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INVASIVE ALIEN SPECIES

Comprehensive review of activities for the prevention, early detection, eradication and control of invasive alien species

Note by the Executive Secretary

1. The Executive Secretary is pleased to circulate herewith, for the information of participants in the sixth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) a comprehensive review of activities for the prevention, early detection, eradication and control of invasive alien species that has been prepared by a consultant commissioned by the Secretariat.

2. The report is being circulated in the form and language in which it was received by the Secretariat.

* UNEP/CBD/SBSTTA/6/1.

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COMPREHENSIVE REVIEW OFACTIVITIES FOR THE PREVENTION, EARLY DETECTION, ERADICATION AND CONTROL OF INVASIVE ALIEN SPECIES

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1. EXECUTIVE SUMMARY

The fifth meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD) has requested the Executive Secretary to develop a paper for consideration by the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) which includes "a comprehensive review on the efficiency and efficacy of existing measures for prevention, early detection, eradication and control of alien species and their impacts". This paper is the first step in that review, and provides an overview of existing activities and programmes for prevention, early detection, eradication and control of alien invasive species. Although no attempt is made to determine the efficiency (or cost effectiveness) of these measures, a sense of the efficacy or biological effectiveness is given.

A review of published and grey literature, consultations with expert groups and analysis of capacities, gaps and synergies, led to the following general conclusions:

- Many tools and technologies are available for the prevention and management of alien invasive species. The application of these tools is very patchy on a global basis, but overall, successes in prevention and management are significant and provide a good platform on which to build future efforts. Practical and viable solutions need to be available to countries that frequently do not have the resources or infrastructure to prevent or deal with severe invasive species problems.

- Basic biological knowledge (e.g. taxonomy) must be combined with evolving technologies and tools for prevention and management. These measures rely heavily on the existence of reliable and taxonomically comprehensive data.

- Prevention of an introduction or eradication of any invasion that does occur is recommended, but there is less experience and fewer tools or measures for achieving these goals than for on-going control. All of these approaches rely heavily on detection measures, which are also limited in availability for some taxa.

- Eradication is most feasible for invasions over a small area and when action is taken early in the establishment process. Frequently pesticides provide the only immediate means of control. Because they are easily applied and often inexpensive to buy, this option is frequently used.

- Frequently action against invasive species needs to be immediate, therefore pesticide use has an important role for the eradication or control of some taxa. This should be on a rational basis that maximises impact while minimising use. Institutions are more likely to achieve this working from contingency plans developed in advance than from a reactive stance at the time of an emergency.

- Long term sustainable solutions, such as biological control measures, frequently require a long research period before implementation can begin and are sometimes expensive to develop. In some methods of biological control, workers studying different taxa are now sharing common experiences. For example, in the introduction approach, more attention is being paid to possible non-target effects of introduced agents because of mistakes made in the past.

- Whilst some measures, such as the introduction approach in biological control, can by themselves provide solutions, it is more often the case that a combination of measures (e.g. pesticides, biological control, physical control) is needed to satisfactorily solve invasive species problems on a long-term sustainable basis. This implies a complexity in the solutions that will require greater capacity in design, management and evaluation of future programmes. Components should be environmentally benign. This will require co-operation among funding agencies and researchers to set environmental quality as a priority.

- For the purpose of control, integrated pest management (IPM) needs to be developed in the context of the biology of the taxa rather than on any single paradigm.

- Physical control and habitat management measures frequently require high levels of input but nonetheless can form an important part of IPM programmes; physical control measures are particularly appropriate for isolated populations of invasive species.

- Measures such as pathway analysis, prediction of spread of an invasion, or the introduction approach in biological control stand to have significant impact as they are particularly appropriate for invasive species problems. However, progress in such areas would benefit from greater interaction between workers dealing with different taxa.

- Environmental and agricultural/forestry/livestock sectors need to take advantage of each other's expertise by forming stronger partnerships. Some tools can benefit from exchange between terrestrial and aquatic based research and implementation experiences.

- One of the most valuable contributions to invasive species management is from groups developing toolkits (e.g. McEnnulty *et al.*, 2000; GISP, 2000a). This enables countries with little expertise or few resources to tap into the global knowledge base, link with existing partnerships/networks and to copy or adapt tools as necessary.

2. INTRODUCTION

2.1 BACKGROUND & OBJECTIVES

The UN-Norway 1996 Conference was the first international response to Article 8(h) of the Convention on Biological Diversity (CBD) which states that contracting parties to the convention should, as far as possible and appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species. The Global Invasive Species Programme (GISP) was initiated as a response to the conference and was formally commenced in 1998. GISP has the objectives of: to assemble and make available best practices for the prevention and management of species; and to stimulate development of new tools in science, policy, information, and education for addressing these problems.

The fifth meeting of the Conference of the Parties to the CBD has requested the Executive Secretary to develop, in collaboration with relevant organisations and instruments, a paper for consideration by the SBSTTA (Subsidiary Body on Scientific, Technical and Technological Advice) which includes "a comprehensive review on the efficiency and efficacy of existing measures for prevention, early detection, eradication and control of alien species and their impacts".

This report is the first step for this review. Here we present an overview of prevention and management (including early detection, eradication and control) measures against alien invasive species in international and national programmes, projects and other activities, and a discussion of their efficacy and efficiency. Where relevant, this will also include a discussion of guidelines for these measures, research and plans, networks and partnerships. An analysis of capacities, synergies and gaps is also made. The definition of 'measure' and other key terms are discussed in the next section.

The overview is restricted to the technical side of the control measures and their implementation. Legal and general institutional frameworks are being covered in separate report on policy and legal measures. Other supportive measures such as stakeholder involvement or technology transfer systems (e.g. to extension workers) are not covered.

All species taxa are covered in this report; however, alien invasive species affecting human health and living modified organisms (commonly called genetically modified organisms), as defined in the Cartagena Protocol on Biosafety, are not covered. Also, the literature on animal health is vast, thus only prevention, early detection, and eradication are covered in this field.

2.2 ALIEN INVASIVE SPECIES: THE THREAT AND THE SCOPE OF APPLIED MEASURES

The scale of species introductions into new areas through human means, either intentional or accidental, has vastly increased since the turn of the nineteenth century. In particular, as trade and travel increase, the risks increase for the movement of existing invasive species, and for new species to be transported and to become invasive. Alien invasive species are found in all taxonomic groups: viruses, fungi, algae, mosses, ferns, higher plants, invertebrates, fish, amphibians, reptiles, birds and mammals (IUCN, 2000). The important point is that measures appropriate for the prevention and management of alien invasive species have not been developed for all species taxa, containing invasive species, or indeed, not necessarily for all 'ecological' groups of species within particular taxa. This will be further discussed in the final sections of this report.

2.3 DEFINITIONS

In this report, 'alien invasive species' is defined as in Shine *et al.* (2000), that is, as follows: 'Invasive species means an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity'.

At the GISP Phase I Synthesis Conference held in Cape Town, South Africa, in September 2000 a decision was made to refer to "alien invasive species" as "invasive alien species". As most of the literature to date refers to the former term, this is adopted here for convenience.

Many terms, such as 'eradication' or 'control' have been defined by the International Plant Protection Convention (IPPC) of the Food and Agriculture Organization of the United Nations (FAO) and these definitions are adopted here (see Annex 1.13), unless stated otherwise. However, the terms 'measure', 'efficacy' and 'efficiency' need some further consideration.

Although the term 'measure' is mentioned in several international conventions, it only appears to be formally defined in the World Trade Organization's 1995 Agreement on the Application of Sanitary and Phytosanitary Measures (the SPS Agreement). Here, we adopt the definition as it applies to animal or plant life or health, i.e.:

'Sanitary or phytosanitary measure – Any measure applied to protect animal or plant life or health within the territory of the Member from risks arising from the entry, establishment or spread of pests, diseases, disease-carrying organisms or disease-causing organisms'.

In this definition, 'animal' includes fish and wild fauna; and 'plant' includes forests and wild flora; and 'pests' include weeds.

The terms 'efficacy' and 'efficiency', in the context of prevention and management measures, are not defined by any of the international conventions. In fact, the use of these terms has varied in relation to factors such as the type of measure under consideration, the type of pathway of introduction of an invasive species, or the type of ecosystem that has been affected and the criteria used to judge the measure. Here, we broadly define these terms as follows:

Efficacy – the general suitability of a measure or tool for prevention or management for a particular invasive species or group of species for a particular system or habitat. For pesticides, efficacy is a statement of achievement of the stated goal of the product and may not include environmental considerations.

Efficiency – indication of the extent that a particular measure or tool provides prevention or management of an invasive species or group of species and its cost effectiveness.

A glossary of terms and a list of abbreviations and acronyms are also included in Annexes 1.13 and 1.14 respectively.

2.4 GENERAL METHODS

An attempt has been made to cover all species taxa which contain alien invasive species and where efforts have been made to apply prevention and /or management measures. An attempt has also been made to cover as many geographic regions as possible when trawling for examples of programmes and activities. To achieve this, information has been collected from a number of sources including:

- existing information already collected by GISP (e.g. see GISP, 2000a);
- relevant, scientific journals;
- 'grey literature', e.g. unpublished reports, where these have been available;
- relevant world wide web sites;
- discussions with organisations, or individual experts in the field and these are acknowledged below.

Much of the available information comes from the fields of agriculture, forestry and livestock for historic reasons. There are two fairly recent listservers on the World Wide Web, ALIENS-L and Bioinvasions (ALIENS, 2000; Bioinvasions, 2000).

The information is reported and analysed as follows. In section II, measures and tools used, or being researched, are identified and characterised, mostly in relation to the species taxa where they have been applied. At the end of the section, examples are given of networks and partnerships that have been set up to undertake specific projects or to co-ordinate a number of activities. In section III, an analysis is made of capacities, synergies and gaps. Finally, in section IV, general conclusions are drawn in the context of Article 8(h).

Web site addresses are provided in the reference section.

3. IDENTIFICATION AND CHARACTERISATION OF MEASURES

Information from the literature and other sources on the use of existing measures against alien invasive species falls into four main groups: agricultural systems (including forestry and livestock), natural/semi-natural habitat systems (including unmanaged forests and coastal areas), freshwater systems, and marine systems.

Thus summaries in the forms of tables of existing measures against taxa containing alien invasive species have been prepared for agricultural and natural terrestrial systems as well as freshwater and marine systems to the degree possible. These Tables appear in the Annex labelled as section 7.3. For each measure and taxon in the tables, information is provided on:

(a) examples of the main tools developed and used

(b) an indication of the extent to which these tools, or a particular tool, have been used geographically and an example of a species targeted or a case study

(c) a reference to a significant review and/or, where there has been very restricted use, to the case study

(d) the effectiveness of the tools, where this is known.

In the tables, 'Not Applicable' (NA) is used when a particular management measure is not applicable to a particular taxon; and 'No Information' (NI) when a measure may be applicable but no significant information has been found on its use or on research within the time frame of this review. Finally a chart on the general availability and effectiveness of measures for prevention, early detection, eradication and control of alien invasive species appears in the analysis of section III.

Summaries of the use of measures, where these exist, against species taxa containing alien invasive species have been prepared in relation to the four main categories of information (See Tables in Section 7.3). The following sections are an attempt to review what amounts to hundreds of fields of specialisation and countless projects and programmes, all existing prior to the development of a global convention for protecting biodiversity, but which now must come together in order to accomplish a new, more coordinated objective.

3.1 PREVENTION

All measures of prevention, early detection, eradication or control have the purpose of reducing the risk from the introduction of an invasive species. (A discussion of risk appears in a companion document on Risk Assessments (see document UNEP/CBD/SBSTTA/6/INF/6). Prevention is generally aimed at reducing the probability of an introduction of a pest, rather than reducing the consequences of an introduction. When a policy of prevention does not succeed, a country may resort to reducing the consequences by developing more resistant varieties, creating a containment area with quarantines to prevent spread, or economic measures such as compensation of losses to farmers in the case of agricultural systems. These measures are discussed under the section on Control.

Prevention can be accomplished by exclusion -- keeping the risk "off shore" or across the land border - or by mitigative measures at the time of entry of a species or at the point of an identified pathway. Since political boundaries are often artificial in biological terms, unless the country is an island or group of islands, some regions have chosen to act together as an area for purposes of exclusion, mitigation or control.

Prevention is the preferred approach from a biological perspective, but in implementation it may be hindered by a lack of funding, institutional capacities, existing infrastructure or available technology, or effective tools. A cost benefit analysis may show that the monetary cost of preventing entry of a species is too high if an effective control measure exists (often a chemical biocide). Environmental costs may not be considered in some of these decisions. Although research has resulted in improved tools for prevention, many of these are not yet accessible to the majority of countries.

3.1.1 Infrastructures, guidelines, available tools

(i) Infrastructures and guidelines

The CBD is essentially a framework convention, presenting the common commitment of its contracting parties and providing guidance on the desired outcomes of its implementation, without prescribing how to achieve these results. It is left to the national level to implement the majority of rights and responsibilities of this convention (Glowka *et al.*, 1994).

The infrastructure for prevention in most countries is entirely governmental. In animal and plant health (including weed control), this infrastructure generally resides within the Ministry of Agriculture and includes:

- an inspection service to implement the policy and provide feedback;
- scientific technical units in charge of conducting risk assessments, identifying organisms, analysing the feedback from the inspection service, reporting on outbreaks, new findings, or emerging threats, and so forth; and
- a policy unit with capabilities and the mandate to take risk assessments and other information and design policies and programmes.

This infrastructure overlaps with and is an integral part of the overall animal and plant health structure for a country, which includes export certification, development and maintenance of domestic programmes, development and enforcement of regulations, and research.

Some of these responsibilities go beyond national interests, appearing in international agreements as well. For example, National Plant Protection Organisation's (NPPO) minimal responsibilities are outlined in Article IV of the revised convention (IPPC, 1997a). Specific responsibilities for the national competent authorities are laid out in the International Animal Health Code (e.g. Chapter 1.2.1, OIE (2000a) and the International Aquatic Animal Health Code (e.g. Chapter 1.5.2 for measures before and at departure, OIE (2000b). With the advent of the World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures (WTO/SPS) (WTO, 1994), the guidance mentioned above became legally binding standards for the 137 member countries of the WTO.

