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INVASIVE ALIEN SPECIES

Status, impacts and trends of alien species that threaten ecosystems, habitats and species

Note by the Executive Secretary

1. The Executive Secretary is pleased to circulate herewith, for the information of participants in the sixth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) a note on the status, impacts and trends of alien species that threaten ecosystems, habitats and species, prepared on the basis of a study undertaken by a consultant commissioned by the Secretariat.

2. The note is available in English only.

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STATUS, IMPACTS AND TRENDS OF ALIEN SPECIES THAT THREATEN ECOSYSTEMS, HABITATS AND SPECIES

FEBRUARY 2001

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STATUS, IMPACTS AND TRENDS OF ALIEN SPECIES THAT THREATEN ECOSYSTEMS, HABITATS AND SPECIES

1. INTRODUCTION

The Convention on Biological Diversity (CBD) requires its Parties, through Article 8(h) to "*prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats and species*". An assessment of the status, trends and impact of these alien species would serve as a basis for action.

Alien species are referred to by several names, which are often used interchangeably: non-natives, introduced, non-indigenous, exotic and foreign species. Those that are harmful to biological diversity in one way or the other are referred to as noxious species, aggressive species, pests and invasive species, and harmful species. The major threats posed by alien species on ecosystems, habitats and species are a consequence of the fact that the introduced alien species can establish and invade the new habitats to the detriment of native species. The term invasive alien species is thus used throughout the document and refers to alien species that threaten ecosystems, habitats and species. Some literature refers to biological invasions or, in short, bioinvasions or biological pollution to refer to the invasions of alien species introduced intentionally, e.g. for use in biological production systems such as agriculture, forestry, horticulture, fisheries, or as biocontrol agents; through escapes from containment or captivity (mariculture, aquaculture, horticulture, zoos, pet-trade, scientific research, etc); or unintentionally through a pathway involving transport, trade, travel or tourism.

The concept of invasive alien species uses ecologically determined boundaries of distribution, not political and artificial ones such that invasive alien species include species that are introduced outside of their native biogeographical ranges, but may still be within the same nation, region, province, canton etc.

The threat to biodiversity due to invasive alien species considered being second only to that of habitat loss[1]. Invasive alien species are thus a serious impediment to conservation and sustainable use of global, regional and local biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems. This problem is exacerbated by the fact that it is not always possible to accurately predict which introduced species will become invasive, and when it will do so[2].

Section 2 of this note presents some generalities on the nature and characteristics of invasive alien species, their mode of introduction and spread, and their environmental and socioeconomic impacts, which are closely linked to the extent of spread. Section 3 provides an overview of the status, trends and impact of invasive alien species under the thematic areas addressed by the Convention on Biological Diversity (CBD) and in additional vulnerable areas. Concrete examples are given in the annexes and in the endnotes.

2. GENERALITIES ABOUT INVASIVE ALIEN SPECIES

2.1 Nature and characteristics of invasive alien species

Invasive alien species are widespread in the world and can be found in most taxonomic groups [3]. Invasive microbial species include bacteria, protozoans, phytoplankton and zooplankton. Invasive plant species have been reported among *inter alia* sea weeds, trees, shrubs, vines, forbs and grasses. In the animal kingdom, a number of invertebrates (including for example sponges, sea squirts, molluscs, insects, crustaceans and worms), fish, amphibians, reptiles, birds and mammals have also been reported as invasive alien species. At present, plants, mammals and insects (e.g., ants[4]) are the most common taxa on the lists of invasive alien species in terrestrial environments. Invasive plant species, in particular trees and grasses constitute the best known examples of terrestrial bioinvasions. Invertebrates, especially molluscs and crustaceans, and algae predominate among invasive alien species in marine and coastal areas while fish, aquatic weeds and other invertebrates top lists of invasive alien species of freshwater areas. The invasive species database of the Global Invasive Species Programme (GISP) (available at the website http://www.issg.org/database) contains a lot of information on the types of species as well as a list of the world's worst 100 invasive species.

Our current knowledge of biological invaders is obviously weighted more towards more conspicuous and accessible-for-study species, while less visible ones are less well known. Most countries take action against invasive species based on known invaders and there may be a tendency to neglect those that have not been reported.

Despite attempts to develop a conceptual and predictive framework for biological invasions[5] the only reliable predictor of a species becoming invasive in a new area is, if it has been invasive elsewhere[6] Even then there are species whose potential invasiveness cannot be known until they invade. Some studies indicate that there are taxonomic patterns to invaders[7]. Out of 300,000 species of the world's vascular plants, nearly 10% are thought to have the potential to invade and affect native biota (GISP, 2001).

2.2 Differential vulnerability of ecosystems

With regard to the question about which ecosystems are more vulnerable to invasive alien species, many studies[8] indicate that:

(a) All ecological communities all over the planet have been invaded to a greater or lesser degree. The parts of the world which are most dominated by invasive plants in large landscape areas are found mainly in North and South America and Australia and to a lesser extent in Africa, India and some islands. Areas set apart for the conservation of biodiversity are no exception to biological invasions: alien plants and animals are spreading in protected areas of various types in nearly all parts of the world

(b) The extent of invasions is influenced by the characteristics of invaded systems and some types of ecosystems are more vulnerable to invasions than others[9].

(c) Invasive alien species usually thrive in disturbed habitats. That does not mean, however, that relatively undisturbed habitats are not affected by invasive alien species.

(d) The problems of invasive alien species are especially acute in geographically and evolutionarily isolated systems such as islands and other isolated areas such as lakes and isolated streams[10].

(e) Species rich ecosystems can be susceptible to a wider range of invasive alien species because they contain a greater diversity of components subject to the impact of invasive alien species[11].

(f) Low diversity ecosystems such as deserts; those that are subject to periodic disturbances, harbours, lagoons, estuaries, areas undergoing successional changes, and edges of water bodies have also been observed to be more prone to invasions (GISP 2001).

2.3 Entry pathways and vectors

The routes by which invasive alien species enter new habitats are known as pathways while the means by which they travel to new destinations are known as vectors. An example is the shipping pathway and the ballast water vector of many marine and coastal invasive alien species. Humans and other organisms can be vectors of new types of disease-causing pathogens that spread through human travel. Pathways and vectors (whether intentional or unintentional) are numerous. They can be a result of many human activities and operate over time and space. Not only are human activities creating new pathways and vectors but they are also increasing conveyance of invasive alien species through already established pathways. Pathways and vectors also appear to be interacting with one another forming a kaleidoscope of means of spread of invasive alien species to all parts of the world[12].

