

CONSERVATION STATUS OF NATIVE TERRESTRIAL
INVERTEBRATES IN HAWAII

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ABSTRACT

The native invertebrate fauna of the Hawaiian Islands consists of some 6,000 arthropod species, 1,000 or more native land mollusks, and an undetermined number of taxa belonging to other phyla. Many elements of this fauna are restricted to narrow geographical or ecological limits. Because the evolution of the fauna took place in a high degree of geographical isolation, its members are unusually vulnerable to novel selection pressures resulting from the introduction and spread of non-native animal and plant species and from ecological disturbance caused by human activities. A great many native invertebrates have become extinct since initial human settlement of these islands, and many other species are now in imminent danger of extinction. Nevertheless, many native invertebrates survive in locations where the native vegetation is relatively pristine or where other favorable conditions are present. Efforts to conserve native invertebrates are hindered by inadequacies of available taxonomic and ecological data and by the low priority usually accorded to invertebrates by those agencies charged with protection of the native biota. Efforts to protect native invertebrates are of 3 types: taxon-specific protection under Federal and State Endangered Species Acts; site-specific actions providing protection to habitat necessary to the survival of native invertebrates; and preventive or eradication actions targeting undesirable alien species. Although all extant species of Achatinella (a genus of tree snails endemic to O'ahu) have been listed as "endangered" by the U.S. Department of the Interior (USDI), no other Hawaiian invertebrates have yet received such legal protection. A preliminary conservation assessment has been made for about 800 species of insects, providing a cross-section of ecological functional groups, i.e., aquatic and semiaquatic (Odonata: 28 species of Megalagrion), anthophagous and cleptoparasitic (Hymenoptera: 63

species of Nesoprosopis), phytophagous (Lepidoptera: 22 species of Hedylepta), and detritivorous (Coleoptera: 140 species of Nitidulidae; Diptera: 500 species of Drosophilidae). Based on this and other information, more than 300 native arthropods have been identified by the USDI as candidates for possible designation as threatened or endangered species. The International Union for the Conservation of Nature and Natural Resources has identified a number of additional invertebrate taxa as endangered or threatened. The National Park Service, The Nature Conservancy of Hawai'i, and the State of Hawai'i provide important protection for habitat necessary for the survival of native invertebrates, although management of lands under State jurisdiction often subordinates wildlife preservation to competing land uses. Restrictions on the importation of alien animal and plant species and the control of established pest species are also important to the conservation of Hawaiian invertebrates. Much additional research is needed to provide data on the biology of Hawaiian invertebrates, to identify taxa at risk of extinction, and to aid in the design and management of natural reserves providing protection to these animals.

INTRODUCTION

An assessment of the conservation status of native Hawaiian terrestrial invertebrates must concern itself with more than 6,000 arthropods, some 1,000 native land snail species, and an unknown number of representatives of various less prominent phyla. Basic taxonomic data are unavailable for many of these species, and significant ecological information has been obtained for only a few of the insects and almost none of the land mollusks. The great diversity, taxonomic uncertainty, and ecological ignorance make any assessment of the conservation status of these animals a formidable, indeed almost impossible, task. As specifics are unavailable, conservationists working with Hawaiian invertebrates have of necessity dealt in generalities; the comparative wealth of species and dearth of data have led them to group ecologically related rather than taxonomically related species into "guilds" or ecological functional groups (e.g., Gagne 1979), or to declare whole genera as endangered (e.g., Achatinella tree snails) or threatened (e.g., picture-winged Drosophila pomace flies). Nevertheless, some ecological constants influence invertebrates in much the same way as they do better-known groups of organisms. Like vertebrate and plant species, invertebrates have certain basic needs for survival:

1. A sufficient amount of the particular habitat to which each species is adapted.
2. The presence of adequate numbers of individuals of other species to which each is reproductively and

ecologically linked.

3. A sufficiently large extant population that the probability of extinction is minimized (Simberloff 1983).

Where data are available, these commonalities permit the conservation needs of invertebrate taxa to be treated in much the same way as those of other taxa.

