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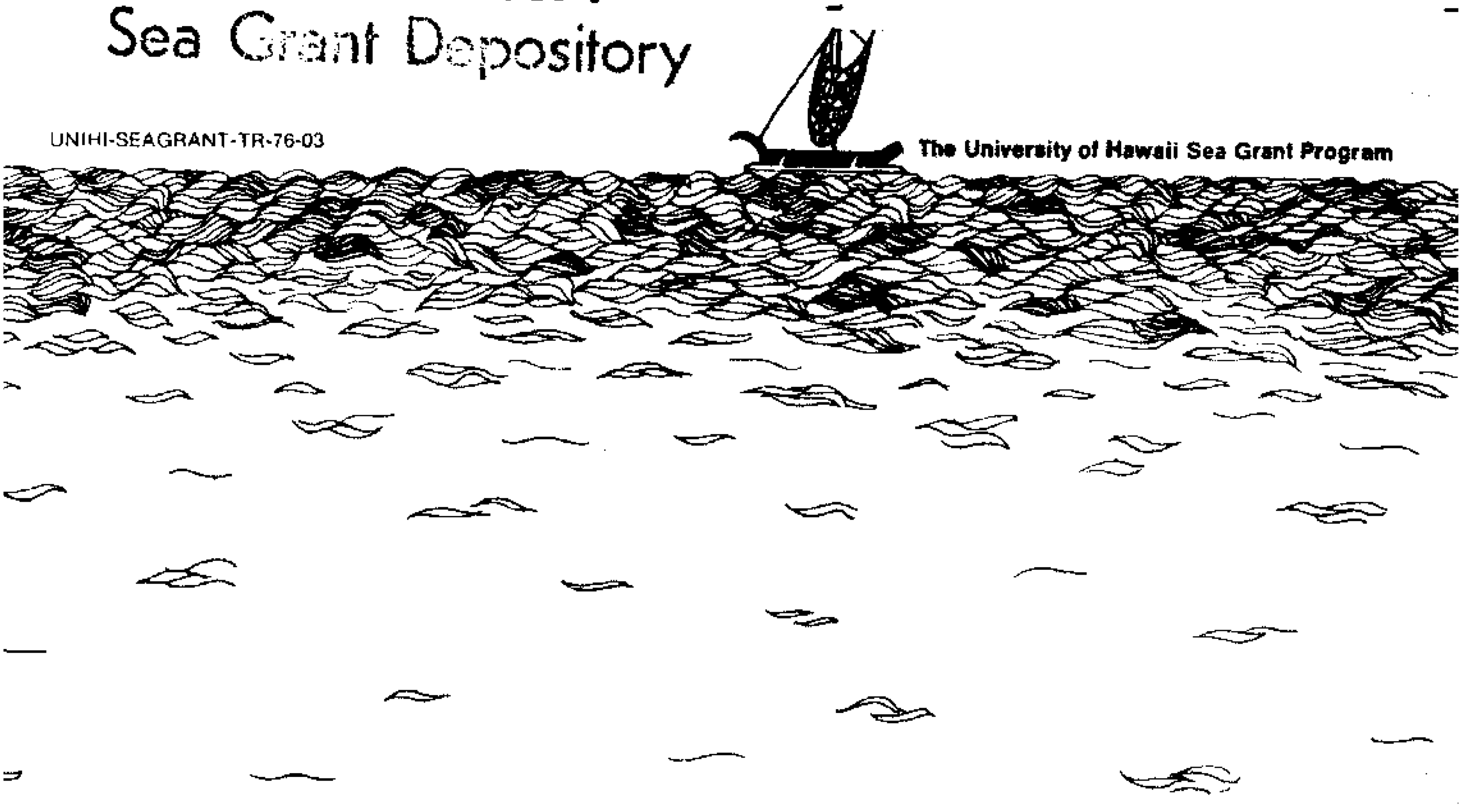

The Potential for Additional Marine Conservation Districts on Oahu and Hawaii

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ABSTRACT

There is some concern at present that Hawaii's nearshore marine resources are being depleted by fishing and collecting pressures. One means of combating this apparent depletion is by the establishment of additional marine conservation districts like Hanauma Bay and Kealakekua Bay. If established, these areas could also serve as natural educational and recreational sites or marine parks and could be used for scientific study.

A poll was conducted through mailed questionnaires and interviews with shoreline users to assess public opinion on marine conservation districts. Of the 1722 responses, over 69 percent was favorable toward the establishment of additional marine conservation districts with only 16 percent opposed.

Three potential marine conservation district sites on the island of Hawaii and four on Oahu were selected for detailed study from a preliminary list. The existing marine conservation districts were added to this list to provide a standard of comparison. Inspections of each site and estimates of abundance and diversity of fish, coral, and macroinvertebrates provided data for the evaluation of these sites with respect to 15 previously established criteria. Comparisons of each site with the others and with the existing marine conservation districts led to the recommendation of several of these sites for new marine conservation districts.

A site south of Kahe Beach Park on Oahu would be the most suitable of the Oahu sites, if the City and County of Honolulu is successful in obtaining the adjoining land for a beach park. The second choice on Oahu is Pupukea Beach Park. On Hawaii, Koaie Cove was rated highly with respect to nearly every criterion applied, so this is the first choice of the Hawaii sites. Honaunau Bay is the second choice on that island.

Two other sites, both on Oahu, were found to be less suitable as marine conservation districts. At Makapuu Beach Park, the most interesting diving areas are distant from shore and diving conditions are often unsafe, so this area would be unsuitable for recreation. It might be suitable as a natural area reserve, but this may not be necessary unless usage of the site increases. The patch reefs in Kaneohe Bay are also not considered suitable because the most noticeable adverse effects of man on the bay are not from fishing or collecting, which would be alleviated by the establishment of a marine conservation district, but from pollution and silt.

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INTRODUCTION

The State Department of Land and Natural Resources has established two marine life conservation districts in Hawaii: Hanauma Bay, established on Oahu in 1967, and Kealakekua Bay, established on the island of Hawaii in 1969. There is also a natural area reserve at the Cape Kinau-Ahihi Bay area on Maui, established in 1970. The selection of these particular sites was made primarily on a geographic basis, with the ease of definition apparently being the foremost consideration.

Since their inception, these conservation districts, especially Hanauma Bay, have enjoyed considerable success as recreational sites: Hanauma Bay typically receives 1500 to 2000 visitors per weekend day and 500 to 800 per weekday (J. Lee, City and County of Honolulu Department of Recreation, 1975: personal communication). There has been an apparent success from the conservation standpoint at Hanauma Bay: fish populations appear to have increased, but this is difficult to prove as there is a lack of data on fish populations before 1969.

The following definitions will be used in this report:

Marine Conservation District: An area in which consumptive use of marine life is prohibited, including pole and spearfishing and collecting of aquarium fish, shells, and coral. This prohibition may extend to all or part of the area.

Marine Park: An area which is intended for underwater recreational use and which is normally also a conservation district. The two terms will be used interchangeably in this report.

Natural Area Reserve: An area in which consumptive use is prohibited and in which recreational use is considered incompatible and, while not prohibited, is not encouraged.

Limited evidence is available which suggests that an increase in consumptive use of Hawaii's marine resources has resulted in a decline of some populations. Casual conversations with fishermen revealed that fishing in many areas has deteriorated. Unpublished data provided by E.A. Kay on the 'opihi, *Patella sandwichensis*, showed that those sold in the market now are smaller than they were 20 years ago. Furthermore, 'opihi found on Hawaii island shores which are accessible to large numbers of people were mostly small juveniles; they were apparently being replenished from breeding adult populations on parts of the shore inaccessible to the public.

Gardner and Nordyke (1974) estimated that the population of the state of Hawaii will continue to increase--exceeding one million by 1995. Based on 1970 birth, mortality, and immigration rates, as the human population grows, it can be expected that the number of fishermen, spearfishermen, and fish, shell, and coral collectors will also grow and that some marine animal populations will decline. There are several alternatives for management of these resources to allow populations of marine animals to stabilize at a reasonably high level. The ideal is a complete fishery management program, using the maximum sustainable yield concept. This is, of course, impracticable from the standpoint of enforcement and because data on present catches and population sizes are extremely scanty. Another possibility is the use of open and closed seasons for various species, a method which seems undesirable in view of the number of people who depend on fishing for income and sustenance. A third alternative is to close large sectors of the shoreline to consumptive use for some period such as a year and to alternate the areas closed from one year to the next. The problem here is that the time actually required for populations of marine organisms to recover to a state resembling the natural one is unknown for many species and may be considerably longer than one year. Corals, for example, have a rather slow growth rate, requiring about 10 years to grow to full size for *Pocillopora meandrina*, the species normally sold by the roadside; a large head of *Porites lobata* may take hundreds of years to grow (Maragos, 1973). What is needed, then, is more information on population sizes and growth rates before a rational management system can be implemented. The establishment of more marine conservation areas or natural area reserves could serve as a stopgap measure to insure that at least some populations of marine organisms are maintained and could later be incorporated into the management system. This would necessitate a much smaller enforcement effort than a more widespread, but haphazardly conceived, system of management. A marine conservation district would also afford an opportunity to study the reaction of the marine ecosystem to the elimination of stress imposed upon it by the removal of organisms.

An additional benefit of permanent marine conservation districts is their recreational and educational values. The use of these areas as marine parks is not incompatible with their conservation function. It further enables people to view marine life in as close to a natural state as possible.

Accordingly, this study is predicated upon the assumption that the way to approach marine conservation, at least for the present, is through the establishment of additional marine parks and conservation areas. It is an attempt to answer the questions raised in the State Division of Fish and Game memorandum of September 25, 1973, which asked the public for input on the choice of sites for new marine parks. The study centers on two questions: (1) Do the people of Hawaii want more marine parks? and (2) What sites show the most potential from the standpoint of their location, their suitability for snorkeling and diving, and the makeup of their marine communities? The study deals with the islands of Oahu and Hawaii only; logistic and time limitations prevented extending it to the other islands.