2.4 Impacts of invasive alien species on biodiversity

Invasive alien species cause significant environmental and socioeconomic impacts[13], some of which can be irreversible.

The impacts of invasive alien species can be direct or indirect and can vary greatly in type, scale and severity. The impacts of invasive alien species can occur at the three levels of biological organization of biological diversity, in other words at the genetic, species and ecosystem levels. Effects on species and communities are more studied than impacts on ecosystems. Impact at the genetic level are the least studied.

Invasive alien species can lead to a decrease of genetic diversity through the loss of genetically distinct populations, loss of genes and gene complexes, and hybridization of introduced species with native ones[14]. At the species and community levels, invasive alien species can compete with native biota; displace them; predate upon them; parasitise and transmit or cause diseases; reduce growth and survival rates; cause decline, extirpation (local extinction) of populations, or extinction; form monospecific stands thereby altering community structure; uproot, and break off parts of plants; affect groewth and survival of other organisms in aquatic and marine environments by changing light levels, decreasing the amount of dissolved oxygen in water, changing soil chemistry and its structure. Invasive alien species can thus disturb the functioning of ecosystems. They can increase surface run-off and soil erosion, disturb the structure, stability and functions of communities, habitat availability and habitat quality for native species. Their impact on ecosystem processes include disturbance of nutrient cycling, pollination, regeneration of soils and energy flows. Invasive alien species can also alter the frequency, spread, and the intensity of fire, and obstruct water flows.

Invasive alien species can be a part of complex interactions. Failure to recognize or understand those have led in the past to ‘chain-reactions’ of problems[15], and/or increased the severity of the impact of invasive alien species. Invasions that have been studied in detail reveal the often hidden, extensive and cascading ecological effects triggered by invaders[16]. Invaders that are keystone species and those that affect the supply and turnover rates of water, nutrients, space and energy flow have big impacts on population, community and ecosystem processes[17]. Invasive alien species such as feral pigs, goats, monkeys, rabbits and donkeys vastly cause and increase physical land disturbances leading to very severe impacts on ecosystems[18]. Overall, impacts of invasive alien species will depend on the invader, the features of the invaded system and chance[19].

The 2000 IUCN Red List of Threatened Species, in a compilation of the major threats to species considers alien invasive species as being a ‘significant direct threat’ affecting 30 % of all threatened birds, 15% of all threatened plants and 10% of all threatened mammals[20]. The third most important problem (next to habitat loss and exploitation) faced by vertebrates is non-native invaders[21]. Globally, alien predators or competitors are the second most important cause of extinction of molluscs[22]. Presence of non-native species can also seriously hamper restoration programmes[23].

The socioeconomic costs due to invasive alien species are huge. They include not only costs of prevention, control and mitigation, but also indirect costs due to impacts on ecological services. Estimates of economic costs of invasives can vary widely. A case in point is the values of ecological services affected by the salt cedar tree, *Tamarix* spp. in the western USA - estimated as between $7-16 billion over 55 years. While the range of these figures indicates their uncertainty, they also indicate the order of magnitude of impact and point to the need for significant investments to prevent the spread and proliferation of these species [24]. These costs are only now being realized but do not often include the value of ecological services from biodiversity. An indicative cost of some invasive species is given in Annex 2.

2.5 Recent trends in the status of invasive alien species

Biological invasions now operate on a global scale[25]. The point to note is that they look well poised to undergo rapid increase [26] in this century due to interactions with other global changes set in motion by humans[27]. Increasing globalization of markets, explosive rises in global trade, travel, tourism, and exchange of goods are conveying more and more species from and to all parts of the world and thus enhancing the possibility of bioinvasions across all ecosystems in all areas of the world. The more disturbed the receiving area, the greater the extent of invasion[28]. Also invaded areas appear to be more prone to further invasions[29]. It is paradoxical that one of the most ecologically acceptable methods to protect natural areas, ecotourism/nature tourism may facilitate the introduction of non-native species into little disturbed natural habitats by bringing in large numbers humans from far away.

A series of recent analyses[30] concluded that:

(a) economic activities can increase the inherent susceptibility of ecosystems to invasions;

(b) the current spread of invasive alien species is inextricably linked to key global changes especially land use change, human induced disturbance of natural systems, habitat destruction, overexploitation of resources, chemical pollution, and climate change;

(c) these factors are interacting with bioinvasions to produce complex effects and patterns, sometimes irreversible; and

(d) invasions and their impacts are increasing in most natural areas but that the problems of invasive alien species are not spread uniformly over the planet.

3. STATUS OF INVASIVE ALIEN SPECIES IN CBD THEMATIC AREAS AND OTHER AREAS

There are reports and research documents on status, impacts and trends of invasive alien species[31], including *inter alia* reports, research papers, databases and other documents on this subject by the Global Invasive Species Programme (GISP) and the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU). However, the existing information covers unevenly all the invasive alien species, and overall quality and quantity of knowledge on invasive alien species do not enable very accurate or quantitative answers to questions such as, which introduced species will invade, when and where? and what is the extent of invasion in each thematic area addressed by the Convention.

3.1 Coastal and marine areas

Invasive alien species are common and highly significant agents of change in coastal and marine environments including estuaries, bays, rocky shores, coral reefs, deep continental waters, mangroves, and open water areas[32]. A variety of taxonomic groups such as protozoans, sponges, cnidarians, flatworms, polychaete worms, mollusks, crustaceans, bryozoans, tunicates, fish, seaweeds have contributed to major invasions in recent years.

Despite the special attention paid to biodiversity of coral reefs, not much is known about their invasive alien species, their impacts and patterns of invasions in these areas. Most available information is from the Pacific islands and Australia[33]. A range of non-natives (e.g. ascidians, molluscs, fish, and algae) have been recorded from reefs, of which some have spread widely e.g., in Hawaii, Guam and Australia[34]. Marine habitats have been studied far more in the temperate regions than in the tropics[35].

Increase of shipping worldwide has made it the most important pathway of spread of invasive alien species attached to surfaces of ships, boats, and drilling platforms (usually as communities of fouling organisms); through ballast water and ballast sediment; and in sea chests. Approximately 80% of commercial goods now traverse the earth by ship. About 10 billion tons of ballast water per year, and *daily* at least 10,000 species are being transported around the world[36]. It has been shown, in an analysis supported by examples from all over the world, that in recent decades changes in the vectors of invasive alien species, which affect the potential of species to travel from one place to another are essential in determining the number and diversity of successful alien species introductions[37]. Indeed, ships have carried ballast water since the 19th century, ballast water became a major vehicle of marine invasive alien species in the latter part of the 20th century[38]. The increase of volumes of shipping, and speed and size of ships means that all stages of a highly diverse introduced biota can be transported over thousands of miles within a matter of few days to marine and coastal areas similar to their native ones.