ENDEMICITY AND VULNERABILITY

Among terrestrial macroinvertebrates, arthropods and mollusks are the most frequent colonizers of tropical oceanic islands. Other groups are only sporadically successful in long-distance over-water dispersal. Even so, successful natural colonizations of the Hawaiian Islands by macroinvertebrates were infrequent. The 6,000+ species of Hawaiian terrestrial arthropods are derived from about 300-400 successful colonization events; similarly, the approximately 1,000 species of native land mollusks are derived from about 22-24 colonizations (Zimmerman 1948). The ability of terrestrial invertebrate colonizers to speciate extensively on tropical oceanic islands is well known. In Hawai'i it is exemplified in the explosive radiations of drosophilid pomace flies (the 800+ endemic Hawaiian species, of a worldwide fauna of 2,500 species, are descended from 1-2 colonizing immigrant species) and amastrid and endodontid land snails (the almost 300 species of the endemic family Amastridae and approximately 200 Hawaiian Endodontidae are apparently each derived from single colonization events). At least a half-dozen insect genera each include more than 100 endemic species. In some instances, members of these radiations have diversified over a relatively short time to fill a broad range of ecological niches, which in continental ecosystems are usually occupied by totally unrelated taxa having a long evolutionary history of adaptation to those niches.

The interplay of isolating mechanisms (geographical, behavioral, ecological, etc.) has resulted in the high degree of localized endemicity and/or narrow niche specialization characteristic of terrestrial invertebrates in Hawai'i. Although no overall assessment has been made, we estimate that the vast majority of our terrestrial insect species are single-island endemics, and that the same holds true for nearly all of the larger land mollusks and many of the minute species. For example, 87% of the 100+ species of picture-winged Drosophila are restricted to single islands, and 9 of the 13 species inhabiting 2 or more islands are shared by Maui and Moloka'i, islands which were joined with Lana'i and Kaho'olawe to form a single island (termed "Maui Nui" by geologists) in periods of low sea level during the Pleistocene. Characteristically, these

flies are found in higher altitude rain forests from

300 to 2,000 m, where they breed on various native plant materials. Like many of the host plants that support them, the fly populations are patchy in distribution. Their population sizes are comparatively small, and most of the species are narrowly host-specific. Similarly, no species of the large achatinelline tree snails (genera Achatinella, Partulina, Perdicella, and Newcombia) is known to occur on more than one island, and populations are often highly localized within islands.

The native Hawaiian invertebrate fauna is unusual in that many ecological niches are occupied by taxa which have only recently evolved the major adaptations necessary to exploit their particular niches. It includes a large number of endemic species, most of them narrowly precinctive in either ecological or geographical terms, or both. Much more than in continental ecosystems, the diversity of Hawaiian invertebrates arose in place from the adaptive radiation of a few progenitor species. The coevolution of native invertebrates and other endemic plant and animal taxa took place in association with a different suite of predators and competitors than those present in continental areas.

The unusual nature of the Hawaiian invertebrate fauna contributes to the vulnerability of its members when their habitats are suddenly altered by human activity; or when habitats are altered by introduction of new predators or competitors, or even other species on which predators or competitors are dependent (Wells, Pyle, and Collins 1983). Invertebrate taxa with restricted geographical ranges are highly susceptible to extinction as a result of habitat destruction caused by human activities. Polynesian and modern commerce has vastly increased the pace of immigration by plant and animal species and of the ecological changes resulting from the establishment of these novel competitors and/or predators. Native species able to adapt to naturally occurring change taking place on a geological or evolutionary time scale are overwhelmed by a multitude of new influences acting simultaneously or in close sequence. The large monophyletic adaptive radiations characteristic of the Hawaiian land snail fauna may be particularly subject to mass extinction, as large numbers of taxa over a wide area may be similarly vulnerable to novel threats. Examples are the hypothesized catastrophic impact of predation by ants on eggs and juveniles of endodontid land snails (Solem 1976) and predation on achatinellid and other snails by the introduced predatory snail Euglandina rosea (Wells, Pyle, and Collins 1983).