Other facets of prevention of alien invasive species introduction to new ranges and habitats (e.g. aquatic, non-agricultural pests) fall under other government agencies in many countries, or are not yet well covered by the existing infrastructure. Many of the responsibilities of the 179 Contracting Parties to the CBD that are listed (particularly in Articles 7-14) are more suited to conservation programmes that fall under the Ministry of Environment, or agencies for parks, protected areas or similar authorities. Because the CBD is a framework rather than a rule-based agreement, it is appropriate to leave the decision about which agency carries out what work to individual countries. Implementing these responsibilities, including monitoring, public education, and incentives for conservation, would contribute to prevention. In article 8 (h) the CBD specifically requires the prevention of the introduction of alien species considered to pose a risk. The full range of international agreements with reference to alien invasive species is discussed elsewhere (Shine *et al.*, 2000; USSD, 2000).

The Species Survival Commission's Invasive Species Specialist Group (ISSG) has added guidelines for the prevention of biodiversity loss (IUCN, 2000) to these existing guidelines. These, in conjunction with the "Global Strategy on Invasive Alien Species" (GISP, 2001), promote the same approaches of border control and quarantine measures, information exchange, and capacity building that are the current approaches and infrastructures. A comparison of these guiding principles with existing phytosanitary standards, for example, shows the similarity of approaches, as well as where they diverge (IPPC, 2000b). What is new is the breadth of these guidelines which encompass invasions across taxa and ecosystems (e.g. terrestrial and aquatic), a step that has been taken by very few countries to date (New Zealand and its Biosecurity Act being the primary example (New Zealand Ministry of Agriculture and Forestry, 1993)). A further possible developments proposed by these guidelines is the weighing of benefits of introductions versus possible costs. This is in contrast to the less trade restrictive approach, which allows for movement of products unless the risk is considered too high for the acceptable level of that country. Fundamentally, these additional guidelines reach the conclusion that the existing organisations were arriving at (IPPC, 2000a, 1999d): that prevention and other management of invasives should be based on assessment of environmental impacts as well as the currently defined economic ones.

Discussions on how to incorporate environmental factors more fully into economic models and existing risk analysis procedures remain in the theoretical phase until several countries apply the recommendations (OECD, 1999a, 1999b; Mumford, 2000). Taking these concerns beyond the risk assessment phase to other aspects of prevention or management programs is another leap. What is clear is that a comprehensive infrastructure for prevention of the entry and establishment of unwanted alien invasive species will consist of a combination of existing infrastructures and possibly new ones. Existing infrastructures employed in the implementation of Article 8 (h) will include any national inspection systems but will also require additional training of human resources, funding, and possibly creation of new services to respond to the gaps identified and discussed in Section III of this report.

None of these guidelines provide specifics for how a country already pressed to meet its international responsibilities can in practical terms carry out what amounts to additional measures to prevent introductions of alien invasive species from newly-recognised or newly-created pathways and from a broader range of taxa than ever before. Additional funding and capacity building for more effective prevention will remain imperative for some years to come.

(ii) Available tools for prevention

A number of tools have been developed and legislated as measures, in some cases for more than a century, to prevent the transboundary spread of unwanted organisms. These come from fields of expertise such as public health, wildlife conservation, plant health, animal health, marine biology, and now from invasion biology. Examples of specific activities, both operational and those specified in regulations, that are used in prevention in plant health are shown in Table 3.1.1.1 (below). Most intentional introductions were carried out by private individuals or groups with out any regulation prior to the 1900s (OTA, 1993) and for some taxa this may still be the case.

Some general groupings of tools for prevention follow. Many of these tools are employed in other phases of the management of invasions in addition to prevention.

Prohibition and Restricted Permitting

Prohibition was the first prevention measure applied to international trade. It remains an important measure for a number of species when the risk posed by an introduction is unacceptable. The use of strict prohibition is discouraged by the negotiation of the General Agreement on Tariff and Trade (GATT) and there is international pressure for the least restrictive trade measures to replace previous prohibitions.

Prohibition is generally carried out based on a list of species, rather than by country of origin or other categories. The landmark study for the Office of Technology Assessment on harmful non-indigenous species in the USA (OTA, 1993) includes a discussion of the "clean" and "dirty" list concept. This distinction has arisen in discussions on the application of the WTO/SPS since many countries continue to list what may be imported rather than indicating the species that are regulated, and supporting this regulation with the appropriate scientific studies. In the past, use of lists of either prohibited or restricted species or hosts of these species degraded into bilateral bartering and was one of the driving factors for elaborating the WTO/SPS Agreement and its requirements for either international standards or the use of risk assessment.

Table 3.1.1.1. Examples of phytosanitary measures used on the national level for prevention of introduction of plant pests and weeds.

Measures to reduce risk of entry (generally take place in country of origin):

- Training, technical assistance, surveys and research in country of origin of a shipment.
- Literature reviews.
- On-going contact with officials, experts, universities, etc in areas of origin of shipment.
- Review of interception lists.
- Development of restricted lists and quarantine pest lists in accordance with SPS guidelines.
- Inspection in country of origin.
- Restricting source of imports to a designated pestfree area in a country with pest.
- Requiring treatment for high- risk items.
- Pathway analysis using above tools and statistics on pathway.
- Genetic fingerprinting on historic introductions to find pathways.
- Environmental modelling for predicting potential range of organism, survival parameters.
- Probability calculations from range of survival parameters.
- Indices of invasiveness.
- Pest Risk Assessment using all of the above tools.

Verification of compliance with measures to reduce risk of entry (generally takes place in the receiving country):

- Inspection:
  visual
  random sampling
  targeted by risk
  x-ray, sound equipment, other
  detector dogs
- Review of permits, phytosanitary certificates, bills of landing.
- Isolation for set period to watch for disease or pests.
- Treatment, re-export or destruction in response to interception.
- Limiting ports of entry according to type of cargo and/or risk.
- Limiting market destination (e.g. portions of Europe)
- Containerisation for transit through vulnerable zone.
- Public education and "amnesty" bins at point of entry.
- Identification of all suspect organisms.
- Policy for unlisted/unknown organisms.
- Other decision guides and headquarters support for inspectors.
- Working relationship with other branches of government such as Customs to receive data.
- Market checks for prohibited materials

Adapted from Quinlan, 2000, in proceedings from the **Symposium of the Regional Fruit Fly Eradication Programme of the Indian Ocean**. Mauritius, June, 2000.

Permitting, phytosanitary certificates, or similar mechanisms are also used as prevention measures. These often impose some conditions for approval of the movement of the live organism or its products. Permits are used for movement of otherwise prohibited materials or species for use in experimentation, research, for zoological collections or other situations that will limit the possibility of introduction into the environment. Permits may also be used to indicate conditions such as limited distribution after entry to a country, limited ports of entry (due to specialists or facilities at those ports), or limited season of entry. The importing country may have a requirement of confirmation of the taxonomic identification or surveillance and evaluation of the program. The success of permitting with conditions relies on some evaluation of the use of these permits and any violations that occur (National Plant Board, 1999).

Risk Assessment

Guidelines and requirements for Risk Assessment are discussed in the companion paper on that topic (Quinlan, 2001). Pathway Analysis is another form of risk assessment of growing importance for implementing the CBD. Important pathways for introductions of alien invasive species in the past include: national and international trade, tourism, shipping, ballast water, fisheries, agriculture, construction projects, ground and air transport, forestry, horticulture, landscaping, pet trade and aquaculture (UNEP, 1999). Development and famine relief programs and military operations, which often move outside the normal trade channels, have been pathways for some invasions (Waage, 1999), or have led to the break down of the systems that would stop invasion from other pathways. Pathways outside the usual regulatory channel include private courier services, mail, cruise ships and private planes, garbage and waste, and transhumance.

Increasing possibilities for tracing outbreaks in an epidemiological manner, a kind of reverse pathway analysis, may not affect current invasions but will facilitate future prevention efforts. One of these tools is the use of genetic "finger printing" to determine the exact origin of an introduced population and thereby assist in identifying the pathway. This has been used for fruit fly incursions in the USA, the citrus canker in Florida and by gypsy moth programmes. Although this technology is not accessible to many countries due to costs, it can apply to a range of taxa. Less costly measures involving labelling of crates or other units of shipment allow officials to trace back to the source of a problem at the time of inspection.

Post-entry measures

Actions taken to verify compliance with those measures in place to reduce risk include the use of a quarantine period during which the organisms are physically segregated, inspection using various technologies and identification of interceptions or detentions of pests found on the shipment, or in some cases confirmation of the permitted species itself when it can be misidentified and/or is closely related to either an endangered or an invasive species.

Quarantine isolation periods are unpopular with travellers taking their companion animals with them or industries that want to move products more quickly, but this measure does compensate in some instances for the rapid transport of planting material, for example, that previously might have shown signs of a disease by the termination of a journey by ship. Concern over zoonoses that could infect humans is another motivation for requiring quarantine periods. The Office International des Epizooties (OIE) includes guidance on quarantine of non-human primates in the animal health code (OIE, 2000a) specifically due to this possibility.

Treatments may be required when the probability of an introduction of an alien invasive species either directly feeding on or "hitch hiking" on the desired product or the consequences are severe. The most common treatment for agricultural trade has been methyl bromide (MB), after another broad range fumigant, ethylene dibromide (EDB) was prohibited in the 1980s.

Methyl bromide is a broad range fumigant used for many pre-shipment and post-arrival quarantine treatments. Currently approximately 15,000 tonnes of MB are used for phytosanitary treatments, for protection of both agricultural and non-cultivated plant resources. Examples of its use include the fumigation of all logs shipped from the US to Europe to prevent the entry of oak wilt. Although the exact cause of this devastating disease or syndrome are not yet clear, it poses a major threat to natural systems in Europe. MB has been useful for this type of situation in which an unknown species must be controlled. The use of MB in China for pre-shipment treatment increased 282% between 1996 and 1998, to a large extent because of requirements to treat against the Asian Longhorned Beetle in all dunnage coming out of that country (Batchelor, 2000). Forest product treatments need more research if use of this ozone-depleting chemical can be reduced while still protecting forests around the world.

Through the Montreal Protocol, countries have agreed to phase out use of MB entirely in developed countries by 2005. An exception exists for Quarantine Pre-shipment treatments. This means application (for quarantine and non-quarantine quality pests if there is an official requirement in place before a certain date) within 21 days prior to export to meet official requirements of the importing country or existing official requirements of the exporting country. The exception could be granted for sectors that have been unable to find effective alternative treatments or for emergency situations (Batchelor, 2000).

Even with this exemption, some countries will lose the use of MB because it will not be re-registered as a pesticide; sources of MB are disappearing and prices are increasing by 40 to

50% (Italian figures); and, in the USA, court cases against the use of the chemical due to health concerns as well as environmental objections. Treatments for a number of pest/commodity combinations do not exist when they are discovered upon arrival to the importing country.

The pressure of losing MB has been a major driving force for development of new treatment of agricultural products, or refinement of very early technologies. These include cold, heat, hot water, vapour, irradiation, controlled atmosphere and a few chemical treatments (Sharp and Hallman, 1994).

Living organisms may be required to be vaccinated, disinfected or have some other treatment before shipment or at the time of arrival to a non-infested country. This provides protection against disease; there are no known cases of allowing entry of animals with the requirement of sterilisation to prevent that species itself from spreading. Escapes from contained areas, such as zoological parks, may add to the exotic population but many more introductions were made either prior to regulation or by amateur hobbyists rather than by professional curators. One dramatic example of an introduction purportedly made by a formal oceanographic museum is the marine alga, *Caulerpa taxifolia,* which was released off Monaco in the early 1980s and now covers the entire Mediterranean (Meinesz, 1999).

Systems Approaches

Traditional treatment regimes for disinfestation were based on the worst case scenario and the statistical level of probit nine for mortality in tests. This mitigation approach reduces risk to essentially zero if the treatment is properly applied. With the move to less trade restrictive measures under the WTO, the members of the IPPC Working Group on the subject have sought to better define an approach that has been used by a number of countries (IPPC, 1999e). This will prevent in the future the misuse of the concept of systems which at times has been taken to mean more and more mitigative measures being added together simply to satisfy the importing country, rather than to further reduce risk.

In this new draft standard, the proposed definition is: "The integration of different pest risk management measures including at least two independent procedures that individually reduce pest risk and may be combined with other measures which cumulatively result in meeting the [phytosanitary requirements] [appropriate level of protection] defined by the importing country" (IPPC, 1999f).

This approach is more complex than single disinfestation treatments. A systems approach requires more knowledge of the pest and pest/host interaction, low prevalence of the pests in the commodity (or other pathway) being regulated, the existence of appropriate management measures, and a high level of consistency in the handling measures employed in packing and transport (IPPC, 1999c).

The advantages, however, include possible reduction of pesticide use, new options to MB application in particular, the acceptance of a wide range of measures and compliance with the requirement for equivalency (IPPC, 1999e). A systems approach also can encompass measures to reduce the prevalence or outright kill the pest and to reduce the probability of entry. These might include use of resistant varieties, harvest before maturity, or precautions at the time of packing for the former, and seasonal shipping or limited ports of entry and distribution for the latter. This approach, in the form of hazard analysis and critical control point (HACCP), has been highly successful in the food processing industry in reducing incidence of food contamination and food poisonings.

Systems approach is a useful framework for combining tools with scientific discipline. It may prove particularly useful for natural systems in which a single disinfestation treatment is impossible. With proper analysis, it can be used to apply a precautionary approach while not disrupting trade and movement.

Public Awareness

The impact of public awareness for prevention has not been well evaluated. The potential impact is tremendous, however, when considering situations such as releases of pets. In the

USA, an estimated half of the 185 species of exotic fish discovered and identified to date are due to the release or escape of aquarium fishes (USGS, 2000b).

