Studies in Avian Biology No. 22:291–304, 2001.

NEWLY EMERGENT AND FUTURE THREATS OF ALIEN SPECIES TO PACIFIC BIRDS AND ECOSYSTEMS

LLOYD L. LOOPE, FRANCIS G. HOWARTH, FREDERICK KRAUS, AND THANE K. PRATT

Abstract. Although the devastating effects of established alien species to Pacific birds and ecosystems are generally well recognized by the avian conservation community, we raise the under appreciated issue of effects of incipient and future invasions. Although special attention to Pacific bird species "on the brink" is to a certain extent appropriate and necessary, a comparable focus on stopping new invasions appears desperately needed. All indications suggest that introductions will escalate with the trend toward ever increasing commerce and unrestricted trade unless stronger preventative measures are implemented very soon. The threat to Pacific island avifaunas from the brown tree snake (*Boiga irregularis*) is well-known, but as many as several hundred of the world's snake species, some of which are repeatedly smuggled illegally as pets, might have similar impacts on native birds if transported to Pacific islands. We touch upon a sampling of obviously severe potential future threats, with the hope of raising awareness and resolve to fix the current woefully inadequate system for prevention of and rapid response to new invasions.

Key Words: biological invasions; invasion and biological diversity; invasive amphibians; invasive invertebrates; invasive plants; invasive reptiles; invasive vertebrates; newly emergent alien species; quarantine; snake invasions of islands.

The biotas of oceanic islands in general, and the Hawaiian Islands and other Pacific islands in particular, are highly susceptible to damage caused by alien plants, animals, and microorganisms transported by humans. The high susceptibility is related to the evolutionary history of island organisms that generally evolved with reduced exposure to certain physical (e.g., fire) and biotic (e.g., ungulates, snakes, ants) forces (Loope and Mueller-Dombois 1989). Although habitat destruction by humans was a very important factor in the decimation of Hawaiian landbirds in the past, the greatest current threats are from alien species. The most important threats include avian diseases transported by mosquitoes; predation by rats, cats, dogs, and mongooses; competition for food and other resources by alien species, especially arthropods and birds; and habitat degradation by feral ungulates, especially pigs, which also facilitate spread of alien plants (Cuddihy and Stone 1990, Jacobi and Atkinson 1995). Alien species also prevent the recovery of native ecosystems after disturbances, thus seriously exacerbating the effects of habitat destruction. We concur that the current focus of conservation agencies on mitigating these threats, with special attention to "species on the brink," is appropriate and necessary. However, we aim in this paper to call attention to the intuitively obvious but seldom mentioned reality that although existing invasions pose formidable threats, the situation promises to get much worse as additional invasive species are introduced and established. We ask the conservation community and public agencies to recognize and address the problem of continued alien species introduction.

Located near the middle of the Pacific Ocean, Hawai'i is increasingly important as an international transportation hub. Honolulu International Airport is the seventeenth busiest airport in the world in terms of total passenger traffic; military air traffic is also substantial. The state is a social melting pot, with much movement of cultural trappings such as ethnic fruits and vegetables as well as the ever increasing repertoire of the international horticulture and pet trades. Tourism is the primary industry, and visitors arrive from all over the world. Agriculture is also an important industry, which routinely moves living material into and out of Hawai'i. All these activities result in the frequent arrival of new alien species (Holt 1996). Furthermore, the increasing globalization of the world economy and the increasing scope of free trade agreements promise to expedite the flow of species (Jenkins 1996).

Our focus on this topic was heightened by recent experience on a technical panel convened by the U.S. Federal Aviation Administration, the Hawaii Department of Transportation, and the U.S. Fish and Wildlife Service to examine likely impacts on endangered species of an expanded airport at Kahului, Maui. We were asked to predict what new species might arrive, particularly on new direct flights from Asia and eastern United States, and how their arrival might challenge the currently minimal quarantine system.

The analysis below makes no attempt to be comprehensive, but only to highlight a range of taxonomic groups and pathways posing obvious threats, with emphasis on potential vertebrate invaders, especially snakes. Our aim is to present a range of examples in sufficient detail to illus-

trate the scope of the problem and to highlight the urgency of finding solutions. Although most examples are for Hawai'i, since that is the island group with which we are most familiar, conclusions largely apply to other Pacific islands. The analysis includes suspected modes of entry, potential threats, and examples of high-risk species not yet known to be established.

VERTEBRATES

Nearly all alien vertebrate species in Hawai'i are pests in some situations, although some also have economic benefits (Stone 1985). The mammals are the best known and provide the best examples of the dilemma created by alien species introductions; this is especially clear with the ungulates. Ungulates have been the most destructive group for native ecosystems but are among the most important groups economically (Cuddihy and Stone 1990). Other herbivorous and frugivorous vertebrates are often important threats to native species and are pests of agriculture as well. The insectivorous and carnivorous species are potentially extremely detrimental to native birds and other animals.

Vertebrates as a group are particularly destructive because of their relatively large size (which gives them more food and water reserves and consequently wider environmental tolerances than smaller animals). They are also often generalist feeders, more mobile, and thus more effective competitors than most invertebrates. On the other hand, an observational bias makes it easier for humans to recognize impacts from vertebrates, especially for the larger species. A few terrestrial vertebrates (especially the smaller ground and den-inhabiting species) can disperse as stowaways in cargo and aircraft, and aquatic species may arrive in ballast. However, by far the most important avenue of dispersal of vertebrates into Hawai'i has been purposeful introductions for economic, recreational, or cultural purposes, often by persons or groups unfamiliar with the potential negative consequences of such introductions.

SNAKES

Hawai'i and virtually all other oceanic Pacific islands lack native terrestrial snakes (Loveridge 1945, Allison 1996). Consequently, the native birds lack adaptive behaviors to deal with these predators. The apparently inadvertent introduction after World War II of the brown tree snake (*Boiga irregularis*) into Guam well illustrates the effects alien snakes may have on native island ecosystems. Within 40 years of introduction, the brown tree snake had attained peak densities of 100/ha, had exterminated nine of Guam's 12 native forest birds and approximately half the native lizard fauna, and had left the three surviving forest bird species and remaining fruit bat highly endangered (Savidge 1987a; Wiles 1987a, 1987b; Rodda and Fritts 1992, Rodda et al. 1998). Huge reductions have also been observed in the populations of introduced birds, mammals, and lizards on Guam (Savidge 1987a, Rodda et al. 1998). The loss of the avifauna has had unknown affects on the native forest ecosystem, but loss of pollinators and fruit dispersers are likely to have important repercussions over several decades (Savidge 1987b). For example, there has been a dramatic bloom in spider populations coincident with the loss of the insectivorous avifauna (Rodda et al. 1998).