PUBLIC OPINION SURVEYS

The public opinion survey was an attempt to answer the question, Do the people of Hawaii want more marine parks? Another goal was to determine which sites the people would prefer to have made into marine parks. Two approaches were used--a brief questionnaire and an interview.

Questionnaire

The intent of the questionnaire was to assess the opinions of residents and voters. It consisted of a single page with questions about the respondents' present use of shoreline areas and a second page about his background--his age, sex, length and area of residence, and whether he was registered to vote. The Oahu questionnaire (Appendix A) asked the question, Would you be in favor of additional marine conservation areas on Oahu? This question was followed by a list of potential marine park sites compiled as described in the next section. The respondent was asked to choose those sites at which he thought a marine park should be established. In the Hawaii version the question asked was, Would you be in favor of additional marine parks on Hawaii? The question, Did you know that Kealakekua Bay is a marine park? was also asked in the Hawaii version of the questionnaire.

The questionnaire, along with a postage-paid return envelope, was mailed to 1286 residents of Oahu and 1500 Hawaii residents. A second copy was sent to each person who had not replied by the third or fourth week after the initial mailing.

On Oahu, names were selected at random from the cross reference telephone directory. The population sampled was comprised of only those persons who had telephones listed in their names; it is likely that this sample under-represented low income people and young people living at home or sharing housing. Most telephones are listed under the names of male heads of household. To enhance the proportion of females in the sample, about a third of the male names selected were changed by the substitution of "Mrs." for "Mr." in the address. Although this may have reduced the number of questionnaires returned, it increased the proportion of returns from females to about 42 percent of all responses.

There is no cross reference telephone directory for Hawaii, so the names were drawn from the voter registration list. A lower rate of return was anticipated because the addresses in the voter registration list were out of date. This list of names, like the list from the telephone directory, probably under-represented low income individuals (Babbie, 1973).

Results

The results of the questionnaires are summarized in Table 1. As had been expected, a greater proportion of the mailings elicited responses from Oahu than from Hawaii. The number of respondents in favor of establishing new marine parks was over two-thirds of the total of the two islands. The proportion of negative responses on Hawaii was higher than on Oahu, probably because the "no opinion" choice was not offered and respondents were forced to choose between selecting an answer and leaving that space blank.

Table 2 lists the respondents' preferences of sites for new marine parks, including only those sites listed in the questionnaire. It is likely that most of the respondents chose the areas that they did because of lack of familiarity with the other areas, rather than a real preference of some sites over others. This can be seen in the high preference on Oahu for the Kapapa Island area of Kaneohe Bay (other areas of the bay were not listed). This area, discussed in the Kaneohe Bay site description, is quite unsuitable as a marine park for a number of reasons, among which are its flat topography, low coral cover, and meager fish populations. The high preference for this site probably reflects well-publicized concern over the turbid, eutrophic waters of the bay and not, in most cases, a genuine knowledge of and wish to preserve this particular part of the bay. In the Hawaii survey the greatest number of respondents preferred Waipio Valley. As with the Kapapa Island area, the value of Waipio Valley as a marine park does not follow from an inspection of the area. It is inaccessible except by four-wheel drive vehicle, the water is somewhat turbid, currents are strong, and there is no reef.

TABLE 1. QUESTIONNAIRE RESPONSES

Island	Mailed	Returned	Opinion on New Marine Parks		
			In Favor	Opposed	No Opinion
			TOTAL RESPONSES		
Oahu	1286	555 43.2%	395 71.2% (92.7%)*	31 5.6% (7.3%)	129 23.2%
Hawaii	1500	385 25.7%	272 70.6% (76.6%)	83 21.6% (23.4%)	30 7.8%
			VOTER RESPONSES**		
Oahu		418	304 72.7% (93.0%)	23 5.5% (7.0%)	91 21.8%

*Percentages given in parentheses are computed from those responses which expressed an opinion. All other percentages are based on the total number of responses.
**Nearly all of the Hawaii responses were from registered voters, so a separate breakdown is not presented.

TABLE 2. MARINE PARK SITE PREFERENCES FROM QUESTIONNAIRE

Oahu			Hawaii		
Site	Number of Times Selected	%*	Site	Number of Times Selected	%*
Kapapa Island area of Kaneohe Bay	211	38.0	Waipio	106	27.5
Pupukea (Sharks' Cove)	137	24.7	Puako	95	24.7
Laie	120	21.6	Laupahoehoe	88	22.9
Blowhole	105	18.9	Onomea Bay	83	21.6
Kahe Point	96	17.3	Kaimu	81	21.0
Black Point	94	16.9	Honaunau	80	20.8
Maili	83	15.0	Punaluu	72	18.7
Makua	80	14.4	Leleiwa	69	17.9
			Keahole	60	15.6
			Koaie Cove	60	15.6
			Pohoiki	40	10.4
			Okoe Bay	36	9.4
			Halape	30	7.8

*Percentages are based on the total number of responses.

Appendix B classifies the responses by the age and sex of the respondents and, for Oahu, by first and second mailing. For Hawaii, it presents a comparison of the respondents' knowledge that Kealakekua Bay is a marine conservation district with their opinions on establishing new marine parks.

Differences between age groups were not statistically significant on the Oahu survey, except that there was a significant increase in the number of "don't know" responses with increasing age (Chi-squared test, $P = .1$). On Hawaii, the 20 to 29 year age group was significantly more in favor with fewer opposed ($P = .01$), while the opposite was true for those over 60. No other trend was detected. The only significant difference between the sexes occurred on Oahu, where more women chose the "don't know" response than men, while more men answered "no" to the question on more marine conservation districts. A comparison of the two mailings on Oahu revealed that there were significantly more "yes" responses to the first mailing, while the second elicited fewer "yes" and more "don't know" responses ($P = .1$); "no" responses were indistinguishable between mailings. In the Hawaii survey, those respondents who indicated that they knew Kealakekua Bay was a marine park were slightly more in favor of additional marine parks ($P = .2$) than those who did not.

Opinions on the establishment of new marine parks did not vary significantly with the respondents' areas of residence or with the shoreline areas they presently use. On Oahu, these two factors could not be correlated with the respondents' choices of marine park sites either, as the sample size for many of the areas was too small. On Hawaii, however, many people who lived on the windward side of the island picked sites on the Kona coast, while few Kona coast residents selected sites on the windward side.

Comparisons of the age distribution of the Oahu returns with the most recent statewide population estimates (DPED, 1974) revealed that the age distribution is significantly different (Chi-squared test, $P = .05$) for males, but different at only the 20 percent level of significance for females. This comparison was not made for Hawaii because such recent population data were available only for the state as a whole. The statewide age and sex distribution should approximate that of Oahu, where 82 percent of the population lives, but not Hawaii with less than 10 percent of the total population.

Space was left on the questionnaire for comments. Appendix C contains a sampling of the remarks made by respondents on the Oahu questionnaire.

Interview

Methods

Users of shoreline areas such as divers, fishermen, and swimmers would be more affected by the establishment of marine parks than the general populace. For this reason and because these people might be more familiar with the need for marine conservation, an assessment of the opinions of shoreline users was necessary. This was provided through interviews with persons encountered at a number of shoreline locations. Interview sites were selected all around the two islands, so that there were several interview sites in each of the segments of shoreline listed in the questionnaire. The interview locations included, but were not limited to, the potential marine park sites listed in the questionnaire. They comprised both sandy beaches and rocky shorelines.

Interviews were conducted by members of the project group and by volunteers from University of Hawaii sociology classes. All underwent a brief training period including several practice interviews in the field.

The interviews took place both on weekends and during the week. Upon arriving at the assigned sites, the interviewers counted the number of people engaged in each activity, such as pole fishing, spearfishing, or sunbathing. They then computed a proportion of each group to interview, so that each activity would be adequately represented. At most Hawaii sites there were only a few persons present, so all were interviewed. The interviews, which lasted from 10 to 15 minutes, consisted of questions similar to those in the questionnaire, along with others concerning what activities the interviewees engaged in, why they liked the interview site, and how they would be affected by the establishment of a marine park at that site. The questions asked in the interview are listed in Appendix D.

Results

A total of 97 interviews were conducted on Hawaii and 685 on Oahu, where considerably more volunteer help was available. Table 3 lists the responses to the question, Would you be in favor of additional marine conservation areas on Oahu (Hawaii)? Favorable responses were again about two-thirds of the total and there were no significant differences between favorable responses on the two islands or between the interviews and the questionnaires. The proportion of respondents who answered "no" was significantly higher on the interview than on the questionnaire and significantly higher on Hawaii than on Oahu.

TABLE 3. INTERVIEW RESULTS

Island	Number of Interviews	Opinion on New Marine Parks		
		In Favor	Opposed	No Opinion
Oahu	685	467 68.2% (78.2%)*	130 19% (21.8%)	88 12.8%
Hawaii	97	67 69.1%	30 30.9%	0

*Percentages given in parentheses are computed from those responses which expressed an opinion. All other percentages are based on the total number of responses.

Table 4 lists preferred locations for new marine parks as determined by the interview. A breakdown of opinion on new marine parks for each respondent activity for Oahu can be found in Table 5. The activities listed were the ones that the interviewees were engaged in or, in the case of water activities, were about to begin or had just completed at the time of the interview. Fishermen were the only group significantly less in favor of additional marine parks, although, of those who ventured an opinion, significantly more were in favor than opposed (P = .1). Divers and surfers, on the other hand, were significantly more in favor of additional marine parks than were others.