PERTURBATIONS AND EXTINCTIONS

It is clear that the Hawaiian invertebrate fauna has suffered widespread recent extinctions, but documenting the extent and chronology of those extinctions is a difficult task. To a considerable extent, this is because of our incomplete knowledge of the true diversity of the pristine biota. Ornithologists have only recently learned of an unsuspected diversity of the native avifauna of the Hawaiian Islands through study of fossils and subfossils from limestone sinkholes and lava tubes (Olson and James 1982a, 1982b). Entomologists who wish to estimate the original diversity of the Hawaiian arthropod fauna and the extent of recent extinctions are frustrated by an absence of fossil data, although hopes remain that such evidence will eventually be recovered. Malacologists have long been aware of the occurrence of fossil land snails in areas now devoid of these animals (Henshaw 1904; Perkins 1913; Zimmerman 1948) and might be expected to have a rather clear understanding of the extent of molluscan extinctions. Unfortunately, this is not the case, as until very recently studies of fossil land mollusks were strictly taxonomic in focus, while detailed information on the recent status of the living fauna was restricted to the large and colorful Achatinella tree snails of O'ahu; even here, post-World War II data are limited. For minute species or for larger species inhabiting islands other than O'ahu, available data are generally few and out of date. Kondo (1970) has estimated that about 50% of the native land snail taxa originally inhabiting the Hawaiian Islands is extinct. In the absence of more precise data, his analysis stands as a first approximation.

It should be remembered, however, that biologists, paleontologists, and archaeologists have only recently begun to study prehistoric and protohistoric extinction phenomena in Hawai'i. Furthermore, it is difficult to distinguish extinction events that may have occurred in the hundreds of years before European rediscovery of these islands, from those that took place in the 50-75 years following Captain Cook's landing and preceding the mid-19th century observations of knowledgeable local naturalists.

Despite the lack of hard data regarding invertebrate extinctions, we shall attempt to summarize their recent history. It is a history dominated by the effects of anthropogenic habitat destruction and the introduction and spread of alien plants and animals. Although human impact is evident throughout, no single agent is influential in all cases; rather, multiple agents acting sequentially or simultaneously have combined to cause catastrophic extinctions.

Prior to the entry of man into the Hawaiian environment, change occurred in geological or evolutionary time scales. Geological events such as erosion, volcanic eruptions, and sea level changes had an influence, but at a pace and on a scale to which native invertebrates could adapt. Coevolution of native plants and animals was also a gradual process, with successful new immigrants reaching the Hawaiian Archipelago every few thousand years or so (inter-island colonizations would of course have been a more frequent occurrence). Such newly arrived colonists must have occasionally adversely affected established residents, but in general the native Hawaiian biota evolved in relative isolation from the outside world. While occasional extinction would of course have been a part of the evolutionary process, catastrophic extinction not restricted to localized geographical areas or to particular evolutionary lineages was probably infrequent.

Prior to human settlement, no significant fossil evidence is available for the native arthropod fauna, and direct evidence of its original diversity is limited, particularly for the lowland areas which have now been most heavily impacted by man. It is logical to assume, however, that these areas once supported numerous now-extinct endemic forms. Studies of relictual faunas on Nihoa Island (Conant et al. 1984) and possibly on certain offshore islands adjacent to the inhabited main islands (see Hobdy 1982 for botanical data from such locations) may yield valuable information on the native arthropods formerly inhabiting lowland regions. Upland areas are less heavily modified, and a greater portion of their arthropod faunas survives.

Fossil evidence from numerous sites in the lowlands of the main Hawaiian Islands provides considerable information regarding the now-extirpated native land snail faunas formerly inhabiting these areas. Fossil deposits in the coastal lowlands of Kaua'i contain representatives of a diverse native mollusk fauna which included a dozen or more now-extinct species of the amastrid genus Carelia (Hawai'i's largest native land snails, some with shells 85 mm in length), as well as other amastrids and numerous helicimid, endodontid, and ground-dwelling achatinellid snails. In windward O'ahu, the arboreal Achatinella may be found in coastal fossil deposits at Kahuku, La'ie, Kailua, and Waimanalo, along with many other native snails. On Moloka'i, tree snails of the genera Partulina and Newcombia are common fossils in coastal dunes at Mo'omomi. Arid leeward regions such as Barbers Point and Diamond Head on O'ahu, western Kaua'i, Ni'ihau, and Kaho'olawe, were inhabited by distinctive assemblages of xerophilous ground-dwelling snails.

