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Biological inventory of anchialine pool invertebrates at Pu‘uhonua o Hōnaunau National Historical Park and Pu‘ukoholā Heiau National Historic Site, Hawai‘i Island

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ABSTRACT

Inventories for major groups of invertebrates were completed at anchialine pool complexes in Puʻuhonua o Hōnaunau National Historical Park (PUHO) and Puʻukoholā Heiau National Historic Site (PUHE) on the island of Hawaiʻi. Nine pools within two pool complexes were surveyed at PUHO, along with one extensive pool at the terminus of Makeāhua Gulch at PUHE. At both parks, inventories documented previously unreported diversity, with pool complexes at PUHO exhibiting greater species richness for most taxa than the pool at PUHE. Inventories at PUHO recorded five species of molluscs, four species of crustaceans (including the candidate endangered shrimp *Metabetaeus lohena*), two species of Orthoptera, four species of Odonata (including the candidate endangered damselfly *Megalagrion xanthomelas*), fourteen species of Diptera, nine taxa of plankton, and thirteen species of ants; inventories at the PUHE pool produced only one species of mollusc, two species of crustacean, at least one species of Orthoptera, four species of Odonata, thirty species of Diptera, five taxa of plankton, and four species of ants. Further survey work may be necessary to document the full diversity of pool fauna, especially in species-rich groups like the Diptera. Inventory data will be used to generate a network wide database of species presence and distribution, and will aid in developing management plans for anchialine pool resources.

INTRODUCTION

Anchialine pools are localized coastal aquatic features that exhibit dampened tidal fluctuations and possess measurable salinities but lack a surface connection to the sea (Holthuis 1973). These pools are restricted to porous substrates, such as the recent lava flows found widely on Hawaiʻi Island. The term "pool" is used to refer to exposures of groundwater along the coast; including visible water in fissures, cavernous irregularities in lava and lava tubes, as well as more typical pools that form in rock basins. This aquatic habitat was originally referred to as "coastal ponds" or "anchialine ponds" by Maciolek and Brock (1974), but the term "anchialine pool" coined by Holthuis (1973) now has wide usage (e.g. Stone 1989). In the United States, anchialine pools are restricted to Hawai'i, with an estimated 600 pools on Hawaiʻi Island, 50 on Maui, three on Oʻahu and one on Molokaʻi (Stone 1989). Anchialine pools are found in most national parks in Hawai'i, including Hawai'i Volcanoes National Park (HAVO), Kaloko Honokōhau National Historical Park (KAHO), Puʻuhonua o Hōnaunau National Historical Park (PUHO) and Puʻukoholā Heiau National Historic Site (PUHE) on Hawaiʻi Island, and Kalaupapa National Historical Park (KALA) on Moloka'i (Chai 1989; Brock and Kam 1997).

Biological Attributes

While Hawaiian anchialine pools support a unique array of biota with representative crustacean communities exhibiting high species endemism (Chai 1989), other taxa are often associated with adjacent estuarine, intertidal, littoral or freshwater habitat. Many pools found on young lava flows lack emergent vegetation but others have welldeveloped plant communities. In Hawai'i's national parks, characteristic native pool vegetation includes succulents, such as ʻākulikuli (*Sesuvium portulacastrum*) and ʻōhelo kai (*Lycium sandwichense)*, and sedges, including kaluhā (*Bolboschoenus maritimus*) and makaloa (*Cyperus laevigatus*). Shrubs, such as pōhuehue (*Scaevola taccada)* and trees including milo (*Thespesia populnea*) favor pool margins and can cover small pools entirely. Alien vegetation, especially the succulent pickleweed (*Batis maritima*) and shrubs and trees including Christmas berry (*Schinus terebinthifolius*), sourbush, (*Pluchea carolinensis*), kiawe (*Prosopis pallida*) *and koa haole* (*Leucaena leucocephala*) have replaced native vegetation in many park pool complexes (Pratt 1998).

A high diversity of algae and cyanobacteria (also called "blue-green algae") has been recorded from anchialine pools on Maui (Wong 1975) and at least some are characteristic components of pools found along the coast of west Hawaii Island. Benthic (or bottom-dwelling) cyanobacteria and/or filamentous chlorophytes and rhodophytes (green and red algae, respectively) often dominate pool basins. Complex cyanobacteria-dominated communities of *Lyngbya* crusts (often orange in color) and *Scytonema* mats (dark green or brown and felt-like) are poorly known, but often prominent features of many anchialine pool systems. In pools with sediment basins, the native aquatic flowering plant, widgeon grass (*Ruppia maritima*), is also often present.

Among the invertebrate fauna, a number of native shrimp occur in anchialine pools. The most common species is the small, red, endemic, hypogeal (meaning subterranean) shrimp, ʻōpae ʻula (*Halocaridina rubra*). ʻŌpae ʻula can cover small pool basins giving them a red appearance. *Halocaridina* are grazers, feeding on detritus, benthic diatoms, phytoplankton, filamentous algae and, possibly, vascular plant tissue (Wong 1975). They move between pools through groundwater, emerging from rock interstices with the incoming tide to feed in the pool and often returning to hypogeal habitat with the falling tide (Wong 1975; Brock 1985).

Another small, usually red, native hypogeal shrimp species, *Metabetaeus lohena*, is a predator of ʻōpae ʻula. *Metabetaeus lohena* can be distinguished from ʻōpae ʻula by its slightly larger size and pincers. Special emphasis is placed on inventories of this species, as it is currently listed as a candidate endangered species by the U.S. Fish and Wildlife Service (2003).

Two native epigeal (or non-subterranean bottom-dwelling) decapod crustaceans, ʻōpae huna (*Palaemon debilis*) and ʻōpae ʻoehaʻa (*Macrobrachium grandimanus*) are also found in, but not restricted to, anchialine pools. ʻŌpae huna, the glass shrimp, is also found in tide pools and coastal waters near the water line along protected rocky shores. ʻŌpae huna are nearly transparent with rows of white spots and various black lines transversing through their body, and have a long upward curving rostrum and bulbous eyes (Hoover 1998). ʻŌpae ʻoehaʻa, the native prawn, also occurs in freshwater habitat, most notably in high island streams. They are light to dark brown in color, sometimes appearing transparent, and have striped pincers, one of which is noticeably larger than the other.

