INVASIVE PLANT PROBLEMS AND REQUIREMENTS FOR WEED RISK ASSESSMENT IN THE GALAPAGOS ISLANDS

Alan Tye
Department of Plant and Invertebrate Sciences, Charles Darwin Research Station, Isla Santa Cruz, Galapagos, Ecuador.
Postal address: Casilla 17-01-3891, Quito, Ecuador
Email: atye@fcdarwin.org.ec

ABSTRACT

Galapagos is a young oceanic archipelago with a native vascular flora of 560 species, few native trees, and an absence of many families present on the neighbouring mainland. It has only recently become subject to human influence. Plants introduced by man have only become problematic in the last 150 years, with most weed problems being less than 50 years old. The rise in plant introductions parallels the human population increase, with a recent introduction rate of 10 plant species per year, 100,000 times the natural colonization rate. Invasive plants include weeds and cultivated species, which cause detrimental effects on agriculture as well as natural habitats. Introduced species are the principal threat to the Galapagos ecosystem, and several species of alien plant are seriously damaging native habitats and threatening endemic species. Examples of some of the worst invaders and of the process and effects of invasions are presented. A weed risk assessment system for Galapagos must take account of the particular requirements of a fragile oceanic island ecosystem and flora. It must include consideration of potential invaders as well as plants already introduced. Factors that need to be included in an objective risk assessment system for Galapagos are discussed in light of the New Zealand Department of Conservation's model.

THE GALAPAGOS AND THEIR FLORA

Galapagos is an isolated oceanic archipelago of volcanic islands lying 1000 km west of Ecuador, straddling the equator. They have never been connected to the mainland and range in age from 1 to 3.3 million years (Simkin 1984). Although it has been suggested that there were earlier visits to the islands by indigenous people from mainland South America, the official date of discovery of the archipelago is recognized as 1535 (Slevin 1959; Hickman 1985). In that year, Tomás de Berlanga's ship was carried there by currents, while becalmed on his way from Panama to Peru (Slevin 1959; Hickman 1985). The islands were uninhabited at that time, and no evidence of earlier human use has been found. The first visitors after discovery were mainly buccaneers, passing sailors, whalers and sealers (Hickman 1985; Gordillo 1990). The first settler established on Floreana about 1807 and other groups there, after short intervals of unoccupancy, in 1832 and 1902; it has been permanently inhabited since 1929. San Cristóbal was settled permanently in 1869, Isabela in 1893 and Santa Cruz in the 1920s (Slevin 1959; Schofield 1989).

The pirates and whalers deliberately or accidentally introduced a number of alien species, including goats, rats and, probably, insects and plants. Even before permanent settlement, Floreana contained large areas dominated by introduced plants such as *Citrus* spp. (Slevin 1959; Hamann 1984). The rapidly increasing settled population, growing at 8% per year in the 1990s through immigration and indigenous birthrate, has been accompanied by an enormous number of new introductions of alien plants and animals (Mauchamp 1997). Although agricultural development began at the time of settlement, the process has been uneven, leading to different rates of introduction of alien species.

Floreana has the longest history of the presence of a large introduced flora, while agriculture on Santa Cruz was minimal until about 1960 (Moll 1990).

The archipelago, although straddling the equator, has a semi-arid, subtropical climate, due to the prevailing Humboldt current from the Antarctic and prevailing winds which also come from the south for most of the year. These factors lead to a vegetation which forms certain well-defined zones according to altitude and aspect (Wiggins and Porter 1971). Progressing from lowlands to highlands, these zones are most commonly defined as: Littoral, comprising mangroves, dune vegetation and other coastal communities; "Arid" (actually semi-arid), comprising scrub and light woodland dominated by cacti; Transition, comprising more or less closed woodland; and Humid, which is broken into a number of sub-zones that vary between islands, but which include Scalesia Zone forest, Miconia zone dense scrub, and Fern-sedge zone highlands. The more humid zones extend lower on the southern, wetter sides of islands, and most islands, which are low, have no Humid Zone. Biodiversity is therefore highest on the larger, more climatically diverse islands. Plant endemicity is highest in the Arid Zone, which is represented on all except the smallest islets.

The Galapagos islands support a native vascular flora of about 560 species, of which about 32% are endemic (Lawesson *et al.* 1987). This includes some of uncertain origin, principally pantropical weeds, which may have arrived naturally or may have been introduced by the earliest human visitors to the islands. Galapagos is a typical oceanic archipelago in that the native flora, like the fauna, is impoverished in the sense that a given area counts many fewer species than would a similar area in the mainland source areas (Loope and Mueller-Dombois 1989; Moll 1990). As a consequence, interspecific competition has also been weaker, and these two factors combine to render the vegetation highly susceptible to invasion by more competitive species (see Simberloff 1995 for review of this point). The relative impoverishment applies unevenly; for example, there are no tree species in some of the highland zones, although the climate and soils are suitable for tree growth. These zones are therefore especially susceptible to invasion by tree and shrub species that overtop and shade out the low-growing native vegetation.

PLANT INTRODUCTIONS TO GALAPAGOS

Weeds in Galapagos

This paper concentrates on the risks posed by introduced plants in natural areas, although this should not imply neglect of the problem of weeds of agriculture. In many cases, the same species, such as *Cinchona pubescens* (= *C. succirubra* Klotzsch) and *Psidium guajava* (authorities for names of alien plants are found in Tables 1–4), are having adverse effects on both agricultural and natural habitats. In other cases, such as *Cedrela odorata*, the primary threat posed by an alien is to the Galapagos National Park. Sometimes, as with *Cestrum auriculatum*, the primary threat is currently to agricultural or livestock production in the inhabited zones, although such species may well become serious invaders of natural habitats in the future. In a very few cases, farmers may regard a native or even endemic Galapagos plant as a pest; an example is some *Cyperus* spp., which are regarded as nuisance weeds in pastures.

A naturalized plant is considered to be one capable of maintaining a population without additional human interference, whether it be in pristine habitats or heavily disturbed ones such as farmland. It is not easy to draw a line between a plant that is only capable of surviving in man-made habitats and one that could, in the future, begin to invade and have detrimental effects on natural habitats. For that reason, all naturalized plants are considered to pose a non-negligible risk.

How and when they came

Mauchamp (1997) has charted the rise in the number of introduced vascular plant species in the islands, which parallels very closely the rise in the human population. Porter (1822) mentioned the first introduced species (pumpkins and potatoes), which were introduced about 1807. Numbers of introduced plant species increased slowly until the 1960s, reaching about 77 in 1971 (Wiggins and Porter 1971), although Porter (1984) implied that 168 were known by the time of publication of Wiggins and Porter (1971). Numbers continued to rise, reaching 195 in 1983 (Porter 1984), 260 in 1989 (Lawesson 1990; Lawesson and Ortiz 1990), 438 in 1995 (Mauchamp 1997) and 471 in January 1999 (Database of the Galapagos Flora, Charles Darwin Research Station). The minimum introduction (or detection) rate has thus been more than 10 per year in the last 30 years. However, the apparent rate of increase is obviously affected by increased interest in recent years in the introduction process, as well as increased sampling effort; Wiggins and Porter (1971) and Porter (1984) considered only naturalized, not cultivated, species, whereas later estimates have included cultivated species.

Porter (1983) suggested that a natural immigration rate of one species every 7000–12000 years would account for the native flora of Galapagos, or an even lower rate if the age of now-submerged islands to the east of the present archipelago is taken into account. Since 1970, the introduction rate has been about 10 species per year, or some 100,000 times the natural arrival rate. Even allowing for the fact that the recent rate may be more due to detection than introduction, the rate since 1800 has been over 2 species per year, or 20,000 times the natural rate. This will obviously have an enormous effect on the ecology and evolution of the Galapagos ecosystem. The process of artificial introduction further differs from that of natural colonization, in that establishment is facilitated by the introduction of more individuals at once, the creation of favourable conditions for establishment (cultivation, disturbed areas), and repeated introduction if the first attempt fails.

