

Invasive plants and animals: Is there a way out?

**Proceedings of a Conference on Alien Invasive
Species on the 26th of September, 2000 in the
National Museum of Natural History Naturalis
in Leiden, the Netherlands**

**Wim Bergmans & Esther Blom
editors**

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Photo cover: Zebra mussel (*Dreissena polymorpha*)

Photo: Gerard van der Velde

Layout: Edith Cremers

Printing: Leeuwenberg, Amsterdam

Production: Cas Besselink

ISBN 90-75909-08-x

Published July 2001 by The Netherlands Committee for IUCN

Plantage Middenlaan 2B

1018 DD Amsterdam, The Netherlands

Website: www.nciucn.nl

With support from:

NCDO (National Committee for international cooperation and sustainable development)

Natuurmonumenten (Dutch society for the preservation of nature)

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PREFACE

During IUCN's first World Conservation Congress in October 1996, the Species Survival Commission announced that presently, alien invasive species are considered the second largest threat to indigenous species, only after habitat destruction. Alien invasive species are species which have been introduced to areas outside their own, and have managed to establish themselves in such areas, increasingly at the cost of indigenous biodiversity and, in a number of cases, at very considerable economic costs.

As the umbrella organisation of the Dutch IUCN members and IUCN Commission members, the Netherlands Committee for IUCN has publicised the statement by the Species Survival Commission and drawn attention to the growing number of invasive species and the apparent need for the development and implementation of adequate policies and regulations. To the same end, it has organised a conference on the issue, in the appropriate and beautiful accommodation of the new National Natural History Museum with its large collections of animals from all regions of the world, and within walking distance from the National Herbarium with its famous collections of the world's plants.

Invasive species are not new to our region. In the first centuries, the Romans brought the rabbit to Northwest Europe, and 18th century sport hunters released the pheasant, to mention but a few examples. Since long, our Flora's have abounded with non-indigenous plants, escaped from gardens or unintentionally imported as seeds by travellers. But also for a long time the phenomenon of alien species has been regarded with curiosity rather than anything else. Botanists did not speak of alien, invasive, or non-indigenous species - or still other derogatory descriptions - and did not worry about them. They called such newcomers simply *adventives*. And when an adventive had managed to establish itself, it was promoted to *neophyt*, and included in the first next printing of the Flora. Both plant and animal lovers have sometimes even tried to actively "promote" biodiversity in very peculiar ways. In the 19th century, colonial Europeans established special "acclimatisation societies" to bring familiar and beloved European species to their new fatherlands.

An unconfirmed story about two zoologists in our own region tells us that on a summer day in the thirties of the 20th century, two entomologists were observed looking at an insect which had landed on a boundary post between the Netherlands and Belgium. They decided it was a new species to the fauna of both countries. However, technically it was sitting in no-man's-land. The entomologists started to blow to make the insect move from no-man's-land. But as they were a Belgian and a Dutchman, and each wanted to add the species to his national fauna list, they blew in opposite directions. Finally, the insect flew up high into the sky, and has never been observed since, in either of the two countries.

There still exists a popular notion among many people, even adhered to by some conservationists, that we should "promote" the biodiversity of a given area by adding species to its fauna and flora; into our days, many people are still often trying to "enrich" their environments by introduction of species they like. According to some of these people, much biodiversity is good biodiversity, and more biodiversity is even better. In some bird studies, species have been counted in primary forest and in adjacent logged over forest, and the logged forest species lists turned out to be longer than the primary forest ones. This increase has been construed by some in favour of logging. This kind of blind appreciation of high species numbers is wholly unjusti-

fied, as a number of primary forest birds leave their forest when it is being logged, and the increase is caused by generalist species which intrude the logged forest from outside. The true difference lies in the higher quality of the primary forest list.

These proceedings are the outcome of the mentioned first conference in the Netherlands on the phenomenon of invasive species. They contain the introductory paper from the reader, the papers that were read and summaries of the discussions held during the conference, and the recommendations emanating from them. The Netherlands Committee for IUCN will forward these proceedings to the Dutch government and the European Commission, with the request to consider the proceedings and take its recommendations into account when dealing with nature conservation issues.

Doeke Eisma
Chairman of the Netherlands Committee for IUCN

ACKNOWLEDGEMENTS

The Netherlands Committee for IUCN wishes to thank Mr. Kees Groen, Mr. Rob Lensink en Mr. Bart van Tooren for their input during the preparation of the conference. Special thanks go to Mr. Lennart Turlings for writing an introduction for the conference reader. This exemplary general introduction to the phenomenon of invasive species has been reproduced as the first chapter of these proceedings.

Thanks are due to Dr. Maj De Poorter in Auckland, New Zealand, coordinator of policy and projects of the Invasive Specialist Group (ISSG) of the Species Survival Commission of IUCN, for coordinating our contact with prof. Dr. Piero Genovesi as European representative of the ISSG and for helping out covering his travel expenses.

The Committee is very grateful to Dr. Aimé Bokonon-Ganta of the Service Protection Végétaux in Benin; Dr. Fernando Espinoza Fuentes of the Charles Darwin Foundation; Prof. Dr. Piero Genovesi, Coordinator Europe of the Invasive Species Specialist Group of IUCN's Species Survival Commission; and Dr. Paul Phifer of the United States Department of State, for fitting this one-day conference in their busy programmes and travelling all the way to the Netherlands and sharing their knowledge and experiences in their papers presented to the conference. The Committee also thanks all the Dutch contributors: Mr. Jacob Jan Bakker of the Netherlands Ministry of Agriculture, Nature management and Fisheries; Dr. Rob Hengeveld of Alterra; and Prof. Dr. Gerard van der Velde of the Nijmegen University.

Further thanks are due to prof. Dr. Pieter Baas of the National Herbarium, who has been so kind to chair the conference, and to Mr. Wim Dijkman, Mr. Gijs Kuneman and Dr. Hans den Nijs who each chaired one of the afternoon discussions. The Committee is very grateful to the Netherlands Commission for Information on and Awareness of Sustainable Development (NCDO) for its financial support for this conference. The National Natural History Museum has supported the Committee in kind by accepting the Committee as an affiliate, resulting in a very significant reduction of the fees for their beautiful accommodation. Finally, IUCN member "Nature Monuments" has kindly supported the production of the proceedings of this conference, and Foundation Ecooperation and the CBDD are thanked for supporting the participation of Dr. Bokonon-Ganta.

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1. INVASIVE PLANTS AND ANIMALS: IS THERE A WAY OUT?

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INTRODUCTION

Biological invasions

The establishment of Black cherry in the Dutch forests is an example of a biological invasion by an alien species. An alien species is defined as a species, subspecies, or lower twain occurring outside of its natural range and dispersal potential and includes any part or gametes of such species that might survive and subsequently reproduce. An alien species can be called invasive when it becomes established in the natural or semi-natural ecosystems or habitat outside its natural range (IUCN, 2000). Biological invasions by animals, plants or pathogens may occur as the result of climatic and tectonic changes as well as through introduction by humans (Vermeij, 1996). Nowadays, most invasions originate from human actions, deliberate or accidental (Williamson, 1996).

Invasion of Black cherry

Black cherry (*Prunus serotina*) has probably been introduced from the U.S.A. in Europe in the 17th century as decoration in gardens and parks (Tweel & Eijsackers, 1987). From 1920, the plant has been used by Dutch foresters as a forest species for fire prevention around pine plantations and planted on a large scale during the afforestations of heather areas during the period 1930-1940. But later, negative effects of Black cherry, like hampering of forest production, became clear. However, eradication of Black cherry in the Dutch forests appeared to be almost impossible. A new name for Black cherry was born: forest pest.

Many invasive species have become pests and have serious consequences for local biodiversity, ecosystem functioning and economy (Davis *et al.*, 2000). Invaders are often claimed to be the second largest threat (globally), after habitat destruction, to biodiversity (Williamson, 1999). Biological diversity encompasses all species of plants, animals, and microorganisms and the ecosystems and ecological processes of which they are part. It is an embrella term for the degree of nature's variety, including both the number and frequency of ecosystems, species, or genes in

Invasion of *Ludwigia grandiflora*

The South American water plant *Ludwigia grandiflora* (in Dutch "Waterteunisbloem") is imported to the Netherlands as a decorative plant in ponds. The floating plant escaped to ditches and channels ten years ago. In the last few years, the plant has spread quickly. It forms closed mats of floating vegetation, which causes a lack of light underneath the floating mat. This causes a decrease of oxygen in the ditch water. Consequently, many plants, fishes and insects are not able to survive. Control is difficult because the plant is able to spread rapidly by vegetative growth. Each little piece of stem is able to grow and turn into a new plant (Dutch Newspapers: De Volkskrant, 17-08-2000; NRC Handelsblad, 19-08-2000).

a given assemblage. It is usually considered at three levels: genetic diversity, species diversity, and ecosystem diversity (McNeely *et al.*, 1990). An example of an invasive species that threatens local biodiversity is the recent invasion of *Ludwigia grandiflora* into Dutch ditches and channels where it causes a decrease in oxygen. Other effects of biological invasions on ecosystem functioning are (Mooney & Drake, 1989): acceleration of soil erosion rates, alteration of biogeochemical cycling, alteration of geomorphological processes, alteration of hydrological cycles, alteration of fire regimes and prevention of recruitment of native species. Currently, invasions are the subject of much interest and ecological research, largely because of the damage done by some invasive species.

The conference

The threat of invasive species to indigenous biodiversity and economy motivated the Netherlands Committee for IUCN (NC-IUCN) to organise a conference on this subject. This conference will take place on 26 September 2000 at Naturalis, the National Museum of Natural History in Leiden, the Netherlands. The aim of this conference is to raise awareness on the risks of invasive species and to help to generate incentives for an adequate Dutch and European policy concerning this area. Discussions on ecological and economic aspects of invasive species and on cooperation with developing countries to manage invasive species will be an important part of the conference.

IUCN & NC-IUCN

The International Union for the Conservation of Nature and Natural Resources (IUCN), now called the **World Conservation Union**, aims to globally protect the integrity and diversity of nature and to promote the ecological and social sustainability of the varying uses thereof. The **Netherlands Committee for IUCN (NC-IUCN)** is a co-operative agreement between the NGO Dutch members of the IUCN, and the Dutch members of the six international IUCN commissions. Nearly all of the major Dutch nature conservation and environmental organisations are members of the Committee. The NC-IUCN aims to promote the conservation and responsible management of nature and natural resources in the international context, in co-operation with the IUCN and its members.

Although Genetically Modified Organisms (GMOs) form a pool of new possible invaders and therefore are also pose a major threat to biodiversity, GMOs will not be discussed during the conference, as this issue is the subject of other meetings already.

This introductory paper on invasive species addresses the biology of invasions and the determinative factors that play a role in the invasion process. Furthermore, it will describe management strategies for biological invasions and the state of that management in policy and practice at this moment. Finally, it will supply a framework for questions and theses that can be discussed during the conference.

THE BIOLOGY OF INVASIONS

Stages of the invasion process

The process of invasion can be subdivided into several stages (Williamson, 1996). The first stage in the invasion process is the **import** (deliberate or accidental) of a species into an area not previously occupied by that species. After import, the species may escape, or be released, and can thus be **introduced** into a natural ecosystem. Together, the import and introduction

represent the arrival of a species into an ecosystem. After introduction into the wild, the species can establish itself; i.e. the population becomes self-sustaining through local reproduction and recruitment. Once established, the species can be called invasive. The invasive species becomes a pest if its presence has negative biological and / or economic effects.

The actual invasion of an environment by new species is influenced by three factors: the number of individuals or gametes of species entering the new environment, the characteristics of the new species, and the susceptibility of the environment to invasion by new species (invasibility) (Davis *et al.*, 2000).

Import and introduction of species

The dispersal of species over the world, accompanied by the number of individuals and gametes entering a new environment, has increased enormously after the great geographic discoveries around 1500 AD (Castri, 1989). Since then, an increasing breakdown of certain biogeographic barriers that once limited the interchange of the world's biota has been accomplished through the intercontinental transport of humans and their goods. The biological invaders have been purposely carried by humans or inadvertently accompanied them (Mooney *et al.*, 1989). For example, new plants are introduced as garden plant and may become introduced into the native ecosystem. In the same way animals, including species from all vertebrate classes and some invertebrates, were and are introduced as domestic animals.

Other causes of invasions are the artificial connections between different watershed areas by canals. These canals connect ecosystems that were never connected before. For example, the exotic flatworm *Dendrocoelum romandanubiale* was recently discovered in the Ketelmeer, a Dutch lake. This flatworm was introduced into the Rhine through the Rhine-Main-Donau-canal and thus introduced in the Netherlands (De Volkskrant, 19-08-2000).

Characteristics of successful invaders

Invasive species may have some qualities that are responsible for their invasive nature and that will provide some advances compared to native species. Although it is to be expected that different characteristics will be important in different places, some general characteristics can be mentioned.

One of the most often-cited invader characteristics is that successful invaders have a high population growth rate (Lodge, 1993). An example is the American grey squirrel.

Invasion of the American grey squirrel (*Sciurus carolinensis*)

The American grey squirrel is introduced into many places, for example in Britain, where it has caused a decline of the Eurasian red squirrel, *Sciurus vulgaris*. The red squirrel is a less efficient forager in the deciduous woodland and anthropogenic habitats of Britain. It can not, for instance, digest acorns, while greys can. The result is both a lower growth rate of the population of the red squirrel and carrying capacity of the ecosystem (the maximum population density an ecosystem can support) for that species (Williamson, 1996).

A high dispersal rate may be another important property of successful invaders. If a species spreads quickly and in large numbers, the chance to reach suitable habitat increases. Furthermore, in order to be effective, possible control measures have to reach the species in all invaded areas at the same time, which will often be very difficult, if not impossible to achieve. Vegetative reproduction is an important property of plant invaders, as can be seen in the invasion of *Ludwigia grandiflora*. Another invader characteristic is the ability of a species to main-

tain itself until conditions are favourable. For example, plants with long living seeds can survive in the soil for many years. When the conditions are good, e.g. a gap in the vegetation causing a high availability of light, the seeds may germinate. In this case, the chance of success of the invasion will be higher than if the seeds would germinate immediately.

Other possible characteristics, which will not be discussed further, are a large native range, human commensalism, single-parent reproduction, high genetic variability, phenotypic plasticity (Lodge, 1993) and maybe many others.

Invasibility of ecosystems

Similar to the characteristics of invaders, ecosystems that are susceptible to invasion may also have certain characteristics. Although there may be no ecosystem on earth that is not invaded by one or more exotic species, some communities are more invaded than others are. Many of the characteristics described below have not been demonstrated to be responsible for a high susceptibility to invasion, but have been suggested to be so.

An invading species must have access to available food. Invading plants must have access to other resources like light and water. Many of the ecosystem characteristics proposed as factor for high invasibility of the ecosystem are based on this assumption. For example, ecosystems that are in an early stage of succession will often have high amounts of available resources and might therefore be susceptible to invasion. Similarly, in disturbed areas more resources will become available. Ecosystems with low native species diversity are often said to be more invulnerable than more diverse ecosystems, because of their high resource availability, but this may be questionable.

Apart from the availability of resources, some other characteristics are important in determining the invasibility of an ecosystem. For example, a lack of enemies for a possible invader in a certain ecosystem will cause the ecosystem to be highly invulnerable for that species. This may be a reason for the relatively high invasibility of islands or, more common, isolated ecosystems like lakes and isolated mountains, and the large consequences that invasions in these ecosystems regularly have.

Finally, the frequency of human visiting to an ecosystem is an important factor in the number of invasions in that ecosystem. This is not a consequence of its invulnerability, but more an expression of the number of individuals (mostly seeds) of possible invaders that may be carried by humans into the ecosystem. In other words, the attractiveness of an ecosystem for humans is also a factor that in general determines the number of invasions.

Successful introductions

It is difficult to estimate the percentage of introductions that become a success, as many unsuccessful introductions remain unknown. However, it is known that of the imported species that are introduced, only a small proportion establishes, and a small proportion of these established species become pests. Williamson (1996) formulated the "tens rule" for this decline of both invading plant and animal species during the invasive process: 10% of introduced invaders become established, and 10% of those established become pests. For plants, 10% of the species that are imported escape to become introduced.

The tens in this rule are only rough estimates and can vary between 5 and 20%. There are also several exceptions to this rule and it is certainly not applicable to all types of organisms. Nevertheless, the tens rule gives a general idea of the percentages of successful introductions. Although this percentage may look somewhat low to some people, a low percentage does not mean that introduction of invasive species is not a problem. The real number of introductions can be high and the introductions that become established can be very harmful indeed.

Prediction of future invasions

Until now, most invasions are unpredictable, caused by poor understanding of the biology of invasions (Williamson, 1999). Ecologists still cannot predict which species will become invasive in which habitat type. The only consistent predictor so far seems to be the success of a certain species in previous invasions. Several approaches have been applied in trying to increase the predictability of future invasions. For example, it was postulated that the establishment of an invader could be predicted from the existence of empty niches or available resources. Also, climatic matching with the native habitat of a possible invader may predict invasion success (Williamson, 1996). Otherwise, these factors are of rather little use in prediction. Another approach that determines the pool of possible invaders has been proposed by Daehler & Strong (1993). In this approach, three aspects should be determined: geographic amplitude of the potential invader in its present native range, past invasion success by the potential invader and past invasion success of closely related species with similar habitats. This approach may overestimate the number of possible invaders, but is said to be relatively cheap to execute. Focused studies on specific potential invaders and target communities are of course also a possibility, but are highly expensive.

CONTROL OF INVASIVE SPECIES

The success of invasive species control strongly depends on the stage of the invasion process in which the species is present when the control measures start. Control should affect the transition of a species from one stage to another, i.e. prevention of imported species to escape, of introduced species to establish, and of established species to become a pest. Control will be most successful in the first stages of the invasion process.

The first step in dealing with the problem of invasive species is to control the import of new possible invaders and to prevent the escape of species that are imported. Thus, introduction into natural ecosystems will be averted. Although this may sound easy, practical implementation may be difficult. Some of the imports of species happen intentionally, but most of the introductions are accidental and therefore difficult to control. When species have become established, control will be even more difficult. At that time, control will be dependent on two factors: the dispersal ability of the invader and the extent of the area over which control is required (Usher, 1989). Wherever the population of an invading plant or animal has been allowed to build up over a large area, control has proven to be either extremely costly or ineffective. Methods used for the control of species that have invaded a certain area are eradication of the species, area-wide suppression, slowing the spread of the species and biological control.

