. It is thus possible to identify relevant plant traits that affect suitability of invading species in a particular man-made habitat. Therefore, the same trait may facilitate invasion in one habitat, but prevent it in another. It is necessary to compare the constraints exerted by the invaded agrosystem with the intrinsic characteristics of invading species and to identify "*response groups*" (Gitay & Noble, 1997). "One reason for the absence of understanding about the success of an invasive species may lie in how little studies have addressed invasion mechanisms from the point of view of the invaded community" (Perrins *et al.*, 1992).

Conclusions

The regulations in France and Spain are inadequate in view of the risks of plant invasions. Even information on potential risks is scarce and unofficial.

Although fears about the impact of invasive species have been expressed by various social groups, there is no evidence that national government, and even less the EU Commission, is really concerned by these biological events. Is it possible that our continent, which has been disturbed by man for a long time and has received many species from all over the world, is just accepting the idea of plant globalization?

The noxiousness of invasive species is not always easy to demonstrate, except for species that cause damage to agricultural crops or are harmful to human health. Control or further eradication of invasive species is costly and difficult to implement. It should be justified and limited to particular circumstances.

Furthermore, in spite of the many studies on invasive weeds, the prediction of invasive success still remains a difficult and imprecise exercise. There is no general predictive theory of invasiveness and we are far from reaching a good overview of invasion mechanisms. The diversity of criteria which should be taken into consideration, and their changing relative importance at different levels, leads to the conclusion that only a highly complicated model might allow a satisfactory approximation. Unfortunately we are not yet in a position to gather sufficient information on most invasive species, invaded lands or processes of invasion to build that model.

However, the most important criterion for predicting weed status in the invaded area is the status of the weed in its original range. So it is essential to create a world database of known weediness and invasive ability of plant species. This knowledge could be used either to limit voluntary plant introductions or to eradicate as early as possible species' incursions that present a high risk of adverse impact.

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WEED RISK ASSESSMENT – AN ATTEMPT TO PREDICT FUTURE INVASIVE WEEDS OF USA

Chris Parker
5, Royal York Crescent, Bristol BS8 4JZ, UK
E-mail: chrisparker5@compuserve.com

Summary
The US Government is seriously concerned about the impact of invasive alien species (including weeds) on their agriculture and natural environment and is funding a range of initiatives to minimize the problems being caused by those already in the USA, and to limit the risks of further exotic species being introduced and gaining a foothold. This paper describes a project aimed at identifying the potentially invasive weed species most likely to be introduced accidentally or deliberately in the future, with the aim of preparing legislation and/ or educational processes to ensure these species are excluded or at least recognized before they can become a significant problem. The conclusions from the first year of the project and preliminary lists of target species are presented, together with a discussion of the current attempts to refine the risk assessment process and ensure it is logically in line with other weed risk assessment procedures being developed in the USA and Australia.

Introduction

Following the signing, in 1999, of Executive Order 13112 on Invasive Species, United States government agencies were mandated to 'mitigate the adverse effects of invasive pests that would harm agricultural, managed and natural ecosystems'. To assist their efforts, the US Department of Agriculture (USDA)'s Center for Plant Health Science and Technology requested the Weed Science Society of America (WSSA) to develop and deliver a model capable of prioritizing pest plants on the basis of their potential to pose a threat to United States ecosystems. In this context, a 12-month project was initiated in April 2000 with the title 'Creation of a Prioritization Model to Identify Weeds of Global Significance'. This paper is based on my experience as principal investigator of the project, which has more recently moved into a second 12-month phase, beginning in December 2001.

Most methods of pest risk assessment (PRA) are designed to predict **whether** an individual species will or will not become invasive, usually in response to a proposal for deliberate introduction for agricultural, ornamental, medicinal or research use. It may also be applied to species of known invasive potential with a view to their proactive inclusion in an official list of prohibited or quarantine pests. Some 90 individual species and six complete genera of the most serious weeds of the rest of the world, including many aquatic and parasitic species, are already included in the Federal Noxious Weed List and prohibited entry into the USA (USDA, 2000). The task in my own case was rather different – to predict **which** alien species (of all possibilities) are most likely to become invasive, so that they could be considered for addition to this prohibited list. Although each species in my final selection has eventually to be assessed in the same way as to **whether** it might become invasive in USA, a selection process was needed to decide which of the approximate 250,000 plant species of the world should be given priority. This required a survey of the very substantial literature on invasiveness and its prediction. This reveals that most authors conclude the range of characteristics of successful invaders is so wide that deciding which species will invade and which will not is virtually impossible without experimentation in the 'target' habitat. (e.g. Newsome & Noble, 1986; Roy,1990). Although detailed study of specific groups of weeds has suggested various characteristics which are associated with invasiveness, such as small seeds and frequent heavy seeding in pines in South Africa (Richardson *et al.*, 1994; Reichard & Hamilton, 1997), these are usually shown to be unreliable when extrapolated to other situations. The most consistent and useful indicator for invasiveness is the evidence of invasiveness or serious weediness elsewhere. This has therefore been used as the first selection criterion. As described below, this still yields at least 700 species, not already naturalized in the USA, which have some documented potential to be invasive. It has therefore been necessary also to devise a scoring system to rank these, so that a more manageable number can be selected for further assessment. The methodology used is described below.

Methodology

Initial selection

Stage 1. Selection of potential invaders. In the light of the studies emphasizing 'weediness elsewhere' as a major predictive character, I chose to use the 'Geographical Atlas of the World's Weeds' (Holm *et al.,* 1979) as my starting point, selecting all those (approximately 450) species not yet naturalized in USA but classified as 'serious' or 'principal' weeds in at least one other country. This includes very few of the 200 'obvious' candidates - the 'world's worst weeds' as defined in Holm *et al*. (1977) and Holm *et al.* (1997), thanks to the vast majority of these already occurring in the USA. To offset the bias of Holm *et al.* towards purely agricultural weeds, as well as to update it with new records, I have added a further 250 species from various sources, as listed in Table 1. The most important have been those listing plant species occurring as serious 'environmental' weeds in other parts of the world or otherwise of concern as invasive species in natural vegetation. Other substantial sources include lists of noxious or 'declared' weeds in South Africa, Australia and New Zealand, Email list-servers, and the general weed science literature.

Table 1. Main sources of evidence for 'invasive or seriously weedy' behaviour

I. Source	II. Content
Holm *et al.*, 1979	Rating of ca. 8000 spp. as weeds, by country
Binggeli *et al.*, 1998	Lists of 'seriously' and 'moderately' invasive woody species of tropics and sub-tropics
Australia, 2000	List of noxious weeds prohibited entry to Australia
Henderson, 2001	'Declared weed' or 'declared invader' in South Africa
NZ	New Zealand list of 'entry prohibited' species
Owen, 1996	Weeds of concern on conservation lands in New Zealand
CABI	CABInternational Weed Abstracts data base
Enviroweeds	Enviroweeds listserver Email discussion group
Aliens	Aliens list-server. Email discussion group
Conference Proceedings	Reports of serious new weed problems
Journal papers	Reports of serious new weed problems

The number selected (now about 700) could have been reduced by selecting a relatively high threshold for the definition of 'invasive or seriously weedy', but appraisal of the species that have already become invasive in USA suggests this would be unwise. A survey of some 123 alien species that are regarded as invasive problems in the USA showed that only 27% of these would have been selected on the basis of occurrence as serious or principal weeds elsewhere, as recorded by Holm *et al.* (1979) while 22% were not listed by Holm *et al.* at all. This discrepancy is largely attributable to the agricultural bias of Holm *et al.,* but many species are not recorded anywhere else in the literature either, as being weedy outside USA, and have apparently become aggressive only after introduction, for a variety of reasons still very poorly understood. This has suggested that it is important to spread the net very wide initially rather than considering only those most obvious candidates.

Stage 2. First ranking of about 650 species. A ranking process has been applied to the first 650 species selected, based on the extent and seriousness of its weediness elsewhere, together with some of the more obvious and readily appraised invasive or noxious characteristics (Table 2).

Table 2. Components of Stage 2 scoring of all species

Component	**Basis**	**Score**
Country index	Based on Holm *et al.* (1979), score of 3 for any occurrence at 'S' or 'P' level, plus score of 1 for any additional occurrences at a lower level.	3 or 1 per country
Extra countries	Occurrence as a serious weed in a country additional to those indicated in Holm *et al.* 1979 (sources listed above)	3 per country
Invasiveness	Highest category of invasive behaviour in Binggeli *et al.* (1998) – score 10 Middle category of invasive behaviour (*ibid*) or with status as 'invasive' weed in South Africa, or as prohibited species in Australia or New Zealand – score 5 Inclusion in national lists of weeds categorized as 'of concern' (mainly from New Zealand) – score 3	10, 5 or 3 per listing
Rhizomes, etc.	Spreading significantly by rhizomes or stolons (but not if merely having short woody rhizome, or corms, bulbs, etc.).	3
Aquatic	Free-floating or fully submerged aquatic – score 5 Plants adapted to aquatic conditions and growing in or alongside water - score 3	5 or 3
Vine	Vines or plants otherwise spreading by climbing or scrambling.	3
Seed production	Estimate of seed production per year.	0-3
Seed size	Seeds (or spores) smaller than 1 mm long - score 3 Seeds 1-2 mm long - score 2 Seeds over 2 mm long - score of 1	1-3
Dispersal	Any special dispersal characteristics, especially pappus etc. for wind dispersal, edible fruits or burrs suitable for bird or animal dispersal - score 3 Aquatic or semi-aquatic species likely to be spread by water - score 2	2-3

Stage 3. Detailed scoring of about 160 species. Approximately 160 of the highest-ranking from Stage 2 have then been subjected to a broader and more detailed scoring process with 4 main elements – **Invasive** potential, **Geographic** potential, **Damage** potential and **Entry** potential (Table 3).

The final scoring has then been obtained by summing the totals within each of the four 'potentials' and multiplying these together (A x B x C x D).

Table 3. Components of Stage 3 scoring (not yet applied to all species)

Component	**Basis**	**Score**
A. Invasiveness potential		
Score from Stage 1	Total from Stage 2 elements.	at least 3
Shade-tolerant		2
Drought-tolerant		2
Insect/disease resistant		2
Frost-tolerant		2
Unpalatable to livestock		2
Congeneric weeds	Other weedy species in the genus.	2
Favoured by rising CO_2		2
B. Geographic potential	Based on estimated proportion of the greater USA with suitable climate and ecology for invasion (default score1.0)	0-1.0
C. Damage potential		Default score 1.0
Competitive to crops	In no/few/many crops, including pastures	0 to +0.2
Cost/difficulty of control	Easy or difficult to control.	-0.1 to +0.1
Related to GM crop	e.g. likely to acquire herbicide resistance.	0 to +0.1
Usefulness	Negative score for useful characters.	0 to –0.2
Reduces value of produce	e.g. tainting, contaminating crop produce.	0 to +0.1
Pest/disease interactions	e.g. alternate host of beneficial or of pest sp.	-0.1 to +0.1
With spines, burrs etc		0 to +0.1
Health hazard to livestock		0 to +0.1
Health hazard to man	e.g. toxic/favouring mosquitoes	0 to +0.1
Allelopathic		0 to +0.1
Changes vegetation structure	swamps or replaces natural vegetation	0 to +0.2
Changes fire regime	e.g. flammable/fire-resistant	0 to +0.1
Nitrogen-fixing		0 to +0.1
Obstructs water flow/use		0 to +0.2
D. Entry potential	(maximum 1.0)	
Already grown in USA	Evidence of cultivation or commercial availability in USA	1.0
Risk of deliberate introduction	e.g. ornamental; available via internet from outside USA	0 to +0.3
Risk of accidental introduction	Default 0.1, raised for crop weed likely to contaminate crop produce, or present in contiguous country (especially Mexico)	0.1 to +0.3
Difficulty of detection		0 to +0.1

Results

The project demanded a short-list of 15 of the species showing the greatest invasive potential. When including those species not yet naturalized in the USA, but already in cultivation or available commercially, the 30 highest-ranking species were all from this category, reflecting their inevitably high scoring under Entry potential. However, USDA, while recognizing the important threat from these species, requested that the short-list of 15 should exclude such plants already 'in cultivation'. These could be considered for listing as prohibited species without concern for commercial interests, while those already in commerce would involve more complex issues. Table 4 indicates these 15, while Table 5 lists the corresponding 15 highest-ranking species in cultivation.

Table 4. Fifteen highest-ranking species selected, not yet in cultivation

	Scientific name(s)	**Common name and notes**	**Score**
1.	*Rubus alceifolius* Poir.	'Giant bramble' – thorny shrub (S.E. Asia.)	21.7
2.	*Acroceras zizanioides* (Kunth) Dandy = *Panicum zizanioides* Kunth	Rampant perennial grass (Africa, Asia and C. America)	18.6
3.	*Gymnocoronis spilanthoides* (D. Don) DC.	'Senegal tea plant' – vigorous aquatic (S. and C. America)	17.3
4.	*Actinoscirpus grossus* (L.f.) Goetgh. & D.A. Simpson = *Scirpus grossus* L.f.	'Giant bulrush' – robust rhizomatous perennial sedge (SE Asia)	16.6
5.	*Cirsium acarna* (L.) Moench. = *Picnomon acarna* (L.) Cass.	'Yellow plumed thistle' - annual thistle (Mediterranean)	16.3
6.	*Isachne globosa* (Thunb.) O. Ktze. = *Isachne australis* R.Br.	'Swamp millet' – tropical perennial grass (S. and E. Asia)	16.2
7.	*Sagittaria pygmaea* Miq.	'Pygmy arrowhead' – temperate/sub-tropical rhizomatous aquatic (E Asia)	15.6
8.	*Digitaria ternata* (A. Rich.) Stapf	'Black-seed crabgrass' - annual grass (Africa, Asia and Latin America)	15.4
9.	*Cyperus aromaticus* (Ridley) Mattf. & Kuk. = *Kyllinga polyphylla* Willd. ex Kunth	'Navua sedge' – tough perennial sedge weed of grasslands and wetlands (Africa and the Pacific)	13.7
10.	*Eupatorium macrocephalum* Less. = *Campuloclinum macroc.* (Less.) DC.	'Pompom weed' – rhizomatous perennial (S. and C. America)	13.7
11.	*Ischaemum muticum* L.	'Seashore centipede grass' - scrambling perennial grass (Asia)	13.5
12.	*Pycreus globosus* Reichenb. = *C. flavidus* Retz.	A vigorous sedge weed of rice and wetlands (Europe and Asia)	13.4
13.	**III.** *Lygodium flexuosum* (L.) Sw.	'Maidenhair creeper' - rhizomatous perennial, climbing fern (SE Asia)	13.0
14.	*Ottochloa nodosa* (Kunth) Dandy = *Panicum nodosum* Kunth.	'Slender panic grass' - spreading perennial grass (S. and E. Asia)	12.6
15.	*Ligustrum robustum* (Roxb.) Blume	A woody shrub (Asia)	12.6

Table 5. Fifteen highest-ranking species selected, in cultivation in the USA

Rank	Scientific name(s)	Common name(s)	Score
1.	*Eleocharis dulcis* (Burm.f.) Henschel = *Scirpus tuberosus* Roxb.	'Chinese water chestnut'	69.6
2.	*Echinochloa pyramidalis* (Lam.) Hitchc. & Chase	'antelope grass'	52.8
3.	*Ludwigia hyssopifolia* (G.Don) Exell = *Jussiaea linifolia* Vahl.	'seedbox'	50.0
4.	*Nymphaea alba* L. = *Castalia alba* (L.) Wood	'platter dock' 'white water lily'	46.8
5.	*Hakea gibbosa* (Sm,) Cav.	'pincushion tree'	35.0
6.	*Hakea sericea* Schrad. & J.C. Wendl.	'pincushion tree'	35.0
7.	*Nymphaea nouchali* Burm. f. = *Nymphaea stellata* Willd.	'lotus lily'; 'water lily'	34.8
8.	*Litsea glutinosa* (Lour.) C.B. Robinson = *L. sebifera* Pers.	'Indian laurel'	33.6
9.	***Limnocharis flava* (L.) Buchenau**	'sawah lettuce'	30.8
10.	*Salvinia cucullata* Roxb. ex Bory	'water fern'	30.0
11.	*Fimbristylis globulosa* (Retz.) Kunth = *Scirpus globulosus* Retz.	'globe fimbry'	28.6
12.	*Crassula helmsii* A. Berger = *Tillaea recurva* (Hook.f.) Hook.f.	'swamp stonecrop'	26.4
13.	*Sagittaria trifolia* L.	'three-leaf arrowhead'	26.4
14.	*Lygodium scandens (L.) Sw.*	'climbing fern'	26.0
15.	*Marsilea crenata* Presl	'pepperwort' 'water clover'	26.0

Discussion

The design of the scoring system does not claim to be justifiable in all its detail and is still subject to further refinement. Although devised without particular reference to official WRA systems in use in the USA and Australia, and other systems as reviewed in Parker (2001), it is now being compared critically with them. However, those various systems themselves show considerable disparity and there clearly remains a wide divergence of views on the optimum design. Some of these differences reflect the somewhat different ways in which they are used. The Australian method (Pheloung *et al.,* 1999) is only applied in a reactive way to requests for importation of particular species (hence the lack of attention to Entry potential). The USDA system (USDA, 2001) is designed to be more pro-active and anticipate the risks of species being introduced accidentally. Even allowing for this difference, there are still significant differences in the range and weighting of factors and characters considered in each case.

The range of sources of information on invasive weeds is expanding rapidly, especially on the Internet, but there is still a lack of any single comprehensive world-wide listing of invasive plant species (i.e. those showing tendency for aggressive colonization outside their native territory) although several organizations or individuals are considering or developing such a database (e.g. Randall, 2002). The list of 700 species that I have prepared could be a useful resource in this context. It excludes many hundred species which are already naturalized in the USA but could still pose a new threat in many other countries. I do, however, now have a list of about 1500 names (perhaps 1300 such species) which I have accumulated as an aid to checking possible new additions to my 700. These are not at present in any way annotated but do represent the balance of about 2000 species that I have considered potentially invasive according to my particular criteria.

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ASSESSMENT AND REGULATIONS FOR PREVENTING ENTRY OF EXOTIC WEEDS INTO CUBA

Jorge Padrón Soroa
Centro Nacional de Sanidad Vegetal, Cuba
E-mail: estadistica@sanidadvegetal.cu

1. Introduction

According to studies carried out by the Ministry of Science, Technology and Environment, Cuba has at present 6,500 species of vascular plants, of which 51.4 % are indigenous (Valdés *et al*., 1998). Most naturalized foreign plant species have been introduced over the past four centuries. Very few species (5%) are considered to be invasives. An earlier study (Acuña, 1974) identified 400 species, of which 11% were indigenous, 24 % came from the "old world" and 65% from the Americas. The introduction of species during the first half of the 20th Century was due to the lack of an effective quarantine regulatory mechanism and the increase in trade and communications. Major weed species in Cuba are listed in Table 1. The most important invasive species is the leguminous shrub *Dichrostachys cinerea*, commonly known as Marabú, which has invaded most pastoral areas and other waste sites in the country. This plant comes from Africa and was introduced during the colonial period by the Spanish authorities, but the reason for its introduction is still unknown. The shrub became a problem as soon as it was introduced but nowadays, due to grazing problems, it is found in abundance in all pasture areas. Burning and the destruction of natural forests in order to plant new areas of sugar cane have also been another cause of Marabú invasion. The main control method of this plant has been the extensive use of 2,4 D ester formulation.

2. Plant Protection Service, Institutions, Legal Bases, Regulations and Standards

In Cuba, under the state plant protection system, there are weed specialists in 14 provincial plant protection laboratories who maintain weed herbaria and provide advice to plant protection specialists in territorial plant protection stations, quarantine inspectors and other agents. A number of legal and institutional instruments are in force to prevent the entry of invasive species: Decree 170 regarding the Civil Protection System and Decree 153 on Plant Health, etc.

2.1 Surveillance and early detection system

Surveillance of invasive species in Cuba is a systematic process for detecting invasive species in order to prevent their entry and spread. The process aims to identify problems, set priorities for decision-making and evaluate the effectiveness of actions undertaken.

The work conducted within the Plant Protection service aims at:

- Establishing adequate surveillance of agricultural areas to protect them from the entry of exotic plants;
- Estimating the magnitude of the problem in the territory where a species is present.;
- Monitoring changes in weed composition;
- Making opportune decisions for the control and eradication of the species.