Most (*c*. 75%) of the alien plant species were introduced deliberately as useful plants, for their ornamental, agricultural, medicinal or timber value, although there are also many examples of accidental introduction of weeds. An even higher proportion (84%) of the worst invaders (27 of the species in Table 1) was introduced deliberately as useful plants. Some 45% of introduced plant species have naturalized (Tables 1–3, Database of the Galapagos Flora).

EFFECTS OF ALIEN PLANTS IN GALAPAGOS

The principal threat to the terrestrial ecosystems of Galapagos is introduced species (Loope *et al*. 1988). Introduced predators, such as cats and dogs, prey on the endemic fauna. Introduced herbivores, especially goats and donkeys, overgraze native vegetation and cause physical damage even to adult trees to the point of killing them. Introduced invertebrates and small mammals are probably causing as yet unstudied effects on seed production and dispersal, as well as attacking the native fauna. The effects of alien plants are even less well known than those of the introduced animals.

96.4% of the land area of Galapagos forms the Galapagos National Park. Inhabited areas (urban and agricultural zones, military bases and airports) make up the rest. Alien plants which have escaped from cultivation are mostly found on the five inhabited islands, especially the four with agricultural and urban zones (Floreana, Isabela, San Cristóbal, Santa Cruz: Fig. 1); the fifth, Baltra, is a military base and civil airport. There are also a number of deliberately introduced species on Santiago, which was formerly inhabited. Aliens that were introduced accidentally often have a much wider distribution in the archipelago. Most alien plant species are found in the more humid, higher altitudes of the four larger inhabited islands. The settled areas are the major source of invasion into the Galapagos National Park.

The threat from introduced plants is greatest in the Humid Zones (Moll 1990). There are many reasons for this. Firstly, most cultivated species are adapted to more humid climates. In addition, the humid zones are almost restricted to the inhabited islands. Agricultural development has destroyed much of the original vegetation in the humid areas (for example, over 80% of the Scalesia Zone on Santa Cruz: Moll 1990), so that remaining areas of native vegetation are small, and adjacent to agricultural areas that serve as sources of invasion.

Most introduced plant species have not significantly affected the ecological equilibrium of the islands. However, some 32 species (Table 1) have invaded large areas and/or appear to be adversely affecting the natural ecosystem to a degree more than simply occupying space within an existing community (e.g. altering community composition or threatening individual species), or (in a few cases) are already naturalized and known to be extremely serious invasives in other parts of the world. A further 50 or so species have naturalized and are still uncommon but are known or suspected to have invasive tendencies (Table 2). Another 120 or so have naturalized and appear to be integrating without causing obvious ecological damage (Table 3), while at least another 24 species present in the islands, which have not yet escaped, are known to be seriously invasive in other parts of the world (Table 4). Many more introduced species are present in cultivation, of which some may become invasive. Lawesson (1990) lists only eight serious invasives, while Mauchamp (1997) lists 11, omitting one of those included by Lawesson. The 32 aggressive species listed in Table 1 include these 12, and the increase represents largely a re-evaluation of the threat posed by certain species (four species listed by Mauchamp 1997 as potential invaders are included in Table 1), as well as a few recently-added species.

In most cases, we know that these are species introduced by man, but in some cases there is doubt or controversy, e.g. of the species in Table 1, *Caesalpinia bonduc* and *Trema micrantha*. These are not useful plants and may have been present for many years. However, their behaviour (rapidly spreading at the present day: *Trema*), or distribution (present in an area occupied by man, and out of the species' normal habitat: *Caesalpinia*) suggests that they are recent introductions. The origin (native or introduced) of many of the common weedy species, including many Asteraceae, Leguminosae and Poaceae (especially in Table 3), is also doubtful.

There have been few rigorous studies of the effects of the invasions, but some species have caused drastic habitat changes, forming monospecific stands, shading out or otherwise replacing native vegetation communities, or preventing seedling regeneration by forming impenetrable carpets. Where detailed studies have been made, dramatic community changes have been revealed (H. Jäger in prep.). The worst effects seem to be caused by woody species, especially trees such as *Psidium guajava*, *Cedrela odorata* and *Cinchona pubescens*, and bushes that form impenetrable thickets, such as *Lantana camara* and *Rubus* spp.

THE WORST INVADERS

The species in Table 1, the worst invaders, may be grouped or ranked informally in terms of area occupied and drastic ecological effects. They fall into six groups in terms of the characteristics of their invasions, and one additional plant with unique effects.

Group 1, which includes *Furcraea*, *Cleome*, *Ricinus* and *Datura*, consists of herbaceous or shrubby plants, which are invading relatively slowly, and whose main effect is to dominate and replace the natural shrub/herb layer. Some plants in this group, such as *Cassia tora*, were probably early

introductions and have spread very widely, while others are either more recent arrivals (*Cleome*, *Ricinus*), or spread more slowly (*Furcraea*).
Group 2, including *Kalanchoe* and the grasses, also consists of herbaceous species, but these have spread faster or more extensively, and not only replace the herb layer with a monospecific stand, but form such a dense carpet that regeneration of the shrub and tree layers also appears to be seriously affected.
Group 3 comprises scramblers and climbers, including *Cucumis* and *Passiflora*, which have spread rapidly and widely. These seem to some extent to have integrated into the natural communities, but probably exert at least intermittent competition and may be having more insidious effects. *Cucumis* forms dense mats during the wet season over shrubs, herbs and even trees, and probably adversely affects the growth of native species. It may also be a direct competitor for the native Cucurbitaceae. *Passiflora* forms less dense mats, but climbs high into trees and cuts down light levels for the plants below it. It has also been implicated in dietary problems suffered by the giant tortoises of Galapagos.
Group 4 consists of shrubs or small trees that form dense stands, preventing other herbaceous or woody growth. These include *Caesalpinia*, *Leucaena*, the *Rubus* spp., *Cestrum* and *Lantana*, and mostly extend by a combination of seeds and vegetative spread. Besides the very serious ecological change caused by the replacement of an entire vegetation community by a monospecific shrub layer, some species, including *Cestrum* and *Lantana*, are poisonous, at least to mammals, and may have effects on the native fauna. Of this group, the most widespread, rapidly-expanding, and damaging species (so far) are *Lantana* and *Rubus*.
Group 5, including *Ochroma*, *Cordia*, *Persea*, comprises trees which are invading slowly; they are either in the early stages of invasion (*Ochroma*, *Cordia*) or have heavy seeds and therefore naturally spread more slowly (*Persea*, the *Citrus* spp.). Most have not yet caused serious ecological damage, but any tree of their size will probably have dramatic effects on the lower-growing native vegetation that it is invading, especially those species (*Citrus*, *Persea*) which tend to form dense monospecific stands. Some (*Ochroma*) could end up as rare emergents, exerting little long-term damage, but in most cases it is not yet clear whether this will be the case, because such species are still too sparsely dispersed to assess their long-term behaviour.
Group 6 comprises trees, which both spread rapidly, by small, wind-borne or animal-dispersed seeds, and form dense stands. These include *Cedrela*, *Psidium*, *Eugenia*, *Cinchona*, *Trema*. Many of these have already invaded large areas. *Psidium guajava* is estimated to dominate more than 40000 ha (Lawesson and Ortiz 1990), including most of the highlands of San Cristóbal and huge areas of the two southern volcanoes of Isabela (Cerro Azul and Sierra Negra). On San Cristóbal, most of the highland areas not dominated by *Psidium* are covered by *Eugenia jambos* forest.
A herbaceous species that stands alone is tomato *Lycopersicon esculentum*. This has scarcely escaped cultivation, but seems to have hybridized with the endemic *L. cheesmanii* Riley, so as to threaten seriously the latter's existence on some islands.