Eradication is the removal of every potentially reproducing individual of a species or the reduction of their population density below sustainable level (Myers *et al.*, 2000). Factors that appear to be important for successful eradication are for example the availability of sufficient resources to fund the programme to its conclusion and clear lines of authority in order to carry out all required procedures at all affected sites. Reinvansion must be prevented and (of course) the biology of the invader must be susceptible to control mechanisms. Another important factor in the success of eradication is the possibility of species detection in low densities. When this is possible, eradication can start in an early stage of establishment and will be achieved more easily. The eradication of an invasive species on islands is likely to be more successful than eradication in continental areas. An example of this is the control of the muskrat in Europe. The prevention of reinvansion is much easier on islands than on continents because of the physical dispersal barriers to islands for many species.

Area-wide suppression and slowdown of the spread of species are measures that will be executed when eradication seems to be impossible. These control methods will inhibit species to become serious pests and have significant economical or biological consequences. Most of the measures will only have a temporary effect and will have to be repeated regularly.

Biological control of an invasive species mostly consists of the introduction of a natural enemy of the invasive species. This introduction might reduce the survival and density of the exotic species. However, impacts on other species than the target exotic species are also possible and can have large consequences. The small Indian Mongoose, a carnivorous mammal (*Herpestes auropunctatus*) has been introduced to many areas to control rats. In the West Indies, it literally wiped out a number of endemic rodents and contributed to the decrease or extermination of a number of bird, reptile and amphibian species. It is eating domestic stock, causing a great damage, and has been found to be a rabies reservoir and vector in Puerto Rico (Lever, 1985). Moreover, introduction of a natural enemy implies the introduction of another exotic species to an ecosystem and should be very carefully handled.

POLICY DEVELOPMENT AND RESEARCH PROGRAMMES

In the last decades, research programmes on invasive species were started and some policy concerning this area has been developed.

On a global scale, the Convention on Biological Diversity (CBD) recognises the importance of the global problem of invasive species and calls in contracting Parties to 'prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats and species' (Article 8(h)). The Conference of the Parties (COP) decided at COP V in May 2000 that it would consider the issue of alien species in depth at its sixth meeting.

The World Conservation Congress of IUCN at its 2nd session in October 2000, will urge IUCN members to promote the IUCN guidelines to the appropriate government and management agencies.

Control of the Muskrat (*Ondatra zibethicus*)

On the British Isles, the muskrat was successfully eradicated in the 1930s, whereas in continental Europe it has spread, and control campaigns have only resulted in some suppression, but were unsuccessful in eradication of the species (Lever, 1985). In the Netherlands for example, the population seems to increase again at the moment. In 1991, 42.000 muskrats were captured. This number decreased to 25.000 in 1998, but last year almost 30.000 rats were trapped. Causes for this population increase are the increase of natural areas in the Netherlands, which causes an increase in suitable habitat, and the come-back of natural edges of ditches and channels for conservation reasons which makes control more difficult (e.g. the placement of traps) (De Volkskrant, 12-08-2000).

To assist governments and management agencies to give effect to Article 8(h) of the CBD, the New Zealand-based Invasive Species Specialist Group (ISSG) has developed the 'IUCN Guidelines for the prevention of biodiversity loss caused by alien invasive species. ISSG is part of the Species Survival Commission (SSC) of IUCN and consists of more than 100 scientific and policy experts from all over the world. The guidelines address principles of invasive species management, including prevention, eradication and control, as well as legislative and regulatory principles and knowledge and awareness-raising requirements.

Furthermore, the COP encouraged an initiative to develop a global strategy for dealing with

invasive species. This Global Invasive Species Program (GISP) is a component of an international program on the science of biodiversity, DIVERSITAS, and is coordinated by SCOPE (Scientific Committee on Problems of the Environment), in conjunction with IUCN, UNEP and CABI, with initial financial support from the Global Environment Facility, UNEP, ICSU and NASA. The GISP will assemble the best information and approaches for prevention and management, and disseminate information in the form of databases, manuals and capacity-building training programs to governments and communities.

In the Netherlands, no all-compassing policy has been developed yet to deal with the threat of invasive species. In the new law on Flora and Fauna the conservation of international plant and animal species is explicitly dealt with, but invasive species and their control are not treated.

FINAL NOTES

This paper makes clear that invasive species are an important threat to global biodiversity and cause major economic damage. Nevertheless, in many cases proper policy on this subject has still to be developed. The conference of the NC-IUCN publicises the invasive species problem, and hopes to contribute to this development. During the conference, three subjects will be discussed: ecological aspects, economical aspects and North-South aspects of the invasive species phenomenon.

The discussion on ecological aspects may be concerned with questions such as: Do examples exist of species that disappeared or have been reduced in numbers and distribution by invasive species? To what extent do invasive species actually cause problems to the functioning of ecosystems in the Netherlands, in Europe and in other places?

Examples of questions in the discussion on economic aspects are: Are there data on the economic damage of invasive species in the Netherlands, in Europe or elsewhere? In which sectors are problems the most serious?

Finally, the discussion' on North-South aspects will focus on among others the following questions: Are developing countries as heavily invaded as industrialised countries? Have programmes been developed, or should they be developed on international cooperation to tackle problems with invasive species?

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2. BIOLOGICAL INVASIONS AS A MAJOR THREAT TO BIODIVERSITY IUCN GUIDELINES AND ACTIONS FOR PREVENTING BIODIVERSITY LOSSES CAUSED BY ALIEN INVASIVE SPECIES

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INTRODUCTION

Invasive alien species are now acknowledged as a major threat to biodiversity (IUCN, 2000), causing an immense, insidious and often irremediable impact at a global scale. Invaders are found in all taxonomic groups, have colonised every ecosystem on earth, changing the ecological relations within communities, altering evolutionary processes, and causing dramatic changes in native populations, including extinctions (Mack *et al.*, 2000). Furthermore, biotic invasions are predicted to become the major engines of ecological disintegration in the future, because of the increase in the spread of alien species, due to the increased mobility of the human population, the rapidly growing technology of transport means, the expanding tourism and travel activities, and the world wide free trade (Cox, 1999, Ruesink *et al.*, 1995).

In addition to threats to biodiversity, biological invasions also affect human health and well being. The direct costs of invasive alien species are in fact immense; despite the difficulty to precisely estimate the economic losses caused by biotic invasions, the impact of weeds on crop production, the increased costs of control, the decreased water supply, the management costs for reducing alteration of protected areas, the impact of introduced pathogens, the impact of marine organisms transported by ballast water, likely exceed tens of billions Euros annually (McNeely unpubl.). For the United States, the costs of alien invaders have been recently estimated to be over a 138 billion US\$ per year (Pimentel *et al.*, 2000).

The severe threats posed by biotic invasions have been repeatedly addressed at an international level: the 1992 Convention on Biological Diversity (CBD) calls on its parties to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats, or species" (Article 8h); the Bern Convention, at Article 11 Paragraph 2.b, recommends that each Contracting Party undertakes action to strictly control the introduction of non-native species. The Bonn Convention on Migratory Species of Wild Animals calls its parties to strictly control the introduction of, or controlling or eliminating already introduced exotic species.

Although the severe threats posed by biotic invasions are recognised, several obstacles limit the implementation of an effective policy to address invasive alien species. On the one hand, our limited knowledge of the biological aspects of the epidemiology of biotic invasions - including vectors, ecological parameters influencing capability of alien species to become invasive, patterns of spread - limit our prediction capability, and thus our ability to develop and implement effective management actions. On the other hand, the issue is particularly complex, comprehending non-biological aspects, as pathways of arrival, per trade, agricultural techniques, import regulations, management roles and responsibilities at a national and international level.

GUIDING PRINCIPLES

A holistic approach is thus fundamental. We need to implement prevention measures, to promote awareness, and to develop effective control methods. However, a critical point is not only the definition of these measures, but also the implementation of these actions at a global scale, because even when we already have tools to limit invasions, these tools may appear not accessible to all nations.

Prevention

The prevention of the arrival of new invasive alien species (IAS) represents the most effective and least costly management strategy to reduce threats posed by biotic invasions, and should always constitute the priority. As a principle, no alien species should enter a country — either intentionally or accidentally —, unless authorised after an appropriate risk assessment procedure.

Target

Although conservation only requires to prevent the arrival of species threatening biodiversity (IAS) or to control them, and although IAS represent only approximately 1% of all alien species (AS), our limited capability to predict the invasiveness of alien species, makes it necessary to prevent the arrival of all AS, unless they are proven not to threat biodiversity or negatively affect human well-being (precautionary principle, see below).

Awareness at the source level

Efforts should be concentrated on the prevention of new introductions already at their source, meaning at their place of origin. The intentional and/or accidental transport of living organisms can be limited by means of increased education, awareness raising and providing information, in particular to tourists, transport operators, and trade organisations.

Major invasive pathways

Alien species arrive through very different pathways. An analysis of the pathways of introduction can allow an efficient control during transport. In this respect it is important to distinguish between the initial entry into a country (or region) and the subsequent natural spread. Natural expansion of an alien species established somewhere else, is particularly critical because: 1) it means that the ecological conditions are suitable to the establishment, 2) it may be more difficult to contain natural spread of a species than to prevent its introduction.

Border control

Border control represents the most effective way to prevent intentional introductions of potentially invasive species, but requires a complex framework of rules, staff, and reference lists.

Precautionary principle

It is possible to describe some general characteristics of the epidemiology of biotic invasions. However, these rules only hold in a very general, statistical sense. The impact that a new invader will cause in the long term, or its future expansion patterns, can only be predicted with a high level of uncertainty.

In this respect, a precautionary approach should be followed when addressing new alien species. The precautionary principle is well synthesised by the definition "guilty until proven innocent" (Ruesink *et al.*, 1995). Such an approach underlines the principle that the introduc-

tion of alien species should be prohibited unless authorised, and links authorisation to a risk assessment procedure.

Black, grey, white lists — Risk assessment

In order to allow an effective filter to the intentional introduction of invasive species to be established, a three lists system should be implemented, based on 1) a "black list": species prohibited from import; 2) a "grey list": allowed for import under conditions restricting their use to specific purposes (research, public education, others), and only after the holding facilities to contain the animals have been inspected and approved; 3) a "white list": allowed for general importation.

The authorisation to import a species included in the grey list should require a Risk Assessment. Risk Assessment is a management tool aimed to predict, on the basis of the current knowledge, the actual risks related to introductions. The aim is generally to provide scientific information, so that decisions are made in a thorough, consistent, logical and transparent way.

An important aspect of Risk Assessment is the Environmental Impact Assessment, aimed to predict potential threats to biodiversity and the environment. Potential adverse effects of an introduction to the environment, and the probability for these effects to occur, can be assessed analysing the intrinsic characteristics of the species, the ecological relations in its original range, and the similarities between its original range and the introduction area.

The three lists system is comprehensive, because all species can be categorised in one or the other list. The system should be dynamic: it should permit the shift from one list to another if new information becomes available. For example, where risk assessment shows that a species is harmless or beneficial, the entry into the country can be authorised, and the species can be included in the white list.

A potential option to reduce costs related to the three lists system is that anyone applying for an authorisation to import a species included in the "grey list" should be responsible for producing a risk assessment.

The authorisation process should explicitly cover import for maintenance in captivity, since accidental escapes from captivity represent one of the most common causes of invasions of terrestrial vertebrates.

Management of introduced alien species

Prevention can reduce new introductions, either accidental or intentional, but cannot halt them completely. When an alien species has been detected, in other words when prevention has not been successful, from the precautionary principle descends that eradication should always be considered. In fact, eradication represents the most coherent solution in terms of biodiversity conservation, and is more effective, cost effective and ethically preferable in respect to other management alternatives as control, containment and do-nothing.

Nevertheless, the experience accumulated in the last century shows that eradication campaigns represent a difficult management alternative, resulting in some cases a huge waste of resources. It is therefore critical to avoid abuses of eradications, and to use the available resources to address those species representing a major threat to biodiversity, and those cases in which eradication has the higher probabilities to result feasible.

Rapid action

Two factors constrain the time lapse after which eradication of an invasive species becomes a non preferable alternative: 1) feasibility: eradication may become non-feasible once the invasive species reaches a certain population level or range expansion; and 2) usefulness: the undesired

effects caused by the invasive species become irreparable. In general terms, feasibility strongly affects time for eradication on main land, where eradication remains feasible for a critical period, whose lapse is difficult, if not impossible, to predict with a good level of certainty. This factor accounts in part for the overwhelming proportion of successful eradications carried out in islands compared to main land. Usefulness is difficult to define, because of the limited capability of predicting long term impacts caused by IAS.

Thus, in most cases, a rapid implementation of eradications represents a critical factor. This means that it is important to set up mechanisms for allowing rapid response 1) early detection mechanisms, 2) a simple authorisation process, and 3) a clear line of authority (Myers *et al.*, 2000). In this respect, the creation of a biosafety agency, formally delegated to remove alien species when detected, is a potentially efficient option.

Early detection

With respect to the need of rapid action, early detection is a general requisite for effective management of invasive species. Early detection requires the circulation of information on invasive species, and the methods to monitor their presence. In this respect the Global Invasive Species Database, implemented by the IUCN Invasive Species Specialist Group and available on the net (<http://www.issg.org/database>) can represent a fundamental tool to effectively circulate information on the invasive species, their ecology, and means of control.

Monitoring efforts should be concentrated in the potential arrival points (airports, harbours, train stations) and in the proximity of places of captivation (breeding farms, zoological gardens, game parks, etc.).

Also in this respect, the creation of biosafety agencies, with the mandate to constantly monitor new introductions, may represent an important step to reduce time needed for the detection of new propagules of alien species.

Prevention of new introductions

The results of eradication campaigns can be totally undermined if new introductions of the species occur again. In this respect, when planning the removal of an IAS, preventing future re-invasions should be carefully addressed.

IUCN ACTIONS

Recognising the need and -urgency to find tools to effectively address threats posed by biotic invasions, in the last decade the World Conservation Union (IUCN) made invasives one of the primary foci for its global action. The Species Survival Commission, supported by the Invasive Species Specialist Group, recently produced the "Guidelines for the prevention of biodiversity loss caused by alien invasive species" (IUCN, 2000). Furthermore, the IUCN is a major partner of the Global Invasive Species Project (GISP) aimed to support the Convention on Biological Diversity in the implementation of art. 8(h), through the development of guidelines and tools defining actions toward IAS. GISP — operated by a consortium of IUCN, the Scientific Committee on Problems of the Environment (SCOPE), CABInternational (CABI) and the United Nations Environment Programme (UNEP) — seeks to improve the scientific basis for decision making on IAS. It develops capacities to employ early warning and rapid assessment and response systems and enhances the ability to manage IAS and reduce the economic impacts of IAS and control methods. Better risk assessment methods are developed international agreements are strengthened. GISP is also developing new approaches to public education about IAS,

improving understanding of the ecology of IAS, examining legal and institutional frameworks for controlling IAS, developing new codes of conduct for the movement of species, and developing new tools for quantifying the impact of IAS. Its work involves dozens of scientists from all parts of the world.

A key limit in the actions to reduce threats posed by invaders, is represented by the lack of communication among experts dealing on the issue at a global scale. In this respect ISSG is promoting communication through the Aliens List, a web forum with over 500 members. Moreover, ISSG published Aliens, a newsletter aimed to rapidly circulate new information on alien species, and on the methods to control them. As already mentioned, ISSG is implementing a Global Invasive Species Database aimed to facilitate the rapid detection of alien species, to circulate information on their ecology and on the methods to control them.

ROLE OF EUROPE

As already underlined, several European conventions deal with IAS; the Bern convention in particular is concentrating its efforts to address biotic invasions. Nevertheless, also comparing the actions carried out at a European level with those carried out in Australia, New Zealand, North America, and in several oceanic countries, the need of promoting a common European policy is evident. For this aim, future efforts should be aimed to improve legal instruments, to define clear decision lines, roles and responsibilities, and to promote public awareness.

IUCN can be a major actor also in this respect, being capable to promote awareness, to provide technical support to the competent bodies, and to promote the implementation of new and more effective policies. ISSG recently created of a European section, confirming the need of concentrating efforts at a regional level. The section includes experts from several countries, and has the explicit aim to support new actions in Europe to reduce the threats posed by biological invasions.

A CASE EXAMPLE: THE THREAT POSED BY RUDDY DUCK TO WHITE-HEADED DUCK IN EUROPE (from: Hughes *et al.*, 1999)

The case of the Ruddy duck *Oxyura jamaicensis* represents a clear example of the complexity of the problems related to the management of invasive aliens species, and highlights the need of an holistic approach, the limited concern and commitment, and the need of international co-operation for dealing with transboundary threats.

The North American Ruddy Duck was introduced into the UK from North America in the 1940's. After escaping from captivity, Ruddy Ducks first bred in the wild in 1960 and increased to about 4,000 birds in 1998. Without control, North American Ruddy Ducks are expected to colonise continental Europe and threaten the native White-headed Duck *Oxyura leucocephala* – a globally endangered species recorded as "Vulnerable" on the World List of Threatened Birds — with extinction through hybridisation and competition.

Between 1965 and 1996, there were over 900 records of some 1,500 North American Ruddy Ducks in 19 Western Palearctic countries. Records are concentrated along the North Sea coasts of the Netherlands, Belgium, and Germany, in France and in southern Spain. Ruddy Ducks now occur annually during the breeding season in eight countries (excluding the UK) and annual breeding attempts probably take place in six: Belgium, France, Germany, Ireland, the Netherlands, and Morocco (not in Spain as most birds are shot). Large flocks of wintering birds

have recently appeared in Spain and France. In January 1997, about 30 Ruddy Ducks were recorded in northern Spain following freezing conditions across northern Europe, and some 30-40 birds have wintered annually at Lac de Grand-Lieu in northern France since 1995/96. The number of Ruddy Duck records in the Western Palearctic is still increasing, at a mean annual rate of 21% between 1976 and 1996. The greatest increase has been in the Netherlands where the number of records increased pith 34% per year between 1984 and 1996.