Table 1. List of Main Weed Species in Cuba

Cassia occidentalis L.	*Vigna vexilata* (L) A.Rich.	*Paspalum conjugatum* Berg
Commelina diffusa burn	*Emilia sonchifolia* (L) DC.	*Paspalum notatum* Flugge
Commelina erecta L.	*Euphorbia heterophylla* L.	*Paspalum virgatum* L.
Commelina longicaulis Jacq.	*Helenium quadridentatum* Labill	*Paspalum paspaloide* (M) Scrinbn
Croton lobatus	*Ipomea alba* L.	*Paspalum fimbriatum*
Cucumis anguria	*Ipomea nil* (L.) Roth	*Rottboellia cochinchinensis (Lour.) Clayton*
Cucumis dipsaceus Rex S	*Ipomea tiliacea* (Willd) Choisy	*Echinochloa colona*
	Ipomea trifida L	*Eleusine índica* L. Gaertn.
Cyperus alternifolius L.	*Ipomea triloba* L.	*Cyperus rotundus* L.
Cyperus esculentus L.	*Lepidium virginicum* L.	*Rhynchosia minima* (L) DC
Cyperus iria L.	*Ludwigia suffruticosa* (L.) H.Hara	*Sida acuta* Burm.f.
Macroptilium lathyroides (L)URK	*Orobanche ramosa* L.	*Sida rhombifolia* L.
Chamaesyce berteriana (B) M	*Merremia umbellata* (L) Hall.f.	*Sida spinosa* L.
Chamaesyce hirta (L) Millsp	*Mimosa pigra* L.	*Sonchus oleraceus* L.
Chamaesyce hisopifolia (L) Small	*Mimosa pudica* L.	*Sorghum halepense (L.) Pers.*
Chamaesyce prostrata (Ait) Sl	*Momordica balsamina* L.	*Sporobolus indicus*
Desmodium canum (Jl)Sching	*Momordica charantia* L.	*Turbina corymbosa* (L) Rof.
Dichrostachys cinerea (L) W & An	*Mucuna pruriens* (L) D.C.	*Vernonia cinerea* (L) Less.
Dolichus minima L.	*Parthenium hysterophorus* L.	*Portulaca oleracea* L
Phaseolus vexillatus L.	*Xanthium strumarium* L.	

2.2 Control of introduction of propagation material

In Cuba there is no official list of plants whose introduction is authorized. In all cases a permit must be requested from the quarantine authorities, indicating the purpose of the introduction, characteristics of the plant and other important data. The request should contain detailed material characteristics, accurate identification up to sub-species and benefits expected from the plant's introduction. Unless the economic or other benefits are not significantly high, the introduction will probably not be authorized.

A list of indigenous plants has been compiled by the Plant Protection Service and the Cuban Institute of Ecology. Species officially introduced, generally by research centres, are regularly checked by quarantine specialists but control of specific sub-categories, varieties and hybrids is almost impossible.

Weed infestations in crop areas are regularly surveyed by the provincial plant protection stations. Data obtained are elaborated and used to map the occurrence of major species in different crops/territories. Such information also enables the planning of effective control methods, including the use of herbicides.

3. Methodology for evaluation of general biological risk

A methodology also exists to assess the biological risk of exotic organisms at several levels and sub-levels, such as:

First Barrier (high risk area): airports, ports, post offices, tourist centres and fishing/landing sites.

Second Barrier (extremely dangerous area): plant protection laboratories, research centres, territorial plant protection stations (ETPP), entry points, centres for the production of biological agents (CREE), quarantine entry-points, breeding stations, seed treatment areas, warehouses and refrigerators for domestic use, railroad loading centres, dryers and toasters, plants for feed production, processing plants, storage depots, vegetable processing and agricultural markets, sawmills, furniture factories and cigarette factories.

Objectives of type III (dangerous): municipal drains, air corridors and migratory bird settlements.

4. The list of plant species subject to quarantine regulations

Prevention is the best means to combat the introduction of exotic invasive plants. Studying sources of introduction and other factors that favour the plants' establishment is necessary in order to draw up a list of plants whose introduction into the country or a territory should not be permitted. The list must be updated regularly with new information, even data gathered from other countries with similar climatic conditions. It should be the joint responsibility of the various institutions involved to provide the necessary information on each plant studied.

The present official list in the country contains the following classifications:

Group I: Not reported officially in the country, which implies that the plant is not present in the country. This group includes plants whose introduction absolutely prohibited, e.g. all *Orobanche* species (except *O. ramosa*) and *Striga* species.

Group II: Not officially found in the country or not widely spread and/or subject to quarantine surveillance/control. In this group are *Amaranthus retroflexus* L., *Convolvulus arvensis* L., *Solanum rostratum* Oun. and *Sonchus arvensis*.

Group of extremely dangerous plants: Reported or not in the country, affecting crops or agricultural areas of economic importance. These plants need to be under permanent quarantine control. The group includes all *Cuscuta* species, *Agropyron repens* (L.) Beauv. and *Cassytha filiformis* L.

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PROBLEMS OF INTRODUCED WEEDS IN WEST AFRICA

Mrs. H. Dantsey-Barry
PGR Officer
ITRA/CRAL, Togo
E-mail : itra@cafe.tg

Summary

Invasive introduced plants are now of worldwide concern. In West Africa, many of these are aquatic plants (*Eichhornia crassipes* [Mart.] Solms-Laub*, Salvinia nymphellula* Desv.), upland (*Chromolaena odorata* [L.] R.M. King & Robinson, *Rottboellia cochinchinensis* [Lour.] W. Clayton) and indigenous plants (*Pistia stratiotes* L., *Azolla africana* Desv.). They are known to cause a great deal of damage to fishing, livestock, navigation, agriculture, the environment and public health. In many African countries they have became a real scourge. Within the Economic Committee of West African States (ECOWAS), members are attempting to reach a common strategy to control these invasive plants, with the financial and technical support of international organizations such as FAO. Legislation and biological control methods are being used, or are envisaged, in national programmes in collaboration with international institutions. Many laws and decrees in force govern plant importation with regard to major pests. However, in ECOWAS member countries, very few written regulations exist indicating which weed species or introduced plants should be subject to quarantine measures. The wide spread of certain species, such as *Calopogonium mucunoïdes* Desv., *Rottboellia cochinchinensis* (Lour.) W. Clayton and *Mimosa invisa* Mart., and the need for their control have been noted. International cooperation has an important role to play in invasive plant management. Information exchange, training and public awareness must be strengthened while strategies and management methods should emphasize the participatory approach, to include all stakeholders.

1. Introduction

For centuries plants have been considered a source of man's essential requirements, providing food, medicinal products and activities to fill his leisure hours. More than 150 countries across the world signed the Convention on Biological Diversity (CBD) at the Earth Summit held in Rio in 1992. Rational collection, conservation and sustainable utilization of biological diversity are a priority of these countries. Nowadays, conservation and environmental protection are the responsibility of various international organizations such as the World Wide Fund for Nature (WWF) and International Plant Genetic Resources Institute (IPGRI).

There is now a greater exchange of information, particularly on plant genetic resources, not only within but also between continents. Explorers frequently introduced plants from foreign parts; these have spread due to the activities of international institutions for research and development purposes and between individuals for agricultural, medicinal, horticultural use, etc. Thus plant introductions have taken place depending, to a greater or lesser degree, on current needs.

Although these introductions generally provided some benefit, many unexpected but important problems also occurred: stubborn weeds resulting in heavy yield losses; destruction of the local biodiversity and, in some cases, entire areas; colonization of lakes and rivers; damage to agricultural and hydroelectric barriers, etc. This has resulted in global concern about the weed problem.

Invasive plant species are detrimental to native flora, particularly to that of oceanic islands and countries such as Australia and South Africa. Invasion of natural and semi-natural habitats by exotic plants is on the increase. Examples of invasive species are the guava, *Psidium cattleianum,* which now dominates large tracts of wet evergreen forest in Hawaii and Mauritius to the detriment of the rich endemic native flora, and *Rododendron ponticum*, which forms a dense undergrowth in woodlands in many parts of the British Isles. Another example is the rapid spread of exotic *Acacia* species into the fynbos of South Africa (World Wide Fund for Nature, 1993).

In this way, the introduction of *Psidium cattleianum* into Mauritius caused the disappearance of *Trochetia parviflora*, a horticultural plant with extremely beautiful flowers. However, this plant has now re-appeared after 138 years, according to Dullo and Florens (1999).

The island of Madagascar is facing invasion by *Opuntia stricta*, which is still uncontrolled today (www.fao.org.).

The Mediterranean bottom ecosystem has been seriously damaged by the accidental introduction of an alga *Colerpa taxifolia*, which was probably poured out of an aquarium into the sea. It would then have been propagated by the anchors of ships or boats navigating between ports in the Mediterranean. Consequently, the fauna and flora are gradually disappearing, making way for a mono-specific flora of this alga.

Similarly, an aquatic cultivated species *Hydrocotyle ranunculoïdes* has caused serious problems in the United Kingdom.

In general in Africa, and particularly in West Africa, the invasion of crops, sites and hydraulic and hydroelectric structures by alien plants has became a real challenge for governments. In West Africa, aquatic plants like *Eichhornia* spp., *Pistia stratiotes* L., *Salvinia molesta* Desv. and others have been the cause of further concern to ECOWAS countries. Plants such as *C. odorata* have caused great damage in many African countries.

Several other aquatic and upland plants, not yet identified as dangerous, could become harmful in the short or long term. These plants need to be managed with care.

Trade exchanges have contributed towards, and will continue to play an important role in, increasing these problems. The development of air transport and Internet communication will further increase such exchanges due to the ease of ordering and delivery. Crossing borders between African countries is an easy matter. Laws and phytosanitary measures based on the International Plant Protection Convention (IPPC), which are on-going in all signatory countries, could be strengthened and actions undertaken to find common solutions to the problem.

2. Background

In West Africa, introduced invasive plants are an important problem for all ECOWAS governments. Legislation relating to the introduction of plants exists, based on phytosanitary laws and regulations in various countries. Some quarantine measures have also been established, and national plant protection specialists are working at land, sea and air borders. ECOWAS countries have established regulations and legislation according to both the IPPC (International Plant Protection Convention, which came into force in 1951 and was amended in 1979 and again in 1997) and the International Plant Health Convention of the OAU (Organization of African Unity) of 1967. These Conventions do not appear to take into account the introduction/importation of invasive plants.

Therefore, many plants, both aquatic and terrestrial, have been introduced from various parts of this sub-region and cause great damage in agricultural activities and the environment. They have a negative consequence on the economy of concerned countries.

Aquatic floating plants (*Eichhornia crassipes* (Mart.) Solms-Laub, *Pistia stratiotes* L., *Salvinia nymphellula* Desv, etc.) are a prime example of this situation. However, they play an important role in aquatic areas where they favour the oxygenation and purification of the water they infest. They could also be used for silage, compost, production of biogas, etc. once conditions for the implementation of these processes are well understood. Aquatic plants in general, and introduced species in particular, have became a real challenge for the sub-region.

ECOWAS countries are concerned at the great economic and environmental damage aquatic floating plants cause by invading crop fields, irrigation canals and hydroelectric barrages, lakes and rivers, thereby destroying the stability of aquatic ecosystems. Species such as *Pistia* and *Salvinia*, which cause the same damage as aquatic invasive species, have been well known in Africa for a long time.

Many upland plants are identified as highly invasive. They have been introduced at various points in time for agricultural reasons or accidentally. This is the case of *Chromolaena odorata* (L.) R.M. King & Robinson, *Echinochloa colona* (L.) Link, *Calopogonium mucunoides* Desv., *Rottboellia cochinchinensis* (Lour.) W. Clayton and *Mimosa* spp., which have become a threat to rice and maize fields where their manual control is almost impossible.

Other plants growing in small areas for ornamental purposes are found in every ecosystem, e.g. *Cyperus* and *Poaceae* species. Their principal means of spread is via machinery, particularly for those plants that are propagated by rhizomes.

Biological control is among control measures being experimented in many countries of the sub-region, and some results appear promising.

In 1988, in order to draw attention to the problem of invasive aquatic plants, the Nigerian Federal Ministry of Sciences and Technology, in collaboration with ECOWAS, organized an international workshop for all member countries entitled "Water hyacinth, threat and resource".

Other aquatic plants mentioned above also constitute a threat for development. Therefore, their management requires the inclusion of integrated control methods in the various sub-regional programmes and projects of ECOWAS. To date various activities have been implemented, ranging from information workshops to the conception and execution of programmes on integrated management.

3. Aquatic plants

It is not possible to determine the exact period when floating plants were introduced into West Africa since they fall into different categories:

- Floating weeds

Water hyacinth (*Eichhornia crassipes*), which originated from South America, today grows in all tropical and sub-tropical zones. It was first reported in Egypt in 1950, from where it spread to central Africa and to Senegal in 1965 and then into West Africa between 1984 and 1985 (Afidegnon *et al.*, 1993).

E. crassipes was certainly introduced as an ornamental plant because of its beautiful blue- coloured flowers (Afidégnon *et al.,* 1996) and highly decorative leaves.

Other floating plants were classified in the same category as *Eichhornia crassipes* due to the similarity of the damage they cause. This is the case of *P. stratios* which has been known to exist for a long time in many countries of tropical and sub-tropical Africa, where it was propagated as a forage plant for livestock and used for compost and green manure in agriculture.

Salvinia molesta, a floating weed, other waterlily species (*Nelumbo*, *Nymphaea lotus*), water lentil (*Lemma* spp.) and other species (*Azolla*), etc. have been identified and should be considered as potential aquatic weeds.

- Emerged plants

These plants are not yet known to cause problems but some of them, such as reed (*Phragmites australis*), reed mace (*Typha spp.*), alligator weed (*Althernanthera philoxeroides*) and some *Poaceae* (*Panicum repens*, *Echinochloa stagnina*), tend to invade waterways across borders.

- Submerged plants

The following species have been identified as belonging to this group: *Hydrilla verticillata*, *Elodea* spp., *Potamogeton* spp., *Ceratophyllum* spp., *Myriophyllum* spp. and *Najas* spp. They are not yet considered as potential weeds (CEDEAO, 1995).

4. Problems posed by aquatic plants

The problems caused by aquatic plants can be divided into several categories:

Fishing: Production decreases due to the lack of oxygen and sunlight (weeds form a dense, impenetrable carpet), a decline in the food for fish, decomposition of organic matter and the production of toxic gases.

Transport: The formation of a dense, impenetrable carpet does not allow pirogues, dugouts and boats to move through the waterways, thereby reducing trade and fishing activities considerably. This has a significant impact on nutrition and the economy of ECOWAS countries.

Agriculture: The problem could be considered in several ways:

- Increase in evapotranspiration, followed by decrease of water in channels
- Blockage of water flowing through irrigation canals
- Damage to canals due to breakage and loss of water
- Invasion of crop fields in lowlands with consequent yield losses

Public Health: The carpet of floating plants is usually the incubation site for disease vectors, e.g. those of malaria, onchocerciasis (river blindness), filariasis, encephalitis, schistosomiasis (Bearzia), etc. Mosquitoes prefer water areas covered by plants for their multiplication, so water covered by hyacinth is ideally suited for the development of *Anopheles* and *Mansonia* larvae.

Environmental: Aquatic plants produce a large amount of biomass, which is finally degraded producing toxic gases which are dangerous for the nearby native population. This is the case of the lagoon of Lomé, which has became an uncomfortable place to visit.

Other problems: Hydroelectric and agricultural barriers could be damaged by the presence of these plants, causing the breakdown of the system.

Control measures should start with prevention, which would consist of limiting proliferation of the species.

Biological control methods seem to be preferred because of the low environmental and health risk involved. These are based on the use of insects, mammals and crabs as predators of weeds. However, it is not the only method of control.

The International Institute of Tropical Agriculture (IITA) in Cotonou, Benin, has carried out experiments and reported the use of the weevil, *Neochetina eichhorniae* as a successful biological control method. Tests are underway in various research centres with the following weevils on aquatic weeds:

- *Neochetina eichhorniae, N. bruchi* and *Sameodes albiguttalis* on water hyacinth;
- *Cyrtobagus salviniae* on water fern;
- *Neohydronomus pulchellus* on water lettuce.

In Mali, apart from the use of weevils, the presence of manatee, an aquatic herbivore belonging to the family of *Trichechidae*, is considered another good control method. *Pistia*, Nenuphars and *Cyperus* constitute a good dietary supplement for this animal. This method should also be integrated into the biological control programme.

The strengthening of surveillance exercises and the application of control measures could contribute towards halting the introduction and propagation of these plants.

5. Terrestrial weeds

Many non-aquatic plants are identified as weeds because they are often found in areas where they are not useful. This is the case of *Chromolaena odorata* (L.) R.M. King & Robinson, *Echinochloa colona* (L.) Link, *Calopogonium mucunoides* Desv., *Rottboellia* *cochinchinensis* (Lour.) W. Clayton [D. E. Johnson, 1997], *Mimosa invisa* Mart. and others, which were probably all introduced into West Africa.

Chromolaena odorata is reported throughout West Africa (in Ghana, Guinea, Côte d'Ivoire, Liberia, Sierra Leone and Togo). According to Hall *et al.* (1972), cited by Akpagana *et al.* (1993), the first plant of *E. odoratum* (*Chromolaena odorata*) in Ghana was identified in 1969 in the experimental plots of the botanical garden of Legon University (Accra). From there, the weed was propagated in Ghana and introduced into Togo where, as in Ghana, it is called "Acheampong". Its spread continued progressively towards the north of Togo, and particularly in the west of the country. In Côte d'Ivoire it is called "Sekou Touré'', and "Bokassa'' in Central Africa. Germplasm exchanges between agricultural institutions, at both the national and international level, have favoured the spread of these species.

The introduction of these weeds was successful for several reasons: as fertilizing plants in the case of *Chromolaena odorata* (L.) R.M. King & Robinson, forage plants like *Echinochloa colona* (L.) Link, or plants used for cover such as *Calopogonium mucunoides* Desv., or a combination of all three. Some have been accidentally introduced with rice seeds, such as *Rottboellia cochinchinensis* (Lour.) W. Clayton.

Mimosa invisa grows on alluvial soils that are rich in organic matter. It is disseminated via seeds (Akobundu & Agyaka, IITA, 1989) and is easily transported by water along rivers and by the wind. When maize or rice fields are infected, control becomes a serious problem for farmers.

6. Problems posed by terrestrial plants

Chromolaena odorata (L.) R.M. King & Robinson, *Echinochloa colona* (L.) Link,, *Calopogonium mucunoides* Desv., *Rottboellia cochinchinensis* (Lour.) W. Clayton and *Mimosa invisa* Mart. have been identified as weeds that cause large amounts of damage in maize and rice fields. Various problems have been identified.

Agriculture

The expansion of *Chromolaena* species is considered a serious obstacle to the development of agricultural activities and a scourge for agriculture and livestock. Bushes of *C. odorata* provide shelter for other enemies of crops such as rodents, insects and birds. In West and Central Africa, it is spreading and invading pastureland although it is not consumed by animals (Akpagana *et al*., 1993; Adru *et al*., 1988).

Echinochloa is particularly harmful for irrigated rice when there is a shortage of water. It is highly prolific and presents many similarities with rice, so that its eradication is difficult. Without control, these weeds could force a farmer to abandon his field, resulting in 100% loss of yield.

Calopogonium is dangerous for fruit and oleaginous plantations, especially during the first years of production. It also invades crop fields by climbing up and winding itself around the plants so that hoeing or hand weeding become impossible without damaging the plants. It requires early control as soon as stems begin to twine around the crops.

Transport
Many of these plants rapidly cover areas surroundings roads and trails. They can form large canopied vaults over roads, thereby reducing visibility and endangering road safety.

Environment
Chromolaena is particularly known for its invasive capacity; it is highly competitive and could quickly transform an ecosystem into a mono-specific system. In Togo, it is especially prolific in the west region where it has transformed entire ecosystems.

Calopogonium invades fallow land, transforming vegetation into a mono-specific system. Control measures should start by curtailing its spread towards other regions (forests, savannah, etc.).

Aphis spiraecola is a greenfly which can successfully invade the apical buds of plants. Its use could constitute a biological control method.

7. Conclusion
Plants have always been transported from one place to another, either on purpose or accidentally. After establishment in the host zone, it becomes difficult to determine their exact origin. Introduced or non-aquatic plants such as *E. crassipes, P. stratiotes, S. molesta,* etc. seem to be more invasive. However, other non-aquatic plants such as *C. odorata*, *R. cochinchinensis*, etc., are equally harmful and can invade crops and pastures. Surveys, identification and evaluation should be carried out to confirm this tendency.

Plants, whether or not accidentally introduced, may become invasive and require human, material and financial means for their control or eradication. The introduction of vegetative material into a given environment must be done with care. Once established, these plants should be well managed, otherwise their eradication becomes more difficult. If eradication is necessary, control actions can be harmful for man and his environment, when non-selective herbicides are used. The best method to use for their management is biological control.

It would be useful to obtain information concerning introduced materials in order to avoid propagation and to limit economic, agricultural and environmental damage in the short or long term. These plants could be used as a basis for composting; however, the success and feasibility of this operation and the quality of the compost produced must be taken into consideration. This applies mainly to aquatic plants, that could contain up to 90% water.

8. Perspectives
In Africa in general, and West Africa in particular, the control of introduced invasive plants and others in the same category must be carried out as a joint operation. This requires international, sub-regional and national collaboration in all domains.

All measures aiming to prevent intentional or accidental introductions should be imposed strictly in order to avoid current problems.

This objective could be achieved if the following actions were undertaken in common agreement between nations:

- development of more rigorous preventive methods;
- measures, strengthened by laws, banning the introduction and propagation of invasive plants
- strengthening of quarantine services by the introduction of stricter legislation and employment of more qualified staff;
- risk assessment of introduced plants;
- preparation of a list of quarantine plants based on regulations in each country;
- publication of a brochure listing quarantine plants and methods for their detection.