In addition, major types of global change affecting marine biodiversity such as overexploitation of resources, chemical pollution, habitat loss and fragmentation, and climate change[39] all interact to form a complex array of variables, that are enhancing the spread and establishment of invasive species in coastal and marine waters[40]. Other pathways of entry of invasive alien species in marine and coastal areas include intentional introductions for mar culture and sport fishing; accidental introductions such as organisms accompanying those introduced for economic purposes; escapees from aquaria, zoos and from scientific facilities; or the facilitation of passage by the opening of canals such as the Suez Canal leading to the 'Lessepsian migrations' from the Red sea to the Mediterranean[41].

3.2 Inland waters

Freshwater habitats worldwide are among the most modified by humans especially in the temperate regions[42]. In most regions, introduction of non-native species is the most important or second most important human activity affecting inland aquatic areas with significant and usually irreversible impacts on biodiversity and the ecosystem functions[43],. Invaded freshwater and estuarine systems often become more open to further invasions[44].

In freshwater and estuarine systems, the major modes of spread of alien species of fish, aquatic invertebrates, plants and microorganisms that usually accompany them are: deliberate introductions for aquaculture, improvement of fisheries (stocking), sport fishing and biological control; and largely unintentional entries through ship-related transport; aquarium releases; escapees from rearing facilities for aquaculture, fish bait and horticultural trade; creation of passage ways such as the building of canals between rivers, and lakes; and recreational boating. Two of the worst aquatic invasive plants of the world, *Eichornia crassipes* and *Salvinia* spp. (Holm *et al* 1997), have a history of being introduced as ornamentals and spreading into water ways after escaping from gardens.

Introduced fish can eliminate native species and cause decline of biodiversity[45]. Fish from cultured populations may have ecological (e.g. competition, habitat alteration, disease introduction) and genetic (e.g. loss of genetic adaptation, genetic homogenization) impacts on wild populations[46]. It has been estimated that 20% of all freshwater species of fish are at risk of extinction in the near future unless the present situation is reversed with freshwater invertebrates such as bivalves and crayfish also being particularly affected[47].

3.3 Terrestrial areas including forests, Mediterranean regions, grasslands and savannas, arid and semi-arid areas, and mountains

Forests

Temperate forests have suffered from invasions by pathogens causing e.g. Dutch elm disease and chestnut blight, insects, such as the gypsy moth, and plant invasive alien species among others. The Asian long horned beetle recently introduced is threatening to devastate native hardwood forests in parts of North America. The relatively few studies conducted in tropical forests[48] hint at the extent of distribution and impacts of invasive plants and animals in tropical forests.

Afforestation has been carried out since ancient times but it is only in this and the last centuries that enormous numbers of trees have been planted very far from their natural ranges, and over very large areas. Especially in the tropics and sub tropics most of the tree plantations with alien species have appeared within the last 50 years or so[49]. Tree plantations and agroforestry are important sources of biological invasions[50]. Reports from all over the world indicate that some trees introduced for economic considerations, as well as those accidentally spread are invading natural and semi-natural habitats, and impacting on biodiversity, ecosystem functions causing unanticipated costs. Of species used for agro-forestry around 7% are said to be weeds under some conditions, but around 1% is weedy in more than 50% of its recorded occurrences and included among others, *Acacia* (8 species), *Casuarina* (2 species), *Prosopis* (3 species), *Calotropis procera*, *Leucaena leucocephala*, *Melaleuca quinquenervia*, *Psidium guajava*, and *Sesbaenia bispinosa*[51]. *Pinus* spp. and *Eucalyptus* spp. are the most commonly planted species for commercial forestry using alien trees, and many of these species are now spreading unaided by humans into natural areas. *Pinus* species, natives of the northern hemisphere are among the most important invasive trees in the temperate areas of the southern hemisphere and that at least 19 species are established as invaders[52]. *Eucalyptus* species are also cited as invasive trees on many records but do not appear to be as successful as the pines and legumes[53].

The impacts of plant invaders on forests range from formation of dense stands, canopy, or mats that excluded nearly all other species; decreased structural diversity; extirpation or extinction of native species; production of allelopathic chemicals that are toxic to other species; increasing surface water run-off and soil erosion, and impacts on ecosystem level processes that include changing water or fire regimes, nutrient cycling patterns, and light intensity and quality, which ultimately threaten functioning and sustainability of the system.

Mediterranean regions

Introduced predators, herbivores, plants and pathogens into the Mediterranean regions and similar types of natural vegetation in the Cape Province of South Africa, parts of Chile and southern Australia, and California have reduced species diversity and disturbed its structure and functioning[54]. One of the best examples is that of the *fynbos* area in South Africa, a unique (68% of its plant species being endemic) global hot spot of plant diversity, where invasions of woody species such as *Hakea sericea*, *Acacia* spp. and *Pinus* spp have caused the extinction of 58 plant species and pose a threat to many more plants[55]. The major impacts of these invading trees on water resources and thus on water availability to the burgeoning human population of this region, to the development of the Working for Water Programme of South Africa, that will also help to preserve the biodiversity of this unique system. In Chile, the Mediterranean type of natural vegetation is the most heavily invaded area[56].

Grasslands and savannas

Grasslands and savannas all over the world have been heavily invaded by many non-native grasses including *Bromus* spp.[57], *Pennisetum* spp.[58], Panicum spp., Paspalum spp., *Brachiaria* spp. and *Eragrostis lehmaniana*[59], as well as by shrubs and woody species (e.g. *Lantana camara*, *Pinus*) (Richardson 1996). Tropical grasslands are rich in biodiversity[60] but establishment of invasive alien species has changed the structure, biomass distribution, decomposition rates, fire regimes, nutrient cycling and energy balance[61]. Invasions in grasslands are also associated generally with grazing, such as the introduction of African grasses into Australian and South American savannas to provide forage for livestock. However, the aliens became invasive and being faster growing have replaced the grazing intolerant native grasses in grasslands and savannas[62]. Introduced legumes also led to increased trampling by large herbivores and decline of soil productivity[63].

