EVALUATION OF ANCHIALINE POOLS IN THE AWAKEE, KOHANAIKI, AND MAKALAWENA LAND DIVISIONS, NORTH KONA, HAWAII

by

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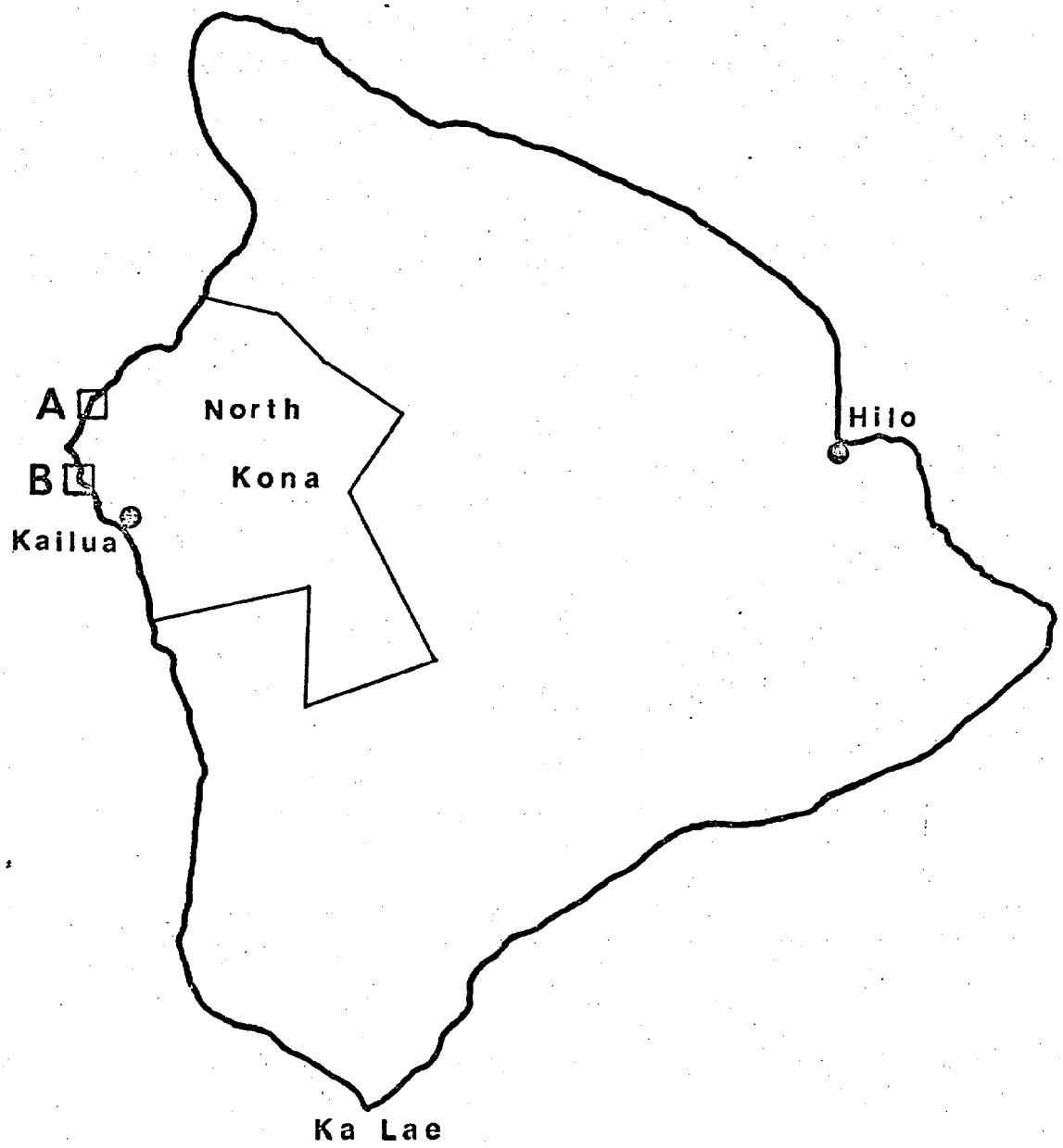
INTRODUCTION

Anchialine pools are isolated coastal exposures of the oceanic water table, mixohaline and tidal in character, and not surface-connected to inshore marine water. They are unique among aquatic ecosystems and are geographically limited in the United States to Hawaii. Their biota is distinctive in community structure and in the endemism of several species of invertebrates. Hawaiian anchialine pools have been described and discussed in various recent literature (see later). A good perspective of them was presented by Brock (1985).

This study concerns an inventory of anchialine pools at two localities in the North Kona District (Fig. 1) sponsored by the County of Hawaii. It originated in the aftermath of a series of recent survey reports by consulting agencies (e.g., OI Consultants 1985, 1986; Brewer and Assoc. 1986; and Dollar 1986). Primary objectives of this project were: 1. to obtain an independent assessment of pools on areas proposed for development; 2. to compare inventory findings with those of other surveys; and 3. to provide perspectives of environmental conditions and values as might be useful or necessary in land use planning decisions.

Selection of areas to be inventoried and the general study approach to be used was done in consultation with personnel of the Hawaii County Planning Department and environmentally oriented agencies (U.S. Fish and Wildlife Service, University of Hawaii, and The Nature Conservancy) beginning in February 1987. It was agreed that survey efforts concentrate primarily on the Kohanaiki area, and that pool biota be inventoried in an intensive manner (repetitive and nocturnal sampling). Field work was designed and accomplished by the author in concert with Mr. David Chai, assisted at times by one or two aides. Permission to do field work on private lands was arranged through the Hawaii County Planning Department, and appreciation is herewith expressed to the respective landowners. The author is solely responsible for the content of this report.

Fig. 1. Reference map of Hawaii Island showing the North Kona District locations surveyed: A = Awakee-Makalawena (Fig. 3); B = Kohanaiki (Fig. 2).



SURVEY APPROACH AND METHODS

Two periods for field survey, 4 - 16 March and 24 May - 2 June 1987 were selected primarily for optimal tidal conditions and secondarily to get the widest possible seasonal spread within time constraints of the contract and personnel availability. Only Kohanaiki was surveyed during the initial period, beginning with an extensive examination of all pools as a basis for choosing representatives for intensive study. Both Kohanaiki and Awakee-Makalawena (designated as a single locality because pool groupings there transcend land division boundaries) were surveyed during the latter period.

During the initial extensive survey of Kohanaiki, salinity of surface waters was measured refractometrically (American Optical Co. temperature compensated refractometer). All subsequent salinities and temperatures at Kohanaiki and Awakee-Makalawena were measured electronically (Yellow Springs Instrument Co. Model 54 T-O meter). Biota was inventoried mainly by visual inspection from the surface, supplemented by trapping and by snorkelling in deeper pools. Traps were fabricated from 0.3 cm square-mesh galvanized hardware cloth to form cylinders approximately 60 cm long and 14 cm in diameter. Plastic funnels at each end provided inverted openings. Traps were used both baited (fish scraps) and unbaited, being deployed mostly in overnight sets. Various maps from previous reports on the areas, cited elsewhere, were used to determine pool locations and to prepare maps used in this report.

