Arthropod pests of conservation significance in the Pacific: A preliminary assessment of selected groups

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Abstract

Arthropod species are by far the most numerous invasive organisms on islands, but those of conservation significance in the Pacific, except for Hawaii and the Galapagos, are not well documented. Ants may pose the greatest arthropod threat to conservation in the Pacific, by predation, direct competition, and creating favourable conditions for other invasive biota. Information is given on some of the potentially most damaging: bigheaded ant *Pheidole megacephala*, long-legged or crazy ant *Anoplolepis longipes*, Argentine ant *Linepithema humile*, little fire ant *Wasmannia auropunctata*, and others. Vespid wasps pose another critical threat; an outline is given of the yellowjacket wasp *Vespula pensylvanica*, recorded only from Hawaii in the Pacific, but with serious potential for invading other Pacific island groups. The other significant pests discussed here are the black twig borer beetle *Xylosandrus compactus*, the coconut rhinoceros beetle *Oryctes rhinoceros*, and the avian malaria mosquito, *Culex quinquefasciatus*. A preliminary bibliography for ants in the Pacific is appended.

1. Overview

The invasion of oceanic islands by non-native arthropods has most likely been an ongoing phenomenon since the first human travelled from one place to settle another. The damage done to natural environments by cattle, pigs, goats and other large mammals is on a scale easily apparent to the human eye. Perhaps for this reason, the effects of their introductions are well documented. The effects of the introduction of non-native arthropods are less obvious and have generally been poorly understood and poorly documented. Nonetheless, the impacts of arthropods on the natural environment are great and deserve the same scale of investigation as exists for their larger cousins.

Given the amount of non-commercial and commercial traffic among Pacific islands, these former oceanic havens have become easy targets for invasive pest organisms in the last half of this century. Arthropods are by far the largest group (in numbers) of organisms that invade islands each year, e.g. an estimated 20 per year in Hawaii—of which four are considered pests (Beardsley 1979). Therefore, a review of existing knowledge of arthropod pests in the Pacific is a necessary preliminary to larger, more comprehensive surveys and detailed reviews of the fauna. This study only scratches the surface of the amount of research that will be necessary to provide adequate knowledge to deal with the alien arthropod pests that threaten native ecosystems throughout the Pacific.

Arthropods of conservation significance in the Pacific, except for Hawaii and the Galapagos, are not well documented. A critical problem is the incomplete basic knowledge of the existing flora and fauna, making impacts difficult to assess. In addition, many Pacific nations lack adequate resources to recognise the problem or potential problem, identify the culprits, and mount an intervention programmeme if necessary. There is no single compilation of the Pacific Island arthropod fauna. Very few works deal with the arthropod fauna of the region as a whole (e.g. Curran 1945); most have dealt with arthropods on: (a) a regional basis, e.g. serial works such as *Insects of Samoa* (1927–1935); *Insects of Micronesia* (1951–present); *Insects of Hawaii* (1960–1992) or single works such as Kami and Miller (1998) or Nishida (1997), or (b) a taxonomic basis (e.g. Evenhuis 1989).

Only selected groups of terrestrial arthropods are dealt with here as a first step toward a necessary and more comprehensive study. The selected groups included the ants, the avian malaria mosquito, the yellowjacket wasp, the black twig borer, and the coconut rhinoceros beetle. Each of these groups of insects does have or has had a deleterious effect on the environment in the areas in which they have invaded, has a realised or potential impact on conservation of native biota, and for the most part, active control programmemes are in progress to attempt to eradicate them from these areas. By dealing with selected groups in this way, it was felt that we could better gauge the resources needed for a more inclusive effort.

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The literature concerning pest arthropods is voluminous and widely scattered and we can in no way do justice to a successful study of the entire group, or even subsets of it, such as the top 10 percent of major pest arthropods in the Pacific area, in this preliminary review. Much of the pest literature is for economic pests, and that body of literature must be consulted to glean conservation information, since detailed and definitive works on the direct effects on native ecosystems are few, although increasing recently.

1.1 Origins of the fauna

Zimmerman (1942) hypothesised the origins of the native insect fauna of the eastern Pacific, Gressitt (1982) discussed the biogeography of Pacific Coleoptera, and Evenhuis (1982) discussed the distribution and origin of Oceanic Bombyliidae, but none considered the origins of non-indigenous species. In fact, most studies of the Pacific island arthropod fauna have not dealt with origins of alien species.

As with the vast majority of studies of alien species in the Pacific, Hawaii has been the primary "research station". Beardsley (1979) summarised the study of 120 accidental insect introductions into Hawaii from 1937 to 1976 and concluded that 36% originated from the west (i.e. Asia); 52% from the east; and 12% from undetermined sources. Virtually all accidentally introduced pests to Hawaii were introduced via commercial traffic. Without reference to other island studies, it is assumed that the origins of arthropods accidentally introduced into other Pacific island faunas are most likely also correlated with shipping and air traffic into these areas.

1.2 Types of pest arthropods

The major groups of arthropods that are considered threats to conservation efforts include chiefly the predators and parasites, and these are the groups of organisms that we deal with in this review. The term "parasite" is used here in a broad definition (for example, boring [e.g. beetles] or piercing [e.g. sap-sucking] insects can be considered parasitic on the hosts in which they feed or bore holes for the nests of their eggs and young). Their impacts on the native biota can be disastrous. There is no telling the exact number of native species of insects and other small invertebrates that have been extirpated from lowland areas of Hawaii solely because of the effects of the big-headed ant, *Pheidole megacephala*. Perkins (1907) laments the extirpation of the native fauna of Mt Tantalus just above Honolulu in just 10 years because of the introduction of this ant.