This grouping has been based on a subjective assessment of what is known of the invasions by these species and their effects. Without a formal assessment system, it is possible to say that Group 6 plants are a greater danger than Group 5, and Group 2 greater than Group 1, and that some species within a group merit higher ranking than others. Other comparisons, for example between herbs and trees, are more difficult. A more objective risk assessment system would enable more precise comparisons and rankings to be made.

TIME LAG, THE PROCESS OF INVASION AND POTENTIAL INVADERS

The species listed in Tables 2 and 4 have only recently begun to invade or have not yet naturalized at all. All of these species are potentially damaging invaders and may be in a "time-lag" phase of the invasion process. Species arriving naturally on the islands have to encounter favourable conditions in order to establish themselves immediately. Species introduced by man are provided with favourable conditions in cultivation but may take time before they begin to invade natural habitats. Factors implicated in this time lag include reaching a critical population size with sufficient genetic diversity to produce varieties that are competitive in the native habitats (Baker 1986).

Several plant species illustrate aspects of the time-lag effect in Galapagos. *Psidium guajava* was reportedly introduced in 1869 and, although it had naturalized by the early 20th century (Mauchamp 1997), it was restricted to plantations and small areas until about 1950 (Lawesson and Ortiz 1990). Since then, it has spread over huge areas of the four large inhabited islands, creating extensive, almost monospecific, forests (Lawesson and Ortiz 1990). It was not introduced to Santa Cruz island until some time between 1930 and 1945, and was still an “inconspicuous part of the vegetation” in 1970 (Eckhardt 1972). It is now one of the most widespread and damaging species on the island.

Lantana camara was introduced to Floreana in 1938 as an ornamental. Despite its rapid growth and copious seed production, it had not apparently spread greatly, nor caused much damage, by 1970 (Eckhardt 1972). Eckhardt commented that he did not understand why *Psidium* had spread so widely in both Hawaii and Galapagos, whereas *Lantana* was also widely naturalized and damaging in Hawaii but had not spread in Galapagos; he suggested that *Lantana* might have the potential to become problematic in the future, which has proved to be the case. During the 1970s it became widely naturalized (Eliasson 1982) and had spread to cover more than 2000 ha on Floreana in 1987 (Lawesson and Ortiz 1990). It has since continued to spread and currently is the single worst invasive species on the island. It has been introduced to other islands, including Santa Cruz about 1985 (Moll 1990), where it has not greatly spread since its introduction, partly because of repeated, if unsustained, control campaigns.

In contrast, other well-documented introductions have shown no time-lag before becoming invasive. *Rubus niveus* was introduced to San Cristóbal in 1983 (or perhaps up to 15 years previously), and has rapidly spread to become one of the most serious invasives in the humid highlands of the island. Similarly, on Santa Cruz, where it was introduced about 1985, it had already escaped and formed dense impenetrable thickets within two years (Lawesson and Ortiz 1990). A brief time-lag was evident with the timber tree *Cedrela odorata*, which was introduced about 1950. It spreads by means of wind-dispersed seeds, and did not become invasive until the first trees began to produce seed some 25 years after the initial introductions (Lawesson and Ortiz 1990). In this case, the apparent time-lag was simply due to the species’ life-cycle, and there was no generational time-lag before a massive invasion commenced.

An intermediate time lag was apparently shown by *Cinchona pubescens*, which was first introduced, for quinine production, before 1925 (Moll 1990; not 1946 *pace* Macdonald *et al*. 1988). It had naturalized, but only as scattered individuals, by 1965 and in 1966 had just begun to invade the highland *Miconia* vegetation zone (Eliasson 1982), despite the fact that it can seed copiously from about 5 years of age. By 1981 it was common in the *Miconia* zone (Eliasson 1982), by 1987 it had invaded about 4000 ha (Macdonald *et al*. 1988), and in 1990 it was estimated to have invaded *c*. 8500 ha (Moll 1990). It has since continued to spread, despite intermittent efforts at control.

RISK ASSESSMENT, PRIORITIZATION AND ACTION

In order to deal adequately with the problem of invasive species in Galapagos, a multi-stage approach is required, comprising risk assessment, prioritization of the problems, and control action. It is not too late to tackle the problem of introduced plants in Galapagos. The comparatively short history of human occupation of the islands has left them so far one of the least damaged oceanic archipelagos in the world (Loope *et al*. 1988). Two organizations exist that could, with adequate funding, develop the capability to tackle the problems of invasive plants. The Charles Darwin Research Station (CDRS) is dedicated to research for the conservation of Galapagos, and is the body responsible for research on invasive species. The Galapagos National Park Service has jurisdiction over the majority of the archipelago and is responsible for implementing management, including control and eradication of invasive plants. What are lacking at present are adequate funding and a system for rationally allocating the limited resources to the worst problems. The development of such an objective risk assessment and prioritization system is therefore of greatest urgency. An action plan for invasive plant research and control in Galapagos therefore comprises design of the risk assessment system, including the selection and definition of appropriate assessment criteria, the application of that system to draw up priorities for control, and the implementation of control measures, or research programmes to develop them.

AN ALIEN PLANT RISK ASSESSMENT SYSTEM FOR GALAPAGOS

A risk assessment system for an oceanic archipelago must take into account all the factors peculiar to such an ecosystem, in addition to more generally applicable factors relating to tendencies to weediness of the introduced species. Islands are especially vulnerable to invasions, due to the impoverished nature of the fauna and flora. Selective pressures that are present in mainland areas are reduced or absent (Loope *et al*. 1988), and species in certain trophic levels may be few or none, so introduced species can more easily find a “vacant niche” than in a more saturated continental environment. Risk assessment for an island ecosystem needs to take these features into account. Assessment also needs to consider all stages of the introduction process, from species not yet introduced but which are likely to be (weeds in major source areas, useful plants), to assessment of the relative risk of species already introduced or already naturalized.

Whether they affect natural areas or agricultural habitats, all introduced species need to be included in a risk assessment system, and that system has to take into account effects on agricultural land as well as on natural areas. The few Galapagos natives that are “weeds” of agriculture (*e.g. Cyperus* spp.), should perhaps be included in the risk assessment system, which would then also need to take into account the fact that their populations should never be allowed to fall to dangerously low levels, and that control should be limited to areas that do not form part of the Galapagos National Park.

Below I discuss many of the factors that need to be included in criteria for assessment of risk for alien plants in Galapagos. Many of these are general and have been included in existing weed risk assessment systems for other areas, while some are more specific to the problems of an island ecosystem or even just to Galapagos. This review is not intended to be exhaustive; for example I do not consider additional risk caused by mutually favourable interactions amongst introduced species (the presence of one alien plant or animal favours invasion by another). The risk assessment system for Galapagos is currently in the planning stage and, as the system is developed, additional factors will come to light that will need to be incorporated.

RISK ASSESSMENT FOR PLANTS NOT YET INTRODUCED: QUARANTINE

Species introductions in Galapagos are today’s problem, not a situation inherited from a long history of human presence. This affects risk assessment, in that an appropriate system has to take into account risks associated with new introductions and species not yet present in the islands, more than might be the case with continental areas or islands that have been inhabited by man for centuries. Such assessment should form part of a quarantine system for the archipelago. Ecuador is currently in the process of establishing an international-standard quarantine system for Galapagos, which will form the appropriate structure for implementing the recommendations of risk assessment, such as lists of prohibited or restricted species. Such lists could be compiled from what is known of the behaviour of a species in areas where it is not native, especially on other islands, or the behaviour of close relatives in Galapagos or elsewhere, using criteria similar to those applied to species already introduced, as discussed below.

RISK ASSESSMENT FOR ALIEN PLANTS ALREADY PRESENT

The New Zealand model

New Zealand has recently developed and implemented a system for risk assessment (NZDC 1997; C. Buddenhagen pers. comm.; C.R. Veitch pers. comm.), which may be applied with modifications to Galapagos. Factors taken into account in the New Zealand model include the following.

