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Technical Report 69

AN INVENTORY AND ASSESSMENT OF ANCHIALINE POOLS IN HAWAII VOLCANOES NATIONAL PARK FROM WAHA'ULA TO KA'AHA, PUNA AND KA'U, HAWAI'I

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February 1989

UNIVERSITY OF HAWAII AT MANOA

NATIONAL PARK SERVICE CONTRACT NO. CA 8015-2-0001

ABSTRACT

Seven sites containing a total of 19 anchialine pools were examined along the coast of Hawaii Volcanoes National Park (HAVO) in May and July, 1988. Location, physical characteristics, aquatic macrofauna, and floral communities were recorded from 14 pools (one had no fauna). Fauna included 17 taxa (seven fishes, nine crustaceans, one mollusk). Flora recorded from the pools was in most cases a mixed community of cyanophytes; relatively few pools contained chlorophytes, rhodophytes, and chrysophytes. Reduction of the native biota in many anchialine pools of HAVO is largely attributed to the alien prawn Macrobrachium lar and the advanced senescence of two pool complex sites. The alien sourbush, Pluchea odorata, accelerates senescence of pools by contributing litter. Results of this study are compared with those from anchialine pools of other locations in Hawai'i, and management recommendations are provided.

INTRODUCTION

During a preliminary aerial survey of coastal ponds by the U.S. Fish and Wildlife Service in 1986 (Yuen 1986), several anchialine pool sites were tentatively identified in Hawaii Volcanoes National Park (HAVO) between Waha'ula and Ka'aha (Figs. 1-4). Anchialine pools are recognized as unique aquatic ecosystems geographically limited in the United States to Hawai'i. Only two other anchialine pool sites in Hawai'i--at Koloko-Honokohau National Historical Park on the island of Hawai'i (Chai, in prep.), and Ahihi-Kinau Natural Area Reserve on Maui (Maciolek 1986)--currently receive some protection.

Anchialine pools are exposed portions of the groundwater table predominantly found on geologically young, porous lavas in the coastal tropics and subtropics. Although anchialine pools have no surface connection to the sea, they exhibit tidal fluctuation and contain water with measurable salinity, indicating a subsurface connection. Most anchialine pools support a unique biota and community structure that is poorly understood. Representative communities in the anchialine habitat exhibit high species endemism, and at least seven aquatic invertebrates and an eel found in these pools are believed to be rare worldwide (The Nature Conservancy of Hawaii 1987).

Two classes of organisms are found in anchialine pools--epigeal and hypogeal species. Epigeal species are light dependent and inhabit the sunlit surface portions of anchialine systems. Many epigeal species that inhabit anchialine pools may be common to other aquatic environments. Hypogeal organisms may inhabit both the sunlit portions of pools and the interconnected subterranean labyrinth within the groundwater table. Hypogeal species are predominantly decapod and amphipod crustaceans, several of which are found only in the anchialine habitat. Anchialine pools have been described as "windows" looking into a vastly unexplored habitat. They are essentially focal points of productivity, providing the major energy source that drives an extensive underground ecosystem (Brock 1985).

Of the estimated 600-650 anchialine pools in the State, East Hawai'i from Leleiwi Point to South Point supports an estimated 169 pools, or approximately 27% of the statewide total. Along the coast of HAVO, 19 pools were examined during the survey, amounting to 11% of the East Hawai'i total. Several more pools are known to exist along the HAVO coast but were not located during this inventory. To date, information on East Hawai'i pools is extremely limited. Only three other sites have been surveyed to some extent along this coastline, including King's Landing, Hilo (Chai 1986); Kapoho, Puna; and Lua o Palahemo, South Point.

The primary objectives of this study were to:

1. Inventory and evaluate the physical and biological resources associated with anchialine pools within HAVO.
2. Assess the scientific and natural value of the Park's pools.
3. Provide a comparative assessment with selected West Hawai'i and Maui pools.

4. Suggest possible management strategies to preserve and restore the Park's native anchialine ecosystem.

APPROACH AND METHODS

The field survey from 'Apua Point to Halape was conducted from May 9 to 11, 1988. Anchialine pool sites at Ka'aha and Kalu'e were surveyed from May 26 to 27, and Waha'ula was done on July 20, 1988. All sites were visually inspected at least once during the day and at night, at or near high tide periods. Since the inventory of aquatic fauna was of primary significance, intensive surveying was conducted during nocturnal high tides (a period conducive to faunal activity in anchialine pools).

Temperature and salinity were measured with a YSI model 33 S-C-T meter and were taken in all pools during a high tide. Temperature was measured in degrees Celsius, and salinity was measured in parts per thousand ($^{o}/oo$). In anchialine pools greater than one meter deep, subsurface and bottom measurements were taken to determine stratification. In pools less than one meter deep, only stable bottom measurements were taken. Surface salinity measurements often fluctuate with the influx of fresh groundwater. Temperature and salinity were selected for measurement because they are two essential limiting factors governing populations of aquatic organisms in the anchialine biotope, and instruments used to measure temperature and salinity are readily obtainable and easily transported in the field. Other water charateristics such as pH, dissolved oxygen, nutrients, reduction-oxidation potential, and specific ions present, are also important factors to be considered in an aquatic ecosystem but were beyond the scope of this study.

Anchialine pools were inventoried by netting, snorkeling, baiting to attract fauna, or visual observation from above, depending on size and depth of the pool. Specimens caught for observation were subsequently released. Algal specimens collected in the field were preserved in a 10% formalin solution and were later identified using a 440X standard microscope. Extreme difficulty was encountered in positively identifying most microalgae. Therefore, algae that could not be identified at the genus or species level were classified to Division with comments on growth form, e.g. matted filamentous cyanophyte community, etc. The anchialine pool data recorded in this study were: dimensions; basin character and composition; temperature, salinity, and turbidity; transient species (birds, etc.); distance and connection to sea; faunal and floral community inventory; and riparian and emergent vegetation. Plant nomenclature is according to St. John (1973).

A map of pool sites was provided by the U.S. Fish and Wildlife Service from its 1986 aerial survey of coastal ponds. Anchialine pool sites observed during this study were recorded on a U.S. Geological Survey topographic map.

RESULTS AND DISCUSSION

A total of 19 pools was examined within eight separate sites. The eight sites are: Waha'ula cave (Fig. 2); two separate complexes between 'Apua Point and Keauhou Point (Fig. 3); Halape crack and Boulder Bay (Fig. 4); Ka'aha crack; and Kalu'e crack (Fig. 4). A pool at Waha'ula nature trail and the pool within Kalu'e crack were only superficially surveyed. The Waha'ula nature trail pool was small (< 1.5 m), littered with coins, and devoid of any fauna, and data from this pool are not included in this report. It may be possible that ongoing lava flows are contributing contaminants to the pool. Further chemical testing should be done to examine the effects of recent lava flows on the groundwater supply in the area. A relatively large pool at Kalu'e is located within a crack with vertical walls and is inaccessible for detailed examination. However, temperature and salinity were measured at the surface and at a depth of 3 m.

A taxonomic list of aquatic fauna found is presented in Table 1; occurrence of the fauna in each of 13 of the 19 pools is summarized in Table 2; physical measurements are given in Table 3; and emergent and terrestrial vegetation are listed in Table 4. The following inventory of anchialine pool complexes and individual pools is presented in progression from northeast to southwest along the National Park's coastline.

WAHA'ULA CAVE - 1

This unique anchialine pool series is located within a dark cave nearly 700 m from shore, inland of Waha'ula Visitor Center. The pool series is an exposed portion of the water table deep within a crack that runs parallel to the shoreline. Within the cave are three distinguishable chambers (A, B, and C), each containing exposed water that is interconnected. Temperature and salinity recorded from this series were 25.5 C and 0.75 $^{o}/_{oo}$.

Chamber A is nearest to the surface opening and contains the largest and deepest portion of the pool series, measuring 12 x 3 x 2.0-2.7 m (length x width x depth). This chamber contained the only fauna recorded from this series. The remaining two chambers (B and C) extend north and contain smaller oligotrophic (organic-free) portions of the pool series and no apparent biota. Dimensions of the pool series in Chambers B and C are 4 x 2 x 2 m, and 3 x 1.5 x 1 m. Salinity and temperature are assumed identical to the portion of the series in Chamber A because of direct subsurface connections. National Park Service archaeologist Laura Carter suggested that the Waha'ula pool was probably used by an extensive population of ancient Hawaiians. The extremely low salinity level (sea water is 32-35 $^{o}/_{oo}$) would undoubtedly have permitted domestic use.

Only four other sites in Hawai'i contain similar anchialine cave pools: King's Landing, Hilo (Chai 1986), 'Opihikao hot cave, Puna, and Waipouli cave, Ka'u, on the island of Hawai'i; and Wai'anapanapa caves, on Maui. Waha'ula cave is a deep crack and not a lava tube, which distinguishes this anchialine pool from all others in Hawai'i.

The abundance of aquatic fauna is predictably low within the cave. However, a moderate diversity of representative anchialine fauna is present. Hypogeal species recorded from the cave include an endemic atyid shrimp Halocaridina rubra ('opae 'ula), a native endemic alpheid shrimp Metabetaeus lohena ('opae 'ula), an epigeal native prawn Macrobrachium grandimanus ('opae 'oeha'a), and a blind amphipod as yet unclassified but similar to others recently found at King's Landing and Waipouli (Chai 1986). The occurrence of the prawn is unusual, since this species has not previously been recorded from a dark cave environment. The absence of pigmentation in the two prawns observed is apparently a partial adaptation to cave existence. Also noted within the pool was a dark-colored supralittoral cockroach, which crawled into the pool and remained submerged for at least 30 minutes. The only sources of energy to support these organisms are derived from Metrosideros polymorpha ('ohi'a) roots and whatever organic material falls into the pools from the surface opening.