Arid and semi-arid areas

Dryland areas have been relatively unaffected. However, since the last century, rapid increase in human populations, transportation and special types of irrigation, large areas of arid lands have been opened for development. Higher levels of disturbance usually mean more opportunities for entry and establishment of invasive alien species to the detriment of unique assemblages of organisms adapted to extreme temperatures and very low moisture levels. Some of the seriously affected native flora are those which have medicinal properties, provide termite resistant wood, food and fiber and act as soil binders[64]. Introduction of invasive alien plants as forage, or for fuelwood and soil stabilization, and unintentional introduction of weeds [65] are examples of human-induced disturbance of biodiversity in these areas. Riparian (strips of land along rivers, streams etc.) habitats within these areas have been more vulnerable to invasions.

Mountains

There is little information on invasive alien species of mountainous areas apart from weeds. Evidence indicates that there are relatively few invasive alien species on mountains [66].

3.4 Agricultural lands

There exists enormous amounts of information on the status and the ecological, economic, social, cultural and political impacts invasive alien species important in agriculture worldwide, collected through a number of disciplines of study such as pest management, weed science and crop protection. Invertebrates, vertebrates, pathogens and plant pests are present in most if not all managed agricultural systems. Many of these species are not native but have invaded from other parts of the world [67] and have done so since time immemorial. A recent and well known example is the pink hibiscus mealybug *Maconellicoccus hirsutus* invasion in the Caribbean. This pest attacks over 200 genera of plants including fruit and forestry trees[68].

3.5 Islands and other geographically and evolutionary isolated areas

The flora and fauna of oceanic islands have generally evolved unique species and biological communities in the absence of selection pressures such as predation, impacts of large herbivores, and a number of diseases found on the Continents. Island biota, also because of their small population sizes, are thus quite vulnerable to biological invasions from the Continents. As a consequence, after habitat loss and modification, invasive alien species are responsible for the largest number of species extinctions[69], including e.g. the loss of nine of the twelve native bird species in Guam due to the brown tree snake[70]; and the fact that nearly all lowland Hawaiian songbirds are alien species that have outcompeted native species[71].

Paleobiological data shows that non-native species have had a large impact on island biota[72] and that large numbers of non-native species currently prevail on islands[73]. In the Galapagos Islands, a World Heritage Site and renowned as a natural showcase of evolutionary processes, the number of introduced plants is approaching that of the natives and native areas are impacted by introduced, mammalian predators, herbivores, insects and plants. Mauritius has more introduced plant taxa than native ones, and more than 50 of the alien plant species are highly invasive[74]. The impact of introduced plants and animals on Pacific islands have been very severe while Hawaii, Guam, Mauritius and New Zealand provide instances of areas isolated over significant periods time leading to evolution of unique ecosystems, and species that are adapted to special conditions[75]. It is suggested that in many of these systems, apart from bats, indigenous plants and animals have evolved in the absence of land mammals.

Species of ‘ecological’ islands (surrounded by very different types of habitats) such as lakes, springs and headwaters of arid areas which have a significantly limited extent, can also be particularly vulnerable to invasive alien species[76].

3.6 Polar regions

The Antarctic

Insects such as cockroaches, rats and mice have been introduced to the Antarctic carried unintentionally on ships. Intentional introductions include a number of plants and animal pets established stations. There is increasing evidence of higher organisms such as plants being able to establish themselves in the far South. Of particular concern in the Antarctic are grasses and other plants reported growing “wild” not just on King George Island, but also on continental Antarctica. Live invertebrates, including earthworms, mites and fly-larvae were discovered in imported soil on the Antarctic continent. So far, no cases of ecological damage have been detected, but introductions of alien species, even micro-organisms, into the Antarctic environment, can affect its pristine nature and its wilderness and scientific values. The remoteness of the Continent, its size, and relative scarcity of human presence would make it less likely that a serious bio-invasion would be detected early. From the point of view of risks to biodiversity, the recent discovery of serological evidence of Infectious Bursal Disease Virus (IBDV)[77] in Adelie and emperor penguins in the vicinity of Australia’s Antarctic Mawson Station is a major concern. The biological significance of IBDV in those penguin species is not known at this stage, but in poultry it is a serious disease, causing immune deficiency and / or death in chicks. The introduction appears related to human activity. The Antarctic Treaty System, through its annual meetings and intersessional work, is discussing how to minimize risks for wildlife, from human-introduced pathogens.

The Arctic

with respect to its invasive alien species introduced to the Arctic are less well known partly due to a low number of bio-invasions, and the remoteness and large size of the area making monitoring difficult. However, in the Eurasian part of the Arctic the alien Racoon dog (*Nyctereutes procyonoides* is spreading, leading to increased predator pressure on other terrestrial mammals as well as being an agent of rabies. In addition, it has been reported that the extensive fish farming in Norway poses serious threats to the native Atlantic salmon populations: through the escapes of fish infected with a parasite (*Gyrodactylus salaris*), and through interbreeding[78]. The introduction of the Alaska king crab (*Paralithodes camtschatica*) in the northwestern part of the Russian federation has resulted in its spread and establishment in the deep waters of the Barents Sea[79] but it is unknown how this species will interact with the ecosystem.

4. GAPS IN KNOWLEDGE

There is increasing interest to understand biological invasions and their causative agents and to develop effective interventions, largely due to the increasing magnitude of this problem and growing interest to halt biodiversity loss. A survey of the information reveals that there are some very significant gaps in the knowledge base on invasive alien species. The priority areas that need to be addressed include in particular the assessment of:

(a) Both short- and long-term impacts of invasive alien species; impacts at community and ecosystem process levels and across landscape and national scales; and cumulative impacts of invasive alien species; and

(b) Extent and rates of spread of invasive alien species.

These assessments need to be conducted especially in mountain areas and in protected areas both in the tropical and temperate zones; tropical coastal and marine areas, forests, and continental islands. Most countries particularly developing countries need to establish their current baselines on status, impacts and trends of invasive alien species.

The historical aspect of invasions at national and regional scales, and comparison of patterns of invasions between geographical areas and links between the degree of naturalness and invasions should be investigated. All this should be underpinned by biological and taxonomic studies to help establish the characteristics and exact identity of invaders.