1. Community type potentially affected. Assesses how resistant or susceptible the community is to invasion by the species in question.
2. Effect on system. Assesses how significantly the alien changes species composition or habitat structure, suppresses regeneration and persists over time (life-span).
3. Biological success rating. Includes an assessment of maturation rate, seed production, seed viability span, means of dispersal, establishment and growth rate, importance of vegetative reproduction.
4. Additional information. Including increase in fire risk, competitive ability, resistance to management.

In addition, factors not taken into account in the formal risk assessment, but included for information, include growth form, year of naturalization in New Zealand, other countries in which the species is a pest, distribution and impact in various regions of the country, bioclimatic zones in which the species is a pest and details of the plant’s recovery after management (NZDC 1997).

The factors included in the New Zealand model are discussed below in the light of needs for risk assessment in Galapagos. Some of the assessment criteria require more precise definition or amplification for a Galapagos system, while some of the aspects included informally in the NZDC (1997) system might be more appropriately included in a formal risk assessment system for Galapagos.

Information

The quality of information available for a species, on each of the factors discussed below, will affect its risk assessment. A species whose biology or distribution is poorly known might merit a higher assessment than would otherwise be the case.

Factors contributing to the ecological and biological impact of an invader in Galapagos

Island, vegetation zone and location

As reported above, most of the archipelago is Arid Zone, and most endemic plants occur in that zone. However, humid areas are much smaller, so that their endemic species have much more restricted distributions in general, and the humid areas are more susceptible to invasion by the majority of the alien plants introducd to date. Ecological requirements of the alien species, plus its location in the islands, must be taken into account in the model. Further, the exact location of a wind-dispersed species on an island, relative to the prevailing winds, will affect the rapidity of its spread. A species capable of invading more than one vegetation zone obviously poses a greater threat. A species restricted to humid zones will probably have a greater immediate impact, whereas a species capable of invading only the arid zones might in the long term threaten more of the native and endemic species and communities. These factors fall into the NZDC (1997) categories “community type potentially affected”, “distribution and impact” and “bioclimatic zones invaded”.

A further factor relates to the life-history characteristics of the species that comprise the native vegetation. The shrub *Miconia robinsoniana* Cogn. in Robins. and the tree *Scalesia pedunculata* Hook. f. (both endemics), which dominate the Miconia and Scalesia Zones of the highlands on some islands, appear to undergo natural cycles of death and recovery, related to El Niño cycles (Itow and Mueller-Dombois 1988; Lawesson 1988). Both of these are susceptible to invasion by species such as *Cinchona pubescens* and *Psidium guajava*, which are not adversely affected by the rain and drought cycles but which can replace the native species during the periods when the majority of their adults die. As suggested by Mueller-Dombois (1987), the long-term maintenance of a native species with such a life cycle is only possible if no canopy species is present to replace it in the gaps; in Galapagos, species other than canopy ones, such as densely-growing grasses, may also be important. An alien plant may therefore be given a higher risk rating if its life cycle predisposes it to invade communities normally dominated by species with a life cycle characterized by mass mortality followed by recovery.

Although disturbance is often considered to favour or even be a prerequisite for invasion (D'Antonio and Dudley 1995), islands, especially young ones such as Galapagos, may be naturally more susceptible to invasion (Macdonald and Cooper 1995) since the natural state of their ecosystems corresponds to man-disturbed habitats in their simplicity and comparative paucity of species. Although the evidence for this is not yet strong (D'Antonio and Dudley 1995; Simberloff 1995), data from the comparatively undisturbed Galapagos support it (Tables 1–3). Taxonomic disharmony (see below) contributes further to this susceptibility (D'Antonio and Dudley 1995; Simberloff 1995). Although the islands might therefore be naturally vulnerable, disturbance can even further weaken resistance to invasion, so that risk may be higher on those islands or in vegetation zones that suffer more severe levels of disturbance by man. This adds to the increased risk posed by higher frequency of deliberate introductions to such islands or areas, in that both introduction rates and susceptibility are higher on inhabited islands or areas. Disturbance may increase the risk already associated with an aggressive species. For example, the invasion and replacement of native *Scalesia cordata* Stewart woodland by *Psidium guajava* thicket was hastened on Isabela island by a severe fire (Delgado 1997). Similarly, extraction of native timber trees, especially from Transition Zone forests, may facilitate invasion of introduced species by opening canopy gaps. The effect of disturbance needs therefore to be taken into account in the risk assessment model, and affects the criteria for the NZDC (1997) "community type potentially affected" and "effect on system" categories.

Phylogenetic considerations

Oceanic island floras are often disharmonic, with representation of families differing from that on the neighbouring mainland (Loope and Mueller-Dombois 1989). Introduced plants in Galapagos include representatives of several families not naturally present on the islands, although a greater number of introduced species are in the same families and genera as endemics (Porter 1984). This leads to two different problems. Firstly, introduced plants from families not otherwise represented on Galapagos have the potential to introduce profound changes in the character of the flora, and secondly, certain options for control may be restricted for introduced plants with close relatives on the islands. Biological control agents, for example, would need to be very carefully tested where the plant to be controlled forms a species pair with an endemic. This applies to *Lantana camara* and *Psidium guajava* for example, both of which have congeners endemic to Galapagos (*L. peduncularis* Anderss. and *P. galapageium* Hook. f.). Since *P. guajava* is so difficult to control by manual and chemical means, this additional difficulty with biocontrol contributes significantly to the assessment of its relative threat. A related factor is extinction by hybridization. This appears already to be happening in the case of the Galapagos Tomato, *Lycopersicon cheesmani*, mentioned above, which is already virtually impossible to find in a pure form on the island of Santa Cruz; most plants there now appear with characters of *L. esculentum*. Risk assessment therefore needs to take phylogenetic relationships into account.

Some aspects of this factor, such as hybridization threat, are not explicitly recognized by NZDC (1997) but may easily be incorporated into the model. Other effects require refinement of the model, including the potential for introduced species from plant groups not naturally present in the islands to cause fundamental but hard-to-measure changes in the islands' ecology. To some extent this is accounted for by the NZDC (1997) factor "effect on system", which considers changes in species composition. However, it needs to be made explicit that this should include effects not only on plant communities but, if possible, potential effects on other ecosystem components such as pollinator communities, where introduced insects could be favoured by the presence of an introduced plant. A "taxonomic uniqueness" rating might be incorporated to take this point into account.

Biology

Noble (1989) discusses plant characteristics that affect the ability to invade. These include habitat range, rapid growth and attainment of maturity, self-compatibility, good dispersal ability, vegetative reproduction, life-history strategy and other aspects of competitive ability (including physiological factors such as photosynthetic pathways). All of these need to be considered in risk assessment and can be incorporated into models of population dynamics that assist in prediction of invasion risk. Most are taken into account in the NZDC (1997) "biological success rating", although a score for self-compatibility should be included. The assessment criteria for some of these components merit careful consideration in Galapagos owing to peculiarities of the native flora and fauna of the islands and, for example, differences between the effects of natural and man-induced dispersal mechanisms. Plants with seeds specialized for dispersal by large mammals tend to spread over areas occupied or visited by man. There are no indigenous large mammals in Galapagos, and plants relying mainly on this means of dispersal find their way into natural areas via roads, paths and sites used by humans and their domestic or feral animals (Moll 1990; Jaramillo 1998). Some aliens whose fruit are eaten primarily by people (e.g. tomatoes, chili peppers) may count human dispersal as their primary means of spread. The criteria used for assessment of dispersal ability must take such factors into account.