Field surveys were accomplished by crews of 2 or 3 persons working together. Kohaniki was explored first during daytime high tides to determine the numbers and locations of pools. Of the 60+ pools identified, 47 were inventoried superficially for aquatic biota; 16 of those were then selected for intensive study ("monitored" pools). A similar approach was used at Awakee-Makalawena where 20 pools were sampled from among the 40+ ones identified. Night inventories were conducted in both study locations, the inventory effort summarized as follows:

	Number of surveys	
	Day	Night
Kohanaiki		
General survey (43 pools)	1	0
Monitored pools (16)	4	7
Awakee-Makalawena		
General survey (23 pools)	1	0
Selected pools (20)	2	1

Visits to a given area were usually staggered so that the same pool set was not surveyed on successive dates. In most cases, surveys were conducted at or above mean tide levels. Dates for night surveys were selected for the occurrence of nocturnal high tides. Important or representative pools were photographed with sufficient background to enable them to be identified later.

Biota inventoried (cf. Appendix A) included all aquatic macrofauna and three submersed plants characterized by obtrusive growths: Ahnfeltia, Chara, and Ruppia. Fauna ranged in size from minute invertebrates (0.1 cm amphipods) to 30-cm fish (mullet).

RESULTS

A. Kohanaiki

Pool distribution at Kohanaiki is shown in Fig. 2. In lieu of a formal engineering survey at very high tide, the total number of pools shown is conservative and their locations are approximate. Pools occur in clusters designated as Areas A through E. Only the group in Area E (pools not shown on recent survey maps) is truly isolated by distance from other pools. Numbered open circles indicate monitored pools, selected for diverse distribution and basin type. Photographs of those pools appear in Appendix E, Plates I through IV. In addition to the pools illustrated in Fig. 2, there are 2 or 3 more inside the stand of large mangroves ("Pine Trees").

The pools occur in a prehistoric pahoehoe flow; some basins are in open depressions (e.g. B-2, Plate II) while others are in collapse holes with considerable overhang (e.g. D-4, Plate IV) or in fissures (C-3, Plate III). A few nearshore basins are formed partly by beach deposits (C-1, Plate III). Significant amounts of fine sediments occur in most of the pools (11 of the 16 monitored pools). Introduced shrubs and trees such as christmas berry and mangrove obscure several pools. Some pools lack riparian or emergent vegetation, while others have moderate to dense growths of trailing succulents, pickleweed, sedges, or grasses. Several nearshore pools north of Wawahiwaa Pt. contain trash (B-4, Plate II) consisting of paper, plastic, cans, bottles, and other hardware. Beachgoers also bathe in some of the deeper pools in Area B.

Water depths at high tide range from a thin film in obscure depressions to about 2 m in one collapse pool. Observed temperatures and salinities (Table B-1) ranged

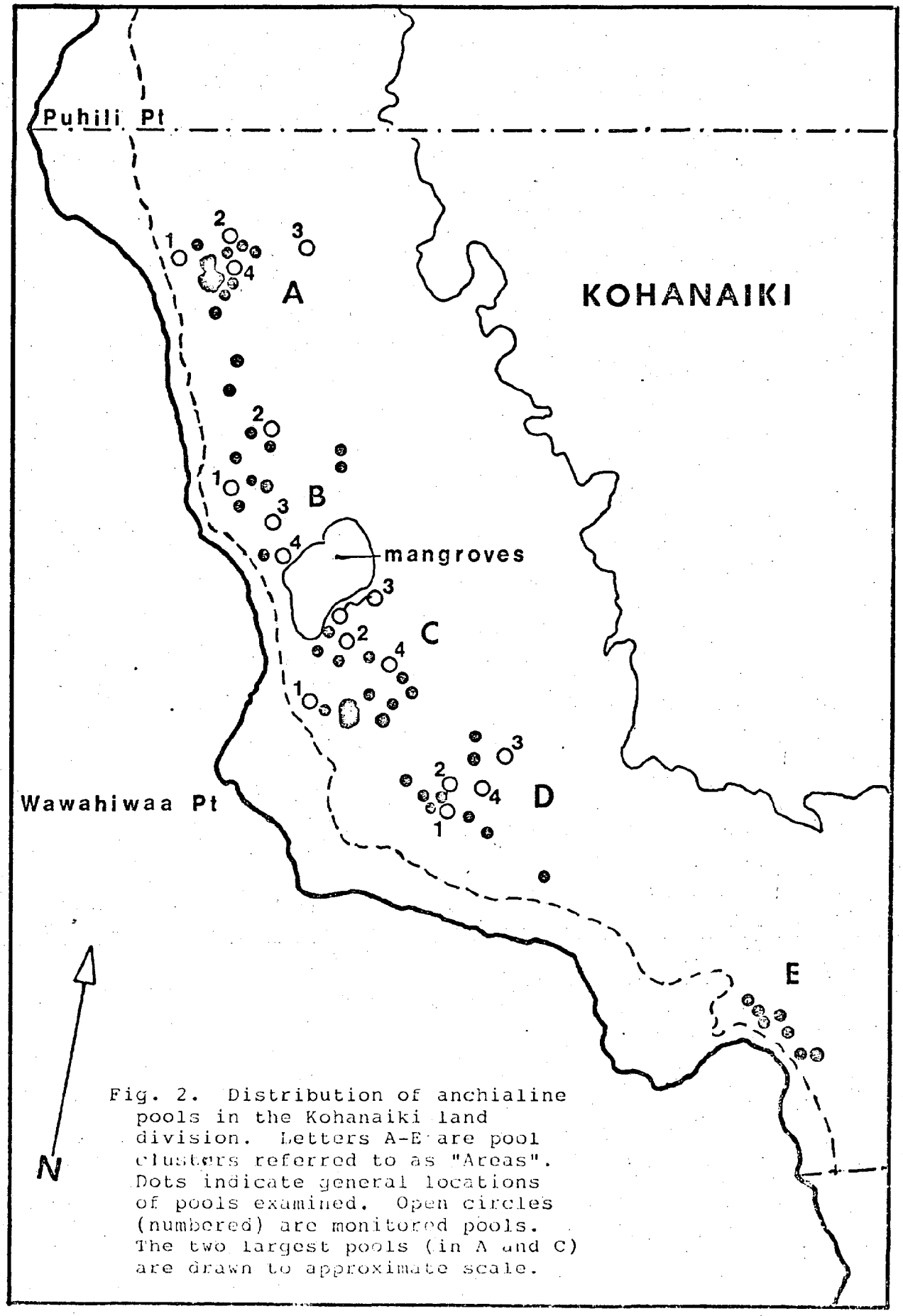


Fig. 2. Distribution of anchialine pools in the Kohanaiki land division. Letters A-E are pool clusters referred to as "Areas". Dots indicate general locations of pools examined. Open circles (numbered) are monitored pools. The two largest pools (in A and C) are drawn to approximate scale.

from 20.8° to 29.9°C and 8 to 16.5 ‰, respectively. A general trend of decreasing salinity from north to south through the land division was noted:

Area	Mean bottom salinity, ‰
A	14.4
B	12.6
C	12.6
D	10.9
E	9.5

Salinities also decreased slightly (5 ‰) in a landward direction. Vertical stratification was slight or absent. The greatest salinity gradient observed was 1.6 ‰ (11.3 to 12,9 ‰) in a pool 1.7 m deep. Another pool, 1.8 m deep, was isohaline at 13.2 ‰ with a slight (2°C) temperature gradient.