TABLE 4. MARINE PARK SITE PREFERENCES FROM INTERVIEW

Oahu			Hawaii		
Site	Number of Times Selected	%*	Site	Number of Times Selected	%*
Pupukea	112	16.4	Honaunau Bay	39	40.2
Kapapa Island	78	11.4	Leleiwa	36	37.1
Makua	68	9.9	Waipio	20	20.6
Makapuu	67	9.8	Puako	18	18.6
Maili	63	9.2	Keahole	17	17.5
Laie	56	8.2	Kaimu	15	15.5
Kahe Point	37	5.4	Okoe Bay	7	7.2
Blowhole	32	4.7	Koaie Cove	6	6.2
Black Point	27	3.9	Laupahoehoe	5	5.2

*Percentages are based on the total number of responses.

TABLE 5. OPINION ON NEW MARINE PARKS FROM INTERVIEW BY RESPONDENT ACTIVITY ON OAHU

Activity	Response			
	In Favor	Opposed	No Opinion	Total
Fishing and spearing	67 46.9%*	53 37.1%	23 16.1%	143
Collecting coral or shells	54 65.1%	18 21.7%	11 13.3%	83
Diving or snorkeling	49 87.5%	3 5.4%	4 7.1%	56
Surfing and bodysurfing	54 81.8%	2 3.0%	10 15.2%	66
Other (nonconsumptive uses, including sunning, swimming, picnicking, etc.)	243 72.1%	54 16.0%	40 11.9%	337
TOTAL	467	130	88	685

*Percentages are based on the total number of responses.

These statistics are, of course, based on the interviews completed, which were not necessarily proportional to the number of people actually engaged in each activity. On Oahu, about 4600 persons were counted on the shorelines. Of these, 6.1 percent were pole or net fishing, .9 percent were spearfishing, 5.6 percent diving or snorkeling but not spearing, 13.9 percent collecting such things as puka shells, 2.2 percent boating, and 14.4 percent board surfing or bodysurfing. The remaining 56.9 percent were engaged in activities such as camping, swimming, sunbathing, and picnicking. Interviews conducted with persons in this group are combined under one heading in Table 5 and labeled "other" to indicate that what they were doing would not be directly affected by the establishment of a marine park. This group was under-represented in the interviews because a large sample of fishermen and divers was sought. If the responses of each group of shoreline users were weighted according to the number of people counted in that group and a total response calculated, there would be a 71.7 percent in favor of and 15.0 percent opposed to additional marine parks. This extrapolation is tenuous, however, because the method used to select sites for interviews was somewhat arbitrary and may have produced bias in the proportions of these activity categories.

Appendix E presents tables of preference on marine parks according to age, sex, and a number of other variables for the Oahu survey. Such a breakdown is not presented for Hawaii because the sample size was too small to produce any meaningful comparisons.

Considerably more males than females were interviewed, mainly because there were more present, especially among fishermen, surfers, and divers. As would be expected, the age distribution was heavily weighted toward the younger groups: the proportion of both males and females younger than age 30 was much greater than in the questionnaire, which had a higher proportion of persons age 40 or over. The question on the establishment of additional marine conservation districts was answered the same by both sexes and, unlike the questionnaire, with a decreasing trend in the "yes" answer with increasing age.

The interviewees were asked what other activities they engaged in besides what they were doing at the time of the interview. Of those who said that they sometimes fished or speared fish, fewer were in favor of more marine parks, while those who said that they dive or snorkel were more in favor. The difference, however, was not as great as it was for those actually fishing or diving at the time of the interview.

Another question asked was, Do you know what a marine conservation district is? Although those who gave a reasonably accurate definition were slightly more in favor of more marine parks than were the others, this difference was not significant. Those who were registered to vote were slightly less in favor than others, but again the difference was not statistically significant.

Significant differences were found between interviews at the different sites, but this was apparently a product of the predominant activities at each site. For example, at Kahe Beach Park and Kaneohe Bay, where most of the interviewees were fishermen, opinion was less favorable toward the establishment of more marine parks than at Pupukea, where there were more divers, or at Makapuu where a large number of bodysurfers were interviewed.

Frequency of use of the interview sites did not affect the interviewees' opinions, but length of residence in the state did: those who were born and raised here were somewhat less favorable toward new marine parks than those who had lived here a shorter period (see Appendix E). No variation was seen with place of residence, but for most of the outlying areas, the sample size was too small to allow any valid inferences to be made.

Answers to the question, Why do you like this place? produced a variety of responses. The most common given were because of the good beaches and for the lack of crowds. The latter contrasts with a previous survey (Department of Planning and Research, 1962) in which the lack of crowds was only the ninth most frequently chosen response. In the present study, good fishing was another frequently chosen reason for liking a site, as was its proximity to home. Over half of the interviewees said that it took them less than 30 minutes to reach the site, while only 14 percent took longer than one hour.

Another question asked how the person would be affected if the interview site were to become a marine park. As can be seen in Appendix D, the greatest number of people said that they would not be affected, while significantly more said they would be favorably affected than unfavorably. Of those who said they would be unfavorably affected, most (72 percent) said that this was because they would not be allowed to fish there and 22 percent said that they would not be allowed to collect shells. Of those who expected to be affected favorably, 48 percent said it was because they expected to see more marine life, 36 percent because snorkeling would be better, and 30 percent because they felt that fishing in surrounding areas would improve.

Responses recorded by different interviewers were significantly different in a few cases. This can be attributed in part to the locations and hence the kind of shoreline users that each interviewer approached. When the responses recorded by each interviewer were compared activity by activity, only one interviewer differed significantly from the others and in only one activity category. His results indicated a less favorable opinion toward the establishment of new marine parks than those of the other interviewers.

A comparison of place of residence and location of the interview with the choice of marine park sites revealed no consistent correlation, except that, when fishermen chose a site, they usually picked one far from the interview site. Conversely, people interviewed at Pupukea and Makapuu showed a high preference for those respective sites over others.

An additional 25 persons were interviewed at several of the small boat harbors around Oahu. All but two of them said that they were going or had gone fishing. Fourteen (56 percent) were in favor of the establishment of new marine parks, with the remaining 11 opposed. The proportion of favorable responses differed from that in the shoreline interview only at the 20 percent level of significance.

Unfortunately, interviewees' ethnic backgrounds were not asked for in the Oahu surveys, so no data are available on how various racial groups would have differed in their opinions on marine parks. As mentioned previously, however, there was a slightly lower percentage of favorable opinions among lifelong residents of the islands than among people from the mainland. Most of the fishermen interviewed were born and raised in Hawaii and this group seemed especially concerned about the loss of their right to fish at a particular site. It would therefore be advisable to select sites for marine conservation districts that would least interfere with existing fishing practices.

INITIAL SITE SELECTION

Criteria

One of the problems encountered in selecting sites was that no fully objective criteria existed for such a selection process. While it is clear that some criteria, such as abundance of marine life, clear water, and a compatible use of the adjacent land, are essential, others are more a matter of opinion. Furthermore, it would be difficult to quantify and compare some features of underwater sites; assigning a number or rank to underwater beauty, for example, would be both arbitrary and meaningless. Standards which can be applied with some degree of objectivity would be preferred, but even the choices of criteria are themselves subjective processes.

If, however, any comparison of sites is to be made at all, some such standards must be applied. Those used in this study fall into three general categories: geography, physical oceanography (including diving safety), and marine life. They are as follows:

Geography

- Ease of definition of area boundaries for recognition and enforcement
- Compatibility of the present and planned use of adjacent land with a marine park
- Access to the shoreline from existing roads
- Access to snorkeling and diving areas from the shore

Physical Oceanography

- Exposure to seasonal surf
- Exposure to trade winds and waves
- Current strength
- Underwater visibility
- Water temperature

Marine Life

- Abundance and diversity of fish
- Coral cover and diversity
- Abundance and diversity of large motile invertebrates

Clearly, other criteria could have been applied, for example, bottom topography or scenic value. The first was not used because it was difficult to assess bottom topography in a way that would have fit into the survey schedule. Accordingly, bottom topography is discussed for each site, but not used as a selection criterion. Comparisons of scenic value would be as subjective as comparisons of paintings or sculpture. The elements which make up an attractive underwater scene probably include, for most people, some of the criteria that were used, but to rationally compare the scenic value of different places would be difficult.

The criteria listed were applied, first in a general way to obtain a list of sites for detailed study, and then in detail to arrive at overall comparisons of these sites. An additional geographic criterion used in the initial selection of sites was proximity to existing population centers.

Two other criteria were considered for application but were not used. One was the uniqueness of the sites. A place which is unique might be considered more valuable as a marine conservation district than other sites, but this uniqueness would be difficult to assess. A statistical analysis of similarity in biological populations between sites could be considered a measure of uniqueness. Such an analysis would, however, ignore such elements as bottom topography and would generally underemphasize the presence of rare species. Unique features of the study sites are therefore discussed but not used directly in the comparison of sites. The other criterion that was not applied was the costs involved in establishing marine conservation districts at each site. This was considered beyond the scope of the project.

Selection of Study Sites

Preliminary lists of potential marine park sites in *Hawaii and the Sea* (DPED, 1974) were augmented with sites recommended in State Division of Fish and Game reports and by University scientists, sport divers, and others knowledgeable about Hawaii's marine environment. The lists thus obtained comprised the following sites:

Oahu

- Kahe Beach Park
- Maili Point
- Makua
- Pupukea Beach Park
- Kahuku (an area west of Kuilima)
- Laie Point
- Swanzy Beach Park
- Kaneohe Bay (several areas)
- Makapuu Beach Park
- Blowhole to Lanai Lookout
- Black Point to Diamond Head
- Waikiki

Hawaii

- Koaie Cove
- Spencer Beach Park
- Makalawena
- Honaunau Bay
- Okoe Bay
- Puako (fronting the residential area)
- Kawaihae (adjacent to breakwater)
- Kapoho Tide Pools
- Halape
- Onomea
- Leleiwa
- Waipio
- Laupahoehoe
- Pohoiki
- Kaimu (Black Sand Beach)

These lists had to be reduced to a few sites to provide for two to three weeks of detailed study at each one. A site on each coast of Oahu was preferred, but none of the south shore sites were suitable from a geographic standpoint. Waikiki and Diamond Head are too much influenced by sediment from the adjacent land. In addition, a previous study of the Waikiki area (Chave et al., 1973) indicated fairly low values of fish abundance and diversity and coral cover. The Blowhole area was eliminated because it is so close to Hanauma Bay and has no beach park facilities. On the windward coast, a location somewhat protected from tradewind waves was preferred, so Makapuu Beach Park and several areas in Kaneohe Bay were selected. The portion of the north shore protected from waves during the summer includes Pupukea and the Kahuku site; the former was chosen for the study because access is easier and because there is a beach park with facilities located there. On the Waianae coast, a location just south of Kahe Beach Park was selected because of its proximity to population centers and because previous estimates indicated high coral cover here than elsewhere on the Waianae coast (E. Reese, 1974: personal communication).