At the international level, cooperation must be developed and strengthened. Countries and institutions with more experience of invasive plants management could help, financially and technically, to strengthen the institutional capacities of developing countries by providing training and adequate equipment in the following areas:

- survey and diagnosis;
- identification and characterization of invasive plants;
- establishment of assessment, prediction and surveillance methods;
- preparation and implementation of projects to serve as guidance for various training;
- provision of technicians and training of plant protection services staff;
- organization of international and sub-regional task forces on prediction, risk assessment and prediction methods;
- facilitating access to information and documentation.

At the sub-regional level:

- exchange of information and experiences;
- updating of available data on invasive plants;
- information and public awareness;
- frequent and periodic training of plant protection officers;
- establishment of sub-regional management programmes.

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INVASION OF EXOTIC WEED SEEDS INTO JAPAN, WITH IMPORTED GRAINS, AND EXISTING PREVENTATIVE REGULATIONS

Shunji Kurokawa
Department of Forage Production
National Institute of Livestock and Grassland Science
National Agricultural Research Organization, Japan
E-mail: shunji@affrc.go.jp

Summary

Recently, many kinds of foreign weeds have begun to cause serious damage to farmers' fields throughout Japan. The source of this invasion is grain imported from overseas: numerous foreign weed seeds mixed in with grain have invaded ports and colonized fields. The viability of most foreign weed seeds is not likely to be affected by the processes of invasion. To control such weeds, several methods have been tried, both chemical and non-chemical. So far, composting manure is the only effective way of preventing weed seeds from germinating. A complete solution is needed to change the structure of national agriculture, otherwise more exotic weeds are likely to invade Japan in the future.

Introduction

Recently, many exotic weeds have been found to cause serious problems in Japan. The invasion pattern is different from that of weeds that had been accidentally introduced in the past. These spread gradually from the primary naturalized point along roads or railroad tracks; in contrast, the new exotic weeds appeared simultaneously in all affected. areas They cause yield losses, even in fields of forage crops where comparatively tall crops are grown.

To determine the cause of invasion by these new foreign weeds and their invasion route, Japan's Ministry of Agriculture, Forestry and Fisheries carried out a research project between 1993 and 1996 (Project Report, 1998a). Some local government institutes also conducted a project to develop ways of controlling the exotic weeds and preventing the spread of their seeds (Project Report, 1998b). This paper gives the results of this study on the source of the weeds, and describes the weed species involved and their distribution.

Distribution of exotic weeds in Japan

Questionnaires were distributed in 1993 and 1996 to at least one research station and/or extension station in each prefecture except Hokkaido and Okinawa, in order to determine the distribution of each exotic weed and the extent of crop losses it had caused. Results showed that several exotic species had become major weeds (e.g. *Abutilon theophrasti* Medic., *Solanum carolinense* L. and *Sicyos angulatus* L.) in most of the regions investigated.

Invasion route of exotic weeds

In order to control exotic weeds, it is very important to specify the route of invasion. In the project, the principal source and route of invasion were determined (Project Report, 1998a).

Source of the weed seeds

Since the weeds appeared suddenly and at the same time in forage fields all over Japan, it was initially believed that fodder crop seeds or imported feed might be the source of the invasion.

Possibility of invasion via fodder crop seeds

Because crop seeds for forage production are usually produced in foreign countries and exported to Japan, they provide an opportunity for exotic weeds to invade. However, fodder crop seeds are subject to strict inspection. It would be impossible for fodder crop seeds which were contaminated with weed seeds to pass inspection. In fact, no weed seeds were found in imported maize seeds during the investigation.

Possibility of invasion via imported feed

The amount of feed such as concentrates and hay imported into Japan has been increasing recently, and it was noted that this increase coincided with the occurrence of foreign weeds.

Imported grain which was used as feed stock for concentrated feed was investigated to determine whether exotic weed seeds were present. All grain imported during one year at the port of Kashima was thoroughly tested for weed seeds. The results showed that many kinds of weed seeds were mixed in with the grain imports, some of which were noxious weeds species (i.e. they were particularly damaging and/or extremely difficult to control).

An increasing amount of hay has also been imported into Japan in recent years, because many dairy farmers are unable to supply all their own feed. Samples from residues of imported hay remaining in the back of trucks arriving at a dairy farmers' cooperative were checked over six months. Although many seeds were included in each sample, they were not those of the recently observed exotic noxious weed species.

These results suggested that the source of exotic weeds was most likely imported feed grain, which is used as an ingredient in concentrated feed. Most of this imported feed grain comes from the United States.

Route of exotic weed seeds from the port to the field

At ports

When pests are found in imported grain, the grain is treated with methyl bromide. However, this treatment does not affect weed seeds. In fact, no remarkable difference in germination was detected between seeds treated with methyl bromide and non-treated seeds.

At the feed factory

Imported grains used as livestock feed are processed in several ways: they may be subjected to:

- mechanical crushing (>2 mm);
- pelletized steaming at 70-80^{o} C after crushing;
- heating under pressure to 130^{o} C, 3 atm.

Many feed grains receive only the first treatment, which does not affect seed viability.

In the digestive system of animals
When the effect on weed seeds of passing through the rumen of cows was studied, only one species, *Abutilon theophrasti*, showed a decreased germination rate. Passing through the digestive system of livestock did not seem to reduce the germination rate of other imported weed species; in fact, germination of many weeds species increased.

Composting
Sometimes animal manure is composted by farmers, or it can be spread directly onto fields. If the compost is well fermented, the viability of many weed seeds is reduced (Nishida *et al.*, 1998). However, if fermentation is not complete or the manure is applied directly onto fields, no weed seeds are killed.

In the field
Many exotic weeds are resistant or tolerant to herbicides currently used in Japan. In many cases, these species have escaped control programmes carried out in their countries of origin. Current weed control methods in Japan tend to leave many exotic weeds unharmed, so the number of exotic weeds invading Japan in imported grains and spreading over farmers' fields is increasing.

Weed species mixed in with imported grains
The seeds of one of the most common foreign weeds, *Abutilon theophrasti*, were found in soybeans produced in the USA and in lupines produced in Australia. A large number of seeds from several *Amaranthus* species were found in a range of grains from several countries. Seeds of an unusual species belonging to this family, *Amaranthus spinosus*, were found in soybeans from the USA. This may have contributed to the spread of this weed species into the northern part of Japan (Shimizu, 1998). Surprisingly, it was found that a number of native species, such as *Setaria faberi* Herrm, had been "reimported". In addition, some species such as *Digitaria sanguinalis* or *Echinochloa muricara*, which do not have Japanese names because they were previously unknown in the country, have also been found mixed in with imported grain.

Losses caused by major exotic weeds
- *Abutilon theophrasti* Medic.
This is an annual plant belonging to the Malvaceae family. It is tall, fecund, self-fertilizing and contains a great deal of fibre. This plant was grown as a fibre crop in Japan until the 1920s. However, the weedy ecotype is genetically different from the crop type (Kurokawa *et al.*, 1998a). Because the weed grows to about three metres in height and competes with crops, it causes serious yield losses. Moreover, the plant has a strong odour that may be transferred into the milk if dairy cows are given feed containing *Abutilon theophrasti*.

- *Solanum carolinense* L.
This plant is a perennial species belonging to the Solanaceae family, which propagates by both seeds and roots. It is very difficult to control as most herbicides are ineffective against it and because it can propagate through its roots. This weed causes serious crop losses, while its sharp thorns can injure both livestock and humans. It also contains alkaloids which are toxic to animals.

- *Cyperus esculentus* L.
This sedge is a Cyperaceae species. It can be spread by vegetative propagation as well as seeds. Most herbicides are ineffective against this plant.

- *Sicyos angulatus* L.
This vine belongs to the Cucurbitaceae family. It winds around the stems of crops such as corn and covers the plants. Although fairly rare, it can cause serious damage to crops.

- *Datura stramonium* L.
This is a poisonous weed which is highly toxic to both livestock and human beings. It can be troublesome even when the frequency of occurrence is low.

Attempts to control exotic weeds
Local governments in Japan have developed two approaches to the control of exotic weeds: one is based on the use of chemical herbicides and the other on non-chemical control methods (Project Report, 1998b).

Chemical control
It was found that *Datura stramonium* could easily be controlled with existing herbicides. However, it is important that control programmes eradicate all plants because of their high toxicity. Many weeds such as *Abutilon theophrasti* or *Sicyos angulatus* are very difficult to control with existing herbicides. Herbicides have no control effect at all over *Solanum carolinense*.

Non-chemical control
Sometimes chemical control is difficult to apply. There may be no existing effective herbicide, while new herbicides take a long time to develop. In addition, it may be difficult to rely on herbicides alone from the viewpoint of sustainable agriculture. During the project, ways of controlling major exotic weeds without herbicide use were examined by local governments and some useful methods were discovered.

Preventing the spread of new exotic weeds
A list containing 316 weed species that might possibly invade Japan in the future was drawn up by Konnai *et al.* (Project Report, 1998a). Later, it was found that the seeds of *Emex australis* (included in the list) had already invaded Japan, mixed in with imported hay from Australia. This weed, which is one of the most serious in Australia, produces a number of spiny fruits. It is clear that, unless precautions are taken, many additional weeds can be expected to become invasive in future.

The only way to prevent weed seed germination is to compost animal waste adequately. The relationship between the temperature of fermenting compost and seed viability has been studied by Nishida *et al.* (1998, 1999). It was found that seeds cannot survive in compost that reaches a maximum temperature of more than 60^{o} C during fermentation. Ensuring that the temperature of waste reaches a sufficiently high level during composting is very important in order to prevent invasion by new weeds. Some new techniques to prevent weed invasions at ports have been tested recently, including electron irradiation (Kurokawa *et al.*, 1998b, 1999). The susceptibility of different species to electron irradiation was found to vary widely.

Circumstances surrounding the problem of exotic weeds

In Japan, a recent fall in milk prices has brought about a financial crisis for dairy farmers. In this difficult situation, farmers have had to increase milk productivity in order to survive.

There were two ways of raising productivity: to increase the number of animals reared and the average milk yield per cow. The first method produced animal waste in too large a quantity for adequate composting. Consequently the seeds remained viable. The second method encouraged farmers to use more feed concentrates, which increased the chances that foreign weeds would invade, mixed in with imported grain. The combination of these factors resulted in the sudden appearance of a serious exotic weed problem.

What will happen in the near future?

It is clear that the causes of the foreign weed problem are complex. If the situation does not improve, what will happen in the near future? This will depend mainly on the exporting countries. It is their actions, rather than those of Japan, which will determine the types and numbers of foreign weeds that will invade.

For example, a tolerance gene for non-selective herbicides has been introduced into some crops grown in the United States. In the future, weeds tolerant to non-selective herbicides may appear and could subsequently invade Japan. It is important to prevent this, and to find a way of changing the social and economic situation of agriculture.

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Weed Risk Assessment in Australia

J.G. Virtue[1] and F.D. Panetta[2]
[1]Animal and Plant Control Commission
Department of Water, Land and Biodiversity Conservation
CRC for Australian Weed Management
[2]Alan Fletcher Research Station
Department of Natural Resources and Mines
CRC for Australian Weed Management
E- mail: Dane.Panetta@nrm.qld.gov.au

Summary

Weed risk assessment (WRA) is the use of standard technical criteria to determine the relative weed threats posed by plant species. Two applications of WRA, prediction of new weeds and prioritization of existing weeds, are discussed from an Australian perspective. Since 1997, the Australian Quarantine and Inspection Service has used a scoring system consisting of 49 questions on weed history, biogeography and biology/ecology (simply answered as yes/no/don't know), to determine if a new plant species entering the country poses a weed risk. This system has enabled Australia to take a pro-active approach against weeds at the quarantine barrier, with the focus on permitted species for import, rather than the former, deficient prohibited list. The use of this system has broadened recently to the assessment of a large number of species held in germplasm collections within Australian Genetic Resource Centres. In 1998, a ranking system to determine weeds of national significance was developed for the National Weeds Strategy. This system has been further refined to prioritize the importance of noxious weeds in South Australia. The system consists of multiple choice questions to derive scores for invasiveness, impacts and potential distribution, which are then combined to give an importance score. A variety of other such systems have been developed in other parts of Australia and an attempt is underway to develop a standard national system. The establishment of the Cooperative Research Centre for Australian Weed Management has provided an opportunity to undertake research in a number of areas relevant to WRA.

Introduction

The economic impact of agricultural weeds in Australia has been estimated at over $3300 million Australian dollars per year, in terms of lost productivity and cost of weed control (Combellack, 1989). Economic costs of weeds in natural ecosystems are not readily quantifiable, particularly on a national scale. However, their biodiversity impacts in Australia are being gradually more recognized by the community, and government funding has increased for research and control programmes. Australia has at least 2750 plant species that have been reported as weeds, mostly exotics but also some invasive native species (Lazarides *et al.,*1997). In the period 1971-1995, nearly 300 new species were found naturalized in Australia, with a trend of increasing naturalization rate with time (Groves & Hosking, 1998). The majority of these species were likely to have been introduced prior to 1970, mostly for intentional use in horticulture and agriculture.

Given the future threat of new weeds and the magnitude of the current weed problem, there is a need for efficient screening procedures to prevent the entry of new weeds at quarantine barriers (border focus) and to prioritize control of weeds that have established (post-border focus). In this paper we describe current Australian weed risk assessment (WRA) systems in both of these areas. Following the commencement of the Cooperative Research Centre for Australian Weed Management (Weeds CRC) in July 2001, there has been a marked increase in research activity under a research programme entitled 'Weed incursion and risk management'. A subsidiary aim of this paper, therefore, is to describe the current research agenda with regard to WRA.

Weed risk assessment at Australia's border

In predicting the potential weed status of plants, approaches to date either focus on factors relevant to specific ecosystems (e.g. Tucker & Richardson, 1995 for woody weeds of south African fynbos; Champion and Clayton, 2001 for aquatic weeds) or take a generalist approach where a plant is predicted to be a weed when it reaches a certain number of risk factors. The latter approach was adopted by Pheloung (1995), in developing the Weed Risk Assessment System to screen plant imports into Australia (hereafter referred to as the Pheloung system).

The Pheloung system (Pheloung, 1995, 2001) consists of 49 questions covering a plant's domestication, climate preferences, weed history, undesirable traits, growth form, reproduction, dispersal and persistence attributes (Figure 1). Questions are mostly answered as yes/no/don't know with a +1 score for a weedy attribute and a −1 score for a non-weedy attribute. A minimum number of questions must be answered to generate a score. The total score determines whether a plant is accepted for import (score of <0), rejected for import (score of >6) or requires further evaluation (score of 0 to 6). Pheloung (1995) suggested further evaluation might include a more intense literature search to answer more questions, an economic cost/benefit analysis to justify the risk of entry, or post-entry experimental assessment under quarantine conditions. Assessment is based on information obtained from literature searches on the species. The Internet and computer databases are also providing increased and more rapid access to information, via abstracting systems (e.g. CABI), search engines, weed databases and specialist email listservers (e.g. ALIENS-l). Scoring is done within a Microsoft Excel spreadsheet.

The Pheloung system was developed as an initiative under the National Weeds Strategy (Anon., 1997). It was first implemented by Agriculture Western Australia. The Australian Quarantine and Inspection Service (AQIS) then adopted the system as part of a significant overhaul of the regulation of plant imports. AQIS underwent a transition from a small list of prohibited weed imports to a permitted list approach in 1998, with funding assistance provided through the National Weeds Strategy (Walton, 2001). It adopted a three-tiered plant screening process (Figure 2) that had been recommended following a workshop commissioned by the Australian Weeds Committee (Panetta *et al.*, 1994).

The first tier is "identification of the species with reference to current lists of prohibited and permitted species and determination of its Australian distribution" (Walton, 2001). A list of species that were already present in Australia (in cultivation and/or naturalized) was compiled. Most of these species were then added to the permitted list. Only those species present that were of limited distribution and under official control (i.e. declared noxious) could be termed quarantine pests and be included on the prohibited list. If a species proposed for import was on neither of the lists then it moved to the second tier.

The second tier states: "If the species is not listed and is not established in Australia, apply a pre-entry assessment procedure to determine the risk of the species becoming a weed in Australia: possible recommendations are accept, reject and further evaluate. Rejected or accepted species are added to prohibited or permitted lists" respectively (Walton, 2001). This involved the implementation of the Pheloung system. Since the adoption of the Pheloung system in 1997 there have been approximately 1300 species assessed. During 2000 approximately 46% of species were accepted, 24% rejected and 25% required further evaluation (5% of species were unable to be assessed because no information was found on the species). The assessments conducted during 2001 resulted in a decrease in the number of accepted species (to 36%) and a corresponding increase in the number of species requiring further evaluation (39%) while the number of rejected species stayed relatively constant at 25%. (Porritt, personal communication). Assessments have required an average of two days working time.

Since there are considerable numbers of species held within the germplasm collections maintained by Genetic Resource Centres in Australia, during 2001 an assessment of a subset of these, considered to be of highest priority for release, was conducted using the Pheloung system. The draft evaluation of these species prompted a vigorous response from a wide range of stakeholders, and consideration of these comments is still underway. Two particular concerns raised were a higher rejection rate (approximately 40%) compared to species proposed for import, and the need to consider the potential benefits of the species for Australian agriculture.

The third tier states: "If an accept or reject recommendation cannot be obtained from the second tier, and the importer wishes to proceed, subject the species to post-entry evaluation either in the field or in glasshouse trials to examine more directly the weed potential (and/or verify potential uses) so that, ultimately, the species can be placed on a prohibited or permitted list" (Walton, 2001). Protocols for the third tier are being developed. These may include further data collection overseas or glasshouse trials in quarantine to enable more questions to be completed in the Pheloung system. Species that then still remain in the "further evaluate" class may have to undergo more rigorous experimental trials (e.g. palatability for potential forage species), under supervision of an expert panel. Field trials could only occur once effective control measures have been demonstrated.

Post-border weed risk assessment

In moving from prediction of new weeds to prioritization for control, the assessment focus shifts from whether a plant species will become invasive to what potential impacts a weed will have, and how soon these impacts will be realized. The feasibility of preventing these impacts (i.e. controlling the weed) is also an important consideration in prioritizing weed control efforts. Important advances in the development and implementation of WRA systems to prioritize environmental weeds at the local or regional level have been made in the USA (Hiebert & Stubbendieck, 1993) and New Zealand (Owen *et al*., 1996; Timmins & Owen, 2001). In 1997, research was commissioned as part of the National Weeds Strategy (Anon., 1997) to develop a ranking system to determine weeds of national significance for Australia. The system had to be robust, relatively simple and sufficiently objective as to be clearly defensible. The system also had to treat agricultural, forestry and environmental weeds equally. The resulting system is thought to be the first attempt at devising a generic scoring system to rank the national importance of established weeds.

A draft ranking system for the National Weeds Strategy was developed in 1997-98 (Virtue *et al.*, 2001). A literature review identified the need for separate criteria scores for invasiveness, impacts and distribution (current and potential). A score for relative invasiveness would provide a substitute measure to rate of spread. Faster spreading weeds are considered more urgent for control and thus of higher priority, but direct measurement of rate of spread was not achievable. A score for relative impacts would indicate the types and severity of damage that a weed could achieve, whilst avoiding the extremely difficult task of estimating the actual dollar cost of the weed's impacts. Multiplying the impacts score by the current or potential distribution would indicate the total damage posed by the weed in the short and long term, respectively.

Current and potential distribution scores were based on a 0.5^o latitude $\times$ 0.5^o longitude grid across Australia. Potential distribution was predicted using the "CLIMATE" software program (Pheloung, 1996), which matches temperature and rainfall parameters of a weed's known world distribution to a climate surface model for Australia. An example weed distribution is shown in Figure 3. Recognizing that weeds are often specific to a particular land use, grid maps of five land uses were developed: aquatic, intensive agriculture, extensive agriculture, native forestry and natural terrestrial environment. Scores for current and potential distribution were calculated as the proportion of a land use at risk.

The draft system (Virtue *et al.*, 2001) proposed multiplying scores for invasiveness, impacts and distribution (current or potential for short or long-term importance, respectively), for land uses affected by a weed. Scores for each weed were then summed across land uses to give a total importance score (short or long-term). This treated each land use as being of equal value. The draft system was changed somewhat after consideration by the National Weeds Strategy Executive Committee. Four main criteria were used in the final version of the system: (i) invasiveness, (ii) impacts, (iii) potential for spread and (iv) socio-economic and environmental values (Thorp & Lynch, 1999; NWS, 1999). The potential for spread looked at the ratio of current to potential distribution. The socio-economic and environmental values used data on current cost of control for agricultural and forestry weeds, and data on threatened species, communities and bioregions currently affected and the monoculture potential for environmental weeds. Seventy-four weeds were nominated for consideration as weeds of national significance (WONS). Expert panels for tropical, sub-tropical and temperate Australia were convened to compare their relevant sets of weeds using the final ranking system. The top twenty weeds were declared WONS (Table 1), and individual national strategies have been developed for these weeds by various state agencies.