WEST 'APUA - 2

This group of pools, located behind a sand-boulder berm nearly 20 m from the sea, consists of a large double pool (A) connected during high tide (Fig. 5) and one small pool (B) 3 m from the larger pools. Dimensions of the connected portions of pool A are 3.5 x 2 x 0.4 m and 2 x 1.5 x 0.3 m. Pool B is 1.5 x 0.2 x 0.1 m. All pools are less than 1 m deep at high tide. Pool A contained flocculent biogenic sediments of 3-4 cm depth overlying a basalt-sand substrate. The remaining basin area, including pool B, contains a sand substrate with an occasional boulder outcrop.

Pool A exhibited a temperature of 32.0 C and salinity of 30.5 $^{o}/_{oo}$). These high values are a result of solar heating and evaporation, accompanied by a poor flushing rate. The poor connection to the groundwater table also explains the absence of motile fauna, which need sufficiently open interstices to access the pools through subterranean passages and escape bird predation. An abundance of shorebird feces was noted on the rocks near the pools. Pool B is shaded by a rock overhang, and biogenic sediments which inhibit flushing were absent. A temperature of 25.2 C and salinity of 4.0 $^{o}/_{oo}$ were measured.

The only representative anchialine species found in moderate abundance was an endemic neritid snail Theodoxus cariosus, attached to rocks in pool A. These mollusks were likely deposited in the pool by high waves. Along the periphery of the largest portion of pool A was a sparse distribution of light-colored algae, identified as a community of filamentous cyanophytes (blue-green algae) and unicellular diatoms.

Riparian vegetation within the entire complex was predominantly native and included a succulent halophyte Sesuvium portulacastrum ('akulikuli) and a sedge Fimbristylis pycnocephala.

EAST KEAUHOU - 3

This shallow-water complex is located nearly 40 m from shore within a large depression with a pahoehoe substrate. The depression contains seven anchialine pools, three of which exhibit no exposed

water during low tide periods and had no apparent macrofauna. These "high tide" pools all contained deep, predominantly organic sediments, with a cyanophyte mat adapted to desiccation covering approximately 98% of the sediment layer. The characteristic hydrogen sulfide odor emanating from the "high tide" pools was an indication that anaerobic processes were at work.

The combined water surface area of all four pools sampled totals 95 m^2. All but two of the pools in the complex were in advanced stages of senescence. Characteristics of advanced senescence include deep organic sediments (4-25 cm), shallow depth (< 0.5 m), encroaching riparian and emergent vegetation, dense algal mats, and reduced flushing rate. Two of the largest direct contributors to the deepening sedimentation in these pools were the alien sourbush Pluchea odorata and a matted algal community.

Pool A

Pool A is an oval, shallow-water exposure measuring 4 x 2.5 x 0.25 m (Fig. 6). Water temperature and salinity were 30 C and 2.8 °/oo. A poor water exchange rate was evident in the pool due to organic sediments up to 15 cm thick.

Nearly 90% of the pool basin was covered by a thin, relatively non-porous cyanophyte mat with traces of filamentous chlorophytes (green algae). Fauna within pool A included Theodoxus cariosus, a grapsid crab Metapograpsus thukuhar, an unidentified gray amphipod, and a gray isopod, the last two approximately 0.5 cm in length. Emergent vegetation included the indigenous sedges Cyperus polystachyus and Fimbristylis pycnocephala. Riparian vegetation was composed of the alien Pluchea odorata and the native Sesuvium portulacastrum.

Pool B

This pool was similiar to pool A in that it contained deep organic sediments of nearly 25 cm and was 95% covered by a thin, cohesive cyanophyte mat (Fig. 7). The dimensions of the pool are 6 x 2.5 x 0.2 m. Temperature in pool B was 30.2 C, and salinity was 2.5 °/oo. A dense thicket of Pluchea odorata surrounded the pool.

The only animals observed were an isopod similar to the specimens in pool A and a single native prawn Macrobrachium grandimanus. This prawn was the only native prawn recorded from the East Keauhou complex.

Pool C

This was the largest "doublet" pool of the complex (Fig. 8), appearing as two pools of similar size and dimension, connected only by a small 30-cm-wide channel. Each half of the pool has approximate dimensions of 6 x 5 x 0.3 m. The water temperature on both sides was 29.0 C, and the salinity was 2.5 °/oo. The basin composition consisted of flocculent biogenic sediments up to 8 cm deep, overlying a pahoehoe substrate. Pool C was without matted cyanophytes, probably because of the abundance of omnivorous crustaceans in the pool. The only macroalgae observed were several clumped growths of a chlorophyte (Enteromorpha sp?).

Pool C had the greatest faunal diversity in the East Keauhou complex, and it was clearly dominated by crustaceans. The various species of crustaceans included (in descending order of abundance): an introduced Tahitian prawn, Macrobrachium lar; a native shrimp, Palaemon debilis; and the two hypogeal shrimps described earlier, Halocaridina rubra and Metabetaeus lohena. Other species were the snail Theodoxus cariosus and a single, large (18 cm) predatory fish, Eleotris sandvicensis ('o'opu 'akupa). During nocturnal sampling, approximately 50-60 juvenile Macrobrachium lar were observed perched over a small (0.5 cm wide) crack containing Halocaridina rubra and Metabetaeus lohena. Upon closer inspection, many of the prawns were seen to capture and consume Halocaridina attempting to exit the crack. No shrimps were observed outside of the crack, an indication of the introduced prawns' efficiency. Since the moon had not yet risen, it was assumed that prawns used tactile senses to locate and capture the shrimps. The predatory behavior of Macrobrachium lar on hypogeal shrimps has not previously been recorded.

Pool D

This pool is nearest to the sea and is the deepest pool within East Keauhou. Its dimensions are 4 x 2.5 x 0.45 m, but an inaccessible lateral crack extends beyond the pool. An adequate water exchange rate prevented the build-up of deep sediments or the occurrence of turbidity in the pool; consequently, portions of the pahoehoe substrate are exposed. A mixed community of epilithic cyanophytes (blue-green algae) was dominated by Lyngbya sp. Small tufts of filamentous chlorophytes (green algae) also occurred in patches on the exposed rock. The temperature in pool D (27.8 C) was slightly lower than the other pools, further reflecting more efficient flushing than in other pools in the complex. Salinity, however, was characteristic of this complex and measured 2.4 $^{o}/_{oo}$.

Nocturnal activity in pool D was characterized by an unusually high density of Macrobrachium lar, estimated at approximately 30-50 individuals/m^2. These prawns ranged in size from 4 cm to nearly 30 cm. Palaemon debilis was also common to this pool but in lower numbers than Macrobrachium lar.

Shorebird feces were present around the perimeter of the pool, suggesting predation on prawns and shrimps. Whatever predation does take place is apparently insignificant, based on the current abundance of crustaceans in the pool.

HALAPE - 4

This complex, southeast of Halape Shelter, consists of four major pools and several smaller ones within an extensive crack shaped like a semi-circle. The crack extends from Boulder Bay at the foot of the Pu'u Kapukapu Cliff toward the east, with the apex 10 m from shore, and curves 80-90 m inland toward the Halape Shelter. Anchialine pools in the crack contain a total water surface area of approximately 170 m^2, making this the largest single complex of pools within the Park. All pools have a rapid water exchange rate, characterized by an absence of turbidity and a lack of bottom sedimentation.

Pool A

This large, oval pool (Fig. 9) is nearly 70-80 m from the sea. Because it is close to Halape Shelter, a popular campsite in the Park, it is often used for bathing. The basin is composed of various sizes of rocks and boulders that have broken away from the walls of the crack. The dimensions of the pool are 12 x 5 x 2.5 m. Both the subsurface and bottom sections of the pool had equivalent temperature and salinity values (27.0 C and 5.0 °/oo), indicating complete vertical mixing.

Flora within the pool includes the epilithic red alga Hildenbrantia sp. and the filamentous blue-green alga Oscillatoria sp., the latter predominantly found on the shaded areas of rocks. A thin (1 cm deep) crust of Lyngbya sp. covers portions of shallow flat rocks.

Faunal activity was quite different in diurnal and nocturnal periods. During the day, only a single fish, Caranx ferdau (papio), was observed patrolling the pool in search of food. Nocturnal observation revealed two additional fish species (three Abudefduf sordidus (kupipi) and several Kuhlia sandvicensis (aholehole)); numerous Macrobrachium lar; and, common to the deeper crevices, Halocaridina rubra. It is probable that Caranx ferdau, Abudefduf sordidus, and Kuhlia sandvicensis were introduced into this pool, as they are uncommon inhabitants of low-salinity anchialine pools so far inland.

Pool B

This interesting pool is located within the crack behind a boulder berm nearly 25 m inland (Fig. 10). Its dimensions are 6 x 2 x 3 m, although a deep hole on the northeastern end of the pool extends farther diagonally. The basin consists of a combination of rocks and boulders. Flushing efficiency is high, as indicated by the absence of turbidity and sedimentation. Unlike pool A, this pool exhibited a pronounced salinity gradient. Subsurface salinity was 6.3 °/oo, while bottom salinity was measured at 15.8 °/oo. Temperature remained constant at 26.0 C.

A unique feature of this pool was the orange-colored algal crusts covering the rocks, dominated by Schizothrix calcicola and Lyngbya sp. This carbonate-producing cyanophyte (blue-green algae) community is relatively common among West Hawai'i anchialine pools but found nowhere else in East Hawai'i. The highest density of cyanophtye crusts occurred in the salinity range of 7-12 °/oo. Aquatic fauna in pool B included a number of common, native euryhaline fishes and native invertebrates: Kuhlia sandvicensis, a tang Acanthurus sandvicensis (manini), a small goby Bathygobius fuscus ('o'opu), the snail Theodoxus cariosus, the grapsid crab Metapograpsus thukuhar, and the shrimp Palaemon debilis.