On Hawaii, the list was limited to sites on the Kona coast because this region is protected from strong winds and high swells most of the year and, as a result, has developed dense stands of coral. Thus, the last seven sites on the list, all on the north and east coasts, were eliminated first. Of the sites near the north end of the Kona coast, Kawaihae was eliminated because the industrial activity around the harbor was considered incompatible with a marine park offshore. Between Spencer Beach Park and Koaie Cove, the latter was chosen because the reef area there is much closer to shore. A State Division of Fish and Game report in 1970 had also indicated that Koaie Cove had a high fish abundance and was suitable as a marine preserve. Further south, Makalawena and Okoe Bay were eliminated because they are difficult to reach except by boat and logistic support of the study in these areas would have been impracticable. Also, coral reefs occupy a lower proportion of the area at these sites than at other sites on the list. Because the Kapoho area had been previously studied (Ford, 1973), it was dropped from the list. This left Honaunau Bay and the area offshore from the residential area at Puako as the remaining study sites on the island of Hawaii.

In order to provide a standard of comparison by which to evaluate the selected sites, the existing marine parks were included in the study (see Figure 1). The final list of sites, then, was:

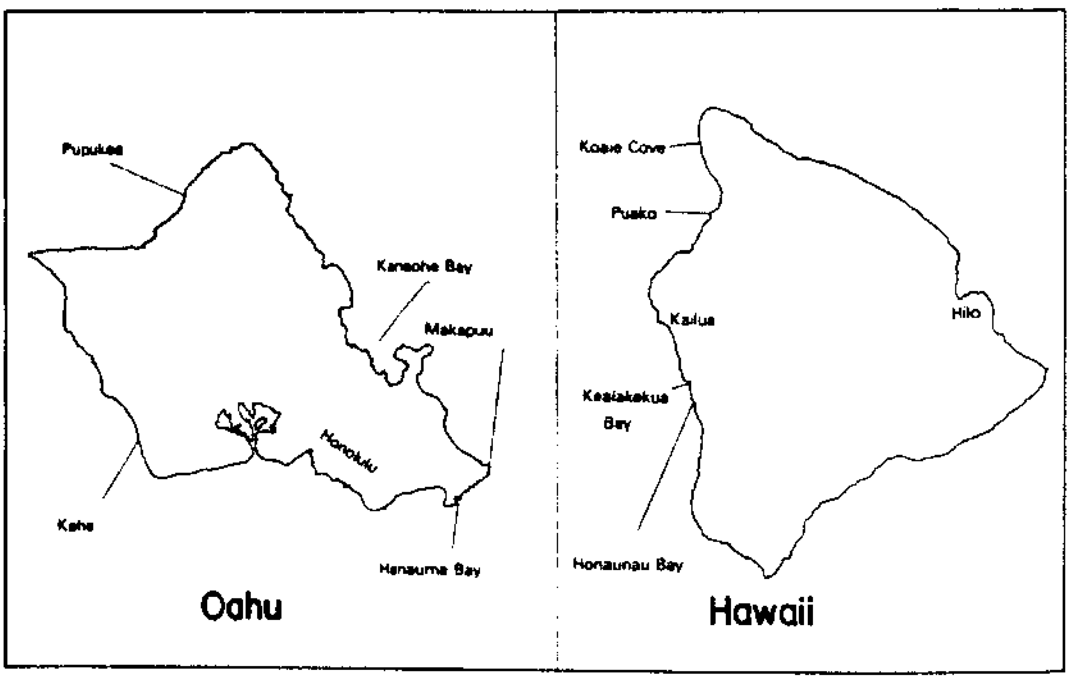


Figure 1. Maps of Oahu and Hawaii showing locations of study sites

Oahu	Hawaii
Hanauma Bay	Kealakekua Bay
Kahe	Koaie Cove
Makapuu	Puako
Pupukea	Honaunau Bay
Kaneohe Bay	

Kaneohe Bay was treated separately from the others for two reasons: first, it was not initially clear which area of the bay would be surveyed; and second, logistic problems severely limited the time available for study in this area. Insufficient data were obtained to enable a fair comparison of this area with the others, so it is excluded from the ranking procedure to be described. There is sufficient data, however, to make a somewhat more subjective judgement and this will be discussed in detail.

SITE SURVEYS

Methods

Two to three weeks were spent studying each site. First, land use planning data and available information about winds and waves were gathered. The site was then inspected in order to evaluate it with respect to the geographic criteria.

Preliminary to the surveys of marine biota, several dives were conducted to provide information for mapping the area. This was done by determining the position of an outboard boat while a diver or group of divers inspected the bottom beneath the boat for depth and bottom type at a number of points in the area surveyed. On Oahu, boat positioning was done using a sextant held horizontally to measure the angles between two or more pairs of existing landmarks. The Hawaii survey team used hand bearing compasses to sight on three markers which had been erected at known positions. This method was superior to that used on Oahu, where distances to the landmarks used for positioning were often too large to get an accurate fix.

The information from these mapping surveys was used to determine what major habitats existed at the site. This division into habitats was later refined using data gathered in the transects.

Several transects were run at each site. First, the boat was anchored and its position determined as described above. A 100-m weighted line was laid along the bottom, as much as possible within a single habitat. After a short wait for the return of the fish which had been frightened away, a fish count was conducted using a modification of the visual transect method (Brock, 1954). A pair of divers swam along the line, each counting those fish seen within 2.5 m on his side of the line. The number of fish of each species and their approximate lengths were recorded on plastic slates. Following the fish team was another diver counting all macroinvertebrates within 1 m on one side of the line; another placed a 1-m square point quadrat with 16 points of intersection at 10 fixed points along the line to estimate percentage of live coral cover of each species, percentage of cover of the various substrates, and relative abundance of macroscopic algal species. Fish, corals, and macroinvertebrates seen in the area but not on the transect were also noted.

The methods described on the preceding page were a compromise between several sampling goals. The sample size for each group of organisms had to be large enough to include sufficient numbers of each species for a realistic estimate of abundance. At the same time, the sample size had to be small enough that the time required to count organisms in each transect would not exceed the diver's allowable bottom time or air supply. The methods used were therefore aimed at the more common organisms. Estimates of abundance of uncommon ones were considered less important and were not as accurate. The fish transects, for example, probably produced good estimates of the more common butterfly fish and the small damselfish. Counts of wider-ranging fish such as pelagic species, however, were probably not as accurate because the sample size was not large enough. Other problems with the visual transect method were that it under-represents cryptic species such as eels and that it is highly dependent upon visibility and the distance to which the fish will allow a human to approach.

Similar problems occurred with the invertebrate transects. Many of the common marine invertebrates are cryptic and, where counts of these were recorded, it was because they were seen in the open. Also, most of the smaller invertebrates were probably missed.

Despite all of these problems, the methods as described provided what was needed: a comparative estimate of the abundance of marine organisms.

At each transect location the survey teams also measured horizontal visibility about a meter above the bottom using a Secchi disk and estimated current strength by observing the drift of floating objects. Salinity and temperature measurements were taken until it was determined that there was little difference in these measurements between sites.

Treatment of Data

The biological data were reduced using the Hawaii Coastal Zone Data Bank computer programs, all data are on file in the Data Bank. Fish counts were converted to numbers per 1000 square meters and to biomass by combining the length estimates with previously computed length-to-weight conversion factors from the Data Bank. A diversity index, the Shannon-Weaver index, was computed for each transect. Although some bias is inherent in this index (Pielou, 1966), it appears satisfactory for the present purpose. The formula used is:

$$H = -\sum_{\text{all } i} p_i \ln p_i$$

where p_i is the proportion of the species "i" in the total fish count. This index is 0 when only one species is present. The maximum possible value depends on the total number of species and the actual value is between 0 and this maximum depending on the evenness of distribution of the species. Thus, of two transects with the same number of species, the one which is dominated by one or a few species will have a lower diversity index than the one in which all species are present in similar quantities. The index has little meaning by itself, but can be used to compare different transects. As an additional measure of diversity, the total number of fish species per transect was used.

Coral and substrate counts were reduced to percentage of bottom cover and the diversity index of corals computed by the method mentioned on the preceding page using the percentage of bottom cover converted to decimal for p_i. Algal species were merely assigned a relative abundance index as follows:

4 Dominant
3 Common
2 Infrequent
1 Seen in the habitat but not counted on any transect

The counts of macroinvertebrates were converted to numbers of individuals per 100 square meters. A diversity index was not computed for all invertebrates because many were identified only as far as family or genus without distinction between species and because many of the mollusks and crustacea are cryptic. Accordingly, a diversity index was computed by the Shannon-Weaver method for echinoderms only (starfish, sea urchins, and sea cucumbers).

The results of the fish and coral transects were compared to determine if the previously identified habitats were in fact distinct. On Hawaii, the same three habitats were identified at every site, making comparisons between sites relatively straightforward. Most of the Oahu habitats, on the other hand, occurred at only one site, with only a few in common between two sites. Furthermore, the number of habitats at each site varied from two to five, making a direct comparison of sites impossible. Habitat descriptions as discussed in the marine biology section of this report should be consulted for details on each of these habitats.