While most arthropod pests have historically been considered as such from the standpoint of their economic impact on agriculture, some are also major threats to conservation of native elements of various ecosystems. Some agriculturally important arthropod pests will not pose any direct significant problem to native biota (for example, *Bactrocera* fruit flies that attack fruit crops and cause significant economic damage to fruits would not pose a significant threat if they were to also attack native fruits since their action does not kill or reduce the reproductive effectiveness of the host). However, other agricultural pests can and do pose a serious threat to native plants, for example *Xylosandrus compactus*, the black tree borer beetle. This has had a deleterious effect on coffee trees and other Rubiaceae in Hawaii, but apparently is not specific to just coffee trees. Surveys have shown that it can attack over 100 different species of mostly woody plants in 44 different families (Hara and Beardsley 1979), some of these being rare or endangered.

1.3 Characteristics of invasive species

Howarth (1985) provides a concise assessment of the features that are necessary for successful colonisation of islands by introduced species. Genetic preadaptation to exploit resources in the new land is a basic requirement. Climatic, seasonal, and other environmental cues must be present, as must proper hosts and other natural resources. The chances of both sexes of a species being present at the time of colonisation is low in most cases, so that hermaphroditic and parthenogenetic species have a better chance of colonisation than other species. However, gravid females, or nests containing individuals of both sexes can be and have been easily introduced.

1.4 Greatest threats

Ants may pose the greatest arthropod threat to conservation in the Pacific. The formation of large, noncompetitive, multi-queen colonies, coupled with the ability to hitchhike readily, highly aggressive predatory behaviour, protection of pests on plants, and few options for control, make ants one of the most formidable pests in the Pacific. Ants have been implicated in the elimination of lowland native invertebrates (Perkins 1913), aquatic and semiaquatic arthropods (Hardy 1979, Moore and Gagné 1982), and snails (Solem 1976), and the death or exclusion of vertebrates (Haines et al. 1994, Swaney 1994). Vespid wasps pose another critical threat. In Hawaii, yellowjacket wasps are systematically "cleansing" areas they have invaded, indiscriminately preying on many types of arthropods to feed their colonies.

Vespids and ants are critical threats, especially to native species existing in small populations occupying limited areas.

Plant-feeding species such as leafhoppers, scales, and aphids are another threat. The results of their feeding often attract ants and degrade photosynthetic capabilities of plants. Another potential threat is the indiscriminate release of parasites and predators for biocontrol purposes in commercial crops leading to unforeseen effects in native forests.

The accidental, usually unobserved, and random nature of arthropod introductions makes it difficult to predict areas of greatest threat. In general, the island groups with the greatest traffic with outside areas remain at greatest risk. Traffic in this sense includes not only commercial and military transport, but conveyances such as privately owned small planes or boats. Locations to which agricultural or horticultural plants or commodities are imported are at increased risk of introduction as are areas importing (or exporting) equipment and materials for construction. An active pet trade makes some areas more prone to introductions. Areas actively exporting agricultural products also increase the risk, as large-scale farming often is susceptible to pests and as a result more prone to use biological control agents. Most pests are associated with human disturbance, and those islands with the greatest remaining natural areas at lower elevation and adjacent to areas under cultivation are at risk.

1.5 Needs for the future

Loope and Medeiros (1995) provide a list of three points that are necessary for proper understanding, management, and control of invasive species and conservation of natural ecosystems. Though they are written for Hawaii, the principles are valid for most of the tropical Pacific. Continuing research is needed to:

- understand the biology and impacts of invasive species,
- provide the tools needed to manage the most destructive invasive species,
- provide tools for ecological restoration,

To this list we must add and emphasise the need for:

- foundational biosystematic research on the introduced and native arthropods,
- baseline surveys and monitoring programmes to anticipate introductions and pre-empt incipient populations.

Any systematic study is an essential first step towards any conservation programmeme. Without proper identification of organisms, attempts to control, abate, or eliminate them may prove costly and fruitless.

Additionally, enhanced quarantine should be a primary consideration for all Pacific islands, and public education should be implemented on each island to augment any control work or preventative measures being done by resource managers and quarantine staff.

As each species may have a different and often unpredictable impact on an ecosystem, and considering the ease with which species are translocated today, perhaps a useful approach may be to provide an inventory of species presently known from each island group. This will allow the tracking of new introductions. A preliminary list is available for ants, but an exhaustive search has not yet been completed and the names have not been fully verified. The foundation for this is compilation of the literature, and a preliminary list is presented in Annex 1.

2. Beetles (Coleoptera)

2.1 Black twig borer

Scientific name: *Xylosandrus compactus* (Eichhoff). Family: Scolytidae.

Distribution

SPREP area: American Samoa, Fiji, Papua New Guinea, Solomon Islands.

Other areas: Hawaiian Islands, tropical Africa, southern India, Indonesia, Japan, Malaysia, Mauritius, Seychelles, Sri Lanka, southeastern USA, Vietnam.

Discussion

The black twig borer, *Xylosandrus compactus* (Eichhoff), belongs to the tribe Xyleborini of the family Scolytidae, which contains species of beetles called ambrosia beetles. The ambrosia fungus is the primary food for the beetle's development and is the causal agent in the infection and resultant weakening or killing of the host plant that the beetle infests. Ambrosia beetles are serious pests of forest trees and, to a lesser extent, shade and fruit trees (Clausen 1978a). Most ambrosia beetles attack primarily weak or unhealthy plants; however, the black twig borer is known to attack healthy plants as well, which makes it a potentially very serious pest to native forest trees as well as other plants.

The black twig borer was first collected in 1931 on the island of O‘ahu from elderberry imported from Singapore (Samuelson 1981), but not reported in the literature until it was collected again on O‘ahu in 1961 (Davis 1963) where it was found attacking pink tecoma (*Tabebuia pentaphylla* (L.) Hemsl.). It has since spread to all the other main islands (Hawaii Dept. Agric. 1975; Samuelson 1981) and the list of hosts includes 108 species of shrubs and trees in 44 families (Hara and Beardsley 1979) including some considered rare or endangered.