Pool C

This pool is nearly 25 m southwest of pool B and 20 m from the shoreline. Pools B and C exhibit many biophysical similarities. The structure of pool C may be described as two linear parallel pools split in half by an elongated, rectangular rock slab. The two pools

are connected at the surface at both ends and between cracks in the rock slab (Fig. 11). The connections really make this series a single pool. The dimensions of pool C are 18 x 5 x 3 m. Several deep cracks and crevasses were beyond measurable depth. Again, a steep salinity gradient was recorded from this pool. Surface salinity measured 6.3 °/oo while salinity 3 m deep was measured at 16.5 °/oo. Temperature readings of 26.0 C were obtained at the surface and 3 m.

Sufficient sunlight is received at both ends of the pool to support the growth of cyanophyte crusts. As with pool B, the highest density of algal crusts occurred within a salinity range of 9.7-13 °/oo.

Fishes were more abundant in pool C than in pool B, consisting of Kuhlia sandvicensis, Acanthurus sandvicensis, and two species of 'o'opu (Bathygobius fuscus and a small unidentified species). Acanthurus sandvicensis, an herbivore, was observed grazing on the cyanophyte crusts. Invertebrates found in pool C were common, native euryhaline species: Metapograpsus thukuhar, Theodoxus cariosus, and Palaemon debilis.

Pool D

Pool D is located approximately 70 m southwest of pool C within the same crack system. The dimensions of pool D are 5 x 1 x 1 m. The pool was accessed through a narrow opening nearly 3 m above the surface. Bottom salinity measured a low 4.0 °/oo and temperature was 26.0 C. The bottom composition consists of broken rock fragments separated by cracks of immeasurable depth. Though difficult to locate from the surface, refuse left by humans littered portions of the pool.

The dim illumination received in pool D was sufficient for the growth of an epilithic rhodophyte (red alga), Hildenbrantia sp., and another unidentified green-colored microalga, presumably a cyanophyte.

Macrofauna within the pool included Metapograpsus thukuhar, Palaemon debilis, and an unidentified hypogeal shrimp. The individual shrimp (observed at night) closely resembled Antecaridina lauensis, an uncommon indigenous atyid shrimp similar in appearance to Halocaridina, though slightly larger and more lethargic (as described by Maciolek in Holthuis 1973). The shrimp may also have been a large individual Halocaridina. This may be more likely, as Antecaridina have been found in only four other locations in Hawai'i, and salinities recorded from three of these four locations were high (>12 °/oo).

BOULDER BAY, HALAPE - 5

This attractive anchialine pool is the single largest inland body of water within HAVO (Fig. 12). Site 5 is located at the foot of the cliff south of Pu'u Kapukapu and west of Halape Shelter. A sand and rock berm nearly 20 m in width separates pool 5 from the sea. The dimensions of this elongated oval pool are approximately 20 x 6.5 x 0.7 m. Large talus boulders from the adjacent cliff are randomly

strewn within and around the pool. The bottom composition consists of an organic sediment layer 5-10 cm deep over a sand substrate. Thick sediments, dense algal mats, and slight turbidity are signs of poor flushing. The odor of hydrogen sulfide, indicative of anaerobic decomposition, was noted. Temperature in the pool was 27.2 C and salinity was 15.0 °/oo.

Despite the advancing senescence, pool 5 supported a diversity of organisms. A combination of cyanophyte mats and dense filamentous and siphonous chlorophytes (green algae) covered nearly 80% of the pool bottom. Fauna present in the southern section of the pool consisted of Halocaridina rubra, Metabetaeus lohena, and Macrobrachium grandimanus. Access to the pool by these crustaceans was via the small cracks and interstices present at the far southern end of the pool. The northern section of pool 5 was inhabited by Theodoxus cariosus. No macrofauna were observed in the central pool area, possibly due to higher levels of hydrogen sulfide and other toxic byproducts.

Riparian vegetation around the pool included the indigenous Sesuvium portulacastrum and Thespesia populnea (milo), and the alien Pluchea odorata. Dense stands of these plants around the pool perimeter presumably contribute substantially to sedimentation. Cyperus laevigatus (makaloa), an indigenous, emergent sedge, was found at the fringes of pool 5.

KALU'E CRACK - 6

This relatively large, deep pool is nearly 35 m from shore within a deep crack and measures 6 x 3 x >3 m. The closest possible approach to the pool without ropes is 4 m above the surface. The basin composition and structure consist of angular rocks and a deeper passage extending diagonally northward. Subsurface temperature and salinity were recorded at 28.0 C and 3.0 °/oo. At a depth of 3 m, the temperature was 27.5 C and the salinity was 10.0 °/oo. Salinity stratification in this pool was apparent.

KA'AHA CRACK - 7

This deep anchialine pool is approximately 100 m from shore within a long crack parallel to the shoreline. The pool's dimensions are 30 x 1.5 x >15 m, and the water level was about 2 m below the surface. The pool depth is greater than 15 m. Since the length of the pool was not entirely connected on the surface, temperature and salinity measurements and observations were made at three points, at the northeastern, middle, and southwestern sections. Macrobrachium lar was observed only in the northeastern section of the crack, where the pool was directly exposed to midday sunlight and supported greater algae growth. The remainder of the crack was dimly illuminated and contained only native prawns and other crustaceans.

Riparian vegetation consisted primarily of Pluchea odorata; tap roots of this alien species extended into the anchialine pool.

Northeastern Section

This section consists of a shallow rock-filled basin. It exhibited a temperature of 28.0 C and salinity of 3.3 °/oo at a

depth of 0.8 m. Algae in this pool, also found in the rest of the crack, were epilithic Hildenbrantia sp. and blue-green algae. Fauna observed were a few Macrobrachium lar and Halocaridina rubra.

Middle Section

The middle section exhibited a subsurface temperature of 27.0 C and a salinity of 3.5 °/oo. The temperature reading at 15 m was 28.0 C and the salinity was 4.0 °/oo. Fauna within this section consisted of native species -- a few Halocaridina rubra, several Macrobrachium grandimanus, and a few Palaemon debilis.

Southwestern Section

This section had a subsurface temperature of 28.0 C and a salinity of 3.2 °/oo. At 15 m depth, temperature was 28.0 C and salinity was 3.4 °/oo. Faunal species were identical to those of the middle section and were similar in abundance.

COMPARISON OF HAVO POOLS WITH OTHER ANCHIALINE SYSTEMS

Although numerous differences distinguish any two pools, there are general biotic and abiotic characteristics that distinguish East Hawai'i anchialine pools from other anchialine systems of West Hawai'i and Maui (Table 5). The most important difference between East and West Hawai'i is coastal and orographic rainfall abundance. Rainfall affects anchialine pool salinity, and the salinity of a pool significantly influences the distribution of anchialine organisms (Maciolek 1983). The average salinity of HAVO's pools was 7.6 °/oo. This value is relatively low, considering that it includes the deep, near-shore cracks of Halape and Kalu'e and the anomalous high-salinity pool at West 'Apua complex (30.5 °/oo). Perhaps wave wash from the nearby ocean, the shallowness of the pool, and evaporation combine to keep salinity in this pool high. Also, annual rainfall received in this area is relatively low (1270 mm). The average salinity of 298 West Hawai'i pools was 7.0 °/oo (Maciolek and Brock 1974). However, only surface salinities were measured for many of these pools, and these generally tend to be lower than bottom salinities. Recent salinity measurements (after 1985) for several specific sites (from U.S. Department of Defense 1985; Chai 1986; Maciolek 1986; Maciolek 1987; The Nature Conservancy of Hawaii 1987; Chai, in prep.) are presented in Table 5.

Overall, anchialine pools at HAVO rate quite low in total surface area, biological diversity, species rarity, and abundance of rare and common species, compared with other sites (Table 5). However, most other sites are the best remaining anchialine systems in the State. HAVO's anchialine pools are poor in biological value, based on the low abundance and diversity of native biota. As a group, the natural value of the pools is good, however. The strongest points are: 1) good structural diversity, including caves, deep cracks, and shallow pools; 2) excellent habitat for rare organisms to occur at Halape; 3) HAVO pools are the only significant group between Kapoho and South Point in East Hawai'i; and, 4) pool preservation and management potential in HAVO is great.

It was not surprising to find an absence of rare species in anchialine pools along the Park's coastline. Also, the diversity and

abundance of common hypogeal species was, as expected, very low. Three important factors contribute to this.

First, excluding the shallow, sedimented pool in the West 'Apua complex, salinity values averaged 5.7 °/oo. Low-salinity anchialine pools, characteristic of East Hawai'i, are not preferred habitat for many of the rare and uncommon anchialine fauna. All of the known rare species, aside from two neritid snail species and an eel (Gymnothorax hilonis), are found in pools with salinities greater than 12 °/oo (The Nature Conservancy of Hawaii 1987). The rare eel was reported from Halape by Ball (1975). However, Gymnothorax hilonis closely resembles the more common Gymnothorax pictus, and without a specimen this sighting remains unsupported.

Second, it is widely accepted by anchialine pool experts that there is a negative correlation between the abundance of alien aquatic species and the abundance of native aquatic invertebrates, primarily hypogeal crustaceans. Unfortunately, most anchialine pools within HAVO are inhabited by numerous Macrobrachium lar, an alien prawn. Pools B and C at Halape display ideal physical parameters necessary to support both rare and common anchialine invertebrates. However, these pools also contain an abundance of native predatory fishes such as Kuhlia sandvicensis and two species of goby, which readily consume small crustaceans.