Ecological effects

The ecological effects of an alien plant are perhaps the most important factor contributing to risk assessment and priority setting for alien control in a natural area. The species introduced by man are selected according to traits which differ in several respects from those that favour natural colonization of an oceanic island, which not only changes the character of the flora, but introduces competitive effects that might normally be absent from the native communities. Growth habit is important, in that certain species, primarily trees, cause conspicuous, drastic changes in species composition and habitat structure, while the effects of other species may be harder to determine. Large alien species may obviously suppress regeneration of lower-growing species, whereas other species may suppress regeneration by less obvious allelopathic effects. Other important features include tendency to form monospecific stands, or change nutrient status (N-fixing species) or soil water regime.

Problems arise in deciding priorities amongst the species with more cryptic effects, and adequate consideration of this factor may require an extensive programme of ecological research. Further, an introduced species, such as a tree introduced to a naturally treeless habitat, may create additional niches that could favour the establishment of other introduced species Loope and Mueller-Dombois 1989). Some of these aspects are taken into account by the NZDC (1997) component "effect on system", but others could be made more explicitly part of the assessment criteria. The factors specified to be taken into account for assessing the significance of the effect on the system need to be as explicit as possible. A balance has to be drawn, however, between completeness and utility; for example, ideally a species' potential effect in favouring the introduction of insect pests which depend on it should be considered, but the amount of research needed to permit this to be done properly would, other than in exceptional cases, render it impossible. However, criteria listings could include all factors to be considered where possible, without requiring a complete review of all of them.

Effects on individual native species need also be taken into account. Not only might island ecosystems be especially susceptible to invasion, but island species may also be unusually susceptible to adverse effects caused by introduced species that invade (D'Antonio and Dudley 1995; Macdonald and Cooper 1995; Simberloff 1995). Certain alien species may have dramatic effects on a naturally rare native species if they share habitat requirements and are present in the same area. As an example, the second rarest endemic plant of Galapagos, *Linum cratericola* Eliass., with only six individuals found at the last count of its only known remaining site on Floreana (pers. obs.), may have been hastened towards extinction partly by invasion of its habitat by *Lantana camara*; its only other known site, at which it is now believed extinct, is heavily invaded by *Lantana*, which forms a thicket overtopping the *Linum*. In NZDC (1997), effects on species must be included in the "effect on system" category in terms of changes in species composition or suppression of regeneration. But these are intended rather as guides to effects at the ecosystem level, rather than effects on individual species. It may be valuable to give a higher rating to aliens that pose a direct threat to an endangered species.

Factors affecting ability to control

Availability of control methods

The problem of invasive plants in natural systems, as opposed to weeds in agriculture, has been neglected both worldwide and in Galapagos, relative to the amount of effort that has been devoted to the control of introduced mammals and other animals. Plant problems have been seen by land managers as less serious and immediate, and scarce resources have instead been directed at the more obvious problems caused by introduced herbivores and predators. In the long term, plants are the more insidious, and almost certainly the greater threat, certainly in Galapagos. Control techniques for introduced vertebrates are comparatively well-developed (e.g. Cuddihy and Stone 1990, Veitch and Bell1990), whereas we are still in the early stages of research into methods of control appropriate for the worst plant invaders in a sensitive island ecosystem. Research into plant control at CDRS currently focusses on the development of appropriate control techniques, mainly manual and chemical at present, while options for biological control may be included in the future. Past trials have generally been poorly applied and monitored, and results have been at best ambiguous (Wilkinson and Tye in prep.). A current trial series is aimed at developing control techniques for some of the worst invaders in Table 1.

Although the assessment of availability of control methods would normally be made for each alien species, some generalizations can be made for species whose control has been little researched. Growth form is important, beyond the ecological effects discussed above, in that species with a certain growth habits, such as vines, may be harder to find or control than conspicuous trees. Predictions of the likelihood of developing an effective control technique can sometimes be made based on better-studied relatives. Criteria to be included in ranking species according to availability of control methods would therefore include not just known techniques for the species in question in the circumstances of interest (since appropriate techniques vary according to habitat, community, season etc), but likelihood of developing such techniques quickly, growth habit, and other characteristics of the species that affect ease of control.

Effectiveness and ecological effects of the control methods

Assuming that one or more control techniques be identified, it is also necessary to take account of percentage control, need for repeat treatments and post-control behaviour (regeneration from seed, resprouting etc.). Other factors, which may need to be incorporated, include non-target or residual effects of the treatment, such as soil damage that may favour regeneration of the same or other alien species. These factors are somewhat taken into account by the NZDC (1997) factors "resistance to management" and recovery after management, but would be formalized in an ideal assessment process for Galapagos. Non-target and residual effects are especially important in a unique natural ecosystem such as Galapagos.

Cost

Risk assessment must also take into account the cost of control action. Few estimates have been made to date. Moll (1990) made a preliminary estimate for the monetary and labour costs of eradication of *Cinchona pubescens*, which has been recently revised at US$ 2 million over 15 years (A. Tye and H. Jäger unpubl.). This cost would also contribute to the control of other selected target species in the same areas. Although absolute costs may be hard to calculate, a consideration of the factors considered above and others, such as distribution, abundance and conspicuousness, should permit assessment of relative costs for different species.

Social factors

Most of the serious invaders in Galapagos were introduced deliberately, as useful plants. Most of the species that are problematic in the National Park are, however, also causing problems for farmers, and this includes cultivated species as well as accidental weeds. To a large extent, therefore, there is little conflict regarding priorities for control or eradication of invasives. However, this is not true in every case, and potential conflict of values between farmers and conservationists needs to be included in risk assessment. In cases such as *Cinchona pubescens* (which produces no economic yield of quinine), all parties wish to see the pest eradicated, whereas *Pennisetum purpureum* is a valued pasture grass and its removal from agricultural areas would be politically difficult. In some cases, a possible strategy would be replacement; Moll (1990) suggested that the invasive form of *Psidium guajava* could be controlled, in conjunction with the introduction of high-producing but sterile cultivars. Social factors can sometimes assist in control planning, since public support will be much easier to obtain for a plant seen as a threat by the public, because it invades farmland or is poisonous, than for something which only affects natural habitats. This could influence the selection of priorities for control and eradication campaigns.

Possibility of eradication vs continued control

It is not yet feasible to eradicate most invasive species from Galapagos. Eradication has so far been confined to the elimination of recent introductions before they have naturalized or spread, as in the case of *Pueraria phaseoloides*, introduced to one farm in 1996 (Mauchamp and Muñoz 1996). A plan for the eradication of *Cinchona pubescens* has recently been drawn up (A. Tye and H. Jäger unpubl.), and would represent the first attempt at eradication of any widespread alien. An assessment of the possibility of eradication might result from assessment of the availability and effectiveness of control techniques. Abundance and spatial distribution within and between islands are also important, especially number of islands occupied, as eradication is more feasible for plants restricted to fewer islands. Should eradication be considered practicable, this would affect prioritization of action against the species, although not strictly affecting risk.

CONCLUSIONS: RESULTS EXPECTED FROM A RISK ASSESSMENT SYSTEM

Knowledge of the invasive plant problems existing in Galapagos and the requirements for a risk assessment system will hopefully allow us to design in the near future a suitable objective system, which will enable revision and refinement of the subjective classifications of introduced species in Tables 1–4. The system should assist in a variety of ways, depending on the characteristics of the species being assessed. Risk assessment for aliens not yet introduced would focus on the construction of prohibited lists. Risk assessment for serious invaders (Table 1) should help reveal which ones are having or will have the greatest ecological effects. Risk assessment for the time-bombs (Tables 2 and 4) should help reveal which might take off first, and which then will cause the worst problems. Risk assessment for apparently innocuous naturalized species (Table 3) might help reveal whether they are doing anything besides using space. Risk assessment should also play a valuable role in revealing gaps in knowledge; for example if the data required to assess under a criterion do not exist, that lack of knowledge and requirement for research will be made explicitly known.

A comprehensive and objective risk assessment system will allow us to refine our comparisons and make rational use of the limited funds available for conservation action. It should contribute significantly to the preservation of an ecosystem world-famous for its comparatively pristine state, in a world beset by invasions of introduced species.