3.1.2 The status of existing tools

Agricultural crops

National programmes for protecting agriculture from some key pests have been in place for a hundred years in many countries. The tools for prevention are well known and appear in Table 3.1.1.1 (see above) and are discussed in recent reviews (USDA, 1997). These tools have proved successful in slowing the entry of alien species. However, the challenge has grown so rapidly in many countries that traditional approaches and existing levels of funding severely impair the outcome today. Preventive measures have been evaluated in national programme reviews of some of the leading countries in plant health: Australia, the USA and the United Kingdom (Nairn *et al.*, 1996; National Plant Board, 1999; Mumford *et al.*, 2000). A parliamentary review is in progress to evaluate the biosecurity approach in New Zealand. Although many countries cannot aspire to the level of resources of these leaders, lessons learned from their programmes can still be applied.

A significant trend both internationally and on the national level is to utilise risk assessment not only to justify measures but for policy decisions on priorities as well. Cost benefit analyses are also used in increasing number as well as in increasing complexity to assist in plant health decisions. This and other economic tools will support all countries in the difficult decisions regarding allocation of human and capital resources.

While new technologies are being developed or applied in new ways (see Tables 7.4.1 and 7.4.2), the fundamentals are being reconsidered. This includes the use of statistics in sampling for inspection and analysis of interception data. These issues are coming up again with the advances in statistical and mathematical modelling and the accompanying rise in demand for capacity to interpret the data. Concern is expressed that there are not enough well-trained taxonomists for forest pest and all disease and nematode identification. This is vital link for successful detection measures as well as other programmes.

Forestry

Because of the long history of trade in forest products, including lumber with bark, many forest pests moved into alien environments and became established before current quarantine methods were in place. This includes the chestnut blight, which arrived to North America in the 1920s, Dutch elm disease, and the first introductions of gypsy moth which caused significantly more damage when it arrived to the North America than it had in its European countries of origin.

In this historic context, the risk of spread of forest pests was greatly reduced over the years through control of nursery stock and planting material. Foresters did not regulate other pathways as effectively, however, resulting in destructive introductions of major pests through shipments of timber and, more recently, in wooden pallets and dunnage. Countries are only now coming to terms with which pathways need regulation.

A new direction among foresters is to agree on a list of the species of greatest concern. This list of the ten or twenty "worst pests" will then serve as a focus for development of more in depth pathway analysis and pest risk analysis (PRA), funding for detection methods, and creation of contingency plans to better prevent or, in worst case, to prepare for the entry of one of these species.

There is also more application of PRA to forest pests than in the past. Climate models are often employed and environmental impact is being considered in addition to economic impacts.

Perhaps the most important change in prevention measures in the past five years is the emerging regulation of wood packing materials including wooden pallets, crates, and other dunnage. Several countries have enacted unilateral measures to prevent the entry of untreated dunnage since 1998. The North American Plant Protection Organization (NAPPO) developed a regional standard on this matter, which is being passed into law in its member countries (Canada, the USA and Mexico). The IPPC has a panel working on an international standard that would be adopted by all member countries, unless they chose to enact more stringent regulations based on additional PRAs.

The disagreement is on harmonisation of a treatment for dunnage to prevent entry of alien invasive species. With the removal of MB from the market, heat treatment is one of the only viable options for killing wood pests. Many countries, or specific ports, do not have the infrastructure in place to carry out these treatments. Scientists do not yet agree on the minimum temperature for such a treatment since some fungi can survive current recommended temperatures, although their vector pests cannot. Risk assessment experts need to quantify the risk from the survival of this fungi given the mortality of the usual vector species and the impact of the heat on the fungus itself. They also need to determine if these fungi species are of quarantine significance (or are invasive, or only alien).

Animal health

Animal health has the advantage of a long history of prevention and management programmes and a well-defined and generally well-trained international network connecting national programmes. The tools for prevention are similarly well-defined and appear to a large extent in the representative international organisation's literature, in particular the International Animal Health Code (OIE, 2000a). Standards for measures, such as the use of disease free zones, are widely available and a standard methodology for diagnosis is set for each disease listed by the OIE. This successful structure revolves around diseases that have been identified as "notifiable" to the international community. As the process is highly transparent, any country can see whether another member country has reported in a timely fashion on surveillance for the notifiable diseases. The principle weakness of this system in terms of preventing alien invasive species would appear to be the decision process for adding a disease to this notifiable list, and therefore engaging the other aspects of the structure into the process of prevention.

The animal code covers mammals, birds and bees. A separate code was introduced in the last five years to begin addressing diseases of aquatic animals (OIE, 2000b). The addition of this code, and the accompanying manual on diagnostic techniques, is an important step forward in prevention of transboundary movement of zoonoses of concern. There remain a number of taxa that are not covered in this structure. Until added to the lists, diseases of reptiles, amphibians, marine mammals and other taxa will either not be addressed at all or will be covered by individual country legislation.

Invasive species of mammals, bird, reptiles, and others

There are numerous case studies of either accidentally introduced or intentionally introduced mammals, birds, reptiles and other taxa that have become invasive and destructive (e.g. GISP, 2000a; USGS, 2000c). Certainly some are problematic to agriculture, especially rodents and birds. But the worst impacts are seen in natural systems. Although risk assessment is much more difficult when applied to competition or indirect effects of an invasive species than when the impact is direct (e.g. predation), most prevention tools developed from terrestrial cropping systems can apply equally to natural systems. Prevention relies heavily on legislative mechanisms at this time (e.g. USSD, 2000; Bartley and Subasinghe, 1996). Public awareness, especially around the impacts of pathways like pet trade and hobbyists releases, could better complement the legislative approach.

Freshwater systems

As mentioned under Animal Health, diseases of aquatic animals are now being addressed. These are still limited to a list of the most severe diseases of fish, molluscs and crustaceans (primarily shrimp) (OIE, 2000b).

Prevention activities of disease in watersheds have focused on monitoring of hatcheries and of aquaculture farms within those waterways. Although free populations may be monitored, there is still little to be done to prevent introductions to new areas once the disease is established in the waterway. The recognition of the role of processing waste/waste water in distributing animal pathogens into the water system should lead to stricter regulation of this pathway. Discarded bait fish has been identified as another pathway to control for both freshwater and marine environments. Regulation of these pathways is in the early stage. Public awareness should be added to the process.

The escape of exotic species or subspecies of fish from aquaculture farms is common; greater regulation is needed. Yet a surprising number of introduced fish are from hobbyists dumping aquarium pets into waterways. An estimated half of the exotic species detected in the US fresh waterways are from this pathway (USGS, 2000b).

Those making decisions about introductions in the future can learn from the results of many intentional introductions for sport fishing or to "improve" the biodiversity. Although many of these mistakes of the past cannot be corrected, risk assessment and pathway analysis are available for decisions taken today. FAO has developed a Code of Conduct for Responsible Fisheries and other groups are developing more guidance within this framework (e.g. Bartley and Subasinghe, 1996). Other relevant codes or guidelines exist, including GISP's Toolkit and IUCN's work on re-introductions and translocation (GISP, 2000a; USSD, 2000).

Prevention is particularly important in aquatic systems since control measures and the possibility of eradication are limited.

Marine

Prevention measures in marine environments are generally aimed at the primary pathways of introduction, rather than individual taxa, although some taxa have been targetted; e.g. the Pacific seastar in Australasia (P. Warren, pers. comm.). Ballast water has been identified as one of the two key pathways for transferring alien invasive species in marine environments. Hull fouling is the other key pathway. Clearly, terrestrial approaches to preventing the movement and entry of an alien invasive species through these pathways will not work. Attempts to inspect ships for their proper handling of ballast water have been ineffective (e.g. National Plant Board, 1999).

The international regime for the management of the transfer/introduction of marine species via ships' ballast water currently consists of voluntary guidelines developed by the International Maritime Organization (IMO) member countries and adopted by the IMO Assembly in 1997 (IMO, 1998). While these are voluntary guidelines only, some jurisdictions have enacted national legislation requiring ships calling at their ports to comply with the guidelines. These include Australia, Canada, Chile, Israel, New Zealand, the USA, various individual States within the USA and various individual ports around the world, such as Buenos Aires in Argentina, Scapa Flow in Scotland and Vancouver in Canada (Raaymakers, 2000).

Management and control measures recommended by the guidelines include:

- Minimising the uptake of organisms during ballasting, by avoiding areas in ports where populations of harmful organisms are known to occur, in shallow water and in darkness, when bottom-dwelling organisms may rise in the water column.
- Cleaning ballast tanks and removing muds and sediments that accumulate in these tanks on a regular basis, which may harbour harmful organisms.
- Avoiding unnecessary discharge of ballast.
- Undertaking ballast water management procedures, including:
- Exchanging ballast water at sea, replacing it with 'clean' open ocean water. Any marine species taken on at the source port are less likely to survive in the open ocean, where environmental conditions are different from coastal and port waters.

- Non-release or minimal release of ballast water.
- Discharge to onshore reception and treatment facilities (which currently do not exist at any port in the world).

All of the approaches recommended under the IMO guidelines are subject to limitations due to safety issues and also lack of effectiveness. Some parties even suggest that reballasting at sea may itself contribute to the wider dispersal of harmful species, and that island states located 'down-stream' of mid-ocean reballasting areas may be at particular risk from this practice (MEPC, 2000). Despite these limitations, IMO member countries recognise that something must be done to curb the transfer of species in ballast water. They have agreed to develop a mandatory international legal regime to regulate and control ballast water. The IMO's Marine Environmental Protection Committee (MEPC) and its Ballast Water Working Group are well advanced with developing this regime and it is hoped that it will be approved by member countries in 2002. It may take the form of a new Annex to the International Convention for the Prevention of Pollution from Ships, or a new international convention or other legal instrument in its own right (Raaymakers, 2000).

In addition to reballasting methods, some countries are working on sampling the species that can be transported in the ballast and designing risk assessments that will assist in targeting specific taxa and shipment, based on where the ballast water was loaded (Dodgshun, 2000). The Global Ballast Water Management Programme (GBWMP, 2000b) is assisting one port in each region with biological surveys of the current species around their ports and co-ordinating on ballast management schemes. New Zealand has put in place import health standards for ballast water that targets particular ports which are considered 'high risk' because the Pacific seastar is known to be present.

In recognition of the limitations of the current IMO voluntary guidelines, the current lack of a totally effective solution and the serious threats still posed by invasive marine species, a number of countries and private organisations continue to research methods for controlling living organisms in ballast water. A Ballast Water Treatment R&D Directory, which can be accessed at the web-site http://globallast.imo.org, summarises all of the current research (GBWMP, 2000a). Options being considered include: mechanical treatment methods such as filtration and separation; physical treatment methods such as sterilisation by ozone, ultra-violet light, electric currents and heat treatment; chemical treatment methods such adding biocides to ballast water to kill organisms; and various combinations of the above (Raaymakers, 2000).

Hull fouling is the other major pathway for transfer of marine organisms. This means of transport for barnacles, algae and other taxa has been a challenge for mariners for centuries.

In the 1970s TBT (tributlytin) based paints were first used. These proved more effective than other methods. By the mid-1980s, however, research showed adverse effects on non-target organisms. Environmental concerns has resulted the restriction of use of TBT antifoulant paints to vessels over 25 m in length and those with aluminium hulls in a majority of countries, and an all out ban in Japan on any vessel (1992) and for use in the lakes in other countries (ORTEP, 2000). Now MEPC has recommended a ban on any environmentally damaging antifoulant paints, which include TBT-based paints.

Scraping and other technologies are used on the smaller vessels. Practical alternatives for larger deep-sea vessels do not exist for this important pathway control. There is no lead agency or international organization co-ordinating work on alternatives to antifoulant paint to prevent hull fouling. The industry association, (Organotin Environmental Programme – ORTEP), funds research on risk assessment of alternative treatments and review of regulations and information (ORTEP, 2000).

3.2 EARLY DETECTION

3.2.1 Available measures, tools and general guidelines on use

Together with eradication, early detection is the most neglected phase of the invasion process (Holt, 1999), the other phases being prevention of entry, and control.

Once prevention has failed, and an alien invasive species has entered a country or ecosystem, the only management options remaining are long-term control or eradication. In most cases eradication is the ideal, although there are exceptions, principally for economic reasons e.g. Nile perch, Lakes Victoria, Kyoga and Nabugabo (Sandlund *et al.*, 1999). However, unless there has been early detection, any eradication will be difficult to achieve. Early detection is the key to successful eradication.

For most countries and ecosystems, there is no clear infrastructure for the early detection of alien invasive species. Monitoring schemes exist in several countries, particularly for crop pests. However, in many instances early detection depends on luck, and is reliant on workers on the ground (farmers, land managers), field naturalists (both amateur and professional) and members of the public. Public awareness schemes are widespread, which together with education and reporting mechanisms, can aid in the early detection of alien species, e.g. in Australia, community monitoring is carried out for marine species such as the giant fan worm, *Sabella spallanzanii,* under the co-ordination of the CSIRO Centre for Research on Introduced Marine Pests (CRIMP) (GISP, 2000a). However, for some species there is the potential for misidentifications, or the species may need trained taxonomists for identification, e.g. nematodes. It is acknowledged that a lack of trained taxonomists at present may be hampering the rapid detection of invasive species.

Specific ecosystems have their own methods and problems.

In forestry, capacity for early detection of alien invasive species is not adequate in many regions for a number of reasons:

- Officials are not doing general surveillance in some situations, or have only started doing it in recent years.
- The tools for monitoring are not available in many cases.
- There has not been a focus or prioritisation for developing these tools in the past, so efforts have been fragmented, inconclusive or inconsistent.
- No attractant or effective monitoring method has been found for some significant pests in recent years, principally wood-boring beetles.

Nonetheless, there are some success stories in early detection. For example, a pheromone for detecting Nunn Moth (*Lymantria monacha*), which could spread from Russia causing much damage, is already available commercially.

Within marine systems, there is currently no international system for the early detection of species introduced to new areas by ballast water (Raaymakers, 2000). A few countries have instituted port biota surveys including Australia and the UK, and IMO is assisting six ports in developing countries to carry out port surveys through the GloBallast programme. These are Brazil - Sepitiba, China - Dalian, India - Mumbai, Iran - Kharg Island, South Africa - Saldanha and Ukraine - Odessa.