Third, the deep sediments of pools exhibiting advanced senescence prevent access for fishes and invertebrates through substrate interstices and do not allow sufficent hiding places for them to escape bird predation.

MANAGEMENT

The anchialine pools discussed in this report are currently the only group within East Hawai'i receiving some protection. Clearly, a majority of anchialine pools in Hawai'i are threatened by impending development and related activities. One of the most harmful of these activities is the introduction of alien aquatic species, which unfortunately has adversely affected many of the pools within the Park.

The greatest management priority for anchialine pools in HAVO is the reduction or eradication of alien species. The adverse effects of introduced aquatic species on the native ecology were discussed by Maciolek (1984). He proposed that detrimental effects on native species may be direct, through predation and competition, or indirect, e.g., through the introduction and transmission of diseases and parasites. Although it is difficult to assess the total effect of Macrobrachium lar on native ecosystems (no pre-introduction baseline data are available), observations from the East Keauhou complex tend to support Maciolek's findings.

Two of the most obvious and severe effects of Macrobrachium lar on native ecosystems are displacement of native prawns and predation on native hypogeal crustaceans. Once introduced into habitat

occupied by native prawns (Macrobrachium grandimanus), M. lar soon dominates. These aggressive prawns are known to feed upon juvenile native prawns and easily displace them in the anchialine habitat (R.E. Brock, pers. comm). Uncertainty exists among experts regarding the scope of effects Macrobrachium lar has on native hypogeal crustaceans. During this survey, immature prawns in pool C of the East Keauhou complex were observed preying upon the native shrimps Halocaridina rubra and Metabetaeus lohena as they attempted to exit a narrow crack. In the absence of efficient herbivores and detritivores such as these shrimps, rapid accumulation of algae increases the rate of anchialine pool senescence (Brock 1985).

The effective eradication of Macrobrachium lar from HAVO would probably require the use of toxicants in combination with electroshocking. However, the prawns may eventually reestablish in the pools through passive ocean dispersal of the larvae. Chemical-electrical treatments may also cause most, if not all, of the native epigeal organisms to be eliminated. The recolonization of epigeal organisms after chemical elimination is currently being studied by Brock. Hypogeal species would be temporarily eliminated but would eventually recolonize in the pools (J.A. Maciolek, pers. comm.).

If controlling the numbers of alien prawns and their cumulative detrimental impacts is the objective, then the Park could encourage periodic hooking, netting, and trapping of prawns. To many people, these prawns are an edible delicacy, and promoting their capture and consumption should not be difficult. However, monitoring the effects of such a program would be necessary. A consistent effort to keep the alien prawn population low would be required for such a program to be effective.

It is necessary to eliminate or control the noxious riparian sourbush Pluchea odorata. This shrub dramatically accelerates the senescence of pools by contributing leaf and stem litter. Continued sourbush growth in the East Keauhou complex and the pool at Boulder Bay should be halted. One possible control technique may be to cut the sourbush surrounding pools and apply a non-persistent topical herbicide to the cut stem.

If the National Park Service determines that it is desirable to slow the senescence of pools and extend their "life," much of the organic sediments and algal mats should be removed. Although it is a natural aging proccess for shallow pools to become completely filled within a span of several hundred years (depending on their flushing efficiency), the effects of alien flora and fauna have dramatically accelerated this process (Maciolek and Brock 1974; Brock 1985). Dredging of senescent pools in conjunction with alien species removal is necessary to improve the habitat for native fauna.

Eventually, signs should be placed near pool sites describing their significance as a natural resource. Use of these valuable natural resources for trash disposal, bathing with soap, or as a supply of water for extinguishing fires should be avoided.

SPECIFIC ANCHIALINE POOL MANAGEMENT STRATEGIES

The following anchialine pools and pool complexes are listed in descending order of protection/management priority. Ranking of these priorities is based on their existing and potential natural resource values and the current threats posed to their native biota. Recommended management actions are listed.

1. East Keauhou complex, site 3 - This potentially unique group of pools is faced with three degradational forces: Pluchea odorata, which should be removed wherever it adds litter to the pools; Macrobrachium lar, which should be reduced to a much lower population level; sediment-filled pools, which should be dredged and have algal mats removed.

2. Boulder Bay at Halape, site 5 - The following management efforts should be instigated: remove riparian Pluchea odorata; remove algal mats; dredge biogenic sediments.

3. Halape, complex 4, pool A - Macrobrachium lar should be eradicated or reduced to a lower population level. Pools B, C, and D - Continue monitoring for presence of rare fauna. Prevent use of soaps or other chemicals during bathing.

4. Waha'ula Cave, site 1 - Prevent use of soaps or other chemicals during bathing. Because of its importance as a habitat for endemic invertebrates, this pool should not be used as a source of water for fire suppression or wet lines. Lowering of the water level and fumes from water pumps could be highly detrimental to native organisms at this unusual wet cave.

5. Ka'aha Crack, site 7 - Monitor and control Macrobrachium lar population.

FURTHER RESEARCH NEEDED

1. It is often stated by scientists that very little can be learned about the habits, distribution, abundance, and migration of anchialine organisms, and especially the significance of the anchialine pool biotope in its relation to a larger underground ecosystem. This concern arises because of our inability to sample the subterranean environment. Waha'ula cave and similar sites afford a glimpse into this unproductive and forbidding habitat. Further periodic sampling of the cave habitat may provide information needed to build a more complete picture of life in the vast subterranean realm.

2. During the survey, a great majority of faunal activity and sightings occurred at night. Other influences on faunal activity that were not examined were the effects of lunar cycles and seasonal variability. Both these potentially important biological influences should be examined in relation to the Park's anchialine pools.

3. Baseline data, including pH, dissolved oxygen, nutrients and specific ions, reduction-oxidation potential, and chlorophyll-a, should be collected. These data should also be obtained at the Waha'ula nature trail pool to determine the effects of recent lava flows on groundwater quality. Voucher specimens for faunal and floral components of anchialine pools should be collected.

4. Very little is currently known about algae in anchialine waters, as this is a hightly specialized field. The only detailed inventory was conducted at 'Ahihi-Kinau on Maui by Wong (1975). A checklist of algal species in anchialine pools is presented in Brock (1985). Since algae are likely an important component of the anchialine ecosystem, a more detailed study of this resource within the Park should be conducted.

ACKNOWLEDGEMENTS

Special appreciation is given to HAVO staff members Steve Anderson and Julie Leialoha, who provided valuable assistance during the field work. Danielle Stone read the manuscript and provided critical comments, and we also thank her for typing final drafts for publication. The study was supported by NPS research funding for Special Ecological Areas at Hawaii Volcanoes National Park.

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TABLES

Table 1. Taxonomic list of aquatic fauna inhabiting anchialine pools, Hawaii Volcanoes National Park.*

Group/Taxon	Description and locality (pool complex - number)
	INVERTEBRATES
CRUSTACEANS	
Unidentified amphipod	Unidentified gray, to 0.5 cm (3-A).
Unidentified amphipod	Unidentified white blind form, to 0.5cm (1)
Unidentified isopod	Unidentified dark brown, 3 mm (3-A, 3-B).
Halocaridina rubra	'Opae 'ula, omnivorous red hypogeal shrimp, to 1.5cm (1, 3-C, 4-A, 5, 7).
Metabetaeus lohena	Predaceous, red, hypogeal shrimp, to 3cm. (1, 3-C, 5).
Palaemon debilis	'Opae huna, omnivorous,transparent dark spotted shrimp, to 5 cm, (3-C, 3-D, 4-B, 4-C, 4-D, 7).
Macrobrachium grandimanus	'Opae kala 'ole, omnivorous brown prawn, to 10cm (1, 3-B, 5, 7).
*Macrobrachium lar	Tahitian prawn, omnivorous, brown-blue, to 25cm (3-C, 3-D, 4-A, 7).
Metapograpsus thukuhar	Dark mottled grapsid crab, to 6cm carapace, (3-A, 4-B, 4-C, 4-D,).
MOLLUSCA	
Theodoxus cariosus	Black neritid snail on rocks, to 4cm, (2-A, 3-A, 3-C, 4-B, 4-C, 5).
	VERTEBRATES
FISHES	
Caranx ferdau	Papio, predaceous young jack, approx. 20cm, (4-A).

Table 1, continued.

Group/Taxon	Description and locality (pool complex - number)
Kuhlia sandvicensis	Aholehole, silvery, predaceous, common to marine, estuarine, and freshwater streams, to 20cm, (4-A, 4-B, 4-C,).
Eleotris sandvicensis	'O'opu akupa, brown predaceous goby, stream and estuarian eleotrid, 15 cm, (3-C).
Abudefduf sordidus	Kupipi, gray-brown marine damselfish, to 17cm, (4-A).
Bathygobius fuscus	'O'opu, marine tidepool goby, dark mottled, to 10cm, (4-B, 4-C).
Unidentified goby	'O'opu, pale marine goby, to 6cm, (4-B, 4-C)
Acanthurus sandvicensis	Manini, striped marine surgeonfish, to 15cm,(4-B, 4-C).

*Taxa preceded by an asterisk (*) are not native.