Among other species of crustaceans frequently reported from anchialine pools are marine isopods (e.g. *Ligia* sp.) and amphipods (e.g. Maciolek and Brock 1974; Chai 1998). Black *Ligia* isopods are frequently observed scurrying under emergent sedges and over moist rocks at low tide and there are other isopod species associated with damp, decaying vegetation or organic matter in littoral habitats (Taiti and Howarth 1996). At least twelve species of amphipods, often appearing white, grey or red and including gammarideans and hadzioideans, may occur in anchialine pool habitats (Barnard 1977; Eldredge and Miller 1997).

Euryhaline molluscs (meaning those tolerant of a wide range of salinities) are also frequently reported from anchialine pool environments. The zebra horn, *Cerithium zebrum*, can extend from the intertidal into anchialine pools and become codominant with *Halocaridina* shrimp on *Lyngbya* crusts. Native neritid snails are also a prominent component of many pools, with different nerites occurring in different microhabitats. Non-indigenous thiarid snails (*Thiara* or *Melania* spp) are often the most abundant mollusc occupying anchialine pool habitat especially in degraded pools (Brock and Kam 1997).

Other invertebrates that have been reported from anchialine pools include sponges, hydrozoans, polychaete worms and aquatic insects (Maciolek and Brock 1974; Brock 1985; Chai 1989; Brock and Kam 1997). Insects are the most poorly represented taxa in surveys of anchialine pool surveys. For example, historical anchialine pool surveys of the west coast of Hawai'i Island refer to only a few taxa, such as “dragonfly nymph” or “springtails” (Collembola) and do not generally include aquatic insect fauna in survey reports (c.f. Maciolek and Brock 1974; Brock and Kam 1997). However, swarms of minute flies and darting dragonflies are often conspicuous features of pool systems.

Historical Use and Current Threats

Prior to European contact Hawaiians frequently excavated or otherwise modified anchialine pools to serve as potable water sources, baths, and fishponds. ‘Ōpae ‘ula were also harvested by Hawaiians for use as palu (pulverized bait or chum) to fish for ‘opelu or mackerel scad (*Decapterus macarellus*) in nearshore marine habitats (Stone 1989).

Because of their proximity to the ocean, anchialine pools frequently occupy areas valued for hotel development. An estimated one-third of Hawai‘i Island anchialine pools have been destroyed as part of landscaping for resort construction in South Kohala (Stone 1989). Increased urbanization and demand for water along the Kona coast has also led to decreased groundwater flux, which in turn can decrease the quantity and alter the salinity of groundwater entering pools (Oki et al. 1999). Anchialine pools can also be impacted by contaminated surface water run-off, groundwater pollution, and the historical use of pool basins as refuse pits.

Maciolek and Brock (1974) considered introduced non-native fishes as one of the greatest threats to the preservation of anchialine pool communities. Tilapia

(*Oreochromis* and *Tilapia* spp.) and poecilid guppies (most notably *Gambusia affinis* and *Poecilia spp.*) have been widely introduced to anchialine pool systems and can both compete with (as in the case of algal-feeding tilapia) or directly prey on native anchialine fauna. Ōpae ʻula appear to be especially susceptibility to introduced predators, such as poecilid guppies, and often exhibit a diel activity pattern in the presence of fish, foraging at night in pools containing diurnally active (day-feeding) guppies (Capps et al. 2009). The introduction of fish in anchialine pools also appears to initiate more complex changes in overall community composition of pools and can lead to physical changes in sedimentation, groundwater circulation, and rates of pool senescence (c.f. Brock and Kam 1997).

Inventory Objectives

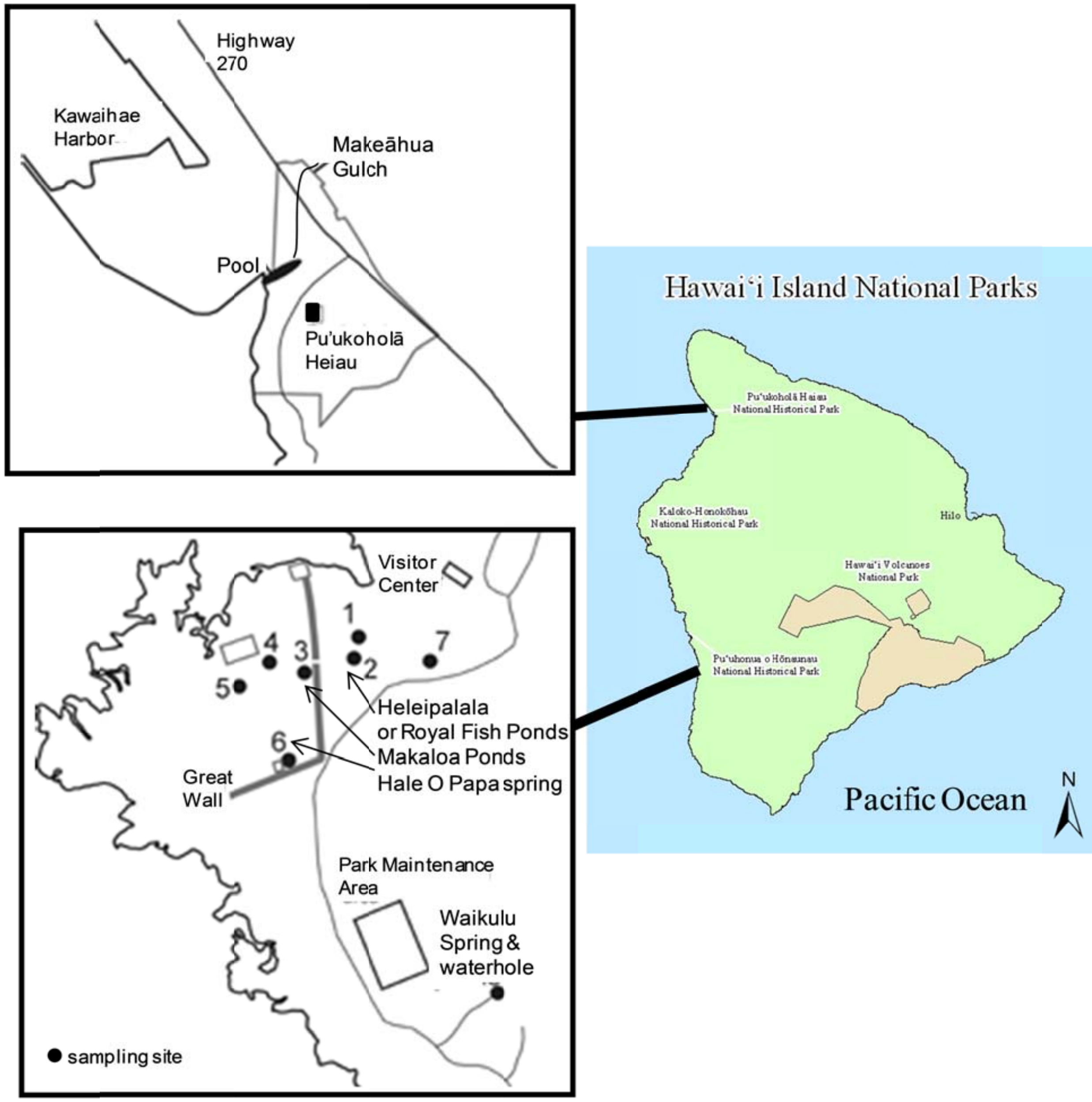
Previous anchialine pool surveys in Hawaiʻi's national parks have focused primarily on crustaceans and other macrofauna, including mollusks and alien fish (e.g. Maciolek and Brock 1974; Chai 1989; Brock and Kam 1997). More comprehensive inventories of anchialine pools were recommended by the Aquatics Working Group at the 2000 NPS Hawaiʻi Bioinventory Workshop. The goal of this inventory was to more fully document aquatic arthropods (crustaceans and insects) associated with anchialine pools at PUHO and PUHE, including candidate endangered species previously recorded from the Kona coast. We also inventoried ants and other non-indigenous arthropods that utilize anchialine pool habitat. These inventories were designed to help provide baseline information necessary for developing management plans for anchialine pools in national parks of Hawaiʻi.