ANNEXES

Annex 1: Examples of complex impacts of invasion

1.1 Lake Victoria in Africa

The unexpected nature, and magnitude of change that can be induced by non-native species into an ecosystem is best exemplified by one of the most well known examples of invasive alien species and biodiversity is as follows. Lake Victoria in Africa is the largest tropical lake in the world, shared between Kenya, Uganda and Tanzania. Lake Victoria Basin is of great importance to its human population, which was estimated to be around 30 million in 1996, and growing at the rate of 3-4% annually. Due to land use changes resulting in loss of vegetation cover, and inflow of agricultural, industrial and domestic effluents, a process of eutrophication commenced in the lake from the early part of this century. The original fish diversity of the lake was very high, including more than 300 species of haplochromine cichlids, 99% of them endemic. Haplochromines, until the 1980s were the most abundant species. While they were too small to be of significance in a fishery, they obviously played a key role in the lake ecosystem and were of value as study material for evolutionary processes such as adaptive radiation. Due to depletion of native species by over fishing, by the early 1950s, the Nile perch *Lates niloticus*, and three other herbivorous non-indigenous tilapia, Nile tilapia *Orechromis niloticus*, and *O. lecostictus*, and *Tilapia zilli* were introduced for replenishment of the fishery in the 1950s and early 1960s. The Nile Perch is a predator which attain body weights of up to 200kg and was expected to convert the significant biomass made up of smaller sized fish into larger fish of greater commercial and recreational value, more suitable for a larger scale fishery. A period of about 20 years elapsed before the Nile perch increased to high population level, with fish catches in the Ugandan part (43%) of the lake increasing more than eight times within 1981 to 1989. These catches consisted almost entirely of the perch and the Nile tilapia.

The increase in numbers of perch was accompanied by a drastic decrease of fish diversity, the haplochromines declining from 83% of the biomass to less than 1%. It now estimated that about 60% of the haplochromines have extinct. Studies have revealed the changes that have taken place in the community and food web structure and function of the lake ecosystem. The haplochromine fishes were extremely diverse and occupied nearly all the trophic levels including planktivores, herbivores, detritivores, molluscivores, insectivores, and piscivores. They assisted in keeping the lake ‘clean’. With the exception of haplochromines that found refuge among rocks and macrophyte cover, rest were the main food of the Nile perch and rapidly declined due to predation. This initiated a cascade of ecological changes that interacted with other human-induced changes already present to produce a lake with its waters low in oxygen, clogged with weeds and highly reduced fish diversity. Eutrophication by increased run-off from land increased primary productivity in the lake but grazing pressure reduced by predation of haplochromines, caused accumulation of organic matter in the lake. This favoured the low oxygen conditions that further reduce habitat available for other species and for deepwater haplochromines and concentrated them (prey species) in areas that made them more vulnerable to the perch. At least 30% of the bottom area of the lake is now very low in oxygen, a very different scenario to that of 30 years ago. Algal blooms and mass fish kills characterize the lake, which also harbours increased populations of molluscs that are hosts of diseases. The lake is invaded since 1990 by one of the worst alien invasive weeds in the world, *Eichornia crassipes*, and the water hyacinth. This weed favoured by eutrophication occupies about 90% of the shore area, which are important as breeding, nursery, and feeding grounds of fish. Water hyacinth infestations reduce suitable habitats for fish and other organisms, inhibits navigation on the lake, clogs water pipes, and provides breeding grounds for disease causing organisms. The Nile perch fishery has brought about benefits by way of increased revenue, employment and food. However, high cost of the price of fish, and decline of total yields coupled with serious environmental costs now threatens capacity of this ecosystem to sustain the humans who depend on it. (Kolar and Lodge 2000, Ogutu-Ohwayo 1996).

1.2 Flathead Lake in Montana

A series of unintended consequences followed the deliberate introduction from 1948 to 1975 of freshwater opossum shrimp *Mysis relicta*, into Flathead Lake in Montana, USA. In the 1980s, *M. relicta* nearly wiped out some species of zooplankton from the lake, and was found to be competing for zooplankton with its intended fish predator (rather than become part of their diet) which then caused the crash of the predator population. The unpredictable cascade of ecological changes unleashed by this event was revealed only when populations some fish eating birds including bald eagles, and mammals including grizzly bears that depended heavily on this fish declined. Bald eagles suffered additional mortality by turning to road-kills to compensate for the decrease of their usual food resources and the tourism in the area also paid a price as the sights of large numbers of charismatic species such as grizzly bears and eagles were almost destroyed (Williamson 1996, Kolar and Lodge 2000).

1.3 *The impacts of alien plants*

The impacts of alien plants can unleash cascading effects just as non-native predators do to native fauna and flora. The introduction of the nitrogen-fixing tree *Myrica faya* (an alien that carries out a new function in its new habitat) in Hawaii Volcanoes National Park, increases the level of nitrogen by as much as four times in the usually nitrogen poor soils of young volcanic ash and the open forest areas in Hawaii. This change favours the establishment of alien plants and soil dwelling animals, especially earthworms. Therefore this single alien species displaces native trees, changes the nutrient cycling and alters the structure, and composition of the forest ecosystem (Vitousek *et al* 1997, Vitousek and Walker 1989).

Annex 2: Indicative economic impacts of some invasive alien species

The indicative economic impacts of some invasive alien species are as follows: impact of knapweed (*Centaurea* spp.) and leafy spurge (*Euphorbia esula*) on the economy of three US states is US$40.5 million per year (direct costs) and US$89 million as indirect costs (Bangsund *et al* 1999); the cumulative costs of damage to US and European industrial plants by the zebra mussel and other aquatic invasives was equivalent to US$3.1-5.0 billion between 1988-2000 (Khalanski,1997; Bright 1999); the cost to restore the South African *fynbos* due to invasions by *Pinus, Hakea, Acacia* species is US$169 million (Turpie & Heydenrych 2000); costs due to water hyacinth *Eichornia crassipes* in 7 African countries is US$71.4 million/year (Kasulo 2000); the costs in Australia in the agricultural sector due to rabbits (*Oryctolagus cuniculus*) is US$373 million/year (White & Newton-Cross 2000); and the impact of the green crab (*Carcinus maenas*) on the North Pacific Ocean fisheries in the states of Oregon and Washington is estimated to be US$44 million per year (Cohen *et al* 1995).

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ENDNOTES

[1] Simberloff 1995, GISP 2001

[2] See Lodge, 1993; Williamson, 1996 and 1999; Williamson and Fitter, 1996a and b; Wittenberg and Cock, 2001; and GISP 2001. Despite attempts to develop a conceptual and predictive framework for biological invasions (Panetta 1993, Carlton 1996b, Kareiva 1996, Moyle & Light 1996, Rejmanek and Richardson 1996, , Williamson 1996, Williamson and Fitter 1996a and b, Reichard and Hamilton 1997, Rejmanek 1999, Richardson *et al* 2000 b) the only reliable predictor of a species becoming invasive in a new area is, if it has been invasive elsewhere (Williamson 1996, Carlton 1996b, Ruesink *et al* 1995, Ruiz *et al* 1997, GISP 2001). Even then there are species whose potential invasiveness cannot be easily known, and where we did not know until they invaded. Some studies indicate that there are taxonomic patterns to invaders (eg. Pysek 1988). Out of 300,000 species of the world's vascular plants, nearly 10% are thought to have the potential to invade and affect native biota (GISP 2001).