An appraisal of the level of implementation of country-by-country recommendations for Ruddy Duck control from the Council of Europe White-headed Duck Action Plan reveals: monitoring of Ruddy Ducks in the wild is adequate in most countries; the legal provision for Ruddy Duck control exists in all countries; and many countries have, or are considering, a national Ruddy Duck strategy.

There is a commitment to eradication in three countries (France, Portugal, Spain) while the UK has conducted research into suitable control measures for Ruddy Ducks and has moved to a regional trial to assess the feasibility of nation-wide eradication. This regional trial may reduce the UK population by over 1,000 birds. Spain, France and Portugal attempt to control all Ruddy Ducks and hybrids, with a total of 135 birds shot to date (68 Ruddy Ducks and 51 hybrids in Spain, 13 Ruddy Ducks in France, and one Ruddy Duck and two hybrids in Portugal). There is no ongoing control in six countries in which annual breeding attempts are thought to occur (Belgium, Germany, Iceland, Ireland, Morocco, and the Netherlands).

Few countries have acted to address the potential threat posed by Ruddy Ducks escaping from captivity (although it was already illegal to keep Ruddy Ducks in Iceland and Norway and there are no birds in collections in Sweden). Few countries have mechanisms in place to monitor the numbers of birds kept in captivity and in four countries (Ireland, Italy, the Netherlands and Portugal) it is not illegal to release Ruddy Ducks into the wild. Ruddy Ducks can be traded freely in most countries.

Few countries have public relations strategies regarding Ruddy Ducks, although these are in place in those countries with ongoing control.

A strategic approach needs to be adopted if North American Ruddy Ducks are to be eradicated from the Western Palearctic. An international eradication strategy needs to be produced and endorsed and implemented by all Western Palearctic states. Individual countries need to produce national eradication strategies, in consultation with relevant interest groups. Both wild and captive birds should be eradicated, the former taking priority as these are thought to be the major source of birds reaching White-headed Duck populations. The immediate priorities (1999-2002) for the control of wild Ruddy Ducks should be to assess the feasibility of eradication from the UK and to ensure that birds do not become established in other countries. With regard to captive populations, all countries should introduce and/or enforce legislation preventing the release and escape of Ruddy Ducks into the wild, introduce schemes to monitor the numbers of birds kept in captivity. The ultimate goal should be to prohibit the keeping of Ruddy Ducks in captive collections.

The Ruddy Duck issue has demonstrated a reluctance to act on the Precautionary Principle with regard to controlling non-native species. A proactive, rather than reactive, approach to the Ruddy Duck problem would have saved much time, energy and money.

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3. INVASION BIOLOGY: FROM THEORY TO PRACTICE

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ABSTRACT

Invasions result from ecological responses of species on a biogeographical scale. As such, they can successfully be described with models that are both biologically and mathematically sound; as such, rates calculated using these models could be tested with actually measured rates. Since species respond specifically to variation in environmental factors, all invasions are unique and, therefore, require individual treatment when control is needed. The model discussed can also be used for simulating expected effects of various control strategies being carried out. Apart from this, other phenomena, like waiting times, are also discussed within the framework of the structure of invasion processes.

INTRODUCTION

This paper discusses invasions as ecological responses of species at a broad, geographical scale. Therefore, species invading into some area or geographical region do not represent a particular type of species, nine stationary species forming the alternative type. Spatial expansion is seen here as the counterpart of a local increase in numbers of individuals, due to factors favourable to it.

This approach does not follow some arbitrary, philosophical stance, but results from testable predictions done with models that are both biologically and mathematically sound. The predicted rates accord with observed ones to a high degree. And they result from data on the life history of the individuals, i.e. on their age-specific rates of survival and fertility, together with those on the distances they can cover. As these data are all sensitive to variation in living conditions, it follows directly that the possibility to invade cannot be a trait characterising a certain type of species.

For practical purposes, this is encouraging, as the rates concerned can in principle be influenced by changing the ecological conditions of the species. In that way, the rate of invasion of a species can be manipulated.

On the other hand, some characteristics also have an inherent component. This applies to, for example, the distances individuals can cover. Some species, even those that fly well, seem not prepared to cover long distances, whereas others, because of a different behaviour in this respect, can be found at very considerable distances from the place where they germinated, hatched, or were born. This difference in distances covered results in a different type of spatial dynamics of the invasion: in the case of short-distances being covered, the invasion front is closed, whereas it breaks up with the formation of hearths far ahead of the spatially more closed occurrence in long-distance dispersers. This means that the control strategy should be different in two cases, with all the intermediate cases in between. However, knowing such a behavioural trait with its consequences means that control measures can be adjusted in such a way that they continue to give effective results.

The first section discusses two species that contrast in several traits, and shows the consequences for control measures to be taken. The section that follows contains an outline of an analytical model to show the main parameters giving structure to the dynamics of invasions. The last and final section discusses the cause probably underlying waiting times between initial settlement of an invader and its eventual outburst.

TWO CONTRASTING INVADERS

There are no two species that invade new territory in the same way. All species differ to a greater or lesser extent from any other species now existing on earth, and probably from any one that has ever existed in the geological past as well. They not only differ in morphology on which all their taxonomic differences are based, but ecologically as well. Sibling species are even morphologically almost identical, and can often be distinguished better by their ecological differences. As invasiveness depends on ecological species responses to ever-changing living conditions, we can expect that no more ball role exists that equally applies to several species. The invasion process may depend on the same type of ecological traits, represented by certain parameters in an equation, but the identity of the species is expressed by the values these parameters take under particular conditions.

Apart from this, there are certain traits that are inherently different from one species to the next. These traits can be represented by parameters with more or less fixed values. Whether a species will expand its range or not, and when this will happen, is usually difficult to say, because this depends on information about its specific ecological responses to particular living conditions, which is usually unknown. In contrast, when such species happen to expand, the second type of traits can allow us to make predictions as to how they might invade into new regions. And this, in turn, allows us to distinguish between species for which immediate and drastic control measures are due, and those that can wait some time, or that may not have noxious effects at all.

Of these two categories, the originally North American Ruddy Duck, *Oxyura jamaicensis*, invading from England into continental Europe, is a representative of the first type, and the Egyptian Goose, *Alopochen aegyptiacus*, which is still expanding within the Netherlands, one of the second.

The Ruddy Duck escaped in 1960 from the Slimbridge bird sanctuary near Bristol in southern England. From then on, it built up its British population to a total of 4,000 birds in 1996 (Hughes, 1999). In 1970, it reached Europe, where the new population amounted to 170 birds in 1996.

The trouble with this species is that it hybridises easily with a closely related European species, the White-headed Duck, *Oxyura leucocephalus*, which as a rare species is highly protected. The ruddy duck can fly great distances, the first settlers forming bridgeheads at great distances from their parents nest. Moreover, it migrates seasonally from the north to the south of Europe. Also, it nests in marshes, where it is found only with great difficulty. The fact that the native species can be lost through hybridisation renders it almost compulsory to take control measures, but these measures are very difficult to be carried out, particularly in the main breeding area of the White-headed Duck in the marshes north of the Caspian Sea. This necessitates quick and drastic action.

This is different in the Egyptian Goose expanding its range since the early 1960s in the Netherlands (Lensink 1997, 1998). Numbers of this species too, increase exponentially, but their young birds hardly disperse over great distances from the nest in which they hatched.

They hardly found new settlements away from previously existing ones; the invasion is therefore mainly fed by the expansion of existing settlements. In the autumn, they form large moulting flocks in meadows, where they can easily be seen and from where they cannot leave because of difficulties with flying in this stage. As they seem not to have any noticeable effect on other species, immediate and drastic action is unwarranted and is, in consequence, not taken.

These species, therefore, differ sharply with regard to the dynamics of the way they invade into new territory, and also in the ease with which their numbers can be controlled. As a consequence, the control measures to be taken differ sharply.

THE STRUCTURE OF INVASIONS

In these two examples, two main processes were mentioned: the exponential growth in numbers of individuals, and the distances these individuals travelled from their parent's nest to their own breeding site. We can estimate both processes from existing literature data for a small number of species only. These data can, as a next step, be fed into a model accounting for these processes as driving forces of the invasion, which allows us to calculate the expected rate of invasion of the species concerned.

The process of the numerical growth of the population results from the rate of fertility, combined with a slightly higher survival rate of particularly the young, reproducing individuals. Therefore, both a higher fertility rate and a lower mortality rate can result in a rate slightly higher than the American one. This means that over a certain period, every female in a population is replaced on average by more than one young female, implying numerical population growth. This replacement rate is normally called the population's net rate of reproduction. It depends on age-dependent rates of fertility and survival.

The dispersal process depends on the distances between their hatching ground and their own breeding-ground that individuals are observed to cover. Usually, most individuals cover only short distances and occasionally very large ones. This frequency distribution of distances is J-shaped and is called a dispersed distribution, a dispersal kernel, or a contact distribution. Although its shape may thus have a similar general appearance, its decay rate — slope — will differ between species. Moreover, its dimension will be specific, in one species running between zero and a few metres, and in another between zero and several hundreds of kilometres. When the slope is very steep, it means that almost all individuals or propagules remain in the vicinity of their hatching site. And this, in turn, means that the invasion progresses along a more or less closed front without any isolated outposts ahead of it. When, in contrast, the slope is shallow, bridgeheads will be formed, breaking up the invasion front. In that case, the invasion progresses mainly through the few individuals settling at large distances, thus starting populations that grow out and fuse as a next step. Particularly this process is reigned by chance, which, together with the large distances covered, makes it highly unpredictable. The invader showing this behaviour is often considered aggressive.

These two processes, the one of reproduction and the other of dispersal, together drive the spatial dynamics of the invasion. This integral spatial process is called a reaction-diffusion process after a similar process known from nuclear physics. For processes of biological spread or expansion, it was adapted by Van den Bosch *et al.* (1990), and it was subsequently tested by Van den Bosch *et al.* (1992) and Lensink (1997, 1998) on several mammal and bird species. According to this test, the expected, calculated rate of invasion should be equal or similar to the observed one in the geographical field, which is indeed the case.

Apart from this, the same model can also be validated, meaning that the sensitivity of the calcu-

lated outcome is tested against greater or smaller changes in data input. If the outcome hardly alters even if the changes artificially made are great, the process is said to be robust against changes in the parameter concerned. If, in contrast, the outcome easily changes even with only slight changes in data input, the process is considered sensitive with regard to the parameter value representing the kind of input. This analysis can be done for technical reasons of modelling only, but we can also use it for learning to know the sensitivity of the processes in the field for particular changes in the values of the process components. And additionally, we can use that information for knowing how to manipulate the process most effectively with the least of effort within a conservational context.

It turns out that the impact long-distance dispersers have — those represented in the tail end of the distance distribution — is relatively great (Hengeveld, 1992). Therefore, in species with a shallower distance distribution, it is most effective to concentrate the control efforts on early, isolated settlements forming the bridgeheads, rather than on the main part of the distribution. In contrast, in cases of a steeper slope, one can best concentrate on controlling the main reproductive phase, that is on that part of the population having the greatest reproductive output. Usually, this can most easily be done by controlling the number of young individuals, as these are often the most common in the population as well as the most fertile.

SLEEPING POPULATIONS

As mentioned, it is usually difficult to say, if at all, how species will respond to environmental conditions, particularly in a new territory. These difficulties do not only occur when we have to predict whether a species will expand even to outbreak conditions before it has ever reached this territory. Often, it has reached this territory already but does not grow out numerically for some time. After a certain period, it can suddenly — and usually quite unexpectedly — grow out quickly from a single or from several populations to outbreak proportions, thereby forming a pest or weed in a short time.

So far, changes, either gradual or sudden, in living conditions or in the genetic constitution of species have been invoked to explain such population explosions (e.g. Crooks & Soule, 1999). Such changes may indeed have occurred in a number of cases, but here, I want to point to another possible mechanism, not involving change, but changeability. In ecological change, one invokes a trend in conditions from unfavourable to favourable to the invading species, whereas in changeability no such trend need to be present. When conditions are changeable, they vary according to a certain chance distribution around some expected value that remains more or less the same during the period of investigation. In sleeping populations in a new territory, conditions would be unfavourable most of the time; only occasionally, as a statistically rare event, they become favourable enough to raise the net reproduction rate above one. This can be observed in the discontinuous age structure of trees in many woods, where distinct cohorts of particular age groups make up the canopy and undergrowth. This may also occur as a spatial trend towards the margin of a species' geographical distribution, the frequency with which favourable conditions occur over time decreasing from the range centre. In such cases, the time lag before the spatial outgrowth of a local population to invasive proportions can express the waiting time between favourable conditions.

Kowarik (1995) gave frequency distributions of waiting times' for trees and for bushes. It appears that, on average, the waiting times are longer for trees than they are for bushes. Also, the frequency distributions are truncated at the left. It may be that waiting times, following a random decay rate, are Poisson distributed, which could accord with the truncated distributions observed.

When the individuals of a species experience favourable conditions, they can start reproducing thus that the net rate of reproduction becomes greater than one. In that case, the population will not only increase numerically, but as a consequence of this, spatially as well. At the same time, long-distance dispersers will settle and as soon as these new settlers rise above the Allee threshold of minimum population size, start founding a population of their own. This means that two spatial processes occur side by side, that of the spatial outgrowth of the initial population and that of the seeding out of this population to a number of daughter populations. At that stage, the initial curvilinear growth of the invasion shifts into a linear one.

Together with these spatial processes directly related to the number of individuals reproducing and dispersing, the temporally favourable conditions also result in a greater proportion of favourable sites. This can imply that the population can start expanding his space, whereas with a low proportion, this would not be possible due to too great a dispersal risk (Hengeveld & Van den Bosch, 1997).

Thus, through various mechanisms started up during favourable conditions occurring only temporary and at a low frequency, invasions can get going. As soon as, according to these mechanisms, some thresholds have been passed, the invader can grow out unhamperedly. This all follows from the same central model of range expansion applied to work in a stochastically varying, ecologically non-uniform environment.

Two examples

An example of further range expansion after a temporary break can be found in the invasion of the Collared Dove, *Streptopelia decaocto*, into Europe. From 1912 onwards, it spread into the Balkan Peninsula, where it halted till 1929. Then, under the temporary warmer conditions of the 1930s and 1940s in Central Europe, it could cross the Swiss and Austrian Alps when the higher temperature values made it habitable for the species. After this, the Collared Dove found itself in the lower lying — and thus warmer — parts of Western Europe. Also because of the more equable Atlantic climate, it was now able to produce more broods in a year, breeding during the greater part of the year. Thus, the expansion of this species took off due to a temporary rise in temperature, which fell back afterwards again to the lower values after mid-1950s.

The North American Muskrat, *Ondatra zibethicus*, expanding in Central Europe, shows a response to combined temporal and spatial variation in its preferred, wet conditions. Here, the expansion rate of its invasion into Western Germany depends on the humidity of the weather, the wetter the more continuous its biotope to the traversed. This wetness, however, varies less randomly between the years concerned. On the other hand, the availability of more favourable biotopes retards the progression of the invasion, as there are plenty of areas where individuals settle to reproduce. Conversely, during the drier years, the advance is most rapid as the animals keep walking and searching before they can find a suitable site for reproduction. Therefore, indirectly, the progression rate of this invasion follows the frequency distribution of favourable conditions for reproduction.

THE PRACTICE OF ERADICATION

There are many practices of eradication of invaders when this seems necessary. One possibility is the prevention of entering new territory, as this is done in Western Australia, for example. Here, any single Sparrow or Starling, for example, is shot at first sighting. In attempts to control the Muskrat in Western Europe, two contrasting strategies have been followed, payment according to the number of tails brought in during the programme and that brought in after

the programme had shown to be a success. Only the latter strategy works, as in the former, a population is soon used as a crop and therefore kept at a certain level to guarantee a regular, annual income. In other cases, attempts are made to reduce the population by a certain percentage, or to bring it back to a manageable level. None of these measures, however, seems to take account of the efficiency of the eradication according to adaptation to the specific biology of the species concerned. Neither is it made explicit what a manageable numerical level might be. For example, up to 1961, the Muskrat was kept in check at a manageable level in the Netherlands, but after this date, when the working week was shortened without proper adjustment of the number of hunters, a steady, exponential rise in numbers started. At present, it seems manageable at a much higher level, but with much higher costs as a consequence.

A type of a biological eradication measure is the introduction of predators or diseases, as has been done in Australia against the rabbit. However, the species introduced may not confine themselves to their intended target, which gives additional problems when at some stage success is yielded. For example, the fox, initially intended to control the rabbit in Australia, is very likely to predate on other mammals including marsupials, and other animals, and this predation will increase the number of rabbits if drastically reduced by a newly introduced disease. The most direct way, therefore, still seems to be to eradicate a species by human measures. A major problem hereby is that, depending on the roughness of the terrain and the visibility in dense vegetation, there is a minimum body size that has to be taken into account. This size is roughly that of a rat, smaller individuals in general escaping notice.

In all instances, it is compulsory to know the biology of the species intimately, that is its ecology and behaviour throughout its lifetime. That is what I have indicated above in the few examples given. If possible, the traits concerned should be quantified and the data should be fed into a sound model with which the relative sensitivities can be estimated. Also, the model can indicate the general behaviour of the invasion, whether it progresses through a closed front, or through the formation of some isolated hearths as bridgeheads far ahead of the spatially more closed occurrence of the invader. This defines the measures that have to be taken in the first place, or that taking measures may not be due at all, nor during the first decade or so.

Knowledge of the behaviour of species throughout their life is necessary as well, as was shown by the temporary moulting areas of the Egyptian Goose. In contrast, shooting during the relatively late breeding periods of the Ruddy Duck, lasting from August to September, can enhance the mobility of individuals and, hence, increase the rate of its spread. Similarly, destruction of nests or eggs may have little effect because of the possibility of second broods being made. Shooting of particularly young birds during migration when they flock together in inland water bodies might be considered to have a greater effect, depending on the results of a proper sensitivity analysis. Measures irrespective of age can have the opposite effect as once shown in muskrats, for example. As the chance of catching animals randomly increases with age — the animals being continuously under the same hunting pressure all their life — the effect will be that the age distribution in the population shifts gradually to the younger, more fertile individuals. On top of this, they can occupy territories left vacant, where they can start reproducing. The consequence of such a measure, therefore, is an increase in reproductive output of the population.