METHODS

Study Sites

Three pool complexes were surveyed at Puʻuhonua o Hōnaunau National Historical Park and Puʻukohola Heiau National Historic Site (Figure 1). PUHO, located south of Kealakekua Bay, is a 74-ha park containing numerous archaeological sites including Hale o Keawe temple, royal fishponds, sledding tracks and coastal village sites. PUHE, the site of Puʻukoholā and Mailekini Heiau, is a 35-ha park immediately adjacent to Kawaihae Harbor to the north and Spencer Beach County Park to the south.

Figure 1. Anchialine pool sampling sites at Pu‘uhonua o Hōnaunau National Historical Park and Pu‘ukoholā Heiau National Historic Site.



Anchialine pools at PUHO have been historically divided by systems of stone walls, with the Great Wall separating the Royal Fishponds on the east and the Makaloa ponds on the west. The Royal Fish Ponds complex is located makai (seaward) of the visitor center along the coastal trail surrounding Hale o Keawe temple. This complex is comprised of approximately seven pools, most of which have been altered, either structurally (e.g. rock wall partitions) or biologically (e.g. introduction of exotic fish). The second complex, Waikulu Springs, is located south of the administrative buildings. It consists of two pools, one clear and deep in a lava crack that is covered with plywood and the other at the base of a large decaying pile of coconut fronds (*Cocos nucifera*). The latter pool is a shallow depression full of sediment and organic matter and contains water only at high tide. It is referred to on early maps as Waikulu water hole (Bryan and Emory 1986). Table 1 provides individual pool descriptions.

Table 1. Anchialine pool site descriptions for Pu'uhonua o Hōnaunau National Historical Park.

Site	NPS No.	Basin type	Dominant vegetation	Location	Prominent Biota
1	HONAUN-2	Rock-walled/ sediment	None	Heleipalala (Royal Fish Pond) east of Great Wall, closest to Ke'one'ele Cove.	Tilapia/ Poecilid fish/
2	HONAUN-3	Sediment/ rock	Milo	Heleipalala (Royal Fish Pond) south of site 1 separated by visitor trail.	Tilapia/ Poecilid fish/Thiarid snails
3	HONAUN-4 HONAUN-6	Sediment/ rock	Makaloa/ 'Ākulikuli/ Milo	Makaloa Pond(s) adjacent to west side of Great Wall-multiple pools joined at high tide.	Tilapia/ Poecilid fish/Thiarid snails
4	HONAUN-5	Rock/ Scytonema mat	None	East and adjacent to Ka'ahumanu Stone; dewatered at low tide	Metabetaeus Macrobrachium
5	unmapped	Rock/ Scytonema mat	None	West and adjacent to site 4; dewatered at low tide	Metabetaeus Nerita polita
6	HONAUN-7	Rock/ Scytonema mat	Pōhuehue	Mapped spring(s) in depression below Hale O Papa near S. wall; dewatered at low tide	Megalagrion Metabetaeus Thiarid snails
7	HONAU-1	Sediment/ Coconut fronds	Sedges/ Coconut	S of Visitor Center restrooms; full of plant litter; no water observed during surveys.	Diptera
8	KEOKEA-3	Rock (covered)	Milo/ Ēkoa	Waikulu Springs covered by wooden board	Halocaridina Metabetaeus
9	KEOKEA-4	Sediment/ rock	Ahu'awa/M akaloa/ Milo/ Ēkoa	Waikulu Springs, mapped "Waikulu waterhole"; dewatered at low tide	Megalagrion Metabetaeus

The PUHE site consists of one long pool in the riverbed of an intermittent stream separated from the ocean by a sand berm. Dominant streamside vegetation is kiawe (*Prosopis pallida*). The bank substrate appeared compacted and eroded along the length of the stream. There was a hardened bedrock-like substance at the mauka (inland) end of the pool approximately 30 m from the pool edge. During the survey, the pool spanned a continuous length of 190 m, but it has been described as at least three pools in previous surveys (cf. Cheney et al. 1977). A gradual bubbling from an underground source was present at the mauka end, suggesting groundwater influx.

Crustacean Trapping

Presence of aquatic crustaceans was measured using two sizes of baited funnel traps. Small traps were made of 3.81 cm diameter black ABS piping with one removable coupling end for a total length of 17 cm. Small mesh drain covers were attached to both ends of the trap. Their respective funnels pointed 2.5 cm into the trap, with a 0.5 cm hole at the base. Traps were baited with four pieces of Purina Friskies Ocean Fish Flavor cat food contained in a mesh envelope. Two 60d galvanized nails were attached to the outside of the trap to provide extra weight. Large traps were composed of 7.62 cm black ABS piping with one removable coupling end for a total length of 15 cm. Large mesh drain covers were attached to both ends of the trap. Their respective funnels pointed 4.35 cm into the trap, with a 1.5 cm hole at the base. Twelve pieces of Purina Friskies Ocean Fish Flavor cat food contained in a mesh envelope were placed inside each trap as bait. Three 60d galvanized nails were attached to the outside of the trap to provide extra weight.