[3] . The following is a selection of examples from around the world:

(a) Ecological havoc was wreaked by introduction of European rabbits into Pacific islands; pigs, goats, and donkeys into Australia; mongooses, cats, dogs and snakes into Mauritius, Guam, New Zealand and Caribbean and Pacific islands.

(b) Feral goats out-competed, and destroyed the shade and habitats of the last remaining population of giant land tortoises of the Indian Ocean Aldabra Island (Seychelles),

(c) European wild boar in South America spread into Uruguay, into the forests of Brazil, and the *pampas* of Argentina.

(d) The Canadian beaver displaced the European beaver from it native range,

(e) The zebra mussel brought ecological disaster to the great lakes of North America.

(f) Widespread decline and destruction of native fish and invertebrate fauna of freshwater habitats worldwide is taking place due to alien species.

(g) Woody plants, shrubs and vines have invaded into natural areas of moist and dry mesic forests in mainland Africa, Asia, North and South America, and Australia.

(h) Some alien trees are decreasing availability of water in already water stressed habitats in South Africa, Asia and Southwestern USA.

(i) There is explosive spread of aquatic and terrestrial weeds in nearly all parts of the world and novel insect pests and pathogens are appearing all over the world threatening native plants, animals and agro ecosystems.

(j) Spectacular declines of native fauna and flora of oceanic islands followed introductions of snakes, mammals, and weeds.

(k) Non-indigenous molluscs, sponges, jellyfish, sea anemones, crustaceans, bryozoans, worms, ascidians, fish and algae are causing large scale changes of the structure and functions of animal and plant communities of estuaries, bays and coastal waters of the Americas, the Mediterranean, Europe, Australia and the Pacific.

Also see case studies and national thematic reports on invasive alien species at www.biodiv.org and poster abstracts in the Technical Paper No.1 of the Secretariat of the Convention on Biological Diversity (2001)

[4] . Tramp ants- species that are associated with humans and their economic activities, are fast spreading across tropical, sub tropical, and temperate areas, including the Mediterranean. Their small size makes them unobtrusive intruders. The most damaging species are little red fire ant *Wasmannia auropunctata*, bigheaded ant *Pheidole megacephala*, long-legged ant *Anoplolepis gracilipes*, the Argentine ant *Linepithema humile*, and the crazy ant *Paratrechina longicornis*. Their impacts include

(a) loss of native invertebrates that serve important functions such as pollinators, scavengers, decomposers, seed dispersers, prey species;

(b) replacement of entire biological communities by ant-tolerant and usually non-native species;

(c) possible cascading effects on ecosystem processes (Bond and Slingsby 1984, Human and Gordon 1998, Wetterer 1998, Wetterer *et al* 1999).

[5] Panetta 1993; Carlton 1996b; Kareiva 1996; Moyle & Light 1996; Rejmanek and Richardson 1996; Williamson 1996; Williamson and Fitter 1996a and b; Reichard and Hamilton 1997; Rejmanek 1999; Richardson *et al.*, 2000 b

[6] Williamson 1996; Carlton 1996b; Ruesink *et al.*, 1995; Ruiz *et al.*, 1997; and GISP 2001.

[7] e.g., Pysek 1988.

[8] Drake *et al.*, 1989; Carlton, 1989, 1992, 1996 a, 1999; Heywood, 1995; Moyle, 1996; Ruiz *et al.*, 1999; GISP, 2001

[9] Williamson, 1996.

[10] See annex. 1

[11] Levine and D'Antonio 1999.

[12] More information on pathways and vectors is available in Wittenberg and Cock (2001).

[13] Lodge, 1993; Heywood, 1995; Drake *et al.*, 1989; Williamson, 1996; McNeely, 1996; Moony and Hobbs, 2000; Perrings *et al.*, 2000; and GISP 2001

[14]. Some taxa such as birds (e.g. ducks), fish and mammals are especially at risk due to erosion of genetic diversity (Simberloff, 1996). For instance, the most important threat to the highly threatened white headed duck *Oxyura leucocephala* of Europe and Asia is hybridization with introduced ruddy headed duck, *O. jamaicensis* a native of North America, which also competes with it (Hughes and Williams 1998). Hybridization can even produce a more invasive hybrid genotype such as observed in some weeds e.g. *Spartina* spp. (Williamson, 1996). Also see Hindar *et al.*, 1991; Waples, 1991; Heggbergt *et al.*, 1993; Heywood, 1995; Levin *et al.*, 1996; and Nummi, 2000.

[15] Sherley and Lowe, 2000

[16] See for example Annex 1, example 1.1)

[17] Lodge, 1993; Mooney *et al*., 1995; Moyle, 1996; Westbrooks, 1998

[18] Mooney *et al.*, 1995; Mack and D'Antonio, 1998; Coblentz,1978; Atkinson and Atkinson, 2000; Strahm, 1998.

[19] GISP, 2001.

[20] Hilton-Taylor, 2000

[21] Tuxill, 1998

[22] The native land snail fauna of the Pacific islands is disappearing rapidly due to introductions of both deliberate and accidental, of exotic molluscs, usually snails and flatworms. Tree Snails (belonging to the Family: Partulidae) of these islands, comprising of 117 species were once widespread, but may now be considered among the most endangered animals of the world ((Mace *et al* 1998). Extremely diverse with very high levels of endemism in some cases (over 99% in Hawaiian islands) most of these species are now extinct, highly threatened or confined to high elevation refuges (Cowie 1998a and b). Each island had its own endemic species, and these partulids were natural experiments in the evolutionary processes of speciation and adaptive radiation (Cowie 1992, Johnson *et al* 1993). The introduction of a predatory snail *Euglandina rosea* (rosy wolf snail) for the control of another introduced species *Achatina fulica* (giant African snail), led to a number of partulid species becoming extinct (Murray *et al* 1989) and many more endangered. The predator has not reduced the African snail. Also see Seddon (1998)

[23] In Mauritius, restoration of the endangered Mauritius pink pigeon, kestrel and echo parakeets remains under constant threat from introduced mongooses, feral cats, introduced crab-eating macaques and ship rats, all of which have to be controlled to re-establish the native bird populations (Jones *et al* 1999). On this same island, attempts to restore populations of the critically endangered plant *Hibiscus liliiflorus* is under threat from introduced scale insects (Mauremootoo pers. com). Introduced invaders including mammalian predators such as rodents, possums, cats and mustelids affect bird reintroductions in New Zealand (Armstrong and Maclean 1995, Clout and Lowe 2000) and reintroductions of native marsupials, rodents and lizards in Australia. Often, the impact of invasive species on native animals and their habitats is one of the major causes for the decline of the species in the first place. Conversely, there are instances of reintroductions gone wrong by mistakenly introducing congeners that have become invasive (Nummi 2000). Introduced insects threaten endangered plants in Mauritius. Also see Hobbs and Mooney, 1993.