The fungus and plant symptoms

The fungus associated with the black twig borer in Hawaii is *Fusarium solani* (Mart.) Synd. and Hans. It is the only food for *Xylosandrus compactus* throughout its life cycle and its pathogenicity on the host plants has been confirmed (Hara and Beardsley 1979). When infected, the plant exhibits necrosis of the leaves and stems extending from the entrance hole made by the beetle distally to the terminal of the branch.

Control programmes

Davis and Krauss (1967) list the introduction into Hawaii of three parasites [*Chaetospila frater* (Girault), *Dendrosoter enervatus* Marsh, and *Ecphylus* sp.] for control of the black twig borer; and Davis and Chong (1970) list the additional introduction of *Dendrosoter protuberans* (Nees). There have been no results on the outcomes of any of these liberations. Hill (1983) comments on the lack of success of the application of cultural methods in suppressing ambrosia beetles as a whole, but said that sprays of dieldrin, with added surfactant and sometimes with Bordeaux mixture, has given adequate levels of control in the tropics. Unsuccessful introductions for control of ambrosia beetles include the predacious clerid beetle *Thanasimus formicarius* (L.) from England into Sri Lanka in 1908 (Clausen 1978a).

2.2 Coconut rhinoceros beetle

Scientific name: *Oryctes rhinoceros* (Linnaeus).
Family: Scarabaeidae.

Distribution

SPREP area: American Samoa, Fiji, Palau (controlled in 1980s), Papua New Guinea, Samoa, Tokelau, Tonga, Wallis and Futuna.

Other areas: Bangladesh, Cambodia, southern China, India, Indonesia, Laos, Malaysia, Pakistan, Philippines, Taiwan, Thailand, Vietnam.

Discussion

The coconut rhinoceros beetle, *Oryctes rhinoceros* (Linnaeus), is one of the most serious pests of the coconut palm. Though, for the most part, coconut palms are considered agricultural crops, this beetle is included in this review because of its record of damage, wherever it has become established in the tropics, to native palm trees and native *Pandanus*.

It is thought to be native to southern India, Sri Lanka, Myanmar, Thailand, the Malay peninsula, southernmost China including Hong Kong, the Philippines, Taiwan, the Ryukyus, and Indonesian Archipelago as far east as Ambon Island (Leefmans, 1884). It has been introduced into Samoa, Wallis and Futuna, New Britain, New Ireland, Palau, Tonga, Guam, Cook Islands, and Fiji (Gressitt 1953; Hill 1983), primarily as a result of the increased sea traffic during World War II. Swan (1974) lists its distribution among Pacific Islands (and years of introductions in parentheses) as Western Samoa (1910); Keppel Island (1921); Wallis and Futuna (1931); Palau (1942); New Guinea (1942); Tonga (1953); Fiji (1953); and Tokelau (1963). Though there are natural factors that keep the beetle under control in its native range, its introduction into insular habitats without these natural control factors allows it to reproduce quickly and spread to become a serious pest.

The beetle

The larvae of this scarab beetle develop in dead palm trunks, logs, and stumps. However, the adults cause the damage by boring into the crowns of mature palms and often killing them. Gressitt (1953) reports that in introductions of the beetle into insular situations such as Palau both the adults and larvae have been reported to survive by host-shifting on to *Pandanus* after the host palm food resource had been depleted. This is evidence of the potential danger to native palms and *Pandanus* from the ravages of this pest beetle elsewhere in the Pacific. In Gressitt's (1953) report, he lists over 45 species of monocot plants (many of which are native species) that the beetle has been reported to infest, including over 30 species of palms.

Control programmes

After World War II, the Insect Control Committee for Micronesia (ICCM) was established through the auspices of the National Academy of Science and plans were made for control efforts of the beetle (Anon. 1947). Subsequent reports follow the progress of this control programme (Anon. 1948a, 1948b, 1949, 1950, 1951, 1952, 1953). Parasites introduced from 1947 to 1950 for control of the beetle included the wasps *Scolia ruficornis* from east Africa and *Scolia patricialis* var. *plebeja* from Malaya. By 1952, surveys failed to recover any wasps, and palms continued to be attacked by the beetle.

Swan (1974) summarises the results of control of the beetle in the Pacific using predators, parasites, and various pathogens. The most promising of the ones listed appear to be the parasite *Scolia ruficornis* (Hymenoptera: Scoliidae) and the virus *Rhabdionvirus oryctes*. Other predators or parasites in the list would have to undergo specificity trials before they could be confirmed as safe for introduction to other Pacific Islands and without the danger of damage to non-target native organisms.

Clausen (1978b) gives a summary of control attempts in Fiji, Samoa, Palau, New Guinea, New Britain, and Vanuatu. In almost all cases, *Scolia ruficornis* was released, but only up to 30 per cent parasitisation was achieved in Samoa, and other areas had significantly less success.

Hill (1983) summarises recommended methods of cultural control (planting methods, general area cleaning and burning of potential host substrata) and states that chemical control can be attained with sprays of various chemicals including diazinon or carbaryl.

3. Flies (Diptera)

3.1 Avian malaria mosquito; southern house mosquito

Scientific name: *Culex quinquefasciatus* Say.
Family: Culicidae.

Distribution

SPREP area: American Samoa, Cook Is, Federated States of Micronesia, Fiji, French Polynesia (Austral Is, Marquesas, Society Is, Tuamoto Archipelago), Guam, Hawaiian Islands, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Marianas, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna.

Other areas: Widespread throughout the tropics, subtropics, and warm temperate regions of the world.

Discussion

Avian malaria has been postulated as one of the leading causes of the reduction and even extinction of some of Hawai'i's forest birds (Warner 1968; Van Riper 1991). The disease has been found in roughly 8% of the birds tested in Hawaiian experiments (e.g. Van Riper et al. 1982). Researchers have also concluded that native birds were more susceptible to acquiring the disease than introduced birds and had a significantly poorer survival rate than introduced species (Van Riper et al. 1982; Atkinson et al. 1995). This fact has serious implications for native bird faunas elsewhere in the Pacific where the mosquito and the disease parasite may occur.