Dextral pupillid snails of the genus Lyropupa were abundant in such sites, as were certain amastrids, succineids, and other taxa adapted to arid conditions. Upland dry forests, as in Kohala and Kona on the island of Hawai'i (Christensen 1983; Christensen 1984b) also supported diverse assemblages of land snails. Moist upland habitats contained diverse land snail faunas, and various native achatinellids (e.g., Achatinella, Partulina, Auriculella, Tornatellides), succineids (Succinea, Catinella) and helicarionids (Philonesia) may still be locally abundant in suitable locations. The original diversity of this zone is unknown, however, since such ground-dwelling taxa as the Amastridae and Endodontidae are probably under-represented in the modern fauna as a result of recent extinctions. Accurate knowledge of the diversity of this zone must await studies of fossils from sediments in lava tubes.

Prehistoric Human Impacts

The colonizing Polynesians converted much of the lowlands to agricultural uses or to anthropogenic grasslands (Kirch 1982). Destruction of the native lowland vegetation could only have had a catastrophic effect on the invertebrate fauna dependent on that vegetation. Direct evidence of extinction of invertebrates during this period is becoming available as a result of interdisciplinary studies of fossil land snails from archaeological sites. Kirch (1975) used such data to demonstrate deforestation in Halawa Valley, Moloka'i. In studies of sediments from limestone sinkholes at Barbers Point, O'ahu, Christensen and Kirch (in prep.) and their associates at Bishop Museum are finding a consistent pattern of extirpation of native amastrid and endodontid snails, probably occurring during the prehistoric period. Land clearance by the Polynesians no doubt also had a devastating effect upon native arthropods.

The immigrant Polynesians brought a number of plant and animal species with them. Many of the 2 dozen or so plant species they introduced were highly domesticated or infertile cultivars with little tendency to invade undisturbed environments, although such species as kukui (Aleurites moluccana), ti (Cordyline terminalis), and a few others became naturalized members of otherwise native communities (see Wagner, Herbst, and Yee, this volume). The impact of predation by introduced gekkonid and scincid lizards is impossible to assess. Of the 4 bird and mammal species introduced prehistorically (the domestic chicken, dog, and pig, and the Polynesian rat Rattus exulans), the last is likely to have had the greatest impact on native invertebrates due to predation on ground-dwelling insects and snails. Although feral pigs (Sus scrofa) now cause massive destruction to vegetation in native

habitats, it is possible that this may be a recent phenomenon (Stone, this volume). The Polynesians did introduce a few invertebrates (including the land snails Lamellaxis gracilis and Lamellidea oblonga, possibly the cockroach Allacta similis, and several arthropod ectoparasites of vertebrates), but these are not presently known to have had major impacts on native invertebrates.

Historic Impacts

Many of the adverse effects of man's direct and indirect impacts on native Hawaiian ecosystems are not specific to invertebrates and will be discussed by other participants in this Symposium. The advent of the historic period saw an increase in the pace of habitat destruction as a direct result of man's activities, as well as an increase in the rate of introduction of alien plants and animals.

Zimmerman (1948) discussed the effects of introduced ants (particularly the big-headed ant Pheidole megacephala) on native insects, and Solem (1976) suggested that predation by ants has been catastrophic for endodontid snails, a particularly vulnerable group. Although some 200 species of Hawaiian endodontids are represented in Bishop Museum collections, mostly from fossil sites, we know of less than a half-dozen occasions in which living endodontids have been encountered in the main Hawaiian Islands within the last 40 years. Probably best-documented is the continuing decrease in the abundance and range of O'ahu's Achatinella tree snails (Hart 1975, 1978; U.S. Fish and Wildlife Service 1980; Hadfield, in press). Here habitat degradation and destruction resulting from land clearance, fire, the activities of alien ungulates, and the spread of alien plants have combined with the effects of predation by rats (Atkinson 1977), shell collectors, and the snail Euglandina rosea (Hadfield and Mountain 1981) to cause the extinction of 50% or more of the 41 recognized species. The introduction of Euglandina as part of a biocontrol program targeted at the giant African snail Achatina fulica was particularly unfortunate; malacologists have long warned of the hazards to native land mollusks inherent in the introduction of such predators (Mead 1956; van der Schalie 1969). Ironically, although biocontrol advocates have introduced Euglandina to numerous Pacific islands over the last 30 years (Mead 1979), they have not yet demonstrated this predator to exercise effective control over the giant African snail (Christensen 1984a). Claims have been made that Euglandina has not been a major factor in recent extinctions of Achatinella and other native land snails, but demonstration of the devastating impact of this species on partulid tree snails in French Polynesia (Tillier and Clarke 1983; Clarke, Murray, and