Many of the habitats had no readily defined boundaries and a few transects were near the boundary between them. The choice of which habitat to place these transects in was based either on the location of the transect or on the similarity of coral cover and species composition, substrate, and fish species composition of that transect with others in the habitat. Once all transects had been placed in the appropriate habitats, median values of each set of biological data were computed for each habitat.

Comparisons

Each site was compared with the others on the same island using 15 criteria. These included the four geographic criteria and four of the five physical oceanographic criteria listed in the section on site selection. Water temperature did not vary enough between sites to be useful as a criterion. Of these eight criteria, all except visibility were applied as follows. The information gathered from zoning maps, available climatic information, and the results of site inspections were compared between sites. The sites were placed in order from "best" to "worst" and assigned rank indices from 4 (best) to 1 (worst) for each criterion. Where two or more sites were considered equal, they received the same rank indices.

Underwater visibility values were also used to assign ranks, but the ranks were obtained by using the Mann-Whitney U Test ($P = .1$) to compare each site with the others on that island.

The seven remaining criteria were based on the results of the biological survey. These were:

Fish

- Abundance
- Diversity index
- Number of species per transect

Coral

- Percentage of cover
- Diversity index

Macroinvertebrates

- Abundance
- Diversity index (echinoderms only)

Like the visibility values, each of these was used quantitatively to compare the sites. This comparison, however, was made more complex by the great variation between habitat median values at each site. This variation precluded a direct comparison of entire sites; instead, transect results in each individual habitat were compared with those in other habitats using the Mann-Whitney U Test ($P = .2$). This level of significance allowed finer discrimination between habitats in a handful of cases, although it had the disadvantage of a high probability (20 percent) of incorrectly showing a difference between habitats when no difference existed.

On Hawaii, each site had essentially the same three habitats, so each habitat could be tested against its counterparts at the other sites. Using each criterion separately, the three habitat comparisons between each pair of sites were combined to rank the sites in the following way: if the U Test showed site A to be greater than site B in more habitats than B was greater than A, then site A was ranked higher than site B. In a few instances an intransitive relationship developed in which site A was greater than B, B equal to C, but C was equal to or greater than A. When this occurred, all three sites were given equal ranking.

The Oahu sites could not be ranked in the same way because habitats were not directly comparable and because there was a different number of habitats at each site. Instead, three categories of habitats were compared. The first category consisted of those habitats which were closest inshore at each site and would therefore be used most often by snorkelers. The second category comprised the largest offshore habitats at each site; these would probably be used most often by SCUBA divers. The habitats in the third category were those at each site with the highest value of the particular criterion (fish abundance, coral cover, etc.) being used for the ranking. Note that the habitat in the third category was not necessarily the same for each criterion and that a habitat could be in two categories at once.

Sites were compared on Oahu by testing the habitats in each of the three categories with the other habitats in the same category. Site rankings were then obtained by treating each category in the same way that the three habitat groups on Hawaii had been treated. The ranking procedure was repeated as for Hawaii to obtain overall rankings for each of the seven biological criteria. Individual rankings in the three categories were also retained and are presented in the discussion section.

Kaneohe Bay was treated as a special case and not ranked with the other sites because its habitats did not fit easily into the first two categories. All habitats at all other sites were included except the Makapuu deep zone, which had been transected only once; hence, it could not be adequately compared with the others.

RESULTS OF SURVEYS

The following sections describe the results obtained in the geographic, oceanographic, and biological portions of this study. In the first two sections, the site rankings are given along with a summary of the way those rankings were obtained. The biological section lists the scores for each habitat and the site ranks and discusses the results for each of the biological variables examined. In all of the site rankings, 4 is considered "best" and 1 "worst."

Geography

Refer to the maps in the site descriptions section for details of site geography.

Definability. This criterion was approached from the following standpoint: would a diver or fisherman be able to readily see the limits of the conservation area and would an enforcement officer be able to tell if a person were fishing or collecting within the regulated area?

Oahu		Hawaii	
Site	Ranking	Site	Ranking
Hanauma Bay	4	Honaunau Bay	4
Makapuu	3	Koaie Cove	3
Pupukea	2	Kealakekua Bay	2
Kahe	1	Puako	1

Hanauma Bay is certainly the most definable of the sites studied; a line connecting the outermost points on either side of the bay mouth marks the seaward limit. On Oahu, Makapuu is nearly as definable. Straight lines joining Makapuu Point and the outer edge of Rabbit Island and the island with Makai Range pier form an easily recognizable seaward boundary. Pupukea is bounded at either end by two rocky points, but the seaward limit is unmarked. At Kahe there are no natural boundaries since the shoreline is relatively straight.

On Hawaii, Honaunau Bay is nearly as well defined as Hanauma Bay--by a line connecting its outermost points. Koaie Cove is similar to Pupukea, with lateral boundaries but no natural seaward limit. Kealakekua Bay as a whole is readily defined, but the portion in which consumptive use is prohibited is not easily recognized. Puako is the least definable site because it lacks prominent landmarks and has a relatively straight shoreline.

Access to the shoreline. The criteria used were accessibility of the shoreline from existing roads, availability of parking facilities, and the distance that a diver would have to carry his equipment to reach the water.

Oahu Site	Ranking	Hawaii Site	Ranking
Pupukea	4	Honaunau Bay	4
Makapuu	2.5	Kealakekua Bay	3
Hanauma Bay	2.5	Puako	2
Kahe	1	Koaie Cove	1

On Oahu, Pupukea was considered the best, because at both the Shark's Cove and the Three Tables areas, the parking facility is within 20 m of the beach. Makapuu and Hanauma Bay are ranked equally. Both have parking facilities but the walk to the beach is longer than at Pupukea. The Kahe site is at present rather inaccessible because it adjoins private property and one must walk from Kahe Beach Park to a small pebble beach near the property line to gain easy access to the water. If the City and County of Honolulu is usccessful in its bid to create a beach park on this private property, the site will become as accessible as Pupukea.

Honaunau Bay is the most accessible of the Hawaii sites, with a road within 20 m of the shoreline and with adequate parking. Access to Kealakekua Bay is nearly comparable to Honaunau Bay, but there is less parking space. Although a public road runs within 50 m of the Puako shoreline, residential development along the road prevents access except at four public rights-of-way, where little parking space is available. At present, Koaie Cove has no access roads open to the public. A road is planned into Lapakahi State Park, but a fairly long walk to the shoreline will still be necessary.

Access to snorkeling and diving areas. The question considered here was the ease with which a snorkeler or diver could reach good diving areas from shore.

Oahu Site	Ranking	Hawaii Site	Ranking
Pupukea	4	Puako	3
Kahe	2.5	Koaie Cove	3
Hanauma Bay	2.5	Honaunau Bay	3
Makapuu	1	Kealakekua Bay	1

Again Pupukea is the most accessible of the Oahu sites. Good diving areas with caves and ledges are situated within 50 m of the two beaches. Furthermore, the bottom slopes rather steeply compared with the other Oahu sites, allowing relatively easy access to the deeper waters. At Kahe, the shallower diving areas are even more readily accessible from shore, but the shelf is very wide and a swim of 500 to 1000 m would be required to reach a depth of 20 m. Hanauma Bay has a shallow limestone reef just off the beach and the water shoreward of this reef is turbid and not particularly suitable for diving. To reach the outer portions of the bay requires a swim of about 700 m or a walk around the sides of the bay. However, the deeper water is closer to shore than at Kahe, so these two areas are considered equal in rank. At Makapuu one must swim at least 600 m to reach the nearest portion of the ledge zone; the area inshore from this zone is rather flat and barren and is not an interesting diving area. To reach the really spectacular areas around Manana (Rabbit) Island would require a swim of about 1500 m.

On Hawaii, Puako, Koaie Cove, and Honaunau Bay all have reefs within a few meters from shore, with the seaward edge of the reef never more than 300 m from shore. Kealakekua Bay, on the other hand, requires a minimum swim of 300 m from shore just to reach the closest part of the reef. To reach the best diving area near the monument would necessitate a swim of about 1500 m. Walking around the side of the bay is precluded by a steep cliff along the shoreline.

Adjacent land use. The use of the adjacent land most compatible with a marine park is a beach park; the least compatible use at any of the study sites is residential development. Consideration was made of proposed future development and zoning and of the inland areas that might have an influence on the marine environment.

Oahu		Hawaii	
Site	Ranking	Site	Ranking
Hanauma Bay	3.5	Koaie Cove	4
Makapuu	3.5	Honaunau Bay	2.5
Pupukea	2	Kealakekua Bay	2.5
Kahe	1	Puako	1

On Oahu, both Makapuu and Hanauma Bay adjoin beach parks and are protected from the influence of inland development by the proximity of steep slopes. These two areas are therefore ranked equally. Pupukea also has a beach park, but the land immediately adjoining it is zoned for residential and commercial use and is rather densely developed. This level of development has resulted in a considerable amount of runoff during heavy rains with concomitant silt deposition. Thus the use of adjacent lands is somewhat less compatible than at Makapuu or Hanauma Bay. The fourth area, Kahe, is located adjacent to private property which has been the subject of negotiations between the owner and the City and County of Honolulu which hopes to acquire it for use as a beach park. It is expected that at least part of this property will become a beach park, especially in light of a recent Land Use Commission decision not to change the designation of this land from a conservation to urban district. The status of property further inland remains in doubt, but long-range plans exist for massive development east of the area, enlargement of the barge harbor a mile to the south, and continued expansion of the electric plant facilities to the north. Kahe is ranked below Pupukea, but if the beach park becomes a reality, it will be equal in rank with Pupukea.