There is currently no international system for the reporting, recording and communication of newly detected marine invasions, although some databases are expanding beyond the national level.

In Australia, as with several other countries, the detection of terrestrial alien invasive plants is thought to be the least problematic step in their management (Australian Parks & Wildlife Service, 1991). However, methods of detection are not stated.

Within the USA, new plant species are stored in one of a number of state or private herbaria, and historically weed scientists learned of the new records through word of mouth or botanical journals. In order to speed up this process, it has been suggested that a "Plant Detection Network" be created, whereby new plants could be reported to a "State Interagency Weed Team" which would co-ordinate a rapid response and eradication programme (Westbrooks and Eplee, 1999).

In Canada, the Ecological Monitoring and Assessment Network (EMAN), has produced a 'Guide to Monitoring Exotic and Invasive Plants (Haber, 1997).

The USA Geological Survey's Biological Resource Division and others in Hawaii are working on a database to help detect alien invasive species which would respond to control or eradication. However, it is thought that remote sensing and other survey methods will have to be improved in order to support these projects (Holt, 1999). The 'INVADERS' database has also been set up for the early detection and tracking of alien invasive plants in the northwest USA and Canada (Rice, 1997-2000) and GISP has a database with Early Warning System (GISP, 2000b).

The IUCN has produced guidelines for the prevention of biodiversity loss caused by alien invasive species (IUCN, 2000). In terms of early detection, these state that "sometimes the information that could alert management agencies to the potential dangers of new introductions is not known. Frequently, however, useful information is not widely shared or available in an appropriate format for many countries to take prompt action, assuming they have the resources, necessary infrastructure, commitment and trained staff to do so." The guiding principles state that "early detection of new introductions of potential or known alien invasive species, together with the capacity to take rapid action, is often the key to successful and cost-effective eradications". However, no methods for early detection are given.

The IPPC has produced guidelines on surveillance, ISPM 6 (IPPC, 1998a) which state that "general surveillance is a process whereby information on particular pests which are of concern for an area is gathered from many sources, wherever it is available and provided for use by the NPPO" and that "specific surveys are procedures by which NPPOs obtain information on pests of concern on specific sites in an area over a defined period of time. See IPPC (1998a) for more details. There are also guidelines for the determination of pest status in an area, ISPM 8 (IPPC, 1998b).

The CBD states that countries should identify and conduct monitoring of "Ecosystems and habitat: containing high diversity, large numbers of endemic or threatened species, or wilderness; required by migratory species; of social, economic, cultural or scientific importance; or which are representative, unique or associated with key evolutionary or other biological processes." In fact, monitoring for alien invasive species should be on-going in all ecosystems and habitats as spread to high diversity or endangered areas may not be stopped once a species becomes established in neighbouring areas.

3.2.2 Overview of existing tools for early detection

The tools available for the early detection of alien invasive species include: general surveillance or collation of information (site-specific surveys, e.g. trapping at likely entry points; species-specific surveys, e.g. to ascertain the distribution of a known invasive); detection of a particular pest by diagnosis or taxonomic identification; and public awareness campaigns.

In agricultural and forestry systems, traps and lures are used to detect insect pests for specific surveys and for on-going monitoring. The attractants for trapping pests for detection purposes are usually pheromone or plant odour based.

Monitoring is carried out for sensitive (conservation) areas. Public awareness campaigns are widespread, and may be a crucial factor for the early detection of larger or more obvious species.

There are several identification manuals which assist with the diagnosis of probable alien invasive species. For example, the European Plant Protection Organization (EPPO), in conjunction with CAB International (CABI), have produced guidelines and data sheets on the quarantine pests (alien invasive species) of Europe (Smith *et al.*, 1992); these outline the identity of the pest, the host, the geographical distribution, the biology, the methods of detection and identification, the means of movement and dispersal, the pest significance, the phytosanitary measures, and a bibliography for each species. FAO, also in conjunction with CABI, have produced a limited number of manuals on the identification and detection of invasive species (arthropods, nematodes, fungi, bacteria, viruses, plants) in crop systems in Southern Africa (FAO / SADC, unpublished) and East Africa (FAO, unpublished).

The USA have a Foreign Animal Disease Diagnostic Laboratory (FADDL) which exists to diagnose exotic diseases in livestock and quarantine centres (USDA-APHIS, 2000d).

3.3 ERADICATION

"Eradication is the destruction of every individual of a species from an area surrounded by naturally occurring or man-made barriers sufficiently effective to prevent reinvasion of the area except through the intervention of man" (Newsome, 1978, quoted in Dahlsten, 1986).

Several types of species have been successfully eradicated, for example weeds, animal pathogens, insects and mammals. Notable examples include fruit flies of economic importance from a number of countries and species from islands or from isolated populations, using a combination of methods, e.g. rabbit eradication on Phillip Island (Coyne, 2000).

Mack *et al.*, (2000) state that control efforts vary enormously in their efficacy, with successful control depending more on commitment and continuing diligence than on the efficacy of specific tools themselves, and this is certainly true of the examples given.

The following factors are thought to contribute to the success of eradication programmes (Mack *et al.*, 2000; Myers *et al.*, 2000):

- the biology of the target species suggested that the eradication techniques would be effective
- sufficient resources were devoted for a long enough time
- there was widespread support from both the relevant agencies and the public.
- there were clear lines of authority
- re-invasion was prevented
- the species were detectable at relatively low densities
- restoration or management of the community or ecosystem was considered.

3.3.1 Available measures, tools and general guidelines on use

The IUCN (2000) has produced 'Guidelines for the prevention of biodiversity loss caused by alien invasive species'. These list several guiding principles and recommendations for successful, cost-effective and ethical eradications and state that eradication is more likely to be successful in the early stages of invasion. The annex provides the following criteria to be satisfied to achieve eradication (see website (IUCN, 2000) for full points):

- The rate of population increase should be negative at all densities.
- Immigration must be zero.
- All individuals in the population must be at risk to the eradication technique(s) in use.
- Monitoring of the species at very low densities must be achievable (to eradicate the last few remaining individuals).
- Adequate funds and commitment must continuously exist to complete the eradication over the time required. Monitoring must be funded after eradication is believed to have been achieved, until there is no reasonable doubt of the outcome.

- The socio-political environment must be supportive throughout the eradication effort.

The International Plant Protection Convention (IPPC) has produced 'Guidelines for pest eradication programmes' (IPPC, 1998c). These describe the components of a pest eradication programme which can lead to the establishment or re-establishment of pest absence in an area.

Before eradication can take place, there must be effective surveillance to investigate the distribution of the pest, and containment to prevent the spread of the pest (IPPC, 1998c). In addition, there must be a good understanding of the biology of the target organism, and sufficient funding for training and follow-up measures to prevent re-invasion (Sandlund *et al.*, 1999).

Once this has been undertaken, the available methods for eradication are many and include: host destruction; disinfestation of equipment and facilities; chemical pesticide treatment; biological pesticide treatment (e.g. bacterial spray); soil sterilants (e.g. heat treatment); leaving land fallow (crop rotation); suppressive soils (often after crop rotation); host-free periods; processing or consumption of infested crop (sanitation); the use of cultivars that suppress or eliminate pest populations; restriction of subsequent cropping; trapping; lures; shooting; inundative release of biocontrol agents; use of sterile insect release (SIR) technique; disruption of mating by releasing chemical sex attractants which confuse insects; antagonistic microorganisms (fungi); trap plants; interplanting of antagonistic crops; radiation; fumigation; disinfestation of warehouses using bleach.

Eradication of an alien invasive species almost always involves a combination of techniques, depending on the species and the severity of the outbreak. Some methods are inappropriate in sensitive areas, e.g. high pesticide use in natural forest ecosystems.

Plant pathogens

There are several eradication techniques used for plant pathogens (including nematodes) within terrestrial agricultural / forestry systems. Most stem from control measures, and eradication, if successful, is at a very local level. Many techniques are used in combination, and would not be successful if used alone.

Higher plants

Alien invasive plants are generally eradicated by the use of herbicides and by mechanical or hand-pulling, often in combination. Hand weeding is very labour intensive, but where labour is cheap, can provide a source of employment. This method has particularly been used along rivers (Sandlund *et al.*, 1999). Invasive plants have been successfully eradicated on oceanic islands and on a localised basis in mainland areas.

Insects

There are several examples of successful eradication in mainland areas: economically important fruit flies from several countries (e.g. Chile, Mauritius, Japan); New World screw worm (*Cochliomyia hominivorax*) from North Africa; coconut rhinoceros beetle (*Oryctes rhinoceros*) in the Tonga Islands (pers. comm., Aliens Listserver); boll weevil in the southern USA (Myers *et al.*, 2000).

The main methods of insect eradication are the use of insecticides (both chemical and biological), and through host eradication. Both of these methods are expensive and are mainly confined to agricultural or forestry (see below) systems, where the financial costs of the invasion are high. Another technique having increasing success (particularly with fruit flies) is the method of 'Sterile Insect Release' (SIR) whereby male insects are sterilised (through gamma radiation) and released to mate with wild insects, thus reducing the overall fecundity of the species (Myers *et al.*, 2000; Mack *et al.*, 2000, GISP, 2000a). This is also expensive and confined to agricultural / forestry systems.

Forestry systems

Within forestry, eradication can , in general, only be considered in situations where the pest has not spread far in its initial outbreak. In many cases, eradication requires destruction of the host. In some countries environmental groups have sometimes protested and effectively stopped destruction of host material in an effort to save trees that in fact will die from the infestation and serve as a source for spread of the pest in most cases. For example, in Canada, national park land specifically has a non-intrusive policy developed in response to earlier attempts to control fires and other often-natural phenomena, including pest outbreaks. In contrast, in New Zealand, there is a legal requirement to eradicate alien invasive species from forest systems (P. Warren, pers. comm.).

Vertebrates

The eradication of vertebrates has centred on mammals. Poisons e.g. Brofidacoum, Warfarin etc are widely used (mostly for rodents), but other control methods are being researched, e.g. biological control, fertility control, chemosterilants and new acute poisons. However, at present, the application of rodenticides is the most practical and cost-effective method of control (Buckle, 1983).

Eradication of certain mammal species e.g. goats, cats, rats, has been possible on islands and localised regions of mainland e.g. Australia, New Zealand. However, it is not thought to be possible to eradicate a species with a continental distribution (Pech, 1999).

Amphibians and reptiles

Although there is some information on the threats from non-native invasive frogs globally e.g. Cane toad, there appears to be very little information on the eradication measures for amphibians or reptiles. However, the banjo frog has been eradicated from New Zealand (P. Warren, pers. comm.).

Marine and freshwater

Within marine and freshwater systems, eradication is problematic (Raaymakers, 2000) but not impossible. There are examples of eradication for very localised populations, e.g. the Caribbean black-striped mussel in Australia, and the Assassin weed in California, which were both treated with large doses of chemicals to prevent their spread. This technique is effective in eradicating the undesired organism, but it also has very grave consequences for the native flora and fauna. The long-term consequences of this method is also unknown (Stensones and Garnett, 1994; Myers *et al.*, 2000).

Eradication may be possible in freshwater systems where the invasion is very localised e.g. small lakes, streams (Sandlund *et al.,* 1999), or where the invasive species is, by nature of it's biology / taxa, easier to eradicate, e.g. coypu in the wetlands of the UK (Gosling, 1989).

3.4 CONTROL

In this section, we first give an overview of control measures currently in use and guidelines on best practice. We then review the use of control measures and tools in relation to specific taxa.

3.4.1 Available measures, tools and general guidelines on use

The aim of control projects against alien invasive species has been either to contain the species within a geographical area or to suppress the overall abundance of the species down to some pre-described level where it no longer causes any significant economic, social or ecological damage. The threshold levels used have varied considerably according to the type of ecosystem being invaded (e.g. agricultural, 'natural' etc.) and the nature of the invader; frequently, the threshold is not clear from a reported study but this will be discussed further below. Thus, overall, methods for the assessment of the efficacy and efficiency of the measures and tools used in these projects have also varied in relation to the particular 'systems' that have been targeted.

A broad review of the literature, and existing projects shows that control measures for either containment or suppression can be divided into the following broad categories:

- Physical or mechanical (e.g., mechanical harvesters, hunting, trapping)
- Chemical (e.g., herbicides, insecticides)
- Biological (this includes a number of tools: the introduction, conservation or augmentation of natural enemies, the application of microorganisms as a biopesticide, host plant resistance (HPR), and other tools such as behaviour modifying chemicals (e.g. pheromones), male sterile release and fertility control)
- Habitat management (e.g. crop rotation, nutrient management)
- Integrated pest management, utilising combinations of the above four main measures

For each of these measures, a number of tools have been developed and used in specific environmental circumstances; these will be discussed in more detail below. One feature of all control measures, with the exception of 'introduction' (or 'classical') biological control, which is self-sustaining, require long-term funding and commitment (GISP, 2000a)

Two major world wide web sites now exist for dialogue and the exchange of information on alien invasive species, including appropriate control measures. These are:

ALIENS-L, the listserver of the invasive Species Specialist Group (ISSG) of the IUCN Species Survival Commission. Subscribing may be done by sending a message to Listadmin@indaba.iucn.org, and

Bioinvasions. For this web site, subscribing may be done by sending a message to bioinvasions@iatp.org

Most published records, and experiences of invasive species control come from the agricultural and forestry sectors largely because of the importance of these sectors to national economies. These information sources date back to the beginning of the last century. The experiences in these sectors has provided valuable information on the advantages and disadvantages of particular measures and for some taxa, the 'best method' (i.e. a particular measure or combination of measures) for control have been developed. In addition, a number of international guidelines and/or 'codes of conduct' now exist for chemical and some biological measures. These provide information for countries on the 'best practice' for these measures, based on current technologies; more specific guidelines on the use of these measures against specific taxa also exist and these are described below. The basis for the more general international guidelines include:

Chemical control – Pesticides still remain the most common control measure for most pest species. During the last two decades, global pesticide sales have increased by about 250%. There has also been an increase in the importance of herbicides, mostly at the expense of insecticides (Bateman, 2000). There are many different types of product and many different types of application. Global markets are changing rapidly as relatively newer products become more widely available. In view of the importance of pesticides, the Food and Agriculture Organization of the United Nations (FAO) have produced an international code of conduct on the distribution and use of pesticides (FAO, 1986). The World Health Organization (WHO) and the Organization of Economic Co-operation and Development (OECD) also play important international roles in the harmonisation of regulations for pesticide use. Furthermore, there are a number of texts available on application methods and the safe use of pesticides, e.g. Matthews (1992).