Johnson 1984) should remove any doubts regarding its influence in Hawai'i. Oxychilus alliarius, an alien snail that became established in Hawai'i in the 1930's, may also prey on native land mollusks (Severns 1984). Although Hyman (1939) regarded the terrestrial flatworm Geoplana septemlineata as a Hawaiian endemic, we suggest that it is not native here and may have had a severe impact on ground-dwelling snails. Parasitism by the nematode Angiostrongylus cantonensis may also be harmful to native land mollusks. If so, this would be an indirect effect of the introduction of Achatina fulica, as this species is one of the principal intermediate hosts of this parasite and may have been the vehicle for its establishment in Hawai'i (Alicata 1966).

The effects of rat predation on invertebrates have been studied in Australia and New Zealand (Best 1969; Gales 1982), where a number of rodent-free offshore islands harbor large, flightless insects that are nearly extirpated on the New Zealand mainland and other offshore islands, where they are recorded only as subfossils or as relicts in restricted favorable locations in these areas (Key 1978; Ramsay 1978; Foggo and Meurk 1981). In Hawai'i, apparently ratless Nihoa Island provides a close parallel, as large flightless crickets and earwigs exist there but are unknown in the main islands (Conant et al. 1984). Nihoa also has numerous species which represent native groups now extirpated from lowlands on the main islands. In Hawai'i, National Park Service workers have recently embarked on studies of rodent impacts on native insects and other animals, which should provide additional information in this regard (Loope and Stone 1984; Stone et al. 1984). Predation or parasitism by other introduced animals adversely affects many other native invertebrates as well, and indirect effects due to destruction of host plants necessary to the survival of particular invertebrate species may also be important; for example, 9 species of pyralid moths (genus Hedylepta) have become extinct since 1900 as a result of biocontrol introductions or because of loss of host plants (Gagne and Howarth, in press). Additional examples could be provided (Howarth 1983a), but those listed are sufficient to outline the dimensions of the problem.

CURRENT DISTRIBUTION AND DIVERSITY OF NATIVE INVERTEBRATES

The classic work of Swezey (1954) provided much data about the occurrence of Hawaiian insects. More recently, Gagne (1979, 1980, 1981) has provided an assessment of the pattern of diversity among native arthropods in Hawaiian ecosystems based on an extrapolation of his sampling of Acacia koa and Metrosideros

polymorpha canopies along an altitudinal transect from sea level to tree line in Hawai'i Volcanoes National Park from 1971 to 1973. From this data base, obtained as part of the Island Ecosystems Subprogram of the International Biological Program (IBP), he derived measures of species diversity, biomass, and richness. It was found that the mid-elevation closed-canopy rain forest (Zone D and the lower portion of Zone E of Ripperton and Hosaka 1942) scored highest for these measures, with lesser values at higher and lower elevations. The low diversity found at high elevations was thought due to low temperature, low relative humidity, and low harvestable productivity in open canopy forests subject to grazing by introduced ungulates. Predation by introduced temperate insects preadapted to cooler elevations might also be a factor. The low diversity of native insects at lower elevations correlated with increasing prevalence of predatory ants which, in conjunction with alien cockroaches, comprised most of the insect biomass. For islands not attaining elevations as great as those of Hawai'i and Maui, the less diverse, high-elevation zone would not be represented, and the general pattern would be one of increasing native arthropod diversity with increasing altitude.

The limited nature of recent field observations of native land snail faunas makes an analysis of their current distribution difficult. Given our current state of ignorance, no species-by-species or habitat-by-habitat analysis is possible, and the following remarks are intended to provide a highly simplified overview of the status of major genera.