It is sometimes claimed or implied that the brown tree snake is somehow unique in its ability to wreak ecological devastation on island communities and that other snake species would not present similar problems (e.g., McKeown 1996:144–145). But this argument derives from ignorance of snake ecology and the fact that the brown tree snake invasion of Guam is the only snake invasion to be well studied to date. In fact, several snake species have invaded other islands (or, in the case of peninsular Florida, areas ecologically similar to islands), and damage to native biotas has been documented or inferred in some instances. Additional snake invasions include the wolf snake *Lycodon aulicus* on Reunion and Mauritius in the 1800s (Cheke 1987), on Christmas Island in the 1980s (Fritts 1993), and perhaps throughout the Philippines and western Indonesia in the past few centuries (Leviton 1965); *Elaphe guttata* (corn snake) on Grand Cayman Island (Schwartz and Henderson 1991); *E. taeniura* (striped racer), *Protobothrops elegans,* and cobras (of an unspecified species) on Okinawa (Rodda et al. 1997, Ota 1998); *Natrix maura* (viperine watersnake) on Mallorca (Corbett 1989); *Boa constrictor* in Florida and Cozumel (Dalrymple 1994, Butterfield et al. 1997; T. Fritts, pers. comm.); and possibly *Acrochordus* in southern Florida (P. Moler, pers. comm.). Especially successful has been the spread of the parthenogenic (lacking a requirement for fertilization) blind snake *Ramphotyphlops braminus* throughout the tropics over the past century, primarily as a stowaway in potting soil associated with horticultural shipments. The invasion of *Lycodon* on Reunion is thought to have resulted in the near extinction of a native lizard (Cheke 1987). An endemic frog, *Alytes muletensis,* is endangered on Mallorca, apparently because of the introduction there of *Natrix maura* (Corbett 1989). The recent introduction of *B. constrictor* to Cozumel is expected to pose a serious threat to the survival of nesting seabirds and several endemic birds and mammals

(T. Fritts, pers. comm.). But most snake invasions remain poorly studied, and their ecological consequences remain largely undocumented.

There is every reason, however, to be concerned with snake invasions more generally; the brown tree snake may be only the vanguard of a potentially great ecological problem. There is nothing especially remarkable about the ecology of the brown tree snake. Its clutch size of 4–12 (mean = 8) eggs (Shine 1991, Rodda et al. 1998) is unexceptional and lower than that of many snakes (Fitch 1985, Seigel and Ford 1987, Shine and Seigel 1996). The brown tree snake apparently produces at most a single clutch per year in its native range (Shine 1991) but may produce two per year in Guam (Rodda et al. 1998); hence, its intrinsic rate of increase is probably fairly low. It is not adapted to extremes of either temperature or humidity, judging from its natural geographic, elevational, and ecological range (McCoy 1980, Cogger 1992, O'Shea 1996, Rodda et al. 1998). The most noteworthy features of the ecology of the species are its catholic diet of vertebrates (Savidge 1988, Greene 1989, Campbell 1996); its arboreal proclivities, which allow it greater access to forest birds than most snakes would have; and its nocturnal habits. But these features are by no means unique to brown tree snakes: many snakes are general vertebrate predators, many are arboreal, and many are nocturnal, especially in the tropics and subtropics. Many arboreal snakes specialize on birds or feed on them opportunistically and could be expected to devastate Pacific avifaunas if they were to become established. Lastly, any snakes to become established on oceanic islands would be in environments largely free of predators and disease organisms, as is the brown tree snake in Guam (the widely touted, terrestrial and diurnal mongoose would have no affect on nocturnal or arboreal snakes, nor on pit vipers, whose strike is faster than the mongoose). Hence, introduced snakes on most oceanic islands could be expected to lack significant predators or other sources of premature mortality. A reasonable estimate is that several hundred of the world's approximately 3,000 snake species could prove damaging to island avifaunas previously unexposed to snakes, although the major effects of many of these would be primarily on ground-dwelling birds. Several potentially invasive snake species are dangerously venomous and could be expected to have negative consequences for humans too.

Snakes are likely to be introduced to islands in two ways. The first is by hitchhiking in cargo or on vessels used for transportation. This is how the brown tree snake is thought to have arrived on Guam (and other islands) and how *Lycodon* and *Ramphotyphlops* have moved around the Indo-Pacific region. The second is by deliberate introduction as pets followed by escape or intentional release. Most of the free-roaming snakes captured in Hawai'i each year are clearly in the latter category (based on examination of Hawaii Department of Agriculture records), as are the foreign snakes established or commonly seen in Florida (Dalrymple 1994; P. Moler, pers. comm.).

The number of snake species that would prove adept at hitchhiking is unknown but probably fairly small. Secretive and nocturnal species having high densities and with facultative (Schuett et al. 1997) or obligate (McDowell 1974, Nussbaum 1980) parthenogenesis are likely to make the most successful hitchhikers. While the group of snakes meeting these specifications is relatively small, it has nevertheless furnished the most accomplished invasive snake agents of ecological destruction so far.

In Hawai'i, the past three decades have seen a dramatic increase in the rate of pet reptile introduction, release, and establishment. Given the burgeoning number of species bred and available within the mainland pet trade, Hawai'i and other Pacific islands remain highly vulnerable to further introductions. Many snake species introduced for the purpose of furnishing pets may well prove just as great a threat to native avifaunas as has the brown tree snake, judging from their ecological attributes. Among the commonly kept species, boas, pythons, rat snakes (*Elaphe*), bullsnakes (*Pituophis*), and most pit vipers (Crotalinae) specialize on endothermic prey, and many of the rat snakes and pit vipers have an ontogenetic switch from ectothermic to endothermic prey. King snakes (*Lampropeltis*) are vertebrate generalists. Many boas, pythons, pit vipers, and rat snakes are arboreal and feed primarily, or to a large extent, on avian prey. All these taxa have clutch sizes of the same magnitude as brown tree snakes or, in the case of the commonly kept *Boa, Eunectes* (anaconda), and *Python* species, are much larger (30–>100; Fitch 1985, Stafford 1986, Seigel and Ford 1987). Several of these species can potentially produce two or more clutches per year when food is freely available (Tryon and Murphy 1982, Tryon 1984), as it is in Hawai'i, where the environment is artificially enriched with an abundance of alien rodents, lizards, and birds. Furthermore, some species are suspected to be facultatively parthenogenic (Schuett et al. 1997), an attribute whose significance for colonizing oceanic islands should be obvious. Most of these species are nocturnal. The only ecological parameter for which some of these common pet species cannot match brown tree snakes is ele-

vational range. In its native New Guinea, brown tree snakes can live at elevations from sea level to 1,400 m (O'Shea 1996). Most commonly kept pythons and boas probably cannot live at such high altitudes, although many *Elaphe, Lampropeltis, Pituophis,* and pit vipers would have no trouble doing so, judging from their native latitudinal and elevational ranges. The significance of these considerations for Hawai'i, and perhaps other islands, is that most of the snakes captured and identified in Hawai'i are in the genera *Boa, Python, Elaphe,* and *Pituophis.* That these snakes have not elicited the same level of concern in Hawai'i that brown tree snakes have is remarkable and probably attributable to the general ignorance about snakes and their biology that prevails at any location in which they are naturally absent.

Other Reptiles

A host of other alien reptile species could also be expected to have negative consequences for native Pacific avifaunas, though they perhaps may not be as damaging as snakes. A handful of large aquatic turtles are noteworthy for their predation upon waterbird chicks (Ernst et al. 1994). Included in this group are several softshelled turtles (Trionychidae), of which two species have been introduced to Hawai'i (McKeown 1996), and other turtles such as the snapping turtle (*Chelydra serpentina*) that have been established elsewhere (McCoid 1995). Several monitor lizards (*Varanus*) grow to large sizes, feed to some extent on birds, and are adept at climbing trees (Daniel 1983, Green and King 1993). These could be expected to have negative consequences for at least some native birds. Reports of wild monitor lizards occur occasionally in Hawai'i and frequently in Florida (Dalrymple 1994).