Biological control – The introduction approach ('classical biological control') has been used extensively against weed an insect pests (Greathead and Greathead, 1992; Julien and Griffiths, 1998) The International Plant Protection Convention (IPPC) of the FAO have produced a Code of Conduct for the Import and Release of Exotic Biological Control Agents (IPPC, 1996). These are intended to 'facilitate the safe import, export and release of exotic biological control agents by introducing procedures of an internationally acceptable level for all public and private entities involved, particularly where national legislation to regulate their use does not exist or is inadequate'.

Harmonised data requirements for the import and inundative release of microbial agents for insect and weed control have been developed by the OECD (Sexsmith, 1998) and proposals for similar data requirements for insect agents are also under consideration (G. Hill, pers. comm.).

More generally, IUCN have produced 'Guidelines for the prevention of Biodiversity Loss Caused by Alien Invasive Species' (IUCN, 2000). These are general guidelines, but include comments on best practice in places. The focus is on alien invasive species (resulting from both intentional and unintentional introductions) that threaten biodiversity and not species that have an impact on agriculture, aquaculture, or human health or culture.

Finally, the Global Invasive Species Programme (GISP) have recently produced a draft document on 'Best Prevention and Management Practices for Alien Invasive Species' (GISP, 2000a). This document will finalised and made available on the web in 2001.

3.4.2 Overview of existing measures for control

In the remainder of this section, summary comments are made on each of the major taxa where measures have been implemented. This will also include a brief review of networks and partnerships and research and plans for each of the taxa, where these are relevant. This is because, nationally and internationally, effort on control has been largely taxon based. For convenience, the information groups mentioned above are pooled into terrestrial and aquatic systems.

(i) Invasive species affecting terrestrial systems

Plant Pathogens (fungi, bacteria and viruses)

Some of the damaging invasive species to date are plant pathogens. The major measures used include physical (heat treatment, isolation of the susceptible crop, the use of barriers, and sanitation) chemical control (fungicides), the development of host plant resistance and habitat management (crop rotation, management of nutrients in the soil and water management). These have been developed largely for local pathogens although the techniques also apply to invasive species as well. Most effort has been in commercial agricultural crops in regions such as North America and Western Europe; for example, against the potato blight (*Phytophthora infestans*) (Fry *et al*., 1992). Control in tropical and sub-tropical regions is largely through the same measures, although some tools, e.g. heat treatment of soil, are not usually available to subsistence farmers. Nonetheless, host plant resistance (e.g., cassava against mosaic virus (Thurston, 1973)) has played an important role in tropical regions.

By and large, these measures have proved effective; occasionally some of these measures have been integrated together although there are only a few examples of these, e.g. gray leaf spot (*Cercospora zeae maydis*) of maize in Africa (Ward *et al*., 1997). Most pathogens of tree crops have been controlled using physical and/or chemical measures; host plant resistance has only been used in a few cases because of the difficulty of keeping resistant clones from being attacked by new races of the pathogen that develop over the long life of the trees (Agrios, 1997). An example is the development of resistance in coffee against leaf rust (J. Waller, pers. comm.).

Few invasive pathogens have been targeted in natural habitats. Where these have, projects have used either sanitation and/or fungicides (Evans and Murphy, 1997). The latter have proved effective (e.g. root-rot fungus in Australia, *Phytophthora cinnamomi* (Weste and Marks, 1987)) but only in the short term.

The corner stone of disease management has been host plant resistance, particularly in agricultural crops. This tool, in combination with other measures, is likely to remain important for the foreseeable future. However, there is now an increasing effort to develop ways in which to improve overall crop 'health' to prevent the likelihood of disease problems occurring in the first place. Also, for some agricultural tree crops, recent research is focussing on the use antagonistic microorganisms to compete or exclude invasives, e.g. frosty pod rot (*Moniliophthoran roreri*) of cacao (Evans, in press).

Higher Plants

A wide range of plant species are now invasive and many of these cause damage to agricultural crops and to the natural environment. Most inhabited regions of the globe are now affected by at least one species. For example, of particular significance in the tropical and sub-tropical regions of Asia are New World invaders such as *Lantana camara*, and *Chromolaena odorata*. Control measures and their effectiveness have recently been reviewed by Cronk and Fuller (1995), particularly in the context of natural and semi-natural ecosytems.

The most common physical measure is hand weeding or digging; this has been reported as forming up to 60% of total pre-harvest labour input in the developing world (Webb and Conroy, 1995). Other methods include cutting and slashing. These forms of control have been found to be effective for some species that do not regenerate from shoots. They are also labour intensive. In Florida, Australian pine and other invasive plants were successfully removed from a nature reserve by volunteers (Randall *et al.*, 1997).

Most pesticide use, globally, is directed at weeds, both native and exotic; estimates in 1995 showed that 47% of the world market in pesticides comprise of herbicides (Woodburn, 1995). Herbicides act in different ways, e.g., through foliar contact or systemic action. Many different products are on the market and there are many reported successes of control of a target plant at a local level (e.g *Mikania micrantha* in Malaysia (Teoh *et al.*, 1985)). But, in general, application has been difficult without seriously affecting non-target plant species and other wildlife and herbicides can be expensive. Commonly used herbicides in the past were 2,4-D, and 2,4, 5-T, but these are poisonous to humans and the latter, which is also persistent in the soil, has been banned in at least ten countries. Less persistent, and relatively safer products such as the systemic, glyphosate are now widely available; some such as glyphosate are effective against herbacious plants and some woody species. The latter can be treated either through application to cut surfaces or through bark injection. Cronk and Fuller (1995) discuss methods of application to herbaceous and woody plants.

Much effort has been put into biological control and this has been reviewed by McFadyen (1998) and Julian and Griffiths (1998); the latter authors provide a complete catalogue of projects and their outcome. The major methods employed include the introduction of insects and fungi that have a high degree of host specificity or the augmentation of agents of the same groups, although the latter has been by far the most commonly used tactic. Recent examples include the introduction of a rust fungus into Australia which is having a significant impact on the target invasive weed, the rubber-vine (*Cryptostegia grandiflora*); this weed is invasive in riverine forest habitats (Evans, 2000). Evaluations of the effectiveness of the introduction approach give a success rate of about 33% (e.g. see Williamson and Fitter, 1996); however, in some countries where research effort has been intense, the success has rate has been much higher, e.g. 83% in South Africa (McFadyen, 1998). Some of these projects have been extremely cost effective. Given the possible risks of the introduction approach to agricultural crops and forestry trees, weed biological control workers have traditionally placed much emphasis on host specificity testing. Protocols for this have been published (see Julien and White, 1997). There has been much interest in the development of biopesticides, based on fungal pathogens and a few products are available but these are mostly used in commercial crops. In general, there have been problems in achieving cost effectiveness, and in getting products registered for use in countries because of possible non-target effects.

A few countries have successfully employed habitat management tactics or integrated management for the control of invasive plants. For example, studies on hill tribes that use shifting cultivation, in northeastern India, have found that exotic weeds such as *Mikania micrantha* are kept under control in long fallow cycles (Swamy and Ramakrishnan, 1987).

Nematodes

An increasing number of species, known to be serious pests of plants, are being transported around the world, e.g. *Radopholus similus*, which attacks bananas and plantains, and *Globodera* spp., which attack potatoes (J.Bridge, pers. comm.). As with the other plant pathogens, measures for control are similar and have largely been evolved for native species, but the techniques also apply to invasive species as well. Some measures (e.g. physical control, habitat management) have been mostly developed for soil pest complexes as a whole, rather than for particular pest species; these measures, used individually, or in combination, are commonly used by subsistence farmers and are effective (Bridge, 1996). Nematacides are mostly used in commercially grown crops and less so by small holder farmers in tropical and sub-tropical regions. The use of host plant resistance has been important, but again, is mostly used in commercial crops, e.g. tomato (Luc *et al.*, 1990) where it has proved effective.

An increasing amount of research effort is now being put into host plant resistance and this includes plants used by subsistence farmers. For example, a recent project in Eastern and Southern Africa has being investigating the presence of resistance in the woody legume, Sesbania sesban, which is commonly grown by subsistence farmers in the region (J. Bridge, pers. comm.).

Flat Worms

One prominent invasive species from New Zealand, *Artioposthia triangulata*, and now present in the Republic of Ireland and the UK has highlighted the importance of this group. To date, the focus has been on biological control, using pathogens but the work is only at the research stage (Alford *et al.*, 2000; Read, 2000). There is a guide to information and current research on the world wide web (Read, 2000).

Land Snails

Many species have been spread beyond their natural range. The classical examples are the giant African snail (*Achatina fulica*) and the golden apple snail (*Pomacea canaliculata*). The most common method of control has been to use molluscicides (Godan, 1983). These have been largely developed in North America and Western Europe although they are now available globally. Traditional molluscicides include metaldehyde and carbamate although many other compounds have been, and are still used. These are applied with a bait or incorporated in barriers to protect crops. Some major problems have been the cost of application and the non-target effects of the chemicals, e.g. on mammals that eat the dead snails. The use of molluscicides has also not always been effective in controlling the target species.

Hand picking has been used with success to remove populations of the giant African snail in Florida, USA (Simberloff, 1997).

Biological control has been attempted, notably against the giant African snail on several tropical islands, e.g. Hawaiian islands. Several predatory snails (e.g. *Euglandina rosea*) and a predatory flatworm (*Platydemus manokwari*) have been used in these attempts. Major problems have arisen because the predatory snails, and possibly the flatworm, also attack snails native to the islands and in some cases have driven the species to extinction. The effectiveness of these biological control agents is also very unclear (Civeyrel and Simberloff, 1996).

Molluscicides probably remain the most widely used method of control against snails in general. Potential biological control agents have been reviewed by Godan (1983) and there is still interest in this measure. However, no active projects have been identified.

Insects and Mites

Along with plant pathogens and higher plants, insects are one of the most important groups of alien invasive species, both in terms of number of species and the damage caused to the environment, human and animal health and to trade. Major efforts to develop control measures against invasive species affecting agricultural or forestry crops have been made since the end of the nineteenth century; some of these measures have been extremely effective, e.g. the introduction approach in biological control. Many different measures have been developed and implemented over the last hundred years or so, but these measures have been developed with native and alien invasive species in mind; an exception is the introduction technique in biological control. There is now an enormous literature on all of these measures; Dent (2000) provides a very recent useful overview of current measures. Only recently have control measures been made against invasive species that affect natural or semi-natural ecosystems.

Control projects have included physical, chemical (insecticide), biological, habitat management and virtually all combinations of these. The concept of integrated pest management was developed as a response to the general problem of over insecticide use against insect pests in the 1940/50s (see Stern *et al.*, 1959).

Sanitation techniques have been used with some success to contain or suppress the first stages of invasion of an alien species. Recently, in the USA, sanitation has been used in an attempt to slow down the spread of the Asian longhorned beetle (*Anoplophora glabripennis*). (USDA Forest Service, 2000; USDA-APHIS, 2000b). Likewise, sanitation has been used to contain the hibiscus mealybug (*Maconellicoccus hirsutus*) in the Caribbean and Central America (Anon., 2000a).

The history of the use of insecticides has been well documented (e.g., see Dent, 2000). Organochlorines, such as DDT, developed in the mid-1940s were the first most extensively used group of insecticides. Because of the persistence property of this class of insecticides their use has been banned in most developed countries although they are still used quite frequently in undeveloped countries. Other types of insecticide include the organophosphates, carbamates, pyrethroids, neonicotinoids, insect growth regulators and newer classes (which are mostly neurotoxins), such as second generation neonicotinoids. The organophosphates, developed shortly after the organochlorines, are mostly non- persistent but are highly toxic to a wide range of organisms, including mammals. They have been important, however, in the control of a wide range of agricultural and veterinary insect pests and are still widely in use. The pyrethroids, and to a certain extent, the neonicotinoids, which are now widely available in most regions of the world, have become some of the most popular of the classes of insecticide because they are frequently more efficacious than organophosphates against a wide range of agricultural, horticultural and other pests and they have a low mammalian toxicity. They do present a hazard to other invertebrates, such as natural enemies, and to fish; a result of the former is that secondary pest problems can develop. However, they are very effective classes of insecticide and thus dosages can be kept very low.

One of the main problems with most of the available insecticides is that insect pests have frequently developed resistance; this has been largely through over usage. There is also sometimes public concern over large scale spray programmes, e.g. the control of the medfly (*Ceratitis capitata*) in California in the USA (Carey, 1992). Nonetheless, insecticides have been used successfully to control alien invasive insect species in natural ecosystems, particularly in forest ecosystems, e.g. the gypsy moth and hemlock woolly adelgid in the forests of eastern North America (Speight and Wainhouse, 1989). Recent products, such as the second generation neonicotinoids (e.g. thiamethoxam), also have a low toxicity to mammals, and have the advantage that they can be used at very low dosage rates in the field. Parallel advances have also been made in formulation and application techniques (see Dent, 2000 for an account) and these are also improving the safety of the newer products.

Tools in biological measures have included the use of natural enemies, host plant resistance, behaviour modifying chemicals and male sterile release. The introduction approach, through the release of host specific and screened natural enemies (most commonly insect parasitoids and predators) from the area of origin of the pest, has proven to be particularly efficacious for the control of alien invasive species and has been implemented on many occasions. This approach has recently been reviewed by Bellows *et al.* (1999). A recent example is the introduction of a predatory mite for the control of the cassava green mite (*Mononychellus tanajoa*) in Africa. Initial indications are that the introduction has resulted in the suppression of the green mite and resulted in an increase in crop yields for farmers (Anon., 1998). The success rate (in terms of reported control of the target pest) has not been high but has increased over the last three decades (Greathead and Greathead, 1992). Also the cost:benefit ratio has often been high; For example, in Australia, the cost to benefit ratio has been 1:10.6 (Tisdell, 1990). Substantial successes have also been achieved in natural ecosystems. In the mid- 1990's, the Orthezia scale (*Orthezia insignis*) was successfully controlled in St Helena through the introduction of a predatory coccinellid beetle (Fowler, 1996).