Large traps were used when pool depth was sufficient to cover traps, otherwise the smaller trap size was deployed. Traps were deployed in the deepest section of the pool to avoid trap dewatering at low tide. Upon retrieval, specimens were emptied from the traps, stored in 70% isopropyl alcohol (IOH) and identified at the field station. Species-level crustacean identifications were made primarily with Holthuis (1973) and the Central Pacific Island Environments Project faunal keys (AECOS 2001).

Orthoptera Pitfalls

Presence of crickets was measured using baited pitfall traps. Traps were composed of one liter plastic bottles with the tapering tops cut off and inverted into the bottom of the bottle. A 2.5 cm strip of duct tape was laid along the inverted funnel to form a ramp into the main cavity of the bottle. Traps were baited with approximately 10 g of Dagupan brand Salted Shrimp Fry placed within an uncovered 1 oz Sweetheart brand plastic portion cup at the bottom of the trap. Each trap also displayed a label identifying them as belonging to the anchialine pool monitoring project.

Typically four zones were trapped overnight with four traps each. The zones included the splash zone (coastal lava rocks), strand vegetation, poolside habitat, and the ‘a‘a lava field mauka (mountain side) of the pools. Traps were placed at least two meters from each other. Traps were laid on their sides with a duct tape ramp on the bottom side. Large rocks were placed on and around the traps to hold them in place. Traps were deployed around 18:00 hrs and retrieved from 6-7:00 hrs the next morning to minimize visibility. All specimens in the trap were collected and brought back to the lab for identification using Otte (1994).

Odonate Observations

Odonate observations were made in and around anchialine pools. Individuals, pairs *in copulo*, tandem pairs, and ovipositing females were recorded. Species level damselfly identifications were made using Polhemus and Asquith (1996). Species level dragonfly determinations were made using Dunkle (2000).

Aquatic Diptera Surveys

Pan traps were used to measure the presence and abundance of Diptera in anchialine pool habitats. Pan traps consist of a single 25.5 cm diameter dark green saucer (3.75 cm deep), filled with approximately 400 ml of water. In order to eliminate surface tension, one drop of non-citrus scented dish soap was added to the water and mixed thoroughly. Pan traps were left out for one night, and collected the next morning or afternoon. Specimens were collected from the traps using funnels, strainers, soft forceps or small pipettes. All specimens were placed in vials with 70% IOH, and brought back to the field station for identification. Representatives in the order Diptera were identified to species using *Insects of Hawaii* (Hardy 1960; Hardy 1964; Hardy and Delfinado 1980; Hardy 1981), and all non-Diptera were sorted and identified to at least Order.

Mollusc Surveys

Pool perimeters and sediment were sampled for molluscs. A comprehensive survey of benthic habitat was not carried out. Visual inspection of rocks, emergent vegetation and sediment was made along pool edges. Molluscs attracted to baited crustacean traps were also noted. Specimens were cleaned, dried and identified using primarily Kay (1979).

Plankton Surveys

Preliminary sampling revealed differences in near substrate and open water biota, therefore efforts were made to sample both aquatic habitats for plankton. Substrate sampling was conducted by selecting an area of dominant pool substrate (bare sediment, *Scytonema* mat, and *Cladorphora* growth), stirring the water column immediately above the substrate with a large bulb pipet, and removing 100 ml into a 120 ml container. Open water sampling was conducted by collecting eight liters of water from beneath the pool surface and pouring it through a 0.2 m diameter 153 μm mesh plankton net. The sample was then rinsed into a 120 ml container using pool water strained through the same net. Both substrate and open water sampling were conducted at PUHO; but due to increased pool volume at PUHE a 100 m open water net tow was used instead, resulting in a sample volume of approximately four m^3. No attempt was made to sample meiofauna (e.g. by sediment sampling or scraping rocks) beyond that component released into the water column by stirring action over the substrate.

All samples were brought back to the field station, stored at room temperature, and sorted as soon as possible, always within five days. Lab analysis consisted of photographing, measuring, identifying, and describing representatives from each taxonomic group using dissecting and compound microscopes. Specimen photos were taken with a Nikon Coolpix 4500 digital camera. Specimen identifications were made using Smith and Carlton (1975) and Thorp and Covich (1991).

Water Quality Assessment

Measurements of water quality (salinity, specific conductivity and temperature) were taken at six of the seven sites surveyed at PUHO. Water quality at Site 7 was not assessed as it did not contain water at the time of sampling. Data were collected using a portable YSI Model 30 multiprobe. To stratify for spatial variability for parameters within a pool, all water quality measurements were taken at five meter intervals around the perimeter of each pool, approximately one meter from the margin at a depth of 10 cm. For pools that were less than five meters in circumference, a single measurement was taken at 10 cm depth at the center of the pool. Surveys were completed as close to high tide (during large to intermediate tide heights) as possible, with sampling occurring between 1.5 hours before and after published high tides for Kailua-Kona. Sites 1–3 were surveyed on 16 June 2005 and sites 4–9 were surveyed on 28 June 2005.

Water quality measurements at PUHE were taken with a Hydrolab Quanta multiprobe. Parameters measured included salinity, specific conductivity, temperature, pH and dissolved oxygen. Measurements were taken every 40 m along the 190m long-axis of the pool, beginning inland and moving toward the beach berm. Four measurements were taken at 0 m, 40 m, 80 m, and 120 m.

RESULTS

Crustacea

The distribution of crustaceans observed at the two parks is listed in Table 2. Trapping efforts at Heleipalala (the Fishponds and Makaloa Ponds) at PUHO yielded no crustaceans; however, representatives of *Halocaridina rubra* and/or *Metabetaeus lohena* were sighted or netted at three of the nearby rock basin pools containing *Scytonema* blue-green algal mats, including the Hale O Papa spring (site 6). A single immature prawn with orange eye-shine, probably ‘ōpae ‘oeha‘a (*Macrobrachium grandimanus*) was observed at night at site 5. No crustaceans were observed at the Royal Fishponds or at the Makaloa Ponds. Both *Halocaridina rubra* and *Metabetaeus lohena* were observed at the covered pool at Waikulu Springs (site 8): a total of 18 individuals of *M. lohena* were trapped at this site. No other crustaceans were observed at Waikulu Springs.

Trapping efforts at the PUHE pool yielded no crustaceans. However, the native prawn, ʻōpae ʻoehaʻa (*Macrobrachium grandimanus*), and glass shrimp, ʻōpae huna (*Palaemon debilis*) were both observed within the pool.

Table 2. Crustaceans observed at anchialine pools in Puʻuhonua o Hōnaunau National Historical Park and Puʻukoholā Heiau National Historic Site. Specimens were sampled with traps or visually identified.