In South Australia (SA), the system developed by Virtue *et al.* (2001) has been developed further by the Animal and Plant Control Commission (APCC) to assist in prioritizing the control of noxious weeds, and for assessing new weeds proposed for proclamation. Scores for invasiveness, impacts and potential distribution (each ranging from 0 to 10) are multiplied to give a weed importance score. The APCC Weed Assessment Scoresheet (Virtue, 2000) is summarized in Box 1. Weeds are assessed separately for various land uses (i.e. aquatic, crop/pasture rotation, forestry, irrigated crops and pastures, native vegetation, non-arable grazing, perennial horticulture or urban), so that the most important weeds of different land uses can be identified. Ranking weeds across land uses has not been attempted, avoiding subjective arguments about the relative value of different land uses. Rather, regional Animal and Plant Control Boards can decide on their relative resource allocations to different land uses, and then examine their weed priorities within these land uses. The system is designed as a Microsoft Excel spreadsheet (Figure 4) and has an explanatory guide (Virtue, 2000).

The current APCC system only considers one aspect of weed control prioritization - the weed's potential importance. Feasibility of control is another major aspect to consider. Can the weed be eradicated or at least contained via government enforcement, or is it so widespread that resources are better directed to developing integrated weed management systems for landholders? A robust scoring system for feasibility of control is still being developed. Key factors would include how widespread a weed is, ease of finding infestations, cost of controlling infestations, difficulty of limiting the weed's dispersal, willingness of landholders and governments to control the weed, and commercial use of the plant.

Current and proposed activities of the Weeds CRC

While there has been general acceptance of the Pheloung system, there are still a number of issues to be dealt with. Current and proposed research is intended to test assumptions embodied within this WRA system and to contribute to its further development.

Designation of high risk groups

Based upon general perceptions of the histories of different types of plants in Australia, aquatic plants, grasses, nitrogen-fixing woody plants and geophytes have been designated as high risk types of plants, gaining higher scores accordingly. These underlying assumptions need to be tested. One of the current projects of the Weeds CRC involves establishing a database that will capture the totality of the exotic species present in Australia, including introduced species that have not naturalized to date. This database will enable us to calculate relevant transition probabilities, from introduced to naturalized, and from naturalized to weed status for different life forms and for different taxonomic groupings. Such information will be invaluable in the determination of the risks posed by these plant groups.

Another approach to determining high risk groups involves an investigation of the assemblage of traits that distinguish introduced species with high environmental impacts from those with low impacts. Research at the Alan Fletcher Research Station is attempting to define such weed functional groups. If this research is successful, its outcomes will be useful both in screening for weediness and in prioritizing newly naturalized species for coordinated control programmes. Other research conducted at the University of Adelaide is aimed at identifying readily measurable species and ecosystem factors that are correlated with dominance of different introduced legume species in natural ecosystems. The objective here is to develop a screening process that can distinguish between weedy and non-weedy species in this agriculturally important group of plants.

The base-rate effect problem

It was noted earlier that the rejection rate from the Pheloung system is running at about 25 percent. However, it has been estimated that introduced plants become weeds at a considerably lower rate (0.1-1%) (Williamson & Fitter, 1996). While the actual figures for this base rate are debatable, the discrepancy between the Williamson and Fitter estimate and the screening rejection rate suggests that a substantial proportion of the rejected species may be 'false positives' (i.e. plants that are judged to be potential weeds but in reality would not be). The establishment of an exotic species database from which better estimates of the base rate(s) can be derived for different life forms and taxonomic groupings will prove useful in the refinement of the Pheloung system. The proper balance between 'false positives' and 'false negatives' (plants that are judged not to be potential weeds but in reality would be so) depends on an assessment of the costs of admitting a pest relative to the costs of losing a potentially useful organism (Lonsdale & Smith, 2001). This suggests a need for an assessment of the costs and benefits of different types of introductions (see below).

Cost-benefit studies for intentionally introduced species
Studies have shown that a large proportion of the species that have become weeds in Australia have been intentionally introduced, mostly for use in horticulture and agriculture (Panetta, 1993; Groves & Hosking, 1998). As stated above, the existence of 'false positives' suggests that a WRA that is too restrictive will exclude plants that could provide substantial benefits to society without incurring harm. Alternatively, it can be argued that the majority of proposals to import new species relate to plants that would provide relatively little benefit, whilst some would provide benefit to only a restricted sector of the Australian community yet pose a risk of substantial future weed costs to other sectors. A project undertaken at the University of New England will utilize a cost-benefit framework to assess a range of potential plant introductions.

Development of a national standard for post-border WRA
During the past five years, there has been considerable activity within Australia with regard to developing WRA systems to use for deciding what species should be declared noxious weeds and in prioritizing species for the allocation of scarce management resources. Various systems have been developed in different states, focusing on different geographic scales or land uses. Many of these systems have been developed independently. In order to maintain the reliability, if not credibility, of this discipline it is important that WRA systems conform to recognized standards. A Weeds CRC-sponsored workshop was held in Canberra during February 2002 in order to identify common elements of the various systems and to explore novel approaches that could be applied to the standard criteria of post-border WRA systems. Development of a standard WRA system is ongoing, as is development of a system for determining feasibility of control.

Conclusion
Weed risk assessment provides standard, robust and objective processes for making weed management decisions. WRA systems are also educational, providing a means to explain and justify these decisions to people with limited weed knowledge (e.g. landholders, politicians). *It is important that systems be kept comparatively simple, with as few questions as possible whilst still retaining accuracy, and with questions that can be answered relatively quickly using existing knowledge or rapid field observations*. WRA systems are a tool for sharing information on weeds, and provide a means to capture both scientific knowledge and field observations. As use of WRA systems increases, international sharing of data on weeds needs to be improved (e.g. weed lists, biological traits, impacts and distributions). Finally, WRA should be seen as evolving and flexible. Scoring systems will change as new knowledge is gained on their

accuracy, and as our understanding of weed invasions and weed impacts increases. Similarly, scores for individual weeds will change as we gain a greater understanding of their biology and management, and as ecosystems/land uses change. Specifically targeted research should be a vital contributor to the development and substantiation of WRA systems.

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Table 1. Australia's Weeds of National Significance (NWS 1999).

- alligator weed, *Alternanthera philoxeroides*
- athel pine, *Tamarix aphylla*
- bitou bush / boneseed, *Chrysanthemoides monilifera*
- blackberry, *Rubus fruticosus* agg.
- bridal creeper, *Asparagus asparagoides*
- cabomba, *Cabomba caroliniana*
- Chilean needle grass, *Nassella neesiana*
- gorse, *Ulex europaeus*
- hymenachne, *Hymenachne amplexicaulis*
- lantana, *Lantana camara*
- mesquite, *Prosopis* spp.
- mimosa, *Mimosa pigra*
- parkinsonia, *Parkinsonia aculeata*
- parthenium weed, *Parthenium hysterophorus*
- pond apple, *Annona glabra*
- prickly acacia, *Acacia nilotica spp. indica*
- rubber vine, *Cryptostegia grandiflora*
- salvinia, *Salvinia molesta*
- serrated tussock, *Nassella trichotoma*
- willows (except weeping willows, pussy willow and sterile pussy willow), *Salix* spp. (except *S. babylonica, S.*× *calodendron* and *S.* × *reichardtiji)*

Figure 1. Three-tiered flowchart used by AQIS to screen plant introductions (from Panetta *et al*., 1994)

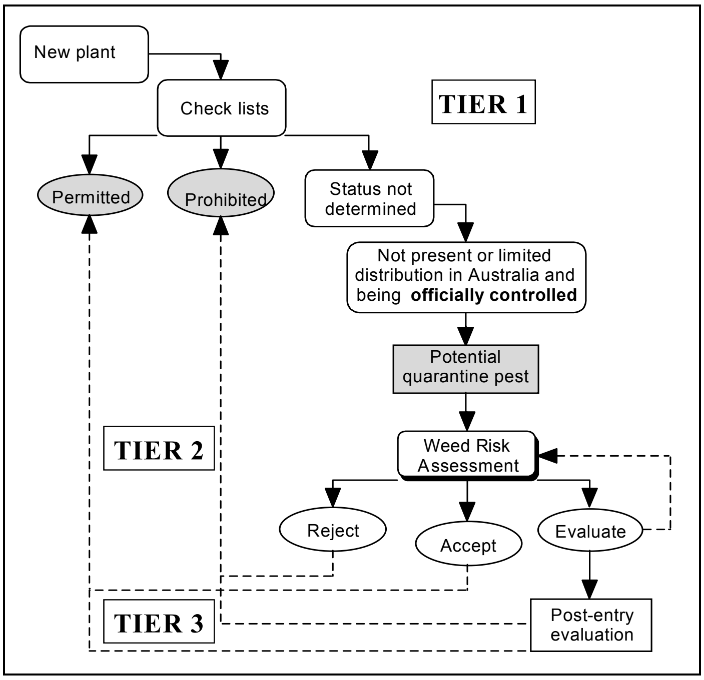
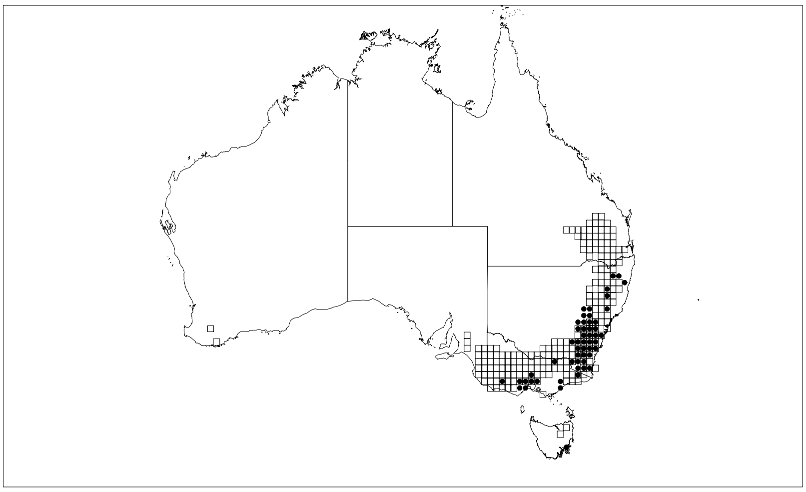


Figure 2 Current (•) and predicted ( ) distribution of serrated tussock, *Nassella trichotoma*, in Australia. (Figure from Virtue *et al*. 2001).



PROPOSED GUIDELINES FOR WEED-RISK ASSESSMENT IN DEVELOPING COUNTRIES

Peter A. Williams
Landcare Research
New Zealand
E- mail: WilliamsP@LandcareResearch.co.nz

Summary

The project guidelines describes the international background to, and the discipline of, weed-risk assessment, details quarantine weed-risk assessment procedures suitable for developing countries, outlines a framework for developing procedures for internal weed-risk assessment and lists the resources required and available to undertake weed-risk assessments. The main findings of this work are as follows:

- International agreements allow countries to specify requirements for the entry of plant material and describe the obligations of countries so that import requirements are not unjustified trade barriers. On the other hand, as invasive species affect productive systems and biodiversity, assessing potential weeds and controlling their spread is a vital international undertaking.
- Weed-risk assessment is a new discipline that aims to predict the future outcome of biological and social interactions. The task is difficult because only a small proportion of all plants become pests and the characteristics that make them so depend on habitats and people.
- A suitable weed-risk assessment system currently available as a quarantine tool is that used by the Australian and New Zealand authorities, termed the WRA system. The details of this system are presented.
- Internal weed-risk assessment involves a greater element of prioritizing of weed control resources and they should be tailored to defined stages of pest spread. The development of systems for detecting pests at the earliest invasion stages is a high priority. Factors to consider and options for scoring systems are described.
- The literature and Internet resources available to help weed-risk assessments are presented.

Introduction

The movement of trade goods and aid of one sort or another throughout the world is essential for the wellbeing of all peoples. Not all these goods and gifts are benign, however, and some come with unwelcome surprises. Invasive species affect agricultural and other systems, and their impacts are second only to habitat destruction in terms of loss of biodiversity. These concerns have generated growing international interest in weed-risk assessment systems to prevent the introduction of new pests and to prioritize existing pests for control. Weed-risk assessment is a new discipline, and the first international symposium on the topic was held only recently in Australia (Groves *et al.*, 2001). This country, along with New Zealand, is at the forefront of developing and implementing strong quarantine protocols. Both countries are relatively isolated from the rest of the world, agriculture is important to their economies, and their citizens value natural landscapes and their ancient indigenous biodiversity.

This report introduces the topic of weed-risk assessment and provides guidelines for countries wishing to strengthen their own quarantine protocols and to use scarce resources efficiently for prioritizing existing pests for control. Fortunately, this task is becoming easier because the Internet allows rapid exchange of information and access to detailed databases on pests, e.g. the global compendium of weeds (http://www.hear.org).

2. International framework of weed-risk assessment

The actions taken to exclude a plant species from a country due to its weed potential must be consistent with the international standards regulating the movement of trade goods. These obligations are defined under the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS agreement) of the World Trade Organization (WTO, 1994), and the International Plant Protection Convention (IPPC) (1997 revised edition) deposited with the Food and Agricultural Organization of the United Nations (FAO, 1996). These two international agreements, whilst allowing countries to specify requirements for the entry of plant material, describe the obligations of countries so that import requirements are not unjustified trade barriers.

A further international convention involving weeds concerns the need to conserve biodiversity. Article 8(h) of the Convention on Biological Diversity states that: “each Contracting Party shall, as far as possible and appropriate, prevent the introduction, control or eradicate those alien species which threaten ecosystems, habitats, or species”. Not all countries are signatories to this convention.

A *quarantine pest*[6] is defined by the IPPC as a *"pest of potential economic importance in an area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled"* (FAO, 2001a). It is accepted for the purposes of this report, that “*economic importance*” includes actual or potential effects on the economy of ecosystems and their component species, and that the IPPC definition of a pest is sufficiently broad to include weeds covering the full range of *ecosystems*, including those covered by the Convention of Biological Diversity (CBD, 2001). In fact, international meetings have recently been held to foster collaboration between the IPPC and the CBD (e.g. Bangkok, 6-8 February 2001).

Pest Risk Analysis (PRA) is a three-stage "*process of evaluating biological or other scientific and economic evidence to determine whether a pest should be regulated and the strength of any phytosanitary measures to be taken against it*" (FAO, 2001b).

These stages are:

Stage 1. Initiating the process by identifying a *pest* that may qualify as a *quarantine pest*, and/or pathways that may allow introduction or spread of a *quarantine pest* that should be considered for risk analysis in a defined PRA area.

Stage 2. Assessing the *pest* risk by determining which pest(s) are *quarantine pests*, and characterizing the likelihood of *entry*, *establishment*, *spread* and economic importance.

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[6] Terms in italics are definitions and guidelines found in FAO publications. References are to recent publications where these definitions are explained, and not necessarily to the original agreement. These are available on the Internet.

Stage 3. Managing the *pest* risk identified in Stage 2 by developing, evaluating, comparing, and selecting options for dealing with the risk.

The initial steps are to determine the *pathway*(s), that is, *any means that allows the entry or spread of a pest*, and correctly identify the *pest.* The identification of high-risk pathways is an important part of an overall weed-risk assessment process, but this report deals only with the individual *pests.*

The criteria used to determine the presence or absence of the potential *quarantine pest* in the *area* are represented in a flow chart in Figure 1, redrawn from the IPPC standard, Guidelines For Pest Risk Analysis (FAO, 1996). *Area* is defined as "*an officially defined country, part of a country, or all or parts of several countries"* (FAO, 2001a). If the species is absent, and has potential economic importance, it can be considered a *quarantine pest*. If it is already present in an *area*, then it can be legitimately considered a *quarantine pest* and evaluated further if it is of limited distribution or under *official* control. *Official* is defined as "*established, authorized, or performed by a national plant protection agency",* and *control* is defined as "*suppression, containment, or eradication of a pest population"* (FAO, 2001a). A *pest* capable of further s*pread,* that is, *expansion of the geographical distribution of a pest within an area* (FAO, 2001a) (Figure 1) that is not controlled, would require to be put under control to justify *quarantine pest* status. Species that are controlled but are at the absolute limits of their potential distribution cannot *spread* further and so cannot be declared *quarantine pests* either. In reality, most exotic species in most countries have potential for further *spread*.

Once the *quarantine pest* status has been confirmed, the next step is to assess the economic (including the environment) importance of the species. This may be high for a *pest*.

Weed-risk assessment is concerned primarily with the first two stages of the *pest risk assessment* involving *pest categorization,* that is, *the process for determining whether a pest has, or has not, the characteristics of a quarantine pest or those of a regulated non-quarantine pest* (FAO, 2001a). The minimum requirement of any weed-risk assessment system is that it satisfies the international agreements outlined in Section 2. To do this it must be built on explicit assumptions and must use scientific data.

Weed-risk assessment systems designed for use only within a single sovereign state*,* and which do not have the potential to limit trade, need not comply with international agreements. But to be effective they must be based on similar sound principles.

3. Plant invasions as a process

Plant species must cross a series of barriers to reach a new area and spread within it[7]. Initially, these are physical barriers on an intercontinental and/or intracontinental scale. Species that have not crossed these barriers may nevertheless be classified as quarantine pests*,* primarily on the basis of their pest history elsewhere. Once they have reached the new

[7] Background reading to this section is in Section 10.

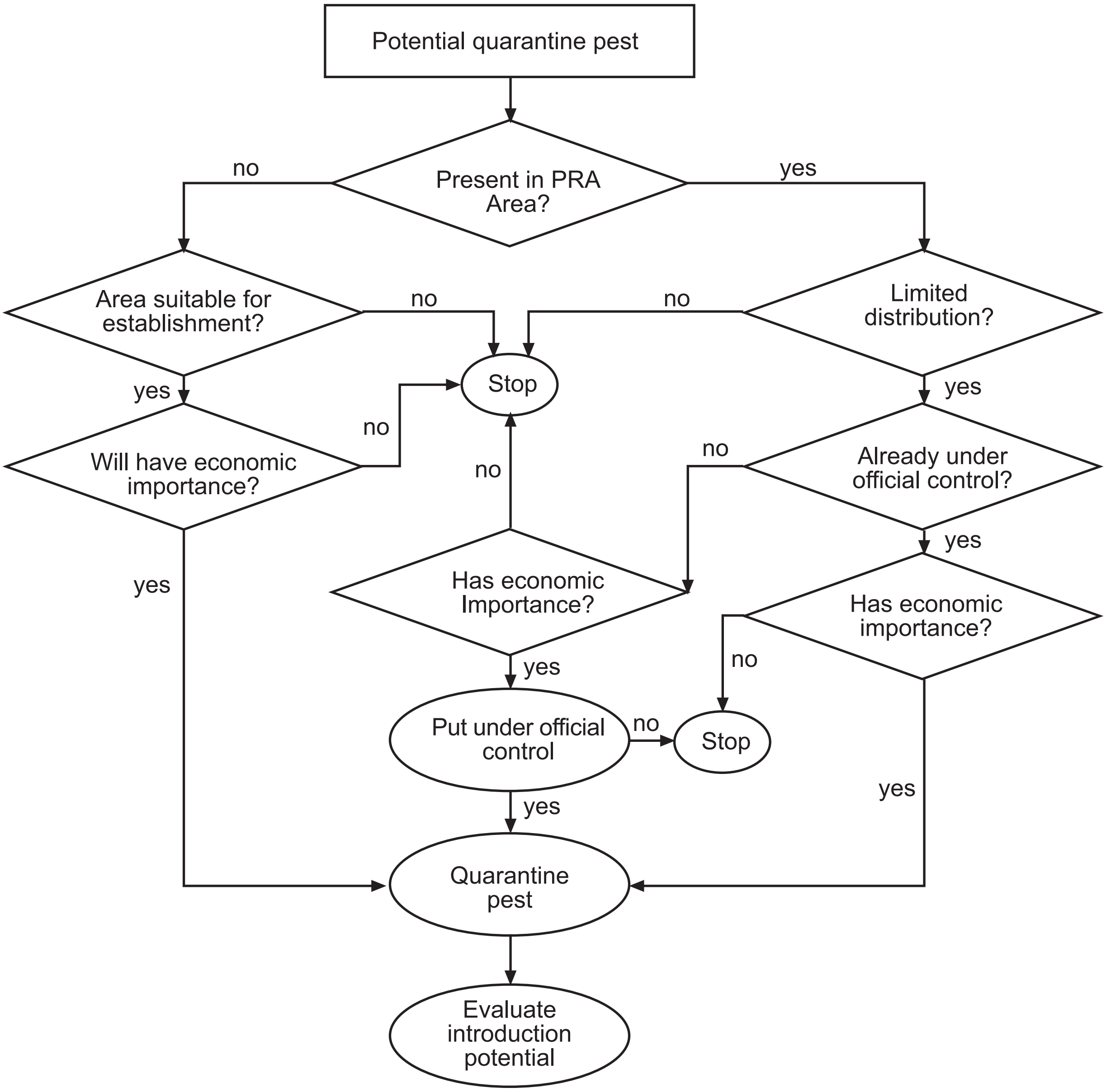

Figure 1 Pest risk analysis (from FAO, 1996)

area, they must overcome a range of abiotic and biotic barriers to establish. Human activities are important in assisting species to cross these barriers. Species arriving in small numbers by accident have a relatively low chance of establishment. In contrast, those species spread widely as seed contaminants, raised in large numbers within a protected environment for horticulture, or planted out in agricultural or natural environments, e.g. crops or erosion control, have a greater chance of establishment. Once a species is growing in cultivation in a new country it may spasmodically appear in the wild beyond the initial plantings. If it was introduced occasionally as a contaminant of crops it may appear on associated land. The term for such sightings is "casual alien" or "casual exotic".