In general, areas of disturbed vegetation at elevations below about 300 m are inhabited by land mollusk faunas dominated by introduced snails and slugs. Native taxa are limited to a few hardy succineids (Succinea), minute ground-dwelling achatinellids (Lamellidea, Tornatellides), and an occasional pupillid (Lyropupa, subgenus Mirapupa). The diverse assemblages of native amastrids, endodontids, and other snails that formerly occupied such sites have been extirpated. Mid-elevation disturbed forests may contain the same few minute achatinellids and the pupillid Pronesopupa, but alien taxa predominate. Significant numbers of native taxa are rarely encountered below about 300 m elevation, their abundance increasing at higher elevations in moist regions of relatively undisturbed native vegetation. Here achatinelline tree snails (Achatinella, Partulina) and other Achatinellidae (Auriculella and several genera of minute snails) may still be found in favored localities, as may succineids (Succinea, Catinella), helicarionids (Philonesia), occasional amastrids (Leptachatina, more rarely Amastra), and an infrequent helicininid (Pleuropoma). Few native snails

are likely to be found in drier areas where native understory vegetation has been replaced by introduced grasses. Alien slugs and snails have invaded most habitats, even in some locations where native plant species predominate, and the predatory snails Euglandina rosea and Oxychilus alliarius are widespread in such localities (the former species occurring to elevations of 1,000 m or more in places, the latter occurring abundantly to elevations in excess of 2,000 m). Although field data are very few, land snail diversity at high elevations (> 2,200 m) is low and was probably never high.

CONSERVATION STATUS AND STRATEGIES

Actions by governmental and other agencies to protect native invertebrates are of 3 main types: taxon-specific protection under the Federal Endangered Species Act or state equivalents; site-specific actions that protect the habitats of native invertebrates (as well as other native wildlife); and preventive or corrective actions targeting undesirable alien species.

Taxon-Specific Actions

Official recognition of threatened or endangered status for native invertebrates has been slow in coming, compared to that for vertebrates. Local specialists recognize large numbers of invertebrate species which merit official recognition. As with the native avifauna and flora, a large percentage of native arthropods appear to have become extinct recently, and many of the survivors should be considered candidates for endangered or threatened species categorization. The situation confronting large-sized terrestrial mollusks is even more grim, for if present trends continue many will probably be extirpated over much of their already greatly reduced range, largely as a result of predation by the introduced snail Euglandina rosea (U.S. Fish and Wildlife Service 1980; Hadfield and Mountain 1981). Most native invertebrates will not soon gain legal recognition without changes in political and public attitudes about the importance of invertebrates in human welfare and natural ecosystem functioning, and without funding for efforts to determine the conservation status of taxa. A trend that should accelerate this process has been to designate as endangered species whole genera or portions of them with similar ecologies or behavior. A recent example is Federal recognition of the endangered status of all extant species (approximately 19 in number) of O'ahu tree snails of the genus Achatinella.

Gagne (1982) has made a preliminary conservation assessment of about 800 native terrestrial arthropod species. These species provided a cross-section of

ecological functional groups as follows: 28 aquatic, semi-aquatic, and terrestrial narrow-winged damselflies of the genus Megalagrion (Odonata, Coenagrionidae); 60 anthophagous and cleptoparasitic bee species of the genus Nesoprotopis (Hymenoptera, Hylaeidae); 22 species of moths in the genus Hedylepta (Lepidoptera, Pyralidae); 140 species of detritivorous and nectarivorous nitidulid souring beetles of various genera (Coleoptera); and 550 species of detritivorous and predaceous pomace flies in the genera Drosophila, Titanochaeta, and Scaptomyza (Diptera, Drosophilidae). From the outset of the project, the problem was how best to determine "endangered," "threatened," and "common" ranking in a manner that would give a uniform basis for assessing the conservation status of each species. A numerical scoring system called the "Index of Rarity" was developed, with values for taxonomic understanding, biological uniqueness, and impacts. According to this ranking, a priority for Federal review could be assigned following the U.S. Fish and Wildlife Service criteria for consideration of listing species as endangered or threatened (these criteria are reviewed by Wagner, Herbst, and Yee, this volume). The ideal situation would be a detailed biological and systematic study of each species following bibliographic and collection analysis. Even though the "Index of Rarity" method is fraught with pitfalls, some elements of this system have been adopted by the Office of Endangered Species for application nationally (G. Drewry, pers. comm.). The arthropod species were arrayed against island, general habitat type, the protection (or lack) afforded by existing reserves, etc., to attempt a systems approach to their conservation and protection.