Table 2. Distribution of aquatic fauna in 14 anchialine pools within Hawaii Volcanoes National Park.*

Group/Taxon	Pool	1	Complex 2 A	Complex 2 B	Complex 3 A	Complex 3 B	Complex 3 C	Complex 3 D	Complex 4 A	Complex 4 B	Complex 4 C	Complex 4 D	5	7
Crustaceans														
Unidentified blind amphipod		X												
Unidentified amphipod					X									
Unidentified isopod					X	X								
Halocaridina rubra		X					X		X				X	X
Metabetaeus lohena		X					X						X	
Palaemon debilis							X	X		X	X	X		X
** Macrobrachium lar							X	X	X					X
M. grandimanus		X				X							X	X
Metapograpsus thukuhar					X					X	X	X		
Unidentified hypogeal shrimp												X		
Mollusks														
Theodoxus cariosus			X		X		X			X	X		X	
Fishes														
Caranx ferdau									X					
Kuhlia sandvicensis									X	X	X			
Eleotris sandvicensis							X							
Abudefduf sordidus									X					
Bathygobius fuscus										X	X			
Unidentified goby										X	X			
Acanthurus sandvicensis										X	X			

*Pool 6 is in a crack too deep and inaccessible to sample fauna.
**Non-native taxon.

Table 3. Anchialine pool temperature, salinity, and depth at Mean High Water. Pools with a depth greater than one meter include subsurface (top) temperature and salinity measurements. Data recorded May-July, 1988 at Hawaii Volcanoes National Park.

Location	Bottom T°C	Bottom S°/oo	Top T°C	Top S°/oo	Depth (m)
Site 1	25.5	0.75			2.7
Complex 2					
pool A	32.0	30.5			0.4
pool B	25.2	4.0			0.1
Complex 3					
pool A	30.0	2.8			0.25
pool B	30.2	2.5			0.2
pool C	29.0	2.5			0.3
pool D	27.8	2.4			0.45
Complex 4					
pool A	27.0	5.0	27.0	5.0	2.5
pool B	26.0	15.8	26.0	6.3	3.0
pool C	26.0	16.5	26.0	6.3	3.0
pool D	26.0	4.0			1.0
Site 5	27.2	15.0			0.7
Site 6	27.5	10.0	28.0	3.0	> 3.0
Site 7					
NE	28.0	3.3			0.8
Mid	28.0	4.0	27.0	3.5	> 15.0
SW	28.0	3.4	28.0	3.2	> 15.0

Table 4. Emergent and terrestrial vascular plants at seven anchialine pool sites of Hawaii Volcanoes National Park.

Life Form/Taxon	Status*	Site*** 1**	2	3	4	5	7
FERNS							
Nephrolepis sp.	U	X					X
Phymatosorus scolopendria	A	X					
SEDGES							
Cyperus javanicus	I				X		
Cyperus laevigatus	I					X	
Cyperus polystachyus	I		X	X			
Fimbristylis pycnocephala	I		X	X	X	X	
GRASSES							
Cenchrus echinatus	A					X	
Chloris sp.	A				X	X	
Dactyloctenium aegyptium	A				X		
Digitaria spp.	A				X		
Heteropogon contortus	I		X				
Hyparrhenia rufa	A			X			
Rhynchelytrum repens	A		X	X	X		X
FORBS							
Boerhavia diffusa	I				X	X	
Desmodium triflorum	A		X				
Emilia javanica	A				X		
Euphorbia hirta	A					X	
Heliotropium curassavicum	I				X	X	
Portulaca cyanosperma	E				X		
Sesuvium portulacastrum	I		X	X		X	
VINES							
Passiflora foetida	A			X	X		
SHRUBS							
Cassia leschenaultiana	A			X			
Indigofera suffruticosa	A				X		
Lantana camara	A				X		
Leucaena leucocephala	A					X	
Morinda citrifolia	P		X	X			
Pluchea odorata	A			X	X	X	X
Scaevola taccada	I		X	X			
Tephrosia purpurea	P			X			
Waltheria americana	I		X	X	X	X	X
Wikstroemia sandwicensis	E	X					

Table 4, continued.

Life Form/Taxon	Status*	Site*** 1**	2	3	4	5	7
TREES							
Canthium odoratum	I	X					
Cocos nucifera	P					X	
Cordia subcordata	P		X				
Metrosideros polymorpha	E	X					
Prosopis pallida	A			X			
Thespesia populnea	I			X		X	

*Status: E = Endemic
I = Indigenous
P = Polynesian introduction
A = Alien, introduced
U = Uncertain

**Vegetation surrounding cave entrance.

*** No vegetation data collected at site 6.

Table 5. A comparison of anchialine pools in Hawaii Volcanoes National Park with other selected anchialine pool systems on Hawai'i and Maui. (VH = Very High; H = High; M = Medium; L = Low.)*

Factor	**HAVO	**King's Landing	Kaloko	Waikoloa	Awake'e	Kohana Iki	Makalawena	Cape Kinau, Maui
ABIOTIC								
Surface area (acres)	< 0.5***	> 3.0	< 0.5	1.5	1.0	2.0	8.2	2.0-3.0
Habitat diversity	H	H	M	L	L	H	M	H
Water quality	H	M	H	L	H	H	H	VH
Salinity (°/oo)	7.6	0.5-4.0	8.5-20.5	9.0	7.5-26.9	8.0-16.5	4.0-26.9	6.0-34.0
BIOTIC (NATIVE)								
Diversity	L	M	H	M	L	H	M	VH
Species Rarity	L	H	H	L	L	H	M	VH
Abundance, Rare Species	L	M	M	L	L	H	L	VH
Abundance, Common Species	L	M	L	H	L	VH	M	VH
DEGRADATION								
Alien species effects	H	M	H	M	H	M	H	L
Senescence	M	M	L	M	L	M	M	L

*Criteria selected for this comparison are believed to be some of the most significant features of anchialine ecosystems. Anchialine systems were selected on the basis of available data. Sources of data are: Maciolek and Brock 1974; U.S. Department of Defense 1985; Chai 1986; Maciolek 1986; Maciolek 1987; Chai, in prep.

**Locations preceded by a double asterisk (**) are in East Hawai'i.

***About 0.13 acre.

FIGURES

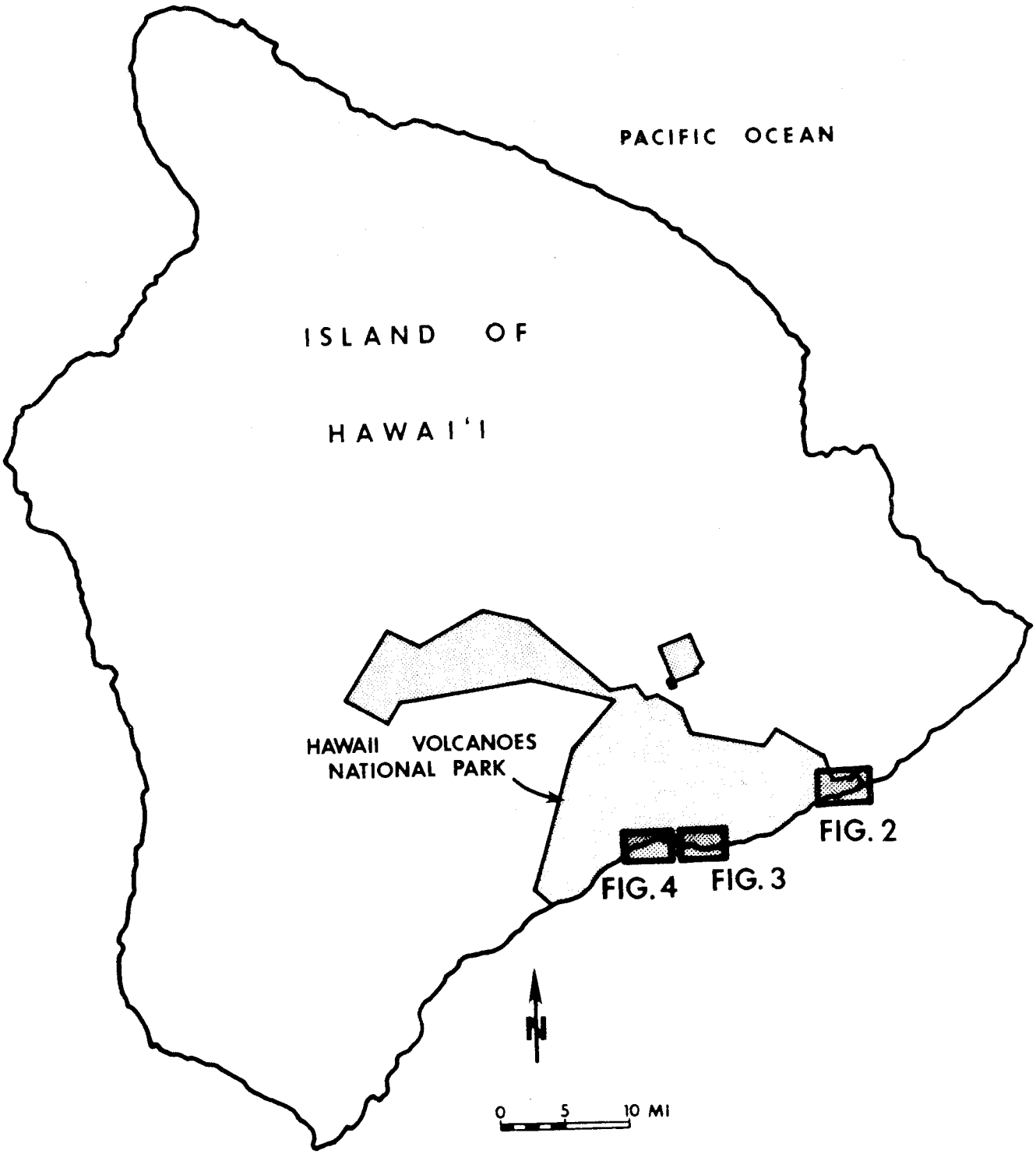

Fig. 1. Location of Hawaii Volcanoes National Park on the island of Hawai'i. Sections of coastline illustrated in subsequent figures are indicated.