The parasite

Several species of the filarial parasite *Plasmodium* are the causal organism for avian malaria. *Plasmodium relictum capistranoae* Russell is the parasite found in infected Hawaiian birds. Sporozoites are the infectious stage of the *Plasmodium* protozoan parasite and are transmitted to a vertebrate host through blood feeding by a mosquito. The disease to the host is caused by the parasite protozoan attacking red blood cells to continue its development. Fully developed erythrocytic schizonts cause rupturing of the red blood cells to release merozoites (to continue the blood cycle in the host) and gametocytes (capable of initiating sexual development if ingested by a mosquito). It is the merozoites with accompanying toxins that cause the chills and fever of malaria.

The mosquito

The transmitting agent of avian malaria is the mosquito. The most prevalent mosquito transmitting avian malaria in Hawaii is *Culex quinquefasciatus*, though a number of other mosquitoes have been found to harbour the parasite in experiments (summary of previous work in Hewitt 1940). *Culex quinquefasciatus*, native to North America, is found throughout the tropics and subtropics, including virtually all the island groups under SPREP as well as Hawaii.

Avian malaria itself has not yet been recorded from native birds on any island group in the Pacific except Hawaii, but this may only be a reflection of the fact that not many rigorous epidemiological surveys to find *Plasmodium relictum capistranoae* or other disease vectors for avian malaria have been conducted in the Pacific outside of Hawaii. The only research known that has surveyed other islands in the Pacific for avian malaria is by Savidge (1985) [Guam] and Steadman et al. (1990) [Cook Islands], and there were no findings of the parasite. Avian malaria is currently not an active threat to conservation on any other island group except Hawaii. However, it is included in this preliminary survey because of the high potential for the disease to spread to other Pacific islands through normal commercial traffic lanes (be it shipping or air traffic). One of the most prevalent methods by which the disease is spread is through the introduction of infected non-native birds.

In Hawaii, avian malaria has been reported from a variety of native bird species, with the 'apapane (*Himatione sanguinea*) having the highest percentage of infected individuals in surveys (e.g. Van Riper et al. 1982, 1986; Van Riper and Van Riper 1985). Other native species recorded in that study as being infected with avian malaria include i'iwi (*Vestiaria coccinea*), amakihi (*Loxops virens*), 'elepaio (*Chasiempis sandwicensis*), oma'o (*Myadestes obscurus*), Hawaiian creeper (*Loxops maculata*), and akiapolaʻau (*Hemignathus munroi*) [the last is on the US Fish and Wildlife Endangered Species List]. Scott *et al*. (1986) add a few more endangered native species to the list of Hawaiian birds found to be infected with avian malaria: Townsend's (Newell's) shearwater (*Puffinus newelli*), and the Hawaiian crow (*Corvus hawaiiensis*). Massey et al. (1996) conducted further observations on the characteristics of the Hawaiian crow after it had become infected with *Plasmodium relictum capistranoae*. Van Riper et al. (1982) showed that introduced species had a substantially better survival rate after being infected than native Hawaiian birds (100% v. 42%).

In Guam, studies were conducted in the 1980s (Savidge 1985) to determine the causes of the precipitous decline of bird populations there. Neither *Plasmodium relictum capistranoae* nor any other avian malarial parasite was found in any of the birds sampled, yet the vector, *Culex quinquefasciatus* occurs on the island. Savidge concluded that the main causes of the decline in bird populations were the brown tree snake (*Boiga irregularis*) and collisions with cars, but did not rule out the possibility that *Plasmodium* might be in the mosquito populations, although at such low levels as to not have been detected.

In the Cook Islands, Steadman et al. (1990) surveyed nine indigenous species of birds with negative results for the presence of protozoan pathogens. Nevertheless, they point out that precautions should still be taken to prohibit the introduction of potentially infected non-indigenous birds or mosquitoes into the Cooks or any other Polynesian island because of the high potential for native birds to be fatally vulnerable to the consequences of the disease should they become infected.

Control programmes

There are no active control programmes for the abatement of avian malaria. Attempts to control mosquitoes in general have been implemented in Hawaii, but have not met with success.

Mosquitoes that harbour the causal organism of avian malaria are container breeders (immatures can be found in both natural and artificial containers). The only effective procedure to reduce populations of mosquitoes is to reduce the number of potential water catchment containers in the area in which the mosquitoes are known to breed.

One way to reduce potential mosquito populations in Hawaiian forests and elsewhere is to reduce the number of pigs. In Hawaii, the introduction of pigs into forest areas has increased the number of potential breeding areas for mosquitoes. In foraging for soft plant food items such as roots, pigs will often fell tree ferns and eat the soft cambium, leaving trough-like depressions that fill with rainwater. Pigs also create wallows in which standing water can attract mosquitoes for long enough for them to fully develop. Mosquitoes have been found in greater abundance in these pig-infested areas than elsewhere. Thus, excluding pigs from conservation areas or eradicating them from forested areas will reduce the number of potential mosquito breeding areas and thus the number of mosquitoes that could potentially spread avian malaria or other insect-borne diseases to native animals.

4. Wasps (Hymenoptera: Vespidae)

4.1 Yellowjacket wasp

Scientific name: *Vespula pensylvanica* (Saussure). Family: Vespidae.

Distribution

SPREP area: Not yet recorded.

Other areas: Hawaiian Islands, throughout North America.

Discussion

Though not yet recorded from any Pacific island other than the Hawaiian Islands, we include a discussion of *Vespula pensylvanica* because of its notorious habits in Hawaii and potential for invading other Pacific island groups. We recommend that frequent and rigorous monitoring at all places of entry (ports and airports) be done on all islands so as to prevent the unwanted entry of this wasp.