Aquatic organisms representing 28 taxonomic categories were found in the Kohanaiki pools (Table B-2). They are listed systematically with brief descriptions in Appendix A. Some taxons include more than one species (e.g. there are at least 5 species of Amphipoda), so that a list of species would probably approach 40 in number. At least one of the amphipods is a new genus being described. In addition to the invertebrates listed, colonies of a lavender-tinted sponge (Haliclona sp., Plate IIII) were found in the pool adjacent to C-1. Other interesting "discoveries" were two unsegmented worms, a pink nemertean (Plate VIII) and a brownish sipunculid, neither of which had been recorded previously from anchialine habitat, and the rare endemic snail, Neritilia hawaiiensis (Plate VIII). Three individuals of the snail were found, one in a pool in Area E and the others in Area D. The worms were also found in a few other pools not tabulated. The nemertean worm is especially interesting because its appearance and habits suggest that it may be limited in habitat to anchialine pools. Another unexpected feature was the diversity of fishes. Most widely dispersed were the mugilids, kuhliids, and poeciliids (topminnows).

Among the 16 pools sampled repetitively (Table B-2), the number of taxons found per pool ranged from 7 to 13, averaging 9.8. Considering only native invertebrates, which as a group are the most representative fauna of anchialine pools, individual pools had from 5 to 9 taxa, averaging 7.2 per pool. Most widely distributed among them were the red shrimps, Halocaridina and Metabetaeus (all pools), the amphipods and thiarid snails (15 pools), the assimineid snail (11 pools), and the palaemonid shrimp (10 pools). Red shrimps were exceptionally abundant in some pools and very scarce in others, especially those

with fish. Careful examination in crevices and among vegetation was necessary to detect shrimps in such pools. Widgeongrass (Ruppia) occurred in 9 of the 16 pools. Further occurrences of some of these taxa are given in Tables D-1 and D-2, and will be discussed later in context with survey comparisons.

B. Awakee-Makalawena.

The general distribution of pools at Awakee-Makalawena is shown in Fig. 3. Other exposures of water occur, particularly within the northern a'a flow and in the kiawe thicket to the south and west of Opaeula Pond. Although 43 pools are shown, the total may approach or even exceed 60. As at Kohanaiki, the pools tend to occur in clusters with the only well isolated group (No. 20 in the figure) occupying depressions in barren lava near the south and west boundary. Those pools were not identified in previous survey reports. Numbered pools have biota inventory data reported herein. Representative pools are illustrated in Appendix E, Plate V. Pools exist in a diversity of settings: fully exposed and densely shaded by trees, in historic a'a and in old pahoehoe, in basins with seaward sides formed by dunes and by rubble bars, and in collapse holes and fissures. Several pools are more or less modified by man. Some pools are heavily sedimented (but proportionately fewer that at Kohanaiki), while others (e.g. No. 20) are the "newest" (most oligotrophic) found anywhere in Hawaii. Riparian and emergent vegetation is restricted to a few pools.

Observed water depths at high tide varied up to 1.5 m. Temperatures and salinities, measured in 23 of the pools (Table C-1), ranged from 21° to 29° C and from 4,1 to 26.9 ‰ , respectively. Salinities in pools south of Opaeula were much lower (4-6 ‰) than those to the north (7.5-27 ‰). A landward decrease in salinity was noted, especially in a transect through the northern a'a field where values dropped progressively from 26.9 ‰ behind the beach rubble bar to 7.5 ‰ along the foot trail connecting Opaeula with Awakee Bay. Vertical salinity stratification (lower part of Table C-1) was pronounced in one pool, increasing from 11 to 26.9 ‰ in a depth of 1.5 m.

Twenty-six taxa of aquatic organisms recorded from 20 pools (Table C-2) included 2 plants, 13 invertebrates, and 11 fishes. Individual pools contained from 3 to 12 taxa, averaging 6.15 per pool. Native invertebrates (11 taxa) ranged from 1 to 6 per pool, averaging 3.65. The only unusual find was a small opisthobranch snail (Acteocina) in pool No. 2, a genus not previously recorded from anchialine habitat. Among the more common invertebrates,