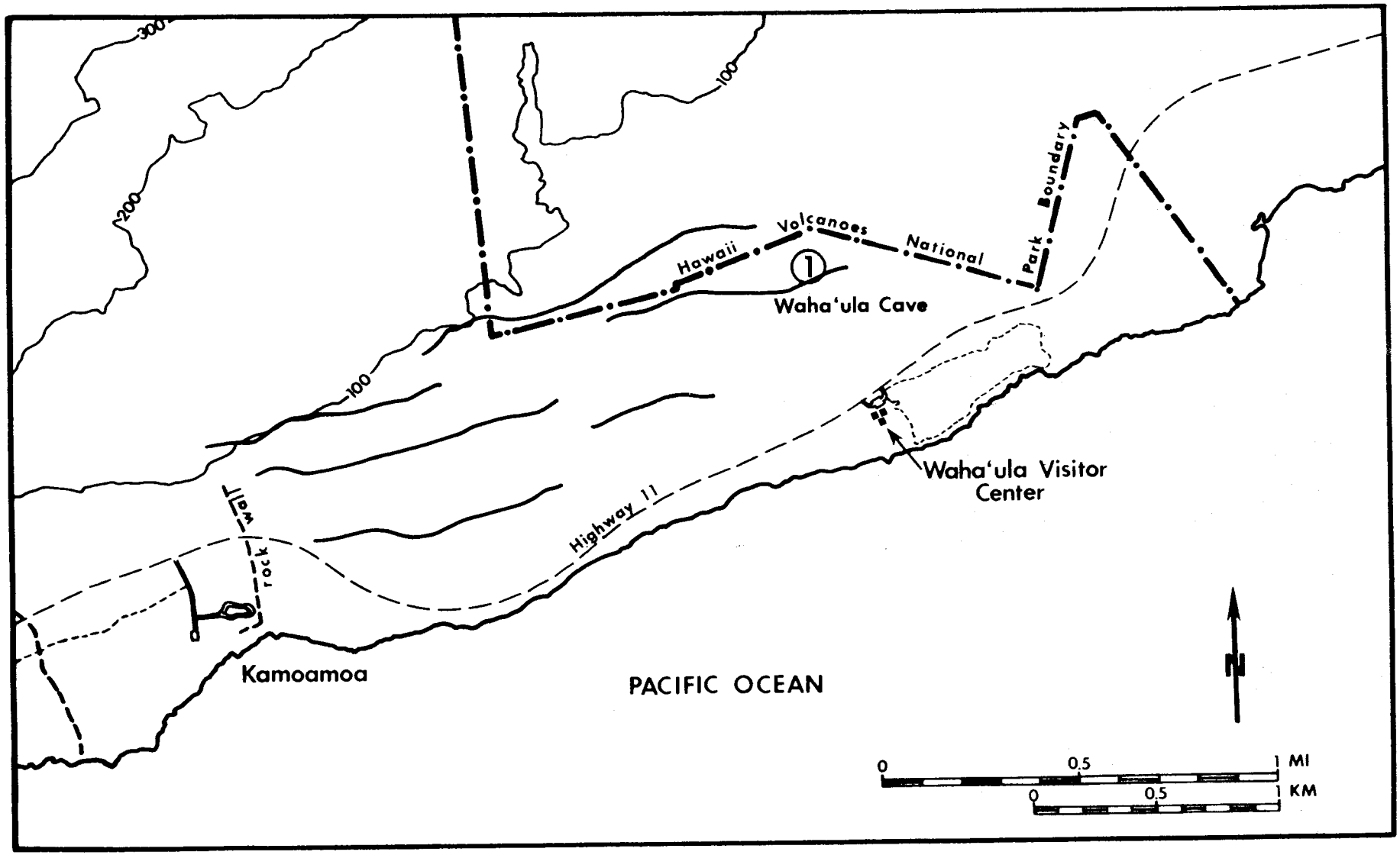

Fig. 2. Coastal area in Hawaii Volcanoes National Park, showing location of site 1, Waha'ula Wet Cave.

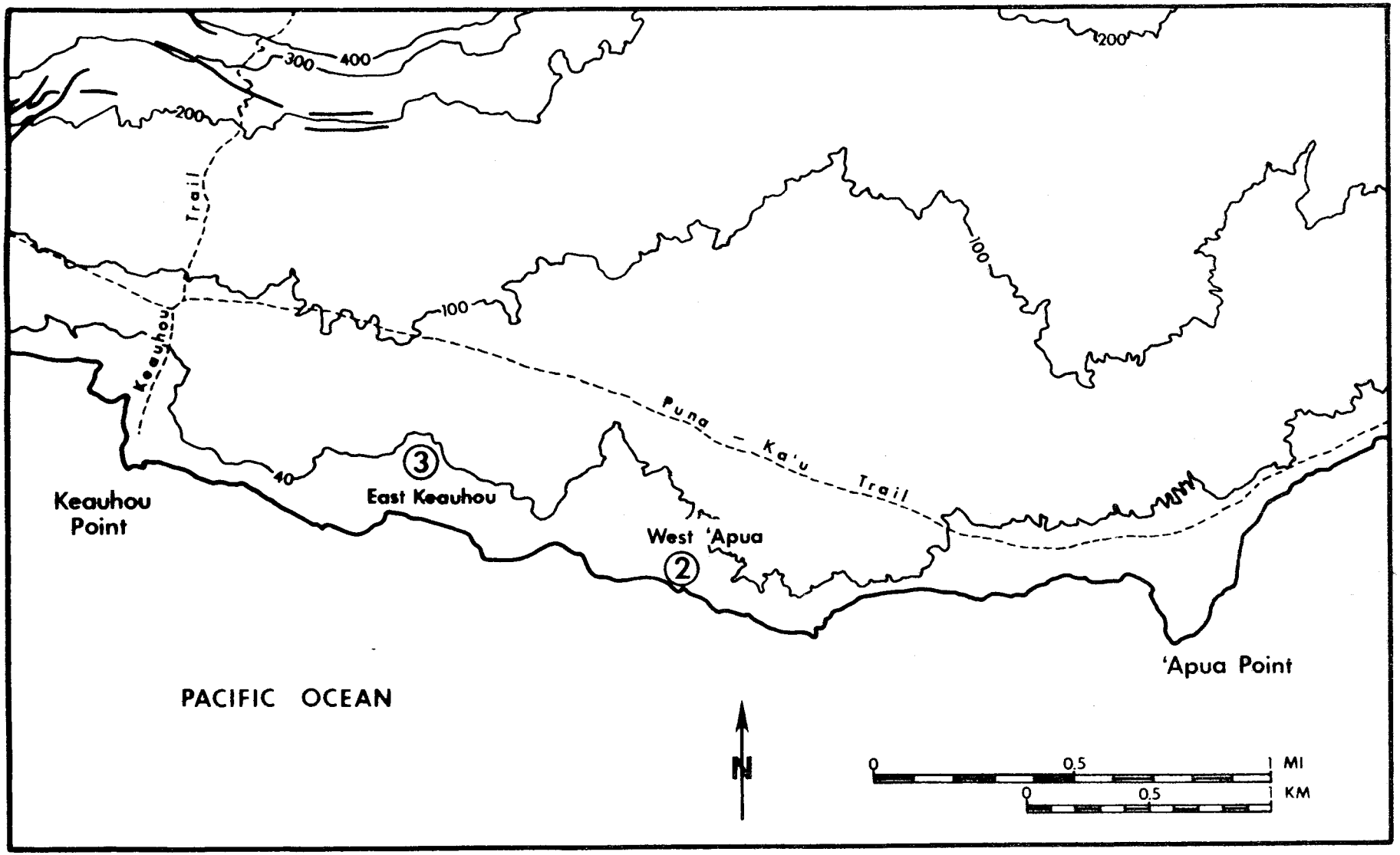

Fig. 3. Coastal area in Hawaii Volcanoes National Park between Keauhou and 'Apua points, showing location of Complex 2 (West 'Apua) and Complex 3 (East Keauhou).