Of potentially significant impact is the introduction of arboreal insectivorous lizards because these species can often reach high population densities and may seriously impact the food resources of native insectivorous birds. Especially problematic in this regard is Jackson's chameleon (*Chamaeleo jacksoni*), which provides an illustrative case history of illegal alien vertebrate establishment in Hawai'i and ineffectual management response to the threat. The Jackson's chameleon became popular in the international pet trade in the 1970s. Some reached O'ahu legally in 1972 under a pet store import permit. These were illegally released in the importer's Kāne'ohe backyard (McKeown 1996), subsequently became free-ranging, and served as the source for a rapidly expanding distribution and trade. The species spread throughout O'ahu during the 1970s and 1980s, reached Maui by the early 1980s, and is now found on most or all of the main islands. In an effort to curb the spread of the species, Hawaii Department of Agriculture prohibited the keeping of Jackson's chameleons in the state until 1994, when the regulation was rescinded because of its ineffectiveness. However, during this same time, sale and export were allowed, providing an economic incentive for people to move the lizards around surreptitiously to begin new populations that could serve as a source of saleable animals. Consequently, the spread of the species to other islands and to new localities within islands was rapid, despite its illegality.

Jackson's chameleon is native to cloud forest (1,800–2,400 m) in Kenya, where temperatures range from 25° C during the day to 10° C at night (McKeown 1996). It forms dense populations at lower elevations (400–1,100 m) in Hawai'i and can be expected to invade forested upland habitats, perhaps as high as the upper tree line. There was an unconfirmed sighting of an individual at Hosmer Grove (elev. 1,830 m) of Haleakalā National Park, Maui, in June 1994. In 1996, Haleakalā Chief Ranger K. Ardoin found one crossing the road at 1,800 m elevation in ranchland just below the park boundary.

In addition to being a voracious and efficient predator of arthropods, Jackson's chameleon attains sufficiently large size that there is concern about its potential ability to take native forest bird nestlings as prey items, although this concern has yet to be scientifically investigated. Other chameleons attain a larger size, are known to eat nestling birds (Schmidt and Inger 1957; C. Raxworthy, pers. comm.), and are available in the pet trade.

Another concern is that any introduced lizard species could serve as an additional food source for many species of introduced snakes, thereby serving to keep introduced snake populations at an artificially high level and thus maintaining a high predation pressure on native birds. This is one means by which brown tree snakes have maintained phenomenally high population densities on Guam, even after the extirpation of most native birds (Campbell 1996, Rodda et al. 1997). The high densities of alien geckos and skinks in Hawai'i suggest a similar scenario could obtain there should snakes become established.

Amphibians

Frogs represent another under appreciated potential threat to native Pacific avifaunas. Bullfrogs (*Rana catesbeiana*), already introduced to Hawai'i, attain a large size and will consume anything they can cram into their mouths, including all classes of vertebrates (Bury and

Whelan 1984). In the western United States, where this species has also been introduced, it has been observed to eat adult passerines, snakes, frogs, fish, and bats, and is partly responsible for the endangered status of one snake and several frogs (Rosen and Schwalbe 1995). It is reasonable to expect bullfrogs to exert some predation pressure on waterbird chicks where they co-occur.

A more insidious threat may be posed by a variety of arboreal tropical frogs, loosely termed "treefrogs" but representing a diverse array of taxonomically unrelated species. It is reported that the Cuban hylid *Osteopilus septentrionalis* is established on O'ahu (McKeown 1996). In 1997, two species of leptodactylids were reported for the first time in the Hawaiian Islands: *Eleutherodactylus coqui* and *E. planirostris* (Kraus et al. 1999). The first is arboreal and has a loud, piercing call; the latter is terrestrial with a quieter chirp. Both species originated in the Caribbean and are associated in Hawai'i, as elsewhere (Conant and Collins 1991, Kaiser 1992, Dalrymple 1994), with greenhouses and nurseries. Both species are currently spreading from nurseries to surrounding areas and are also being transported and established by landscaping of resorts and residential areas with plants from infected nurseries. These species are easily spread in plants and associated soil because eggs are hidden in these areas and directly develop into small froglets, bypassing a tadpole stage and, hence, any need for standing water. *E. coqui* occurs to elevations of 1,200 m in its native ranges (Schwartz and Henderson 1991), has already established at higher elevations in Hawai'i, and, hence, has potential to invade upland rain forest in Hawai'i.

Both species of established Hawaiian *Eleutherodactylus* and many other species of hylid, leptodactylid, and rhacophorid "treefrogs" form high-standing biomass and can be expected to exert a significant impact on native insect faunas and, indirectly, on the insectivorous birds dependent upon them (Kraus et al. 1999). Because they will have few or no predators in the Pacific, such species may serve as energy sinks, producing large quantities of biomass that do not get transferred to higher trophic levels and, consequently, may exert ecosystem-level changes as well (Dalrymple 1994).

Again it needs to be emphasized that unsupported claims that only a single species of treefrog "has the capacity to do great harm to island ecosystems" (McKeown 1996:20) and that other alien species would be beneficial if introduced to Hawai'i are simply statements of faith combined with a studious disregard for general ecological principles. It is usually impossible to comprehend fully the potential ecological impacts of a species before it is introduced. However, an invasion is unlikely to benefit most native species because all species engage in a web of interactions with a large host of other species. The nonlinear nature of many of these interactions makes complete prediction of a species' effects inherently difficult, but breaking established webs or creating energy sinks (e.g., amphibians discussed above) will inevitably be detrimental to some native species. Consequently, blanket claims that particular aliens are "kama'āina" (native-born) species or "harmless" or "helpful" (e.g., throughout McKeown 1996) can clearly be seen to be unscientific statements deriving from a different agenda than the impartial description of reality. Dissemination of such complacent ignorance of and unconcern for the native biota is perhaps the greatest long-term threat to the Pacific avifauna.

Birds

Alien birds threaten native birds directly through competition and transmission of diseases and parasites, and indirectly through aiding habitat conversion and ecosystem alteration by dispersal of seeds of alien plants (Stone and Loope 1987). Over 150 species of alien birds have been introduced to the Hawaiian Islands (Hawaii Audubon Society 1989), but only 54 have successfully established breeding populations (Pyle 1997).

In contrast to Florida (James 1997), opportunities for alien bird stowaways and "natural" colonizations of Pacific islands are highly limited. In Hawai'i, all successfully established alien bird species were deliberately brought to the islands for some purpose. Therefore, limiting introductions has mainly relied on regulating trade in live birds. If this trend continues, future introductions of alien birds are likely to be derived from four main groups: waterfowl, galliforms (chickenlike birds), psittacids (parrotlike birds), and passerines (perching birds), especially finches. Birds are also increasingly smuggled as eggs, which means that almost any species might be introduced in the future.

Escaped Mallards (*Anas platyrhynchos*) threaten the endangered Hawaiian Duck or Koloa (*A. wyvilliana*) ecologically and genetically through hybridization (USFWS 1985, Rhymer *this volume*). Apart from Mallards and Cattle Egrets (*Bubulcus ibis*), all populations of alien waterfowl have been ephemeral (Berger 1981). New wild populations derived from collections belonging to resorts or private individuals are likely, but their long-term establishment is less likely, because Hawai'i has relatively few wet-

lands and the largest of these are managed for native wildlife by government agencies.

All wild populations of galliforms in Hawai'i (12 species) have been authorized releases. Such releases still take place, but now for the purpose of providing birds to shoot rather than to establish new populations. This unmonitored practice appears to involve mainly the Ring-necked Pheasant (*Phasianus colchicus*) and Wild Turkey (*Meleagris gallopavo*), but the practice has the potential for escalating. The small trade in "ornamental" galliforms (tropical pheasants, etc.) could be a latent source of new introductions.

Over the history of releases in Hawai'i, there has occurred an important shift in the taxa released. Besides establishing the Mallard and many galliforms, early acclimatization projects and escapes successfully introduced the Cattle Egret, Chestnut-bellied Sandgrouse (*Pterocles exustus*), Barn Owl (*Tyto alba*), Guam Swiftlet (*Aerodramus bartschi*), 13 species of insectivorous and frugivorous passerines, and 19 species of finches (Pyle 1997). The egret, owl, and swiftlet were government releases for biological control.

