HAWAI'I'S WETLANDS, STREAMS, FISHPONDS, AND POOLS

Wetlands, streams, and anchialine pools are among the most threatened of Hawaiian environments because they are located where conflicts with other human needs are increasing dramatically.

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The Hawaiian Islands have a number of increasingly rare plant and animal **communities** that deserve special consideration. Among these are various cave and grassland communities and some important areas that will be considered here--those dependent upon fresh water or a mixture of fresh and sea water. **Wetlands**, the transition zones between terrestrial and aquatic **ecosystems**, are characteristically saturated with or covered by water, at least periodically, and soil development and plant and animal communities are determined by water (Cowardin *et al.* 1979). Natural wetland **habitats** include **marshes, swamps**, and **bogs** (the last of which are discussed by Cuddihy, this volume). Anthropogenic (man-made) wetlands include taro patches, prawn ponds, some fishponds, and other irrigated croplands.

Deepwater habitats for plants and animals lie beyond the boundaries of wetlands in the form of lakes, **estuaries**, the ocean, streams, man-made **reservoirs**, and some fishponds and pools. In these areas, water rather than air is the main medium in which dominant organisms live. Reservoirs in Hawai'i are primarily used for irrigation rather than for municipal water. The few natural lakes are distinguished from ponds by surface area and depth (Maciolek 1982). Lake Wai'au on Mauna Kea (island of Hawai'i), at 13,020 ft (3,970 m), is considered the second-highest freshwater lake in the United States. It is an alpine lake (above most vegetation in elevation; see Cuddihy, this volume) resting in the center of a cinder cone, about 40 acres (16 ha) in size, and reaching a maximum depth of 10 ft (3 m) (Cruikshank 1986). Lake Wai'ele'ele, at 6,700 ft (2,000 m) on the slopes of Haleakala on Maui, is an example of a montane (mountain) lake, with a maximum depth of 21 ft (6 m). In Hawai'i, lakes do not often develop because substrates of **basalt** are extremely permeable and rain water is quickly lost to the **groundwater table**. **Evapotranspiration** is also high in some areas with low to moderate rainfall. Upper-elevation lakes are **species**-poor but of value because of their rarity and uniqueness. Lower-elevation lakes and reservoirs receive use by **waterbirds**.

Many streams in Hawai'i are interrupted (flowing only part of the year) because of steep stream gradients, shortness of streambeds, seasonal rainfall, and the permeability of soil and rock. Hawaiian streams are also quite variable in volume of flow. Plants and animals living in streams must often be adapted to extreme variations in temperature, turbidity (cloudiness), and amount of aquatic habitat available at different times. Consistent stream

flow is most likely in mountain areas with more regular **orographic** rainfall (Armstrong 1983).

Anchialine pools are small bodies of water located near the ocean. They have no surface connection to the sea but have measurable **salinity** (salt content) and show tidal rhythms. They are found in the **Tropics** and **subtropical** areas and support a unique but poorly understood **biota**. Hawai'i's anchialine pool complexes have a greater percentage of **endemic** species and perhaps the highest **biological diversity** of any such pools in the world (Maciolek 1986). They, like many of the special Hawaiian areas which will be discussed in this essay, are especially at risk because of intensive human use of the coastal and lowland areas in which they occur.

WETLANDS

A major reason for concern about wetland areas in Hawai'i today is their importance for **native** waterbirds. The most important areas are lowland freshwater marshes and associated deepwater areas (ponds, lakes, and reservoirs); cultivated wetlands; and shallow margins of some anchialine pools. Marine-dependent wetlands such as mangrove communities (first introduced in 1902 to Moloka'i) and estuaries will not be discussed in this essay, although they are also used by waterbirds. (See Stemmermann 1981 for a discussion of eight natural and anthropogenic wetland vegetation types on Pacific islands.)