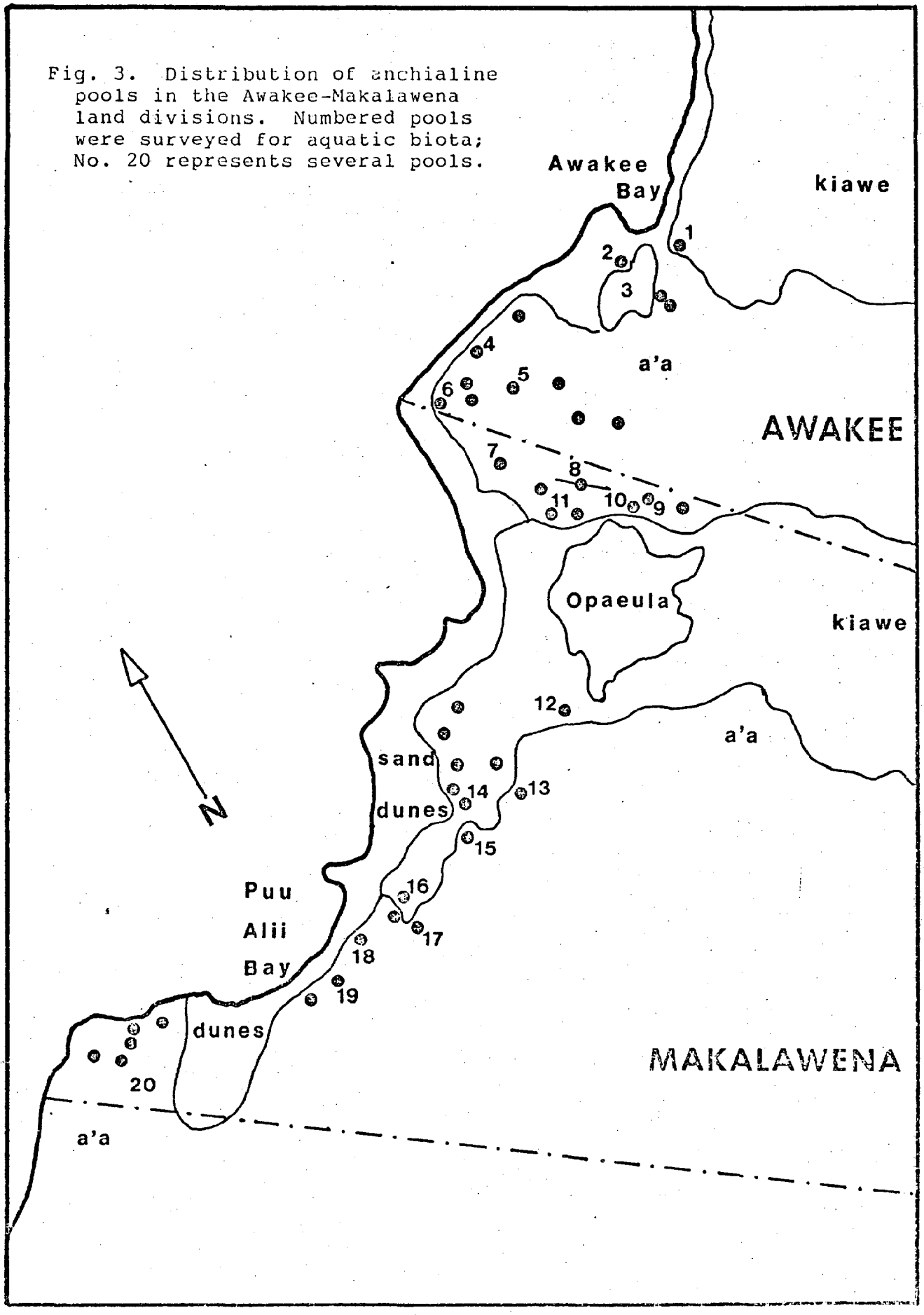


Fig. 3. Distribution of anchialine pools in the Awakee-Makalawena land divisions. Numbered pools were surveyed for aquatic biota; No. 20 represents several pools.

the red shrimps Halocaridina and Metabetaeus were found in 16 and 14 pools, respectively. The snails Thiara and Theodoxus were found in 13 and 9 pools, respecively. As at Kohanaiki, a diversity of fishes was observed. Most of the 13 or so species occurred in three pools north of Opaeula, one of which contained 9 species (including 2 labrids and 2 mugilids). Most widely distributed were topminnows (Poeciliidae: Poecilia reticulata and possibly Gambusia affinis), the taxon being found in 13 of the 20 pools. Kuhlia (aholehole) was the next most common fish (7 pools). Tilapia (Oreochromis) was observed in a pool directly north of No. 13 (Fig. 3). At least 29 species of aquatic organisms exclusive of algae were present in this locality.

An added feature of our survey was the documentation of predation on hypogeal shrimp by fishes. A large aholehole netted in a pool south of Opaeula had red gut contents that consisted primarily of shrimp fragments. Another pool (No. 14) provided direct evidence of topminnow predation. Viewed superficially, that pool seemed to have no red shrimp. However, a handful of Chara plucked from the bottom contained about 2 dozen Halocaridina among the branching filaments. As the shrimp were dropped individually into the pool (where water was 0.5 m deep over the benthic vegetational mat), they were devoured by the topminnows present. Only a few of the larger shrimp escaped to benthic shelter.

DISCUSSION AND SURVEY COMPARISONS

A. Kohanaiki.

In overview, Kohanaiki land division contains an impressive array of about 60 anchialine pools in a setting marred only by incipient littering and vegetational encroachment. That most of the trees and shrubs associated with such pools are exotic species has been noted elsewhere (Maciolek and Brock 1974). Two introduced plants appear to be particularly troublesome: mangrove (Rhizophora mangle) and pickleweed (Batis maritima). Some changes caused by the encroachment of these plants is shown in Appendix E, Plate VI which compares views of pools taken 15 years apart (1972 and 1987). Mangrove forms dense tree stands, as evidenced by the long-established "Pine Trees", whose shade and leaf litter eliminate most aquatic fauna. Pickleweed, a succulent shrub, overgrows sedimented pools causing early senescence. Other pools have been relatively unaffected vegetatively in 15 years as shown by the photographs in Plate VII.

Pool salinities are uniformly higher than in other pool groups of the Kona Coast (cf. Maciolek and Brock 1974), leading to a greater diversity of aquatic biota. The number of taxa found, particularly among the invertebrates, is second only to Cape Kinau, Maui (cf. Maciolek 1986) among surveyed localities. Discovery of new organisms (unsegmented worms, amphipods) and unusual species (sponge, Neritilia snail) considerably enhances the biological value of Kohanaiki pools. Among the described anchialine amphipods, Barnard (1977) reported only one species from Kohaniki. As noted above and in Appendix A, about 5 different ones were found including a new genus which is being described. In planning this project, it was hoped that some of the rarer shrimps (e.g. Procaris and Calliasmata) might be found at Kohanaiki because of the known higher salinities there, a requirement of certain shrimps (Maciolek 1983). It was also the main reason for repetitive trapping. Although no such shrimps were discovered during this survey, their appearance in surface pools at Kohanaiki remains a possibility.

The diversity of marine-derived fishes at Kohaniki (Table B-2) was unexpected since the original survey (Maciolek and Brock 1974) detected no fishes there, and a more recent survey (OI Consultants 1985) reportd only introduced species. Fishes of marine origin are usually found as individuals in scattered pools nearest the coast. As Brock (1977, 1985) pointed out, these fishes are basically inshore marine inhabitants most likely to be swept into anchialine pools as juveniles by storm surf. Such a situation probably occurred at Kohanaiki several months prior to our survey. Generally, such fishes cannot reproduce in anchialine pools and therefore disappear when their lifespans terminate. During their presence, however, they can deplete many representative invertebrates such as shrimps and amphipods.

The value of repetitive sampling was demonstrated by the continual finding of a new or previously unrecorded organism, and by additional pool occurrence records of organisms known to be present in the area. Each day, one new "find" was made up to and including June 1st, at which time the puffer fish (Arothron)was discovered in pool B-4.

In July 1985, anchialine polls at Kohanaiki were inventoried by OI Consultants (OIC 1985, 1986). Our survey attempted to inventory, at least in a cursory way, all pools tabulated in the OIC reports for comparative purposes. Minor difficulties were encountered in positively identifying a few of the pools. On the other

hand, some adjacent pools, identified as individuals by OIC proved to be surface-connected during our survey at high tide. Therefore the 56 pools indicated by OIC reduced to 43 common pools. To compare biota distributions objectively, it is necessary to use only those taxa common to both studies, which are far fewer than we found. One problem was in the fish group. OIC reported tilapia, but we do not believe they have ever occurred there. It is assumed here that OIC mistook juvenile Kuhlia or a similar fish for tilapia. Therefore, the following comparison considers only two fish categories, "large" fish and Poeciliidae.