CONCLUSION

Application of biological knowledge and sound theory are compulsory for any programme to yield good results. But however obvious this may seem, exactly this is often left out of consideration in eradication programmes.

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4. ECOLOGICAL AND ECONOMIC DAMAGE BY INVASIVE SPECIES IN INLAND WATERS AND HOW TO DEAL WITH IT

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Biological invasions have an unpredictable nature. Bright (1998) states that we do not know when an invasion will take place, where it will take place and what an invasion will do, although Williamson (1996) mentions regular patterns in invasions with respect to arrival and establishment, spread, equilibrium and effects.

Many unintentional and intentional introductions or immigrations of aquatic organisms have been reported in the literature. Since such species are unable to escape from their original distribution area without human assistance, exotic invasions occur only when natural barriers to dispersal are circumvented due to human activities. Human impact can lift barriers in several ways. Increased shipping means that aquatic organisms can be transported in ballast water in major cargo vessels all over the world from one harbour to another, where the ballast water is discharged. It is estimated that 8-10 billion tons of ballast water per year are carried by such ships and that an average of 3,000-4,000 species are transported in this way each day (Bij de Vaate *et al.* submitted). Other routes for dispersal are interlinked canals, rivers, lakes and whole catchment areas (an example is the Main-Danube canal, which has constituted a migration highway for Ponto-Caspian species from the Danube to the Rhine since 1992 (Van der Velde *et al.*, 2000)), the intentional introduction of species (especially fish and fish food), escapes from aquaculture, aquaria, garden ponds and so on. Nowadays there is a rapidly increasing trade and transport, with many hitchhikers.

Most introductions are not very successful (see chapter 1 on the "tens rule") in the sense that the species concerned are caught only sporadically, are restricted to certain non-important habitats often occupying under-utilised niches like cooling water discharge areas, or occur in such small populations that they have negligible effects on the ecosystem. Sometimes, such species can threaten endangered or protected indigenous species by hybridisation, predation or competition. Many invasions, however, are reflections of other changes rather than being agents of change themselves and in such cases, biological invasions can be regarded as indicators of environmental change.

It has been observed that continuing invasions in an ecosystem lead to an exponential rise in exotic species (Cohen & Carlton (1998) for San Francisco Bay; see e.g. Van den Brink & Van der Velde (1998) for the Netherlands). This may be due to increased transport and propagule pressure, but this does not explain why the communities are so susceptible to invasions and how all of these species can coexist with indigenous species. Several hypotheses have been suggested to explain this phenomenon, including undersaturation of the ecosystems, or in other words, the presence of vacant niches. This may be due to several environmental conditions or events in the past. For example, the ice age has led to an impoverishment of species, leaving vacant niches. The ice age also created new lakes, which have been colonised rather recently, e.g. the Great Lakes. Interestingly, some aquatic organisms which died out during the ice ages in Europe have now returned due to human activities. Examples include Asiatic clams (*Corbicula* species)

(Meijer & Preece, 2000) and the water fern *Azolla filiculoides*. Another explanation is the intermediate disturbance theory, which claims that invasions are due to environmental disturbances or that the invaders create disturbances themselves. Increasing competition leads to chaotic fluctuations, which render the coexistence of many species possible (Huisman and Weissing, 1999). Nowadays it is not just one or two exotic species which invade the ecosystem, but sets of organisms with the same origin, while native communities are often weakened. The invaders already had relations with each other and interactions are quickly established. This can lead to an invasional meltdown.

Community vulnerability to invasion increases with the number of vacant niches, disturbance before or during immigration and fluctuating resource availability with an increase in unused resources e.g. through eutrophication, pests and diseases (Davis *et al.*, 2000).

Biological invasions can also lead to interactions between species that have never met before and to replacement of native species by exotic relatives. An explosive and catastrophic growth in population size of the invaders can cause drastic changes in an ecosystem as a whole due to depressed local populations, individual species extinction and influence on vertical and horizontal food-chain processes, even leading to a restructuring of the ecosystem. Depending on the trophic level at which the invader acts, the effects on the ecosystem can be top-down control or bottom-up control. Even then, there is often a lack of evidence that such an invasion has a significant ecological impact. This is due to the unpredictable nature of invasions, which means that pre-invasion data are usually not available. The speed with which changes can occur is such that changes immediately after the start of the invasion are often missed. The impact of a mass invader is usually large at its population peak, after which the population fluctuates and other factors influencing the communities may mask the effect of the invasion.

Mass invasions attract special attention when they cause economic problems, while concern is also aroused by related problems of ecological changes, possible genetic influence on native species and the introduction into native populations of non-endemic pathogens; even human health may be endangered. Economic problems caused by aquatic organisms are related to professional and recreational fishery, aquaculture, damages to crops (rice), damage to ditch walls, stream banks and shorelines and biofouling.

I will consider here the invasion of the Zebra mussel (*Dreissena polymorpha*) as an example of a very successful invasion with profound effects, ecologically as well as economically. The Zebra mussel originates from the so-called Ponto-Caspian area (Black Sea, Asov Sea, and Caspian Sea), where it was endemic. It was able to expand its range after 1700 AD via new shipping links between rivers. Each new link enabled it to spread further westward. Two routes were used for its expansion to western Europe, first a northern route towards the Baltic, and secondly a central westward route. It managed to reach Great Britain and the Netherlands from the Baltic via the timber trade as early as 1824-26, and its most recent success is the invasion of Ireland in 1997 via boats on trailers.

In 1985 it migrated into the Great Lakes in the U.S.A. It is most likely that the Zebra mussel in the U.S. originates directly from the Black Sea and was introduced via the discharge of ballast water. There are nowadays also other Ponto-Caspian species in the Great Lakes, such as the Quagga mussel (*Dreissena bugensis*), gobies and amphipods (Ricciardi & MacIsaac, 2000). The Zebra mussel has dispersed over the whole Mississippi catchment area.

Success factors for the Zebra mussels include the possession of planktonic larvae, byssal attachment to hard substrates, some tolerance to brackish water and filter feeding, taking advantage of eutrophication.

Its effects on the ecosystem have been profound. Huge densities have been reached on the rocky bottom of the Great Lakes, where the bottom is nowadays coated with Zebra mussels (ten thousand per square metre and more). It influenced the abiotic as well as the biotic environment, including water transparency and suspended matter, the cycling of nutrients, the cycling of contaminants, the benthic substrate and native biodiversity, and shows food-web effects.

Water transparency can be increased by 20-100% through its effective filter feeding activities. A major lake like the IJsselmeer in the Netherlands can be filtered once or twice per month. In comparison with other bivalves, studies in a lake found that the Zebra mussel could consume 160 tons of seston (dry weight), while unionids consumed only 2.5 tons and sphaeriids 2 tons. It can consume 9% of the primary production of the plankton and contribute 13% to the annual sedimentation of tripton by pseudofeces and feces.

It can also alter the cycling of nutrients. A several-fold concentration increase of total phosphorus, ammonia, nitrate and nitrite has been observed. This leads to an uncoupled phosphorus-chlorophyll relationship.

With respect to the cycling of contaminants, these mussels are bioaccumulators. They form a food source for fish and water fowl, allowing a transfer of contaminants to these predators. Zebra mussels can cause an increase in the sedimentation of contaminants of up to ten times (PCBs, Cadmium). They can also cause benthic substrate alterations by changing soft bottom into shell gravel, creating hard substrate for other sessile organisms on formerly uniform soft bottoms, and in this way create new niches for zoobenthos. Native biodiversity is also influenced by its contribution to local species richness, as it reduces the variation in species diversity, conditions for other Ponto-Caspian invaders, and threatens unionid mussels by settling on the shells, preventing the opening of the siphons of the unionids by their byssus threads (in Europe there are ca. 22 species of unionids, in North America ca. 300 mostly endemic species!). They also have a positive influence on associated species by creating refuges from large predators.

Food-web effects are evident for plankton as well as zoobenthos. From the plankton it removes especially the larger bacteria. It stimulates developments of heterotrophs by nutrient secretion into an oligotrophic environment. Its filtering and ingestive activities cause declines in phytoplankton biomass (30-90%), as well in zooplankton (70-90%), to the disadvantage of pelagic fish species, while the Zebra mussel veligers contribute 10-25% to the zooplankton production. It has further been suggested that the Zebra mussels can enhance *Microcystis* blooms by consuming algae like diatoms but avoiding or refusing colonies of this cyanobacterium. The food-web effects on zoobenthos are also pronounced. Other macroinvertebrates on rocky substrate increase by factors of 2-8, especially amphipods, gastropods, leeches, flatworms and water mites. There is a food supply for this fauna in the form of the Zebra mussels' feces and pseudofeces. The Zebra mussels themselves can contribute more than 95% to the benthic biomass. They constitute food for benthivorous fish, crayfish and water fowl. By making the water more transparent they enhance the growth of macrophytes, which leads to an increase in macrophyte inhabiting fish, and to an increase in benthic algal biomass by a shift from diatoms to filamentous algae, which can penetrate deeper due to better light conditions.

Furthermore, this mussel created an enormous biofouling problem by attaching itself to the hulls of ships and to underwater equipment as well as inside pipes for cooling and drinking water. The shells accumulate in pump chambers and clog condenser tube openings in power stations (Jenner *et al.*, 1999). The negative economic impact in the Great Lakes over five years has been estimated at 120 million USD (Hushak, 1996).

Interestingly, the Europeans have a different perception of the Zebra mussel invasion than the Americans. The important difference is that the invasion of western Europe took place before the industrial revolution of the 19th century. This means that engineers were confronted with Zebra mussel biofouling problems from the start. In the period 1878-1893, problems with Zebra mussels were recorded by drinking water services (Van der Velde *et al.*, 1994). Since that time a lot of knowledge has been gathered on Zebra mussels and how to deal with the problems they present. Up to now, alleviation of fouling by the mussels of water intake pipes has been achieved by adding chlorine to the water and by heat treatment. Furthermore, ideas have been developed for using Zebra mussels as pollution monitors and filters, and for lake restoration after eutrophication. The colonisation by Zebra mussels of the IJsselmeer, which is the enclosed former Zuyder Sea, is actually appreciated, as it increases the natural values of this lake by attracting large numbers of water fowl.

This means that when invasions occurred a long time ago, the invaders are no longer considered to be intruders in the ecosystem but are regarded as native species. This is clear from the titles of important books on the Zebra mussel from North America and Europe. The American books have titles with words like impact, control and nuisance species (Nalepa & Schloesser, 1993; Claudi & Mackie, 1994; D'Itri, 1997), while the European book (Neumann & Jenner, 1992) on the Zebra mussel has the subtitle 'applications for water' quality management.

Biofouling damage can be increased by continuing invasions, making the biofouling community more complex and increasing the risk of highly tolerant species. An example is the dreissenid mussel *Mytilopsis leucophaeata*, which originates from the Atlantic coast of North America and the Gulf of Mexico. It was introduced into the Antwerp harbour through ballast water in 1835 and was later recorded in the harbour of Amsterdam. It is a brackish water mussel which causes serious biofouling problems in the power plants and industries along the Noordzeekanaal, the canal linking Amsterdam harbour with the North Sea. It turned out that this mussel species was far more tolerant to chlorine (Rajagopal *et al.*, 1997a) as well as high temperatures (Rajagopal *et al.*, 1997b) than other fouling mussel species like the Blue mussel (*Mytilus edulis*) and the Zebra mussel.

So what can be done to prevent serious problems by invading species? Measures which can be taken at different stages of the invasion include prediction and prevention of entry, eradication, control (Mack *et al.*, 2000) and evacuation of threatened species.

Prediction of invasions is possible on the basis of extensive knowledge about successful invaders elsewhere, but is impossible for new invading species. We have to accept that we are living in a changing world, with many winners and losers. Global changes can alter the fates of invasive species.

Prevention of invasions is much less costly than post-entry control. The U.S. has introduced laws on ballast water management and ships have to discharge their ballast water at sea and not in the harbours.

Eradication is only possible when the species invades small or isolated areas (e.g. islands) (Myers *et al.*, 2000). An example of successful eradication is the case of the dreissenid mussel *Mytilopsis (sallei) adamsi*, which was introduced into an Australian bay in the spring of 1999 (Cullen Bay). Within 9 days after the discovery in this manmade dredged marina, 160 t of bleach and 54 t of copper sulphate were released into the bay, which killed all life in a 600 mega-liter bay. Nearly all ships were inspected and cleaned. The cost of eradication was more than \$Au 2.3 million and over 280 people were involved in it. Regular surveys are carried out of international ports in Australia (Bax, 1999).

Control is most effective as a long-term, ecosystem-wide strategy, rather than merely combating individual invaders. Control can be carried out mechanically, chemically, biologically and by changing the environment. However, these control measures must not contribute to further environmental damage.

We have to protect our indigenous faunas and floras against invaders. If an invasion cannot be stopped and the negative influence on the native species continues and cannot be controlled one final option is to evacuate the threatened species, although this can create new invasions. For that we need a new arc of Noah.

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5. ALIEN INVASIVE SPECIES IN THE GALAPAGOS ISLANDS

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The following document is a compilation made by the scientists of the Charles Darwin Foundation during the production of the operative plan last year. Also, it uses the final document delivered to the Global Environment Facility (GEF) for the project GEF EC 098/64/.

PROJECT CONTEXT

Environmental Context

The Galapagos Islands are world renowned as a storehouse of unique terrestrial and marine biological diversity; as a natural laboratory for biological evolution and speciation; and for their role in stimulating development of Darwin's theory on Natural Selection. This volcanic, oceanic archipelago was formed approximately four million years ago, 1,000 km from any other landmass. It has 5 islands larger than 500 km², 14 smaller ones, and over 50 islets and rocks. Initially devoid of life, the islands were gradually colonised by a variety of life forms, many of which continually isolated from the mainland, evolved into new species. The archipelago now supports a rich diversity of flora and fauna including 541 species of vascular plants, 106 species of vertebrates and over 1,995 species of invertebrates. An exceptionally high percentage of these are endemic, including 42% of the vascular plants, 67% of the land vertebrates, amongst which are the famous Darwin finches, and 20% of the 2,584 species of coastal fish, marine algae and marine invertebrates. Inter-island variation is also very high with the various islands harbouring genetically distinct populations, races and species, reflecting different stages of genetic diversification/ radiation.

While evolutionary processes culminating in high endemism are characteristic of oceanic archipelagos in general, most such archipelagos were colonised by humans several hundreds if not thousands of years ago. In colonising the islands, humans intentionally and unintentionally introduced new species to these isolated environments. As a rule, competition between introduced and endemic species led to high rates of extinction among the endemics. Losses of up to 50% of the original species endowment have been recorded in such archipelagos. The Galapagos has been an exception to this rule. Over 95% of its original species composition remain extant. This is attributed both to the late arrival of humans to the area and to the archipelago's inhospitable conditions, which discouraged rapid population expansion. Many of the islands are still uninhabited.

In effect, the Galapagos Islands are one of the most ecologically intact large, complex, and diverse oceanic archipelago's remaining today. Its global significance is unquestionable. However, accelerated demographic growth in the Islands over the past 20 years has exerted new pressures on native ecosystems. The increased movement of goods from the continent and between islands poses the steady threat that alien species will be introduced into the archipelago from the mainland, or dispersed within it, thereby altering the composition of the biota. The risk to endemic species from invasive species is often considerable. Invasive species directly affect habitat integrity and also interrupt the natural evolutionary processes that produced the

archipelago's unique biological endowment. The well-recognised global conservation values and this growing pressure, make the Galapagos Islands one of the highest priorities for regional and global conservation intervention.

Alien invasive species in Galapagos have a history as long as human presence on the islands, probably going back as far as 1535, the year of the official discovery of the islands by the Spaniards. During the 17th and the 18th century, buccaneers and whalers used the islands as hideouts, storage supplies and hunting grounds; it is highly probable that these activities prompted the introduction of non-native mammals, like rats (accidentally introduced by cargo), goats and pigs (introduced on purpose as a permanent supply of fresh meat), as well as domestic species (cats and dogs). After the incorporation of the islands into Ecuador in 1835, human colonisation started a rapid and ever-increasing process of biological invasion. Farm animals, pets, crops and ornamental plants spread on the inhabited islands with varying success; collateral introduction of insects was unavoidable. Beginning in the 1970's, the development of a complex tourism industry as well as an increase in flights and sea connections to the mainland caused the invasive species problem to explode.

Proximate Threat 1: Introduced Species

The growing number of aggressive invasives occupying ecological niches in the Galapagos constitutes the main cause of biodiversity loss, directly through displacement of native and endemic species and indirectly through competition for food, breeding and nesting sites, degradation of habitat and disruptions in ecological and evolutionary processes. Introduced species occur in all islands where biodiversity losses have been registered. Habitat degradation is the most immediate concern, with some islands showing considerable losses, particularly those with feral goat populations. North Isabela, for example, has the largest goat population in the Archipelago with an estimated 100,000 animals present. Vegetation loss on the Alcedo volcano is critical, directly affecting the endemic Galapagos tortoise populations. At the species level, visible losses have occurred, particularly among reptiles and mammals. Eight of 11 species of endemic rats have disappeared. At least 15 other extinctions have been registered at the level of subspecies, races, varieties or populations of vertebrates and plants. At the population level, (highly significant if evolutionary trends are to be preserved), higher losses are registered including 20 bird populations, 12 reptiles and more than 50 plant populations. Despite these trends, the vast majority of endemic biodiversity is still largely intact and in most cases habitat disruptions are believed to be reversible.

There are currently about 785 documented introduced species in the Galapagos of which 25 are vertebrates and the rest invertebrates. Not all of these threaten native and endemic biodiversity but many require immediate control to avoid irreversible losses to native species and habitats. Most of these are found in the larger islands that also have the highest biological diversity and thus require the most immediate action.

The high numbers of invasive species, the ways they compete with native and endemic species and disperse within the archipelago, impede the adoption of one single approach to their overall control. Three main approaches can be identified for existing invasive species. The first, and most ecologically advantageous, is *eradication* throughout the entire archipelago or from specific islands and islets. This is normally a one-time intervention if re-introduction risk is low. However, given existing institutional capacities, and present levels of scientific knowledge, eradication is not feasible for many invasive species and islands. In these cases a second option is to *control* populations of invasive species to levels that do not threaten ecosystem integrity. This could be in localised areas, islands or throughout the entire archipelago. When these two options are not possible, *mitigation* measures provide normally short-term protection to

endangered populations whilst more permanent solutions are being developed and tested. These include measures such as fencing endemic species to maintain seed banks or exclude predators; introducing endangered species into invasive-free environments to maintain populations levels; and captive reproduction programmes followed by re-introduction into natural habitats (where the survival probability is relatively high).