Yellowjackets are predators, feeding on a wide range of arthropod taxa, with great potential for negative impact on the native fauna in insular habitats. This is especially troublesome in Hawaii, which compared to mainland areas where *Vespula* occur, has a high degree of endemism for arthropods that, for the most part, have evolved without anti-predator defence mechanisms selected for elsewhere (Gagné and Christensen 1985).

The yellowjacket wasp is native to North America. It and other members of the genus *Vespula* have natural distributions that are primarily north temperate. Climate is a major constraint on its reproductive behaviour; cold weather depletes normal food supplies, resulting in a reduction of colony individuals during cold winter months. However, in Hawaii with its warmer year-round climate, colonies appear to enlarge during warm winter months causing population explosions in areas it has invaded (up to 300 sorties per minute have been observed at some nests [Gambino 1991]).

Vespula pensylvanica was first reported from Hawaii in 1919 (on Kaua'i) and subsequently on O'ahu in the 1930s where all reports were primarily about it being a nuisance to humans, with concurrent reports of stinging. However, Williams (1927), misidentifying it as *V. occidentalis*, was prescient to note that "This fierce insect will probably be of no benefit to the endemic fauna". However, it was not until an aggressive race of this species was reported from the island of Hawai'i in 1977 (Asquith 1995) that its almost simultaneous population explosion and resultant intensive predatory habits began to have repercussions on the native invertebrate populations. Gambino and Loope (1992) provide a detailed account of surveys done over a ten-year period in Hawaii Volcanoes National Park (Hawai'i Island) (1984–1990) and Haleakala National Park (Maui) (1981–1990) and identified 24 arthropod prey items at least to genus, of which 14 (58%) were endemic taxa (including some taxa that are currently considered as Species of Concern by the US Fish and Wildlife Service).

Control programmes

Almost as soon as the 1977 population was discovered, nest eradication and/or control programmes were initiated on various islands in Hawaii to attempt to control the yellowjacket. The toxicant bendiocarb, used for nest eradication, is not registered in the USA for use in agricultural situations, so its implementation had to be outside of agricultural fields. Chang (1988) discusses the use of toxic baiting in the control of yellowjackets. His results showed that the most effective combination of bait and chemical toxicant was 0.5% microencapsulated diazinon mixed with canned Figaro brand tuna cat food. Amidinohydrazone in a similar bait mix was also effective, but less so than than diazinon mix. Dispenser colour for the bait also proved critical, the preferred colour of bait dispenser being translucent white.

5. Ants (Hymenoptera: Formicidae)

The best-documented ant conservation problems in the Pacific are mostly from the Hawaiian Islands and the Galapagos. Most of the conservation pests listed below are exclusionary; they occupy an area, outcompete any native ants, prey on native fauna or exclude them from the area. They affect plants by harvesting seeds, pruning foliage and encouraging the increase in populations of some sap-sucking insects. Most of the beneficial aspects of alien ant species appear to occur in cultivated areas. However, Compton and Robertson (1991) point out that the presence of *Pheidole megacephala* reduces seed predation and increases the number of pollinators in figs. Documentation on effects of ants in native ecosystems in the Pacific has been slow in arriving, but recent research has revealed a number of problems and potential problems. The major potential problem ant species for conservation are discussed below.

5.1 Bigheaded ant

Scientific name: *Pheidole megacephala* (Fabricius). Family: Formicidae

Distribution

This ant is Afrotropical in origin and seems to be circumtropical in distribution (Wilson and Taylor 1967), although it is also found in heated greenhouses in temperate areas (Bernard 1968). In the Pacific, it has been reported from the Hawaiian Islands, Line Islands, Society Islands, Cook Islands, Austral Islands, Gambier Islands, Marquesas Islands, Fiji, Marshall Islands, and Guam, but is likely to be widely distributed throughout the Pacific. This species was first reported from Hawai'i in 1879 (Smith 1879), but was probably established some time before that, as Blackburn and Kirby (1880) noted that it was already quite common.

Discussion

Perkins (1913) documented the loss of native species in Hawaii as a direct result of predation by the bigheaded ant. He specifically reported beetles and moths being affected, but included all arthropod groups in his assessment. Zimmerman (1948) reported the elimination of most endemic species in the bigheaded ant's range. *P. megacephala* has also been implicated in the exclusion of native spiders (Gillespie and Reimer 1993).

In Hawaii the bigheaded ant is primarily restricted to dry and mesic lowland areas although it may occasionally be found up to 1220 m altitude (Reimer 1994, Wetterer 1998, Wetterer et al. 1998). It is the dominant ant in many areas, although other aggressive ants such as *Linepithema humile*, *Anoplolepis longipes*, *Iridomyrmex glaber*, *Solenopsis geminata*, and *Pheidole fervens* have displaced it in less suitable environments (Reimer 1994).

In addition to the negative effects of general predation on the native fauna, the big-headed ant feeds on the honeydew of scale insects and other homopterans, increasing their rates of survival by protecting them from parasites and predators (Jahn and Beardsley

1994), and possibly by removing waste material (Rohrbach et al. 1988). This behaviour may foster the depredation of native host plants by increasing the parasite load and by increasing growth of sooty moulds on leaf surfaces, disrupting photosynthesis.

Large-scale programmes to control this species in non-cultivated areas appear not to have been attempted in Hawaii. Su et al. (1980) in searching for an alternative to the mirex baits withdrawn for environmental concerns, found that AC-217,300 was effective in controlling the bigheaded ant in pineapple fields. McEwen et al. (1979) and Reimer et al. (1991) reviewed chemical controls for *P. megacephala* in Hawai'i.

5.2 Long-legged ant, crazy ant

Scientific name: *Anoplolepis longipes* (Jerdon).
Family: Formicidae.

Long-legged ant is the common name for this species in the list of common names published by the Entomological Society of America (ESA) (Bosik 1997), but crazy ant is in wide use in the Pacific. In the ESA list, *Paratrechina longicornis* is called the crazy ant.