Based on data from this and other sources, the U.S. Fish and Wildlife Service has identified 335 species of native Hawaiian invertebrates as candidates for possible inclusion on the List of Endangered and Threatened Wildlife (U.S. Fish and Wildlife Service 1984). The bulk of these are "Category 2" taxa, for which available information indicates listing as endangered or threatened is possibly appropriate, but for which biological data on vulnerability and threats are as yet insufficient to justify listing. No Hawaiian invertebrates were identified as "Category 1" taxa, those for which currently available data support the appropriateness of proposals for listing. No Hawaiian insects have yet been listed, although insects comprise the great majority of the recently identified animal candidate species. Two Kaua'i cave invertebrates, the no-eyed big-eyed spider Adelocosa anops and the Kaua'i cave sandhopper Spelaeorchestia koloana, were once under consideration for recognition, but with the seemingly interminable changes of criteria for completing the review procedures necessary for listing, their

processing has lapsed and needs to be re-initiated. Future lists of candidate taxa should include additional native arthropods, as well as a much-expanded selection of terrestrial mollusks. (The amastrid genus Carelia, the only Hawaiian mollusks on the recent list of candidates, was assigned to "Category 3A," taxa believed to be extinct.)

Hawai'i has a State Endangered Species Act to determine the conservation status of endemic invertebrates, but so far responsible State agencies have taken little initiative other than to follow Federal determinations. This inaction on the local scene reflects a general lack of awareness or concern by governmental officials and the general public, about the unique nature of the Hawaiian biota (particularly its terrestrial ecosystems) and its vulnerability to disturbance. A concerted effort to instill a conservation ethic needs to be directed at all educational levels.

At the international level, the International Union for the Conservation of Nature and Natural Resources (IUCN) publishes the Red Data Books that indicate the global conservation status of plant and animal species as endangered, threatened, vulnerable, commercially threatened, etc. The Invertebrate Red Data Book (Wells, Pyle, and Collins 1983) lists the ca. 100 species of Hawaiian picture-winged Drosophila as vulnerable, and the 19 or so extant Achatinella tree snails and the no-eyed big-eyed spider as endangered. The IUCN is considering the once widespread narrow-winged damselfly, Megalagrion pacificum (Moore and Gagne 1982), for endangered status.

Site-Specific Actions

Federal lands under the jurisdiction of the National Park Service (Hawai'i Volcanoes National Park, Haleakala National Park) and U.S. Fish and Wildlife Service (Northwestern Hawaiian Islands National Wildlife Refuge, particularly Nihoa and Necker Islands) contain important habitat for native invertebrates and receive considerable protection from activities unfavorable to their continued survival. The full protective provisions of the Federal Endangered Species Act are applicable to other federally owned land in Hawai'i. At the State level, the Natural Area Reserve System provides protection to some habitats vital to native invertebrates, but additional reserves need to be designated, and management efforts within existing reserves need to be increased. With regard to State regulation of designated Conservation District lands, preservation of native wildlife habitat is often accorded a low priority when conflicts arise with such competing land uses as hunting, commercial forestry, and energy development. One non-governmental agency, The

Nature Conservancy of Hawai'i, has become active in the preservation of natural areas and has initiated a State Natural Heritage Program to more accurately pinpoint areas needing protection (Holt and Fox, this volume). In addition to those invertebrates recognized as threatened or endangered by international, Federal, and State levels, species which are recognized by local authorities as being de facto endangered or threatened (whether this arises from systematic analysis of published data or merely from a "best-guess" assessment) are considered in the setting of priorities for preservation of natural areas.

Restrictions on Importation of Alien Organisms

Many of the problems confronting native invertebrates stem from the introduction of alien plant and animal species that may compete with, prey on, parasitize, or otherwise adversely affect native invertebrates or their host plants (see Howarth this volume). A first step in reducing such impacts should be a strengthening of quarantine and inspection regulations for materials shipped to Hawai'i from outside the State. Candidate biocontrol agents should be subjected to careful environmental review prior to release. The demise of native moth species of the genus Hedylepta and of various tree snails points out the hazards sometimes associated with such well-intended introductions.