On Hawaii, Lapakahi State Park, which is being developed adjacent to Koaie Cove, extends from the shoreline into the Kohala Mountains. This park encompasses the entire cove and will preclude large-scale development in the immediate area. The shorelines at Honaunau and Kealakekua Bays are each divided into a residential area and a park. The land behind these areas is zoned for open areas and agricultural uses which are not expected to influence the offshore areas. Puako was ranked lowest because of the intensive residential development along the shoreline and the zoning for future expansion inland which could produce detrimental effects on the reef area.

Physical oceanography

Exposure to seasonal surf. Large northerly swells arrive in the Hawaiian Islands from winter storms in the North Pacific. Kona storms, which occur throughout the year but are most frequent in late winter and early spring, produce southerly waves. Southern hemisphere storms produce a swell from the south in the summer. The criterion used here was the length of time exposure occurs, as well as the degree of exposure.

Oahu Site	Ranking	Hawaii Site	Ranking
Hanauma Bay	3.5	Honaunau Bay	2.5
Kahe	3.5	Kealakekua Bay	2.5
Makapuu	2	Puako	2.5
Pupukea	1	Koaie Cove	2.5

On Oahu, Kahe and Hanauma Bay were ranked equally; although both are protected from heavy northerly swells, Kahe receives occasional northwest to southwest swells, while Hanauma Bay is subjected to surf whenever swells arise from the south. Makapuu receives heavy easterly swells, and is a favorite among body surfers. Pupukea, located between the well-known surfing sites at Waimea Bay and Sunset Beach, is essentially closed for diving from September to May.

Hawaii sites are affected by ocean swells about equally. Honaunau and Kealakekua Bays are susceptible to strong northwest or southwest swells, while Puako and Koaie Cove are influenced by strong northerly swells.

Exposure to trade winds and trade wind waves. Northeast trade winds blow in the Hawaiian Islands approximately 70 percent of the time, with accompanying waves 4 to 12 ft high. Exposure to these winds and waves can have a significant effect on diving and snorkeling safety and comfort and upon visibility in the water.

Oahu Site	Ranking	Hawaii Site	Ranking
Kahe	4	Honaunau Bay	3.5
Pupukea	3	Kealakekua Bay	3.5
Hanauma Bay	2	Koaie Cove	1.5
Makapuu	1	Puako	1.5

The exposure of the Oahu sites is least severe at Kahe, where trade winds average only 10 to 12 knots and fetch is short. Pupukea is located just inside the lee of the Koolau Mountains and is nearly as well protected as Kahe. The shape and orientation of Hanauma Bay provide some shelter for the leeward portion of the bay, but during strong trade winds the waves can be large throughout the bay. Also, reflected waves and seiches produce a strong chop in some areas. Exposure is most severe at Makapuu, which is unprotected from trade winds averaging 18 knots; the fetch here is also the greatest.

Mauna Loa, Mauna Kea, and Hualalai mountains block virtually all of the trade winds into Honaunau and Kealakekua Bays. Koaie Cove and Puako are equally influenced by trade winds blowing from the direction of the Kohala Mountains. These winds can be quite strong, although fetch is short and resulting waves are smaller than in windward areas.

Currents. Information on the strength of currents is available, but applies either to the island chain as a whole or to a few local areas. Currents were estimated at each transect location, but these are predominantly tidal currents which depend upon time of day. The current estimates were made at the time of the transects, which were conducted at about the same time each day. Thus, the estimates occurred on different parts of the current cycle for each location. Estimates of the bottom currents were crude and did not correspond well with values found on charts or in the literature. Therefore, a somewhat subjective ranking of sites is used, based on a combination of published data and measured currents. The foremost consideration was diving safety and comfort.

Oahu		Hawaii	
Site	Ranking	Site	Ranking
Pupukea	4	Honaunau Bay	3.5
Hanauma Bay	3	Kealakekua Bay	3.5
Kahe	2	Koaie Cove	1.5
Makapuu	1	Puako	1.5

Of the Oahu sites, Pupukea was the least affected by currents; only a slight drift was detected here during this study. Hanauma Bay is unaffected by currents over most of its area, except for a very strong current running past the mouth and a moderate current flowing out of a channel through the inner reef. Kahe has strong currents in the deeper water, but these appear to lose strength near shore. The strongest currents were found at Makapuu, where the survey team often had difficulty getting back to the boat after a dive.

Honaunau and Kealakekua Bays were not perceptibly influenced by currents. Koaie Cove and Puako are influenced somewhat by an offshore surface current during high winds.

Visibility. The following rankings were obtained by a comparison of the visibility values obtained at each site using the Mann-Whitney U Test. Table 6 gives median visibility values and Figure 2 provides medians and ranges for each site.

Oahu		Hawaii	
Site	Ranking	Site	Ranking
Makapuu	4	Honaunau Bay	4
Pupukea	3	Koaie Cove	3
Kahe	1.5	Kealakekua Bay	1.5
Hanauma Bay	1.5	Puako	1.5

Comparison of all visibility values at each site with other sites revealed that Makapuu had significantly clearer water than the other Oahu sites. Pupukea was ranked lower than Makapuu, but greater than the other two sites. Visibility at Pupukea was somewhat reduced by silt carried into the water from the residential areas during heavy rains. Kahe and Hanauma Bay both had visibility reduced by silt. At Hanauma Bay, this was largely confined to the waters near shore and in areas of strong surge, while the deeper areas of the bay were very clear. Kahe was strongly affected by the silt carried from construction at the power plant to the north. Visibility did not vary with the depth but did appear to vary with the tidal cycle at Kahe.

Visibility values for the Hawaii sites were generally greater than on Oahu, with maximum values of 45 m at three of the four sites. Honaunau Bay had the

TABLE 6. MEDIAN VISIBILITY VALUES BY SITE

Oahu		Hawaii	
Site	Visibility (m)	Site	Visibility (m)
Makapuu	24	Honaunau Bay	41.5
Pupukea	20	Koaie Cove	35
Kahe	17	Puako	26
Hanauma Bay	15.5	Kealakekua Bay	25
Kaneohe Bay	9		

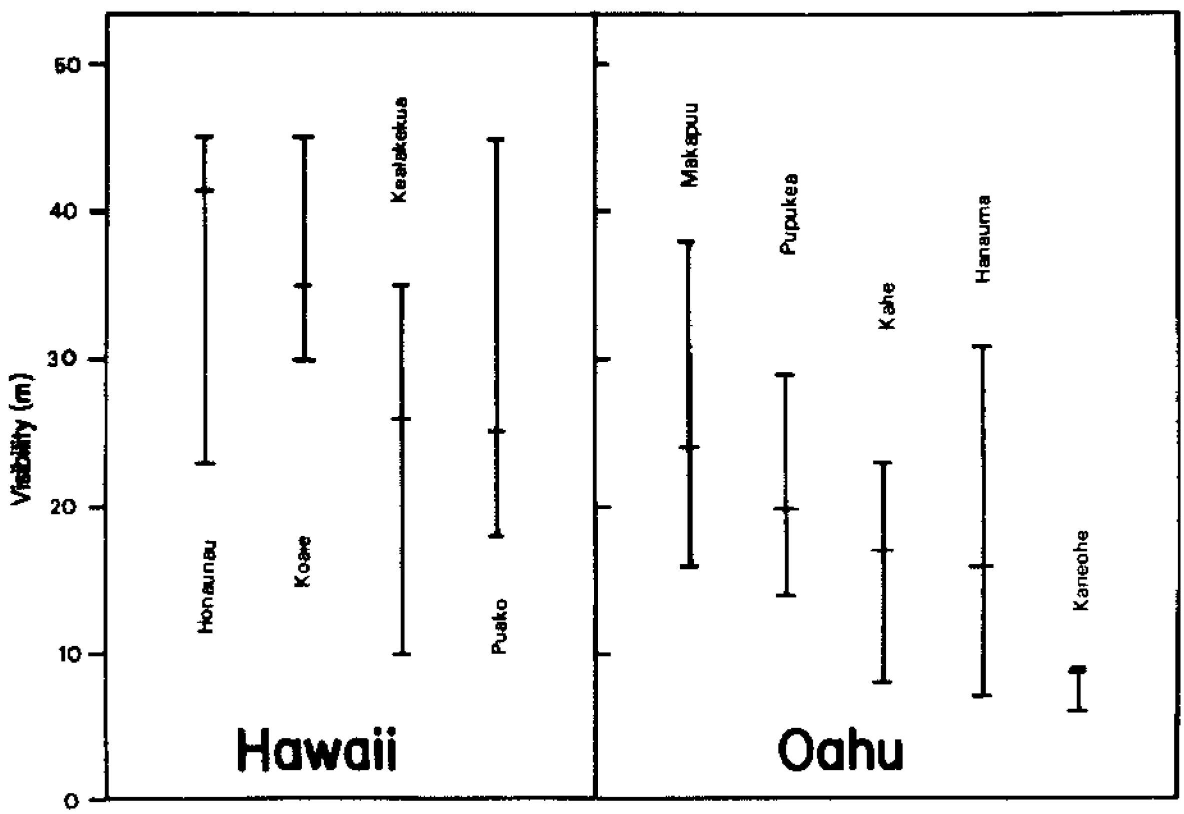


Figure 2. Medians and ranges for visibility at each site

clearest water, although the inshore waters were slightly more turbid than at Koaie Cove, which was ranked second. Puako and Kealakekua Bay were the lowest and neither of these had significantly higher visibility than Makapuu, which had the clearest water of the Oahu sites. Inshore visibility at Puako was restricted by a freshwater lens on the surface. The other sites also had lower visibility in the inshore waters than in the deeper areas.