Other biological measures (the conservation and augmentation of insect natural enemies and pathogens, host plant resistance, behaviour modifying chemicals and male sterile release) have not been used to the same extent for the control of alien invasive insects, although in some cases, some significant successes have been achieved. Lack of native natural enemies in the adventive ranges of invasive insects that can adapt to a new host, and the lack technologies for the production of viable biopesticide products has hindered the development of conservation and augmentation biological control. However, some biopesticides are available for the management of forestry pests (e.g. gypsy moth in North America) and research on biopesticides has now reached a point where a diversity of products could become available in the foreseeable future. A major problem in host plant resistance work has been that resistance to insects in plants has frequently been found to be only partial; where it has been used, it has often broken down. Thus research into host plant resistance has tended to take second place to research into either insecticide or biological control through the use of natural enemies.

More progress has been made with behaviour modifying chemicals and male sterile release. The most common examples of the former are insect pheromones: either used for mate disruption or for mass trapping. Success using the mate disruption technique has been reported from Australia where commercial stone fruit growers now use this tool for the control of pests such as the oriental fruit moth (*Cydia molesta*) (CSIRO, 2000a). The male sterile release technique has been used successfully for the control of invasive fruit flies species in the USA and in the Middle East. Research is progressing in both of these fields but viable products take many years to develop, and even after development, are expensive to implement.

Habitat management techniques, such as crop rotation, are commonly used in agriculture for the management of a range of insect pests; however, in natural ecosystems, perhaps the only definite use of these techniques are in forest ecosystems where silvicultural methods are used to prevent population outbreaks.

The general problems of the development of resistance within insect populations as a result of over pesticide use, coupled with the realisation that the use of single control measures are often inadequate to suppress pest species numbers down to densities where they cause no significant damage, has fuelled research into integrated pest management. This measure is now used in many countries for the control of a variety of insect pests. However, there are few definite projects reported on the control of alien invasive species; apart from glasshouse pests in North America and western Europe.

Amphibians

Although there are several invasive species worldwide, the reported control measures are against the cane toad, *Bufo marinus*, in Australia. At a local level, cane toad skins are used commercially for various products such as handbags (Twyford, 1991). A more national effort has focussed on the potential of using biological control with viruses, collected from cane toads in their natural range in Venezuela. This work has recently been conducted by the Commonwealth Scientific and Industrial Research Organization (CSIRO) Australian Animal Health Laboratory. While it was found that the viruses were lethal to the immature stages of cane toads, they were also lethal to at least one species of native frog. Although these viruses will not be used as biological control agents, work will continue into biological control possibilities (Tyler, 1996; CSIRO, 2000b).

Reptiles

As with amphibians, there are only reported measures against one species, the brown tree snake, *Boiga irregularis*. In Guam, funnel traps have been successfully used, baited with live common quail (Savidge, 1987) The traps have also been reported to be equally successful if the droppings of these birds are used.

More recent attempts are examining the potential of biological control with pathogens but this is at the research stage only and little information is available.

The work is being coordinated by the US Geological Survey, Midcontinent Ecological Science Center. They have an information sheet on the web (USGS, 2000a).

Birds

Many bird species have been reported as 'pests', but few of these are alien invasive species. Indeed, on the whole, little effort has been made to control birds, despite the fact that they can cause serious economic damage to crops and be a disturbance in natural habitats (Lever, 1994). Physical measures have included hunting and relocation of populations. The former has been used in several countries; in Australia, it is reported as a 'casual' form of control for a range of species (Newsome and Noble, 1986). In the UK, populations of Canada geese (*Branta canadesis*) have been relocated, but without much success as this just transfers the problem elsewhere. Fences have also been used to exclude Canada geese from crops; this is effective but impractical because of the impracticability of the technique at many sites and the cost (Watola *et al.*, 1996)

Current research in the UK for the control of geese populations is being directed at the development of integrated control strategies, based on culling, the use of non-lethal chemical repellents and habitat management (Watola *et al.*, 1996)

At the international level, Bird Life International (BLI) coordinate monitoring and research work on birds. BLI have produced a monograph on invasive bird species.

Mammals

Many species were originally introduced for hunting, for the fur trade, as biological control agents or for other purposes; other species, notably rodents, have been accidentally introduced. Control measures used to date are mainly physical or chemical. Exclusion, using fences has been used with effect for relatively small areas on islands, e.g. for the control of pigs and deer on Mauritius (Mungroo, 1999). Hunting and trapping techniques have been used in many countries, e.g. red deer and possums (*Trichosurus vulpecula*) in New Zealand (Mack *et al.*, 2000); in some situations this can reduce the density of the invasive as in the case of the red deer in New Zealand (P. Warren, pers comm.). However, goats have been successfully removed from some of the islands of the Galapagos (see Eradication in this review).

Chemical control has involved the use of poison baits. These are frequently used against rodents (Meehan, 1984), and include anticoagulants (e.g. warfarin), which are the most common, and other compounds such as alphachloralose. Baits are also used for the control of deer and possums in New Zealand (Clout, 1999). The problems with these chemicals are their relatively high cost, development of resistance, toxic effects on other animals and the general problem of public acceptance. Rodenticide baits (containing brodifacoum) have been successfully used to eradicate rats from the Channel islands (see Eradication in this review). Nonetheless, public concern over the use of chemicals for mammal control has fuelled new research in biological control.

Biological control has been attempted against some species. Early attempts involved the introduction of species such as the stoat into New Zealand for the control of rodents. These efforts were unsuccessful because of the polyphagous nature of these vertebrate predators and the technique has been stopped. However, host specific viruses have been used successfully on at least a couple of occasions. The most well reported example is that of a myxoma virus for the control of the European rabbit (*Oryctolagus cuniculus*) (Fenner and Myers, 1978). More recent work on viruses in Australasia has now raised public concern over pathogens (Anon., 2000b).

New research in biological control is focussing on fertility control. This work is largely being developed in New Zealand and the USA. The principal focus is on immunocontraception but other techniques are possible such as hormonal contraception (Anon., 2000b). In California, USA, the immunocontraceptive method, administered through a vaccine, has been used successfully in domestic and semi-captive wild horses (*Equus caballus*). This approach is now being developed for rabbits, foxes (*Vulpes vulpes*), and mice (*Mus domesticus*) in Australia by the Pest Animal Control Cooperative Research Centre (PAC CRC), and for possums in New Zealand in a cooperative programme involving Landcare Research, New Zealand and the Cooperative Research Centre for the Conservation and Management of Marsupials in Australia (Anon., 2000b). Particular consideration is being given to delivery systems for the vaccines in these populations of mammals. Models in this field of work suggest that these techniques will not control mammal populations without other interventions. Work on mice in Australia is attempting to combine biological control with best farm practices (Singleton and Brown, 1999).

(ii) Invasive species affecting aquatic systems

Macroalgae

Because of the continuous nature of the sea as a medium and the use of planktonic life-stages as a dispersal mechanism by most marine species, the opportunities for effective containment and suppression of introduced marine species are orders of magnitude less than for terrestrial species.

There are only a few cases on record and this includes the use of a biocide against a 'contained' population of the alga *Caulerpa taxifolia* in an enclosed bay in California in 2000 (Raaymakers, 2000). There are already toxic effects in the local environment as a result of the application but the extent of these, and the effectiveness of the control are unknown.

New Zealand has developed a management plan to control the spread of the Asian Kelp *Undaria pinnatifida*, which is already widely spread in the south of the North Island and north of the South Island. The effectiveness of the plan remains to be seen.

Higher Plants

The measures discussed under this group for terrestrial systems, also apply to aquatic plants. Examples of projects are given in Tables 7.3.4.1 –7.3.4.3.

Comb jellies

The Atlantic comb jelly, *Mnemiopsis leidyi*, is a serious invader of the Black, Azov, Marmara and Mediterranean Seas. There are no physical or chemical measures available for this creature; the use of nets is considered to be inappropriate, as damaged ctenophores heal quickly (McEnnulty *et al.*, 2000).

Biological control is considered to be the only practical solution to the problem (GESAMP, 1997). Ideas include: enhancing native fish populations that feed or compete with the comb jelly; or to introduce a specific predator or parasite. Although there are several candidate predators, concern has been expressed about this strategy because of possible non-target effects (McEnnulty *et al.*, 2000). A collaborative project between the University of Delaware College of Marine Studies and the Middle East Technical University Institute of Marine Sciences in Turkey is looking at bacteria from *M. leidyi* in the Black Sea and the Mediterranean (Anon., 1999a).

Bristle worms

The species, *Sabella spallanzanii*, has been invasive around Australia for about four decades. Control measures are being developed in Australia as no measures were found in the literature (see McEnnulty *et al.*, 2000). Physical removal by divers has been attempted and found to be effective, but for small areas only. This is most effective if a population is detected before reproduction has occurred. Dredgers have not been recommended because they may fragment the worms; *S. spallanzanii* can regenerate damaged body parts. Hot water application could have potential in harbour areas to clean equipment. Chemical control is being considered although no active work is reported; Reish and Gerlinger (1997) review the possibilities for native polychaetes in North America. Copper has been identified as one agent that might have potential.

Biological control, through the introduction of agents is also being considered. A wide range of potential agents (parasites and predators) are known but research is needed on the efficacy of this approach.

The work is coordinated by CSIRO's Centre for Research on Introduced Marine Pests, Tasmania.

Crabs

The European green crab, *Carcinus maenas* has become invasive on both coasts of North America, and South Africa, Australia and Japan. A review of control measures is provided by McEnnulty *et al.* (2000) Several physical tools have been suggested for the control of this crab, e.g. trapping, physical barriers, electrical pulses and the development of a crab fishery, but only trapping has been implemented to any extent in the adventive range of the species. However, the traps have not proved efficient, as, in general, they do not seem to have much impact on population structure in fairly open areas.

Chemical control, possibly using carbaryl (a broad spectrum organocarbamate, developed for insect control) is being considered in some countries because this biocide is routinely used for control of other crustaceans on oyster beds in the USA. The effects of carbaryl on non-target species has been studied in the terrestrial environment and in general, it has been found to have a relatively low toxicity in mammals and arthropods, although some species of arthropod can be affected in the short team.

Biological control studies have been carried out in the USA and in Australia. There are many predators, parasites and pathogens which are known to attack *C. maenas*. Major techniques suggested include the introduction of agents and the enhancement of native predator populations. No work has been done on the latter technique. Research on the introduction of agents has focussed on parasites. A rhizocephalan (barnacle) parasitic castrator from Europe has been found to infect native Australian crabs as well as C. maenas in laboratory trials. This has raised questions about non-target effects should this species be used in Australia. In the USA, at the University of California, work is being conducted on the parasitic barnacle to determine its likely effects on native crabs there (Anon., 1999a). Other microorganisms are also being investigated for their biological control potential.

Water Snails

Some species, such as *Biomphalaria glabrata*, which one of the vectors of *Schistosoma mansoni,* now have wide distributions. Control measures have been developed with native freshwater species in mind and these include chemical and biological techniques. There are several molluscicides for use against freshwater snails (e.g. Niclosamide, NaPCP), and these are generally effective but most suffer from being toxic to other organisms (Godan, 1983).

The control of the snail vectors of schistosomes, using other snails as competitors or predators is reported as successful. For example, *Biomphalaria glabrata* has been displaced by the introduction of competitor snails in parts of the West Indies (Pointier *et al.*, 1991). Concern about this approach, because of possible unknown non-target effects, has been expressed by some researchers via the Aliens listserver.

Mussels

A number of species of mussel have become invasive in tidal, estuarine, marine and freshwater systems. Notable examples include black striped mussel (*Mytilopsis* sp.) which has invaded the coastal systems of a number of countries in the East; e.g. India, Taiwan, Japan and Australia. There is also the zebra mussel (*Dreissena polymorpha*), which has invaded the Great Lakes systems in North America. Several measures, each involving a variety of tools, have been used to control invasive mussel species and these are reviewed by McEnnulty *et al.* (2000). The use of a particular tool has depended on habitat of the target species and the likely impact on the environment. Physical control tools have included manual or mechanical collection, filters, temperature treatment, salinity manipulation, desiccation, oxygen deprivation, electric current protection, ultraviolet light treatment and water flow velocities. Collection techniques have proved effective for small populations; e.g. *Perna canaliculus* was successfully removed from a shipping canal in South Australia. Dredging is not recommended as this can disturb the bottom substrate and make it unsuitable for other organisms. Other physical tools have been used with effect in more specialised situations, e.g. filters and thermal shock have been used to control *D. polymorpha* in hydroelectric stations in the USA.

Chemical control, particularly the use of chlorine, has proved to most effective in enclosed water systems such as pipes. For example this measure is frequently used to control *D. polymorpha* in the USA and in Europe. Other chemicals (e.g. copper sulphate) have been used, but to a much lesser extent. The problems with chlorine are its broad toxicity and maintaining high concentrations in warm, shallow water systems. New legislation on effluent discharge in some countries (e.g. the USA) may make the use of chlorine more difficult. Chemical control was successfully used to eradicate *Mytilopsis* sp. from marinas in northern Australia (McEnnulty *et al.*, 2000).

Biological control has been considered in the literature. The introduction of parasites has received particular interest. There has been research on the impact of native predators on *D. polymorpha* in North America (e.g. see French and Morgan, 1995) but the impact of these predators has proved to minimal; they usually prefer thinner-shelled native invertebrates to the invasive bivalves.

Starfish

Reported work (see McEnnulty *et al.*, 2000) is on the northern Pacific seastar (*Asterias amurensis*) which has become a particular problem along parts of the coast of southeast Australia. Current measures include physical and chemical control. The latter has included manual removal and trapping: attempts were made by divers in 1993 to collect seastars off the coast of Tasmania, but this was ineffective because it was only possible to remove a fraction of the population; trapping has also proved ineffective. Chemical control, using quicklime has been used in Korea. In Australia, trials have been conducted with this chemical but the results were not promising as it was found that the seastars need to be in contact with quicklime for long periods for it to be effective.