Polynesian Aquaculture

Polynesian peoples established a well-managed environment in Hawai'i's lowlands, including shifting "slash and burn" agriculture and areas in which water was controlled for plant and animal cultivation. The peak of Polynesian agricultural development probably coincided with highest human populations, which occurred about 1650 A.D.; human numbers then declined until European contact (Kirch 1982). Clearing of large areas of forest below 2,000 ft (600 m) elevation negatively affected the original lowland biota but allowed dense populations of humans to exist (see also Burrows, this volume). Forests above such areas as Kawainui Marsh and Kahana Bay on O'ahu, Hanalei Valley on Kaua'i, and Waipi'o Valley on Hawai'i Island may have been removed partly to encourage erosion of upland soils into lowland wetland areas used for taro (*Colocasia esculenta*) cultivation. (See Spriggs 1985 for a full discussion of prehistoric landscape modification.) Acreages of fishponds and irrigated fields at lower elevations were much greater in pre-contact days than at any time since and undoubtedly favored some native species of plants and animals.

Fishponds: Over 350 fishponds of various kinds have been identified on the eight major Islands. Although some provided only deepwater habitat for **birds**, others were true wetlands. Stationary sluice gates were the technological invention which probably allowed Hawaiians to convert fish traps (with openings to the sea) to artificial fishponds independent of tidal fluctuations (Apple and Kikuchi 1977). Smaller sluice gates used in irrigated taro fields (*lo'i*) to control water flow may have been the origin of fishpond gates. Fishponds were apparently not developed by other pre-contact cultures of the

Pacific but were used especially from the 14th to 19th centuries in Hawai'i (Kikuchi 1976).

Two major kinds of Hawaiian fishponds were recognized by Summers (1964): 1) Shore ponds or salt water ponds included *loko kuapa* and *loko 'umeiki*. Kuapa were made either by extending a semicircular wall from the shore into the sea and back to shore, or by walling off the narrowest part of an entrance to a small bay or inlet. Most of the Moloka'i fishponds were built this way. Loko 'umeiki were "surrounded by a low wall that is submerged at high tide and has openings walled on each side like lanes, leading in or out of the pond" (Summers 1964). These served as fish traps but were regarded as ponds by the Hawaiians. 2) Inland ponds or **brackish** and fresh water ponds were divided into three categories, *loko pu'uone* (not fresh water) and *loko i'a kalo* and *loko wai* (fresh water). Loko pu'uone were usually connected to the sea by a ditch or stream. Loko i'a kalo were the "taro fish ponds," and loko wai were natural ponds.

Pond sizes ranged from 0.5 to over 500 acres (0.2-200 ha), according to Cobb (1902), and the largest ponds were usually loko kuapa. Fishes raised in loko kuapa included *'ama'ama* or mullet (*Mugil cephalus*), *awa* or milkfish (*Chanos chano*), *awa'aua* (*Elops machnata*), *aholehole* (*Kuhlia sandvicensis*), and *'o'opu* (*gobies*). The loko 'umeiki also had 'ama'ama and awa but contained a number of ocean fishes that entered the ponds but were not raised in them. Fishes raised in loko pu'uone included 'ama'ama, awa, aholehole, and 'o'opu, while loko i'a kalo contained 'ama'ama, awa, 'o'opu, aholehole, and *'opae* (shrimp). Loko wai held 'o'opu and 'opae.

Hawaiian fishponds were undoubtedly very productive areas for aquaculture of **fishes, algae**, crabs, and shrimp. They may have attracted and benefitted mobile species of waterbirds that previously fed only in comparatively unproductive ocean waters or uncommon natural wetlands. Few fishponds exist today because of siltation, clogging by **alien** plants (especially red mangrove, *Rhizophora mangle*), overgrowth by California grass (*Brachiaria mutica*), pollution, tsunami, lava flows, earthquakes, and overall disrepair (Kikuchi 1976; Apple and Kikuchi 1977).

Irrigated Fields: Evidence for irrigated fields dating back to 600 A.D. has been recorded for Hanalei Valley on Kaua'i and to 1200-1400 A.D. for Moloka'i and O'ahu (Yen *et al.* 1972; Kirch and Kelly 1975; Kirch 1982), the last coinciding with the period of rapid human population increase. By Captain James Cook's arrival in 1778, nearly all bottomlands with permanent streams contained irrigation systems, and vast areas of wetlands had been created (Kirch 1982). Irrigated croplands may have predominated on all Islands except Hawai'i, where leeward field systems prevailed (Newman 1972). Olson and James (1982) hypothesized that increased wetland areas created by Polynesians allowed permanent colonization by waterbirds. They believed that the absence of waterbirds in the fossil record, together with lack of substantial differentiation of Hawaiian forms from Mainland ancestors, suggests recent establishment in the Islands, probably dependent on wetland habitat developed by humans. Whether this is true or not, **populations** of these birds and probably others such as now-extinct rails (Rallidae) and ibises (Plataleidae) may have responded to increased wetland habitat. Polynesian hunters, rats (*Rattus exulans*), and avian predators may also have benefitted from increased availability and numbers of some birds in the anthropogenic habitat.