Marine Biology

The following abbreviations are used for the sites in the tables and figures to follow:

HA	Hanauma Bay	KE	Kealakekua Bay
KA	Kahe	KO	Koaie Cove
PP	Pupukea	PK	Puako
MP	Makapuu	HO	Honaunau Bay
KB	Kaneohe Bay		

Habitats are described below with their abbreviations in parentheses. The habitats identified and present at all sites on Hawaii were:

Inshore	(IN)	Predominantly rock substrate, with moderate coral cover mainly of two species, *Porites lobata* and *Pocillopora meandrina*. Depth 1 to 8 m.
Mid-reef	(MR)	Dominated by the massive coral, *P. lobata*, with some finger coral, *P. compressa*. Depth 4 to 17 m.
Outer reef	(OR)	Predominantly a reef of *P. compressa*, with *P. lobata* abundant in some areas. Defined primarily by its location near the outer edge of the reef in 11 to 25 m of water.

Oahu sites had few habitats in common. Each habitat is listed below along with the sites at which it occurred:

P. lobata reef (Hanauma Bay, Kahe)	(LO)	Analogous to the Hawaii mid-reef zone, but not present as consistently and not as high in coral cover. Depth 1.5 to 19.5 m. The largest offshore zone at these sites.
P. compressa reef (Hanauma Bay, Kahe)	(CO)	Analogous to the outer reefs of Hawaii, but again not defined geographically. Occurs in patches instead of a continuous strip and has lower coral cover than the Hawaii counterpart. Depth 9 to 15 m.
Shallow zone (Hanauma Bay)	(SH)	Area inside the limestone reef at Hanauma Bay, with sand and limestone bottom, little coral. Depth 1 to 4 m. The inshore zone at Hanauma Bay.
Sand area (Hanauma Bay)	(SA)	Large sand patches with some rock outcrops. Although sand areas were present at all other sites, they were in deep water, while those at Hanauma Bay occur as shallow as 7 m.
Mixed coral (Kahe)	(MX)	Similar to *P. lobata* zone, but with lower coral cover and more sand and limestone. Depth 3 to 14 m. The inshore zone at Kahe.
Pavement (Kahe)	(PV)	Flat rock area with a few pockets of coral and rubble. Depth 10 to 13 m.

Flat zone (Makapuu)	(FL)	Area of low relief, low coral cover, and much sand and rubble. Depth 4 to 7 m. The inshore zone of Makapuu.
Ledges (Makapuu)	(LG)	Steep cliffs and ledges, dropping off steeply from 5 to 21 m. The largest offshore area of Makapuu.
Boulder (Pupukea)	(BO)	Huge boulders with sand patches between, crevices and caves beneath. Depth 3 to 14 m. The inshore area of Pupukea.
Deep (Kahe, Makapuu, Pupukea)	(DP)	Actually three distinct habitats; not directly comparable. Kahe deep zone consists of the dropoff and an outer area of sand and rubble. Makapuu deep area is that area seaward of the ledges and cliffs. Pupukea deep zone is an area of lower relief than the shallower boulder zone and is the offshore area for habitat comparison. Depth varies between sites, ranging from 15 to 26 m.
Patch reef (Kaneohe Bay)	(PR)	Steep outer edge of patch reefs, where coral growth is greatest. Depth 2 to 10 m.
Patch reef flat (Kaneohe Bay)	(RF)	Flat zone within the coral ring, where coral cover is low, with sand and rubble bottom. Depth 1 to 3 m.

Three other zones--the cave (CA), tidepool (TP), and bench (BE)--are described in the Pupukea site description section.

Table 7 lists median values for each datum used as a criterion in the comparison of sites, plus fish biomass, number of coral species, and number of algal species per transect, for each habitat at each site. The median values are presented only to introduce the results and not for comparison of sites. However, a few trends can be seen in the median values. One is that the values for Hawaii are more consistent from one site to the next than those on Oahu. Another trend is that fish biomass, fish abundance, coral cover, and invertebrate abundance are generally higher on Hawaii. Figure 3 presents mean values of percentage of bottom cover for each substrate type by habitat. Again, the generally higher coral cover on Hawaii reefs can be seen. The percentage of cover of sand is lower for Hawaii sites, possibly because the island is younger than Oahu.

The following sections expand upon Table 7 and present transect results in greater detail. Habitats are compared with respect to the following criteria:

Fish abundance
Number of fish species per transect
Fish diversity index
Coral cover
Coral diversity index
Macroinvertebrate abundance
Macroinvertebrate diversity index (echinoderms only)

TABLE 7. MEDIAN VALUES OF BIOLOGICAL DATA, WITH NUMBER OF TRANSECT LINES AND DEPTH RANGES FOR EACH HABITAT

Site-Habitat*	Number of Transects in Habitat	Depth Range of Transects (m)	Fish Abundance (no./1000 m^2)	Fish Biomass (kg/1000 m^2)	Fish Diversity Index	Fish Species Per Transect	Percentage of Coral Cover	Coral Diversity Index	Coral Species Per Transect	Macroinvertebrates (no./100 m^2)	Macroinvertebrate Diversity Index	Algae Species Per Transect
KE-IN	2	3.0- 5.0	987	24.9	2.56	40	60	0.3	4	297	1.1	0
KE-MR	26	3.0-13.0	1163	25.1	2.34	34	72	0.9	3	376	1.1	2
KE-OR	10	12.0-25.0	1125	30.8	2.40	35	60	1.1	3	123	0.8	3
KO-IN	4	3.0- 8.0	1422	38.2	2.28	36	33	0.4	3	284	1.1	3
KO-MR	20	4.0-17.0	1624	38.3	2.68	42	59	0.6	4	133	1.4	2
KO-OR	6	13.0-23.0	1588	59.8	2.61	42	53	0.8	4	137	1.5	4
PK-IN	16	1.0- 3.0	693	8.9	2.21	28	30	0.6	3	841	0.4	1
PK-MR	16	8.0-14.0	717	21.5	2.58	35	79	0.9	5	160	1.3	3
PK-OR	8	11.0-24.0	773	25.7	2.72	37	64	0.9	4	68	1.1	4
HO-IN	6	1.0- 7.0	1098	25.6	2.53	37	25	0.2	2	305	1.2	1
HO-MR	26	3.0-16.0	1312	25.2	2.36	38	57	0.7	4	141	1.5	3
HO-OR	4	12.0-20.0	1379	25.9	2.22	35	52	0.9	5	66	1.4	3
HA-LO	16	1.0-20.0	625	28.3	2.84	36	26	0.9	4	58	1.1	5
HA-CO	7	9.0-18.0	1088	23.5	2.52	35	59	0.7	2	164	0.9	5
HA-SA	3	7.0-24.0	8	0.2	0.63	2	0	0	0	1	0	1
HA-SH	4	0.5- 2.0	228	8.3	2.04	17	0	0	1	5	0.5	5
KA-LO	12	3.0- 5.0	797	18.9	2.39	28	48	1.0	7	6	0.9	2
KA-CO	7	7.0-18.0	1101	29.1	2.40	36	50	0.6	4	330	0.9	4
KA-MX	9	3.0-14.0	606	18.0	2.48	33	16	1.0	5	64	1.1	2
KA-PV	4	10.0-14.0	540	14.8	2.72	27	9	0.6	3	85	1.5	7
KA-DP	5	17.0-26.0	844	28.0	3.18	48	1	0	1	23	0.9	1
MP-FL	7	4.0- 6.0	376	5.7	2.73	28	1	0.8	3	176	1.1	5
MP-LG	18	6.0-21.0	1156	30.2	2.82	41	15	1.1	5	148	0.9	4
MP-DP	1	25.0	456	28.2	3.06	40	6	0	1	49	0.8	9
PP-BO	21	3.0-14.0	807	10.9	2.98	41	10	1.4	6	45	1.0	6
PP-DP	8	15.0-22.0	591	15.7	2.94	39	2	0.7	2	47	0.6	7
KB-PR	8	1.0- 8.0	1065	33.4	2.55	30	64	0.2	2	80	0	3
KB-RF	2	1.0- 2.0	244	3.4	1.11	14	9	1.3	7	97	1.3	10
Kapapa	2	1.0- 2.0	158	1.0	1.62	9	0	0	0	425	0.8	17

*See pp. 23-24 for keys.