Current opinion on these measures is that both are likely to be useful, but only in small areas, e.g. around marine farms. Other physical measures are being considered such as the use of seastar 'mops', but the impact on native seastars needs to be assessed. Biological control, using the introduction of agents, the use of natural chemicals or the genetic or molecular manipulation of seastar physiology, is being researched in Australia. Habitat manipulation is also being considered.

Most of the research and trials in Australia is being conducted by CSIRO's Centre for Research on Introduced Marine Pests (CRIMP), Tasmania. A draft review on 'best methods' has been produced by McEnnulty *et al.* (2000) and is available on the web for comment and input.

Fish

Around the world fish have introduced into lakes and rivers, accidentally, or for sport, aquaculture, water treatment and other purposes; many species have now become problematic in these water systems (Lever, 1994). Fish control measures have been discussed and summarised by Meronek *et al.* (1996) and McEnnulty *et al.* (2000). Generally, physical tools such as traps or nets are largely ineffective because frequently they do not capture sufficient individuals and/or they are too costly to implement. Electro- fishing has been used in freshwater to control carp but there is no information on how effective this technique is. Barriers are being used to some effect in the river systems of the Great Lakes in North America to restrict the movement of sea lampreys. (*Petromyzon marinus*) (Marqette Research Station, 2000).

Chemical control techniques have been used for several decades. The most commonly used piscicide has been rotenone; e.g. this has been used successfully to control small populations of European carp (*Cyprinus carpus*) in Australia and predatory invasive species, such as white bass *(Morone chrysops)* in Californian reservoirs (see Barnham, 1998). However, rotenone is toxic to other fish and to some freshwater invertebrates and can persist in water; rotenone can also effect human health. Other more modern piscicides are in use in Australia and the USA. In the USA, TFM (3-trifluoromethyl-4-nitrophenol) and Bayluscide are registered for use against sea lampreys only; the former has been used to control sea lampreys in Canadian freshwater systems. TFM is fairly specific and meets all the safety requirements of the American EPA. None of these chemicals are effective in water systems with strong currents.

Biological control work is still at the research stage. Work in Australia is investigating the use of introduced viruses; initial work on a rabies – like virus was stopped because of possible risks to other fish. More generally, other fish have been introduced to control others but this has rarely been effective.

McEnnulty *et al.* (2000) report that CSIRO are currently involved in a multi-divisional effort to develop repressible sterility techniques with applications currently directed at zebrafish and Pacific oysters; the former is acting as a model for carp (also see Thresher and Grewe, 1998, and mammal control in this review).

3.5 NETWORKS / PARTNERSHIPS / SOCIETIES / WORKING GROUPS

3.5.1 General networks and partnerships

In this section we cover initiatives, either at the international or national levels, which are engaged in some kind of activity related to the prevention or management of alien invasive species from several species taxa.

At the international level, the Global Invasive Species Programme (GISP) was started in 1997. GISP is managed by the World Conservation Union (IUCN), CABI Bioscience, the United Nations Environment Programme (UNEP), and the Scientific Committee on Problems in the Environment (SCOPE). GISP is part of the DIVERSITAS programme of UNESCO. GISP operates on the contributions of an international team of biologists, natural resource managers, economists, lawyers and policy makers. The Programme's goal is to enable local, national, and multi- national communities to draw on the best available tools to immediately improve alien invasive prevention and management systems, and to identify priorities and lay the groundwork for new tools in science, information management, education, and policy that must be developed through collaborative international action. GISP has been organised under ten activities; one of these has been to produce a toolkit of 'Best Management Practices for Alien Invasive Species' A draft of this toolkit (GISP, 2000a) was presented at a GISP Synthesis Workshop, held in Cape Town, South Africa in September 2000. The toolkit will now be finalised and published in 2001; it will also be put onto the world wide web.

Information on the identification of invasive species and the problems they can cause, can be found on many websites, e.g. USDA-APHIS (2000a). Some species, particularly plant pathogens, can often be hard to identify, so early detection is very difficult, e.g., Karnal Bunt (USDA-APHIS, 2000c).

There are some examples for which a particular approach to management is the topic of the network or conference. For example, there is going to be a conference on 'Eradication' methods and their efficiency later this year (2000) in Auckland, New Zealand which will cover all taxa of alien invasive species.

There are several examples of nationally coordinated efforts. For example, in the USA there are linkages between the National Parks (USA) and the Biological Resources Division of the US Geological Survey, the Servicewide Inventory and Monitoring Programme. The Federal Interagency Committee for the Management of Exotic and Noxious Weeds has a "Strategy

For Containment And Control Of Harmful Non-indigenous Plant Species" which gives guidance on early detection through education and public awareness.

On the state level, Hawaii has the 'Cooperative Extension Service' which, together with associated field agents from other agricultural agencies, is dedicated to the early detection of pests, the compilation of pest information and the provision of advice to field practitioners (Holt, 1999) There is apparently no equivalent within natural systems.

The US Fish and Wildlife Service (FWS) and the Ontario Ministry of Natural Resources have carried out joint surveillance e.g. ruffe, Great Lakes (Busiahn, 1996).

3.5.2 Joint efforts by field of specialisation

Most network and/or partnership initiatives against invasive species fall into one of two categories: economic/environment based (e.g., plant protection) or, management measure based (e.g. biological control). Within these categories, these initiatives can take several forms, from specific projects to activities coordinated by international organisations or societies. Several organisations and societies exist which provide mechanisms and forums for information exchange and for the operation of working groups (mostly on methods and standards) on particular control measures.

(i) Economic and environment based initiatives

Plant protection

The International Plant Protection Convention provides information through its information office and its web site, located at FAO's web site (FAO, 2000). The Secretariat hosts the global network of member countries at their annual meeting of the Interim Committee on Phytosanitary Measures, as well as a number of panels and working groups. FAO carries out other programmes in plant health including crop protection, Integrated Pest Management, migratory pest control, and emergency support and technical cooperation.

On a regional basis, the European and Mediterranean Plant Protection Organization (EPPO), together with CAB International, have produced an extensive series of data sheets on 'quarantine pests' for Europe potentially injurious to plants or plant products (Smith *et al.*, 1992). 'Quarantine pest' is defined in the IPPC as 'a pest of potential national economic importance to the country endangered thereby and not yet present there, or present but not widely distributed and being actively controlled'. The data sheets cover fungi, viruses, bacteria, insects and nematodes. Methods of control, where known, are included.

EPPO is also a leader in providing notice of new pests through its Pest Alert service (EPPO, 2000b). The North American Plant Protection Organization (NAPPO) has recently begun a similar system (NAPPO, 2000a). Other regional plant health organisations, including Organismo Internacional Regional de Sanidad Agropecuaria (ORISA) and Comite de Sanidad Vegetal del Cono Sur (COSAVE), also provide information, via web sites, on regional standards, treatments, research, projects and other items of interest (OIRSA, 2000; COSAVE, 2000).

A journal for plant health practitioners is being published by the American Phytopathological Society. *Plant Health Progress* has a partnership arrangement with other professional societies and covers the range of issues in plant health (see Plant Health, 2000)

In forestry, the International Union of Forest Research Organizations (IUFRO), with its secretariat based in Austria, coordinates working groups which cover a range of topics in forestry; some of these cover control measures for pathogen and insect pests, including invasive species.

Several 'plant based' international congresses, which are held on a regular basis, provide a forum for scientists to exchange information on invasive species. Notable ones include the International Plant Protection Congress and the World Forestry Congress.

Animal health

The Office International Des Epizooties (OIE), is the world organization for animal health. Within this international organization are working groups for particular topics. In addition to traditional livestock and poultry diseases, OIE works with aquatic animal health and wildlife translocation issues (OIE, 2000b, 2000c).

Industry also is involved in improving prevention measures for animal health. In 2001 the Animal Transportation Association (AATA, 2000) is holding a conference for world port veterinarians to discuss biosafety, equipment, and staff issues in animal transport.

Marine

The International Maritime Organization, based in London, UK, covers all aspects of marine issues related to shipping. Also, the FAO Fisheries Division, Rome, Italy has a database which covers invasive species and their control. In Australia, the CSIRO Centre for Research on Introduced Marine Pests (CRIMP), in collaboration with scientists in Japan, Russia, Europe and the USA are currently investigating the biological control of two widely distributed marine invasives: the northern Pacific seastar (Asterias *amurensis*) and the European green crab (*Carcinus maenas*). This is the first major international collaboration for the control of marine invasives.

The shipping industry has been very active in helping to address invasive marine species and participates actively in the IMO Marine Environment Protection Committee (MEPC) Ballast Water Working Group. In particular, the International Chamber of Shipping (ICS) and the International Association of Independent Tanker Owners (INTERTANKO) have published an excellent Model Ballast Water Management Plan. This gives practical guidance for the implementation of the IMO voluntary guidelines on board ships.

The GloBallast programme has a major focus on improving networks and partnerships, is establishing a global information resource centre and web-site and publishes a quarterly newsletter updating latest developments in the area of ballast water management which has a global circulation of 15,000. As the GloBallast programme proceeds, networks and partnerships will be developed in each developing region represented by the six initial demonstration sites, including replication of these sites (Raaymakers, 2000).

The Smithsonian Environmental Research Centre (SERC) in Maryland, USA is establishing the Aquatic Invasions Research Directory (AIRD) (see SERC, 2000)

Finally, a number or regional networks and partnerships have been established, including Baltic Research Network on Invasions and Introductions (see BRNII, 2000), the European Union Concerted Action Programme (see EUCAP, 2000), and the Russian Group on Aquatic Alien Species (see RGAAS, 2000).

(ii) Management measure based initiatives

Biological control

The International Organization for Biological Control (IOBC) is a global organization but is split into regional sections. IOBC's mandate covers all species taxa but to date, the focus of the working groups has been on weed and insect pests. For example, IOBC has a global working group on the alien invasive weeds *Chromolaena odorata* and the water hyacinth (*Eichhornia crassipes*), and on several invasive alien insect pests.

CAB International (CABI), partner in GISP, has provided since 1927 a non-profit, international service in biological control of invasive alien pests, with an emphasis on the needs of developing countries and agricultural and environmental weeds and insect pests. Assistance is given to national programmes in evaluating invasive species and in determining prospects for biological control, including exploration, safety testing of natural enemies, evaluation of programmes and policy support. This service operates out of Centres in tropical America, Africa, Asia and Europe.

The International Symposium on Biological Control of Weeds holds regular meetings.

Integrated Pest Management

For integrated pest management, the Consortium for Integrated Crop Protection, in the USA, provides a database on IPM resources for practitioners (Consortium for International Crop Protection, 2000); they also publish an international journal 'IPM Net News'.

General

At the international level, there are several regular international congresses which cover control measures, including measures for invasive species. Prominent ones include: the International Weed Science Congress, and the International Congress of Entomology.

At the national level, many scientific societies actively encourage the development of control measures for invasive species. These societies frequently have an international membership. One example is the Association of Applied Biologists (AAB), based in the UK.

4. CAPACITIES, SYNERGIES AND GAPS IN PREVENTION AND MANAGEMENT

4.1 CAPACITIES AND GAPS IN MEASURES AND TOOLS

The extent of use of available measures and tools and their limitations in relation to species taxa for terrestrial and aquatic systems are summarised in Tables 7.4.1 and 7.4.2. The tables also give an indication of significant research on particular tools. Here we focus on some selected generic points.

A number of new tools and technologies and the refinement of existing ones are supporting prevention, detection, eradication and control. Currently, the application of these tools is very patchy on a global basis, but successes in the prevention and management of alien invasive species are significant and provide a good platform on which to build future efforts.

In prevention, most tools including risk assessment have been applied on the criteria of economically important agricultural systems and have ignored natural systems in the past. The lack of pathway analysis has already been cited as a gap in prevention programmes. For example, in the forestry sector the lack of intelligence regarding what pests are present and their behaviour in other countries has plagued even the larger, better-funded forest services in the world. Each entry of a new forest pest has traditionally been treated in an isolated, ad hoc manner without an understanding of the risk in advance or the tolls to detect the species early on. The reactive control programmes often come too late.

Ironically, gaps in prevention tools are being created by the elimination of fumigants and pesticides due to environmental concerns. This is true for agricultural trade, a major pathway for potential introductions, because of the loss of Methyl Bromide (MB); although its use has increased in some countries, e.g. China. Through the Montreal Protocol, countries have agreed to phase out use of Methyl Bromide entirely in developed countries by 2005. An exception exists for Quarantine Pre-shipment treatments; but even with this exemption some countries will lose the use of MB because it will not be re-registered as a pesticide; sources of MB are disappearing and prices are increasing by 40 to 50%. In some countries (e.g. Canada) court cases against the use of the chemical due to health concerns as well as environmental objections have stopped its use already, particularly near schools. Without MB treatment for a number of pest/commodity combinations do not exist when they are discovered upon arrival to the importing country (e.g. Batchelor, 2000).

The same devastating loss of a tool is coming up for marine systems, in which hull fouling is a major means for transfer of maritime organisms along shipping routes. Traditionally, antifoulant paint has been a means for control of hull fouling along with physical scrapping of the hull. The most effective active ingredient in antifoulant paint by far is Tributyltin (TBT). This chemical is being banned due to environmental impact to non-target organisms under recommendation by the Marine Environmental Protection Committee (MEPC) of the International Maritime Organization (IMO). Alternatives do not exist for this important pathway control.

Many tools exist for early detection and eradication, although for some taxa, urgent work on new methods are required. Effective attractants do not exist for some species of particular concern; for example, in forestry, there are no good attractants for the Asian longhorned beetle which has invaded the forests of Western Europe and North America during the last five years. However, the main problems with these measures is that many countries, particularly in the developing world, do not have the technical knowledge, or the necessary infrastructures, or the policy support to be able to effect early detection and eradication programmes.