Vegetation

Many lowland freshwater ponds have a central area of free water surrounded by **emergent vegetation** rooted in the soil of pond margins. In less disturbed ponds, vegetation of the shallows is dominated by **indigenous** grass-like plants called **sedges**, particularly tall bulrushes such as *makai* (*Bolboschoenus maritimus* subsp. *paludosus*) and *'aka'akai* (*Schoenoplectus lacustris* subsp. *validus*), and the less robust *makaloa* (*Cyperus laevigatus*). In some ponds and wetlands, the even larger California bulrush (*Schoenoplectus californicus*), probably not native to Hawai'i, grows intermixed with native bulrushes or is the dominant plant. Other native plants often seen at the edges of ponds in muddy areas are water hyssop (*Bacopa monnieria*), beach dropseed grass (*Sporobolus virginicus*), and *'akulikuli* (*Sesuvium portulacastrum*). Where water is brackish, the introduced pickle weed (*Batis maritima*) now dominates. Non-emergent freshwater aquatic vegetation growing in ponds, reservoirs, or slow-moving streams includes floating plants and submerged or partially submerged plants without well-developed supporting tissue. Many aquatic plants are important foods for waterbirds.

An unusual type of wetland that is today restricted to a few localities on O'ahu is the vernal (spring) pool, in which natural vegetation is composed of the rare water fern *'ihi'ihi lauakea* (*Marsilea villosa*), a **Candidate Endangered** species. These pools occur in very dry, leeward lowlands, primarily in craters or other depressions. Standing water is present only seasonally, during periods of heavy rainfall. The remainder of the year, the soil is dry and the water fern turns brown and greatly decreases in cover. Well adapted to such extreme fluctuations in moisture, the endemic *Marsilea* persists and holds its own despite the presence of many alien plant species.

Apart from vernal pools, natural wetland vegetation in Hawai'i is characterized by a relatively low percentage of endemic plants. Most native wetland plant species are also found in similar habitats on other Pacific islands and in tropical regions on continents. Even though Hawaiian wetlands cannot be considered rich sites for rare plants, their restricted distribution, small size, importance to native animals, and the danger of destruction by development are compelling reasons for the conservation of what remains.

Cultivated wetlands are usually dedicated to taro in Hawai'i, but a number of weeds ranging from herbaceous to woody species also invade on different substrates and with different amounts of cultivation. Watercress (*Nasturtium microphyllum*), lotus (*Nelumbo nucifera*), and rice (*Oryza sativa*) are also grown in limited quantities.

Birds of the Wetlands

Six species of native Hawaiian birds are dependent upon natural and cultivated freshwater wetlands in Hawai'i. The Federally Endangered *'alae 'ula*, also called Hawaiian gallinule or moorhen (*Gallinula chloropus sandvicensis*), and the *'alae ke'oke'o* or Hawaiian coot (*Fulica americana alai*) are all that remain of 11 known species of the rail **family** present when the first Polynesians arrived. Both birds are currently considered subspecies of North American forms and prefer either thickly vegetated marshland with associated open water or taro fields. Nesting moorhens are abundant in taro fields on Kaua'i at Hanalei National Wildlife Refuge; and on O'ahu at Paradise Pacifica (in deep ponds with a bulrush marsh), at James Campbell National Wildlife Refuge, and in Hale'iwa lotus fields. Hawaiian coots prefer more open water than gallinules and tolerate a range of fresh to saline (rarely)

conditions, such as are present in ancient coastal fishponds and at Pearl Harbor National Wildlife Refuge (U.S. Fish and Wildlife Service 1985). Coots have probably always been numerous on O'ahu, Maui, and Kaua'i.

The Endangered Hawaiian stilt or *ae'o* (*Himantopus mexicanus knudseni*) is a subspecies of the North American form. Stilts are still known from all the major Islands except Lana'i and Kaho'olawe and favor small islets in brackish, fresh, or salt water for nesting. They often feed in shallow freshwater, brackish, or saltwater areas other than those in which they nest. In recent years, the estimated population size has been 1,200-1,500 birds (Scott *et al.* 1988), but numbers have varied widely in the past.