ACKNOWLEDGMENTS

I thank Sarah Wilkinson for help with the research for this paper and Chris Buddenhagen and Dick Veitch for advice about the New Zealand risk assessment model. Heidi Snell kindly allowed me to use and adapt her map of the islands, and Mark Gardener and Sarah Wilkinson provided helpful comments on a draft. The background research was partly financed by Monsanto Corp. and the European Union. This is contribution number 539 of the Charles Darwin Research Station.

REFERENCES

Baker, H.G. (1986). Patterns of plant invasions in North America. In ‘Ecology of biological invasions in North America and Hawaii’. (Eds H.A. Mooney and J.A. Drake) pp. 44–57. (Ecological Studies 53, Springer, Berlin.)

Cuddihy, L.W. and Stone, C.P. (1990). Alteration of native Hawaiian vegetation: effects of humans, their activities and introductions. (University of Hawaii, Honolulu.)

D’Antonio, C.M. and Dudley, T.L. (1995). Biological invasions as agents of change on islands versus mainlands. In ‘Islands. Biological diversity and ecosystem function’. (Eds P.M. Vitousek, L.L. Loope and H. Adsersen) pp. 103–121. (Ecological Studies 115, Springer, Berlin.)

Delgado T., P.I. (1997). Distribución de *Scalesia cordata*, su interacción con *Psidium guajava* y biología reproductiva, Isabela sur, Galápagos. (Unpublished licenciatura thesis, Pontífica Universidad Católica del Ecuador, Quito.)

Eckhardt, R.C. (1972). Introduced plants and animals in the Galapagos islands. *Bioscience* **22**, 585–590.

Eliasson, U. (1982). Changes and constancy in the vegetation of the Galapagos islands. *Noticias de Galápagos* **36**, 7–12.

Gordillo, J. (1990). The colonization of San Cristóbal, Galapagos Islands—a historical perspective. In ‘Botanical Research and Management in the Galapagos Islands’. (Eds J.E. Lawesson, O. Hamann, G. Rogers, G. Reck, and H. Ochoa). *Monographs in Systematic Botany from the Missouri Botanical Garden* **32**, 247–250.

Hamann, O. (1975). Vegetation changes in the Galapagos islands during the period 1966–73. *Biological Conservation* **7**, 37–59.

Hamann, O. (1984). Changes and threats to the vegetation. In ‘Key Environments. Galapagos’. (Ed. R. Perry) pp. 115–131. (Pergamon Press, Oxford.)

Hickman, J. (1985). The enchanted islands: the Galapagos discovered. (Nelson, Oswestry.)

Itow, S. and Mueller-Dombois, D. (1988). Population structure, stand level dieback and recovery of *Scalesia pedunculata* forest in Galapagos islands. *Ecological Research* **3**, 333–339.

Jaramillo, P. (1998). Distribución espacial de la vegetación vascular y dispersión de especies introducidas en sitios de actividad humana en el Parque Nacional Galápagos. (Unpublished thesis, Universidad Central del Ecuador, Quito.)

Lawesson, J.E. (1988). Stand level dieback and regeneration of forests in the Galapagos Islands. *Vegetatio* **77**, 87–93.

Lawesson, J.E. (1990). Alien plants in the Galapagos islands, a summary. In 'Botanical Research and Management in the Galapagos Islands'. (Eds J.E. Lawesson, O. Hamann, G. Rogers, G. Reck, and H. Ochoa). *Monographs in Systematic Botany from the Missouri Botanical Garden* **32**, 15–20.

Lawesson, J.E. and Ortiz, L. (1990). Plantas introducidas en las islas Galápagos. In 'Botanical Research and Management in the Galapagos Islands'. (Eds J.E. Lawesson, O. Hamann, G. Rogers, G. Reck, and H. Ochoa). *Monographs in Systematic Botany from the Missouri Botanical Garden* **32**, 201–210.

Lawesson, J.E., Adsersen, H, and Bentley, P. (1987). An updated and annotated checklist of the vascular plants of the Galapagos islands. *Reports from the Botanical Institute, University of Aarhus* **16**.

Loope, L.L., Hamann, O. and Stone, C.P. (1988). Comparative conservation biology of oceanic archipelagoes. Hawaii and the Galápagos. *Bioscience* **38**, 272–282.

Loope, L.L. and Mueller-Dombois, D. (1989). Characteristics of invaded islands, with special reference to Hawaii. In 'Biological invasions, a global perspective'. (Eds J.A. Drake, H.A. Mooney, F. di Castri, R.H. Grove, K.J. Kruger, M. Rejmánek, and M. Williamson) pp. 257–280. (Scope 37, Wiley, Chichester.)

Macdonald, I.A.W. and Cooper, J. (1995). Insular lessons for global biodiversity conservation with particular reference to alien invasions. In 'Islands. Biological diversity and ecosystem function'. (Eds P.M. Vitousek, L.L. Loope and H. Adsersen) pp. 189–203. (Ecological Studies 115, Springer, Berlin.)

Macdonald, I.A.W., Ortiz, L., Lawesson, J.E. and Nowak, J.B. (1988). The invasion of the highlands in Galápagos by the Red Quinine-tree *Cinchona succirubra*. *Environmental Conservation* **15**, 215–220.

Mauchamp, A. (1997). Threats from alien plant species in the Galápagos Islands. *Conservation Biology* **11**, 260-263

Mauchamp, A. and Muñoz, M.L. (1996). A kudzu alert in Galápagos: the urgent need for quarantine. *Noticias de Galápagos* **57**, 22–23.

Moll, E. (1990). A report on the distribution of introduced plants on Santa Cruz island, Galapagos. (University of Cape Town, Cape Town.)

Mueller-Dombois, D. (1987). Natural dieback in forests. *BioScience* **37**,575–583.

Noble, I. (1989). Attributes of invaders and the invading process: terrestrial and vascular plants. In 'Biological invasions, a global perspective'. (Eds J.A. Drake, H.A. Mooney, F. di Castri, R.H. Grove, K.J.Kruger, M. Rejmánek, and M. Williamson) pp. 301–313. (Scope 37, Wiley, Chichester.)

NZDC (1997). Ecological weeds database. (Unpublished database, New Zealand Department of Conservation, Wellington.)

Porter, D. (1822). Journal of a cruise made to the Pacific Ocean, vol. 1. (Wiley and Halstead, New York.)

Porter, D.M. (1983). Vascular plants of the Galapagos: origins and dispersal. In 'Patterns of evolution in Galapagos organisms'. (Eds R.I. Bowman, M. Berson and A.E. Leviton) pp. 33–96. (American Association for the Advancement of Science, San Francisco.)

Porter, D.M. (1984). Endemism and evolution in terrestrial plants. In 'Key Environments, Galapagos'. (Ed R. Perry) pp. 85–100. (Pergamon Press, Oxford.)

Schofield, E.K. (1973). Galapagos flora: the threat of introduced plants. *Biological Conservation* **5**, 48–51.

Schofield, E.K. (1989). Effects of introduced plants and animals on island vegetation: examples from the Galapagos archipelago. *Conservation Biology* **3**, 227–238.

Simberloff, D. (1995). Why do introduced species appear to devastate islands more than mainland areas? *Pacific Science* **49**, 87–97.

Simkin, T. (1984). Geology of Galápagos islands. In 'Key Environments, Galapagos'. (Ed R. Perry) pp. 15–41. (Pergamon Press, Oxford.)

Slevin, J.R. (1959). The Galapagos islands. A history of their exploration. *Occasional Papers of the California Academy of Sciences* **25**, 1–150.

Veitch, C.R. and Bell, B.D. (1990). Eradication of introduced animals from the islands of New Zealand. In 'Ecological restoration of New Zealand islands'. (Eds D.R. Towns, C.H. Daugherty and I.A.E. Atkinson) pp. 137–146. (Conservation Sciences Publication 2, Department of Conservation, Wellington.)