The comparison of 43 pools is given in Tables D-1 and D-2. Eleven of the 12 taxa listed were found in more pools in this study (H. Co.) than by OIC. Comparing the number of taxa per pool, we found more than did OIC in 29 of the 43 pools, the average number of taxa per pool being: H. Co. = 4.7, OIC = 2.6. A similar difference in survey results can be seen in comparing native invertebrate taxa only.

Data presented by OIC (1985) permit a comparison of biota distribution by area that is independent of the numbers of pools sampled or identifications of individual pools. Table D-3 shows survey findings for two pool groups, Kohaniki N. (Areas A+B of this survey) and Kohanaiki S. (Areas C+D). Taxon categories are those used by OIC with the omission of four filamentous algae not inventoried by us. Comparisons of percentages of pools containing a given taxon show that in only one instance (excluding the doubtful tilapia), that of "Melania" (Thiara) in Kohaniki S., did OIC have a greater representation of any taxon.

A final comparison of surveys involves rating an area (pool group) based on the occurrence of selected native taxa as proposed by OIC (1985, p. 33). This rating approach expresses the taxonomic diversity of a pool or pool group on a common numerical basis, facilitating the comparison of different pools, different areas, and independent survey findings. It could prove useful in future surveys. OIC ratings utilized 9 "key" species (3 plants, 3 snails, and 3 shrimps), the maximum diversity value for a given pool or site thus being 9.0. Because two plant taxa (algae) used by OIC were not surveyed by us, the following comparison substitutes two groups of amphipods (purple and others, cf. Appendix A.). Amphipods are characteristic native anchialine invertebrates represented by several species in four families (Barnard 1977). Any bias of this substitution theoretically should favor higher rating values by OIC inasmuch as the algae appear to be more common and more easily observed. The

following compares our (H. Co.) findings with those of OIC (1985, Table 3) for three areas of Kohanaiki:

	No. pools - taxon diversity (0-9 scale)		
	North Areas A+B	South Area C	Far South Area D
OIC - 1985	27 - 1.37	16 - 2.81	13 - 3.92
H. Co.- 1987			
One survey	15 - 2.87	9 - 3.33	7 - 3.29
Monitored	8 - 5.75	4 - 7.50	4 - 7.25

Our diversity values for single-surveyed pools to the south do not differ much from those of OIC, but in the north, they are twice as great. Pool sets we monitored show a striking difference for all three areas, being 2 to 4 times greater than those of OIC. These differences again point out the importance of repetitive pool inspection, and suggest that this rating method cannot be useful to compare independent surveys without a standard inventory approach. Both surveys considered, the lower rating values for Area A+B compared to those south of the mangrove stand is associated with a greater distribution of fishes (15 pools in the north, 5 pools in the south).

B. Awakee-Makalawena.

The Awakee-Makalawena locality, like Kohanaiki, contains an impressive array of pools, a few of which are shown in Plate V. The setting differs somewhat in vegetation and pool-basin formation. Kiawe is the only significant occluding plant, succulents and emergents being scarce or absent except in Opaeula and pool No. 3 (Fig. 3). Pool basins are more diverse. Litter is absent; the main human influences being the excavation of rocks from some pools, wall construction, and the introduction of exotic Poecillidae and Oreochromis. No pools are overgrown with pickleweed.

Pool salinities generally averaged lower that at Kohanaiki but were more extreme with marked stratification. Discounting fishes, biotic diversity was lower, but still impressive in the broad spectrum of Kona Coast pools (cf. Maciolek and Brock 1974), and one unique invertebrate was found. The abundance of Theodoxus in some pools was notable as was the occurrence of 9 fish species in a single pool. The red shrimp Halocaridina was the most ubiquitous invertebrate. Although supressed by fish in some pools, it was observed at night inhabiting small fissures in the tilapia pool. The tilapia, a large population of stunted individuals, was observed 15 years previously (Maciolek and Brock 1972) but does not appear to have spread since then. The other introduced fish

taxon, Poecillidae, was also present in 1972 (3 pools) but has since spread noticeably (13 pools), probably by invading adjacent pools via fissures and crevices. Generally, biota distribution found in this survey was similar to that in 1972 with a few noteworthy exceptions: Palaemon and Metopograpsus occurred less widely in 1987, but more pools presently have Halocaridina, Metabetaeus, and Poecillidae, raising the average number of taxons per pool from 4 in 1972 to 6 in 1987. Increase in apparent shrimp distribution was likely due to our somewhat more intensive survey including nocturnal observations. Trap sampling contributed to the greater observed distribution of Metabetaeus.

Comparisons of this with other recent surveys follow those in the Kohanaiki discussion. Table D-3 compares aquatic biota north of Opaeula inventoried by us (H. Co., 11 pools) and by OIC (1985, 18 pools) as percentages of pools having a given taxon. Distributions of 9 taxa, including the two red shrimps, were considerably greater in our survey. Three other taxa (Assiminea, Palaemon, and Poeciliidae) were about the same in both surveys, and only the crab Metopograpsus was found more widely by OIC. Applying the diversity index of 9 key species, we rated pools of this area 3.91, while OIC (1985, Table 3) rated them 2.14.

Two more recent surveys (Dollar 1986 and Brewer & Assoc. 1986) provide additional comparisons (Table D-4). Because of the way data are presented in the cited reports, only two of the Awakee-Makalawena areas can be compared as percentages of pools containing a given taxon (first two columns). For Awakee, Dollar reported all pools (9) as having Assiminea, Thiara, and Poecillidae. However, Dollar considered our single large pool (No. 3) as several pools, and apparently did not sample others that we did. Among the remaining taxa, our percentages were overwhelmingly greater with special significance in the native invertebrates, For example, Dollar did not find Metabetaeus in pool No. 2 where we not only saw it during the day, but also captured about 200 individuals in a single trap set. In the area "Makalawena-N", comparison with Brewer and Assoc. (B&A) findings is even more extreme. We found twice as many (11) invertebrate taxa, and of the four common to both, our occurrence percentages were higher in three.

Comparisons for the areas south of Opaeula (columns 3 and 4, Table D-4) are based only on occurrence of a taxon in the area. In "Makalawena-S" we found 12 taxa (6 invertebrates) while B&A reported only 1 invertebrate and 4 total taxa, despite sampling twice as many pools as we did. Comparison of the "Dunes" data shows similar

findings in both studies. Our sampling intensity at Awakee-Makalawena was much less than at Kohanaiki. Therefore our findings of greater diversities and distributions of biota over those of other surveys must be due largely to more careful observation.