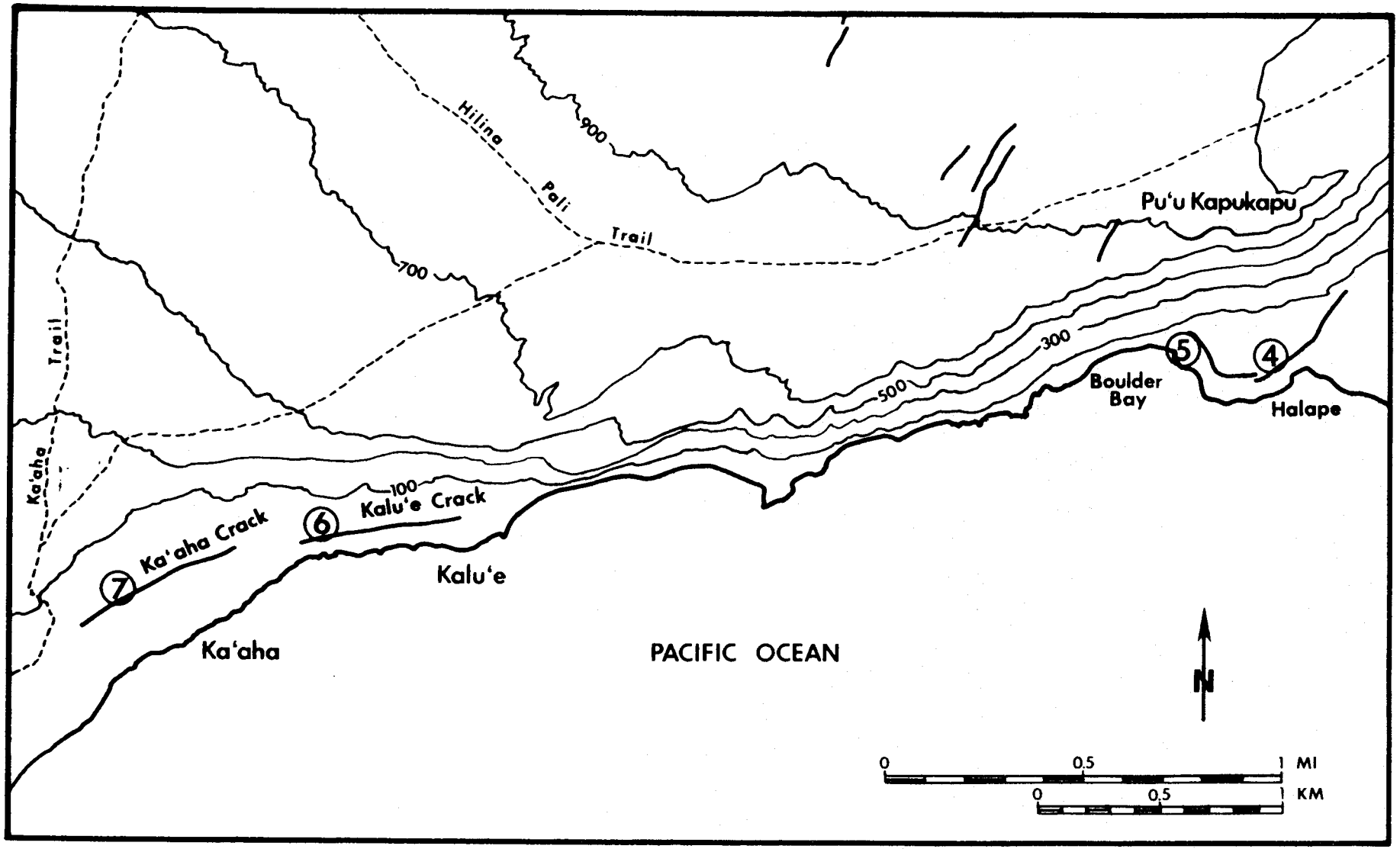

Fig. 4. Coastal area of Hawaii Volcanoes National between Ka'aha and Halape, showing location of Complex 4 (Halape), site 5 at Boulder Bay, Site 6 (Kalu'e Crack), and Site 7 (Ka'aha Crack).

Fig. 5. Complex 2, Pool A - West 'Apua: A shallow-water complex found immediately behind a sand and boulder berm. Pool A is the larger of two pools and contained organic sediments in water with high temperature and salinity.

Fig. 6. Complex 3, Pool A - East Keauhou: This pool exhibited characteristics of intermediate senescence. Although water was present at low tide, its depth was only a few centimeters. Its basin was typical of this complex, consisting of deep organic sediments of up to 15 cm, covered by a thin, cohesive cyanophyte mat.

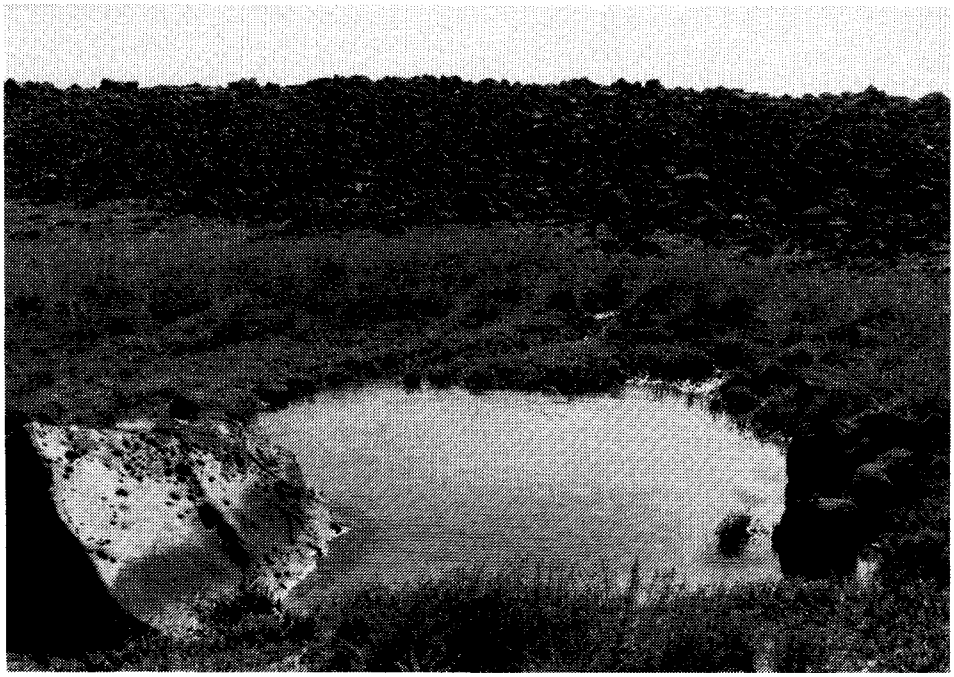

Fig. 5.

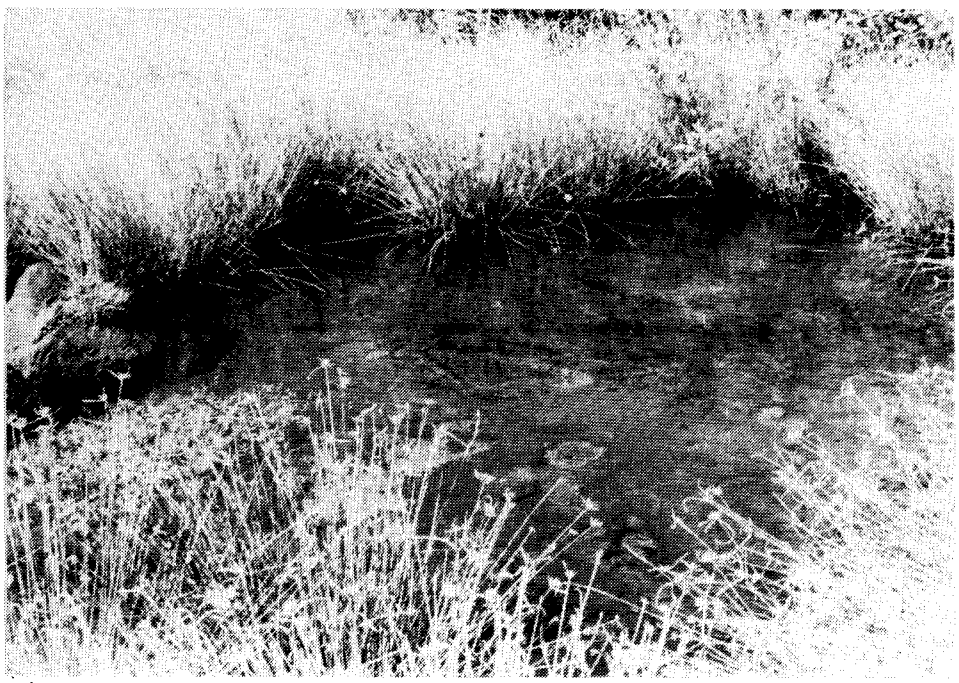

Fig. 6.

Fig. 7. Complex 3, Pool B - East Keauhou: Biophysical characteristics of Pool B were very similar to those of Pool A. One difference was that Pool B supported a single native prawn, Macrobrachium grandimanus.

Fig. 8. Complex 3, Pool C - East Keauhou: This photograph shows one side of a "doublet" pool. Pool C contained the only native hypogeal shrimps (Halocaridina rubra and Metabetaeus lohena) and fish (Eleotris sandvicensis) recorded from this complex.

Fig. 7.

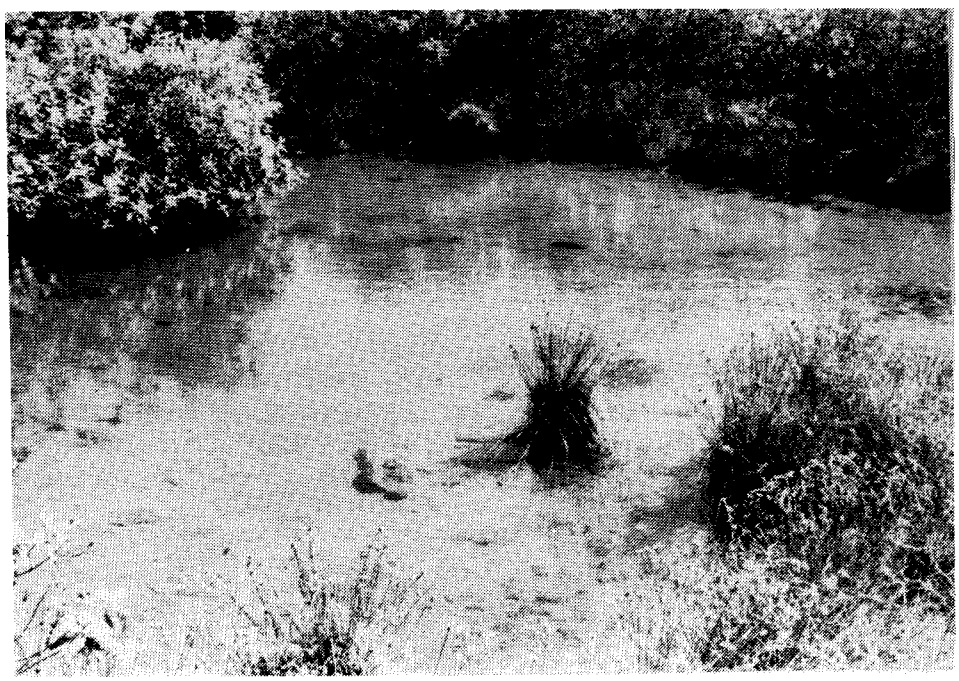

Fig. 8.