		Survey Site*		
Family and Species	**Status**	**PUHO-FP**	**PUHO-WS**	**PUHE**
FAMILY ALPHEIDAE				
Metabetaeus lohena (Banner & Banner 1960)	Indigenous	+	+	–
FAMILY ATYIDAE				
Halocaridina rubra (Holthuis 1973)	Endemic	+?	+	–
FAMILY PALAEMONIDAE				
Macrobrachium grandimanus? (Randall 1940)	Indigenous	+	–	+
Palaemon debilis (Dana 1852)	Indigenous	–	–	+

*PUHO-FP = Puʻuhonua o Hōnaunau National Historical Park, Heleipalala (Fishponds)
PUHO-WS = Puʻuhonua o Hōnaunau National Historical Park, Waikulu Springs
PUHE = Puʻukoholā Heiau National Historic Site

Orthoptera

A total of 25 crickets were collected from the Royal Fishponds at PUHO. All identifiable individuals (88%, n = 22) were the indigenous *Thetella tarnis*, found primarily in the poolside vegetation and splash zones. A single individual *T. tarnis* was observed foraging on exposed *Scytonema* mats at low tide at site 6. The remaining three crickets collected were either juveniles or unidentifiable species. Two species of unidentified crickets were also collected from the Waikulu Springs. Two unidentified crickets were collected from the mauka (mountainward) zone at PUHE, but did not match either *Thetella* or *Caconemobius*.

Odonata

A single male orangeblack Hawaiian damselfly, *Megalagrion xanthomelas*, was sighted perched on sedges at the water hole at Waikulu (site 9). Another male and a tandem pair of this endemic damselfly were also observed at the Makaloa pond (site 3) along with several male non-indigenous Rambur's forktail damselflies (*Ishnura ramburii*). A lone indigenous globe skimmer dragonfly (*Pantala flavescens*) was observed near the trail leading to Waikulu spring and later one was observed flying over Haleipalala. A tandem pair of the indigenous green darner (*Anax junius*) was observed ovipositing at the water's edge at the Makaloa pond. These same two native dragonflies, the green darner and globe skimmer, were observed at PUHE along with the adventive black saddlebags dragonfly (*Tramea lacerata*) and Rambur's forktail damselfly. *Megalagrion* damselflies were not observed at PUHE.

Table 3. Odonates observed at anchialine pools in Puʻuhonua o Hōnaunau National Historical Park and Puʻukoholā Heiau National Historic Site.

		Survey Site*		
Family and Species	**Status**	**PUHO-FP**	**PUHO-WS**	**PUHE**
FAMILY AESHNIDAE				
Anax junius (Drury 1770)	Indigenous	+	+	+
FAMILY COENAGRIONIDAE				
Ishnura ramburii (Selys-Longchamps 1876)	Adventive	+		+
Megalagrion xanthomelas (Selys-Longchamps 1876)	Endemic	+?	+	–
FAMILY LIBELLULIDAE				
Pantala flavescens (Fabricius 1798)	Indigenous	+	+	+
Tramea lacerate (Hagen 1861)	Adventive	-	-	+

*PUHO-FP = Puʻuhonua o Hōnaunau National Historical Park, Haleipalala (Fishponds)
PUHO-WS = Puʻuhonua o Hōnaunau National Historical Park, Waikulu Springs
PUHE = Puʻukoholā Heiau National Historic Site

Diptera

A total of twelve Diptera families were detected at PUHO and PUHE (Table 4). Fourteen species representing eight families were collected from eight pan traps at PUHO. Of those, four were native (endemic or indigenous), four were adventive, and six were of unknown status. The last includes those that could not be keyed out to species as well as species apparently not described from Hawaiʻi. A total of 40 flies were collected from PUHO; the most abundant was the adventive phorid *Puliciphora lucifera* with 11 individuals, followed by 10 specimens of an unknown, probably adventive species of dolichopodid. All other flies collected at this site were represented by less than five individuals.

Table 4. Numbers of Diptera collected at anchialine pools in Pu‘uhonua o Hōnaunau National Historical Park and Pu‘ukoholā Heiau National Historic Site.

		Survey Site*		
Family and Species	**Status**	**PUHO-FP**	**PUHO-WS**	**PUHE**
Cecidomyiidae				
Cecidomyiinae		1		116
Contarinia sorghicola (Coquillett 1899)	Adventive			35
*Lestodiplosis fimicola (*Hardy 1960)	Endemic			1
Ceratopogonidae				
Dasyhelea calvescens (Macfie 1938)	Indigenous	1		
Dasyhelea hawaiiensis (Macfie 1934)	Endemic	1		
Dasyhelea sp. 1				2
Chironomidae				
Ablabesmyia sp.				15
Chironomus crassiforceps (Kieffer 1916)	Adventive			81
Chironomus hawaiiensis (Grimshaw 1901)	Endemic?			10
Chironomus sp. 1			2	4
Chironomus sp. 2				4
Polypedilum nubiferum (Skuse 1889)	Adventive			326
Pseudosmittia sp. 1		1		3
Tanytarsus sp. 1				451
Chloropidae				
Dicraeus sp.?		1		1
Liohippelates collusor (Townsend 1895)	Adventive			7
Culicidae				
Aedes albopictus	Adventive			1
Dolichopodidae				
Chrysotus longipalpus (Aldrich 1896)	Adventive	3		
Dolichopodidae gen. sp.		9	1	1
Drospohilidae				
Drosophila simulans (Sturtevant 1919)	Adventive			1

Table 4 (continued). Numbers of Diptera collected at anchialine pools in Pu‘uhonua o Hōnaunau National Historical Park and Pu‘ukoholā Heiau National Historic Site.