Since 1970, all new introductions have been unauthorized and have included parrots and finches. This shift has resulted from a tightening of restrictions imposed on importers by the state of Hawai'i and by changes in federal laws regarding importation and quarantine of birds into the country, particularly by the Wild Bird Conservation Act of 1992. Importers prefer seed-eating birds that can survive the long wait through quarantine rather than the more delicate insectivores and frugivores with their difficult diets; however, other passerines continue to appear occasionally in Honolulu pet stores.

Hundreds of species of parrots and other psittacids are available through the pet trade, and their availability is increasing as new populations are established in captivity. Fortunately, members of the most potentially damaging group, the lories and lorikeets, are prohibited from legal importation into Hawai'i, yet in the past small colonies have been illegally held by private breeders. Many species of these aggressive nectar feeders would thrive in high-elevation rain forests and compete for food with endangered Hawaiian honeycreepers.

Unfortunately, there is little or no accountability for releases of parrots. Three species have established breeding populations, and others are trying. The world's most successfully invasive parrot, the Rose-ring Parakeet (*Psittacula krameri*) now inhabits Kaua'i, O'ahu, Maui, and Hawai'i, though no population estimates exist (Hawaii Audubon Society 1993). From three birds, an O'ahu population of Red-crowned Amazons (*Amazona viridigenalis*) grew to more than 30 individuals by the late 1980s (T. K. Pratt, pers. obs.). While there are no recent estimates for this parrot, a flock of 40 was seen in 1998 (E. VanderWerf, pers. comm.), suggesting a slow rate of increase. Rapidly growing colonies of Mitred Conure (*Aratinga mitrata* and, possibly, related species) appeared on O'ahu, Maui, and Hawai'i in the 1990s (T. K. Pratt and L. L. Loope, pers. obs.). The Maui, and perhaps the Hawai'i, population of conures stem from deliberate releases. The population in the Huelo area of Maui is expanding, and now numbers at least 80 (F. Duvall, pers. comm.). This species may well become numerous, being adapted in its original range to open and disturbed habitats. We expect escapes and releases of parrots to increase as the number of parrots bred in captivity exceeds the demand for these long-lived birds as pets.

Parrot invasions would seem to pose a threat of additional diseases to Pacific birds. Certainly, agricultural and ecological problems caused by parrots are well-known. Viewed by farmers as little more than winged rodents, parrots damage seed and fruit crops. In Hawai'i, parrots have depredated crops of corn, mangos, and lichee; permits have been issued for their control (T. K. Pratt, pers. obs.). A very serious concern is the potential ecological role of parrots as seed predators and herbivores of native trees. Sulfur-crested Cockatoos (*Cacatua galerita*) introduced to Palau depredate native palms. Cockatoos "fed heavily on the heart of two species of endemic palms, and large stands of these trees have been destroyed" (Engbring 1992:32). The native Hawaiian flora includes many trees and shrubs with large seeds potentially vulnerable to predation by parrots. The role of parrots in the spread of alien plants is unclear. Research is needed to determine which seeds are digested and which are viable after passage. Seeds that pass undigested will be transported long distances by parrots.

Nineteen species of finches (Fringillidae and Passeridae) now swarm the gardens and grasslands of Hawai'i (Pyle 1997). Yet only the House Finch (*Carpodacus mexicanus*), Northern Cardinal (*Cardinalis cardinalis*), Yellow-faced Grassquit (*Tiaris olivacea*), Nutmeg Mannikin (*Lonchura punctulata*), and Common Waxbill (*Estrilda astrild*) reside in edges or gaps in native forests (Scott et al. 1986; T. K. Pratt, pers. obs.). Apart from the House Finch, which serves as a reservoir of avian poxvirus (Warner 1968, Docherty and Long 1986), introduced finches play an undetermined role in transmission of diseases.

Another important component of alien bird

species issues arises from past, successful introductions currently restricted to only one or a few islands but with potential for spread to other islands. Species raising concern include the insectivorous and frugivorous species, which have a potentially great effect on native birds through their ability to colonize native ecosystems and compete with endemic species.

The Red-vented Bulbul (*Pycnonotus cafer*) and Red-whiskered Bulbul (*P. jocosus*), among the worst of all possible avian alien seed dispersers, have been established on O'ahu since the 1960s (Long 1981) and threaten to spread to other islands. Red-vented Bulbuls discovered on both Maui (F. Duvall, pers. comm.) and Hawai'i (R. Bachman, pers. comm.) have been eliminated. The Red-vented Bulbul is a major disperser of the notoriously invasive tree *Miconia calvescens* in Tahiti (Meyer 1996). Continued exclusion of bulbuls from Hawaiian Islands besides O'ahu must continue to be a very high priority.

The Kalij Pheasant (*Lophura leucomelanos*), a forest pheasant native to Nepal and adjacent countries in central Asia (Long 1981) was legally introduced to Pu'u Wa'awa'a Ranch on the island of Hawai'i in 1962 (Lewin and Lewin 1984). It dispersed rapidly and by the late 1980s had reached the forests of Hawai'i Volcanoes National Park on the opposite side of the island, but it has not as yet spread to other islands. Every effort should be made to keep this disperser of alien plants (Lewin and Lewin 1984) off other islands.

Currently, the main source of new alien bird species is the pet trade. The list of birds permitted into the state should be reassessed to eliminate species with high risk of invasion. But even more important is the commitment to eliminate incipient wild populations and to hold owners of released or escaped birds responsible for the effort and cost of recovering free-flying birds.

Mammals

Mammals, especially ungulates, rats, and mongooses, have been and continue to be the single group of alien organisms in Hawai'i most damaging to native ecosystems. For jeopardizing survival of native birds, impact of mammals is challenged for primacy only by diseases and parasites. As with birds, most established mammals in Hawai'i have been intentionally introduced (Tomich 1986). The highly significant exceptions to date are the rats (*Rattus rattus, R. exulans, R. norvegicus*) and mice (*Mus domesticus*), which have successfully established as stowaways on most Pacific islands.

The greatest newly emergent mammalian threat for Hawai'i may be the European rabbit (*Oryctolagus cuniculus*). Rabbits have been liberated on at least 700 islands throughout the world. Devastation resulting from their establishment has been well documented in several areas, most notably Laysan, in the Northwest Hawaiian Chain, and Round Island, near Mauritius in the Indian Ocean (Atkinson 1989). The threat of rabbits to Hawai'i has been raised by the case of their incipient establishment and eradication (100 removed) in Haleakalā National Park on Maui in 1989–1991 (Loope et al. 1992). Hawai'i state statutes permit importation and possession of rabbits, but they specify that they must be kept in cages off the ground (to prevent tunneling). In practice, rabbits commonly escape, and no agency has been given the responsibility for preventing their establishment. Rabbits released in areas without free-ranging dogs (usually, but not necessarily, at high elevations) are likely to multiply and result in geometrically increasing, uncontrollable populations within one to two years; the Haleakalā population was detected after nine months and prompt action taken.