CONCLUSIONS AND EVALUATION

This survey has confirmed a prediction made 13 years ago (Maciolek and Brock 1974, p.14): "Other new animal species will most likely be discovered in Kona coast ponds." In view of the large number of intervening surveys, it is surprising that it has taken so long to happen. Discovery of at least four new anchialine invertebrates and a new distributional record for a rare endemic snail (Neritilia hawaiiensis) can be attributed largely to intensive (repetitive, nocturnal) sampling. Also attributable to such sampling effort is the enhanced biotic diversity of pools (both localities) over the findings of all earlier surveys. Considering also the numbers and physical diversities of pools in both localities, as well as the pristine condition of most of them, the assessment of high natural quality given them in the original survey (Maciolek and Brock op.cit., pp. 16-18) is substantiated. Thus, pools at Kohanaiki may well be the best representation of this unique ecosystem remaining on the Kona Coast, with the Awakee-Makalawena group close behind. As a valuable natural resource collectively, they should be protected and perpetuated in toto.

On the negative environmental side, there has been noticeable degradation of some pools in recent years via physical modification, contamination, and encroachment by undesirable exotic biota. Considering the intrinsic value of this unique resource, its relative scarcity, and the continuing inroads being made upon it, some effort should be applied to reverse the degradational trend. Most serious is the impact of introduced fishes on native invertebrates which are the most representative members of the anchialine community. If such fish can be controlled or eliminated, the fauna they have suppressed is "waiting in the wings" to re-establish normal populations.

Our survey findings stand in strong contrast to those of other recent surveys which have inadequately characterized pool biota in the two localities and thus shed doubt on qualitative evaluations or recommendations derived therefrom. Because the coastal zone is the focus of developmental effort and many of its areas still contain natural anchialine pools, aquatic surveys will

surely continue to be made. It is suggested here that any future survey results be disregarded for objective or decisional purposes unless a certain minimal survey effort had been applied. It is further suggested that the sampling effort be a minimum of two daytime and two nighttime inventories of any given pool, all being done with respect to tides at or above MHHW (mean higher high water). Such minimum effort would help make comparisons of independent survey findings (and also those of single pools or pool groups) more objective. That effort could not account, however, for variations in findings arising from differences in the observational acuity among survey personnel.

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APPENDIX A. Taxonomic list of aquatic biota from anchialine pools of the Awakee, Kohanaiki, and Makalawena land divisions, North Kona, March - May 1987. Taxons preceded by an asterisk (*) are not native.

Group/taxon	Description and locality
Plant	
Ahnfeltia	A. concinna, thallophyte (brown alga) attached to rock; to 5 cm; Kohanaiki.
*Chara sp.	Branching chlorophyte (green alga) attached in sediment; to 20 cm; Makalawena.
Ruppia	R. Maritima, vascular plant, rooted in sediment; to 1 m+; Kohanaiki and Makalawena.
Worm	
Nemertina	Class Anopla, probable Order Heteronemertea; pink, unsegmented worm; to 20 cm; nocturnal on rocks; Kohanaiki.
Sipunculida	Thin, brownish, marine worm (unidentified sp.); 10 cm+; Kohanaiki.
Crustacean	
Amphipoda-G	Unidentified (2 spp.?), light grey or tan; free swimming or under rocks; to ca. 0,7 cm; all areas.
Amphipoda-P	Probably Parhyale hawaiiensis, abundant purplish form; free swimming; to 0.3 cm; all areas.
Amphipoda-W	Unidentified (2 spp.?), one being described as new genus; unpigmented, blind forms; to 1.2 cm; Kohahaiki.
Halocaridina	H. rubra (opae'ula); red, hypogeal shrimp, to 1.5 cm; all areas.
Macrobrachium	M. grandimanus (opae kala'ole); brownish prawn; to ca. 10 cm; Awakee, Makalawena.
Metabetaeus	M. lohena; predaceous, red, hypogeal shrimp; to 3 cm; all areas.
Metopograpsus	M. thukuhar; brownish grapsid crab; to ca. 7 cm carapace width; all areas.
Palaemon	P. debilis (opae huna); transparent, dark-spotted "glass" shrimp; to 6 cm; all areas.

APPENDIX A. (cont.)

Group/taxon	Description and locality
Insect	
*Anisoptera	Dragonfly (Odonata), 2-3 introduced spp.; nymphs to 5 cm; Kohanaiki, Makalawena.
Dytiscidae	Black diving beetle (Coleoptera); free swimming; to 1 cm; Kohanaiki, Makalawena.
*Trichocorixa	T. reticulata (water boatman); light-colored bug; 0,5 cm; Kohanaiki, Makalawena.
*Zygoptera	Damselfly (Odonata), several spp., one or native; in benthic vegetation; nymph to 3 cm; Kohanaiki.
Snail	
Acteocina sp.	Opisthobranch; tiny whitish form; on rocks; Awakee.
Assiminea	A. nitida; small, pointed, brownish shell; benthic; to 0.3 cm; all areas.
Neritilia	N. hawaiiensis; tan to white, weakly whorled shell; rare; to 0.5 cm; Kohanaiki.
Theodoxus	T. [Clithon] cariosus; black, limpet-like shell on rocks; to 4 cm; all areas.
Thiara	T. [Melania] granifera; brown, spiralled shell; to 2.5 cm or larger; all areas.
Fish	
A. abdominalis	Damselfish - Abudefduf (mamo); marine pomacentrid; all areas.
A. sordidus	Damselfish - Abudefduf (kupipi); marine pomacentrid; Kohanaiki, Makalawena.
Acanthurus	A. triostegus (manini); marine surgeonfish; all areas.
Adioryx	A. lacteoguttatus (ala'ihi); marine squirrelfish; Kohanaiki.
Arothron	A. hispidus (o'opu hue); marine puffer fish; Kohanaiki, Makalawena.
Bathygobius?	B. fuscus (o'opu); small marine goby; Awakee.

APPENDIX A. (cont.)

Group/taxon	Description and locality
Fish (cont.)	
Chaetodon	C. lunula; marine butterfly fish; Awakee.
Chanos	C. chanos (awa); euryhaline milkfish; Kohanaiki.
Eleotris	E. sandwicensis (o'opu akupa); stream and estuarine eleotrid; all areas.
Kuhlia	K. sandvicensis (aholehole); euryhaline, also streams and estuaries; all areas.
Labridae	Wrasse (hinalea); 2 unidentified marine species; Awakee.
Mugilidae	Mullets: Mugil cephalus (ama'ama) and Neomyxus chaptalii (uouoa); euryhaline; all areas.
*Oreochromis	O. [Tilapia] mossambica; introduced euryhailine cichlid; Makalawena.
*Poeciliidae	Topminnows: Gambusia affinis (mosquitofish) and Poecilia reticulata (guppy); small introduced cyprinodonts; all areas.

APPENDIX B

Kohanaiki Survey Data

Tables B-1 and B-2

Table B-1. Temperature and salinities of anchialine pools on the Kohanaiki land division, North Kona, observed in March and May, 1987. May data taken at or near high tide. Locations shown in Fig. 2.