Wilkinson, S.R. and Tye, A. (in prep.) Introduced species in the Galapagos Islands: control efforts to date 1997. (Charles Darwin Research Station, Puerto Ayora.)

Table 1. Invasive species in Galapagos, known or suspected to be causing significant ecological change.

	Family	Species
1	Agavaceae	Furcraea cubensis (Jacq.) Vent.
2	Bombacaceae	Ochroma pyramidale (Lam.) Urban
3	Boraginaceae	Cordia alliodora (R. & P.) Chum.
4	Capparidaceae	Cleome viscosa L.
5	Crassulaceae	Kalanchoe pinnata (Lam.) Pers.
6	Cucurbitaceae	Cucumis dipsaceus Ehr.
7	Euphorbiaceae	Ricinus communis L.
8	Lauraceae	Persea americana Mill.
9	Leguminosae	Caesalpinia bonduc (L.) Roxb.
10	Leguminosae	Cassia tora L.
11	Leguminosae	Leucaena leucocephala (Lam.) de Wit
12	Meliaceae	Cedrela odorata L.
13	Myrtaceae	Eugenia jambos L.
14	Myrtaceae	Psidium guajava L.
15	Passifloraceae	Passiflora edulis Sims.
16	Poaceae	Brachiaria mutica (Forssk.) Stapf
17	Poaceae	Digitaria decumbens Stent.
18	Poaceae	Melinis minutiflora Beauv.
19	Poaceae	Panicum maximum Jacq.
20	Poaceae	Panicum purpurascens Raddi
21	Poaceae	Pennisetum clandestinum Hochst.
22	Poaceae	Pennisetum purpureum Schum.
23	Rosaceae	Rubus niveus Thunb.
24	Rubiaceae	Cinchona pubescens Vahl
25	Rutaceae	Citrus aurantiifolia (Christm.) Swingle
26	Rutaceae	Citrus limetta Risso
27	Rutaceae	Citrus limon (L.) Burn.
28	Solanaceae	Cestrum auriculatum L'Her.

29	Solanaceae	Datura stramonium L.
30	Solanaceae	Lycopersicon esculentum Mill.
31	Ulmaceae	Trema micrantha (L.) Blume
32	Verbenaceae	Lantana camara L.

Table 2. Naturalized species, which are still relatively uncommon but are known to be damaging aggressives in other parts of the world or suspected of capacity to be so in Galapagos. Most of those listed will probably move into Table 1 unless action is taken to control them.

33	Amaranthaceae	Amaranthus gracilis Desf.
34	Anacardiaceae	Spondias purpurea L.
35	Annonaceae	Annona cherimolia Mill.
36	Annonaceae	Annona muricata L.
37	Araceae	Colocasia esculenta (L.) Schott
38	Asclepiadiaceae	Asclepias curassavica L.
39	Asteraceae	Bidens cynapiifolia HBK.
40	Asteraceae	Flaveria bidentis (L.) Kuntze
41	Asteraceae	Gnaphalium purpureum L.
42	Asteraceae	Porophyllum ruderale (Jacq.) Cass.
43	Bixaceae	Bixa orellana L.
44	Brassicaceae	Raphanus sativus L.
45	Cannaceae	Canna lutea Mill.
46	Caricaceae	Carica papaya L.
47	Chenopodiaceae	Chenopodium ambrosioides L.
48	Chenopodiaceae	Chenopodium murale L.
49	Convolvulaceae	Ipomoea pulchella Roth
50	Cyperaceae	Cyperus rotundus L.
51	Euphorbiaceae	Chamaesyce hirta (L.) Millsp.
52	Euphorbiaceae	Jatropha curcas L.
53	Leguminosae	Acacia nilotica (L.) DeLisle
54	Leguminosae	Cassia bicapsularis L.
55	Leguminosae	Geoffroea spinosa Jacq.
56	Leguminosae	Inga edulis Mart.
57	Leguminosae	Lablab purpureus (L.) Sweet
58	Leguminosae	Mimosa pigra L.
59	Lythraceae	Cuphea carthagenesis (Jacq.) Macbr.
60	Malvaceae	Hibiscus diversifolius Jacq.
61	Malvaceae	Hibiscus rosa-sinensis L.
62	Malvaceae	Malachra alceifolia Jacq.
63	Malvaceae	Malvastrum coromandelianum (L.) Garcke
64	Meliaceae	Melia azederach L.
65	Nyctaginaceae	Mirabilis jalapa L.
66	Papaveraceae	Argemone mexicana L.
67	Passifloraceae	Passiflora ligularis Juss.
68	Passifloraceae	Passiflora quadrangularis L.
69	Phytolaccaceae	Rivina humilis L.
70	Piperaceae	Pothomorphe peltata (L.) Miq.

71	Poaceae	Axonopus compressus (Sw.) Beaur.
72	Poaceae	Bambusia guadua HBK.
73	Poaceae	Cynodon dactylon (L.) Pers.
74	Poaceae	Dactylotenium aegypticum (L.) Beauv.
75	Poaceae	Echinochloa colonum (L.) Link
76	Poaceae	Eragrostis pilosa (L.) Beauv.
77	Polemoniaceae	Phlox sp.
78	Rubiaceae	Coffea arabica L.
79	Solanaceae	Brugmansia candida L.
80	Solanaceae	Datura innoxia Mill.
81	Solanaceae	Nicotiana tabacum L.
82	Solanaceae	Physalis peruviana L.
83	Tiliaceae	Triumfetta semitriloba Jacq.
84	Urticaceae	Urera caracasana (Jacq.) Griseb.
85	Verbenaceae	Verbena brasiliensis Vell.
86	Zingiberaceae	Hedychium sp.

Table 3. Naturalized species, which are either long-established and still rare, or which appear to have integrated into the natural ecosystem while causing less obvious damage than those in Tables 1 and 2. Some of these may be damaging aggressives in other parts of the world, and all require monitoring. Some may be better placed in Table 2.

87	Acanthaceae	Elytraria imbricata (M.Vahl) Pers.
88	Amaranthaceae	Alternanthera lehmannii Hieron.
89	Amaranthaceae	Alternanthera sessilis (L.) R.Br.
90	Amaranthaceae	Achyranthes aspera L.
91	Amaranthaceae	Amaranthus dubius Mart.
92	Amaranthaceae	Amaranthus lividus L.
93	Amaranthaceae	Amaranthus quitensis HBK.
94	Amaranthaceae	Amaranthus spinosus L.
95	Apiaceae	Apium leptophyllum (Pers. f.) Muell.
96	Apiaceae	Petroselinum crispum (Mill.) A. W. Hill
97	Asteraceae	Acanthospermum microcarpum Robins.
98	Asteraceae	Adenostemma platyphyllum Cass.
99	Asteraceae	Ageratum c. conyzoides L.
100	Asteraceae	Ageratum conyzoides latifolium Cav.
101	Asteraceae	Ambrosia artemisiifolia L.
102	Asteraceae	Bidens pilosa L.
103	Asteraceae	Brickellia diffusa (Vahl) A. Gray
104	Asteraceae	Conyza bonariensis (L.) Cronq.
105	Asteraceae	Delilia biflora (L.) Kuntze
106	Asteraceae	Erechtites hieracifolia (L.) DC.
107	Asteraceae	Fleischmannia pratensis (Klatt) King & Robins.
108	Asteraceae	Galinsoga urticaefolia (HBK.) Benth.
109	Asteraceae	Gnaphalium vira-vira Molina
110	Asteraceae	Jungia hirsuta Cuatr.
111	Asteraceae	Pectis linifolia L.