Aside from the usual array of domestic mammals, few other species are commonly kept in captivity in Hawai'i. Importation of mammals is tightly regulated, first by authorizing few species for import and second by a lengthy quarantine for rabies in state run facilities, at least for the carnivorous species. We see the rate of new mammalian introductions as much lower than that for other groups of vertebrates. Nineteen species of mammals are established in the wild in Hawai'i (Miller and Eldredge 1996). Most invading mammal species still occur on only a few islands, and none have reached their full potential distributional range within Hawai'i. Preventing their further spread and mitigating their damage would be worth the effort, as their effects on vulnerable native ecosystems and avifauna can be predicted from evidence of damage where they occur. Hawai'i and other Pacific islands should not relax vigilance, since new rodents and insectivores, such as the musk shrew (*Suncus murinus,* nonindigenous in the Mariana Islands), can arrive with increased shipping activity. Undetermined North American shrews have been found alive in shipments of Christmas trees to the islands. The Asian rat, *R. tanezumi,* which is virtually indistinguishable externally from *R. rattus,* is found in the Marianas (Musser and Carleton 1993) and on many other Pacific islands but has not yet been discovered in Hawai'i.

For deliberately imported mammals, we view monkeys as the most serious threat to Pacific ecosystems. *Macaca fascicularis,* transported to Mauritius in the seventeenth century, is among

the most destructive of alien mammals there, severely damaging native trees and epiphytes and dispersing alien plants (Strahm 1996). We note with alarm that three species of monkeys have become established in Florida (Layne 1997), including the squirrel monkey (*Saimiri sciureus*). A fenced colony of squirrel monkeys maintained by Pana'ewa Zoo in Hilo could potentially be freed by the next hurricane to strike the island of Hawai'i. Ferrets and other small wild carnivores, which are commonly kept as exotic pets (although illegally in Hawai'i; Tomich 1986), also represent serious threats to native birds if any become established.

INVERTEBRATES

Nearly 4,000 species of alien invertebrates have been recorded from Hawai'i (Miller and Eldredge 1996), but many species remain undiscovered, especially the smaller, cryptic ones. More than three-quarters of the established alien invertebrates in Hawai'i are arthropods, which are represented by over 2,500 insect species and over 500 other arthropods (Nishida 1994). Between 15 and 20 alien species of arthropods are added to the list each year (Beardsley 1979), and one or more become pestiferous. Most alien invertebrates arrived inadvertently through commerce, or associated with their purposely introduced hosts. Over one-fifth of the insects and a few other invertebrates were purposefully introduced for biological pest control.

For most of the recorded alien species of invertebrates little is known of their biology and even less of their impacts on native species. What is known indicates that some species can affect native ecosystems in profound ways (Howarth 1985a, Howarth and Ramsay 1991). Alien invertebrates have invaded virtually all ecosystems from the seacoast to the summits of the highest mountains, and probably few native species escape at least some feeding damage. Some change ecosystem processes; for example, earthworms change nutrient cycling in soils thus favoring invasion by alien species (Vitousek and Walker 1989). Over two-thirds of the 750 native land snails are extinct or endangered, and alien predators (particularly the purposefully introduced predatory snail *Euglandina rosea*) are believed to be the major culprits in their decline (Cowie et al. 1995). *Euglandina* has not yet reached its full potential range, and as it expands, it threatens additional populations.

Four phyla contain species that can potentially invade and directly affect the survival of landbirds in Hawai'i. Three of these (Platyhelminthes, Acanthocephala, and Nematoda) include parasitic worms capable of causing disease in birds. A few alien bird-infecting species are known from Hawai'i (references in Miller and Eldredge 1996), but many additional harmful species could be introduced with alien hosts brought in through the pet trade (Nilsson 1981).

The major groups of arthropods affecting native birds are the parasitic and blood-feeding species (including several mites, fleas, and flies) and the insectivorous species (especially wasps) that compete for avian food (Howarth 1985a; G.J. Brenner, pers. comm.). The parasitic and blood-feeding species affect birds not only by causing disease and worrying their hosts, but also by serving as vectors for avian diseases (van Riper 1991). Mosquitoes, especially *Culex quinquefasciatus,* are considered among the most severe current threats to Hawaiian landbirds because they are the vector for malaria, bird pox, and other diseases among wild bird populations (van Riper and van Riper 1985, Jarvi et al. *this volume,* Shehata et al. *this volume*). Only five blood-sucking mosquitoes are established in Hawai'i, but several hundred more could potentially invade if given the chance. Many of these are associated with leaf axils and could be imported with bromeliads, which are currently popular in horticulture. The Central American mosquito, *Wyeomyia mitchellii,* is believed to have arrived in this way in the 1980s.

Unlike many introduced vertebrates, most invertebrates are narrowly specialized to exploit particular environments; thus, to succeed, invading invertebrates generally must find a new environment that closely matches their requirements. Hawai'i, with its benign, perpetual spring-like climate and great range of elevation, temperature, and moisture regimes, could host a large percentage of the world's tropical, subtropical, and warm temperate invertebrates since they could find a suitable environment if given the opportunity. With increasing travel and world commerce, the pool of potential invaders is immense, and a thorough analysis of their potential threats daunting. Thus, we describe examples from just two arthropod groups to illustrate the scope of the problem in hopes of divining long-range solutions.

Ants (Hymenoptera: Formicidae)

Ants are notorious invaders and recognized as a cause of native species extinctions, both in Hawai'i and elsewhere (Cole et al. 1992, Gillespie and Reimer 1993, Hölldobler and Wilson 1994, Reimer 1994, Wilson 1996). Ironically, many of the same invasive ant species are also regarded as beneficial for their role as biocontrol agents (Way and Khoo 1992), and some species have been purposely introduced to new areas for biocontrol (Greenslade 1965, Way and Khoo 1992, Zenner de Polania and Wilches 1992). For ex-

ample, in the 1980s, a group of businessmen introduced the ant, *Paratrechina fulva,* into Colombia, South America, in an effort to control snakes at lumber mills. Subsequently, Zenner de Polania and Wilches (1992) reported that species richness decreased over 90% in areas invaded by the ant. Native ant species were especially affected, but other arthropods and some vertebrates also declined or completely disappeared from invaded areas.

There are no native ants known in Hawai'i. About 40 species of alien ants are established (Nishida 1994), and of those the 16 species with large, aggressive colonies are the most troublesome (Howarth 1985a, Reimer 1994). There are numerous other ant species that could invade new habitats or attack different prey if they became established in Hawai'i. Two examples are described: the fire ants, which are currently serious invaders of southern North America, and the weaver ants, which are dominant forest canopy predators in the Old World tropics and subtropics.

Fire ants

Two species of fire ants were inadvertently introduced from South America into southeastern United States: *Solenopsis richteri,* which arrived about 1918, and *S. invicta,* which arrived about 1940, and both have become problem invasive species (U.S. Congress 1993, Callcott and Collins 1996). *S. invicta,* especially, has been implicated in the extirpation of native species in areas where it has invaded. *Solenopsis* nests in the ground, usually in open habitats and open woodlands. If these warm temperate species established in Hawai'i, they probably would invade at least low- and mid-elevation dry forests and open country. Their upper elevation limit is unknown, but their subterranean nests are protected from most frosts.

Two species of fire ants already occur in Hawai'i and are widespread on all the main islands. The native North American fire ant, *S. geminata,* prefers to nest in loose soil and sandy areas, and in Hawai'i it remains confined to sandy coastal habitats and in dry leeward areas up to 300 m altitude, mostly in disturbed sites (Huddleston and Fluker 1968, Reimer 1994). *S. papuana* prefers wetter habitats and forests, nesting under rocks or wood on the ground in wet to mesic forests between 300 and 1,100 m. Its large polygyne (multiple-queen) colonies may contain over 1,000 workers (Reimer 1994).

Fire ants are voracious predators of small animals, feeding the protein to their larvae. Few native invertebrates would escape their depredations. Naive ground-nesting birds would be especially vulnerable, if the ants can survive near the bird colonies. Adult ants also feed on sweets such as nectar and honeydew. Thus, they could disrupt reproduction and survival of native plants and favor invasions of certain alien plants and honeydew-producing insects. Many plant and animal extinctions would be expected to occur in invaded habitats.