		Survey Site*		
Family and Species	**Status**	**PUHO-FP**	**PUHO-WS**	**PUHE**
Ephydridae				
Atissa oahuensis (Cresson 1948)	Endemic	3	1	6
Brachydeutera sp. 1				4
Clasiopella uncinata (Hendel 1914)	Endemic	1		7
Hecamede granifera (Thomson 1869)	Adventive	1		
Psilopa girschneri (Von Roeder 1889)	Adventive			3
Scatella stagnalis (Fallen 1813)	Adventive			2
Milichiidae?				2
Phoridae				
Megaselia sp. 1				12
Puliciphora lucifera (Dahl 1897)	Adventive	10	1	1
Psychodidae				
Psychoda inornata (Grimshaw 1901)	Adventive			5
Psychoda pseudalternata (Williams 1946)	Adventive			15
Psychoda savaiiensis (Edwards 1928)	Adventive			1
Psychoda spp. male				11
Sciaridae				
Bradysia sp. 1		2		1
Plastosciara adrostylata (Hardy 1956)	Endemic		1	

*PUHO-FP = Pu‘uhonua o Hōnaunau National Historical Park, Haleipalala (Fishponds)
PUHO-WS = Pu‘uhonua o Hōnaunau National Historical Park, Waikulu Springs
PUHE = Pu‘ukoholā Heiau National Historic Site

PUHE pan traps produced high levels of both abundance and diversity of Diptera. Only four traps were set out, but they collected 1,129 individuals representing 30 species in 12 families. Of the 30 species, three were native, 13 adventive, and the remainder of unknown status. However, two adventive chironomid midge species accounted for over two-thirds of the individuals: an unidentified species of *Tanytarsus* (40%) and *Polypedilum nubiferum* (29%). Largely due to these two species, members of the family Chironomidae comprised 79% of trap contents. Next in abundance were unidentified species (possibly more than one) in the taxonomically difficult family Cecidomyiidae (10%), *Chironomus crassiforceps* (7%) and *Contarinia sorghicola* (3%). All other Diptera collected were represented by less than 15 individuals (<1.5%).

Molluscs

A small unidentified non-indigenous thiarid snail (probably the “Melania” snail reported from other anchialine pools in Hawaii, *Terebia granifera*?) was the most frequently encountered at Haleipalala and the Makaloa Pond (sites 1-3), followed by clusters of the likely indigenous black purse-oyster (*Isognomon californicum*) concentrated in cracks at the rock-basin pools. Site 5 contained the highest diversity of molluscs, including *Isognomon* and the pulmonate snail, *Melampus parvulus*, along with *Nerita polita* and *Neripteron neglectus* that were observed under rocks. Littorines were also observed at pool 5 high up on rock surfaces but were not collected. *Neripteron cariosum* was observed at Haleipalala and Makaloa Ponds. Alien thiarids were also recovered from crustacean traps at the waterhole at Waikulu.

The molluscan fauna at PUHE appeared to be restricted to the intertidal zone and were not observed in the pool.

Table 5. Molluscs observed at anchialine pools in Pu‘uhonua o Hōnaunau National Historical Park and Pu‘ukoholā Heiau National Historic Site.

		Survey Site*		
Family and Species	**Status**	**PUHO-FP**	**PUHO-WS**	**PUHE**
FAMILY ISOGNOMONIDAE				
Isognomon californicum (Conrad 1837)	Endemic?			
FAMILY MELAMPIDAE				
Melampus parvulus (Pfeiffer 1846)	Indigenous	+	–	–
FAMILY NERITIDAE				
Neripteron cariosum (Wood 1828)	Endemic	+	–	–
Neripteron neglectum (Pease 1861)	Endemic	+	–	–
Nerita polita (Linnaeus 1758)	Indigenous	+	–	–
FAMILY THIARIDAE				
Thiarid sp.	Adventive	+	+	–

*PUHO-FP = Pu‘uhonua o Hōnaunau National Historical Park, Haleipalala (Fishponds)
PUHO-WS = Pu‘uhonua o Hōnaunau National Historical Park, Waikulu Springs
PUHE = Pu‘ukoholā Heiau National Historic Site

Plankton

Zooplankton sampling revealed a very high diversity of organisms, spanning three kingdoms (Bacteria, Protista, and Animalia) and seven phyla (Table 3). Taxon richness was particularly high at Haleipalala and Makaloa Pond at PUHO. Between the six sites sampled, Crustacea was represented by six different taxa: two copepods (orders Harpacticoida and Cyclopoida) and four taxa of ostracods. Four of these crustacean taxa occurred in more than one pool. Of the 13 protist taxa found, 10 belonged to phylum Ciliaphora (including families Euplotidae and Trachelliidae) and three belonged to phylum Diatomatae (order Pennales, groups Surirelloid and Eunotioid). Two rotifers and at least one nematode were also found. Zooplankton sampling at PUHO's two Waikulu Spring sites revealed only one taxa of crustacean (subclass Copepoda, order Harpacticoida), and four Ciliaphora protists.

Plankton diversity at PUHE was largely limited to bacterioplankton and protists. Bacteria of the phylum Spirochaetae were encountered in high densities, along with five different diatoms (orders Centrales and Pennales) and three types of ciliaphores. Additionally, one microturbellarian specimen (Platyhelmenthes, Turbellaria) was found.

Table 6. Plankton taxa present in anchialine pools in Puʻuhonua o Hōnaunau National Historical Park and Puʻukoholā Heiau National Historic Site. Numbers of distinct morphotypes are given.

Taxa	Survey Site* PUHO-FP	PUHO-WS	PUHE
ARTHROPODA: CRUSTACEA			
Copepoda: Cyclopoida	1		
Copepoda: Harpacticoida	1	1	
Ostracoda	4		
NEMATODA	1		
PLATYHELMENTHES			
Turbellaria			1
PROTISTA			
Ciliophora: Euplotidae	1		
Ciliophora: Trachelliidae	1		
Ciliophora: Other	8	4	3
Diatomatae: Centrales			1
Diatomatae: Pennales	3		4
PROKARYOTE			
Bacteria: Spirochetae			1
ROTIFERA	2		

*PUHO-FP = Puʻuhonua o Hōnaunau National Historical Park, Haleipalala (Fishponds)
PUHO-WS = Puʻuhonua o Hōnaunau National Historical Park, Waikulu Springs
PUHE = Puʻukoholā Heiau National Historic Site

Other Invertebrates

<u>Ants</u>

Formal ant surveys using baited traps were not conducted at PUHO and PUHE. However, a considerable level of ant diversity was detected in the pitfall and pan trap samples. A total of 12 species of ants were found at PUHO, with much higher diversity at Haleipalala than at Waikulu Springs (Table 7). *Tetramorium bicarinatum* was the most abundant species present at Haleipalala (39%), followed by *Tetramorium simillimum* (20%), *Anoplolepis gracilipes* (19%) and *Paratrechina vaga* (17%). The remaining nine species collected from this complex were represented by less than 10 individuals. At the Waikulu Springs, *Tetramorium insolens* was the most abundant species (94% of specimens collected) followed by *Paratrechina vaga*, *Camponotus variegatus* and *Tetramorium simillimum*, the latter three represented by less than 10 individuals.

Four ant species were found at PUHE, all in very low numbers (less than five individuals each). *Monomorium floricola* (represented by two individuals) was the only species found at PUHE but not at PUHO.