Selection and Design of Natural Preserves

Natural preserve selection and design are topics of considerable current research and debate (see bibliographies by Harty, Harnish, and Lehman 1981; Killian 1982; Pearsall 1983; and Franklin, this volume). Most studies address preserve design requirements of vertebrates, especially birds, and to a lesser extent of plants; a number debate the applicability or limitations of island biogeographic theory to conservation practices. Few studies deal with habitat design for invertebrates. Despite the limited consideration given invertebrates in these studies, natural habitat preserve design that contains sound scientific reasoning should have applicability to all native biota. A suitable approach may be to join elements of a systems approach which combine the identification of critical area conservation (which delineates most threatened insular ecosystems) with endangered species determination (see Jacobi and Scott, this volume). Both efforts, when combined and when based on sound scientific data, could be productive conservation measures (see Eckhardt 1983). For now, conservationists concerned with Hawaiian invertebrates will have to be content with preserve selection and conservation programs that are tailored to birds and showy flowering plants, biotic elements that are better-known scientifically and that more easily gain the attention of the public.

Fortunately, almost any native habitat in some semblance of its original condition will contain many invertebrate species, and some Hawaiian invertebrates such as the Achatinella tree snails have gained a certain degree of public recognition in their own right. Invertebrate zoologists should, however, urge the protection of certain unique ecosystems that do not harbor endangered vertebrates but which are of sufficient importance to justify particular efforts on their behalf based solely on the presence of rare invertebrates or diversity of taxa. The recently discovered aeolian ecosystems atop Hawai'i's highest mountains are worthy of protection, as are lava caves inhabited by endangered invertebrates. These latter sites are the subject of study by the Cave Species Specialist Group of the IUCN's Species Survival Commission; investigations will include terrestrial invertebrates in cave ecosystem conservation (Howarth 1983b). Small islands offshore from the main Hawaiian Islands are likely to harbor relict populations of native invertebrates, as well as of endangered flowering plants.

Research Needs

As the foregoing discussion has demonstrated, our understanding of the conservation status and management needs of native Hawaiian invertebrates is deficient in a number of areas. Excluding general topics not specifically related to invertebrates, we believe the most important research tasks to be undertaken are as follows:

1. Completion of conservation assessment of selected terrestrial arthropods (particularly candidate endangered and threatened species), including analyses of both field and archival data.

2. Identification of additional candidate endangered and threatened species among native terrestrial mollusks. Achatinelline tree snails of the genera Achatinella, Partulina, Newcombia, and Perdicella should be given priority consideration because distributional data are relatively good; the extreme vulnerability of endodontid land snails recommends them also for consideration.

3. Biosystematic and ecological study of those high ranking species determined by available criteria to be most vulnerable to extinction.

4. Development of methods to eliminate or ameliorate influences (habitat destruction, spread of introduced organisms, etc.) that increase the vulnerability of native invertebrates to extinction.

5. Determination of the extent of suitable habitat necessary to support populations of particular vulnerable taxa and, if possible, the population size necessary to ensure their continued survival.

6. Design, delineation, and management of natural reserves to provide protection to native invertebrates

in conjunction with conservation needs of other biotic elements.

Though gathering this much information for a significant portion of Hawai'i's diverse invertebrate fauna is a tall order, a similar effort has already been completed for 6 species of endangered Mainland butterflies (Arnold 1983a, 1983b), and it is possible to do the same for any of our species or species groups given the necessary commitment of resources. What we learn about each species will speed--but not obviate--research on the remainder (Simberloff 1983).

CONCLUSIONS

We hope we have not painted too discouraging a picture of the conservation outlook for native invertebrates in Hawai'i. Although much has already been lost, recent discoveries of invertebrates living in previously unknown cave and high-altitude ecosystems and of such unexpected creatures as the predatory geometrid caterpillar Eupithecia demonstrate that the natural environment of Hawai'i still includes a diverse assemblage of native invertebrates. We disagree emphatically with those who say that it is already too late to salvage a significant fraction of that assemblage. One conclusion that is clear to any student of Hawaiian invertebrates is the need to educate the general public, and those in positions to influence land-use and conservation planning, about the uniqueness and diversity of this important element of the Hawaiian biota. We hope that future conservation efforts in Hawai'i will accord invertebrates an appropriate place alongside the vertebrate and plant taxa that are the usual focus of such efforts.

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