The Endangered Laysan duck (*Anas laysanensis*) lives only on Laysan Island in the **Northwestern Hawaiian Islands**, and several hundred birds remain. The Endangered *koloa maoli* or Hawaiian duck (*Anas wyvilliana*) is now found mostly on Kaua'i in montane stream habitat between 1,000 and 4,000 ft (300-1,200 m) elevation. A population has been reestablished in the Kohala Mountains on Hawai'i through the State **captive breeding** program (see Giffin, this volume). The birds use stock ponds, reservoirs, irrigation ditches, and native stream habitat (U.S. Fish and Wildlife Service 1985). On O'ahu, koloa maoli are found on James Campbell National Wildlife Refuge, Punaho'olapa Marsh at Kahuku, and other wetlands.

The *'auku'u* or black-crowned night heron is not considered a distinct Hawaiian subspecies of the mainland species (*Nycticorox nycticorox*). It nests on all the main islands in wetland habitat. It is a predator on fishes, **crustaceans**, and the young of other marsh birds and has become a pest at aquaculture facilities. Its numbers have increased in recent years. Another bird of the wetlands, although also found elsewhere, is the introduced cattle egret (*Bubulcus ibis*). It is sometimes a hazard to aircraft near airports, and, like the 'auku'u, it preys on the young of marsh birds.

Migratory **shorebirds**, which use marine and freshwater wetland habitat while they winter in Hawai'i, include the *'ulili* or wandering tattler (*Heteroscelus incanus*), the *'akekeke* or ruddy turnstone (*Arenaria interpres*), the *hunakai* or sanderling (*Calidris alba*), the *kioea* or bristle-thighed curlew (*Nemenius tahitiensis*), and the *kolea* or Pacific golden plover (*Pluvialis dominica*); the last is often found far from wetlands, in pastures and suburbia. Most migratory shorebirds are more adaptable to human activities than are the resident native waterbirds in Hawai'i.

Problems

Loss of wetland habitat, both natural and man made, has been continual since at least the 1850s. Taro fields and rice paddies have been replaced by other agricultural crops such as sugar cane (*Saccharum officinarum*) and by development, until only a few hundred acres remain in wetland agriculture. Hotels, golf courses, housing developments, shopping centers, landfills, highways, military and industrial sites, and other crops have replaced extensive Polynesian wetland systems as well as natural habitats. Modern aquacultural areas, stock ponds, ditches, settling ponds, and golf course water hazards are used by waterbirds in Hawai'i today. However, they probably cannot replace the loss of areas such as Waikiki marsh, the Ahuimanu, Salt Lake, and Ke'ehi wetlands, Kuapa and Ka'elepulu ponds, and Hawaiian fishponds and flooded taro fields.

Introduced plants such as California grass, pickle weed, mangroves, and water hyacinth (*Eichornia crassipes*) have reduced open water, mudflats,

and shallows used by birds (Shallenberger 1975). **Mammals** such as **feral** cats, mongooses, dogs, and rats (*Felis catus*, *Herpestes auropunctatus*, *Canis familiaris*, and *Rattus* spp.) and other introduced avian predators such as the cattle egret have reduced breeding success of waterbirds. Human disturbance of birds in limited habitat, especially during avian nesting seasons, has also reduced nesting success. A well-publicized oil spill adjacent to a marsh in Pearl Harbor, O'ahu, recently disturbed waterbird nesting efforts in a U.S. Fish and Wildlife Service National Wildlife Refuge, a "protected" area.

When breeding birds use cultivated wetlands, disturbance during the nesting season often becomes a problem. For example, at Hanalei National Wildlife Refuge on Kaua'i, it is necessary for taro plants to be left around active nests during harvest. The effects of water level management of flooded croplands on birds and their food plants must also be considered. Boating activities, including tourist trips and filling of boat engines on the Hanalei River, have been restricted during waterbird nesting season. Temporary fencing is used to reduce predation in some areas. Pesticides (for example, heptachlor) are special hazards to birds dependent upon agricultural fields for feeding and breeding.