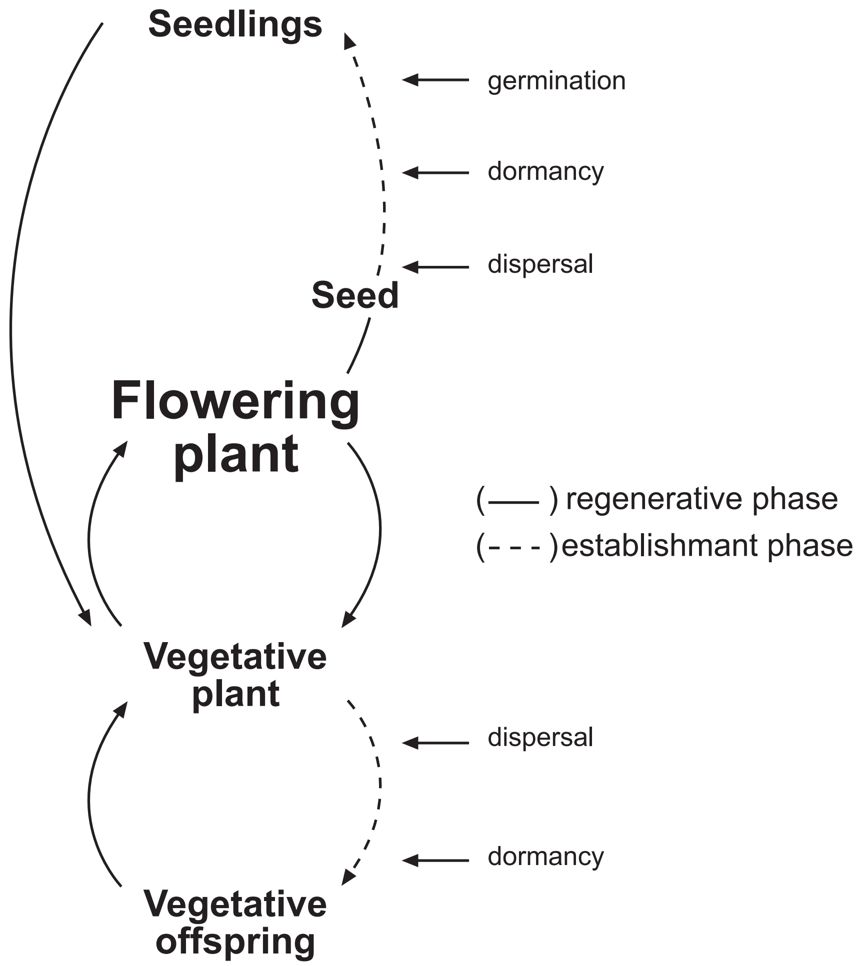

Figure 2 Life cycle of perennial plants producing both seeds and vegetative organs (from Williams, 1997).

To become a naturalized alien, or fully naturalized alien or exotic depending on the definition being followed, a species must then develop self-maintaining populations in the wild. These loci are the points from which it may spread within the area.

Different species characteristics and life-cycle stages (Figure 2) may be important at different barriers. For example, colourful flowers may be the selection criterion for transcontinental transportation in the first place. Rapid reproduction by seed and/or vegetative offspring (e.g. bulbs and tubers) (Figure 2) may then assist its spread once it has been introduced. Its persistence through periods of unfavourable climate may depend on long-lived seed banks. Crossing any of these series of barriers is reversible. A species may be extirpated locally or even driven to extinction within an area if, for example, there are severe climatic fluctuations or new predators and diseases are introduced. The process of arrival and extinction by natural means or control may be repeated over many years until the species finally becomes fully naturalized.

The spread of a pest may follow a number of patterns in time and space, depending on such factors as its means of dispersal, life-cycle, and so on. Many follow a simplified "S" shaped pattern (Figure 3, solid line) that can be illustrated graphically as the proportion of all potential habitat occupied by the pest at any point in time. The essential features are a long tail at the beginning of a species spread as it crosses the first series of barriers, a steep rise as it breaks through these barriers and finds suitable habitats, and then a flattening off as these habitats are saturated. As the pest spreads, the proportion of the uninfested habitat declines at a rate defined by a "reverse S" (Figure 3, dotted line). The process of spread may be continuous, but points are still recognizable (usually only with hindsight) where the rate of change alters markedly from the preceding period. For management purposes, the "S" shape can be idealized as stages based on the extent and rate of spread. This concept can be applied at any geographic scale, from a field to a continent.

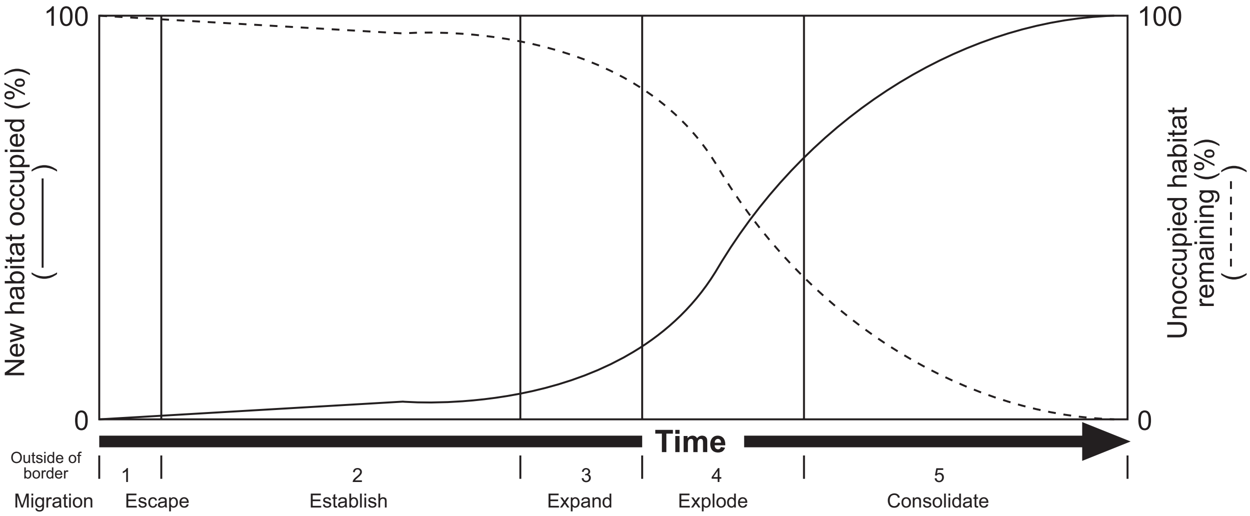

Figure 3 Conceptual phases in the invasion of a weed through time, and the way these relate to the percentage of occupied and unoccupied land (from Williams, 1997).

Migration phase

The species must first reach the border of the area. Once it has arrived it may or may not enter, depending on a variety of factors. Where there are efficient quarantine protocols and risk management procedures it will be detected and, hopefully eliminated, if a quarantine pest.

Escape phase

Once inside the area it may escape only occasionally, or finally become fully naturalized. The locations of these naturalization points are likely to be associated with the pathway of introduction, e.g. in fields planted with contaminated corn, or adjacent to erosion control plantings. They have been referred to as “sentinel sites.”

Establishment phase

During this phase, the plant is able to reproduce in the new environment, and population numbers slowly begin to build up. Virtually all potential habitat is still uninfected.

Expansion phase

Eventually, the number of sites occupied expands beyond the initial loci. Expansion is fastest where there are multiple loci. The causes of this expansion differ among species and are not well documented. Factors are diverse, including particularly favourable growing seasons, the arrival of new pollinators or dispersers, the species becoming adapted to its new environment by the formation of new genotypes. New habitats may be created, e.g. by changes in land use.

Some local areas of habitat are noticeably infested, but most potential habitat is uninfested. It is often only at this stage that the plant begins to be perceived as a pest.

Explosion phase

The period where the pest expands rapidly and often where it begins to attract official concern. Many potential habitats are infested during this phase.

Entrenchment phase

The pest slowly spreads to the last remaining habitats over its full range within the area. This does not mean that it occurs on all suitable land at any one time, but that it has a high chance of occurring there.

Further spread can occur only if more suitable habitat is created, e.g. by fire. Importantly, the pest may be present only in a dormant stage of its life-cycle, as shown in Figure 2.

These potential changes in the spread of a pest have implications for weed-risk assessment imperatives:

- The most cost-effective means of avoiding pest impacts is to prevent their introduction or establishment in an area. Failing that, the greatest return for expenditure of money and effort comes from controlling a pest before it has spread.
- Once it has established and begun to spread, the ongoing effort required to eliminate it increases dramatically (Figure 4).
- During the earliest spread phases, when the required funds to extirpate a pest are low, these may be effectively obtained as an adjunct to other pest control programmes. Once the pests begin to spread rapidly, the effort required to obtain the funds may be orders of magnitude greater. To rephrase this, at one extreme, only the person with the spray gun (or spade or slasher) needs to be persuaded to act, while at the other, it may require the approval of government.
- There are no recorded successful weed extermination attempts (A, Figure 4) worldwide where the pest covered more than a few hectares. Species with persistent seed or other regenerative life features that require repeated visits to the site(s) are particularly intransigent.
- The total accumulative costs over time are the effort required obtaining the funds, the money spent on actual control, plus the impacts on the economy and environment. These accumulated costs become progressively greater with time if control attempts are delayed, as illustrated by the differences in the three shaded curves in Figure 4.
- Effective weed-risk assessment systems must be appropriate to: whether or not a pest has established and spread; the pest's biology and ecology; the values being threatened; the extent to which it has or has not established in an area; and the technologies and resources available.

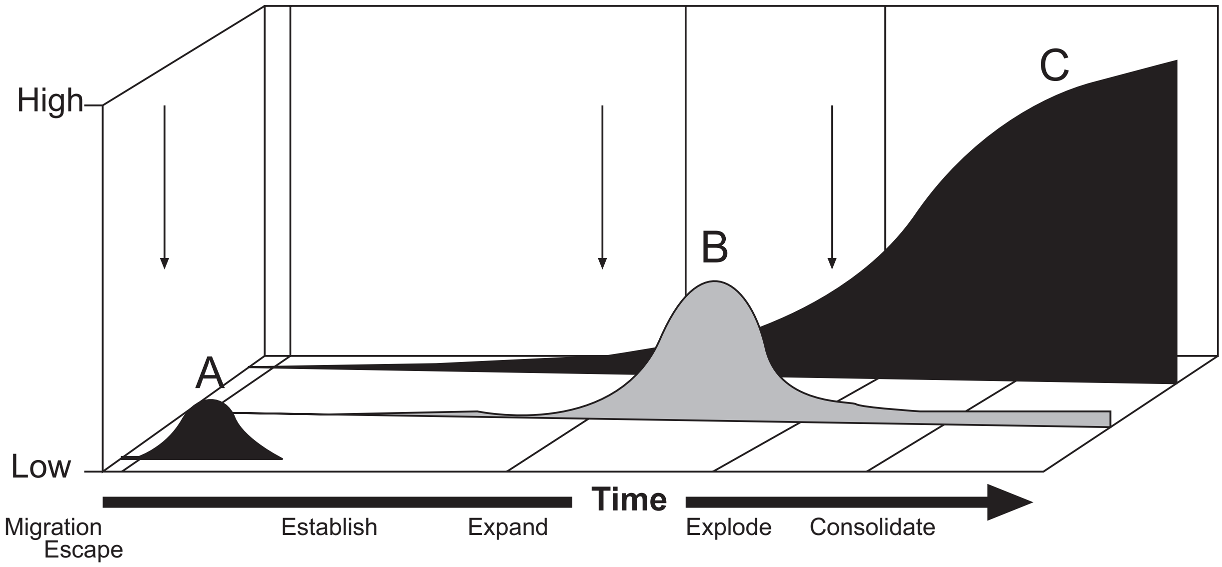

Figure 4 Relative combined monetary and environmental costs of undertaking an eradication programme (A), together with those of initiating ongoing control programmes at an early (B) and late stage (C) of the invasion. Arrows indicate programme starting points. The differences in area beneath the curves (B–A, C–A, C–B) represent the benefit of control action at the earlier stage (from Williams, 1997).

Three important factors change as a pest crosses the various barriers:

The location and amount of information

Before a species has been introduced to an area, all information needed to undertake pest categorization will be derived from experience of the species outside the new area. In most cases, this will mean obtaining information from its country of origin and elsewhere. The quality and amount of information will depend largely on whether the species has a history as a pest, or perhaps as a crop or ornamental. Once a species has been introduced, much information can be obtained, particularly about its growth and reproductive biology. Only as it spreads, however, will its environmental tolerances and impacts within the new area be revealed.

The certainty of a correct assessment

As a result of this increasing information as the pest spreads, the reliability of a weed-risk assessment increases, and conversely, the chance of the assessment being incorrect decreases.

Identification of those affected

The ecosystems on which a pest might impact cannot be reliably predicted before it has begun to spread. Neither then, can the individuals or interest groups directly affected by the potential impacts be identified. As a pest spreads through its potential habitats and range (Figure 3), those affected become increasingly identifiable. The corollary of this situation is that those who are likely to benefit from the management of the pest become increasingly identifiable. It means that at one extreme, all those within the area potentially benefit from the detection of a quarantine pest that has not reached there. At the other extreme, only those whose land the pest occupies benefit directly from the local control of a widespread pest.

It is ironic that weed-risk assessments have the greatest chance of being wrong when they are most effective in preventing accumulative impacts and costs of control, and in potentially benefitting the widest range of interest groups. That some risk is acceptable, however, is recognized by the third stage of the pest risk assessment process concerned with managing the risk.

4. Limitations of weed-risk assessment

Risk assessment systems concerned with both quarantine pests and established pests aim only to predict the potential harmful effects of a species. The weighing of these aspects against any potential beneficial outcomes, e.g. production of a new crop, or food in a shipment of contaminated grain, is an entirely separate exercise involving value judgements. It is not a component of weed-risk assessment as such.

Two important issues are faced in selecting a weed-risk assessment system. These are particularly acute when considering species new to an area as opposed to those that are spreading. First, it is difficult to predict a pest from only the characteristics of the potential pest. Second, that amongst any group of organisms, those attaining pest status do so at a very low rate.

Many studies have attempted to identify the characteristics of pests, as distinct from benign species. Early studies attempted to identify an “ideal weed”. More recent studies have concentrated on groups of similar plants within a country, a continent or throughout the world. A few variables are associated with weediness that is broadly applicable over whole groups of plants, e.g. herbaceous agricultural weeds, or plant families, e.g. pines. These rarely have predictive value when extended to broader groupings, as from agricultural systems to the natural environment, from pines to non-pines amongst the conifers. The consensus appears to be, that no traits are universally important for all species in all habitats. The characteristics of the receiving environment are equally important.

The importance of any particular plant trait in determining the success or failure of invasion becomes discernible only after the species has either established or is known to have failed in a new habitat. As the species’ fate becomes apparent through time, the reliability of the prediction will therefore increase. Even then, there may be no suit of endogenous plant characters readily obtainable from the literature that reliably predicts potential weediness. However, the chance of a plant species establishing in a new area is related to the pressure of its propagules on that area. This may be defined as the rate of individual whole plants, or vegetative or sexual reproductive parts, that are dispersed into an area over a given time period. Propagule pressure can operate at any special scale. Examples of low propagule pressure are the infrequent arrival from year to year of an occasional wind-blown seed from a distant source, the occasional seed of an unwanted species in a seed lot, or the infrequent planting of a timber species that produces few seeds. Examples of high propagule pressure are the frequent arrival on a regular basis of wind-blown seeds from a distant source, abundant seeds of an unwanted species in a widely planted seed lot, or abundant viable and readily dispersible seed from widespread plantings of timber trees.

The proportion of imported species that become pests has been calculated as ranging from about 0.01:100 for British angiosperms, 1.3:100 for grasses into tropical Australia, and 12.0:100 for pines in New Zealand. However, this wide diversity of ratios, and the effects of time lags between establishment and species acquiring recognized pest status changing the ratios, means the search for any constant ratio is futile. As a consequence of the low proportion of pests amongst a random selection of related organisms, any system designed to detect pests is likely to be wrong as often as it is right. The results of a false positive assessment (excluding a species when in fact it would not become a pest) could have long-term economic consequences for a country, e.g. in the case of a potential new crop. In contrast, a false negative assessment (accepting a species that becomes a pest) could result in serious economic damage.

It is equally important to realize that introductions supposedly for beneficial purposes also have a very low success rate. For example, hundreds of grasses and herbs were introduced into Australia and New Zealand, yet the agriculture of these countries is based on only a handful of species. Similarly, the exotic forest plantations of New Zealand and southern South America are dominated by a single species, *Pinus radiata*. Furthermore, some estimate of economic benefit can be predicted for agricultural/forestry systems assuming a certain level of uptake, or deleterious effects assuming a certain level of spread as a pest. In contrast, there is no adequate ecological theory to underpin predictions of the future impact of potential environmental weeds. There is great difficulty therefore, in predicting both the positive and negative effects of new introductions.

Despite the apparent theoretical impasse in the prediction of pest status, the task must be undertaken because of the consequences of not detecting potential new pests at the border, of benign species becoming pests, or of the spread of existing pests. 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). A few systems are used by national risk assessment authorities for use as quarantine tools, i.e. the United States Department of Agriculture (Lehtonen, 2001) and the Australian Quarantine Inspection Service (AQIS) (Pheloung *et al.*,1999). A common failing of these systems, is that they do not calculate the probability of the realisation of a predicted impact. Such predictions can be made only with large sample sizes of all individual cases in a class. They would require large databases of known plant histories. In New Zealand for example, where the total number of exotic species is known, the probability of a species naturalizing – the first step to having an impact – has been calculated for all families and genera. These data can be incorporated in weed-risk assessments.

Weed-risk assessment systems have limitations, but their widespread use will encourage the international recognition of weed-risk assessment as a discipline.

Risk assessment systems operating at the border of an area to detect quarantine pests not yet established there, and those assessing established pests, have potential fundamental differences related to managing the risk. Managing newly detected quarantine pests may mean simply prohibiting the entry of the species. There may be costs in doing so, related, for example, to loss of profits from the sale of a shipment of seed containing the pest, or a potential new agricultural crop foregone because of the potential pest status of the species. However, for any additional species undergoing weed-risk assessment there will be relatively little cost to the administrating authorities unless it involves monitoring a new pathway. In contrast, the outcome of a risk assessment identifying an entirely new pest within an area may require substantial management expenditure to extirpate the infestation. Unless additional funds are available to do this, they will need to be reallocated from elsewhere, usually from other pest control efforts. Thus there is a need to determine the potential impacts **relative** to those of existing pests. Internal weed-risk assessment systems therefore have **priority** of management and expenditure as an important component of their process.

5. Procedures for quarantine weed-risk assessment

5.1 The Australian WRA system

The weed-risk assessment (WRA) system (Pheloung *et al.*, 1999)[8] was developed in Australia and is the most widely known and applied border weed-risk assessment system encompassing all plant groups. The central "argument" is that if a species has had the opportunity to become a weed in another country, and it has done so, then it should be classed as a weed, provided, that is, the climate and environment are compatible with the new country (they are assumed to be so if there is no information). While this argument is essentially circular – it is a weed elsewhere, therefore it will become one here – a history of weediness elsewhere has reliably predicted weediness in several studies (Scott & Panetta, 1993; Reichard & Hamilton, 1997; Williamson, 1998; Maillet & Lopez-Garcia, 2000). The WRA system was tested in Hawaii where it was found to be the most successful of those compared (Daehler & Carino, 2000). Until such time as weed-risk theory can contribute greater precision to the practice of weed-risk assessment, the WRA system is a suitable tool for use as a quarantine tool in developing countries. This argument is further reinforced by the imperatives of these countries to protect productive lands of one sort or another from weeds likely to arrive from developed countries (or via their neighbours) in trade goods, e.g. grass seed for sowing, or as a result of aid projects, e.g. re-vegetation schemes fostering legume shrubs. Because the actual or potential weediness of such species is commonly recognized in the developed countries where these goods or schemes originate, the central argument of weed history will be a powerful one in identifying quarantine pests in the developing countries. Ironically, the reverse is increasingly not the case. For example, in the last 20 years, 70 plant species have naturalized in New Zealand that are not known in the wild in any other country outside their native range. These were introduced mostly for urban horticulture and they come mostly from developing countries where their potential weediness has not been realized, e.g. *Cotoneaster* spp. from China.