Distribution

After many years of interception in quarantine, *A. longipes* was discovered established in Hawaii on O'ahu in 1952. Wilson and Taylor (1967) list Africa as the source area. This ant has been spread throughout the world by human activity. Wilson and Taylor (1967) gave its distribution as the Old World tropics, and called it the dominant ant in disturbed habitats in Melanesia and Micronesia. More specifically, in the Pacific, it has been reported from Guam, Kosrae, Marshall, Kiribati, Tuvalu, Wallis and Futuna, Samoa, Fiji, Cook, Tokelau, Ellice, Austral, Tuamotu, Gambier, Marquesas, and Solomon Islands, in addition to Hawaii, and is likely to be found on other Pacific islands.

Discussion

This ant is usually found from sea level to 800 m in the Hawaiian Islands, but has been collected as high as 1220 m altitude (Reimer 1994, Wetterer 1998). Hardy (1979) first noted the effect of the long-legged ant on formerly common native insects in riparian habitats. Beardsley (1980) confirmed the threat to endemic arthropod fauna. Moore and Gagné (1982) implicated *A. longipes* as one of the causes for the depletion of the native lowland damselfly fauna. Gillespie and Reimer (1993) demonstrated that confrontations between *A. longipes* (and *P. megacephala*) and native or alien spiders resulted in the death of the native species and not the alien species. Gillespie and Reimer suggested the exclusion of native spiders in lowland areas occupied by *A. longipes*.

The long-legged ant is considered beneficial for agricultural purposes, often preying on agricultural pest species and reducing their numbers. At the same time, it can be a household nuisance (Haines et al. 1994). Haines et al. (1994) reported that, in addition to their predation of arthropods and similar to the big-headed ant, *A. longipes* affects plants by removing soil from roots and tending coccid populations and greatly enhancing their populations, increasing sooty mould growth.

The long-legged ant may also exclude vertebrates. In the Seychelles, Haines et al. (1994) noted that the ants killed newly hatched chickens and newly born domestic animals and forced older animals to leave the area. In Tonga, *A. longipes* has been shown to kill hatchlings of an endemic bird (*Megapodius pritchardii*) (Swaney 1994). This ant and similar aggressive species could potentially be a problem for native vertebrates throughout the Pacific, as even snakes and lizards were affected.

In the Solomon Islands, Greenslade (1971) noted that species diversity decreased wherever *A. longipes* populations flourished. Though Greenslade was referring to coconut plantations, the observation should also hold true for native forests.

An educational programme coupled with toxic baits were used in the Seychelles to control *A. longipes* and prevent its spread to islands of greater conservation significance, those with higher populations of native species (Haines et al. 1994). Partial success of the programme ensued, but full eradication failed for a variety of reasons. However, populations of *A. longipes* declined, perhaps as a result of natural factors associated with invasion by a new species (invasion, slow increase in numbers, explosive growth, high densities, decline in densities) (Simmonds and Greathead 1977). Lewis et al. (1976) reviewed earlier efforts using chemical controls in the Seychelles.

5.3 Argentine ant

Scientific name: *Linepithema humile* (Mayr).
Family: Formicidae

Distribution

The Argentine ant is a tramp species that is so far reported in the Pacific only from Hawaii. This species is apparently native to Brazil and Argentina, and has a worldwide distribution, mostly in the 30°–36° latitude belts of the Northern and Southern hemispheres (Fluker and Beardsley 1970, Lieberburg et al. 1975).

Discussion

The Argentine ant was intercepted in quarantine many times before it finally became established in Hawaii in 1940 (Zimmerman 1941). At first, these ants were observed eliminating other ant species. Wilson and Taylor (1967) stated that *L. humile* excluded other larger ant species, including *Pheidole megacephala*, and Majer (1994) confirms this. However, Reimer (1994) states that *L. humile* has been displaced by other ant species, such as *P. megacephala* in Hawaii, and is now limited to the cooler higher altitudes from 900 to 2800 m. Medeiros et al. (1986) reported the Argentine ant in two slowly expanding populations at Haleakala on Maui, at altitudes of 2000–2260 m and 2740–2830 m.

Medeiros et al. (1986) suggested *L. humile* negatively affected endemic organisms, particularly ground-dwelling or ground-nesting native moths and bees. Cole et al. (1992) discussed the effects of the Argentine ant on the invertebrate fauna at higher altitudes and concluded that the ant locally reduced the abundance of many endemic species, including arthropods and snails, and could negatively affect the pollination of native plants. They also mentioned that spiders were negatively affected, although Gillespie and Reimer (1993) noted that native spiders co-existed with *L. humile* between 300 m and 1500 m altitude.

Bartlett (1961) showed that, in the absence of Argentine ants, certain parasitic species suppressed populations of scale insects, indicating that Argentine ants may also foster increases in scale insect populations to the detriment of the host plant and its surrounding environment.

Majer (1994a) suggests that the exclusivity of *L. humile* offers a potential control mechanism by giving selective advantage to competing native species. Krushelnycky and Reimer (1996) reviewed the efforts of ant control at Haleakala. Use of Maxforce baits has been effective in trials to control the Argentine ant at Haleakala (Reimer 1999).

5.4 Little fire ant

Scientific name: *Wasmannia auropunctata* (Roger). Family: Formicidae

Distribution

The little fire ant is a native of tropical America. It was first found in the Pacific over 35 years ago, but within the last few years has been rapidly expanding its range. *W. auropunctata* was first reported from the Galapagos in 1972 (Silberglied 1972), New Caledonia in 1972 (Fabres and Brown 1978), Wallis and Futuna (Passera 1994); and Wetterer (1998) adds the Solomon Islands. More recently, it has been found in Fiji (personal comm. J.K. Wetterer to J. Wright and G. Sherley) and Vanuatu (Rapp 1999). In addition, this ant may have just been found in Hawaii (N. Reimer, personal comm.). The sudden increase of sightings may be attributable to the work of Wetterer and others who have done much to increase the awareness of the threat of this species. Wetterer considers this ant to be "perhaps the greatest threat in the Pacific". Much of the work documenting the problems caused by this species is from the Galapagos. Though the Galapagos is not part of SPREP, those references are included here for background information and for use by SPREP members.