Conservation of Birds

Hunting of all wetland birds, one of the major factors in population declines, stopped in 1941 in Hawai'i, and a captive breeding program for koloa maoli has been in operation since 1958 (see Giffin, this volume). A State wetlands sanctuary system for waterbirds was begun in Hawai'i in 1952 with Kanaha Pond (145 acres or 59 ha) on Maui, followed by nearby Kealia Pond (385 acres or 156 ha). The koloa and 'alae 'ula were listed as Endangered in 1967, and the stilt and coot followed in 1970. Hanalei National Wildlife Refuge (917 acres or 367 ha) was created on Kaua'i in 1973, followed by Hule'ia National Wildlife Refuge (238 acres or 95 ha) also on Kaua'i in 1973; Kakahai'a National Wildlife Refuge (45 acres or 18 ha) on Moloka'i in 1976; and Pearl Harbor National Wildlife Refuge (61 acres or 24.5 ha) and James Campbell National Wildlife Refuge (142 acres or 57 ha) on O'ahu in 1976. An additional State sanctuary (Paiko Lagoon) and two sanctuaries on military land (Nu'upia Ponds and Lualualei) on O'ahu have also been established. Two of the most valuable breeding and nesting sites on leeward Hawai'i Island, Kapo'ikai Pond at Makalawena and Aimakapa Pond at Honokohau, are slated for protection in the near future.

Active management on some refuges, sanctuaries, and management areas has included: development of artificial nesting structures for birds; habitat improvement such as clearing vegetation, planting bird foods, and manipulating water level to enhance habitat; fencing and predator control by trapping to reduce predation; reduction of human disturbance; and annual and semi-annual population counts to monitor population trends. Completion of the Hawaiian Waterbirds **Recovery Plan** in 1977 provided objectives necessary for removing birds from the Federal Endangered Species list.

STREAMS

Most of Hawai'i's 366 perennial streams (on five major Islands) have had some form of water diversion or alteration. Less than 14% are physically pristine (Parrish *et al.* 1978), and far fewer are biologically intact. Many

streams drain small areas, and only two, the Hanalei River on Kaua'i and the Wailuku River on Hawai'i, discharge over 150 million gallons per day (6.6 m^2/sec). Most of the rest average less than 50 million gallons per day (1.2 m^2/sec) (Armstrong 1983).

Animal Life

In addition to native **insects**, Hawai'i's freshwater streams contain fishes, crustaceans, and **mollusks**, all of which have marine ancestors. Freshwater forms have adapted to changes in salinity and to dramatically variable flows of water, which result in periodically reduced habitat and changing water temperature and turbidity (muddiness). Some species may have been **pre-adapted** to freshwater streams through life in the variable **intertidal zone** of the ocean. Yet it is startling to observe a fish, the *'o'opu hi'ukole* or goby (*Lentipes concolor*), that climbs upstream over nearly vertical surfaces with wiggling tail and pectoral fins modified into a "suction cup." Tiny *'opae kala'ole* or "spineless shrimp" (*Atya bisulcata*) also travel upstream from sea level to as high as 3,900 ft (1,200 m) elevation!

'O'opu, 'opae, and the endemic freshwater snail or *hihiwai* (*Neritina granosa*) spend their adult lives in fresh water, but **larvae** are washed out to sea and float as **plankton** for a time. The *hinana* or fingerling gobies return to freshwater streams to mature and spawn, as do young shrimp and snails. Planktonic dispersal among the Hawaiian Islands is efficient, as shown by the fact that few species of freshwater gobies (five), shrimp (one), and snails (one) have become isolated and evolved in the Islands. Further evidence of efficient planktonic dispersal is the fact that the newly introduced Tahitian prawn (*Macrobrachium lar*), with a freshwater and ocean life cycle similar to that of the native shrimp, had spread to most Hawaiian streams 10-15 years after its introduction to only two streams.

Adult native damselflies and dragonflies or *pinao* (*Megalagrion* spp.) and their predaceous larvae (naiads) or *lohelohe*, together with adult and larval midges (Chironomidae), crane flies (Tipulidae), shore flies (Ephydridae), and other insects, comprise unique **food chains** associated with Hawai'i's freshwater streams. The damselflies are excellent examples of **adaptive radiation**, with 28 species using a number of different aquatic and terrestrial **niches** in Hawai'i. Some aquatic forms also depend upon nutrients from insects or decomposing fruits and vegetation that drop into streams from adjacent habitat. The introduced long-legged ant (*Anoplolepis longipes*) threatens stream biota such as pinao.