Much capacity in control measures exist for some species taxa; this is particularly true for species that are a problem in the agriculture, forestry and livestock sectors; some control measures have been researched and used for over a century, e.g. physical, chemical and introduction biological control measures.

The most commonly used control measure in all systems is the use of pesticides. This is frequently the only option available to control workers in some countries. In many situations, the older generation of persistent, broad spectrum compounds, or compounds with high mammalian toxicity are used because these are still readily available and cheap to purchase. However, this has been, and is, a rapidly developing field and many other classes of less persistent and safer pesticides have been developed and some products are also now widely available in most regions of the world. Advances have also been made in formulation and application techniques which further improves the safety of the newer classes of compounds. Recognising that pesticides do have a useful role in some IPM programmes, some workers are now developing the concept of 'rational pesticide use' (e.g. Bateman, 2000); this involves minimum usage with maximum impact.

Low technology, physical control measures are readily available in most countries and have proved effective in some instances, for example, against weeds. Nonetheless, these methods often require a high input, in terms of labour, if they are to be effective.

Significant capacity now exists in introduction biological control in the agricultural and forestry sectors of many countries and this measure has proved to be highly cost-effective in insect and weed projects. The approach has also been used, albeit on a limited number of occasions, but with great success to control invasives in natural ecosystems. The approach is limited by the idiosyncratic nature of each new project and the generally long research period needed to identify and screen suitable exotic agents for introduction. Although in the earlier history of introduction biological control, generalist predators were used in some projects in terrestrial systems, few countries would contemplate such an approach now. However, there have been recent concerns, in terrestrial and aquatic systems, about the possible non-target effects of carefully selected agents with narrow host specificity, but new research is now addressing these points.

Biopesticides are used to a limited extent for the control of weeds and insects. There has considerable progress on formulation and application techniques but the level adoption is low, especially in developing countries. The main problems relate to general lack of expertise, proper investment and the need for a multi-disciplinary approach to develop a biopesticide from start to finish. Some countries are also concerned about non-target effects, and thus registration of some products has been difficult.

Other biologically based methods are also important and again, much capacity exists for the management of particular taxa. Host plant resistance has been used for the management of a range of plant pathogens (viruses, bacteria, fungi and nematodes) to great effect in agriculture. But this method has seriously lagged in insect control largely because of the partial nature of resistance in many plants to insects and the long research time to develop resistant cultivars for field testing.

Sterile male release and behaviour modifying chemicals have proved effective for the control of some invasive insect species but the technologies are expensive to develop and implement and thus have been limited to a few species to date. Tremendous advances are being made in research into mammalian biological control, through fertility control and the challenge now is to develop suitable delivery systems.

Integrated pest management (IPM) technologies, with an emphasis on a reduction in pesticide use, have been developed most strongly for the management of insect pest problems in agriculture. These technologies are frequently directed at a complex of pests that affect a particular crop system. Good progress has been made in implementation but uptake in the developing world is still relatively poor. Much research is now being directed at this problem, particularly on farmer needs and technology transfer systems. Until recently, much of the effort was based on IPM for arthropods, where pesticides still frequently dominate. Attempts are being made to develop IPM technologies for species in other taxa (e.g. mammals); these technologies have not been found to be very useful. New research is focussing more on biological control as a basis for IPM, particularly for mammals and birds. As experience accumulates for all the taxa, it is becoming consistently apparent that integrated approaches, for example IPM, provides the most practical solution.

The threat posed to natural or semi-natural ecosystems by alien invasive species has only been recognised relatively recently and thus much work on prevention and management measures for these species is fairly new in comparison with that on agricultural systems. Thus, although many of the measures and tools are suitable for use against a range of taxa in natural ecosystems, little practical implementation has taken place. For some invasive species in these systems, there are currently few available effective measures, e.g. for amphibians, reptiles and birds.

4.2 CAPACITIES, SYNERGIES AND GAPS IN NETWORKS AND PARTNERSHIPS

There are a vast array of collaborative activities and initiatives, which address in some part the prevention and management of invasive species; these have developed during the course of the last century in response to the problem of pests as a whole, in agricultural, forestry or livestock systems. These partnerships have rarely included links to environment sectors.

With few exceptions, strong networks exist within each area of concern. International organisations such as the OIE, IMO and IPPC have been working with member countries for often fifty years to implement regulations affecting the environment. The experiences in implementation and operating procedures of these groups were largely ignored by environmental initiatives. Communication among these groups is currently on the rise.

Collaboration between ecologists and regulating officials has altered the prevention and management of weeds. In the past, the best practice for risk assessment of the potential of a plant to become a weed in the importing country was to review literature on weeds of the world. This relied on publication of the information, but also overlooked the change in behaviour that accompanies plants introduced to a new and often disturbed environment. Now several countries have screening mechanisms for plants that may become weeds in order to properly design prevention and control programmes (Reichard, 2000; Tucker and Richardson, 1995).

Design of eradication programmes of alien invasive species has benefited from the research on extinction of native species, since "extinction" is the goal of this management method on the localised or even country level. Species whose populations cluster are better detected with tools from ecological research. This application has emerged as a field in of itself in the form of invasion biology (Liebhold, 2000).

Technologies developed for other purposes are supporting the detection and management of invasive species. Remote sensing has been successfully employed in projects for control of noxious weeds in the western states, insect infestation in forests, aquatic weed in Texas waterways, and the spread of Chinese Tamarisk (*Tamarix chinensis*) in the USA (Greenfield, 2000). In this case invasive species programmes are benefiting from years of plant health activities. These technologies (e.g. GIS, remote sensing) have been employed in animal health projects as well, and are applied to wild life situations with increasing frequency (Freier, 2000).

Some countries that have developed particular strengths in invasive species management have formed partnerships that build on each other's expertise; e.g. Australia and New Zealand have a collaborative programme to develop fertility control in mammals.

The exchange of knowledge and experiences between agricultural and environmental sectors is generally on an ad hoc basis. Despite the advances noted, experts from across fields rarely share from lessons learned, particularly between natural and cultivated terrestrial systems or between terrestrial and aquatic ones. Regulating agencies urgently need training and funding to expand their activities to prevention, detection and management of alien invasive species beyond the historic trade based plants and animals and their pests and diseases.

Nonetheless, the Global Invasive Species Programme (GISP) is providing new opportunities for workers in the agricultural/forestry/livestock sectors to come together with those from the environmental sector to share experiences for mutual benefit; e.g. traditionally the agricultural sector has focused on the development of control methods for invasive species, while work in the environmental sector highlights the need to understand the role of pathways of movement of invasive species in order to implement control measures effectively. As part of this process, the "Global Strategy on Invasive Alien Species" will be published in 2001 and made available to countries.

5. CONCLUSIONS

Article 8(h) of the Convention on Biological Diversity states that:

> Each Contracting Party shall, as far as possible and as appropriate:
>
> (Prevent the introduction of, control or eradicate those alien species
>
> which threaten ecosystems, habitats or species.

This paper provides an overview of existing activities and programmes for prevention, early detection, eradication and control of alien invasive species. Although no attempt is made to determine the efficiency (or cost effectiveness) of these measures, a sense of the efficacy or biological effectiveness is given. General conclusions based on the evidence presented in this review are:

- Many tools and technologies are available for the prevention and management of alien invasive species. The application of these tools is very patchy on a global basis, but successes in prevention and management are significant and provide a good platform on which to build future efforts. Practical and viable solutions need to be available to countries that frequently do not have the resources or infrastructure to prevent or deal with severe invasive species problems.

- Basic biological knowledge (e.g. taxonomy) must be combined with evolving technologies and tools for prevention and management. These measures rely heavily on the existence of reliable and taxonomically comprehensive data.

- Prevention of an introduction or eradication of any invasion that does occur is recommended, but there is less experience and fewer tools or measures for achieving these goals than for on-going control. All of these approaches rely heavily on detection measures, which are also limited in availability for some taxa.

- Eradication is most feasible for invasions over a small area and when action is taken early in the establishment process. Frequently pesticides provide the only immediate means of control. Because they are easily applied and often inexpensive to buy, this option is frequently used.

- Frequently action against invasive species needs to be immediate, therefore pesticide use has an important role for the eradication or control of some taxa. This should be on a rational basis that maximises impact while minimising use. Institutions are more likely to achieve this working from contingency plans developed in advance than from a reactive stance at the time of an emergency.

- Long term sustainable solutions, such as biological control measures, frequently require a long research period before implementation can begin and are sometimes expensive to develop. In some methods of biological control, workers studying different taxa are now sharing common experiences. For example, in the introduction approach, more attention is being paid to possible non-target effects of introduced agents because of mistakes made in the past.

- Whilst some measures, such as the introduction approach in biological control, can by themselves provide solutions, it is more often the case that a combination of measures (e.g. pesticides, biological control, physical control) is needed to satisfactorily solve invasive species problems on a long-term sustainable basis. This implies a complexity in the solutions that will require greater capacity in design, management and evaluation of future programmes. Components should be environmentally benign. This will require co-operation among funding agencies and researchers to set environmental quality as a priority.

- For the purpose of control, IPM needs to be developed in the context of the biology of the taxa rather than on any single paradigm.

- Physical control and habitat management measures frequently require high levels of input but nonetheless can form an important part of IPM programmes; physical control measures are particularly appropriate for isolated populations of invasive species.

- Measures such as pathway analysis, prediction of spread of an invasion, or the introduction approach in biological control stand to have significant impact as they are particularly appropriate for invasive species problems. However, progress in such areas would benefit from greater interaction between workers dealing with different taxa.

- Environmental and agricultural/forestry/livestock sectors need to take advantage of each other's expertise by forming stronger partnerships. Some tools can benefit from exchange between terrestrial and aquatic based research and implementation experiences.

- One of the most valuable contributions to invasive species management is from groups developing toolkits (e.g. McEnnulty *et al.*, 2000; GISP, 2000a). This enables countries with little expertise or few resources to tap into the global knowledge base and to copy or adapt tools as necessary.

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7. ANNEXES

7.1 GLOSSARY OF TERMS

TERM	DEFINITION
Alien invasive species	An alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity. [1]
Alien species	(Non-native, non-indigenous, foreign, exotic) means a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes or propagule of such species that might survive and subsequently reproduce. 1
Containment	Application of phytosanitary measures in and around an infested area to prevent spread of a pest.[2]
Control (of a pest)	Suppression, containment or eradication of a pest population. [2]
Ecosystem	A complex of organisms and their environment, interacting as a defined ecological unit (natural or modified by human activity, e.g. agroecosystem), irrespective of political boundaries. [2]
Eradication	Elimination of the entire population of an alien species, including any resting stages, in the managed area. Application of phytosanitary measures to eliminate a pest from an area. [2]
Invasive alien species	Organisms (usually transported by humans) which successfully establish themselves in, and then overcome, otherwise intact, pre-existing native ecosystems. [3] An alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity. [1]
Monitoring	An official ongoing process to verify phytosanitary situations. [2]
Natural ecosystem	An ecosystem not perceptibly altered by humans. [2]
Phytosanitary measure	Any legislation, regulation or official procedure having the purpose to prevent the introduction and / or spread of pests. [2]
Semi-natural ecosystem	An ecosystem which has been altered by human actions, but which retains significant native elements. [1]
Spread	Expansion of the geographical distribution of a pest within an area. [2]
Suppression	The application of phytosanitary measures in an infested area to reduce pest populations. [2]
Surveillance	An official process which collects an records data on pest occurrence or absence by survey, monitoring or other procedures. [2]
Survey	An official procedure conducted over a defined period of time to determine the characteristics of a pest population or to determine which [2]

[1] IUCN Criteria Review: Report of the Scoping Workshop, March 1998 (IUCN, 2000)

[2] IPPC (1999b)

[3] ISSG (2000)

species occur in an area. [2]

7.2 ABBREVIATIONS AND ACRONYMS

APHIS (USA)	Animal and Plant Health Inspection Service
BLI	Bird Life Intrenational
CABI	CAB INTERNATIONAL
CBD	Convention on Biological Diversity
COP	Conference of the Parties
COSAVE	Comite de Sanidad Vegetal del Cono Sur
CRIMP	Center for Research on Introduced Marine Pests
CSIRO	Commenwealth Scientific and Industrial Research Organization
EDB	Ethylene dibromide
EMAN (CANADA)	Ecological Monitoring and Assessment Network
EPPO	European and Mediterranean Plant Protection Organization
EUCAP	European Union Concerted Action Programme
FADDL (USA)	Foreign Animal Disease Diagnostic Laboratory
FAO	Food and Agriculture Organization of the United Nations
FWS (USA)	Fish and Wildlife Service
GATT	General Agreement on Tariff and Trade
GBWMP	Global Ballat Water Management Programme
GEF	Global Environment Facility
GESAMP	The Joint Group of Experts on the Scientific Aspects of Marine Environment Protection
GISP	Global Invasive Species Programme
HACCP	Hazard analysis and critical control point
IMO	International Maritime Organization
IPM	Integrated Pest Management
IPPC	International Plant Protection Convention
ISPM	International Standards for Phytosanitary Measures

ISSG	Invasive Species Specialist Group
IUCN	The World Conservation Union
IUFRO	Interantional Union of Forest Resaerch Organizations
MB	Methyl bromide
MEPC	Marine Evironmental Protection Committee
NAPPO	North American Plant Protection Organization
NPPO	National Plant Protection Organizations
OECD	Organisation for Economic Co-operation and Development
OIE	Office International des Epizooties
ORISA	Organismo International Regional de Sanidad Agropecuaria
ORTEP	Organotin Environmental Programme
OTA (USA)	Office of Technology Assessment
PACCRC (AUSTRALIA)	Pest Animal Control Cooperative Research Centre
PRA	Pest Risk Analysis
SBSTTA	Subsidiary Body on Scientific, Technical and Technological Advice
SCOPE	Scientific Committee for Problems of the Environment
SERC (USA)	Smithsonian Environmental Research Centre
SPS	Sanitary and Phytosanitary Measures
SSC	Species Survival Commission
TBT	Tributlytin
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational , Scientific and Cultural Organization
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USSD	United States State Department
WHO	World Health Organization
WTO	World Trade Organization

7.3 TABLES

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