The WRA produces a score for weediness and converts this into an entry recommendation for a specified taxon. It also satisfies several other requirements of an acceptable biosecurity assessment system (Hazard, 1988; Panetta, 1993). It can be calibrated and validated against a large number of taxa already present in the recipient country. These should represent the full spectrum of taxa likely to be encountered as imports into that country. It has some success in discriminating between weeds and non-

[8] The acronym WRA applies exclusively to the system described by Pheloung *et al.* (1999) and in Appendices 2–4, whereas the term weed-risk assessment is used in a generic sense to cover all aspects of the topic.

weeds, such that the majority of weeds are not accepted, non-weeds are not rejected, and the proportion of taxa requiring further evaluation is kept to a minimum. The system also identifies which major land use system the taxon is likely to invade. This aids an economic evaluation of its potential impacts. In this respect it appears to be more successful at identifying agricultural weeds than environmental weeds. The WRA attempts to separate economic plants from those unlikely to have any economic benefit in a new country. However, where a taxon may have significant economic benefits, economic value should be scored in a transparently separate exercise and balanced against weediness in appropriate risk assessment evaluations (Walton & Parnell, 1996).

The WRA is not obligatorily computer based, but when operated on a computer it becomes interactive. This allows assessors to measure the influence of different attribute values on the scores generated. Finally, the system has proved to be cost effective to prospective importers and to border control authorities in Australia and New Zealand

Permitted list approach

The process which the WRA operates as described here is based on the concept of a Permitted List of plant species (or defined taxa). This system is used by quarantine authorities in Australia (Walton, 2001) and New Zealand. The underlying concept is that if a species, or any subspecific taxon, with the potential to be a pest in an area is not on a list of taxa permitted to be in that area, then it will be **prohibited** until it has undergone pest categorization (Figure 5). Many countries, for example the United States of America, have lists of quarantine species, but they do not have permitted lists. They do not determine if every species new to a country should be on either list. One advantage of the involvement of a permitted list is that it automatically triggers a pest risk analysis in circumstances where there might otherwise not have been an analysis.

There are three stages to the prohibited list approach (Walton, 2001):

Tier 1

The first task is to identify a taxon correctly and determine whether it is listed as **prohibited** or **permitted**. This requires checking its species, genus and family names, and whether there are synonyms. The next step is to check its presence in the country, either in cultivation only or in the wild. If a species is neither **permitted** nor **prohibited**, its spread within the area and whether or not it is under official control have to be determined. The kinds of information necessary to determine this are given in Appendix 1.

In some cases, the gathering of information on its status in the area may reveal both its presence, and sufficient evidence to justify an internal pest risk analysis. The outcome may result in the taxon being subjected to official control. Those with limited spread would automatically go on the prohibited list. Data should be entered into appropriate databases at all stages, e.g. Appendix 1.

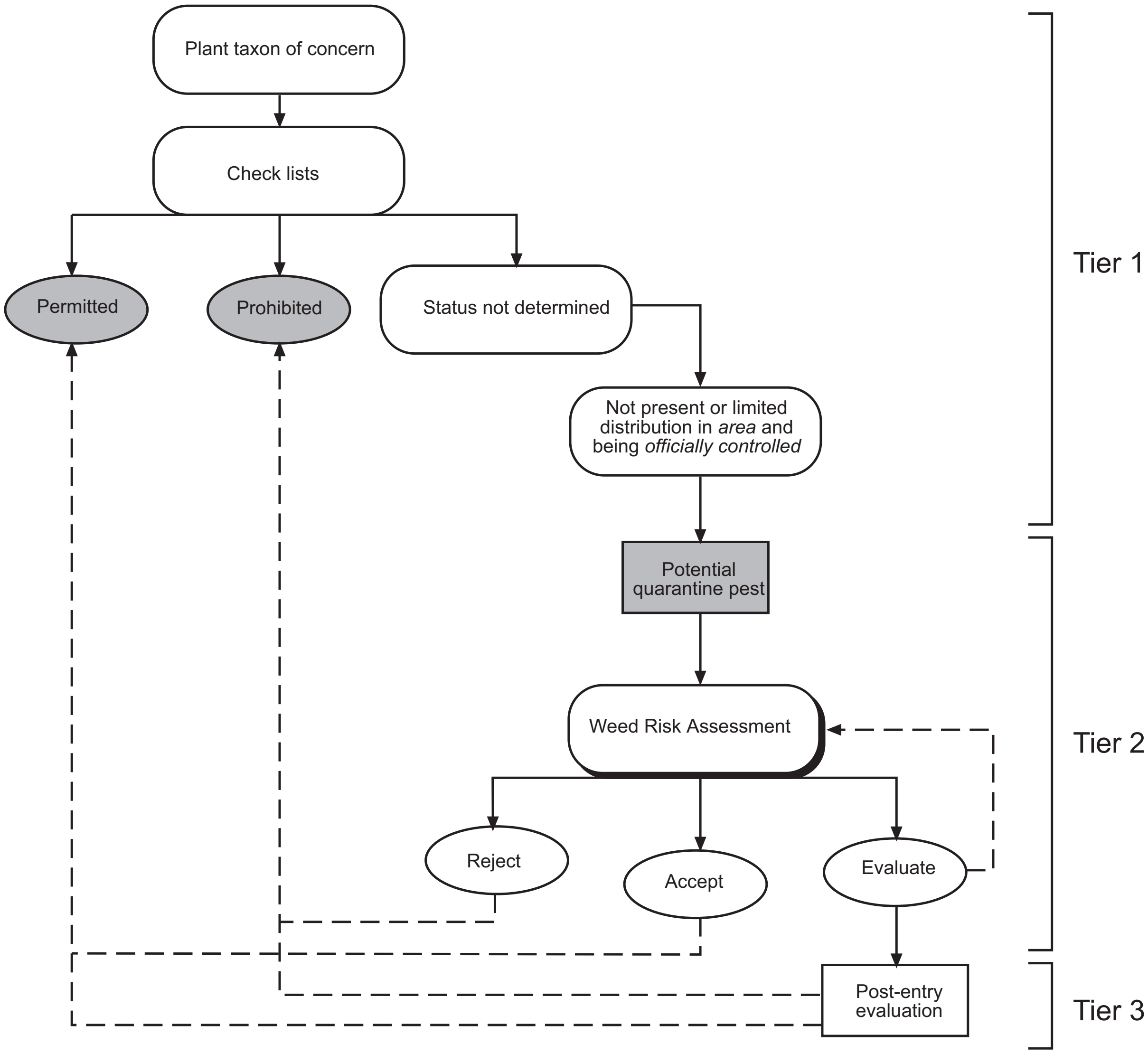

Figure 5 A flowchart for screening plant introductions incorporating the permitted list approach (from Panetta *et al.*,1994).

Tier 2

Once a taxon has been classified as a potential quarantine pest, it undergoes a weed-risk assessment. This involves the WRA system, which recommends a species be **rejected, accepted** or undergo **further evaluation**. Rejected or accepted species are added to the prohibited and permitted lists, respectively. Otherwise, further evaluation may be required if the importer wishes to proceed.

Tier 3

A classification of accept or reject cannot always be obtained from the second tier after the gathering of further information. It may then be appropriate to conduct field or glasshouse trials to further evaluate a species. These would need to be conducted in a secure environment from which the species could not escape via wind-blown seed, for example, or “hide” in persistent seed banks. Whether the prospective importer considers this additional effort is warranted may depend on the potential gains from the plant species.

5.1 WRA operation

The WRA is based on the answers to 49 questions covering a range of weedy attributes in order to screen for taxa that are likely to become weeds of the environment and/or agriculture. The questions are divided into three sections producing identifiable scores that contribute to the total score (Appendix 3).

Biogeography (Section A) encompasses the documented distribution, climate preferences, history of cultivation and weediness of a plant taxon elsewhere in the world, i.e. apart from the proposed recipient country. Weediness elsewhere is a good predictor of a taxon becoming a weed in new areas with similar environmental conditions. The question concerning the history of cultivation recognizes the important human component of propagule pressure. Such data are obviously never available for the proposed new country. Global distribution and climate preferences, where these are available, are used to predict a potential distribution in the recipient country.

Undesirable attributes (Section B) are characteristics such as toxic fruits and palatability to stock, or invasive behaviour, such as a climbing or smothering growth habit, or the ability to survive in dense shade.

Biology/ecology (Section C) are those attributes that enable a taxon to reproduce, spread and persist, such as whether the plant is wind dispersed or animal dispersed, and whether the seeds would survive passage through an animal's gut.

Availability of information is often limited for new species, and the score system recognizes that a minimum of information is required to provide a score and recommendation. The WRA system requires the answers to two questions in Section A, two in Section B and six in Section C before it will give an evaluation and recommendation. The recommendation can be compared with the number of questions answered as an indication of its reliability. This improves as more questions are answered.

Answers to the questions provide a potential total score ranging from -14 (benign taxa) to 29 (maximum weediness) for each taxon. The total score is partitioned between answers to questions considered to relate primarily to agriculture, to the environment, or common to both (Appendix 3). The total scores are converted to one of the three possible recommendations by two critical score settings. The lower critical score (0) separates **acceptable** taxa from those requiring **evaluation**, and the higher critical score (6) separates taxa requiring **evaluation** from those that should be **rejected**. Evaluation could mean either obtaining more data and re-running the model, or undertaking further investigations such as field trials.

The questions within the WRA would ideally be changed slightly for each significantly different area. They need to take into account regional differences in soils and climate. This was done in adopting the model for New Zealand. The critical settings to alter the likelihood of a species being accepted or rejected may be adjusted according to a different level of acceptable risk. This would require testing the new settings against a large number of species in the area.

All details on using the WRA are available on line at the Australian Quarantine Inspection Service site (http://www.affa.gov.au), or from the author.

6. Procedures for internal weed-risk assessment

6.1 Choice of a system

The objectives in characterizing potential quarantine pests are relatively straightforward because species are uniformly at their migration phase (Figure 3). In contrast, the objectives and information requirements of an internal weed-risk assessment system change as the species spreads. Decisions are made at an increasingly local level. Politics and economics may enter increasingly into the analysis as beneficiaries of control become identifiable and competition for resources between sectors increases (Panetta *et al*., 2001). These latter issues are not dealt with exhaustively here, but see Wainger and King (2001). The selection of internal weed-risk assessment systems must therefore consider the spread stage(s) of all pests being compared, impacts on the systems they affect, the likely benefits (and beneficiaries) of control efforts and the quality of the available information. These factors vary widely within countries and between countries. There are numerous internal weed-risk systems in use. Often several are in use simultaneously within one country, even at a national level.

A sound and practicable system for application at a local level is that of Randall (2000). More precise and ecologically defensible systems focus on specific biomes, such as the shrub lands of South Africa (Tucker & Richardson, 1995) or aquatic weeds (Champion & Clayton, 2001). Aquatic systems are almost a class on their own and authorities should be circumspect about any new wetland species. Overall, generalized systems are probably required first in most countries. Besides, the detailed relationship between species attributes and the environment that make biome-specific systems effective is poorly understood for most biomes.

Table 1 The main systems used primarily for internal weed-risk assessment and prioritizing.

Author(s)	Approach
Champion & Clayton, 2001	Scores for plants ecology, biology and weediness of aquatic weeds
Esler *et al.*, 1993	Sums scores for ability to succeed with a score for weediness
Hierbert, 1997	Weighs relative impact against ease of control and cost of delay
Randall, 2000	Scores for invasiveness/impacts/potential distribution/invasion stage
Tucker & Richardson, 1995	Models attributes of species and matches them with environment
Timmins & Owen, 2001	Explicit weed-led approach cf. site-led. Considers value of area potentially impacted
Virtue *et al.*, 2001	Multiplies scores for invasiveness, impacts and distribution (current and potential)
Wainger & King, 2001	Relates likelihood of damage/defined functions of landscape/ and the scale of threat to appropriate response

A single, widely applicable system cannot be recommended until the objectives of the internal weed-risk assessment system are determined. Countries establishing weed-risk assessment systems at the national level should ensure that the data collected are applicable to a range of spread stages and spatial scales of weed control. National resources for assessment made available by central government should be allocated where the long-term benefits will be greatest. This means first a border screening system, followed by a system for prioritizing species in the early establishment or expansion phases, and only then to species that have consolidated their spread (Figure 3). For this last group, the detailed system of Virtue *et al.* (2001) at a national level could be improved only with considerable effort, but would need to be adapted to the area concerned.

6.2 Factors to consider

This section describes the factors to consider, the kinds of information needed and likely to be available at different spread stages, and the process of determining what kind of weed-risk assessment system is required for particular sets of circumstances. Many of these considerations are relevant at a range of scales, from a single property to a whole country, and they are always constrained by the total resources for pest control within the particular area.

Weed history of congeners

Weed-risk assessment systems developed for the border, e.g. the WRA, usually consider the weediness of an assessed species' relatives as indicators of potential pest status. This factor has seldom been considered as a risk component of systems designed for species at the earliest spread stages. Exceptions are where this association is implied by the group of species being ranked, e.g. pines (Tucker & Richardson, 1995). The behaviour of species relatives (e.g. family, genus) at several levels of taxonomic grouping may usefully be incorporated in internal weed-risk assessments. This applies particularly to species at their earliest invasion stages where, in the absence of much other information, it may contribute to a stated probability of a successful invasion. Weediness is concentrated within certain genera in some families and widely dispersed among many genera in others. Whether these probability estimates can be made at the family level or sub-family level depends on the size of the plant family and genera. Many genera are too small to give statistically reliable ratios.

Weed-led and site-led control

There is a tendency to control only those familiar species that have traditionally been controlled. This inertia demands a prioritizing system that reallocates resources away from individual species that have become uncontrollable at a defined scale, to those that are potentially controllable at the same scale. Once attempts to extirpate a species or reduce it to below a defined population density over the entirety of a defined area (species-led control) have failed, then it should be controlled only in specific high value places within the area (site-led control). The concept was developed for conservation weeds in New Zealand (Williams, 1997) and the application of this principle to crown owned conservation land is explained by Timmins & Owen (2001). It is relevant to a range of systems, including agricultural systems, and can be used in prioritizing pests to be controlled at a national level.

Invasion stage
Some estimate of a species' stage of infestation, or its surrogate, is required to determine the practicality of control. A clue to spread rate may be indicated by resident time within the area, if this is known, compared with the present distribution. However, unless a plant species is already listed as an unwanted organism for a specific area, often only range expansion (Figure 3) prompts the realisation of a new potential pest. By this stage, most newly recognized pests are well established and spreading. Where historical distributions are unknown, the simplest approach to the infestation stage that avoids the difficult interpretative question of spread rate is to ask how well the species is established, i.e. the present number, size and distribution of infestations. This also relates most closely to potential control of the species – those spreading rapidly will usually be well established with many loci, and will be more costly to control if widespread. These factors of range and expansion rate need to be considered within the context of the species' regeneration time. A species does not necessarily spread to the most favourable or potentially damaging habitats first. Consideration needs to be given to the more favourable habitats and/or more vulnerable land uses it might encounter as it spreads.

Pre-requisites for pest extirpation
Systems to determine whether the species is a candidate for weed-led or site-led control need to result in a yes or no outcome. Predictions of management outcomes may be more reliable than those concerning more complex ecosystem and economic interactions; "can it be killed?" is easier to answer than "will it affect biodiversity?" or "what economic impact will it have?". Even for well-established serious weeds, particularly of natural systems, the most meaningful trigger for the management may also be determined primarily by the cost and efficacy of control measures (Panetta & James, 1999).

Species extermination has seldom been achieved over areas of greater than a few hectares anywhere in the world. Irrespective of the area covered or the perceived impacts a pest may be having, there are critical questions for preventing, selecting and determining the level of management:

- Can all individuals of the species be located;
- are practicable control measures available;
- can all individuals be targeted within a defined time period dictated by the plant's life-cycle;
- are the plant's responses to control known; and
- are resources to treat new plants, at least as fast as they appear, available to undertake follow- up work?

Those with "yes" answers to these questions are higher priority for weed-led control than those with "no " answers. Information on several aspects of a species is necessary to answer these questions, among others.

Biological attributes
A cautionary note: a wide range of biological attributes have been used in attempts to characterize weediness and prioritize species for control. The WRA also considers these factors (Appendix 3). Most detailed biological attributes are only assumed to equate to

invasiveness, even if this is taken to mean spread, as opposed to impacts. While some very general rules relating species attributes to invasiveness are emerging, these apply to only a few groups of plants in specific habitats. These often have particular disturbance regimes, including those determined by human activities. In many natural or semi-natural systems the relative importance of various dispersal modes is unknown. For example, until the relative number of potential wind-dispersed and fleshy-fruited woody plants potentially available to colonized lowland wooded vegetation in New Zealand are known, it is uncertain certain whether the fleshy-fruited syndrome *per se* has led to the relative abundance of the latter group. Thus, attributes such as dispersal mode may be used with more integrity if used indirectly in determining management options, such as search frequency, rather than in attempting to predict invasion rates *per se*.

Ease of eradication

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, multiplied by the frequency of visits to re-treat the infestation. If a plant species has a history of weediness then it is likely to have certain identifiable attributes that make it so, e.g. persistent seed bank, and to have been the subject of control attempts elsewhere. These can help assess the difficulty of control in the new area. Where there is no history even of cultivation, or of weediness in its home region, ease of 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.

Time to detection: Detection of new infestations within one or two generations is important if the species is to be eradicated or contained within a small area. This requires that the species is recognizable as a weed at this early stage. Species cryptic in the wild, such as a short grass or a vine with inconspicuous foliage, are likely to be confused with desirable species by the moderately informed observer. They are likely to spread before they are identified as weeds. They will be more difficult to control than conspicuous species.

Reproductive capacity: The amount of viable seed and vegetative reproduction may be critical components of invasion success. However, there is less certainty about the relative importance of these factors to invasion or to ease of eradication. Species with persistent seed banks can be just as difficult to eradicate as those lacking seed banks but with vegetative reproduction. There is evidence that species with more than one reproductive system are more invasive, on average, than those with only one system. This is partly because the different strategies may enable the species to cross a wider range of barriers to invasion. As the population increases the barriers change. Species can therefore be ranked according to the number of reproductive strategies they have, without making assumptions about the relative importance of these strategies.

Dispersability: Potential for dispersal is obviously essential but the relative importance of different dispersal mechanisms should not be overstated in assessing weed-risk – most plants have a dispersal system of some sort. Wind-blown seeds are commonly blown long distances, and small seeds can be consumed and dispersed by a wider range of animals than large seeds. However, seed-size must always be considered within the context of the range of available dispersers and the potential dispersal mechanisms within the area. Passive dispersal by water, machinery, etc., and through contaminants in produce, may be more important than biological characteristics. Alternatively they may interact, e.g. small seeds are more likely to be carried by machinery than large seeds. In assessing risk from invasion, likely dispersal routes (waterways, farm tracks, randomly) also need to be considered, along with the suitability of the surrounding landscape to the species. In the early stages of invasion, an important contribution of dispersability to weediness is the ability to hide, as discussed above.

People: People's attitudes to plant species varies widely. While some species are considered a nuisance by everyone, others are useful to various sectors of the community. The outcomes of human activities involving these useful species, including recognized pests, can have an overriding influence on their spread. Attitudes to a species need to be considered, and as a rule those species favoured for one reason or another will be the most difficult to extirpate. For a species to qualify for a programme aimed at extirpating it from a defined area, the probability of re-invasions from outside sources should be nil or very low. This is often not possible for those species grown commercially that are also pests. Here it may be possible to minimize the risk to land beyond the plantings by preventing the species regenerating within the defined area. This option may apply when a decision is made that the benefit of a new species outweighs the risk, and pest-risk management procedures are put in place while the species is grown commercially.

Climate matching

The utility of climate matching to weed-risk assessment changes as a pest spreads. At the earliest stages only the broadest match between source area (native and/or adventive range) and potential range is required to consider the species a potential pest, because climate may or may not be the major barrier limiting spread. Many grasses originally from tropical Africa, for example, are now widespread in temperate regions. At the latter stages and on a local scale, climate matching is less important because the species has shown its potential to spread, and the ranking systems are required only to prioritize amongst known pests. Thus, climate matching between current and predicted range is most useful as a prioritizing tool at the intermediate stages of spread, particularly when viewed on a country scale. Climate matching requires thorough distributional data within the areas being considered. On a country-by-country basis this requires comprehensive national databases. If data were collected on a regional basis, e.g. southern South America, perhaps under the umbrella of organizations such as COSAVE Comité de Sanidad Vegetal del Cono Sur) [the South Cone Plant Protection Committee], it would have greater utility than on merely a national basis. Climate matching is a specialist activity beyond the scope of this report, but the reader is referred to Kriticos & Randall (2001) for a summary of the applicability of several software packages to this topic in Australia.

Impact

Pests have economic, ecological and or/social impacts, and the assessment method must define which of these it is attempting to assess. Reliable estimates of impact are possible only after the pest has begun to spread. Estimates of impact often involve a calculation of unit impact times a measure of the area covered. Several kinds of impact may be determined, or estimated, for one or more species, and incorporated into a scoring system (Virtue *et al.*, 2001). Impacts may be determined at a very coarse scale and equated merely with presence, e.g. a species is present in "x" number of land use systems in ”y” number of regions of a country. Much finer scales may be used, and extrapolated over the potential range of the species, e.g. a weed is sprayed at a cost of “w” dollars on “x” no. of ha. that would amount to “z” dollars over its potential range.