Problems

Fresh water on **oceanic islands** is especially precious for agricultural, industrial, and individual use. Diversion and **channelization** of streams by humans for these purposes or for flood control is a continual threat to stream life, even in lowland areas, because most island freshwater animals need the connection to the sea to complete their life cycles. Agricultural chemicals, siltation, municipal wastes, alien species, and changes in turbidity, oxygen content, flow rate, and water temperature can all create conditions to which native aquatic animals are not adapted and with which they cannot survive. Feral animals and livestock, or land use practices that remove streamside plant cover that provides shade, change temperature and light conditions to which stream animals have adapted, increase nutrients and soil in the water, and effectively degrade or destroy habitat for aquatic organisms.

Conservation

Protection of the few remaining pristine freshwater streams in the State Natural Area Reserves System or in preserves managed by The Nature Conservancy of Hawaii, or protection in other ways, is vital. A new State Water Code provides a Commission on Water Resources Management to establish what water resources should be protected as habitats for fish and wildlife. Forty-four streams on Kaua'i and East Maui have been proposed for protection from water diversion under standards required by the State Water Code. In 1988, legislators asked the State Commission on Water Resources to set up a Wild and Scenic Rivers System. Some of the important remaining freshwater streams include Kahana Stream on O'ahu; Kahakuloa and Hanawi on Maui; Waimanu on Hawai'i; Kilauea, Hanalei, and Lumaha'i on Kaua'i; and Wailau and Pelekunu on Moloka'i.

Protection of streamside vegetation to preserve natural aquatic temperature and light conditions and sources of food for stream organisms is important. Feral animals and livestock should be removed from **watersheds** drained by nearly pristine streams, and prevention of pollution from development and agriculture in these areas should be emphasized. Channelization projects that result in replacement of natural substrate with artificial bottom material, reduction of stream channel length, and vegetation removal should be avoided where feasible (Parrish *et al.* 1978). Hydroelectric facilities have potential adverse impacts such as blockage of fish migration and stream diversion, although some effects can apparently be mitigated. Aquacultural production of some native species has been recommended in this regard (Timbol and Heacock 1986). In a three-year Statewide stream survey 25 species of fishes and crustaceans were recorded, only eight of which were native. Native stream species were found to thrive only in areas free of development (Parrish *et al.* 1978).

Active **conservation education** about the value of Hawaiian streams is also necessary if we are to preserve the few unmodified streams that remain. The Conservation Council of Hawaii posters on aquatic life, available from environmental groups, are excellent educational aids to help inform the public about conservation values and problems.

ANCHIALINE POOLS

Physical Characteristics

Anchialine ("near the sea") waters occur around the world in lava and elevated fossil reefs. In the Hawaiian Islands they are found on O'ahu, Maui, Moloka'i, and Hawai'i but are most abundant on Hawai'i Island and Maui (The Nature Conservancy of Hawaii 1987). There are an estimated 600-650 on Hawai'i, perhaps 50 on Maui, 3 on O'ahu, and one on Moloka'i, most on private lands. The term "pool" includes typical small bodies of water as well as water in cracks, open wells, and places under lava rock overhangs (Maciolek and Brock 1974). About half of 318 pools surveyed along Hawai'i Island's leeward (Kona) coast showed cultural modification, by either Polynesians or modern humans. Prior to arrival of Europeans, Hawaiians used anchialine pools as potable water sources, as bathing pools, and as fishponds. Although all larger pools (larger than 0.02 acre or 100 m^2 surface area) were modified, many have reverted to more or less natural conditions through lack of use in recent years. Surface areas of 91% of the Kona pools were less than

0.02 acre (100 m^2), and 91% had depths less than 5 ft (1.5 m). Some ponds surveyed held water only at high tide. Almost no physical or biological data have been collected from about 175 pools between Hilo Bay and South Point on Hawai'i Island (see Yuen, n.d.).

Salinities (where seawater = 35 parts per thousand and fresh water = 0) were less than 15 parts per thousand for 93% of 298 ponds sampled on Hawai'i Island. However, salinity varies with evaporation in different seasons, tidal influx, and changes in groundwater resulting from rainfall fluctuation. Variations in salinity were usually less than a few parts per thousand for a given pool (Maciolek and Brock 1974). Surface temperatures of 210 ponds ranged from 35° to 63° F (19-35° C), with 71% of the ponds having surface temperatures between 43° and 50° F (24-28° C).