	Winter (4-7 March)	Spring (25 May)				
		Subsurface		Bottom		
				Depth		
Area-Pool No.	S,‰	T,°C	S,‰	M	T,°C	S,‰
A-1	17	24.0	16.1	0.6	23.6	16.5
A-2	14	24.9	14.4	0.9	23.1	14.2
A-3	10	23.9	13.0	0.7	21.7	13.1
A-4	14	23.5	14.4	0.3	23.9	14.9
Other pools (2)	13,15					
B-1	14	25.0	12.6	0.9	22.9	12.6
B-2	13	25.1	12.9	1.1	24.2	12.8
B-3	11	29.5	11.8	1.0	27.0	12.0
B-4	13	29.9	11.8	0.7	20.5	12.9
Other pools (6)	11-13					
C-1	16	25.1	14.7	0.4	25.5	16.1
C-2	9-12	23.3	11.7	1.1	22.1	12.7
C-3	11	27.0	10.5	1.1	21.8	11.7
C-4	10-12	26.0	11.4	0.6	22.1	11.3
Other pools (6)	9-16					
D-1	9-13	26.0	10.4	0.5	23.6	11.4
D-2	10-13	27.2	10.9	1.1	23.0	10.4
D-3	11-12	23.8	10.3	0.7	20.8	10.4
D-4	12-13	25.9	10.2	0.7	21.8	10.8
Other pools (7)	10-13					
E (2 pools)	8,11					

Table B-2. Occurrence and distribution of aquatic biota in 16 monitored pools on Kohanaiki land division, North Kona, in March, May and June 1987. Pool locations are shown in Fig. 2.

	Area and pool number															
	Area A				Area B				Area C				Area D			
Taxon	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Plant																
Ahnfeltia							x	x		x		x		x		x
Ruppia				x		x	x		x	x		x	x	x		x
Worm																
Nemertina					x		?							x	x	
Sipunculida						x	?									
Crustacean																
Amphipod-G		x	x				x	x	?			x		x		x
Amphipod-P	x	x	x	x	x	x	x	x	?	x	x	x	x	x	x	x
Amphipod-W			x		x		x				x				x	
Halocaridina	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Metabetaeus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Metopograpsus	x						x	x	x	x						
Palaemon			x	x			?		x	x	x	x	x	x	x	x
Insect																
Anisoptera										x			x	x		x
Dytiscidue														x		
Trichocorixa					x				x				x	x		x
Zygoptera										x	x	x	x			x
Snail																
Assiminea		x	x	x	x					x	x	x	x	x	x	x
Neritilia															x	
Theodoxus									x	x	x					x
Thiara	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Fish																
A. sordidus		x														
Acanthurus											x					
Adioryx											x					
Arothron								x								
Chanos									x							
Eleotris									x							
Kuhlia	x						x			x	x	x				
Mugilidae	x									x	x					
Poeciliidae	x			x		x										
Total taxons	8	7	8	8	8	7	10	7	10	14	13	11	10	13	9	13
Native invertebrates	5	6	8	6	7	5	7	5	6	9	9	8	7	9	9	9

APPENDIX C

Awakee-Makalawena Survey Data

Tables C-1 and C-2

Table C-1. Temperature and salinity observations of anchialine pools on Awakee and Makalawena land divisions, North Kona, 26-28 May 1987 (cf. Fig. 3)

Pool Group	No. pools samples	Bottom Values T, °C mean	T, °C range	S, ‰ mean	S, ‰ range
A. (adjoining Awakee Bay)	4	24.0	22-29	8.3	7.8 - 9.0
B. (in a'a flow)	5	23.4	22-28	12.9	7.5 -26.9
C. (N. of Opaeula)	4	23.3	22-25	12.5	10.4 -15.2
D. (S. of Opaeula)	6	22.4	22-23	4.5	4.1 - 4.9
E. (behind sand dunes)	2	21.5	21-22	4.9	4.9 - 5.0
F. (in a'a near S. boundary)	2	22.0	---	5.8	5.5 - 6.1

Vertical salinity stratification

Pool Number	Subsurface T, °C	Subsurface A S, ‰	Bottom Depth (m)	Bottom T, °C	Bottom B S, ‰	B - A ‰
3	22.7	10.0	1.0	23.0	20.0	10.0
6	27.0	11.0	1.5	28.5	26.9	15.9
8	23.9	9.4	0.5	22.5	15.2	5.8

Table C-2. Occurrence and distribution of aquatic biota in anchialine pools of the Awakee and Makalawene land divisions, North Kona, inventoried 25-31 May 1987.

	Pool number and area[1]																			
	Awakee						Makalawena N.					Makalawena S.						Dunes S.		
Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Plant																				
Chara														x						
Ruppia									x	x	x			x				x		
Crustacean																				
Amphipoda		x					x				x	x								x
Halocaridina	x	x	x	x	x		x	x	x	x		x	x	x	x	x		x	x	
Macrobrachium	x						x				x									
Metabetaeus	x	x	x				x	x	x	x		x	x	x	x	x		x	x	
Metopograpsus						x	x													
Palaemon				x	x	x							x							x
Insect																				
Anisoptera									x											
Dytiscidae									x	x										
Trichocorixa							x		x											
Snail																				
Assiminea		x									x									
Theodoxus			x	x	x	x		x	x		x	x								x
Thiara	x	x	x				x		x		x	x		x	x	x	x	x	x	
Fish																				
A. abdominalis						x		x												
A. sordidus											x									x
Acanthurus				x																x
Arothron											x									
Bathygobius			x			x					x									
Chaetodon						x														
Eleotris			x			x		x			x									
Kuhlia			x			x	x	x			x						x			x
Labridae						xx														
Mugilidae				x		xx	x				x						x			
Poeciliidae	x		x				x	x	x	x			x	x	x	x	x	x	x	
Total taxons	5	5	8	5	3	12	10	7	9	5	12	5	4	6	4	4	4	5	4	6
Native invertebrates	4	5	4	3	3	3	6	3	6	4	6	5	3	4	3	3	1	4	3	3

[1]Pool locations are shown in Fig. 3.

*Addendum: Add under Snail - Acteocina sp., Awakee pool 2.

APPENDIX D

Data Comparisons

Tables D-1 through D-4

Table D-1. Comparison of aquatic biota found in 20 anchialine pools on the northern half of Kohanaiki land division, North Kona, during this study (H.Co., X's in table) with that reported by OI Consultants (OIC 1985 and 1986, O's in table). Only taxons common to both surveys are included.