112	Asteraceae	Pseudelephantopus spicatus (Juss.) C. F. Baker
113	Asteraceae	Pseudelephantopus spiralis (Less.) Cronq.
114	Asteraceae	Sonchus oleraceus L.
115	Asteraceae	Spilanthes acmella (L.) Murr.
116	Asteraceae	Synedrella nodiflora (L.) Gartn.
117	Asteraceae	Tridax procumbens L.
118	Boraginaceae	Heliotropium rufipilum (Benth.) Johnst.
119	Brassicaceae	Brassica campestris L.
120	Brassicaceae	Coronopus didymus (L.) J. E. Smith
121	Brassicaceae	Lepidium virginicum L.
122	Callitrichaceae	Callitriche deflexa A.Br.ex Hegelm.
123	Caryophyllaceae	Stellaria media (L.) Vill.
124	Convolvulaceae	Ipomoea alba L.
125	Convolvulaceae	Ipomoea batatas (L.) Lam.
126	Convolvulaceae	Ipomoea nil (L.) Roth
127	Convolvulaceae	Merremia umbellata (L.) Hallier f.
128	Cucurbitaceae	Citrullus lanatus (Thunb.) Mats.& Nakai
129	Cucurbitaceae	Momordica charantia L.
130	Cyperaceae	Cyperus compressus L.
131	Cyperaceae	Cyperus odoratus L.
132	Cyperaceae	Fimbristylis littoralis Gaud.
133	Cyperaceae	Hemicarpha micrantha (M. Vahl) Britt.
134	Cyperaceae	Rhynchospora n. nervosa (M. Vahl) Boeck.
135	Euphorbiaceae	Chamaesyce lasiocarpa (Kl.) Arthur
136	Euphorbiaceae	Chamaesyce opthalmica (Pers.) Burch
137	Lamiaceae	Hyptis rhomboidea Mart. & Gal.
138	Lamiaceae	Hyptis sidaefolia (L'Her.) Briq.
139	Lamiaceae	Mentha piperita L.
140	Leguminosae	Canavalia dictyota Piper
141	Leguminosae	Cassia hirsuta L.
142	Leguminosae	Desmodium canum Schinz & Thell.
143	Leguminosae	Desmodium glabrum (Mill.) DC.
144	Leguminosae	Desmodium limense Hook.
145	Leguminosae	Galactia tenuiflora Wight & Arn.
146	Leguminosae	Glycine max (L.) Merr.
147	Leguminosae	Inga schimpfii Harms
148	Leguminosae	Mimosa acantholoba (Willd.) Poir.
149	Leguminosae	Mimosa albida HBK.
150	Leguminosae	Mucuna rostrata Benth.
151	Leguminosae	Phaseolus lathyroides L.
152	Leguminosae	Zornia curvata Mohlenbrock
153	Leguminosae	Zornia piurensis Mohlenbrock
154	Lythraceae	Cuphea racemosa (L.f.) Spreng.
155	Malvaceae	Abelmoschus manihot (L.) Medic.
156	Malvaceae	Anoda acerifolia DC.
157	Malvaceae	Malva parviflora L.
158	Malvaceae	Malvastrum americanum (L.) Torrey
159	Malvaceae	Malvastrum scoparium (L'Her.) A. Gray

160	Malvaceae	Sida acuta Burm. f.
161	Malvaceae	Sida glutinosa Cav.
162	Malvaceae	Sida paniculata L.
163	Malvaceae	Sida rhombifolia L.
164	Nyctaginaceae	Boerhaavia coccinea Mill.
165	Oxalidaceae	Oxalis corniculata L.
166	Oxalidaceae	Oxalis corymbosa DC.
167	Plantaginaceae	Plantago major L.
168	Poaceae	Anthephora hermaphrodita (L.) Kuntze
169	Poaceae	Bouteloua disticha (HBK.) Benth.
170	Poaceae	Cenchrus echinatus L.
171	Poaceae	Chloris mollis (Nees) Swallen
172	Poaceae	Chloris pycinothrix Trin.
173	Poaceae	Chloris radiata (L.) Sw.
174	Poaceae	Chloris virgata Sw.
175	Poaceae	Coix lacryma-jobi L.
176	Poaceae	Digitaria horizontalis Willd.
177	Poaceae	Eleusine indica (L.) Gaertn.
178	Poaceae	Eragrostis cilianensis (All.) Lutati
179	Poaceae	Eragrostis ciliaris (L.) R. Br.
180	Poaceae	Leptochloa filiformis (Lam.) Beauv.
181	Poaceae	Leptochloa virgata (L.) Beauv.
182	Poaceae	Oplismenus setarius (Lam.) Roem. & Schult
183	Poaceae	Paspalum conjugatum Bergius
184	Poaceae	Setaria vulpiseta (Lam.) Roem. & Sch.
185	Polygonaceae	Antigonon leptopus Hook. & Arn.
186	Polygonaceae	Rumex crispus L.
187	Portulacaceae	Portulaca oleracea L.
188	Portulacaceae	Talinum paniculatum (Jacq.) Gaertn.
189	Rhamnaceae	Gouania polygama (Jacq.) Urban
190	Rubiaceae	Diodia radula Cham. & Schlecht.
191	Rubiaceae	Galium canescens HBK.
192	Rubiaceae	Oldenlandia corymbosa L.
193	Rubiaceae	Spermacoce confusa Rendle
194	Scrophulariaceae	Stemodia verticillata (Mill.) Sprague
195	Solanaceae	Browallia americana L.
196	Solanaceae	Capsicum frutescens L.
197	Solanaceae	Capsicum pendulum Willd.
198	Solanaceae	Nicandra physalodes (L.) Gaertn.
199	Solanaceae	Physalis cordata Mill.
200	Solanaceae	Solanum americanum Mill.
201	Solanaceae	Solanum quitoense Lam.
202	Urticaceae	Pilea microphylla (L.) Liebm.
203	Valerianaceae	Astrephia chaerophylloides (Sm.) DC.
204	Verbenaceae	Phyla nodiflora (L.) E. Greene
205	Verbenaceae	Priva lappulacea (L.) Pers.
206	Verbenaceae	Stachytarpheta cayennensis (Rich.) M. Vahl
207	Verbenaceae	Verbena litoralis HBK.

208	Zygophyllaceae	Tribulus cistoides L.
209	Zygophyllaceae	Tribulus terrestris L.

Table 4. Potentially invasive species (known to be damagingly aggressive in other parts of the world), not yet escaped from cultivation on Galapagos, which require monitoring or immediate eradication.

210	Aizoaceae	Carpobrotus sp.
211	Amaranthaceae	Alternanthera lanceolata (Bentham) Schinz
212	Amaranthaceae	Amaranthus caudatus L.
213	Anacardiaceae	Mangifera indica L.
214	Anacardiaceae	Schinus molle L.
215	Asteraceae	Conyza canadiensis L.
216	Asteraceae	Lactuca sativa L.
217	Asteraceae	Tagetes erecta L.
218	Bignoniaceae	Spathodea campanulata Beauv.
219	Casuarinaceae	Casuarina equisetifolia L.
220	Euphorbiaceae	Euphorbia pulcherrima Willd.
221	Euphorbiaceae	Euphorbia tirucalli L.
222	Juglandaceae	Juglans neotropica Diels
223	Leguminosae	Delonix regia (Hook.) Raf.
224	Leguminosae	Pueraria phaseoloides (Roxb.) Benth.
225	Leguminosae	Tamarindus indica L.
226	Moraceae	Ficus carica L.
227	Myrtaceae	Eucalyptus spp.
228	Myrtaceae	Eugenia malaccensis L.
229	Nyctaginaceae	Bougainvillea spectabilis Willd.
230	Pinaceae	Pinus radiata D.Don
231	Rosaceae	Rubus bogotensis Kunth
232	Rosaceae	Rubus other spp.
233	Solanaceae	Tropaeolum majus L.

Figure 1. Map of the central part of the Galapagos archipelago, showing all islands mentioned in the text.