[24] Zavaleta, 2000.

[25] Mooney and Hobbs, 2000

[26]. The rate of invasions in the San Francisco bay and delta region, USA has risen from an average of one new species established every 55 weeks from 1851-1960, to an average of one new species every 14 weeks during 1961-1995 (Cohen and Carton 1998). In a 1998 study, Randall *et al* demonstrated that the rate of establishment of exotics in the flora of California, USA had increased exponentially until the late 1950s or 1960s and then onwards increase more slowly. They conclude that number of exotic species will continue to increase, e.g. between 1994 and 1998, more than twenty-five new species of alien plants had been reported from this state with records of fifteen more potential ones.

[27] GISP, 2001

[28] Mack and D'Antonio, 1998

[29] Simberloff and van Holle, 1999; Kolar and Lodge, 2000

[30] Mooney and Hobbs, 2000; Perrings *et al.* (in press) and GISP, 2001

[31] E.g. Mooney *et al* 1986, Brown 1989, Heywood 1989, McDonald *et al* 1989, OTA 1993, Heywood 1995, Huntley 1996, McNeely *et al* 1995, Mooney *et al* 1995, Vermeiji 1996, Sandlund *et al* 1999, SPREP 2000, Carlton and Ruiz (in press).

[32] Here are a few examples:

(a) introduction of the American comb jelly *Mnemiopsis leidyi* to the Black and Azov Seas with the subsequent collapse of the anchovy fisheries in the late 1980s and early 1990s;

(b) the introduction of toxic 'red tide' causing dinoflagellates that caused serious impacts on fisheries, aquaculture and recreation based industries of Australia (Hallegraf 1993);

(c) planktonic diatom species that have been introduced by ballast water into open, coastal waters, both in America and in Europe (Carlton and Ruiz in press);

(d) *Caulerpa taxifolia* a green alga once cultivated as an aquarium ornamental spreading rapidly in the non-estuarine open waters of the Mediterranean, strongly competing with native Mediterranean species and threatening endemic algae, invertebrates and fish communities (Bourdouresque *et al* 1995, Ribera and Bourdouresque 1995, Jousson *et al* 1998);

(e) invasion of San Francisco Bay, USA by the Asian clam *Potamorcorbula amurensis* (Carlton *et al* 1990);

(f) predatory snails, diseases of oysters, and many other molluscs, worms, crustaceans that were conveyed by cultured oysters to many parts of the world (Wittenberg and Cock 2001);

(g) the European periwinkle *Littorina littorea* that now dominates New England rocky shores;

(h) the Mediterranean mussel *Mytilus galloprovincialis* found on the outer wave-swept coast of South Africa;

(i) the New Zealand seaslug *Philine auriformis* (introduced by ballast water) on the California continental shelf (30-50 + meters depth); and

(j) the Asian seaweed *Codium fragile tomentosoides* that in the 1980s-1990s appeared in the cold sublittoral, open ocean waters off Massachusetts, New Hampshire and Maine states of the US. (Carlton and Ruiz in press).

See also Ben-Tuvia 1973; Norse 1993, Ruiz *et al.,* 1997; Ruiz *et al.,* 2000.

[33] Eldredge, 1987.

[34]. Known invasions on Hawaiian coral reefs, include the Indo-Pacific mantis shrimp, *Gonodactylus falcatus*, a variety of seaweeds, and various hydroids. Out of nineteen species of algae introduced into Hawaii, some appear to have spread throughout all of the main Hawaiian Islands. These alien algae possess novel competitive strategies and unique ecological characteristics that may allow them to become highly successful (Smith *et al* in press) Alien species present in harbours and ports of Australia, Guam, and Hawaii, may be of significance as invaders of coral reefs (Coles and Eldredge in press, Stiger and Payri in press). Research on biotic interchanges in a coral reef of Guam demonstrates that ship hulls (carrying communities of fouling organisms on them) were the main vectors for the introduction of alien organisms (Pauley *et al*, in press). Floating or fixed structures such as marina floats, buoys, boats, harbour pilings can be surfaces on which invasives (eg. some ascidians) can colonize. These in turn, can act as local sources of invasions into near shore habitats. Most often, human activities are also concentrated around coral reefs, and this appears to be a factor in the introduction of invasives to them. Also see Eldredge and Carlton in press, Pauley *et al* in press, Stiger and Payrie in press

[35] Hewitt, 2001.

[36] Carlton 1998, 1999

[37] Carlton, 1996b

[38] Carlton 2000.

[39] Ruiz *et al* 1999

[40] Carlton 2000.

[41] Bourdouresque 1996

[42] Allen and Flecker, 1993; Courtenay and Stauffer, 1990; Mills *et al.,* 1993.

[43]. A selection of reports of invaders in freshwater ecosystems from all parts of the world will serve to illustrate the scale of the problem. Extensive areas of wetlands and highly diverse native fish species of Bangladesh are at risk from introduced fish (Khan *et al* 2000); biodiversity of wetlands of the Lower Mekong River (of concern to Cambodia, Thailand, Lao PDR and Vietnam) is threatened by invasive aquatic weeds, the golden apple snail and commercial fish species (Friedrich 2000); 37% of the fish fauna of Italy are introduced from outside (Bianco 1995); introduced tilapia are becoming the more and more abundant species in Lake Nicaragua (McKaye *et al* 1995); non-native fish dominate the freshwater portion of the San Joaquin estuary in California in terms of numbers and biomass (Meng *et al* 1994); and apple snails are threatening rice plants and wetlands in Asia. (Cowie 1998). Two of the worst aquatic weeds of the world, *Eichornia crassipes*, and *Salvinia molesta* have invaded large areas of freshwater systems in tropical countries with impacts ranging from impeding water transport, decreased native species diversity, decreased oxygen levels; increased siltation, to provision of greater refuges for vectors of human disease; *Hydrilla verticillata* , native aquatic plant of Asia, Africa and Australia infests the waterways in some parts of the USA decreasing diversity of aquatic life (TNC 1998); and *Mimosa* spp growing along riverbanks, streams edges and other waterways is aggressively displacing the native vegetation, forming dense monospecific stands and

impacting upon water resources in countries as far apart as Australia, Malaysia, Sri Lanka, and Vietnam (Lonsdale 1993, Ismail and Sivapragasam 2000, Marambe 2000, Triet 2000).