Although these are three clearly different approaches, the complexity of ecological processes rarely permits the adoption of one single option in a given scenario. Effective interventions require the selection of the most appropriate actions from a wide spectrum of management options that range from specific unidimensional measures to the simultaneous or sequential application of combinations of one or more approaches.

The Galapagos National Park Service (GNPS) and the Charles Darwin Foundation (CDF) were involved in the control of alien species since the establishment of both organisations in 1973 and 1959, respectively. Some spectacular successes are on record; although these mostly involved relatively small populations, total eradication of specific alien mammals on islands like Santa Fe or Espanola were achieved. However, by the end of the 1980's the rate of introduction and dispersal by far exceeded the institutional capabilities of response.

In 1998, after several years of failed attempts and under the threat of being included in the UNESCO Endangered World Heritage Sites list, the Ecuadorian Congress passed the "Special Law for Galapagos", a complex body of regulations aimed at organising the development of the islands under a framework of strict environmental parameters incorporated in the strategy description, but four general statements in the law that relate to introduced species are worth noting:

- Its preamble recognises that "the principal threat to the biodiversity of the province of Galapagos is the presence of exotic species";
- The definition of sustainable development includes a specific requirement that the development must not run the risk of causing directly or indirectly the introduction or dispersion of alien species;
- The glossary also includes a comprehensive definition of "total control" of introduced species, which covers all aspects of control and eradication, including both prevention of new introductions and eradication of those already present;
- Two of the seven guiding principles for policy-making and planning are (a) the maintenance of the ecosystems, taking account of genetic isolation; and (b) the need to reduce the risks of introducing alien organisms.

When the Ecuadorian Government recognised as a priority the control of invasive species in order to protect the biodiversity in Galapagos, Charles Darwin Foundation, Galapagos National Park and the Ministry of Environment designed two projects:

- United Nations Foundation Project (UNF), which is being executed at the moment, and;
- Global Environment Facility Project that will start on the second semester/2001.

Those projects are supposed to cause the following effects:

- A co-ordinated inspection and quarantine system, with local participation;
- Adaptive management mechanisms established to develop and up-date the bio-invasion control programme;

- A series of eradication, control and mitigation pilot projects;
- A financial mechanism to support invasive species control activities in Galapagos;
- A bio-invasion overlay developed for regional planning.

PROJECT OUTPUTS, INDICATORS AND ACTIVITIES

Output 1:

A co-ordinated inspection and quarantine system for Galapagos is in place with the full participation of local institutions and with defined procedures and detection techniques.

Activities would strengthen and operationalise the Galapagos Inspection and Quarantine System (SICGAL). GEF resources will be used to improve and extend quarantine and inspection infrastructure (i.e. control points, fumigation centres) and thus increase the efficiency of alien species detection. GEF resources will develop specific operation manuals for quarantine and inspection procedures for the Galapagos system operators and train them in relevant detection methods. Materials will be up-dated periodically as findings from the research, monitoring and pilot activities become available, thereby gradually focusing actions on species that present the highest risk to biodiversity. GEF resources will also be used to develop an optimal internal transportation protocol reducing dispersal rates within the archipelago, and to fund periodic workshops with the different institutions involved in SICGAL, ensuring the uniform adoption of inspection procedures and circulation of new procedures arising from adaptive management mechanisms. UNF, GoE and GEF resources will be used to systematically monitor areas with a high risk of introduction, such as seaports, airports and agricultural zones, complementing general baseline biological monitoring.

Output 2:

Adaptive management mechanisms established to develop and up-date a scientifically sound, well-programmed and cost-effective bio-invasion control programme.

An array of adaptive management tools will be put in place to ensure that efforts to control the permanent threat of bio-invasion will be cost-effective, ecologically appropriate and continually updated, as new information and techniques become available. This will include prescriptive and predictive models for establishing priorities and selecting the most appropriate and cost-effective interventions from a range of bio-invasion management options. These models, to be developed with GEF resources, will be based on the evaluation and correlation of a wide range of information including the contextualisation of existing methods and experiences from around the world, biological monitoring reports and the results from the demonstration component. They will also draw on a well-structured experimental research programme to be developed with GEF resources to cover critical gaps in the scientific knowledge required to address specific introduced species management challenges.

Output 3:

A series of eradication, control and mitigation pilot projects are implemented to solve the key invasive species management dilemmas, strengthen the operational and technical capacity of parties responsible for invasive species control, and eliminate critical populations.

A series of pilot projects will test the effectiveness of different combinations of management options, providing an essential body of information for overcoming invasive species management challenges and contributing towards the design and execution of cost-effective, and tech-

nically feasible, long-term management intervention throughout the Galapagos archipelago. These projects will also raise the technical and operational capacities of key institutions responsible for invasive species control, further contributing to institutional learning and strengthening nascent control efforts. They will adopt robust replicate and control procedures that accurately measure the response of the endemic target organism or system, and have been selected to protect the most endangered species and habitats and solve the most pressing bio-invasion management dilemmas.

One group of pilot projects, to be funded largely by the UNF, will focus on *control* and *mitigation* management challenges. Three will target control of introduced black rats under different conditions and locations: (i) in Isabela island, where black rats threaten the endangered mangrove finches, impacts will be measured and optimum levels of control determined to increase reproductive success in these birds; (ii) in Santa Cruz, Floreana and San Cristobal islands, where they threaten the Galapagos petrel, the optimum intensity of control measures will be identified; (iii) in Pinzon island, where it is thought to be responsible for low tortoise recruitment rates, studies will determine its relative impact compared to the Galapagos hawk, and subsequently required control and mitigation measures will be applied. Two further pilot projects in this group will focus on mitigating the impact of pigs on the recruitment rates of endemic green sea turtles and giant tortoise species in Southern Isabela. These will test combinations of control and mitigation mechanisms to determine the most cost-efficient means of protecting these species. UNF and GEF resources will fund a pilot project that combines elements of control with eradication by reducing high-density stands of quinine (*Cinchona succyruba*) in Santa Cruz to prevent it spreading to other islands and determining the feasibility of full eradication.

A second group of pilot projects funded through UNF will focus on overcoming the challenges of *eradicating small-scale animal* invasive populations and will include: (i) the eradication of a newly established population of smooth-billed anis (*Crotophaga ani*) on Fernandina island to develop and test a rapid response team using advanced technology (GPS, GIS); (ii) the eradication of the only three populations of rock doves in Galapagos to remove this threat completely and to demonstrate how to address invasive species intimately associated with human activity and settlements; (iii) the eradication of feral cats on Baltra island using control measures used in other parts of the world and up-grading them to plan and implement larger-scale cat eradication programmes on other islands; (iv) the eradication of black rats from islets surrounding Santiago island to test eradication methods for small islands and provide an invasive free habitat for re-introduction of the endangered Santiago rice rat to maintain populations until a full ecological restoration of Santiago is complete; (v) eradication of the red fire ant from Marchena island, where it was introduced several years ago, to replicate and test lessons-learned from a previous fire ant eradication campaign in much smaller areas on Santa Fe island; (vi) eradication of the small invasive black fly populations in San Cristobal Island to protect freshwater endemic species and develop new technologies/methods for dealing with invertebrates.

Finally, one large, resource-intense pilot project, funded by the GEF, GoE and CDF, will focus on the problem of eradicating megapopulations. This will remove the most critical invasive species threat in the archipelago and establish the technical, operational and managerial capacity to plan and implement campaigns on this scale. It will eradicate the 100,000 strong feral goat (*Capra hircus*) population on northern Isabela Island and, together with local communities, design the subsequent eradication of the much smaller population on the southern half of the island. This island represents more than half the archipelago's total land mass and has more endemic species than any other island, with 66% of the endemic vertebrates and 40% of the endemic vascular plants represented.

Output 4:

An expanded and efficiently operating financial mechanism is operationalised permitting the permanent funding of invasive species control activities in the Galapagos.

The project would create a permanent financial mechanism to provide sustained financing to manage environmental threats to the Galapagos archipelago. An endowment fund will be created, the proceeds of which will be used *exclusively* to address conservation management priorities identified in the Management Plan for the Galapagos in a manner consistent with specific provisions of the Special Law of the Galapagos. In the medium term, the activities of the fund will be geared primarily to addressing the threat posed by invasive species. Accordingly, the fund will provide incremental financing to cover the bio-invasion control campaigns of the GNPS and CDF (as per their designated responsibilities under the Special Law).

Output 5:

An awareness and participation programme for bio-invasion control is developed.

Existing capabilities for communication and public participation campaigns will be strengthened with GEF and UNF funds to specifically include bio-invasion concerns and to raise the awareness of residents and tourists on the danger this presents and on actions that they can take to reduce it. Interamerican Development Bank (IDB) and GEF resources would be used to strengthen the capacity of GNPS and CDF for sustained campaigns in the medium term and to produce didactic materials for public participation in spearheading prevention efforts.

Output 6:

A bio-invasion overlay developed for regional planning with a set of guidelines and instruments that ensure that sector development fully addresses invasive species control.

A bio-invasion management overlay will be developed with funding from the GEF and the Spanish Agency for International Cooperation, United Nations Development Program, United Nations Foundation Program and private enterprises to provide a complement of policy guidelines, principles and procedures for those sectors contributing to the establishment and propagation of invasive species. These include the infrastructure, agriculture, transport, and tourism sectors, and settlement planning, migration and waste management, with a specific focus on the agricultural and tourist sectors. Legal backing for the reviews is provided by the SLG.

It is expected that these programmes as well as the permanent international support the CDF and the GNPS are currently enjoying will guarantee that enough funding will be available in order to keep the campaigns up and running. Previous experiences have failed mainly due to the lack of continuity, this in turn because of unavailable financial and human resources. However, the next step is to ensure that the international scientific community becomes involved in our own activities, while we immerse ourselves in the worldwide efforts against alien invasive species.

**6. INTRODUCTION, ECONOMIC IMPORTANCE AND CONTROL OF
INVASIVE PESTS IN AFRICA; WITH SPECIAL REFERENCE TO THE MANGO
MEALYBUG, *RASTROCOCCUS INVADENS* WILLIAMS
(HOMOPTERA: PSEUDOCOCCIDAE)**

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ABSTRACT

Invasive pests accidentally introduced into Africa from other parts of the world with similar agro-ecological conditions are the most important pest problems recorded in the continent in the last 30 years. Fortunately, most of these pests have been partially or completely controlled by specific, exotic natural enemies. However, a strong need remains for information, training and development of adequate facilities to manage the already introduced dangerous invaders and avoid further introductions. The paper addresses the major invasive pests of economic importance introduced into Africa in the last 30 years, with special reference to the mango mealybug, *Rastrococcus invadens* Williams (Homoptera: Pseudococcidae). Different management strategies are suggested for effective and sustainable pest control and development.

Key words: Invasive pests, Africa, economic importance, plant quarantine, *Rastrococcus invadens*, management policies, management strategies.

INTRODUCTION

For almost three decades, climatic disturbances, linked with serious soil degradations have significantly affected the development of Tropical Africa. Added to these, the increasingly rapid development of transportation and consequently of trade between Africa and the rest of the world led to the introduction of a number of invasive and dangerous pests. The populations of these newly introduced pests or diseases increased rapidly in the absence of their natural biotic and abiotic constraints and became problems for man and the environment.

This paper reviews the status of dangerous invaders in Africa with special reference to one of the latest and best documented invasive pests, the mango mealybug, *Rastrococcus invadens* Williams (Homoptera: Pseudococcidae) (Williams, 1986; Agouunké, Agricola & Bokonon-Ganta, 1988; Boussienguet & Herren, 1992; Ivbijaro, Udensis, Ukwela & Anno-Nyako, 1992; Matokot, Reyd, Malonga & Le Rü, 1992; Neuenschwander, Boavida, Bokonon-Ganta, Gado & Herren, 1994; Narasimham & Chacko, 1988, Noyes, 1988; 1990; Willink & Moore, 1988; Cross & Moore, 1992, Boavida, Neuenschwander & Herren, 1995; Boavida, Ahounou, Vos, Neuenschwander & van Alphen, 1995; Bokonon-Ganta & Neuenschwander, 1995; Boavida, 1996; Bokonon-Ganta, 1996). This review together with information recorded on other invading pests will be used to discuss the introduction, socioeconomic importance and control of invasive pests in Africa.

DANGEROUS INVADERS AND THE NATURAL ENVIRONMENT

The artificial and immense borders between African countries and the inherent difficulties in controlling the movement of people and goods across them, facilitate the rapid spread of invasive pests after their introduction into the continent. Many of the important pests occurring in Africa, and in various other parts of the world, were introduced through human activities. Once introduced, these pests attacked the food, fibre and forest crops that represent the resource base for agricultural and rural development.

Within the African continent there is little pest migration, aside from that of locusts, because of the general stability of the climate. The unpredictable incidence of pests and diseases outbreaks are major sources of environmental risks. Once introduced in Africa, invasive pests disperse easily by winds. Other means of dispersal include man and animals among which birds and rodents play a very important role.

Benin is a tropical African country situated in West Africa, between latitude 6°30' and 12°30'N and longitude 1°00 and 3°40'E, with a total land area of 112,622 km². It extends along the gulf of Guinea for about 125 km and has a length of about 750 km. Benin is bordered by Niger and Burkina Faso in the north, Nigeria in the West and Togo in the East. The country is divided into 12 departments, with approximately 10,000,000 inhabitants. The country is characterised by diverse inter-tropical bioclimatic conditions with decreasing amounts of rainfall from the south to the north (Adam and Boko, 1983). The long-term rainfall patterns are reflected in the plant cover leading to numerous agro-ecological zones (Igue, Bokonon-Ganta, Afouda & Soule, 1992; Ehouinsou, 1992; Bokonon-Ganta *et al.*, 1996). Pests and diseases may thus enter Benin from four immediately neighbouring countries. In addition, the port and airport are potential direct points of entry for different invasive pests introduced from other countries.

DANGEROUS INVADERS AND THE SOCIO-ECONOMIC ENVIRONMENT

Environmental damage due to invasive pests and diseases have had important negative consequences for the economy of Africa. In general, the economy of African countries is dominated by subsistence agriculture which occupies more than 70% of the population. The principal food crops are maize, sorghum, cassava, yam, and cowpea. Export crops include cotton, oil-palm, coffee, and cocoa. Trees are valuable resources in Benin. Reforestation programs involving fast growing species are inaugurated in many places to counter desertification. Fruit trees such as mango, citrus, avocado and pomme d'Afrique, all rich in vitamins A and C, play important roles in the farming systems of tropical Africa and are widely sold at the markets. These major crops distributed by traders around the world, were introduced in many cases accompanied by their pests and diseases, and unfortunately in the great majority of cases without their natural enemies. One of the best examples is the introduction of cassava, *Manihot esculenta* Crantz, to Africa by Portuguese colonizers who brought it to the African coast from Brazil (Jones, 1959). The neotropical cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Homoptera: Pseudococcidae), accidentally introduced in Africa in the seventies, has gained the status of worst agricultural pest in the tropics (Herren & Neuenschwander, 1991).

All these introduced plant and crop species make the country extremely vulnerable to invasion and establishment of numerous pests and diseases of foreign origin. The likelihood of introduction of pests and diseases of foreign origin is exacerbated by an increasing traffic of goods, facilitated by the permeability of the artificial borders within Africa and development of transportation and communication within and to Africa.

DANGEROUS INVADERS AND PESTS SPECIES DIVERSITY IN AFRICA

Insect pests and weeds of economic importance reported from different crops and in various environments in Africa are presented in Table 1.

Table 1 : Major invasive species introduced into Africa and their effect

Name	Origin	New environment	Effects
<i>Goniopertus scutallatus</i>	Australia	South and East Africa	Reduces productivity of <i>Eucalyptus</i> spp.
<i>Icerya purchassi</i>	Australia	South Africa	Reduces productivity of citrus and other fruit trees
<i>Rastrococcus invadens</i>	South East Asia	West and Central Africa	Mango fruit yield loss up to 90% and numerous non-quantifiable sociological effects
<i>Phenacnumerosnon quantifiable</i>	South America	West, central, east and south Africa	Reduces cassava yield by up to 80%
<i>Aleurodicus dispersus</i>	Central America	West and central Africa	Reduces productivity of cassava, citrus and other fruit trees
<i>Prostephanus truncatus</i>	Central America	West and Central Africa	Causes up to 30% loss of maize and significant loss of cassava tubers in storage
<i>Eichhornia crassipes</i>	Central America	West, Central and East Africa	Most noxious of all water weeds. Reduces water oxygen levels and fish populations; affects transport and navigation.
<i>Salvinia molesta</i>	Central America	West, Central and East Africa	Reduces water oxygen level and fish population
<i>Liriomyza trifolii</i>	Florida, USA	West and Central Africa	Reduces photosynthesis and affects production
<i>Chromolaena odorata</i>	Tropical and Subtropical America	West and Central Africa	Noxious weed in both arable and plantation crops; alternate host for an important insect pest, <i>Zonocerus variegatus</i>
<i>Mononychellus tanajoa</i>	South America	West, Central, East and South Africa	Reduces cassava yield by up to 80%

Table 2 : Major invasive species introduced into Africa : the ways in and present status

<i>Name</i>	<i>Origin</i>	<i>Means of introduction</i>	<i>Present status</i>
<i>Goniopterus scutallatus</i>	Australia	Accidental introduction	Controlled by an egg parasitoid and cultural control measures
<i>Icerya purchassi</i>	Australia	Accidental introduction on infested planting materials	Controlled by a coccinellid beetle and an agromyzid fly
<i>Orthezia insignis</i>	Hawai	Accidental introduction	Partially controlled by a coccinellid beetle
<i>Pineus pini</i>	Holarctic region?	Accidental introduction	Partially controlled by an introduced predator
<i>Cinara cypressi</i>	Europe? Malawi/Tanzania	Accidental introduction on infested planting materials	No known sustainable control
<i>Rastrococcus invadens</i>	South East Asia	Accidental introduction on infested planting materials; active dispersion by the wind and passive dispersion by man and animals	Under control by two introduced parasitoids
<i>Phenacoccus manihoti</i>	South America	Idem as above	Under control by an introduced parasitoid
<i>Aleurodicus dispersus</i>	Central America	Idem as above	Under control by two species of accidentally introduced parasitoids
<i>Prostephanus truncatus</i>	Central America	Accidental introduction on foodstuffs and other infested plant parts	On going classical biological control with a predator and other integrated pest management strategies
<i>Eichhornia crassipes</i>	Central America	Accidental introduction by man as ornamental	On going classical biological control with two weevils species.
<i>Salvinia molesta</i>	Central America	Accidental introduction	On going classical biological control
<i>Liriomyza trifolii</i>	Florida, America	Accidental introduction	Under control by an introduced parasitoid
<i>Chromolaena odorata</i>	Tropical and Subtropical America	Accidental introduction	On going biological control; partial control with an introduced leaf defoliator
<i>Mononychellus tanajoa</i>	South America	Accidental introduction on infested planting materials; active dispersion by the wind and passive dispersion by man and animals	Important and sustainable population reduction with introduced phytoseiid predators

The establishment and dissemination of pests occurs passively or actively. Passive dissemination occurs on infested plant materials transported by man. Introduction via materials probably was the way many invasive pests entered Africa and the major means of spread and distribution over long and short distances. In some localities, the activity has been transport and dispersal occur via wind and likely occurs slowly and over small distances. The activity of bats and other animals, including fruit eating birds has been responsible for inland dispersal of pests. These flying mammals were frequently observed flying between infested and non infested trees, carrying pests over long and short distances.