A colony of *S. invicta* was intercepted in Honolulu in a package from Texas in 1991 (CGAPS 1996). As the species expands its range in North America, it will have greater opportunity to be transported to Hawai'i. *S. invicta* reproduces in two ways: individual fertile queens establishing new colonies, and polygyne colonies dividing and part of the colony walking to a new nest site (Shoemaker and Ross 1996). Polygyne colonies pose a greater invasive threat and are more likely to establish if transported, but they are also far less likely to disperse long distances, although they might be transported to Hawai'i in a containerized shipment or in soil on earth-moving or construction equipment. Fertile females, on the other hand, could become stowaways in planes, cargo, and containers.

Weaver ants

The Asian arboreal weaver ant (*Oecophylla smaragdina* [Fab.]) is widely distributed from Asia to Australia, where it occupies a wide range of forest habitats from savanna and monsoon dry forests to more mesic habitats and rain forests (Hölldobler and Wilson 1994). A closely related species lives in Africa. Weaver ants use their larvae as spindles to weave nests in the canopy, and their ability to select an optimal environment within the canopy for their nests gives the group a wide tolerance for different forest types. Given the Asian weaver ant's known distribution and preferred environments, it would be able to invade all forested habitats in Hawai'i except perhaps the wettest and coldest rain forests.

The ant is a voracious arboreal predator, which can exclude all sensitive animals from its nest tree as well as closely neighboring trees. Colonies can contain 500,000 or more workers and can control a territory of a dozen or more large trees (Hölldobler and Wilson 1994). They control the entire tree surface from the ground up and kill virtually all animals found within their territory (Hölldobler and Wilson 1994). Native forest birds would be naive to such a competitor and probably would be unable to nest or forage near an active ant nest. Both native invertebrates and several native forest bird species, as well as the endangered tree-roosting native bat, would be severely affected, and the extinction of many currently listed species as well as many currently nonendangered species would

be expected if this species established in Hawai'i.

The Asian weaver ant is often considered beneficial by farmers, who have lionized the ants and introduced them to their orchards for pest control for centuries (Way and Khoo 1992). The species has been introduced to south Pacific islands for biocontrol of palm pests (Greenslade 1965). However, its effects on either the intended target or potential nontargets have not been recorded. It could be introduced into Hawai'i illegally by well-intentioned gardeners returning from Asia. Less likely is the possibility that fertile queens could arrive as stowaways in aircraft or in shipments of cut flowers or other plant material.

The weaver ant's exceptionally complex behavior makes them popular research animals. The related African species is established in entomological laboratories in the continental United States (Hölldobler and Wilson 1994) and could be moved to Hawai'i. Hölldobler and Wilson (1994) describe a method to transport small colonies within hand luggage on aircraft.

Biting Midges (Diptera: Ceratopogonidae: *Culicoides*)

Biting midges in the genus *Culicoides* are important veterinary and public health pests in most areas of the world (Linley and Davies 1971). There are over 1,000 valid species, and many more still to be discovered and described (Borkent and Wirth 1997). Over 175 species are known from Japan and Southeast Asia (Arnaud 1956, Wirth and Hubert 1989), and about 135 from North America (Wirth 1965). The biology of most species remain unknown. The larvae are scavengers or predators on tiny invertebrates in semi-aquatic and aquatic habitats; larval substrates include damp rotting plant material, animal dung, mud, and soil in tree holes, leaf axils compost heaps, rotting vegetation, margins of water bodies, and a variety of aquatic habitats (Jamnback 1965, Howarth 1985b). Each species prefers particular larval habitats, and in concert most potential larval substrates are exploited.

Adult females of many species are specialized to suck vertebrate blood: some generalists, some attacking birds, others small or large mammals, reptiles, amphibians, or even larger arthropods (Jamnback 1965, Wirth and Hubert 1989). They are important transmitters of diseases, including blood protozoans (especially the primitive bird malarias), filarial worms, viruses, and other parasites among birds (Kettle 1965, Wirth and Hubert 1989). In addition, they also would increase the spread of mechanically transmitted diseases of birds (e.g., avian pox). Adult females of most species are readily dispersed by wind (Linley and Davies 1971) and attracted to lights at night (Howarth 1985b); thus they could become stowaways on aircraft departing infested areas at night. Leaf axil breeding species could be introduced in bromeliads and other plant material. *Culicoides* are very small; most adults are less than 2 mm long. Unless the species bit humans (which many do) or otherwise became conspicuous, their impact on endangered birds would go unnoticed until too late. To illustrate the potential impacts of these alien species in Hawai'i, the potential threats posed by two species will be described: *C. arakawae* and *C. obsoletus.*

Culicoides arakawae

C. arakawae is widespread in Asia from Japan south to the Indonesian islands and west to India (Arnaud 1956, Wirth and Hubert 1989). The species does well in both tropical and temperate climates, but whether its range results from different strains is unknown. Arnaud (1956) reported it to be the most abundant and widely distributed *Culicoides* in Japan. It breeds in mud and soil at water margins, especially where polluted, such as animal wallows, ditches, flumes, streams, and pools (Kitaoka and Morii 1963, Howarth 1985b). Near Tokyo (35°–36° N), the species has two to three generations per year with a minimum life cycle of 30 days (Kitaoka and Morii 1963). The species probably can breed continuously in the tropics; adults were collected in most months of the year in Laos (Howarth 1985b).

The adults readily attack birds and sometimes mammals (Arnaud 1956), and the species is considered to be the most important vector of the bird protozoan parasite *Leucocytozoon caulleryi,* a serious disease of poultry in east Asia (Kitaoka 1978), and fowl poxvirus (Fukuda et al. 1979). Fowl pox is already recognized as a severe disease among Hawaiian endangered birds (van Riper and van Riper 1985); thus the establishment of an efficient new vector would pose a significant new risk. Adult *C. arakawae* are readily attracted to lights (Arnaud 1956) and are easily transported on the wind; they are, therefore, potential stowaways on aircraft departing from infested areas at night.

Female *C. arakawae* disembarking in Hawai'i would find abundant ideal breeding habitats in the immediate area surrounding most island airports. For example at Kahului, Maui, Kanahā Pond and the irrigation ditches and pools in and near neighboring cane fields would be ideal. From these lowland habitats the species could easily disperse on the wind to rain forest habitats on both east and west Maui. The endangered waterfowl at Kanahā Pond and other wetlands could be severely impacted both from exsangui-

nation and from exposure to new diseases. Breeding habitats may be more limited in the upland rain forests, except for pig wallows and some natural pool margins; however, the species might adapt over time to breed in the constantly moist soil in the wet forests of Hawai'i. If it did become abundant, it could cause the declines of several native forest birds.

Culicoides obsoletus

C. obsoletus is one of the most widespread species of biting midges, occurring in North Africa, Eurasia, and North America (Jamnback 1965). It is recorded from both South Korea and Japan, where it is widespread on Honshu and Hokkaidō (Arnaud 1956). In North America *C. obsoletus* is found from southern Canada to North Carolina and Tennessee in the east and from British Columbia and Alberta to northern California in the west (Jamnback 1965). It is a serious pest of humans and animals on Hokkaidō (Arnaud 1956) and in North America (Jamnback 1965). There are two generations a year (Kitaoka and Morii 1963).