Table 7. Ant species (numbers of individuals) observed at Puʻuhonua o Hōnaunau National Historical Park and Puʻukoholā Heiau National Historic Site.

Species	Survey Site* PUHO-FP	PUHO-WS	PUHE
Anoplolepis gracilipes (F. Smith 1857)	70		
Camponotus variegatus (F. Smith 1858)	7	6	2
Monomorium destructor (Jerdon 1851)	1		
Monomorium floricola (Jerdon, 1851)			2
Ochetellus glaber (Mayr, 1862)	1		
Paratrechina vaga (Forel, 1901)	60	7	
Pheidole fervens (Smith 1858)	1		
Plagiolepis alluaudi (Emery 1894)	1		
Solenopsis papuana (Emery 1900)	3		4
Tapinoma melanocephalum (Fabricius 1793)	1		3
Tetramorium bicarinatum (Nylander 1847)	139		
Tetramorium insolens (F. Smith 1861)		217	
Tetramorium simillimum (F. Smith 1851)	72	2	
unidentified	3		

*PUHO-FP = Puʻuhonua o Hōnaunau National Historical Park, Haleipalala (Fishponds)
PUHO-WS = Puʻuhonua o Hōnaunau National Historical Park, Waikulu Springs
PUHE = Puʻukoholā Heiau National Historic Site

Additional Trap Contents

In addition to ants, many pitfalls were teeming with Blattaria (cockroaches), *Ligia* isopods (slaters) and terrestrial amphipods (landhoppers). Excluding Orthoptera, isopods composed 47% (n = 41) of the trap contents at Haleipalala followed by amphipods (39%, n = 34), cockroaches (13%, n = 11) and spiders (<1%, n =2). Similarly, at the Waikulu Springs amphipods comprised 52% (n = 212) of the pitfall trap contents followed by isopods (38%, n = 156), cockroaches (9%, n = 35) and one *Polistes* wasp (1%).

No amphipods or cockroaches were trapped at PUHE. *Ligia* isopods made up the vast majority, 86% (n = 6) of the pitfall trap contents along with one spider (14%).

Pan traps at PUHO also revealed a diversity of other groups of arthropods (Table 8). Acari (mites) were most abundant (50% of individuals) at Haleipalala followed by Collembola (springtails, 28%) and Hymenoptera (bees and wasps, 9%). The remaining eight orders collected from pan traps at these pools were represented by five or fewer individuals. At the Waikulu Springs, Collembola were extremely abundant, comprising 88% of the pan trap contents. Coleoptera, Homoptera, Hymenoptera, Isopoda, and Thysanoptera (thrips) were also trapped from the Waikulu Springs but in small numbers.

Collembola was also the most abundant arthropod collected from pan traps at PUHE. Springtails comprised 31% of trap contents followed by Homoptera and Hymenoptera (both 22%), Araneae (spiders, 9%), Coleoptera (beetles, 6%) and Lepidoptera (moths, 6%). A few Acari and Thysanoptera were also collected.

Table 8. Pan trap contents (by order, excluding Diptera) from anchialine pools sites in Puʻuhonua o Hōnaunau National Historical Park and Puʻukoholā Heiau National Historic Site.

	Survey Site*		
Order	PUHO-RFP	PUHO-WS	PUHE
Acari	71		1
Amphipoda	1	71	
Aranea	5		11
Blattaria	1		
Coleoptera / Coleoptera larvae	4	1	7
Collembola	40	621	37
Hemiptera			
Homoptera	3	5	26
Hymenoptera	12	2	26
Isopoda		2	
Lepidoptera / Lepidoptera larvae	1		7
Orthoptera	2		
Thysanoptera	1	1	3

*PUHO-FP = Puʻuhonua o Hōnaunau National Historical Park, Haleipalala (Fishponds)
PUHO-WS = Puʻuhonua o Hōnaunau National Historical Park, Waikulu Springs
PUHE = Puʻukoholā Heiau National Historic Site

Water Quality

Table 9 summarizes water quality measurements made at the three anchialine pool complexes. At PUHO, the major difference between pool complexes was the lower salinity of the Waikulu Spring pools in contrast to Haleipalala and the Makaloa Ponds. The pool at PUHE also exhibited low salinity.

Table 9. Water quality summary for anchialine pools at Pu'uhonua o Hōnaunau National Historical Park and Pu'ukoholā Heiau National Historic Site.

	Survey Site*								
	PUHO-FP (n = 6)			PUHO-WS (n = 2)			PUHE (n = 4)		
Parameter[#]	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Temp (°C)	28.35	31.4	25.5	27.4	31.6	23.2	29.26	29.37	29.13
SpC (mS/cm)	21.50	26.58	17.87	12.14	12.3	12	4.86	4.87	4.85
DO (mg/L)							8.66	9.64	8.01
pH							8.71	8.87	8.55
Salinity (PSS)	12.82	16.2	10.3	6.95	7.1	6.8	2.61	2.61	2.6
DO% (Sat)							138.20	155.1	119.3

*PUHO-RFP = Pu'uhonua o Hōnaunau National Historical Park, Haleipalala (Fishponds)
PUHO-WS = Pu'uhonua o Hōnaunau National Historical Park, Waikulu Springs
PUHE = Pu'ukoholā Heiau National Historic Site
[#] Temp = temperature, SpC = specific conductivity, DO = dissolved oxygen

DISCUSSION

This report documents the presence of a number of anchialine pool crustaceans and a greater diversity other aquatic arthropods within PUHO in contrast to generally lower endemism and species diversity at PUHE. Two candidate endangered arthropods (the hypogeal shrimp, *Metabetaeus lohena*, and the orange black Hawaiian damselfly, *Megalagrion xanthomelas*) were found at PUHO. Earlier anchialine pool surveys at PUHO focused on Haleipalala and Makaloa Pond (e.g. Oceanic Institute 1992; Chai 1999) and did not detect hypogeal crustaceans, while the endemic damselflies (along with many other endemic aquatic insects) have been generally overlooked during biological assessments of anchialine pools in Hawaii. This is the first report of these candidate endangered anchialine pool arthropods at PUHO.

Heleipalala and the Makaloa Ponds are separated by the Great Wall, yet likely formed one large contiguous wetland prior to human settlement of the area. These anchialine pools support several native plant species and have probably acted historically as sediment accumulation basins supporting dynamic wetland plant communities (Pratt 1998). Descriptions of Haleipalala from 1919 indicate that at least sections of it were full of sediment and dewatered at low tide (Bryan and Emory 1986). The sediment load may have increased with erosion resulting from the introduction of ungulates or increased nutrient input (e.g. possibly as a result of construction of a cesspool nearby - see Doty 1969). However, it is not clear that this wetland ever formed suitable habitat for hypogeal crustaceans given the native plant community and history of sedimentation. While alien fish, such as Tilapia, may precipitate the conversion of anchialine pools to wetlands (c.f. Brock and Kam 1997), the wetland marsh at PUHO appears to predate the introduction of alien fish.