Discussion

Smith (1965) indicated that *W. auropunctata* prefers cultivated areas and buildings, but this was in temperate and urban eastern USA. Silberglieb (1972) early pointed out the potential conservation problems with *W. auropunctata* as it replaced indigenous ant fauna, attacked other terrestrial insects and invertebrates, and tended a variety of honeydew secreting insects. Lubin (1984) documented the exclusionary behaviour of *Wasmannia* and found that it reduced species diversity, reduced overall abundance of flying and arboricolous insects, and eliminated populations of arachnids. *Wasmannia* is also known for its painful stings (Spencer 1941, Silberglieb 1972). Clark et al. (1982) quantified the diet of *Wasmannia* and showed that prey included eight orders of insects, chilopods, arachnids, crustaceans (mainly isopods), gastropods, annelids, and seeds and other plant parts.

In the Solomon Islands, it is considered partially beneficial because of its ability to control the coconut nutfall bug, *Amblypelta cocophaga,* in coconuts and cocoa (GPPIS 1999apr30). In New Caledonia the ant induces severe outbreaks of the coffee berry borer, *Hypothenemus hampei*, through interfering with parasitisation of the pest (GPPIS 1999apr30).

More recently, informal information suggests that *W. auropunctata* severely affects vertebrates, both domestic and native species (J.K. Wetterer to E. van Gelder in response to a query about the effects of *W. auropunctata,* April 1999). According to Wetterer, the ants attack vertebrates, including giant tortoises in the Galapagos, attacking eyes and cloacas and potentially rendering them infertile. The little fire ant also reportedly eats the hatchlings of the Galapagos tortoises (Hayashi 1999). In New Caledonia and the

Solomon Islands, local reports indicate that dogs are blinded by the ant's venom (Wetterer to van Gelder, Hayashi 1999).

Spencer (1941) reviewed control measures against *W. auropunctata* in citrus groves. Abedrabbo (1994) reviewed control efforts in the Galapagos using commercial formulations in chemical baits. Heraty (1994) offers a potential method of control, suggesting that host-specific eucharitid wasps of the genus *Orasema* might provide biological control of *Wasmannia* and *Solenopsis*.

5.5 Other ants

The following ant species are treated together as they were cited as conservation problems as a group, not individually.

Fire ant

Scientific name: *Solenopsis geminata* (Fabricius). Family: Formicidae

[Ants without common names]

Scientific name: *Monomorium floricola* (Jerdon). Family: Formicidae

Scientific name: *Tapinoma minutum* Mayr. Family: Formicidae

Scientific name: *Technomyrmex albipes* (F. Smith). Family: Formicidae

Nafus (1993) presented evidence that the ants listed above were significant factors in reducing populations of native butterflies on Guam. The most important species attacking eggs were *Monomorium floricola, Solenopsis geminata*, and *Tapinoma minutum*. The most commonly observed predators attacking butterfly larvae were *T. minutum, S. geminata*, and *Technomyrmex albipes*.

According to Wilson and Taylor (1967), *Monomorium floricola* is one of the most widespread of all pantropical ant species and probably originated from tropical Asia. It occurs virtually on all island groups in the Pacific. *Solenopsis geminata* is similarly widespread, but is native to the tropics and warmer parts of temperate New World. It prefers drier habitats. *Tapinoma minutum* is tiny, inconspicuous and often overlooked. It may be indigenous to the Southwest Pacific and has been recorded from Samoa, Micronesia, tropical Australia, New Guinea, Solomon Islands, and Fiji as well as Hawaii. *Technomyrmex albipes* is probably the most widespread member of the genus, ranging from India to eastern Australia and throughout the Pacific including Polynesia, Melanesia and Micronesia. These species are all present in Hawaii, and although recent studies on impacts of their presence (e.g. Gillespie and Reimer 1993) did not implicate them as excluding native species of spiders, their presence may have an unobserved effect, such as predation of eggs or larvae as demonstrated by Nafus (1993).

Other ants may also be problems though not documented, especially if inserted into previously antless island ecosystems or if more aggressive species invade and disrupt the ecosystem. Some ants are potential problems, but their impact is unknown. Wetterer (1998) suggests that colonisation by more cold-tolerant ants such as *Pheidole bourbonica, Cardiocondyla venustula*, and *Linepithema humile* poses a general threat to the remaining native enclaves in Hawaii. The following two species are potential threats to native ecosystems, though their actual impact has not yet been confirmed.

[Ant without a common name]

Scientific name: *Solenopsis papuana* Emery

Gillespie and Reimer (1993) found a significant inverse relationship between the abundance of *S. papuana* and native spiders in Hawaii. Although exclusion was not shown as in the case of *Pheidole megacephala* and *Anoplolepis longipes*, they suggest this species may be the most serious threat to native Hawaiian arthropods. They suggest the present coexistence of ant and spiders is due to the recent invasion of *S. papuana* (first reported as *Solenopsis* sp. "b" by Huddleston and Fluker 1969). The basis for the threat is that this ant has successfully invaded native and disturbed wet forests, areas that retain the highest level of endemism in Hawaii.

Glaber ant

Scientific name: *Ochetellus glaber* (Mayr)

Though not included in Gillespie and Reimer's (1993) study, another ant that may bear careful observation is *Ochetellus glaber*. This ant was first reported in 1978 in Hawaii and is aggressively invading areas formerly occupied by other species of ants.