Fig. 9. Complex 4, Pool A - Halape: This is the largest pool in the Halape crack series and is the one nearest to the shelter and beach.

Fig. 10. Complex 4, Pool B - Halape: This pool is near the sea and exhibited a remarkable salinity stratification between the subsurface layer (6.3 $^{o}/_{oo}$) and the bottom layer 3 m deep (15.8 $^{o}/_{oo}$). The rocks were covered by calcium carbonate-producing cyanophytes. Several species of common marine fishes also inhabited this pool.

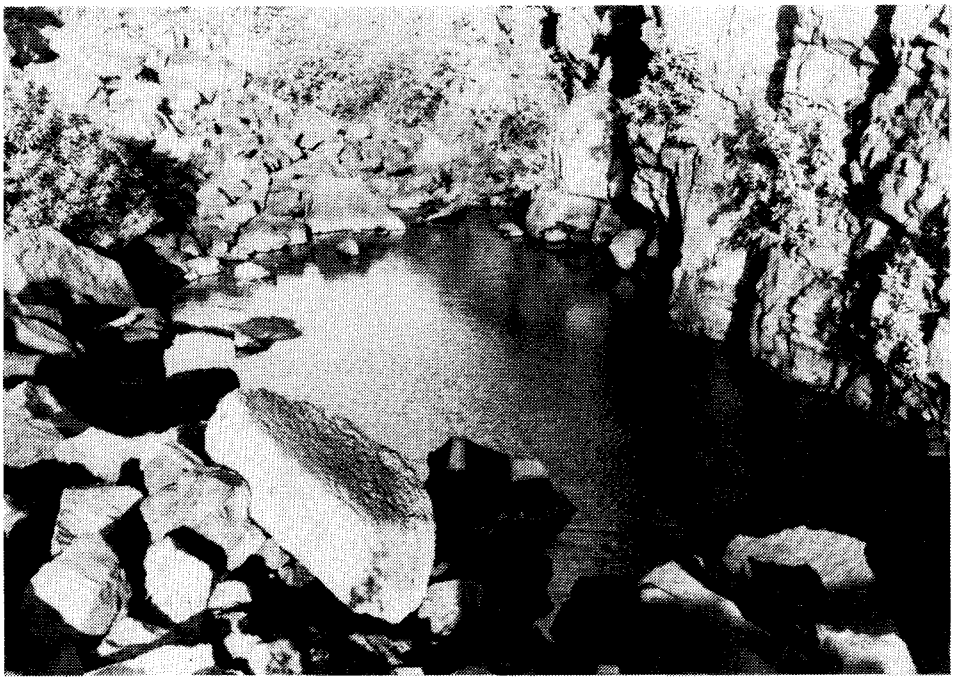

Fig. 9.

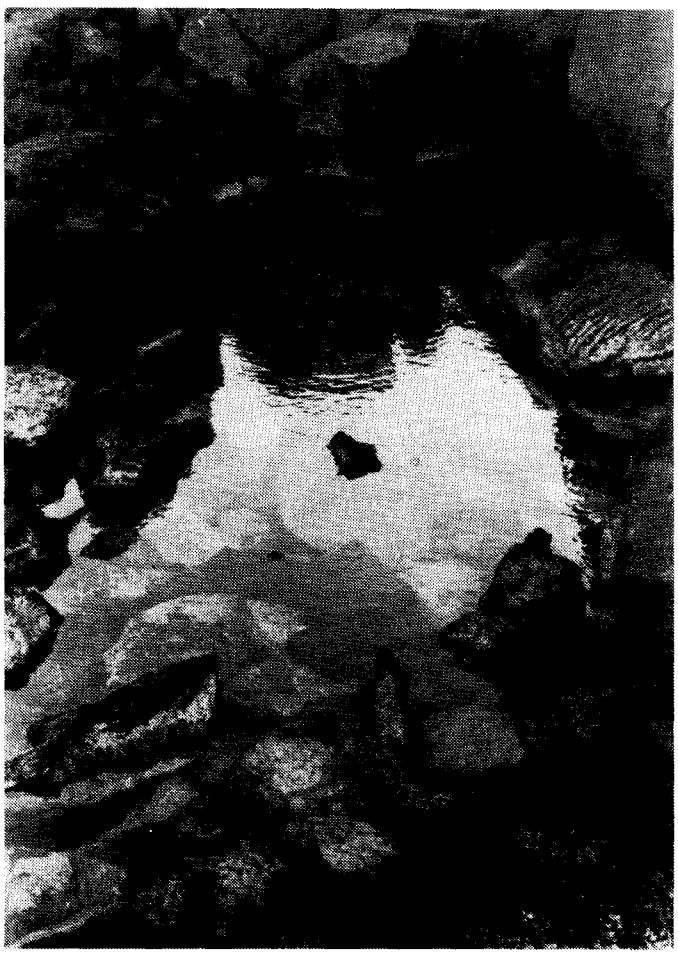

Fig. 10.

Fig. 11. Complex 4, Pool C - Halape: Found within a steep-sided crack west of Halape, this pool is the deepest one of the complex.

Fig. 12. Pool 5 - Boulder Bay at Halape: This is the largest pool in the National Park and contains a diversity of native fauna, consisting of three crustaceans and one mollusk. Pool 5 has an aesthetic appeal, even though it is approaching late senescence and may turn into a shallow salt-marsh within several years.

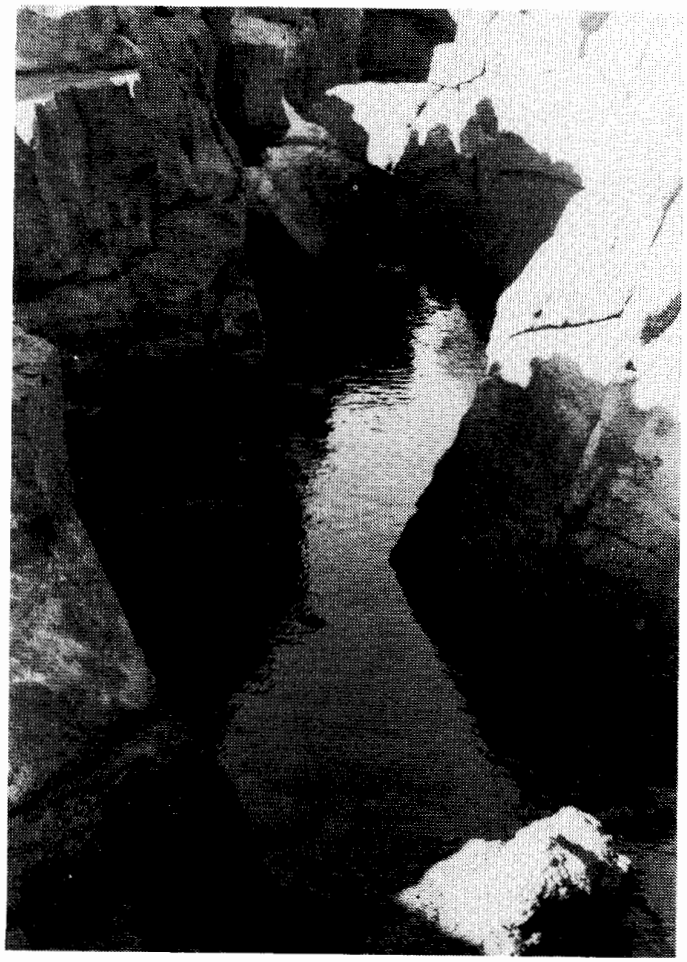

Fig. 11.

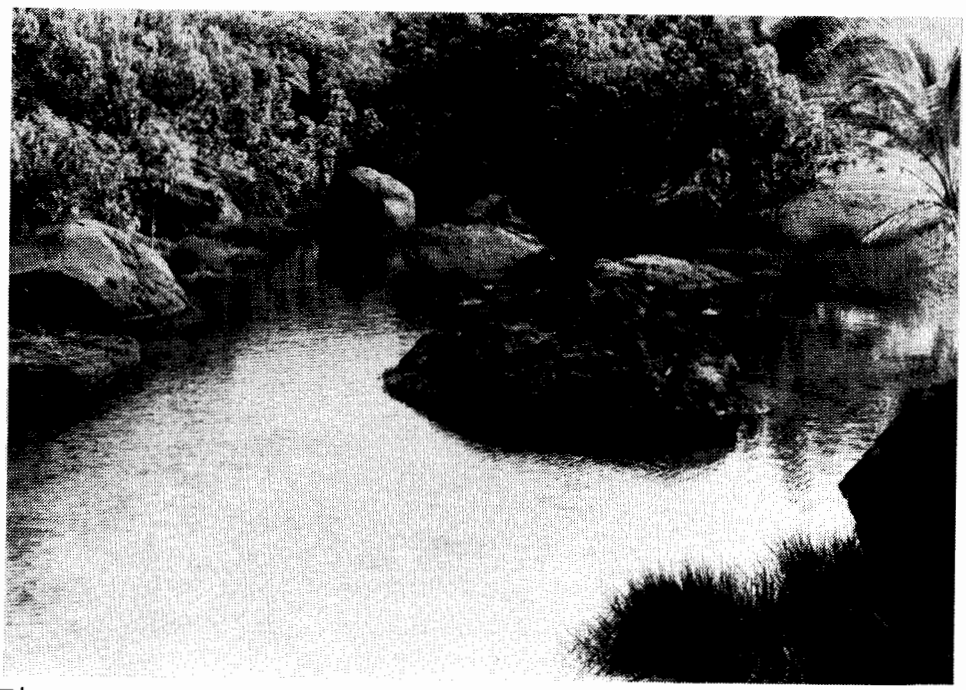

Fig. 12.