	Area A - OIC pool number									Area B - OIC pool number											
Taxon	1	2+3+ 4+39	30+ 31	32	37	38	40	41+ 42		7	9	10	11	12	26	27	28	33	35	36	44+ 45
(H.Co. pool No.)	(2)				(1)		(4)							(4)					(3)		
Plant																					
Ahnfeltia		X												X					X		
Ruppia		XO					X			X	X								XO		
Crustacean																					
Amphipoda	X				X		X				X		X	X	X		X	X	XO	X	O
Halocaridina	X	X	XO		X		XO	X		X	X		XO	X	X	X	X	XO	XO	XO	X
Metabetaeus	X	X	X		X		X	X			X		X	X	X	X	X		X	X	
Metopograpsus					X									X	X		X		X		
Palaemon		X				O	X					O								X	
Snail																					
Assiminea	X		X				X														
Theodoxus																					
Thiara	XO	XO	XO	O	X		X	XO				X	O	XO			XO	XO	X	X	XO
Fish																					
Large[1]	X	XO			X						O			X	X				X		XO
Poeciliidae	O	XO	O	XO	X	XO	X	XO		X	XO	XO									
No. of taxons:																					
H.Co.	6	8	4	1	7	1	8	4		3	5	2	3	7	5	2	5	3	8	5	3
O.I.C.	2	3	3	2	0	2	1	2		1	1	2	2	1	0	0	1	2	3	1	3
Invertebrates:																					
H.Co.	5	4	3	0	5	0	6	3		1	3	1	3	5	4	2	5	3	5	5	2
O.I.C.	1	1	2	1	0	1	1	1		0	0	1	1	1	0	0	1	2	2	1	2

[1] Includes all possible fishes listed in Appendix A except Poeciliidae. O.I.C. reported tilapia (Oreochromis) from this land division, a species not found in our survey (cf. Tables B-2 and D-3).

Table D-2. Comparison of aquatic biota found in 20 anchialine pools on the northern half of Kohanaiki land division, North Kona, during this study (H.Co., X's in table) with that reported by OI Consultants (OIC 1985 and 1986, 0's in table). Only taxons common to both surveys are included.

Taxon	Area C - O.I. pool number													Area D - O.I. pool number										Pools with taxon[2]	
						21+		23+									59+			63+						
	13	17	18	19	20	53	22	48	29	46	51	54	55	56	57	58	62	60	61	64	65	67	68	H.Co.	OIC
(H.Co. pool No.)	(4)					(1)			(3)				(2)			(4)	(1)			(2)					
Plant																									
Ahnfeltia	X												X		X?					X		X	XO	8	1
Ruppia	XO	XO		O		XO	XO	XO		X	XO	XO	XO	O	XO		X			XO		O		18	16
Crustacean																									
Amphipoda	X	O				X		XO	X	X			X		X		XO			X		XO		21	6
Halocaridina	XO	XO	X			XO	XO	XO	X	X	XO	XO	XO	X	XO	XO	XO	XO	XO	XO	X	XO	XO	38	22
Metabetaeus	XO		X			X			X			X	X	X	X	XO	X	X	X	XO	X	X	X	30	3
Metopograpsus						X							XO											7	1
Palaemon	X	XO		X	X	XO		X	X		XO		X	O	XO	XO	XO			XO	X	O	O	17	13
Snail																									
Assiminea	X								X			O	X		X	O	XO	O		XO				9	6
Theodoxus					X	X	XO	X	X		X	X	X		X									9	1
Thiara	XO		O	O		XO	O	XO	XO	X	O	O	XO	O	XO	XO	XO	XO	XO	XO	XO	O	O	26	30
Fish																									
Large[1]	X			X		X			X				XO											12	4
Poeciliidae																								9	8
No. of taxons:																								204	111
H.CO.	9	3	2	2	2	9	3	6	8	4	4	4	11	2	9	4	7	3	3	8	4	4	3		
O.I.	4	4	1	2	0	4	4	4	1	0	4	4	5	3	5	5	5	3	2	6	1	5	4		
Invertebrates:																									
H.Co.	6	2	2	1	2	7	3	5	7	3	3	3	8	2	7	4	6	3	3	6	4	3	2		
O.I.	3	3	1	1	0	3	4	3	1	0	3	3	3	2	3	5	5	3	2	5	1	4	3		

[1] See footnote on Table D-1.

[2] Includes all pools jointly sampled (cf. Table D-1).

Table D-3. Comparison of survey inventories of anchialine pool biota in three areas of North Kona as reported herein (Hawaii Co. = H.Co.) and by OI Consultants (OIC 1985).

	Percentage of pools containing taxon					
	Awakee-Makalawena N.		Kohanaiki N.		Kohanaiki S.	
Taxon[1]	H.Co. 1987	OIC 1985	H.Co. 1987	OIC 1985	H.Co. 1987	OIC 1985
Plant						
Ruppia	27	29	25	11	57	52
Invertebrate						
Assiminea	18	14	15	4	26	21
Melania	55	38	65	48	57	86
Theodoxus	64	29	0	0	39	3
Amphipoda	27	5	55	7	43	14
Metabetaeus	64	5	70	0	70	10
Halocaridina	82	19	85	22	91	69
Palaemon	27	24	15	7	61	45
Macrobrachium	27	0	0	0	0	0
Metopograpsus	18	19	15	0	9	3
Fish						
Mugil	45	0	15	0	4	0
Kuhlia	45	5	20	0	17	0
Eleotris	36	10	0	0	9	0
Oreochromis	0	0	0	11	0	0
Poeciliidae	55	62	45	44	0	0
Total pools inventoried	11	21	20	27	23	29

[1]Taxons limited to and in the order presented by OIC (1985) See Appendix A for descriptions of categories.

Table D-4. Comparisons of aquatic biota found in anchialine pools on Awakee and Makalawena land divisions in this survey (H.Co.), and in those reported by Dollar (Dol.1986) and Brewer & Associates (B&A 1986).

	Percentage of pools sampled				Taxon occurrence			
	Awakee		Makalawena-N		Makalawena-S		"Dunes"	
Taxon	H.Co.	Dol.	H.Co.	B & A	H.Co.	B & A	H.Co.	B & A
(No. of pools)	(6)	(9)	(5)	(6)	(6)	(14)	(2)	(6)
Plant								
Chara					x			
Ruppia			60	17	x		x	x
Crustacean								
Amphipoda	17	0	40	0	x			
Halocaridina	83	11	80	50	x		x	x
Macrobrachium	17	0	40	0				
Metabetaeus	50	0	80	0	x		x	
Metopograpsus	17	0	20	17				
Palaemon	50	11	0	17	x			
Insect								
Anisoptera			20	0				
Dytiscidal			40	0				
Trichocorixa			40	0				
Snail								
Assiminea	17	100	20	0				
Theodoxus	67	33	60	17	x			
Thiara	50	100	60	33	x	x	x	x
Fish								
A. abdominalis	17	11	40	0				
A. sordidus			20	17				
Acanthurus	17	0						
Arothron			20	0				
Bathygobius	33	0						
Chaetodon	17	0						
Eleotris	33	0	40	0				
Kuhlia	33	0	60	0	x			
Labridae	17	11						
Mugilidae	33	0	40	17	x	x		
Oreochromis					x	x		
Poeciliidae	33	100	80	83	x	x	x	x
Total taxons	18	8	19	9	12	4	5	4
Native invertebrates	9	5	9	5	6	1	3	2

APPENDIX E

Photographs

Plates I through VIII