5.6 Tramp species of ants

Most of the ants listed above exhibit similar characteristics that categorise them as "tramp" species (Hölldobler and Wilson 1990, Passera 1994). Tramp species are attracted to perturbed environments and thus are often associated with human activities. They are unicolonial or show the absence of aggressive behaviour to individuals of the same species from different nests. They are polygynous where nests have multiple queens and the queens do not exhibit dominant behaviour. Their colonies tend to expand by budding rather than by nuptial flights and aerial dispersal. These ants are particularly aggressive to other species of ants. Tramp species also tend to be smaller in size (<1.5 to 3.5 mm in worker length). Brandao and Paiva (1994) include opportunistic with regard to nest sites and omnivorous as additional characteristics of tramp species. Jourdan (1997) suggests the rapid spread of tramp species such as *Wasmannia auropunctata* may be partly a result of paucity of ant species and ant-filled niches in the Pacific.

Ants attracted to perturbed environments are more likely to become hitchhikers on machinery and plants associated with humans and from areas where habitat modification is commonly practised, such as farms, nurseries, greenhouses and the like. The lack of intraspecific aggression, multiple queens, and budding permit the establishment of large numbers of individuals in a single area, maximising foraging efficiency.

The traits listed for tramp species also have implications for control measures. For example, in Hawaii, Reimer (1994) states the Argentine ant occupies limited areas in Haleakala National Park and suggests it could be eliminated or contained with an appropriate bait. Colonies multiplying by budding rather than aerial dispersal could be more easily eliminated because of the restricted area of occupation. However, the budding also makes it more difficult to determine whether the entire colony has been eliminated.

5.7 Methods of ant control

Chemicals, particularly those used in conjunction with baits, seem to be the most effective method to control established unwanted species at this time (Lewis et al. 1976, Abedrabbo 1994, Reimer 1999).

Apart from other ant species, few biological control options exist. Predators such as antlions and ant-feeding vertebrates such as anteaters have either minimal impact on the large populations or are inappropriate to introduce. Relatively little is known about pathogenic microorganisms and fungi (Hölldobler and Wilson 1990). Parasitoids have been a major means of controlling plant pests such as scales, aphids, and caterpillars, but have not been widely used for ant control. Hölldobler and Wilson (1990) did not even include a section on ant parasitoids in their comprehensive treatment of ants. Recently, however, some effort is being made to identify and assess the impact of ant parasitoids such as eucharitid wasps (Heraty 1994) and phorid flies (Disney 1994, Morrison and Gilbert 1998).

Effective quarantine measures, continuous monitoring, and immediate response upon finding newly established ant species may be more effective than attempting to eradicate established species.

5.8 Summary (ants)

Many tramp species of ants are found throughout much of the Pacific. Some of these were introduced to Pacific islands very early. As many of the lowland ecosystems are quite disrupted, the damage, if any, done by these species perhaps cannot be established. For example, when first observed in Hawaii, *P. megacephala* was considered beneficial as it was found in sugar cane fields and was observed feeding on many pest species (e.g. Perkins 1907). Perkins was completing an inventory of the arthropod species of Hawaii at the time he noted the absence of native beetles, moths and other groups in areas occupied by *P. megacephala,* and began documenting the predation on native species. Other areas of the Pacific other than the Galapagos did not have the combination of baseline inventory and field observation at the time of invasion by the pest species of ants, and the effects of the invading species are probably unknown.

Perhaps one of the greatest threats to Pacific conservation is *Wasmannia auropunctata*, which is spreading rapidly. Though much of the previous evidence of their impact was anecdotal, a substantial number of reports on the negative consequences of their introduction to Pacific islands are beginning to emerge. The damage to native ecosystems from this species is likely to be considerable.

In Hawaii, except for *Linepithima humile*, which is found as high as 3000 m, most of the environmental depredations caused by ants have been at lower elevations. This would suggest that intact lowland ecosystems with high diversity of native species would be most at risk. However, Wetterer (1998) states that ants continue to spread in the Hawaiian Islands, and cites unpublished data indicating that *P. megacephala* is found as high as the saddle area between Mauna Kea and Mauna Loa, up to 2020 m in altitude. Though populations of most ant species have not deeply penetrated native forest at higher altitudes, the situations posed by *Linepithima humile* and possibly *Solenopsis papuana* should serve as warnings about the potential threats posed by ants to native flora and fauna at even the higher elevations and in wet forests. Others have pointed out that ants can exclude vertebrates. For example, Wetterer et al. (1998) suggest that ants rather than avian malaria at upper elevations on the island of Hawai‘i may be responsible for the exclusion of the endangered palila (*Loxioides bailleui*). Ants are also predators of other invertebrates including snails, and invertebrate biodiversity must be considered also when assessing ant invasions.

Particular care should be taken in introducing ants as biological control agents, and Majer (1994b) cautions against such an approach. Zenner-Polania (1994) documents the effects on the native ant fauna of introducing *Paratrechina fulva* (Mayr) into Colombia, and many authors discuss the exclusion of native species of ants by aggressive invaders.

A review of the information cited above indicates that much more information must be gathered to understand the true impact of ants on native ecosystems, especially considering the uniqueness of Pacific floras and faunas. Their actual impact may not have been observed nor fully understood, as monitoring of Pacific island ecosystems has not usually been done. Only recently have some of the negative aspects of their presence been documented and these present increasing and extremely disturbing evidence of environmental modification. Based on the information presented above, it appears that many if not most ants may have an effect on any environment they invade. Except for a few species, the size of the impact, whether positive or negative, and the extent of the impact are usually poorly known.

Current methods of eradicating ant invasions in native forests are for the most part, inadequate, ineffective, or inappropriate. Control is often obtained by the use of baits with pesticides. More research is needed in this area.

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Annex 1.
Pacific ant references

A large body of literature exists pertaining to the ants of the Pacific. The following is not complete, and is biased towards the Hawaiian Islands, but it is a beginning towards building the reference base for the Pacific.

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