The wide range of larval breeding habitats indicates that the species could become invasive in Hawai'i. Suitable breeding habitats include stream and pond margins and irrigation ditches in the lowlands, as well as moist forest floor in rain forests. If overwintering larvae diapause, they would not be successful in lowland habitats, except as continual re-invaders from upland sites, but this species would probably survive very well in cool upland forests where the major populations of endangered forest birds survive. Emerging females do not require a blood meal to develop their first clutch of eggs, making establishment of colonizers more likely but perhaps decreasing their role in disease transmission. In suitable habitats, they can become incredibly abundant, severely worrying their hosts. Like *C. arakawae,* adult *C. obsoletus* are readily attracted to lights and are potential stowaways on aircraft. Additionally, immatures of this and other problematic species could be inadvertently imported on sphagnum or other moist materials used to pack shipments of living organisms and cut flowers.

In summary, the prospect is grim for future invertebrate introductions unless we can learn how to prevent them and are given the political support (including adequate funding for quarantine) to apply what we have learned. The examples above give only the merest glimpse of the thousands or tens of thousands of potentially damaging species with potential to reach Pacific islands.

PLANTS

Invasions by alien plants can alter the population dynamics and community structure of native species and change the large-scale functioning of native ecosystems (Vitousek 1992). The prevention of recruitment of native plant species by invasive alien plant species is often the mechanism of long-term conversion of ecosystem structure and function (Macdonald et al. 1989). Alien plant invasion in Hawai'i frequently alters ecosystems, jeopardizing and eventually eliminating habitat for most native birds (e.g., Scott et al. 1986, Cuddihy and Stone 1990, Stone et al. 1992). For example, invasion of the vine banana poka (*Passiflora mollissima*) reaches elevations as high as 1,500 m and smothers koa and 'ōhi'a forest, killing mature trees and preventing recruitment, and degrading habitat for native birds (Warshauer et al. 1983, Jacobi and Scott 1985). Shrubs and trees such as clidemia (*Clidemia hirta*), strawberry guava (*Psidium cattleianum*), kāhili ginger (*Hedychium gardnerianum*), firetree (*Myrica faya*), Australian tree fern (*Cyathea cooperi*), and miconia (*Miconia calvescens*) can potentially reach similarly high elevations, alter ecosystems, and degrade bird habitat. At Kanahā and Keālia ponds on Maui, dense thickets of fleabane (*Pluchea indica*) convert extensive areas of habitat for Hawaiian Stilts (Ae'o; *Himantopus mexicanus knudseni*) and Hawaiian Coots ('Alae ke'oke'o; *Fulica alai*) to nonhabitat. In Tahiti, 40–50 species of the 107 plant species endemic to the island are believed to be on the verge of extinction primarily because of invasion of miconia (Meyer and Florence 1997). Effects on bird habitat in Tahiti remain unanalyzed.

Alien plant invasions of Hawai'i and Pacific islands already pose an acute problem in preservation of ecosystems and bird habitat. Much effort is expended in Hawai'i and elsewhere on weed control. Managers of natural areas and agencies are struggling to address immediate problems through manual, chemical, and biological control of invasive alien plants. However, most weed control programs get underway only after an alien species is an obvious problem. Managers and agencies normally have their resources directed at dealing with the major weed problems that are already highly conspicuous.

There is a concurrent urgent need for dealing with incipient and future plant invasions which is only beginning to be addressed. Whereas approximately 100 plant species are currently recognized as serious invaders of native ecosystems in Hawai'i (Smith 1985, Stone et al. 1992), over 8,000 plant species had been introduced to Hawai'i by the late 1980s (Yee and Gagne 1992),

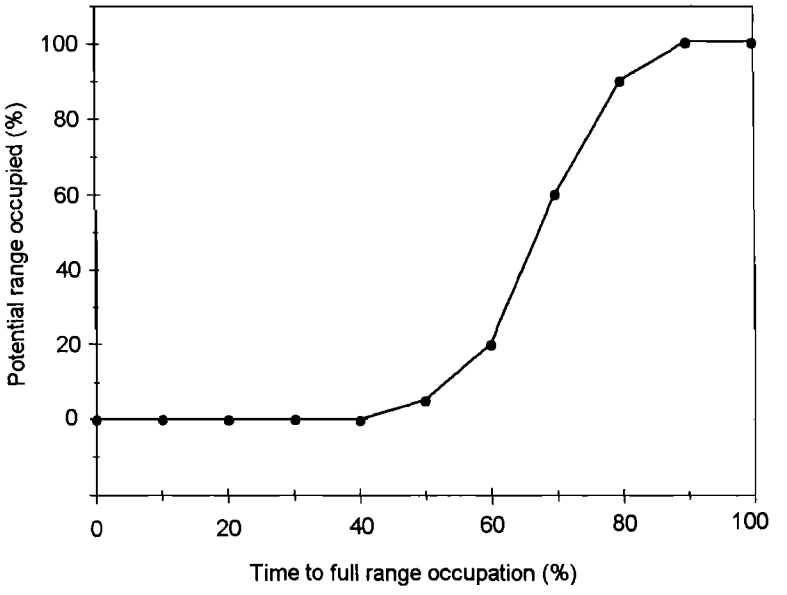

FIGURE 1. Stylized representation of the spread of an invasive plant species over time (Hobbs and Humphries 1995).

and at least 861 had been recognized as exhibiting reproduction in the wild (Wagner et al. 1990a,b). An ongoing up-to-date analysis of plant introductions in Hawai'i places the number at over 13,000 (G. Staples, Bishop Museum, pers. comm.), or roughly 3–4% of the world's known vascular plant species. A substantial number of the world's most invasive plant species are already present in Hawai'i but not yet widely perceived to exhibit alarming invasiveness. Examples include *Arundo donax* (giant reed), *Cinchona pubescens* (quinine), *Cryptostegia grandiflora* (rubber vine), *Hiptage benghalensis, Ligustrum* spp. (privet), *Lonicera japonica* (Japanese honeysuckle), *Pittosporum undulatum,* and *Thunbergia grandiflora.* Some of these were not included in the 861 species regarded as naturalized by Wagner et al. (1990a,b), and others were included as "sparingly naturalized." Most of them are probably in a so-called "lag phase" (see below).

Furthermore, whereas there is currently government scrutiny of proposed legal introductions of animal species in Hawai'i and many other Pacific islands, there is still almost no government-sponsored effort to prevent the potentially invasive plant species which have not yet reached the shores from being introduced. The phasing out of sugar cane and pineapple in Hawai'i is contributing to a quest for agricultural diversification and experimentation. And with increasing travel combined with botanical curiosity and industry, the number of possible future experiments in invasive potential becomes enormous. One proponent of enriching Hawai'i's flora with more introductions recently wrote (Bezona 1996), "After visiting Ecuador, I realize we have barely tapped the potential for new plant materials, including bamboo in Hawai'i." A recent effort in Hawai'i at developing defoliator-resistant, nitrogen-fixing trees which can aggressively invade degraded lands of the tropics has hybridized 22 species in the genus *Leucaena* on O'ahu (Brewbaker and Sorensson 1994), creating a source for a new wave of invasion in the Pacific by that genus.

A large amount of literature on alien plant biology, impacts, and management exists in Hawai'i (e.g., Smith 1985, Stone et al. 1992) and worldwide (e.g., Cronk and Fuller 1995, Hobbs and Humphries 1995). Experience in Hawai'i and elsewhere suggests that plant species which have proved invasive when introduced to one part of the world are highly likely to be invasive when introduced to similar habitats elsewhere (Cronk and Fuller 1995, Loope and Stone 1996, Reichard and Hamilton 1997). However, there is often a "lag phase," in which a newly introduced potentially invasive species is slow in spreading and therefore easily controllable (Figs. 1, 2).