In Africa, the rapid distribution of the invasive pests is facilitated by ethnic communities and families distributed across borders. Such distribution complicates monitoring and restriction of movement of food stuffs.

Among the invaders from table 1, several species clearly illustrate the nature and magnitude of problems caused by dangerous invaders. These are:

- The cassava mealybug, *Phenacoccus manihoti* (Homoptera: Pseudococcidae), and the cassava green mite, *Mononychellus tanajoa* (Acari: Tetranychidae), were introduced into Africa from South America in the early 1970s and have since spread to all cassava growing regions of Africa, causing high yield losses (Herren *et al.*, 1991; Yaninek & Herren, 1988; Neuenschwander, 1996).
- The vegetable leaf miner, *Liriomyza trifolii* Burgess (Diptera: Agromyzidae), introduced into Africa from Florida, USA and the Caribbean in the late 1970s (Spencer, 1973), has spread very rapidly in Senegal (Neuenschwander, Murphy & Coly, 1987) and later to several African countries (de Lima, 1979).
- In the early 1990s, the spiralling whitefly, *Aleurodicus dispersus* Russel (Homoptera: Aleyrodidae) was introduced from Central America and found for the first time in Nigeria (Akinlosotu, Jackai, Ntonifor, Hassan, Agyakwa, Odebiyi, Akingbohunbe & Rossell, 1993). It quickly spread to Benin, Togo and Ghana, causing great damage on many shade and fruit trees as well as on cassava (Neuenschwander, 1996).
- One of the most recent and best documented dangerous invaders is the mango mealybug, *Rastrococcus invadens* Williams (Homoptera: Pseudococcidae). Described by Williams (1986), the mealybug originated from south east Asia and was introduced accidentally, probably on infested plant material, into the Ghana and Togo region in the early 1980s from where it quickly spread to Benin. It has since invaded different countries in West and Central Africa (Agounke *et al.*, 1988; Boussienguet *et al.*, 1992; Ivbidjaro *et al.*, 1992; Matokot *et al.*, 1992; Neuenschwander *et al.*, 1994). Its rapid spread was facilitated by the openness of the borders, the movement of many travellers and major agricultural projects such as horticulture and reforestation programmes. All these factors involved introduction and transfer of plant material from region to region. The importance of the problem was evident in the high populations and polyphagy of *R. invadens* and the often desperate remedies (e.g. felling mango trees) sought by people. Also, the fruits attacked by the mealybug constitute important sources of energy and vitamins for local populations, especially of rural areas. Therefore, a rational and efficient control strategy for the mango mealybug was needed. *R. invadens* and its natural enemies were investigated in India (Narasimham *et al.*, 1988), and two promising parasitoids, *Gyranusoidea tebygi* Noyes and *Anagyrus mangicola* Noyes (Hymenoptera: Encyrtidae) were studied in quarantine by the IIBC in Silwood Park (Noyes, 1988; 1990; Willink *et al.*, 1988; Cross *et al.*, 1992). A biological control program against this pest, involving introduction and establishment of *G. tebygi* and *A. mangicola*, was started in

1987 in Togo and shortly after extended to Benin and other affected countries (Neuen-schwander *et al.*, 1994; Boavida, 1996; Bokonon-Ganta *et al.*, 1996; Boavida, 1996; Bokonon-Ganta, 1996).

All these pests have invaded the African continent in the last 30 years from different continents in addition to several other invasive pests reported by different authors (Holm *et al.*, 1970; Barret & Forno, 1982; Golol & Hodges, 1982; Kega & Warui, 1983; Harnisch & Krall, 1984; Katary & Krall, 1988; Crutwell, 1988). Fortunately, most of them have been brought under control by specific natural enemies introduced from the pests' areas of origin.

These examples demonstrate the urgent need for African scientists and governments to tackle the problem of exotic pests through effective and sustainable approaches.

DANGEROUS INVADERS : THE WAYS OUT

Most of the insect pests and weeds that have been introduced into Africa (Table 2) were brought into the continent on or in infested plant or animal imports. This occurred in the cases of the cassava mealybug and green mite introduced on cassava cuttings or tubers from South America; the mango mealybug introduced on infested planting materials from Southeast Asia; the American serpentine leaf miner, transported via air freight on ornamentals from Florida, USA and; the water hyacinth, introduced as an ornamental from Central America.

The following actions, considered important management tactics, are suggested. These actions are suggested on the bases of an assessment of the problem, the present status of knowledge on pests, especially of their ecology, control and economic impact, and the increasing importance of producers and traders in the agricultural sectors as the result of market liberalisation and globalisation.

1 Quarantine

The term "plant quarantine" is used to describe all the legal restrictions and activities related to the movement of commodities for the purpose of preventing or delaying the introduction and establishment of plants pests and diseases in areas where they are not to exist (M'Boob, 1991). The objectives of plant quarantine are twofold: (1) prevent the introduction and establishment of an exotic species of plant pest or disease; and (2) eradicate, control or retard the spread of any such pest or disease that already has been introduced.

The recent spread of a number of new pests and pathogens into the African continent highlighted the vital role that plant quarantine must play in the improvement of African agricultural productivity. The artificial and immense frontiers between African countries, and the inherent difficulties in controlling the movement of people and goods across them, often means that new pests once introduced into the continent spread very rapidly when unchecked, from country to country, as has been demonstrated by the pests in Table 1.

Many, if not all pests introduced into Africa could have been denied access and/or have their arrival greatly delayed by effective plant quarantine measures (Odera, 1991). Most of the losses of crops and commodities attributed to such pests and the high costs of control measures which they now require could have been avoided.

2 Surveys

It is urgent and important to investigate all potential pests for a country, paying special attention to spread from other parts of the world with similar agro-ecological conditions.

3 Funding

Post-entry stations with excellent facilities created in some countries are unfortunately unable to meet the recurrent costs involved in their maintenance. In others, like in Benin, the minimum physical and technical facilities are deficient or lacking, which hampers effective and reliable plant quarantine services. Therefore there is an urgent need to make available adequate resources to agriculture ministries to meet the specific needs of integrated pest management to avoid dangerous invaders and control already introduced ones.

4 Regional and International Cooperation

Theoretically, the movement of commodities between continents should be done within the framework of plant quarantine laws and regulations based on national and international agreements.

Benin, as well as other African countries, is a signatory to the International Plant Protection Convention of 1951, administrated by the Food and Agriculture Organisation (FAO). Benin is also a member of the Inter-African Phytosanitary Council established in 1956 and now administrated by the Organisation of African Unity (OAU).

Besides the international measures, importation of plant materials in Benin is governed by Phytosanitary Law 198 of 1986 and its different Acts of Application that empowers the Ministry of Agriculture to make provisions for preventing the introduction and spread of agricultural diseases and pests.

In the case of the mango mealybug, the biological control project was originally financed by the FAO with the agreement of the Inter-African Phytosanitary Council of the Organisation of the OAU, and later by the Gesellschaft für Technische Zusammenarbeit (GTZ) and special complementary funding from the government of Switzerland. The programme was conducted in close collaboration between IITA, IIBC and national plant protection services in training, introduction of natural enemies, and research. The aim of the project was to introduce exotic parasitoids to supplement indigenous predators that were not capable of controlling *R. invadens* (Agounke *et al.*, 1988).

5 Information, education and communication

The introduction and dispersal of invasive pests is easily effected by active or passive transport. Therefore, an invasive pest should not be considered a problem of officials of "Plant Protection and Quarantine Services" only.

In the case of the mango mealybug various information and communication means were used to educate the population at large, including executive and legislative politicians, on the risks associated with movement of infested planting material from infested areas to uninfested areas with favourable conditions. Numerous technical leaflets and posters were edited and distributed in schools, public administrations and important meeting places.

6 Staffing and training

There is no positive relationship between the high number of potential points of entry of a country and the number of official quarantine border posts or entry points. The few existing posts are characterised by chronic staff shortages due to budgetary constraints and inadequate training for existing staff. Moreover, there is a shortage of biosystematists and trained taxonomists capable of giving authoritative identifications of pests in many African countries (Kumar, 1981; Ritchie, 1987). Although some progress has been made recently in entomology and phytopathology, a strong need remains for training personnel at different levels as far as rodent management is concerned.

CONCLUSION

The present conference presented a unique opportunity for international cooperation in invasive species policy development implementation. With the African and all other continents facing the common problem of invasive pests, it is important and essential that strategic plans are designed to tackle this problem.

The objective of such plans should be to facilitate the establishment in different continents of permanent plant quarantine capacities to reduce the spread and economic damage of already established pests and to establish between countries with similar agro-ecological conditions on different continents, effective and sustainable physical and technical capacities against dangerous pests to reduce the threat of new introductions.

ACKNOWLEDGMENTS

I wish to acknowledge the financial and technical support given by the International Institute of Tropical Agriculture (Benin Station) during the course of execution of my research on dangerous invaders including the cassava and mango mealybugs. I am grateful to the Netherlands Committee for IUCN for extending an invitation to attend this working conference.

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7. NATURE POLICY AND INVASIVE SPECIES POLICY IN THE NETHERLANDS

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SUMMARY

Alien invasive species policies have existed in the Netherlands from 1857. Up to 35 species had been subject to regulations aiming at control in the period 1857-1995. The present number of species under control regulations is lower due to modern nature policy and generic pest control measures. Although the total number of species that have invaded the Netherlands since the Middle Ages is much larger than 35, the majority of the species were not considered a major problem, and only for a small number of species have measures been taken. Nowadays, active control is practised in case an alien invasive species causes major problems for the human society, forestry, horticulture or agriculture. It is estimated that more than 80% of the recent invasions result from intended imports, for example, related to the horticulture industry. From 1994, the Netherlands have developed legal instruments and structures to control deliberate introductions that may be harmful to the natural environment.

The government of the Netherlands recognises the detrimental impact of alien invasive species in some countries. It supports the development of global guiding principles and joint working programmes that should lead to a better understanding of the processes involved and of the possibilities for control, prevention and eradication. Guidelines, control structures and control standards should be developed in close co-operation with present pest control agencies.

In addition, research is needed for a better understanding of invasions. Moreover, special attention should be given to public awareness and training.

INTRODUCTION

Mrs. G.H. Faber, the State Secretary of Agriculture, Nature Management and Fisheries of the Netherlands, has recently presented a new policy plan for nature: *Natuur voor Mensen, Mensen voor Natuur* (NvM; Nature for People, People for Nature). NvM implies a further development of a strategy for nature management which has been adopted by the Dutch government in the beginning of the '90s. In that era, Dutch nature policy changed from being defensive to being offensive. In stead of only protecting the existing nature areas against external pressures, the new policy set new goals for the number of hectares and quality of nature in the Netherlands. As a result, new nature areas have emerged from former farmland and management policies have been developed for nature areas and for the maintenance of natural values on agricultural land. NvM underlines the importance of the continuation of an offensive nature policy. In addition, NvM sets new goals for the quality of landscapes in the Netherlands. The new policy also puts more weight on the importance of nature and landscapes for a viable and sustainable society. Thus, Dutch nature policy aims at becoming an issue that is at the heart of social development in the Netherlands. Invasive species policy in the Netherlands is part of the overall nature policy in NvM as well as of the strategic goals of NvM.

PRESENT SITUATION

At the end of the 19th century, following a private initiative to protect natural areas, an active nature protection policy was adopted in the Netherlands. However, in spite of the many protection efforts, natural values still declined. Only recently national policy lead to some success. During the last ten years, with the help of provincial and local authorities, NGOs and private owners, the total area of nature reserves in the Netherlands has increased. Moreover, a so-called ecological infrastructure (EHS) to inter-connect and to enlarge different nature areas throughout the country is under construction.

The EHS is regarded as a useful concept in Dutch society and politics. In the next decades, the total EHS area has to increase from 10% to almost 15% of the total terrestrial area of the Netherlands. In addition, plans for nature areas and agricultural land management have been developed that should result in an improved quality as well as in the protection and sustainable use of biological diversity in those areas. The plans have already been shown to be successful for various endangered species and ecosystems such as orchids, birds of prey and wetlands.

There are multiple challenges left, however. The spatial cohesion of the EHS in the Netherlands still leaves much to be desired. Moreover, the diversity of landscapes in the Netherlands diminishes and Dutch economic policies take the protection of ecological values too little into account. For example, fisheries policy only takes the sustainable use of commercially attractive species into account, whereas other marine species and habitats may still disappear. Agricultural policies too, often only explicitly consider the species that are interesting from a commercial point of view. Further, the protection of endangered species and ecosystems in the Netherlands is severely hampered by activities such as the construction of new houses and roads. For example, over the last two decades, the number of cars in the Netherlands has increased from 4 million to 6 million. It has also been estimated that almost a million new houses should be built in the next 30 years in the Netherlands to meet the demand.

NvM: THE NEW DUTCH PLAN FOR NATURE POLICY

NvM is a new Dutch nature policy plan which deals with these challenges for the next two decades. The main objectives of NvM are:

- to improve the EHS by creating wide ecological corridors, by further enlarging the EHS area, and by giving more attention to the role of water quality and quantity in ecosystem development;
- to improve the identity of landscapes by putting more emphasis on landscape-architectural design and by creating so-called 'green-blue veins' in landscapes: new waterways, hedgerows and other connecting landscape elements;
- to improve the sustainable use and conservation of biodiversity by management plans for areas both within and outside the EHS, by specific measures for endangered species, and through the integration of practices that support the sustainable use of biological diversity in agriculture, fisheries and other economic sectors.

Within these objectives, maintaining and improving the quality of ecosystems is a priority issue. The quality criteria applied include the robustness and completeness of ecosystems compared to natural references. The problems caused by alien species are to be addressed within this framework.

INVASIVE SPECIES

Compared to the problem of disruptions of habitats and landscapes, the effects of alien invasive species on habitats, ecosystems or species in the Netherlands can be considered an insignificant problem. Since the Netherlands have a long tradition in dealing with "unwanted" species, the control of alien species which may cause problems has been well regulated or dealt with. Table 1 summarises species-specific legislation primarily or secondarily aiming at the 'control' of wild animal species in the Netherlands in the period 1857-1995 (Knegtering *et al.*, 2000). Table 2 presents the data obtained by Knegtering *et al.* on the individual species which had been under this legislation (the species are arranged by the total length of time in which the species had been under the legislation; the Sparrow Hawk is the species with the longest total time). Table 2 also indicates the species which may be labelled as alien for the Netherlands (i.e. (imminent) introductions during roughly the last 150 years).

Dutch species-specific legislation aiming at the control of aliens has existed since 1875 (Tables 1 and 2). Most of the aliens having been under 'control' (Table 2) were so to protect economic interests, including agriculture, infrastructure and fisheries. In recent years, legislation has been adopted which includes the protection against aliens of the natural environment in the Netherlands. The Council of Europe, monitoring control measures for introductions of non-native organisms into the natural environment (Publ. Nature and Environment, no. 73, Council of Europe 1996), commented that *'since the beginning of 1994 the Netherlands possesses an effective legal instrument for the control of deliberate introductions and the prevention of at least some accidental introductions. There appear however to be some gaps. In particular there do not seem to be any penalties for introductions effected by negligence and there is no mention of civil liability.* Further, the new Dutch Flora and Fauna Act, which has been sent to parliament since, will generally prohibit the introduction of exotic species of animals and plants that may be harmful for the natural environment. However, the act will not contain rules for civil liability. In many cases it is very difficult to prove beforehand that a species is harmful to the natural environment. Consequently, it is difficult to predict the effectiveness of the new act in preventing all major damage.

ACTIVE CONTROL

Table 2 shows that, since the 19th century, only a relatively minor number of alien invasive animal species was legally controlled. Apparently, the effects of most non-deliberate invasions had not been regarded a serious problem to be regulated. In recent years, the number of deliberate invasions has increased in the Netherlands. It is presently estimated at more than 80% of all introductions. Since some of these deliberate introductions are considered potentially harmful for the natural environment, new legal instruments for the control of deliberate introductions and for the prevention of accidental introductions have been developed. In case one or more of the following effects occur, active measures to control alien and invasive species may be executed:

1. Detrimental effects on ecological quality,
2. Significant effects on public health,
3. Significant damage to crops, forests or commercial fish or shellfish populations,
4. Unacceptable abundance of populations.

On the basis of these criteria, active control measures have been carried out against invasive species such as Musk rats. In the management of such species in the Netherlands, regional and local authorities as well as regional Water Boards are responsible for taking appropriate actions, whereas the national government provides support (subsidies, education programmes).