[44] Cohen and Carlton, 1998; Kolar and Lodge, 2000

[45] Moyle and Leidy, 1992; Moyle and Williams, 1990

[46] Ferguson, 1990; Wilde and Echelle, 1992; Moyle, 1996; Doupe and Lymbery, 1999

[47] Moyle and Leidy, 1992; Bogan, 1993; Taylor *et al.*, 1996

[48] e.g. Strahm, 1996; van Wilgen, 1996; Richardson, 1996; Richardson *et al.*, 2000 a; Randall 1998; Meyer, 2000

[49] Richardson 1996.

[50] . Bingelli (1996) compiled a list of invasive woody plants, which contained 184 species that are highly invasive. Of these 18% had been introduced for forestry and another 27% for amenity purposes, which indicates

[51] Richardson, 1996

[52] Rejmanek, 1999.

[53] Richardson, 1996

[54] Mooney *et al.*, 1986; Fox, 1990; Groves and di Castri, 1991.

[55] Huntley, 1996

[56] Arroyo *et al.*, 2000

[57] Amor and Piggin, 1977; Mack, 1981; Mooney *et al.*, 1986; Hunneke *et al.*, 1990; Westbrooks, 1998

[58] Williams *et al.*, 1995

[59] D' Antonio, 2000

[60] Huston, 1994

[61] Versfeld and van Wilgen, 1986

[62] Mott, 1986

[63] Holmes and Mott, 1993

[64] Khatoon, 1998

[65]. The *Prosopis* species have invaded large areas of *karoo* (dry tableland) and arid land in South Africa where they and their hybrids have formed dense stands. Effects of *Prosopis* on native biodiversity has revealed a complex suite effects: stands of *Prosopis* reduce species diversity of dung beetles in shrubland and grassland (Steenkamp and Chown 1996); reduces herbaceous vegetation, thus increasing run-off and soils erosion (Martin and Morton 1993); and reduces availability forage for herbivorous game animals and livestock (Richardson *et al* 2000a). Of particular importance for water stressed areas is its impact on water regimes. *Prosopis* is likely to reduce water availability to farms, villages and small-scale agricultural activities (Richardson *et al* 2000a). *Prosopis* spp. in the Thar desert of India has displaced other flora of the area (McNeely 2000) while *Prosopis juliflora* introduced to a semi-arid area Sri Lanka in the early 1950s, has become an invasive seriously threatening the biodiversity of the only Ramsar listed wetland of the country (CEA 1993, Algama and Seneviratne 2000). *Prosopis juliflora* (introduced over 100 years ago to afforest the desert) is an important invasive in Pakistan now threatening natural habitats by formation of dense stands, out competing indigenous flora, by release of phytotoxins, and replacement of a native *Acacia* species in the riverine forests of Sindh province. Disturbance during afforestation plantings appear to make the land more prone to further invasions by weeds.

Species of introduced saltcedar (*Tamarix* spp.) is wreaking ecological havoc in the drainage systems of South Western United States. A deep-rooted species such as this is calculated to take up five million-acre feet of water per year in the arid Southwest of USA (TNC 1998) and has dramatically altered water regimes (Blackburn *et al* 1982) of invaded areas. Saltcedar has also greatly impacted upon the riparian habitats within desert ecosystems, and has severely limited the number of germination sites for riparian species leading to a steep decline in the abundance of some (eg. Cottonwood). It has also altered or eliminated habitats of desert taxa such as fish, salamanders, butterflies, birds and mammals (TNC 1998). Interior riparian communities of the Southwest desert in the US which support highest levels of biodiversity in these arid areas have had their structure and stability affected by this species. These riparian habitats of water-limited systems are among the rarest in North America (Westbrooks 1998). The increase in frequency of fires in the Great Basins ecosystem and Mojave desert of the United States of America, and the Sonoran desert of Mexico is attributed to changes wrought by invaders. (D'Antonio 2000).

[66]. Arroyo *et al* (2000) found that the heavily forested and mountainous region of Chile is relatively free of invasives. However, in heavily invaded habitats of central Chile, altitudes above 3000 m were observed to have invasive plants such as *Taraxacum* spp. and *Erodium* spp; in the eastern Patagonian mountains, alien invasives made up 10 percent of the vegetation; and the California poppy a rapidly spreading invasive was found from sea level to above 2000 meters in the Andean mountains. Randall *et al* (1998) report that more than four fifths of California's alien flora occurs below 6000 ft elevations. The Sierra Nevada high regions for example, contain fewer alien taxa than their foothills while only four alien plant species have been reported from above 9000 ft in California.

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[67] . The Weed Science Society of America recognizes about 1200 plant species as weeds, in Canada and the USA. Of these about 65% in the US are non-natives (Westbrooks 1998).

[68] Wittenberg and Cock, 2001

[69] SPREP, 2000

[70] Savidge, 1987

[71] Tuxill, 1998

[72] Lodge, 1993

[73] The native forests of the Galapagos islands are seriously invaded by the non-native quinine tree *Cinchona succirba*, the guava *Psidium guajava*, and introduced timber trees *Cedrela odorata* and *Cordia alliodora*, and attacked by introduced insects (Richardson 1996, Ospina 1998, Tye 1998) while the forests of Mauritius have been damaged by introduced deer, pigs, monkeys, rats, and insects. Meyer (2000) found that even natural areas with less disturbance and high ecological value such as the cloud forests of Tahiti were invaded by *Miconia calvescens* which is said to be the 'purple plague' in Hawaii and 'green cancer' in Tahiti for its rapid spread and destructive effects forests. *Clidemia hirta*, (a shrub) is an invasive known to spread widely in some moist tropical forests (C. Bossard, pers. com). Many of the most significant invasive plants recorded from the Pacific including *Leucaena lecucocephala*, *Psidium* spp., *Syzgium* spp., *Lantana camara*, *Rubus* spp., *Mikania micrantha*, *Panicum* spp., *Paspalum* spp., are known to be invasive in other tropical islands or countries ((Meyer 2000).

[74] Strahm 1998

[75] Holt, 1996; Strahm, 1996; Clout and Lowe, 2000; SPREP, 2000

[76] Moyle and Williams, 1990

[77] IUCN, 1998

[78] Hansen *et al.*, 1996

[79] Carlton and Ruiz in press