Pool Life

In contrast to anchialine pools, coastal ponds with surface connections to the sea usually contain a diversity of species, and most of them are marine. Anchialine pools, with only subterranean connections to the sea, have fewer but more distinctive animals (Maciolek and Brock 1974). Crustaceans and mollusks are the most abundant and characteristic animals in these ecosystems, and some are apparently restricted to anchialine ecosystems. Minute, red, herbivorous shrimp or *'opae 'ula* (*Halocaridina rubra*) are probably the most characteristic species, but several other crustaceans and some mollusks and fishes are also quite typical. 'Opae 'ula mixed with red cinders were valued as *palu* (chum) to catch *'opelu* (mackerel scad) by ancient Hawaiians (H. Springer, personal communication).

Algae of different forms were present in all anchialine ponds surveyed on leeward Hawai'i, and many serve as food for aquatic animals and add to the complexity of the pool habitats. The indigenous aquatic **vascular plant** tassel pondweed or widgeon grass (*Ruppia maritima*) is also characteristic of leeward ponds on Hawai'i Island.

Nine of the 55 animal species present were considered representative of Kona anchialine pools (Maciolek and Brock 1974). These included: *Assiminea* sp., a small snail also found on damp beaches; *Melania* sp., a larger snail widely distributed in streams and lowland ponds; *Theodoxus cariosa*, a black limpet-like snail also found in estuaries and brackish bays; *Metabetaeus lohena*, a small red shrimp limited to anchialine waters and predaceous on 'opae 'ula, also limited to anchialine waters; *Palaemon debilis* or *'opae huna*, a medium-sized, largely transparent shrimp common in estuaries and protected inshore waters; *Macrobrachium grandimanus* or *'opae 'oeha'a*, a larger shrimp from estuaries and streams; *Eleotris sandwicensis* or *'o'opu 'akupa*, a goby-like predatory fish also found in estuaries and lower streams; and aholehole, a silvery, carnivorous fish normally found in the sea.

A number of other rare species of **invertebrates**, including six shrimps, a **hydroid** (*Ostromouvia horii*), two snails (*Neritilia* spp.); and a rare moray eel (*Gymnothorax hilonis*) are also known from leeward anchialine pools. Some variants of more widely distributed forms are also characteristic.

Conservation

Anchialine pool inventories need to be completed to determine the most valuable areas to protect. The Nature Conservancy of Hawaii and the U.S. National Park Service are among the current sponsors of such surveys, and the Conservancy has recently completed a biological database (The Nature

Conservancy of Hawaii 1987; see also Newman, this volume). Maciolek and Brock (1974) presented a number of recommendations based on the results of their survey. Most of the pristine pools that they recommended highly for preservation were in remote locations and of particular importance because of their use by waterbirds, or because of their anthropological value. The U.S. Fish and Wildlife Service has classified one anchialine pool mollusk, seven crustaceans, and a rare moray eel as Candidate Endangered species (John I. Ford, personal communication). Three of the crustaceans are new species recently discovered at South Point, Hawai'i Island (Kensley and Williams 1986).

Major threats to anchialine pools include development and alien species. Native and alien fishes in pools do not appear to coexist well, and fishes (especially introduced fishes) and shrimps also seem incompatible (Maciolek and Brock 1974). The influence of past Hawaiian culture on the pools has been slight, but the degradation or destruction caused by development and modern human use threatens many areas of substantial value. For example, about one-third of Big Island anchialine pools have been destroyed by hotel development in the district of South Kohala.

CONCLUSIONS

Wetlands, streams, and anchialine pools are among the most threatened of Hawaiian environments because they are located where conflicts with other human needs are increasing dramatically. It is essential that research and monitoring to determine the value, status, and interrelationships of the biological resources involved be supported. Protection of the best sites and educational programs to enhance understanding about these areas should also be stressed. Preservation of a network of natural and modified wetlands and pools, together with adjacent deepwater habitat including streams and marine areas, presents a unique opportunity to coordinate historical, cultural, economic, and biological values in the areas most used and abused by humans in Hawai'i.

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