Species impacts elsewhere may be applicable in the new area. In the absence of history, impact has to be estimated from the attributes of the species. These will differ with the land use likely to be affected. In agricultural systems, the impact of related pests may be relevant. For conservation land however, there is no universally applicable measure of impact. Parker *et al.* (1999) proposed parameters that might eventually be quantified as: I (overall impact)= R (range) x A (abundance) x E (impact per capita).

Species vary widely in the biomass at maturity that can be generated from a single propagule (seed) or ramett (piece of stem or root). An estimate of the biomass and extent of a species can contribute to a rudimentary estimate of impact. There may be evidence of its growth rate in terms of height and area covered. They are likely to range over tens of orders of magnitude, e.g. from a single grass plant 10 cm tall by 25 cm^2 (0.002 m^3), to a typical perennial herb, 1 m^2 and 1 m tall (1 m^3), to trees 10 m tall and with crowns 10 m in diameter (1000 m^3). “E” is likely to be related to the log of the volume of a single individual plant: 1, 10, 100, 1000, 10 000. These data can be reduced to scores ranging from 1 to 5. Biomass as a surrogate measure of impact is probably modified by the species’ physical interaction with desirable vegetation. Information is generally available on whether the species co-occurs or replaces the desired vegetation. The long-term effects of weeds in either the canopy or a lower regenerative layer are mostly unknown. Intuition suggests that replacing the vegetation canopy will, in the short term, displace more species, including invertebrates, than simply occupying a sub-canopy position. This generalization may not hold, e.g. for herbaceous species increasing the effects of fire in natural systems. Similarly, impact is likely to be related to persistence at the site, whether this is via a single generation or successive generations.

6.3 Designing a scoring format

A scoring or ranking system for internal weed-risk assessments should embody all the principles of a quarantine assessment system other than the requirement to meet international obligations (unless they were likely to impact on international trade). It should be designed to produce ranks or other forms of classification. These should be based on the premise that weed management options are a function of the magnitude of risk, that the greatest benefit is achieved by controlling populations at the earliest stages of invasion, and that the score will be modified by the position of the manager to reduce the risk. It should identify the invasion stage(s) targeted and the ecosystems potentially affected. It should be no more comprehensive than is necessary to utilize the available information. Because weed control technology and resources available to manage the risk can change, these should be considered as separate modules and incorporated into the decision process.

Ranking systems in use differ in the information required to operate them, and also in their internal rules structure. The simplest systems give numerical ratings to a set of criteria. These may or may not be divided into sections, and are then summed. The questions may have equal or unequal value. The individual scores may, or may not, be modified by the answers to others (Pheloung *et al.*, 1999). The subtotals from one section may be modified by other subtotals (Owen, 1998; Randall, 2000). Aspects of the species sometimes appear twice, as in its innate ability to be a pest and the ease with which it can be controlled (Hierbert, 1997). There may or may not be default scores where questions are not answered, and points may be deducted if answers to certain questions are negative (Pheloung *et al*., 1999). Others operate via hierarchical decision trees (Reichard & Hamilton, 1997). In a completely different approach, Tucker & Richardson (1995) used an expert system where a series of questions filtered out species of high or low risk before progressing to the next question.

An internal weed-risk assessment system should confirm, more or less, the existing ranking of weeds within an area for predefined spread stage, if this has been undertaken by experts (Hiebert, 1997; Pheloung *et al*., 1999), rather than produce a reordering of priority species. In other words, the outcomes from any new system must be intuitively sound if the system is to gain acceptance and be applied. This approach then captures all knowledge of the weeds of an area and formalizes it within a system that is transparent, repeatable and applicable to newly recognized species.

The development of these systems on spreadsheets allows the component scores to be adjusted and the effects on species rankings examined.

7. Resources required for weed-risk assessment

A weed-risk assessment is primarily a "book exercise" involving the collection of all available information about a potential pest, interpreting it and making a decision. There are basically three kinds of information necessary, as well as access to the Internet for gathering it:

- The primary resource required to comply with the IPPC standards is a list of exotic plant species in the country, and whether they are under official control. To collect such information for both cultivated and wild species is a huge task and it has been achieved for very few countries. The first priority for most countries lacking this information is to restrict the list only to exotic plants under official control. Their names must be valid, and ideally there should be a voucher specimen. Once this is achieved, the task can be expanded to include wild exotic plants not under control. These tasks require the close cooperation of a range of national and regional organizations including herbaria, universities, libraries and agriculture departments.
- Books are an important source of information on plants. Those undertaking weed-risk assessments should have access to all the relevant regional flora and the numerous books on weeds of the world or of regional weed lists. A basic collection of such books is given in Appendix 4. The two most important are Holm *et al.* (1979), describing the world's worst weeds, and Huxley (1999) (these are in Appendix 4) which lists all the families, most of the genera and many of the world's species.
- On-line information sources are now critical to weed-risk assessment. These are outlined in Appendix 4. They can be used for checking identification and plant names, determining weed history and noxious status elsewhere, and investigating control methods. Email is also a critical tool for communicating with numerous experts around the world who are familiar with these resources. In many cases, they can also supply information on species not recorded in any form.

• Computer software is not critical for weed-risk assessment on a case-by-case basis but it is potentially a very important tool. It is necessary, however, if climate matching tools are to be used. Apart from this purpose, the basic software requirements are database software and, if it was decided to use the Australian WRA system, a recent of version of EXCEL.

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Appendix 1. Species validation data

Example of data required for the validation of a species presence in an *area* and its status. The data in this example are for some species in the genus *Abelia* in New Zealand (some data slightly changed).

Fields:
Genus:
Species:
Validation check for name (name checked, OK if a valid name):
Authority:
N.Z. Source (source of data confirming presence in NZ):
Synonym (genus or species may have synonym):
Common name:
Family:
Life form (tree, shrub, herb, etc.):
Distribution (e.g. parts of *area* where present):
Status (Prohibited/Permitted):

Genus	Species	Valid?	Authority	N.Z. sources
Abelia	*genus*	OK	R.Br.	MAF reference index
Abelia	*chinensis*	OK	R.Br.	CHR herbarium, Dunedin botanical garden
Abelia	*floribunda*	OK	Decne.	Sykes database, CHR herbarium, N.Z. Plant finder
Abelia	*graebneriana*	OK	Rehd.	Eastwood Hill catalogue
Abelia	*grandiflora*	OK	(Andre) Rehd.	CHR herbarium, Denes nursery, Duncans nursery
Abelia	*rupestris*	OK	Lindl.	CHR herbarium
Abelia	*schumannii*	OK	(Grabn).	CHR database, N.Z.Plant finder

Genus	Species	Synonym	Common name	Family	Life form	N.Z. distribution	Permitted
Abelia	*genus*			Caprifoliaceae	Shrub	N, S, St	Yes
Abelia	*chinensis*	Syn. *A. rupestris*		Caprifoliaceae	Shrub	N, S, St	Yes
Abelia	*floribunda*			Caprifoliaceae	Shrub	N, S.	Yes
Abelia	*graebneriana*			Caprifoliaceae	Shrub	N, A, Ch	Yes
Abelia	*grandiflora*	= *A.xgrandiflora*		Caprifoliaceae	Shrub	N.S.K	Yes
Abelia	*rupestris*	= *A.chinensis*		Caprifoliaceae	Shrub	N.S.St	Yes
Abelia	*schumannii*		Schumann's abelia	Caprifoliaceae	Shrub	N.S.K	Yes

Appendix 2. Weed-risk assessment process form

The kinds of information required to trace the history and outcomes of a weed-risk assessment. Ideally the data would be maintained on a database linked with the species validation data in Appendix 1.

Quarantine Station: ………………………. **Date submitted: …………**

Species name: Synonyms:

Common name(s): Family name:

PRA initiated by Pathway or Pest:

Nature and source of consignment:

Purpose of Consignment:

Date assessed: Assessor:

Weed-risk assessment score: Weed-risk assessment recommendation:

Economic impacts overseas:

Estimate of probability of introduction *(High, Medium, Low):*

Estimate of economic/environmental impact in area *(High, Medium, Low):*

References:

Appendix 3. The basis of the Australian Weed Risk Assessment (WRA) system to assess new plants

The following notes are from the WRA manual prepared by Craig Walton and Neil Ellis of AQIS (http://www.affa.gov.au). Only the questions and the scoring form are included here. Further detail is available at the AQIS website. The questions would need to be changed slightly to suit particular "areas".

The Weed Risk Assessment (WRA) system is a question-based scoring system. Using the system involves answering up to 49 questions on the new species. The questions include information of the plants; climatic preferences, biological attributes, reproductive and dispersal method. The system uses the responses to the questions to generate a numerical score included below (Form B, following these notes). The system uses the score to determine an outcome: accept, reject or further evaluate for the species. The system also makes a prediction as to whether a species may be a weed of agriculture or the environment.

The answer to most of the questions in the system is yes (y), no (n) or don't know (leave blank). The system translates these responses into a numerical score.

A typical score for a question is: Yes = 1 point, No = -1 or 0, and Don't Know = 0.

The Climate and Weed Elsewhere questions differ from the typical scoring system in that they generate a score using a weighting system. The score given for Questions 2.01 and 2.02 is used to weight the scores for 'yes' answers in the Weed Elsewhere questions (3.01 to 3.05). The quality of climate data greatly affects the climate match. A good climate match increases the probability that a species will behave the same way in Australia as it does overseas. The weediness score increases if the information used to produce the climate match is not comprehensive, due to the greater uncertainty introduced by these data.

Two other questions do not fit into the standard scoring system. A score of 'no' for Question 3.01, whether a plant has naturalized overseas, is modified by the score to Question 2.05, its history of repeated export. Species with repeated introductions outside of their native range that have not established are a lower risk. Question 6.07, the minimum generative time, requires the input of a numerical score. This generative time is standardized by the use of a correlation factor (1 year scores 1, 2-3 years score 0, greater than or equal to 4 years score -1).

The system compares the total score for a species to the critical values to determine the recommendation for the species. The threshold values for the system are, if the plant scores:

less than 1, accept the plant for import;
greater than 6, reject the importation of the plant and;
from 1 to 6, further evaluate the plant.

The threshold values are the product of the assessment of over 370 species. This species used for the calibration of the system ranged from severe agricultural and environmental weeds to benign and beneficial plants.

The system tallies the number of questions answered in each section. The WRA system allows for knowledge gaps, while still requiring responses to a minimum number of questions in each of its three different categories. The minimum number of questions for each section is:
2 for section A, 2 for section B and 6 for Section C.

The WRA system has some capacity to suggest the type of ecosystems likely to be affected by the plant assessed. The system indicates if the plant is more likely to be a specific weed of agriculture or the general environment, once it has assessed the plants potential to become a weed in Australia. A species may be assessed to be a weed of both categories. The partitioning helps to identify areas most at risk from the characters assessed for the species.

The Weed Risk Assessment questions are:

HISTORY/BIOGEOGRAPHY

1 Domestication/cultivation

1.01 *Is the species highly domesticated? If answer is 'no" go to Question 2.01*
The taxon must have been cultivated and subjected to substantial human selection for at least 20 generations. Domestication generally reduces the weediness of a species by breeding out noxious characteristics.

1.02 *Has the species become naturalized where grown?*
Is a domesticated plant, which has introduced from another region, growing, reproducing and maintaining itself in the area in which it is growing. A 'yes' answer to question 1.01 will be modified by the response to this question.

1.03 *Does the species have weedy races?*
Only answer this question if the species you are assessing is a sub-species, cultivar or registered variety of a domesticated species. If the taxon is a less weedy subspecies, variety or cultivar, then there must be good evidence that it does not retain the capacity to revert to a weedy form. A 'yes' answer to question 1.01 will be modified by the response to this question.

2 Climate and distribution

2.01 *Species suited to Australian climates (0-low; 1-intermediate; 2-high)*
This question applies to any one Australian climate type, or more than one. Ideally, base the climate matching on an approved computer prediction system such as CLIMEX, BIOCLIM or Climate. If no computer analysis is carried out then assign the maximum score (2).

2.02 *Quality of climate match data (0-low; 1-intermediate; 2-high)*
The score for this question is an indication of the quality of the data used to generate the climate analysis. Reliable specific data score 2, general climate references score 1, broad climate or distribution data score 0. If a computer analysis was not carried out assign the maximum score of 2.

2.03 *Broad climate suitability (environmental versatility)*
Score 'yes' for this question if the species is found to grow in a broad range of climate types. Output from the climate matching program may be used for this question. Otherwise, base the response on the natural occurrence of the species in three or more distinct climate categories. Use the map of climatic regions provided or one available in a comprehensive atlas.

2.04 *Native or naturalized in regions with extended dry periods*
The species is able to grow in areas with rainfall in the driest quarter less than 25 mm. Plants from this group may potentially grow and survive in arid Australian conditions.

2.05 *Does the species have a history of repeated introductions outside its natural range?*

This history should be well documented. A potential weed must have opportunities to show its potential. A score for Question 2.05 will modify the score for a 'no' answer to Question 3.01. Species with repeated introductions that have not established are a lower risk.

3 Weed elsewhere

3.01 *Naturalized beyond native range*

A naturalized species will be cited in flora of localities which are clearly outside of the native range. If the native range is uncertain and the known extent of the naturally growing plants is within the area of uncertainty, then the answer is 'don't know.'

3.02 *Garden/amenity/disturbance weed*

The plant is generally an intrusive weed of gardens, parklands, roadsides, quarries, etc. This question carries less weight than 3.03 or 3.04. If a plant is listed as a weed in relevant references but the type of weed is uncertain or it is a minor weed, score 'yes' for 3.02.

3.03 *Weed of agriculture/horticulture/forestry*

The plant is generally a weed of agriculture/horticulture/forestry and causes productivity losses and/or costs due to control. This question carries more weight than 3.02. If a plant is listed as a weed in relevant references but the type of weed is uncertain or it is a minor weed, score 'yes' for 3.02.

3.04 *Environmental weed*

The plant is documented to alter the structure or normal activity of a natural ecosystem. This question carries more weight than 3.02. If a plant is listed as a weed in relevant references but the type of weed is uncertain or it is a minor weed, score 'yes' for 3.02.

3.05 *Congeneric weed*

Documented evidence that one or more species, with similar biology, within the genus of the species being evaluated are weeds.

BIOLOGY/ECOLOGY

4 Undesirable traits

4.01 *Produces spines, thorns or burrs*

The plant possesses a structure on the plant known to cause fouling, discomfort or pain to animals or man. If the taxon is a thornless subspecies, variety or cultivar, then there must be good evidence that it does not retain the capacity to revert to a thorny form.

4.02 *Allelopathic*

The plant is well documented as a potential suppresser of the growth of other species by chemical (e.g. hormonal) means. Such evidence is rare throughout the whole plant kingdom.

4.03 *Parasitic*
The parasite must have a detrimental effect on the host and the potential hosts must be present in Australia. This question includes wholly and semi-parasitic plants. Such plants are rare.

4.04 *Unpalatable to grazing animals*
Consider the plant with respect to where the plant has the potential to grow and if the herbivores present could keep it under control. This trait may be found at any stage during the life-cycle of the plant and/or over periods of the growing season.

4.05 *Toxic to animals*
There must be a reasonable likelihood that the toxic agent will reach the animal, by grazing or contact. Some species are mildly toxic but very palatable and could cause problems if heavily grazed.

4.06 *Host for recognized pests and pathogens*
The main concerns are plants that are hosts of toxic pathogens and alternate or alternative hosts of crop pests and diseases. Where suitable alternative or alternate hosts are already widespread in cropping or natural systems, the answer should be 'no' unless the species will affect the current control strategies for the pathogen or pest. Apply a reasonable level of specificity; a pathogen of an entire family, such as takeall, should not be the basis for answering 'yes' for an individual species.

4.07 *Causes allergies or is otherwise toxic to humans*
This condition must be well documented and likely to occur under normal circumstances, for example, by physical contact or inhalation of pollen from the species.

4.08 *Creates a fire hazard in natural ecosystems*
This question applies to species that have a documented growth habit that leads to the rapid accumulation of fuel for fires when growing in natural or unmanaged ecosystems.

4.09 *Is a shade-tolerant plant at some stage of its life- cycle*
Shade tolerance can enhance the invasive potential of a species.

4.10 *Grows on infertile soils*
Australian soils are generally very infertile. Species that tolerate low nutrient levels could potentially grow well here. Legumes, tolerant of low soil phosphorus, are a particular concern since they would also modify the soil environment.

4.11 *Climbing or smothering growth habit*
This trait includes fast growing vines and ivies that cover and kill or suppress the growth of the supporting vegetation. Plants that rapidly produce large rosettes could also score for this question.

4.12 *Forms dense thickets*
The thickets produced should obstruct passage or access, or exclude other species. Woody perennials are the most likely candidates, but this question may include densely growing grasses.

5 Plant type

5.01 *Aquatic*

The question includes any plants normally found growing on rivers, lakes and ponds. These species have the potential to choke waterways and starve the system of light, oxygen and nutrients. Consequently, the score is high (5).

5.02 *Grass*

A large proportion of the grass family (Poaceae/Gramineae) are weeds in some context. As with congeneric weed species, there is a high probability that a species from this family will be a weed.

5.03 *Nitrogen fixing woody plant*

A large proportion of woody legumes (family Leguminosae/Fabaceae) are weeds, particularly of conservation areas. As with congeneric weed species, there is a high probability that a species from this family will be a weed.

5.04 *Geophyte*

Perennial plants with tubers, corms or bulbs. This question is specifically to deal with plants that have specialized organs and should not include plants merely with rhizomes/stolons (see 6.06). Plants from this group can be particularly difficult to eradicate from a site.

6 Reproduction

6.01 *Evidence of substantial reproductive failure in native habitat*

Predators and other factors present (e.g. disease) in the native habitat can cause substantial reductions in reproductive capacity. The reproductive output of a species may greatly increase when the plant grows in areas without these factors.

6.02 *Produces viable seed*

If the taxon is a subspecies, variety or cultivar, it must be indisputably sterile. The male plants of a dioecious species are regarded as seed producers.

6.03 *Hybridizes naturally*

A 'yes' answer for this question requires documented evidence of interspecific hybrids occurring, without assistance, under natural conditions.

6.04 *Self-fertilization*

Species capable of self-seeding can spread from seed produced by an isolated plant.

6.05 *Requires specialist pollinators*

The invasive potential of the plant is reduced if the species requires specialist-pollinating agents that are not present or rare in Australia.

6.06 *Reproduction by vegetative propagation*

The plant must be capable of increasing its numbers by vegetative means. This may include reproduction by rhizomes, stolons, or root fragments, suckers or division.

6.07 *Minimum generative time (years)*

This is the time from germination to production of viable seed, or the time taken for a vegetatively reproduced plant to duplicate itself. The shorter the time span, the weedier a plant is likely to be. The score for this trait uses the correlation factor (1 year scores 1, 2-3 years score 0, greater than or equal to 4 years score -1).

7 Dispersal mechanisms

7.01 *Propagules likely to be dispersed unintentionally*

Propagules (any structure, sexual or asexual, which serves as a means of reproduction) unintentionally dispersed resulting from human activity. An example is plants growing in heavily trafficked areas such as farm paddocks or roadsides.

7.02 *Propagules dispersed intentionally by people*

The plant has properties that make it attractive or desirable, such as an edible fruit, an ornamental or curiosity. The species is readily collected as a cutting or seed. This group includes most horticultural plants.

7.03 *Propagules likely to disperse as contaminants of produce*

Produce is the economic output from any agricultural, forestry or horticultural activity. An example is grain shipments that contain seeds of weed species.

7.04 *Propagules adapted to wind dispersal*

Documented evidence that wind significantly increases the dispersal range of the propagule. An example is an achene with a pappus. This group includes tumbling plants and plants with seeds contained within an explosive capsule or pod.

7.05 *Propagules buoyant*

This question includes any structure containing the propagule that typically becomes detached from the plant and is buoyant. An example is a pod of a legume. This is a limited method of distribution of land plants.

7.06 *Propagules bird dispersed*

Any propagule that may be transported and/or consumed by birds, and will grow after defecation. An example is small red berries with indigestible seeds.

7.07 *Propagules dispersed by other animals (externally)*

The plant has adaptations, such as burrs, and/or grows in situations that make it likely that propagules become temporarily attached to the animal. This can include the spread of plant parts on clothing. This dispersal group includes seeds with an oily or fat-rich outgrowth that aids in ant seed dispersal.

7.08 *Propagules dispersed by other animals (internally)*

The propagules are eaten by animals, dispersed and will grow after defecation.

8 Persistence attributes

8.01 *Prolific seed production*

The level of seed production must be met under natural conditions and applies only to viable seed. For grasses and annual species a rate of (>5000-10 000/m^2/yr) would be considered high, for woody annual a rate of (>1000/ m^2/yr) would be considered high. Specific data on this attribute may be unavailable; however, an estimate can be made from the seed/plant and the average size of the plant.

8.02 *Evidence that a persistent propagule bank is formed (>1 yr)*

Greater than 1% of the seed should remain viable after more than one year in the soil. This bank may include both canopy and soil seed banks. Long seed viability increases a plants invasive potential.