The latest addition to the list of alien species being under active control is the water plant *Ludwigia grandiflora* which originates from South America. This species was originally imported into the Netherlands as an ornamental plant for ponds, but it has been spreading in natural environments since then. Due to its high growth rates, it blocks waterways and deteriorates the biological quality of fresh water systems. Therefore, Dutch regional Water Boards have set up programmes for a total removal of the species from natural habitats.

ALIEN INVASIVE SPECIES IN THE CONVENTION ON BIOLOGICAL DIVERSITY

The issue of alien invasive species has been recognised as a major issue by the Convention on Biological Diversity (CBD) and it has been discussed in three successive Conferences of the Parties (COPs) to the Convention. The Netherlands are also a Party of the CBD. The discussions in the COPs have been supported by case studies and thematic reports of the Parties. Although invasive alien species may have severe effects on biodiversity, most countries are extremely limited in their abilities to address the issue. Therefore, both national capacity building and facilitation of collaborative efforts are obvious areas to be tackled.

At the third meeting of the COP (COP-3) to the CBD, the Scientific Committee on Problems of the Environment (SCOPE) and the invasive species specialist group of IUCN — the World Conservation Union — were encouraged to continue their efforts to develop a global strategy and an action plan to deal with the problem of alien invasive species. At the fourth meeting of the COP (COP-4), the parties agreed to address the implementation of article 8h of the CBD on alien species which threaten ecosystems, habitats or species (hereafter referred to as "invasive alien species"). At its fifth meeting (COP-5; Nairobi, May 2000), the COP made some initial decisions on the issue and requested a further series of actions prior to a full consideration of the issue at its sixth meeting (COP-6; The Hague, April 2002). The decisions and requests include:

1. Other governments, relevant bodies and organisations are requested to submit case-studies, to develop mechanisms for transboundary co-operation;
2. Other governments and relevant organisations are urged to apply the interim guiding principles, to give priority to the development of invasive alien species strategies and action plans;
3. The Executive Secretary of the CBD (ES) is requested to further elaborate the interim guiding principles and to co-operate with other international treaties or bodies such as RAMSAR, CITES, IPPC, the Bern Convention, UNESCO, FAO and IMO¹ with the aim of co-

¹ RAMSAR: Convention on Wetlands of International Importance especially as Waterfowl Habitat; CITES: Convention on International Trade in Endangered Species of Wild Flora and Fauna; IPPC: International Plant Protection Convention; Bern Convention: Convention on the Conservation of European Wildlife and Natural Habitats; UNESCO: United Nations Educational, Scientific and Cultural Organisation; FAO: Food and Agricultural Organisation of the United Nations; IMO: International Maritime Organisation.

ordinating work on alien invasive species and to report on potential joint work programmes and to develop:

4. Standardised terminology;
5. Criteria for assessing the risks of the introduction of alien species;
6. Processes for assessing socio-economic implications;
7. Means and ways to enhance the capacity of ecosystems to resist or to recover from alien species invasions, and;
8. A system to report new invasions.

Within the framework of the IPPC, the relationship between the plant protection convention and the CBD is currently being discussed. In order to close the existing gaps between the protection of plants and protection of natural species and habitats, the ways and means of the IPPC might be adapted.

The scientific committee of the CBD (SBSTTA) is preparing itself for COP-6. At SBSTTA's 6 (12 -16 March 2001) and 8, the issue of alien invasive species will be discussed to prepare for an in depth discussion at COP-6.

COP-5 invited Parties to address this issue of alien invasive species through projects and the incorporation of activities into national strategies, programmes and action plans. COP-5 also requested SBSTTA to develop guiding principles for the prevention, introduction and mitigation of impacts of alien species, to identify the priority work pertinent to the issue of alien species in geographically and evolutionarily isolated ecosystems; and to explore collaboration with the Global Invasive Species Programme (GISP).

The ES has prepared a note which discusses the adverse effects of certain alien species on biodiversity. The note also examines the matter in the context of Articles 6 and 8 of the Convention, and of the various thematic and cross-cutting issues, including the precautionary and ecosystem approaches, and it surveys relevant processes and activities. From the analyses of the ES, the following conclusions may be drawn:

1. Relevant international instruments have been developed under different multilateral processes. The instruments include: multilateral environmental agreements, sanitary and phytosanitary instruments, guidelines for the transportation sector, and instruments to regulate intentional species introductions;
2. Gaps, overlaps and inconsistencies are apparent in the existing instruments at all levels;
3. Different terminology is used in different sectors;
4. Conservation instruments often fail to define relevant issues;
5. Effective instruments for particular animal groups, such as birds, are lacking;
6. There is a lack of binding instruments for aquatic species.

Some species groups, in particular those related to agricultural and horticultural production, such as weeds and insects, are well covered by international rules and regulations. However, most countries have separate legal and institutional systems for the environment, agriculture, fisheries, international trade and other key sectors. A strategy that cross-cuts these systems is lacking. Moreover, the issue of alien species involves vast economic interests and trade issues. Therefore, within the biodiversity realm, it may be difficult to reach agreement on a common policy that may count on a broad acceptance by different sectors. Consequently, co-operation with other organisations and other sectors will be a decisive factor for the success of the efforts of the CBD. Nonetheless, the CBD may play an important role in the development of a com-

mon approach by the adoption of the guiding principles and by bridging noted gaps and inconsistencies, i.e. with a non-binding list of terms most commonly used.

The ES, in co-operation with GISP, has also developed interim guiding principles for the prevention of the introduction of alien species and for the mitigation of impacts of alien species. In addition, the ES has made an outline for case studies on alien species. On the basis of these interim guiding principles and more than a dozen case studies from different regions, COP-5 has decided to consider the issue of alien species in depth at COP-6. In their comment on the principles, the delegation of the Netherlands stated that the principles should also take existing regulations into account, such as regulations on plant pests. This statement was effected in a request of COP-5 to the ES to prepare a detailed examination of the guiding principles and to closely collaborate with GISP as well as with relevant instruments and bodies such as the FAO (which provides the secretariat of the IPPC), the IMO, RAMSAR and UNESCO.

Besides this discussion, the agenda of COP-6 also shows the following priority issues with regard to alien invasive species:

1. Standardising of terminology;
2. Development of research on: risk assessment, understanding invasions, species and genetics;
3. Monitoring and reporting;
4. Information and education.

TOWARDS COP-6

Prior to COP-6, a vast amount of information will be available from a great number of parties and international organisations. The information will allow for an in depth discussion of the issue and for decisions that may be instrumental to more integrated, binding and effective global measures to control alien invasive species. Clear decisions at COP-6 will encourage parties to implement article 8h of the CBD in national strategies and international co-operation. The government of the Netherlands will strongly support that decisions to this effect will be taken at COP-6. Such decisions could include:

1. The adoption of the Guiding Principles;
2. Recognition of the importance to develop an international instrument or instruments and adoption of an appropriate strategy;
3. The adoption of a working programme that may include the development of additional instruments, as appropriate, the closing of existing gaps in the ways and means for the prevention, detection, eradication and control of alien invasive species, the implementation of the guiding principles in national strategies and action plans, the international co-operation and exchange of information through the Clearing House Mechanism;
4. The ratification of the revised Plant Protection Convention as appropriate;
5. Further recognition of the essential role of co-operation with other international organisations and conventions and of the importance of enhanced information sharing between parties, other governments and organisations.

ACKNOWLEDGEMENTS

We would like to thank Ingeborg de Boois, Henk Stigter and Bert Wetsteyn for their information on the alien status of several species in Table 2.

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Table 1. Chronology of main species-specific legislation aiming at the control of non-domestic free-to-roam animals in the Netherlands during 1857-1995. Between brackets: primary objectives of the legislation (capital letters): C = 'control, U = 'use, P = 'protection'; secondary objectives of the legislation (small letters): c = 'control, u = 'use, p = 'protection' (source: Knegtering *et al.*, 2000)

1857-1923	Hunting and (inland) Fishing Act 1857 (U, c, p)
1875-1911	Colorado Beetle regulations (<i>Leptinotarsa decemlineata</i>) (C)
1883-1951	Grape Phylloxera regulations (<i>Daktulosphaira vitifoliae</i>) (C)
1898-1922	San Jose Scale regulations (<i>Quadraspidiotus perniciosus</i>) (C)
1914-1936	Bird Act 1912 (P, u, c)
1914	Amendment of Hunting and (inland) Fishing Act 1857
1923-1954	Hunting Act 1923 (U, c)
1928-1994	Various specific regulations concerning: - Cherry Fruit Flies (<i>Rhagoletis cerasi</i>) (C), - Colorado Beetles (C), - Ox Warble Flies (<i>Hypoderma bovis</i> and <i>H. lineatum</i>) (C), and - Asparagus Flies (<i>Platyparea poeciloptera</i>) (C)
1930-	Various Musk Rat regulations (<i>Ondatra zibethicus</i>) (C),
1935-	Regulations concerning Large and Small Elm Bark Beetles (<i>Scolytus scolytus</i> and <i>S. multistriatus</i>) (C),
1936-	Bird Act 1936 (P, u, c)
1954-	Hunting Act 1954 (U, c)
1977	Amendment of Hunting Act 1954
1993	Amendments of Hunting Act 1954 and Bird Act 1936

Table 2. Species subject to species-specific legislation aiming at control in the Netherlands during 1857-1995. Alien species are indicated with +.

Species	Alien	Period under legislation
"a Falcon "		1857-1914
"a Kite "		1857-1914
"an Eagle "		1857-1914
"Starfish"		1892-1911
American mink (<i>Mustela vison</i>)	+	1978-1995
Asparagus Fly (<i>Platyparea poeciloptera</i>)		1948-1991

Table 2 (continued)

Badger (<i>Meles meles</i>)		1857-1923; 1924-1947
Black-headed Gull (<i>Larus ridibundus</i>)		1937-1994
Buzzard (<i>Buteo buteo</i>)		1857-1914
Carrion Crow (<i>Corvus corone corone</i>)		1914-1977
Cherry Fruit Fly (<i>Rhagoletis cerasi</i>)		1928-1951; 1955-1991
Collared Turtle Dove (<i>Streptopelia decaocto</i>)		1985-1994
Colorado Beetle (<i>Leptinotarsa decemlineata</i>)	+	1875-1911; 1932-1994
Common Seal (<i>Phoca vitulina</i>)		1914-1923; 1947-1954
Cormorant (<i>Phalacrocorax carbo</i>)		1914-1985
Coypu (<i>Myocastor coypus</i>)	+	1978-1995
Domestic Cat (<i>Felis catus</i>)		1857-1923; 1924-1977
Goshawk (<i>Accipiter gentilis</i>)		1857-1914
Grape Phylloxera (<i>Daktulosphaira vitifoliae</i>)	+	1883-1951
Great Black-backed Gull (<i>Larus marinus</i>)		1937-1994
Grey Heron (<i>Ardea cinerea</i>)		1914-1985
Herring Gull (<i>Larus argentatus</i>)		1937-1994
Hooded Crow (<i>Corvus corone cornix</i>)		1937-1977
House Sparrow (<i>Passer domesticus</i>)		1914-1995
Jackdaw (<i>Corvus monedula</i>)		1949-1977
Jay (<i>Garrulus glandarius</i>)		1914-1977
Large Elm Bark Beetle (<i>Scolytus scolytus</i>)		1935-1961; 1977-1995
Magpie (<i>Pica pica</i>)		1914-1977
Merlin (<i>Falco columbarius</i>)		1914-1928
Musk Rat (<i>Ondatra zibethicus</i>)	+	1930-1995
Mute Swan (<i>Cygnus olor</i>)		1985-1994
Otter (<i>Lutra lutra</i>)		1857-1923; 1924-1954
Ox Warble Flies (<i>Hypoderma bovis</i> + <i>Hypoderma 1 ineatum</i>)		1942-1992
Peregrine (<i>Falco peregrinus</i>)		1937-1985
Pheasant (<i>Phasianus colchicus</i>)		1923-1954
Pine Marten (<i>Martes martes</i>)		1857-1923; 1924-1947
Portuguese Oyster (<i>Crassostrea angulata</i>)	+	1900-1911
Rabbit (<i>Oryctolagus cuniculus</i>)		1857-1977
Raccoon (<i>Procyon lotor</i>)	+	1978-1995
Raccoon dog (<i>Nyctereutes procynoides</i>)	+	1978-1995
Red Fox (<i>Vulpes vulpes</i>)		1857-1923; 1924-1977
Red Squirrel (<i>Sciurus vulgaris</i>)		1954-1977
Rook (<i>Corvus frugilegus</i>)		1947-1977
San Jose Scale (<i>Quadraspidiotus perniciosus</i>)	+	1898-1922; 1951-1995
Small Elm Bark Beetle (<i>Scolytus multistriatus</i>)		1935-1961; 1977-1995
Sparrow Hawk (<i>Accipiter nisus</i>)		1857-1985
Starling (<i>Sturnus vulgaris</i>)		1937-1995
Stoat (<i>Mustela erminea</i>)		1857-1923; 1947-1977
Stock Dove (<i>Columba oenas</i>)		1953-1954
Stone Marten (<i>Martes foina</i>)		1857-1923; 1924-1947
Tree Sparrow (<i>Passer montanus</i>)		1914-1937
Weasel (<i>Mustela nivalis</i>)		1857-1923; 1924-1977
Western Polecat (<i>Mustela putorius</i>)		1857-1923; 1924-1977
Wild Boar (<i>Sus scrofa</i>)		1923-1972
Woodpigeon (<i>Columba palumbus</i>)		1914-1977

8. ADDRESSING INVASIVE SPECIES IN THE UNITED STATES

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Invasive species represent one of the world's most significant environmental issues, in a category of environmental threats that includes habitat loss and global climate change (Sala, 2000). Not only are invasive species a growing ecological concern as global trade, transport and tourism increase — moving goods around the world at a rate six-times faster than four decades ago (Bright, 1998), invasive species are also expensive, costing the U.S. an estimated \$137 billion annually in direct and indirect expenses, and prevention and control measures (Pimentel *et al.*, 2000). Further, invasive species present significant threats to human health worldwide. The recent West Nile virus outbreaks in New York City is but one example of the costs and public concern a new invasive species can generate. In recognition of this increasingly significant issue, more than 500 scientists and resource managers sent President Clinton a letter in 1997 expressing concern and asking for better coordinated U.S. Government action in response.

EXECUTIVE ORDER 13112 AND THE INVASIVE SPECIES COUNCIL

The Clinton Administration responded by issuing Executive Order (E.O.) 13112 on February 3, 1999. E.O. 13112 establishes a system for increased federal agency cooperation and public involvement aimed toward an effective national invasive species strategy. This E.O. establishes the Invasive Species Council (ISC) to give the issue the needed national leadership.

The ISC's direct mandate is to ensure that Federal agency actions concerning invasive species are coordinated and effective. To fulfil this mandate, the Council leaders represent a cross-spectrum of U.S. Federal agencies, including Administrator of the Environmental Protection Agency, and the Secretaries of State, Commerce, Agriculture, Treasury, Defence, Transportation, and of the Interior. The Council co-chairs are the Secretary of the Interior, the Secretary of Agriculture, and the Secretary of Commerce. Representatives from these three agencies are also part of the newly established full-time staff dedicated to this issue, a staff that includes an Executive Director and two Assistant Directors.

One of the initial priorities of the ISC has been to create a National Invasive Species Management Plan. The E.O. outlines multiple objectives for the Plan:

- Encourage planning and action at the local, tribal, state, regional, and ecosystem level;
- Develop recommendations for international cooperation;
- Provide guidance on incorporating invasive species issues into the U.S. National Environmental Policy Act (NEPA);
- Facilitate development of a communication process to document, evaluate, and monitor impacts from invasive species on the economy, environment, and human health, and;
- Initiate the development of an information-sharing system that facilitates the exchange of information, nationally and internationally, concerning invasive species.

In accordance with U.S. Federal law, the Management Plan will be made available to the public for comments. These comments will be considered and potentially incorporated. The final draft of the plan will be available by the end of 2000, and can be accessed via the World Wide Web at www.invasivespecies.gov. This Management Plan is a living document and will be updated by the ISC every two years.

INVASIVE SPECIES ADVISORY COMMITTEE

To complement and inform the activities of the ISC, the E.O. also required the establishment of the Invasive Species Advisory Committee (ISAC), which consists of non-federal participants. The ISAC allows representatives from academia, industry and the general public to play a significant role in assisting the ISC to achieve the E.O.'s outlined objectives.

As the invasive species issue crosses multiple sectors, such as trade, agriculture and scientific research, and requires multiple approaches to ensure effective management, the ISAC has created six working groups to help inform its activities. Each working group includes Federal and non-Federal participants and is charged with providing information for the Management Plan, helping consolidate information, and identifying methodologies needed. The areas of focus for the six working groups are:

- International issues;
- Communication, outreach and education;
- Policy and regulation;
- Research, information sharing, documentation and monitoring;
- Risk analysis and prevention, and;
- Invasive species management.

The Working Groups meet periodically and have provided a means of organising suggestions regarding the formation and implementation of the Management Plan. The ISAC will also continue to advise the ISC after the Management Plan is completed and the focus turns to matters associated with implementation.

The ISAC serves as a useful mechanism for assessing and incorporating the views and experiences of non-government representatives. Such perspectives are a vital aspect of any successful effort as invasive species prevention, control or eradication measures will undoubtedly involve and affect the public. Without reasoned, early and consistent input from the public into the Plan's formation and implementation, it is doubtful the ISC's invasive species efforts will be as successful as needed.

NEXT STEPS

The E.O. has set ambitious objectives for the ISC, yet given the magnitude of the problem, these objectives are justified. After completion of the Management Plan, ISC will work across agencies to coordinate efforts and facilitate the implementation of the Plan. Cooperation across agricultural, environmental and trade sectors or agencies is difficult and time consuming, however coordination is vital. Invasive species represent a multi-sectoral problem that requires a multi-sectoral response. Also, invasive species represent an international problem that require international management efforts. Co-ordination, across governments, government agencies,

and between the government and non-government representatives, must involve the sharing of information, resources and abilities, and it must entail consistent communication and planning (such are the goals of E.O. 13112 and its creation of the ISC and ISAC).

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9. CONCLUDING REMARKS AND RECOMMENDATIONS

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As subtitle of the Working Conference on invasive plants and animals the programme committee had chosen a question: "Is there a way out?". During the conference it has been made very clear that many alien species do indeed cause problems, and deserve the epithet 'invasive pest'; and that in a number of cases one would wish to know methods to get rid of the invaders or, indeed, to find the way out.