This is also probably the situation at PUHE, where large quantities of sediments are washed down Makeāhua Gulch during heavy rainfall and appear to build-up behind the sand berm at the terminus of the gulch. Access to interstitial groundwater zones supporting hypogeal crustaceans is probably blocked by accumulated fine sediments.

In contrast, springs and rocky basin pools at PUHO do support hypogeal crustaceans and endemic damselflies. In 2004, at least one historical mapped spring along the Great Wall was full of rock and coral rubble, but had been cleared out at least once in 1919 following past tsunami or storm surge events (Bryan and Emory 1986) only to be filled in again. Keeping these historical springs and other rock-basin pool sites free of accumulated rubble may enhance viewing opportunities for hypogeal crustaceans as well as help to interpret historical and cultural use of groundwater.

Several spring sites at PUHO were overgrown with either milo (*Thespesia populnea*) or naupaka (Scaevola taccada) and it was at these sites where candidate endangered orange black damselflies were observed. This association between dense poolside vegetation and the presence of this endemic damselfly has also been observed at several other anchialine pool complexes where the damselfly persists, including naupaka-shaded pools near ‘Ahihi Kina‘u on Maui and milo-shaded pools at Kaloko Honokōhau and Keaukaha on Hawai’i Island (Foote, unpubl. data). Vegetation cover may be important for thermoregulation and/or protection from predators for populations of *Megalagrion* damselflies. It has been recommended that dense stands of milo should be allowed to remain at PUHO to serve as a visual screen between the Royal Grounds and park access roads (Pratt 1998). These same stands of milo, including those found at Waikulu Spring, as well as naupaka encroaching on some pools (i.e. site 6) may also form important habitat for the candidate endangered damselfly, *Megalagrion xanthomelas*. The habitat requirements for this species needs to be better defined prior to restoration programs that involve vegetation removal.

Pitfall trapping was successful in detecting the characteristic native cricket fauna. *Thetella tarnis*, the most abundant species collected at PUHO, is distributed throughout the Pacific and Maldives and typically inhabits rocky coastal areas among wet boulders in cracks and crevices in the splash zone (Otte 1994). At least two species of *Caconemobius*, *C. anahulu* and *C. sandwichensis*, are also reported from the Kona Coast (Otte 1994), but none were detected at either park.

The diversity of Diptera detected using pan traps was high at both parks. Among the Diptera, in contrast to other groups of arthropods, diversity was considerably higher at PUHE than at PUHO. However, most aquatic Diptera breed in freshwater, and the abundance of chironomids at PUHE compared to their near-absence from PUHO may be related to the much lower salinity of the PUHE pool. Also unusual is the fact that many of the species (43% at PUHO and 47% at PUHE) could not be placed with species in *Insects of Hawaiʻi* or Nishida (2002), and are either undescribed endemics or recently-arrived aliens. The proximity of PUHE to the Kawaihae harbor and the general depletion of the native lowland fauna make the latter explanation more likely, although the *Pseudosmittia* and *Dasyhelea* species belong to genera with several native species that persist in the lowlands, and lack known adventives.

Several species had been previously recorded from the state but not the island of Hawaiʻi. These include the endemic ephydrid *Atissa oahuensis* as well as adventive species such as *Liohippelates collusor* and *Psychoda pseudalternata*. One species in particular, *Ablabesmyia* sp., is of special interest as it was only recently documented in Hawaii on Oahu and was previously known only from larvae collected from an Oʻahu stream (Wolff et al., 2002). Larvae of two genera of Tanytarsini (Chironomidae) were also found by Wolff et al. (2002), but the species found here does not belong to either of those and is probably a species of *Tanytarsus*. The rapid arrival of at least three species in a tribe that was previously represented by only a single endemic radiation is notable. The unidentified *Tanytarsus* fly at PUHE was the most abundant species collected in the pan traps there, and it will be interesting to determine its full range and impact on Diptera communities in other areas of Kona.

The relative scarcity of freshwater along the Kona Coast means that ants frequently congregate at anchialine pools and may have undesired impacts on other arthropod fauna. Although PUHE has the potential for many ant introductions due to its proximity to Kawaihae harbor, it is also located in one of the driest parts of the island and ants are generally absent from xeric (dry) habitats in Hawaii. The fact that ants were both more common and abundant at PUHO compared to PUHE may also reflect PUHO's longer history of public use. For example, long-legged ants, *Anoplolepis gracilipes,* a species frequently associated with human activity, was absent from PUHE, but relatively common at PUHO, even despite the dominance of three species of *Tetramorium* there. It would be useful to carry out specific baiting for ants to better determine their distribution.

Springtails (Collembola) were the most abundant arthropod collected in pan traps. They were extremely abundant in the samples from Waikulu Springs and this may be a consequence of the use of this site as a green waste dump, creating large quantities decaying organic matter. The majority of springtail species feed on decaying plant material (in this case, coconut fronds) and associated fungal hyphae. Collembola were also relatively abundant at PUHE, where the sampling site was a soil bank along the length of the pool with a layer of decaying leaf litter. In contrast to these sites, Haleipalala and the Makaloa Pond are surrounded by relatively open basalt with little surface organic matter, and had correspondingly low numbers of Collembola.

At PUHO, pool salinities and water temperature were greater at Haleipalala and Makaloa Pond than at the Waikulu Springs. Pool salinities Haleipalala were almost twice as high as values of the Waikulu Springs, while the pool at PUHE had only mildly brackish water with the lowest recorded salinity. The pool at PUHE has been described in some park literature as “hypersaline”. However, our measurements showing mildly brackish water conditions are consistent with past surveys (e.g. Maciolek and Brock 1974; Cheney et al 1977).

More information is needed to determine the habitat requirements of the two candidate endangered arthropods found in association with anchialine pools at PUHO. Details on the interrelationships of pool sediment loads, vegetation, water quality and alien aquatic species will allow development of anchialine pool management plans that will help preserve these and other rare anchialine pool species and communities. Park anchialine pools appear to be ideally suited for joint interpretation of cultural and natural resource values. This report contributes to building an appreciation of the full biological diversity supported by anchialine pool ecosystems in national parks of Hawaii.

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