8.03 *Well controlled by herbicides*

Documented evidence is required for good chemical control of the plant. This control must be acceptable in the situations in which it is likely to be found. Chemical management should be safe for other desirable plants that are likely to be present. This information will be poorly documented for most non-agricultural plants.

8.04 *Tolerates or benefits from mutilation, cultivation or fire*

Plants that tolerate or benefit from such disturbance may out-compete other species. This question does not apply to seed banks.

8.05 *Effective natural enemies present in Australia*

A known, effective, natural enemy of the plant may or may not be present in Australia. The answer is 'don't know' unless a specific enemy/enemies are known.

Form B. Weed Risk Assessment Scoring Sheet

	a	b	c	d	e
Section	Question	Response[1]	Score[2]	N score	Y score
A C	1.01			0	-3
C	1.02			-1	1
C	1.03			-1	1
	2.01		The response for these questions is 2 unless a climate analysis is done		
	2.02				
C	2.03			0	1
C	2.04			0	1
	2.05				
C	3.01			Refer to lookup table	
E	3.02				
A	3.03				
E	3.04				
C	3.05				
B C	4.01			0	1
C	4.02			0	1
C	4.03			0	1
A	4.04			-1	1
C	4.05			0	1
C	4.06			0	1
C	4.07			0	1
E	4.08			0	1
E	4.09			0	1
E	4.10			0	1
E	4.11			0	1
C	4.12			0	1
C E	5.01			0	5
C	5.02			0	1
E	5.03			0	1
C	5.04			0	1
C	6.01			0	1
C	6.02			-1	1
A	6.03			-1	1
C	6.04			-1	1
C	6.05			0	-1
A	6.06			-1	1
C	6.07				
A	7.01			-1	1
C	7.02			-1	1
A	7.03			-1	1
C	7.04			-1	1
E	7.05			-1	1
E	7.06			-1	1
C	7.07			-1	1
C	7.08			-1	1
C	8.01			-1	1
C	8.02			-1	1
A	8.03			1	-1
A	8.04			-1	1
C	8.05			1	-1
	Total score [3]				
	Outcome [4]				
	Agricultural score[6]				
	Environmental [6]				

Lookup table for section 3.

Locate value of inputs and lookup output for each question

	Yes to questions 3.01 - 3.05									**default**
Inputs	2.01	0	0	0	1	1	1	2	2	**2**
	2.02	0	1	2	0	1	2	0	1	**2**
Results	3.01	2	1	1	2	2	1	2	2	**2**
	3.02	2	1	1	2	2	1	2	2	**2**
	3.03	3	2	1	4	3	2	4	4	**4**
	3.04	3	2	1	4	3	2	4	4	**4**
	3.05	2	1	1	2	2	1	2	2	**2**
	No to questions 3.01 - 3.05									
Input	2.05	?	N	Y						
Results	3.01	-1	0	-2						
	3.02-3.05	0	0	0						

Procedure

1 Record appropriate responses in column b.
2 Look up score in columns d & e and record result in column c.
3 Calculate total score.
4 Lookup and record recommendation.
5 Verify that minimum number of questions from each section are answered.
6 Compute Agricultural (A&C) and Environmental (E&C) scores: if either score is less than 1, the outcome pertains to the other sector.

Lookup table for 6.07			
years	1	2	4
score	1	0	-1

Score	Outcome
< 1	Accept
1-6	Evaluate
> 6	Reject
Section	Minimum # questions[5]
A	2
B	2
C	6
Total	10

Appendix 4. Information resources for weed-risk assessment

Core set of books for weed-risk assessment

Häflinger E.& J. Brun.1968. CIBA-GEIGY weed tables. A synoptic presentation of the flora accompanying agricultural crops, 41 parts. CIBA-GEIGY Agro-Chemical Division, Basle.

Holm L., J.V. Pancho, J.P Herberger & D.L. Plucknett D.L. 1979. A Geographic Atlas of World Weeds. John Wiley and Sons, New York.

Holm L., D.L. Plucknett, J.V. Pancho & J.P. Herberger. 1991. The World's Worst Weeds. Kreiger, Malabar, Florida.

Huxley A. 1999. The New Royal Horticultural Society Dictionary of Gardening. MacMillan Reference, London (Paperback Edition). [The Index to this dictionary is also available at lower cost and summarizes the key information.]

Mabberley D.J. 2000. The Plant Book. Cambridge University Press, Cambridge.

Parsons W.T. & E.G. Cuthbertson., E. 2001. Noxious weeds of Australia. 2nd edition. CSIRO Publishing. Collingwood.

Wells M.J., A.A. Balsinhas, H. Joffe, V.M. Engelbrecht, G. Harding & C.H. Stirton. 1986. Catalogue of problem plants in southern Africa incorporating the national weed list of South Africa. Special publication of the Botanical Research Institute, Capetown.

On-line resources

Note: In most cases only the home pages to the host organizations are given because of the rapid changes that frequently occur within websites.

Libraries

- AGRICultural OnLine Access (http://www.nal.usda.gov). Index of agricultural articles going back to 1970. (Also available on CD-ROM).
- Commonwealth Agricultural Bureaux International (CABI)(http://www.cabi-publishing.org). Index of agricultural articles but available only to subscribing organizations. (Also available on CD-ROM).

Herbaria with (some) collection data online

Many herbaria are trying to index their whole collections and put the result online. However, online data at this time usually consist only of type specimens or lists of names. These can be useful in verifying a plant identification or name.

- Harvard Herbaria Databases (http://www.huh.harvard.edu/databases/). Searchable for American type specimens.
- USDA PLANTS National Database (http://plants.usda.gov/). Distribution in the USA by State links to many other USA sites.
- Flora of Texas Consortium (http://www.csdl.tamu.edu/). Specimen data from university herbaria in Texas.

- PERTHherbarium (http://florabase.calm.wa.gov.au). Database of names accessible with free registration; other information including all specimen details available for a price.
- Australian National Botanic Garden (http://www.anbg.gov.au).Canberra Botanic Garden herbarium and live collection searchable by gopher.
- Catalogue of Type Specimens of the Dutch Herbaria (http://www.nationaalherbarium.nl/rhb). Type material held at several herbaria (AMD, L, U and WAG).
- Catalogue of Type Specimens in the Ottowa Herbarium (DAO) (http://sis.agr.gc.ca)
- Linnean Herbarium at the Swedish Museum (http://linnaeus.nrm.se). Images of some of Linnaeus's type specimens.
- Kew Databases (http://www.rbgkew.org.uk). This page has potential but is not yet in full production.
- Smithsonian Institution botany databases (http://www.mnh.si.edu). Type specimen holdings.

Checklists of plant names and taxonomic issues

- Index Nominum Genericorum (http://rathbun.si.edu). Searchable index of all published names of plant genera.
- Flowering Plants Gateway (http://www.csdl.tamu.edu). Index to pages dealing with alternative systems of classification of families and genera.
- Census of Plants in Australian Botanic Gardens (http://www.anbg.gov.au). An unsorted compilation of each botanical garden's inventories.
- Flora of China checklists (http://www.mobot.mobot.org). Held at Missouri Botanic gardens, USA.
- Flora of New Zealand (http://nzflora.landcare.cri.nz). Held at Landcare Research, Lincoln.
- IUCN Red List (http://www.wcmc.org.uk/species/plants/overview.htm). A weed in one country may be a threatened species in another.
- The families of flowering plants (http://biodiversity uno edu/delta/angio) Lists and descriptions of all families of flowering plants.
- Grass genera of the world (http://biodiversity.uno.edu/delta/grass). Lists and descriptions of all grass genera.

Lists of pest plants

- USDA APHIS Pest Plant Lists (http://www.aphis.usda.gov). Home page of the United States Department of Agriculture Animal and Plant Health Inspection Service, Declared noxious plants of the United States.
- Weeds Australia Database (http://www.weeds.org.au/noxious.htm). Lists of noxious weeds for each Australian State.

Contact details of plant taxonomists

- Plant Taxonomists Online (http://waffle.nal.usda.gov). Plant taxonomists, their email and postal addresses, and areas of expertise.
- Index Herbariorum (http://www.nybg.org). Searchable database of herbaria and their personnel with contact information.

Herbicide resistance

- International Survey of Herbicide-Resistant Weeds (http://www.weedscience.org). Ian Heap's lists of herbicide-resistant weeds; frequently updated.

Weed pages

- Weed Science Group, Agriculture WA (http://www.agric.wa.gov.au). One of the best sites available, and it includes a large and frequently updated list of links.
- USDA APHIS Noxious Weeds Home Page (http://plants.usda.gov). Lists of all noxious plants in USA by state.
- Weeds in New Zealand (http://www.boprc.govt.nz). A guide to weeds in one major region of New Zealand.
- Invasive Woody Plants in the Tropics (http://www.bangor.ac.uk). An overview of woody weeds in the tropics.
- The Nature Conservancy Wildland Weeds (http://tncweeds.ucdavis.edu).
- FAO weed page: http://www.fao.org/ag/AGp/agpp/IPM/Weeds
- Hawaiian Ecosystems at Risk project (HEAR) (http://www.hear.org). Weeds of Hawaii, and the host page for the Weed Risk Assessment Workshop. This site also has access to the largest weed list database in the world, some 22600 species compiled by Rod Randall of the Western Australia Department of Agriculture.
- Florida Exotic Pest Plant Council (http://www.fleppc.org/). One of the best USA weed sites.

The weed-risk assessment system

- AQIS Weed risk assessment (http://www.affa.gov.au). The background and scoring system of the Australian quarantine inspection service system.
- APHIS weed risk assessment system (http://www.aphis.usda.gov). The weed risk analysis system used by the United States Department of Agriculture.
- 1st International Weed Risk Assessment Workshop (http://www.hear.org). The official website of the workshop with outcomes and papers from the workshop.

International Organizations and Conventions

- International Plant Protection Convention (http://www.ippc.int).
- Food and Agriculture Organization of the United Nations (FAO) (http://www.fao.org).The Secretariat of the IPPC.

Appendix 5. Phytosanitary terms and definitions used

Definitions given here are from FAO, 2001a: International Standards for Phytosanitary Measures, Glossary of phytosanitary terms. *Publication No. 5.* Rome, Secretariat of the International Plant Convention of Food and Agriculture Organization of the United Nations (FAO)[9]. The origins of these definitions are in FAO, 2001a.

area	An **official** defined country, part of a country or all or parts of several countries.
bulbs and tubers	A **commodity class** for dormant underground parts of **plants** intended for **planting** (includes corms and rhizomes)
commodity class	A category of similar commodities that can be considered together in phytosanitary regulations
containment	Application of **phytosanitary measures** in and around an infected **area** to prevent **spread** of a **pest**
control (of a **pest**)	**Suppression, containment,** or **eradication** of a **pest** population
ecosystem	A complex of **organisms** and their environment, interacting as a defined ecological unit (natural or modified by human activity, e.g., agro ecosystem), irrespective of political boundaries
entry (of a **pest**)	Movement of a **pest** into an **area** where it is not yet present, or present but not widely distributed and being **officially controlled**
germplasm	**Plants** intended for use in breeding or conservation programmes
grain	A commodity class for **seeds** intended for processing or consumption and not for **planting**
International Plant Protection Convention	International Plant Protection Convention, as deposited with FAO in Rome in 1951 and subsequently amended
IPPC	**International Plant Protection Convention,** as deposited in 1951 with FAO in Rome and subsequently amended

[9] All definitions in **bold type** not defined here are to be found in the Glossary for phytosanitary terms itself.

micro-organisms	A protozoan, fungus, bacterium, virus or other microscopic self-replicating biotic entity
National Plant Protection Organization	**Official** service established by a government to discharge the functions specified by **IPPC**
official	Established, authorized or performed by a **National Plant Protection Organization**
official control	The active enforcement of mandatory **phytosanitary regulations** and the application of **phytosanitary procedures** with the objective of **eradication** or **containment** of **quarantine pests** or for the management of **regulated non-quarantine** pests
organism	Biotic entity capable of reproduction or replication, vertebrate or invertebrate animals, **plants** and micro-organisms
pathway	Any means that allows the **entry** or **spread** of a **pest**
pest	Any species, strain or biotype of plant, animal or pathogenic agent injurious to **plants** or **plant products**
Pest Risk Analysis	The process of evaluating biological or other scientific and economic evidence to determine whether a **pest** should be regulated and the strength of any **phytosanitary measures** to be taken against it
phytosanitary measure	Any **legislation, regulation** or **official procedure** having the purpose to prevent the **introduction** and/or **spread** of **pests**
plant products	**Unmanufactured material** of plant origin (including **grain**) and those manufactured products that by their nature or that of their processing, may create a risk for the **introduction** and **spread** of **pests**
plants	Living plants and parts thereof, including **seeds** and **germplasm**
quarantine pest	A **pest** of potential economic importance to the **area endangered** thereby and not yet present there, or present but not widely distributed and being **officially controlled**

seeds A **commodity class** for seeds for **planting** or intended for planting and not for consumption or processing (see **grain**)

spread Expansion of the geographical distribution of a **pest** within an **area**

suppression The application of **phytosanitary measures** in an infested **area** to reduce **pest** populations

CONCLUSIONS AND RECOMMENDATIONS

1. The meeting on weed risk assessment understood that each country must have technical information and/or a data base on various aspects of exotic plants, that may potentially become weeds in their countries. The major elements for such an assessment should be:

(i) Origin of Plants

(ii) Weediness

- History of weediness
- Impacts

(iii) Pathways (accidental, intentional)

(iv) Likelihood of Establishment and Spread

(v) Biological Characteristics

2. There is a need for guidelines for weed risk assessment. The draft prepared by Dr. Peter Williams from New Zealand should be revised. It should have the following basic framework:

(i). Sufficient Legal Authority

(ii) Sufficient Infrastructure and Expertise (Capacity)

(iii) National Flora List

3. These guidelines should be used to assess all plant introductions (on purpose and accidental) determining which weed species to be regulated.

4. In addition, FAO in partnership with other relevant international and regional agencies and institutions should promote and organize various other follow-up activities as a support to the implementation of WRA guidelines, such as:

(i) Educational programme for strengthening WRA capacity in developing countries (regional courses in Africa (French-English), Asia, Latin America, Mediterranean and Middle East).

(ii) Develop web-based information system and printed literature to assist in conducting WRAs.

(iii) Develop national early warning and rapid response systems for detection, assessment and eradication of incipient (new) invasive plants.

(iv) Develop international system for monitoring electronic commerce in invasive plants.

(v) Develop an internal WRA process for determining management priorities within a particular land unit.

(vi) Implement a national awareness campaign to help raise public awareness and support of WRA and early warning efforts.

LIST OF PARTICIPANTS

Dr. Cesar Fernandez-Quintanilla
Centro de Ciencias Medioambientales
CSIC, Serrano 115 dpdo
28006 Madrid, Spain
Phone: +34 91 745 25 00 (ext. 210)
Fax: + 34 91 564 0800
E mail: cesar@ccma.csic.es

Mrs. Dantsey-Barry Hadyatou
Spécialiste
ITRA/CRAL, BP 1163 Lomé, Togo
Phone: +228 225 21 48
E mail : hadyabarry@yahoo.fr

Dr. Shunji Kurokawa
Crop Production & Physiology Lab.
Department of Forage Production
National Institute of Livestock and
Grassland Science
National Agricultural Research Organization
Japan
Phone: +81 287 37 7802
Fax: +81 287 36 6629
E mail: shunji@affrc.go.jp

Dr. Jacques Maillet
Directeur adjoint
Ecole nationale supérieure agronomique de
Montpellier
Place Viala
34060 Montpellier cedex, France
Phone: +31 4 99 61 24 58
Fax: +31 4 99 61 29 00
E mail: maillet@ensam.inra.fr

Ing. Jorge Vicente Padrón Soroa
Especialista
Centro Nacional de Sanidad Vegetal
Calle Ayuntamiento # 231 e/San Pedro y
Lombillo,
C. Habana, Cuba
E.Mail: cnsv@ceniai.inf.cu

Dr. Franklin Dane Panetta
Principal Scientist/Professional Leader
Alan Fletcher Research Station
Department of Natural Resources and Mines
& CRC for Australian Weed Management
PO Box 36 Sherwood, Queensland 4075
Australia
Phone: +61 7 3375 0735
Fax: + 61 7 3379 6815
E mail: dane.panetta@nrm.qld.gov.au

Mr. Chris Parker
Flat 45, Royal York Crescent
Bristol BS8 4JZ, United Kingdom
Phone: + 44 272 739680
E mail: chrisparker5@compuserve.com

Dr. Randy G. Westbrooks
Invasive Plant Coordinator
U.S. Geological Survey
Biological Resources Division
Office of the Invasive Plant Coordinator
233 Border Belt Drive
Whiteville, North Carolina 28472, USA
E mail: rwestbrooks@intrstar.net

Dr. Peter A.Williams
Landcare Research
Private bag 6
Nelson, New Zealand.
Phone: + 64 3 545 7715
Fax + 64 3 546 8590
Email WilliamsP@Landcare.cri.nz

Dr. Carlos Zaragoza Larios
Unidad de Sanidad Vegetal
Servicio de Investigación Agroalimentaria
Diputación General de Aragón
Avda/ Montañana 930
50016 Zaragoza, Spain
Phone: +34 976 716322
Fax: +34 976 716335
E-mail: carza@aragob.es

FAO
Dr. Ricardo Labrada Romero
FAO Weed Officer
Viale delle Terme di Caracalla
00100 Rome, Italy
Phone: + 39 06 57054079
Fax: +39 06 57056227
E mail : Ricardo.Labrada@FAO.org

Observers
Dr. Mariano Muñiz
Centro de Ciencias Medioambientales
CSIC, Serrano 115 dpdo
28006 Madrid, Spain
Fax: +34 91 564 0800

Dr. Ricardo Gonzales Ponce
Centro de Ciencias Medioambientales
CSIC, Serrano 115 dpdo
28006 Madrid, Spain
Fax: + 34 91 564 0800

Ms Judit Barroso Perez
Ph.D Student
Centro de Ciencias Medioambientales
CSIC, Serrano 115 dpdo
28006 Madrid, Spain
Fax: +34 91 564 0800

Mr. Jaime Chao
Student
Centro de Ciencias Medioambientales
CSIC, Serrano 115 dpdo
28006 Madrid, Spain
Fax: +34 91 564 0800

Expert Consultation on Weed Risk Assessment
11-13 June 2002
Consejo Superior de Investigaciones Científicas (CSIC), Madrid, Spain

PROGRAMME OF THE WORKSHOP

Monday 10 June

Arrival of participants

Tuesday 11 June, morning session

Opening of the meeting

Introduction to the meeting: the work of FAO on matters related to pest risk assessment. *Dr Ricardo Labrada, FAO*

Brief description of the work on weed management by Centro de Ciencias Medioambientales, Madrid, Spain. *Dr Cesar Fernández Quintanilla (CSIC)*

Problems of introduced weeds in West Africa. *Mrs Dantsey-Barry Hadyatou,ITRA/CRAL, Lomé, Togo*

New Global Strategies for Weed Prevention through Mandatory Prescreening, Early Warning and Rapid Response, and a New Biological Protection Ethic. *Dr Randy Westbrooks, Invasive Plant Coordinator, U.S. Geological Survey, Field Office for Invasive Species, Whiteville, North Carolina, USA*

Afternoon session

Invasion of exotic weed seeds into Japan, mixed in imported grains, and existing preventative regulations. *Dr Shunji Kurokawa, Crop Production & Physiology Lab., Department of Forage Production, National Institute of Livestock and Grassland Science, National Agricultural Research Organization, Japan*

Discussion

Wednesday 12 June, morning session

Some considerations about weed risk assessment in France and Spain. *Drs Jacques Maillet, Ecole Nationale Supérieure Agronomique de Montpellier, France and Dr*

Carlos Zaragoza, Servicio de Investigación Agroalimentaria, Diputación General de Aragón, Spain

The Status of Weed Risk Assessment in New Zealand. *Dr Peter Williams, International Business Group, Landcare Research NZ Ltd, Lincoln, Canterbury, New Zealand*

Weed risk assessment: an attempt to predict future invasive weeds of USA. *Mr Chris Parker, Consultant, Bristol, UK*

Assessment and Regulations for Preventing Entry of Exotic Weeds in Cuba. *Ing. Jorge Padrón Soroa, Centro Nacional de Sanidad Vegetal, Habana, Cuba.*

Afternoon

Field visit: new invasions of *Amsinckia calycina* in dry-land cereals and *Solanum physalifolium* in irrigated agriculture in the Segovia Province (70 km north of Madrid).

Thursday 13 June 2002, morning

Weed Risk Assessment in Australia. *Dr Dan Panetta Principal Scientist/Professional Leader, Alan Fletcher Research Station, Department of Natural Resources and Mines & CRC for Australian Weed Management, Sherwood, Queensland 4075 Australia.*

Presentation of draft guidelines (Assessing the risk of weeds at the border and within a country). *Dr Peter Williams, International Business Group, Landcare Research NZ Ltd, Lincoln, Canterbury, New Zealand*

Discussion of draft guidelines.

Afternoon session

Discussion of draft guidelines (cont'd)

Closure of the consultation