In some cases, as with several invaders in e.g. the Galapagos Islands, and islands off New Zealand, eradication efforts have been successful, or partially successful. In other cases, such as marine coastal invaders spread with the ballast water of sea-vessels taken on board at one harbour and simply dumped near another, often in an entirely different part of the world, efforts have just started. To prevent such invaders of settling at their coasts, the United States have recently ruled that ballast water must be discharged in the open sea and may no longer be dumped near their coasts.

In still other cases, such as the North American muskrat (*Ondatra zibethicus*) which has established itself in many European countries from the 1920s on, the efforts conducted can only be described as very costly and — as an eradication effort -largely hopeless. The muskrat will stay, and a manageable population is all one can hope and strive for. In still other cases, such as the invasion of the West European watershed area of the river Rhine by many aquatic invertebrate species from the Southeast European watershed area of the river Danube, enabled by a canal dug in 1992, getting rid of the many invaders appears to be utopian and is not even considered. In this case, the damage in West Europe until now appears to be largely the displacement of indigenous species, and not so much disturbed ecosystem functioning.

From the examples mentioned above it appears that in many cases of harmful invasions something can be done, either to eradicate the invasive organisms, or to limit their numbers in order to mitigate the possible harm they may cause. In the latter case, of course, a lasting effort is necessary, and even then one is never sure what the future will bring. Measures to try and counteract an invasion should be taken as early as possible, and not be hampered by bureaucracy or ignorance. An example of the latter is the case of the North American grey squirrel (*Sciurus carolinensis*) in northern Italy, which could possibly have been eliminated if not for well-meaning but ignorant animal welfare activists and a likewise ignorant and non-comprehending judiciary. Thanks to these, the grey squirrel has now begun its 'triumphal march' to displace the Eurasian red squirrel (*Sciurus vulgaris*) in its entire Eurasian distribution area — as it is doing, and has nearly completed, in the United Kingdom.

In the afternoon of the conference, the attendants have discussed these and other invasive problems in three groups, covering ecological, economic, and North-South aspects respectively, with the aim to formulate recommendations for Dutch and other policy makers in the European Union.

ECOLOGICAL ASPECTS (CHAired BY DR. HANS DEN NIJS)

- The discussion first centred on the need for good and generally accepted definitions of terms like non-native species, invasive species etc. It was agreed that the *IUCN guidelines for the prevention of biodiversity loss caused by alien invasive species* (Species Survival Commission — Invasive Species Specialist Group, 2000; also on Internet, via www.iucn.org) provide for these definitions.
- There was general consensus on the fact that invasive species do pose threats to ecosystems, species and genes on a global scale; there are examples of ecosystems that have changed in composition and/or functioning through invasive species; of species that have been reduced in numbers or altogether disappeared because of invasive species; and of the loss of genes due to invasive species.
- It was emphasised that there is an important difference between invasions of islands and invasions of continents.
- It was also agreed that in individual cases solutions should be based on proper scientific knowledge of the biology and ecology of the invading species and its competitive advantage in the invaded ecosystem, and that funds should be made available for studies of alien species.
- In the light of the need for energetic national and international policies it was considered most unfortunate that, at present, invasions of alien species cannot be predicted. This inevitably leads to great emphasis on the need for a precautionary approach regarding alien species, which procedure is not readily accepted by politicians.
- Participants agreed that the Netherlands should discuss and adopt policies regarding alien invasive species, i.e. apply the principles of the *Convention on Biological Diversity*, and of the *IUCN guidelines for the prevention of biodiversity loss caused by alien invasive species*, and implement systems for the prevention and eradication of invasive species as are in use in e.g. the United States, Australia and New Zealand. This should happen in good cooperation with the other countries of the European Union, and preferably as part of an integrated policy for the EU as a whole.

ECONOMIC ASPECTS (CHAired BY MR. GIJS KUNEMAN)

Invasive species create problems for various economic sectors, such as agriculture, fisheries, and water management. On the other hand, these sectors may also be at the root of some of the problems.

Especially in the United States the economic impacts of invasive species have been well studied. In many other countries, only few data are available.

The discussion continued about the advantages and disadvantages of an economic approach to biodiversity, i.e. putting money value on species. Advantages are that this makes it easy to communicate to policy makers, and the public at large will appreciate financial issues and costs rather than other, scientifically based approaches and arguments. Among the disadvantages are the difficulty to put prices on biodiversity, and the ethical argument that we should not be doing this.

Another topic was the question, whether the drawing of species lists would help. These could be either 'white' lists of alien but harmless species, or 'black' lists of alien invasive pest species. There are objections against both. White lists would be too restricted in scope, black lists would be scientifically very difficult to complete. Some of the benefits of having such lists are that they

may help in designing and implementing regulations regarding invasive species and that they may enable a precautionary approach in particular cases.

A further issue was, that the European Union might learn from the experience in the United States. It appeared that in the absence of sufficient data in the cases of many European invasives, in this stage the methodology as developed in the United States could possibly be useful. It was strongly recommended that the Netherlands should take the initiative for an integrated effort in the European Union. First, the usefulness of a preparatory policy council should be investigated.

NORTH-SOUTH ASPECTS (CHAired BY MR. WIM DIJKMAN)

Two of the speakers of the conference came from developing countries: Benin, with which the Netherlands has a Sustainable Development Agreement including a chapter on conservation and sustainable use of biodiversity, and Ecuador, where the Netherlands assists in projects for the conservation of biodiversity and tropical rainforests. In Benin, the major problems with invasive species are economic. In Ecuador, and especially in the Galapagos Islands, the major problems are ecological.

It is observed that "North-South aspects" include both ecological and economic aspects. Economically relevant species invading developing countries, e.g. disease vectors or agricultural pests, are often originating in other southern countries, and South-South aspects should therefore not be neglected. Examples are the Nile perch in Lake Victoria and elsewhere, pine species from tropical mountainous areas, and many insect pests in agriculture.

In North-South aspects of the invasive species problem, trade, transport and travel (the three T's) should be considered as the means of potential species exchanges.

It is recommended that the issue of invasive species should be part of any North-South and South-South (development) cooperation agenda and policy. This may include:

1. training and research issues;
2. applying the clearing house principle; although still more knowledge is needed, we should also focus existing results on the management perspective of policy makers dealing with invasive species. This not only requires a database but also reanalysing and rewriting relevant knowledge.
3. awareness raising among the people who are working in natural resource management;
4. phyto- and zoosanitary regulations; these should be more precise.

It is observed that the Biodiversity Convention, and especially the 6th Conference of the Parties in 2002 in the Netherlands, is a good instrument for the implementation of several recommendations. A critical note from scientists is that a too rigid application of international regulations, such as the Convention on International Trade in Endangered Species (CITES), may hamper good collaboration by making international transport of scientific zoological or botanical material very tiresome.

RESULTS OF THE FINAL PLENARY SESSION

After the three group discussions, the conference was concluded with a plenary session. The three chairs of the discussion groups reported. Dr. den Nijs (ecological aspects) stressed the fact

that although there is, indeed, a wealth of literature on invasive species, there are also many only seemingly similar and even contradictory results. We do not yet know enough. Therefore, it is still much too early to make generalizations. (It remains questionable, moreover, if the availability of many more data will allow for such generalizations.) A case by case approach is recommended. On top of that, it is also important that the biota of the region where an invasion is to be studied or counteracted is well known. Policy makers should be made aware of this situation.

In the ensuing discussion it is added that it is of paramount importance for policy makers and politicians to be very cautious and careful when dealing with invasive species problems, and to apply the precautionary principle whenever necessary, i.e. when our knowledge is incomplete.

An example is the Egyptian goose, which has settled in the Netherlands and of which it is not clear whether it should be regarded as harmful (locally, to other species) or not. At present the population appears to remain limited, but we do not know how the species' biodynamics and behaviour will develop, and how the situation will be 10 or 20 years hence. The time dimension is extremely important.

At the same time one should realize that many alien species have already settled themselves. The example of New Zealand is mentioned, where many alien species have become invasive, to the detriment of indigenous species, and where programmes to remove certain species from certain ecosystems (e.g. islands) have always included detailed advice to the government on the one hand, and entailed more research on the other. Advice is given on a case by case basis. In particular cases the advice is that certain decisions cannot be made because not enough is known.

A plant specialist of Botanical Gardens International points out that scientific exchange of plant material has already become very difficult and time consuming. The regulations dealing with international border crossings of plants involve tremendous amounts of paperwork. Such plants are well looked after and the danger of becoming alien or invasive does not really exist. The additional application of the precautionary principle here would be like trying to shoot mosquitoes with a gun. Others think that it is a matter of scale. We are dealing with many plant species which have ended up as aliens or invasives in the wild unintentionally. We should admit that scientists such as botanists maintaining collections may experience problems. It is suggested to apply a — more flexible - precautionary *approach* rather than a — too rigid — precautionary principle, to create some room for interpretation where needed.

A question is asked about the Dutch policy to create new natural areas. Are alien species being used in the process? The representative of the responsible ministry responds by saying that such initiatives are generally based on the principle that no introductions are allowed. At the same time he points out that a number exotic (though mostly non-invasive) species of trees and shrubs are found in the wild today, and that it will be difficult, in the long run, to prevent them from settling in new environments.

Finally, the discussion turns to species traffic related to biotechnological activities, such as gen technology. In the United States, the Invasive Species Council of the Department of the Interior does not focus on this admittedly very much related area, because it is very politicised, and considered a separate issue by most people involved. Having said that, its representative emphasizes that different kinds of invasions need different approaches. The introduction of alien biological pest control species must be very deliberate and surrounded by precautions. The purchase or acquisition of plants for the tropical greenhouse of a botanical garden in e.g. the Netherlands is much less hazardous because the chances of survival in the wild of such species are at most very low. Nevertheless, precaution remains necessary. (For very much the same reasons, the organisers of the present conference also deliberately left the issue out. It is sufficiently comprehensive

to deserve a conference of its own, the discussions are of a generally different, often more political nature, and if included today it would easily have dominated the issue of wild invasive species. Moreover, other groups of non-governmental organisations are dealing with it in a focussed way.)

In his final remarks the chair of the day concludes that the problem of invasive species is multifaceted, ranging from the case of Benin, where the essential problems are agricultural, to the Galapagos Islands, which offer a classical example of the threat of invasives to vulnerable island biota — where, as has also been shown, substantial funding may make a big difference.

He continues to say that in the Netherlands many if not most species are (natural) invaders, which illustrates the need for good definitions. Furthermore, he emphasizes the need to assemble what we do know about the damage caused by invasive species, on a European level, adding that such a study would not cost a fraction of this damage itself. He concludes from what has been said and discussed today that it is really necessary that policy makers become active in the study of the invasives problem and the development of policies dealing with it.

RECOMMENDATIONS

Policy

1. Considering that alien invasive species may pose threats to indigenous biological diversity on genetic, species and ecosystem levels, it is recommended that the Netherlands, in good cooperation with other countries of the European Union, becomes more active in the study of the invasives problem, and develop and adopt a policy regarding alien and alien invasive species of plants, animals and micro-organisms, preferably as part of an integrated policy for the European Union as a whole, applying the principles of the *Convention on Biological Diversity* and of the *IUCN Guidelines for the Prevention of Biodiversity Loss caused by Alien Invasive Species*, and implement systems for the prevention and eradication of alien invasive species.
2. Considering that as yet there appear to be no specialized institutions in the Netherlands or elsewhere in the European Union dealing with the systematic collection of data on alien, alien invasive, and alien invasive pest species, and that as a consequence there are no sufficient data in the case of many alien invasives in Europe, it is recommended that the Netherlands, and the European Union, in their necessary efforts to develop an overall alien invasive species policy, take good notice of the institutions, mechanisms and methodologies as already developed in other countries, such as the United States, and consider the establishment of similar institutions and mechanisms and the application of similar methodologies on national and European Union levels. In this light, the feasibility and usefulness of a Preparatory Policy Council should be investigated.
3. Considering that alien invasive pest species problems occur in many countries all over the world, and that in developing countries these problems have the same ecological and/or, possibly more often, economic negative aspects as elsewhere, it is recommended that the issue of alien invasive species is included in the agendas for the implementation of the Convention on Biological Diversity in the framework of development cooperation programmes between the Netherlands and the European Union on the one hand, and developing countries on the other. Important topics to be considered for these agendas are training and research; the clearing house principle; trade; tourism; awareness raising; and biosanitary regulations.

Implementation

4. Considering that in spite of the fact that globally there are many publications on alien invasive pest species the collected knowledge of such species has not yet enabled a systematic and sufficient problem solving approach, it is recommended that at this stage in the case of each alien, alien invasive, or alien invasive pest species, a precautionary and individual, or case by case, approach is applied.
5. Considering that alien invasive species are unpredictable in their invasive behaviour, e.g. for years on end pose no harm to their environment but later on may grow exponentially, it is recommended that measures to try and counteract invasions should be taken and implemented as early as possible.
6. Considering that the introduction of biological pest control species may result, next to the intended benefits, in the introduced species becoming an alien invasive, it is recommended that such introductions are extremely deliberate and surrounded by extensive precautions, in developed and developing countries alike.

Definitions

7. Considering the need for an internationally agreed and co-ordinated policy regarding alien invasive species, there is a need for good and internationally accepted definitions of terms related to alien species invasions, it is recommended to promote the use of a set of fixed definitions, preferably based on the *IUCN Guidelines for the Prevention of Biodiversity Loss caused by Alien Invasive Species*.

Research

8. Considering that there is at present no database on alien invasive species and the damage caused by them in the countries of the European Union, it is recommended that the Netherlands promotes the establishment of such a database.
9. Considering that solutions of problems caused by alien invasive pest species should always be based on proper scientific knowledge of the biology and ecology of the invading species, and of its competitive advantage in the invaded ecosystem(s), it is recommended to promote research of alien invasive species and, in that context, of the biota of the invaded area or region, and to make available the necessary funds for this research.
10. In this respect it is also recommended, that the Netherlands explores the possible benefits of the listing of alien, alien invasive, and alien invasive pest species in enabling a precautionary approach.

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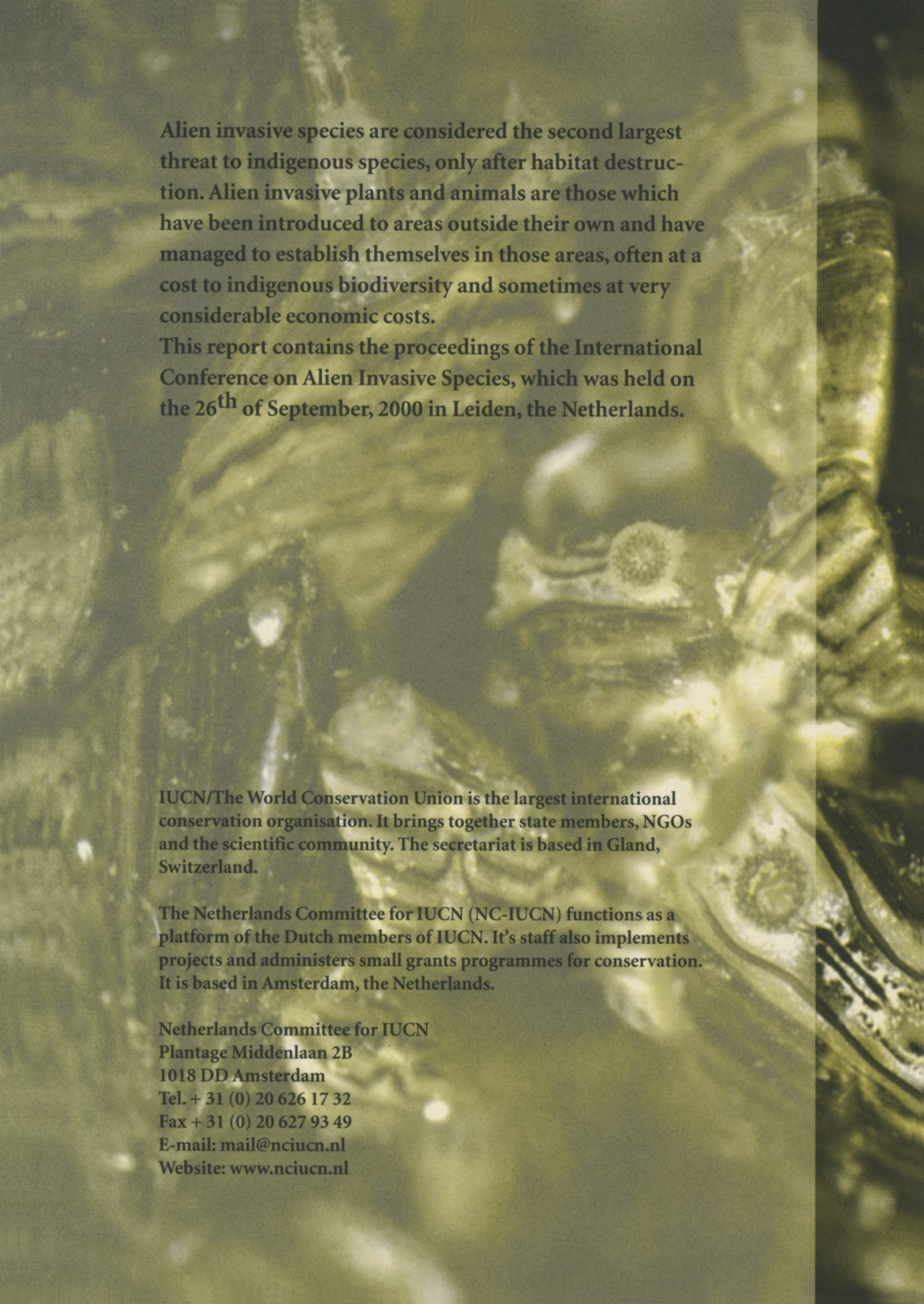
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Alien invasive species are considered the second largest threat to indigenous species, only after habitat destruction. Alien invasive plants and animals are those which have been introduced to areas outside their own and have managed to establish themselves in those areas, often at a cost to indigenous biodiversity and sometimes at very considerable economic costs.

This report contains the proceedings of the International Conference on Alien Invasive Species, which was held on the 26th of September, 2000 in Leiden, the Netherlands.

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