Recognizing (1) the desirability of early detection and local eradication of such species (as advocated by Hobbs and Humphries 1995, Westbrooks and Eplee 1996, Loope and Stone 1996), and (2) the increasing danger of arrival of ad-

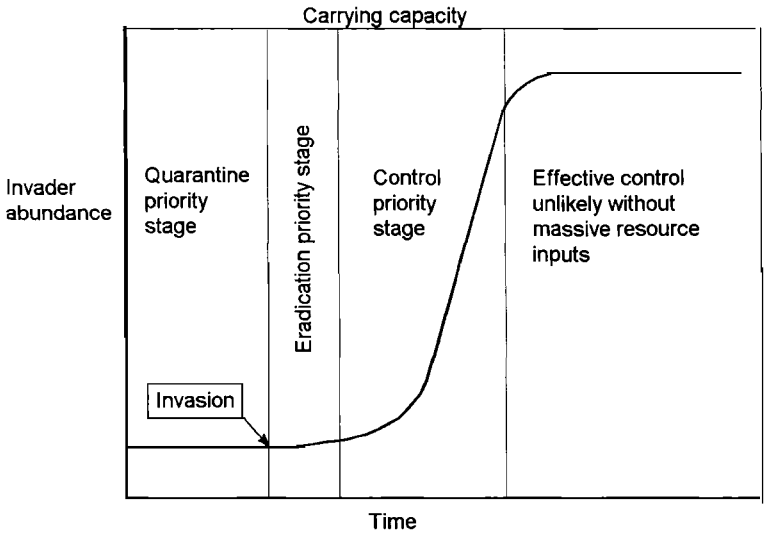

FIGURE 2. Phases of weed invasion and priorities for action at each phase. Ease of treatment of an invasion problem declines from left to right (Hobbs and Humphries 1995).

ditional potentially invasive species because of accelerating international trade (Jenkins 1996), prompt action to deal with newly emergent and future plant threats is obviously urgently needed. Two examples of the consequences of being "slow on the draw" follow.

Firetree, a small tree from the Azores, Madeira, and the Canary Islands, provides a representative example of the potential for rapid alteration of natural areas. One of the worst invaders in Hawai'i Volcanoes National Park, firetree often forms dense stands that shade out native competitors. It fixes nitrogen in root nodules and alters early successional ecosystems through nutrient enrichment (Vitousek and Walker 1989). Brought to Hawai'i in the 1920s for reforestation, firetree was an incipient invader in Hawai'i Volcanoes National Park in the 1960s, at which time an intense debate arose over whether aggressive control or allowing natural succession to take its course was the proper response (D. Reeser, National Park Service, pers. comm.). In an eight-year period between 1978 and 1986, firetree expanded its range twentyfold within the park (Whiteaker and Gardner 1992). It currently occupies 14,800 ha within Hawai'i Volcanoes National Park in spite of concerted control efforts (Satchell 1997).

The most dramatic current example of an incipient invasive plant threat in the Pacific involves the invasive tree *Miconia calvescens* (Melastomataceae), native to neotropical forests at 300–1,800 m elevation, and now known to be an unusually aggressive invader of moist island habitats. Introduced to Tahiti in 1937, dense thickets of miconia had by the 1980s replaced the native forest over most of the island, with dramatic reduction of biological diversity. After the late F. R. Fosberg saw this species in Tahiti in 1971, he reported that "it is the one plant that could really destroy the native Hawaiian forest." Yet because of its attractive purple and green foliage, it had already been brought to Hawai'i as an ornamental in the 1960s, and nobody did anything about it until it got well established. After its detection on Maui by conservation agencies in 1990, an alarm was raised; miconia seemed to be an especially severe threat to the high-elevation rain forest habitat of many forest birds. Now miconia has become something of a household word in Hawai'i and an aggressive campaign against it is being conducted, especially on the islands of Maui and Hawai'i (Conant et al. 1997, Medeiros et al. 1997), at costs that will soon approach $1,000,000. The government of French Polynesia is also aggressively involved in preventing miconia from taking over forests in islands neighboring Tahiti (e.g., Meyer and Malet 1997). *Miconia* needs to be stopped, and we need to watch out for future miconias.

Unless a proactive approach is taken by governments to prevent continued or even accelerated introduction of invasive weeds, we are very likely to have many more examples like firetree and miconia in the future.

PROSPECTS FOR IMPROVEMENT IN SLOWING INVASIONS

We have attempted to describe the nature of the threats that we believe loom ominously be-

low the tip of the iceberg represented by the currently recognized threats to avian "species on the brink" and Pacific ecosystems in general. Hawai'i is the biological invasions capital of the United States (and consequently the endangered species capital of the United States) and in many ways is at the forefront in confronting the problem, if not yet in effectively dealing with it. Yet biological invasions constitute a national and global problem (Vitousek et al. 1997), and Hawai'i could well be regarded as a laboratory for addressing alien species issues.

Hawai'i is a microcosm—a small world in itself where boundaries are clear, allowing opportunity as well as challenge in dealing with alien species problems. Lessons learned in Hawai'i are highly relevant to other Pacific islands and to continental situations. The state of Hawai'i, dominated by urban politics (with 75% of the state's population on O'ahu, which has <10% of the state's land area), is clearly overwhelmed with the problem. Much more attention to the problem from the federal government as well as from the state government is clearly warranted and desperately needed.

The Honolulu-based interagency Coordinating Group on Alien Pest Species (CGAPS) is an alliance of biodiversity, agriculture, health, and business interests that has been working since 1995 to seriously address the alien pest crises in Hawai'i (Holt 1996). A major public relations campaign was launched in late 1996 to increase public awareness of alien species problems (CGAPS 1996). The intentions of CGAPS are extremely good, but their effectiveness remains to be demonstrated, largely because of an inadequate political (and thus bureaucratic) response to the challenge.

A better-funded, better-staffed, better-equipped, and better-legislated quarantine system for Hawai'i is desperately needed (yet the Hawai'i legislature and agencies involved are not pushing for it). Additionally, early detection and treatment of invaders before explosive spread occurs can potentially prevent many future problems. As of late 1997, agencies and individuals on the island of Maui, which have been working together at a grassroots level for six years to deal with the weed tree miconia invasion, envision evolution toward an interagency working group with subcommittees dealing with major categories of invaders. The group sees itself as a grassroots component of CGAPS. An island-wide plan would establish categories (exclusion, eradication, containment, large-scale management), and set priorities and responsibilities for pest management. The greatest challenge appears to involve obtaining funding and personnel to do the control work in an era of shrinking government. Is success possible? All agree that public education is a crucial ingredient of the anti-alien species strategy, to gain broad political support. Direct public involvement in selected eradication efforts is an important tool. Achieving and publicizing success stories is an effective strategy. Given much more resources than are currently on the political horizon, Maui's successes and failures could guide efforts statewide.

Concurrent research is needed to (1) examine and explain the lag phase phenomenon for both plants and animals; (2) detect and predict what specific incipient invader populations need attention statewide; (3) determine the specific pathways by which these recent invaders arrived and are being spread in the state; (4) develop techniques for eradicating various groups of invaders once detected; and (5) develop the biological basis for needed legal tools to ameliorate current problems and prevent future problems.

ACKNOWLEDGMENTS

LLL thanks D. Reeser for inspiration, practical progress, and insight for how to realistically confront alien species issues in Hawai'i. FGH thanks N. L. Evenhuis, S. E. Miller, and R. H. Cowie of Bishop Museum for reviewing earlier drafts of the invertebrate section and for locating critical references. FK thanks E. Campbell, R. Crombie, G. Rodda, P. Rosen, and A. Wolf for assistance in locating relevant references.