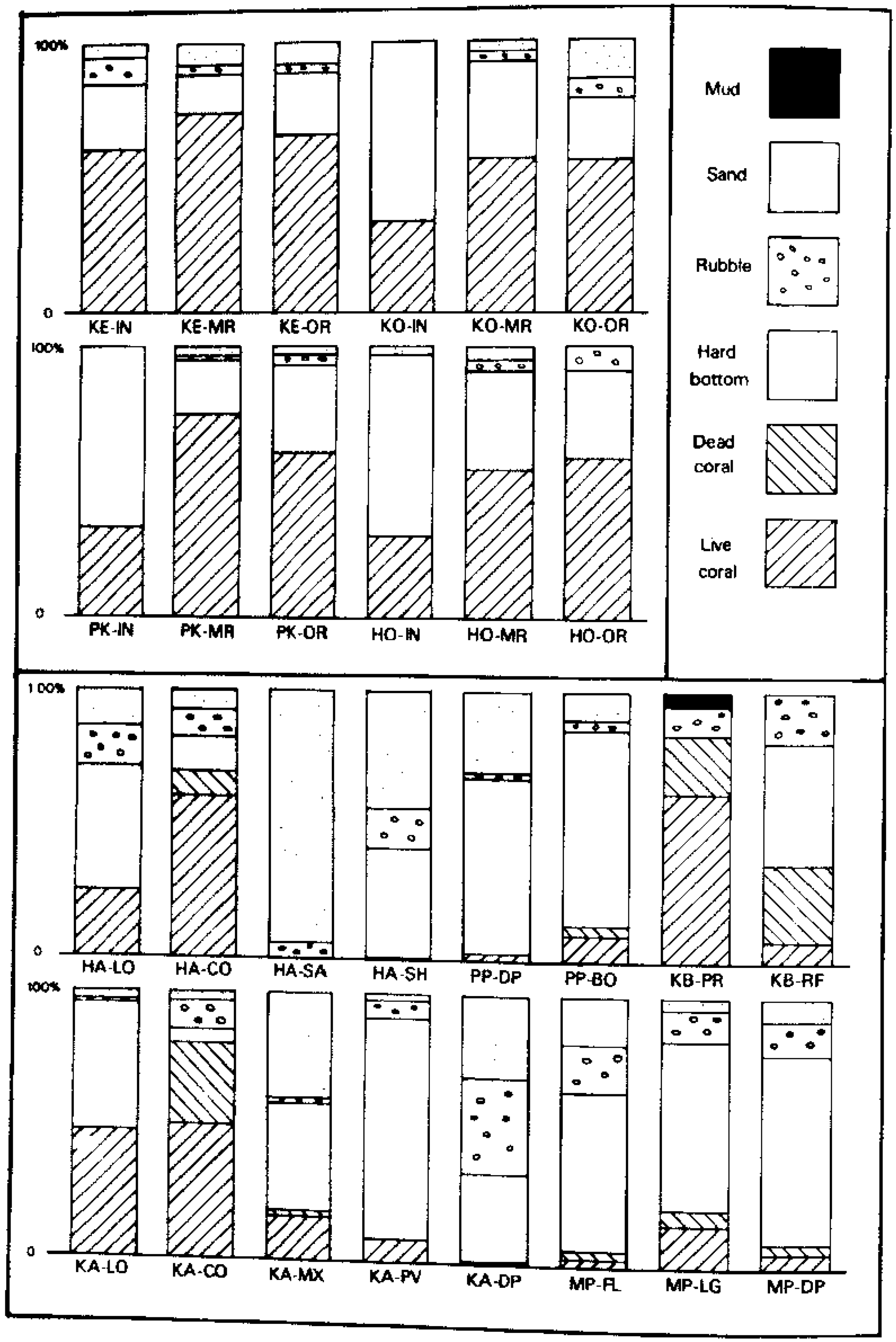


Figure 3. Mean values of percentage of bottom cover of each substrate type by habitat

Table 8 includes two keys to be used with tables on comparisons of habitats and sites. After the habitats have been compared, the site rankings, obtained as described in the methods section, are listed in each table. Note that intransitive results occurred between sites: A greater than B, B greater than C, but C equal to or greater than A. Where this occurred all three sites were considered equal. For the ranking of sites in only one of the three habitat types, see the discussion section.

TABLE 8. COMPARISON OF HABITATS AND SITE RANKINGS FOR FISH ABUNDANCE

Habitat Comparisons										
Oahu						Hawaii				
	HA	KA	MP	PP			KE	KO	PK	HO
HA		- - =	= - =	- = +	(CO)	KE		- - -	+ + +	= - =
KA	+ + =		+ - =	- + +	(CO)	KO	+ + +		+ + +	= = =
MP	= + =	- + =		- + +	(LG)	PK	- - -	- - -		- - -
PP	+ = -	+ - -	+ - -		(BO)	HO	= + =	= = =	+ + +	

Site Rankings			
Oahu		Hawaii	
Kahe	3.5	Honaunau Bay	3.5
Makapuu	3.5	Koaie Cove	3.5
Pupukea	1.5	Kealakekua Bay	2
Hanauma Bay	1.5	Puako	1

KEY TO HABITAT COMPARISONS: Three symbols are given to compare habitats for each pair of sites. The one on the left is for the inshore habitats; in the middle for the outer (Oahu) or mid-reef (Hawaii) habitat; and the one on the right for the highest (Oahu) or outer reef (Hawaii) habitat. "+" means that the habitat on the left is greater than the one at the top of the column, "-" means that it is lower, and "=" means that there was no difference between them at the 20 percent significance level. The symbols to the right of the Oahu comparison are the particular habitats that were the highest at each site.

KEY TO SITE RANKINGS: These ranks were obtained from the habitat comparisons of each pair of sites. If the number of "+" marks exceeded the "-" marks in the habitat comparison, then the site on the left was ranked higher than the one at the top of the column. In the above table, for example, Kahe exceeds Hanauma Bay in 2 of 3 habitats, so it is ranked higher than Hanauma Bay.

Fish

Abundance (see Table 8 and Figure 4). On Oahu, four habitats had equally high fish abundance: the Makapuu ledge area, the *P. compressa* reefs of Kahe and Hanauma Bay, and the patch reefs of Kaheohe Bay. As explained in the section on site selection, the latter was not included in the ranking procedure. All other habitats were significantly lower than these, even the Hanauma Bay *P. lobata* zone which had the highest single fish count on Oahu. This count was inflated by a large school of pualu, *Acanthurus xanthopterus*, which crossed the transect line. The Hanauma Bay inshore shallow zone and the Makapuu flat area had an equally low fish abundance; at Makapuu, fish abundance increased with distance from shore, so a diver or snorkeler swimming near the shore would see a very low number of fish.

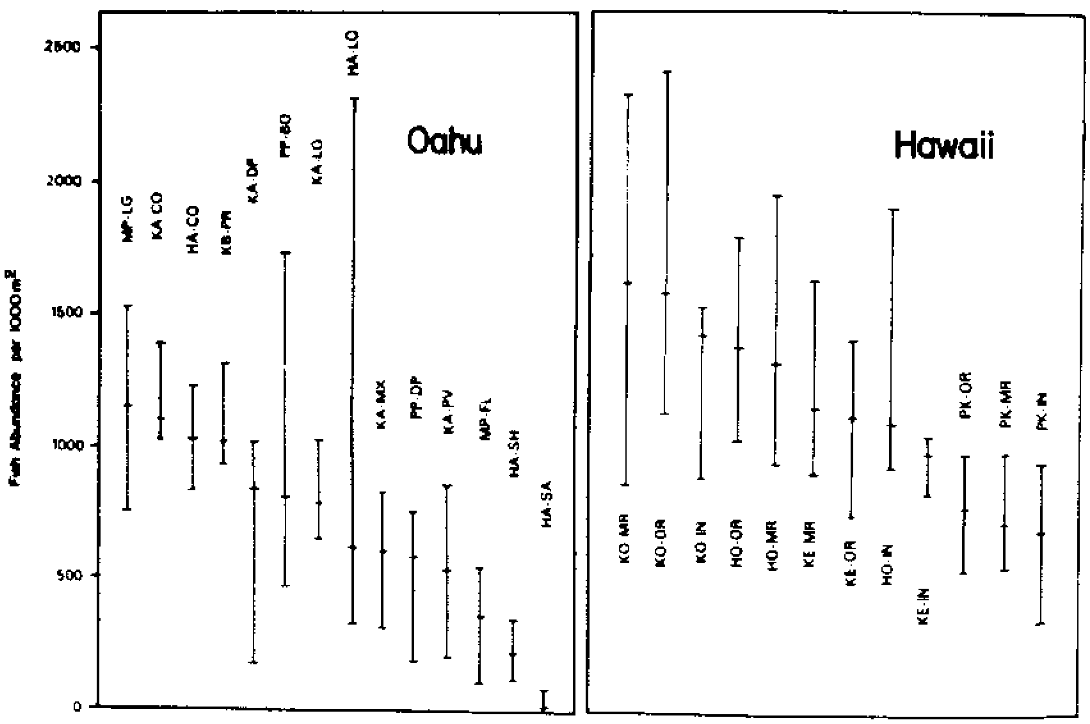


Figure 4. Medians and ranges for fish abundance by habitat

Hawaii fish abundance was highest at Koaie Cove, where the three habitats had the three highest median values. Comparison of the sites showed that, in all three habitats, Koaie Cove had higher fish counts than Kealakekua Bay, which exceeded Puako. Honaunau Bay had more fish than Puako in all three habitats, exceeded Kealakekua Bay in the mid-reef habitat, and was never significantly lower than Koaie Cove. Unlike Oahu sites, where fish abundance was higher on *P. compressa* reefs, the middle and outer reefs of Hawaii had fish counts which were not significantly different at any site. Inshore areas, however, had significantly lower values than at least one of the offshore reefs at every site.

Comparison of Oahu and Hawaii sites revealed that abundances of fish were generally higher on Hawaii. All of the Koaie Cove habitats and the two offshore habitats at Honaunau Bay exceeded the most densely populated Oahu habitats. Likewise, the habitat with the lowest fish counts on Hawaii was significantly higher than the three lowest habitats on Oahu.

Species per transect (see Table 9 and Figure 5). The number of species per transect was widely spread in the Oahu data, with individual transect values as high as 57 and as low as 2. The Kahe deep area had the highest median and only one transect had fewer than 40 species. The Pupukea boulder area had the highest individual transect but a much wider range of values. The lowest numbers were recorded in the Hanauma Bay sand area, as could be expected, and in the shallow zone at Hanauma Bay. The Makapuu flat zone again had lower species counts near the shore than out near the dropoff.

Koaie Cove again dominated the Hawaii results, significantly exceeding all other sites in the two reef zones. Fish species counts in the Puako inshore area were significantly lower than in the same habitats at the other three sites. At Koaie Cove and Puako, the inshore area was lower than the other two habitats; at Honaunau Bay all three were about the same; and at Kealakekua Bay the inshore area exceeded the outer reef in number of fish species per transect.

TABLE 9. COMPARISON OF HABITATS AND SITE RANKINGS FOR NUMBER OF FISH SPECIES PER TRANSECT

Habitat Comparisons*

Oahu	HA	KA	MP	PP		Hawaii	KE	KO	PK	HO
HA		- + -	- - -	- = -	(LO)	KE		= - -	+ = =	= - =
KA	+ - +		+ - +	- - +	(DP)	KO	= + +		+ + +	= + +
MP	+ + +	- + -		- = =	(LG)	PK	- = =	- - -		- - =
PP	+ = +	+ + -	+ = =		(BO)	HO	= + =	= - -	+ + =	

Site Rankings*

Oahu		Hawaii	
Pupukea	4	Koaie Cove	4
Kahe	3	Honaunau Bay	3
Makapuu	2	Kealakekua Bay	2
Hanauma Bay	1	Puako	1

*See Table 8 for the key.

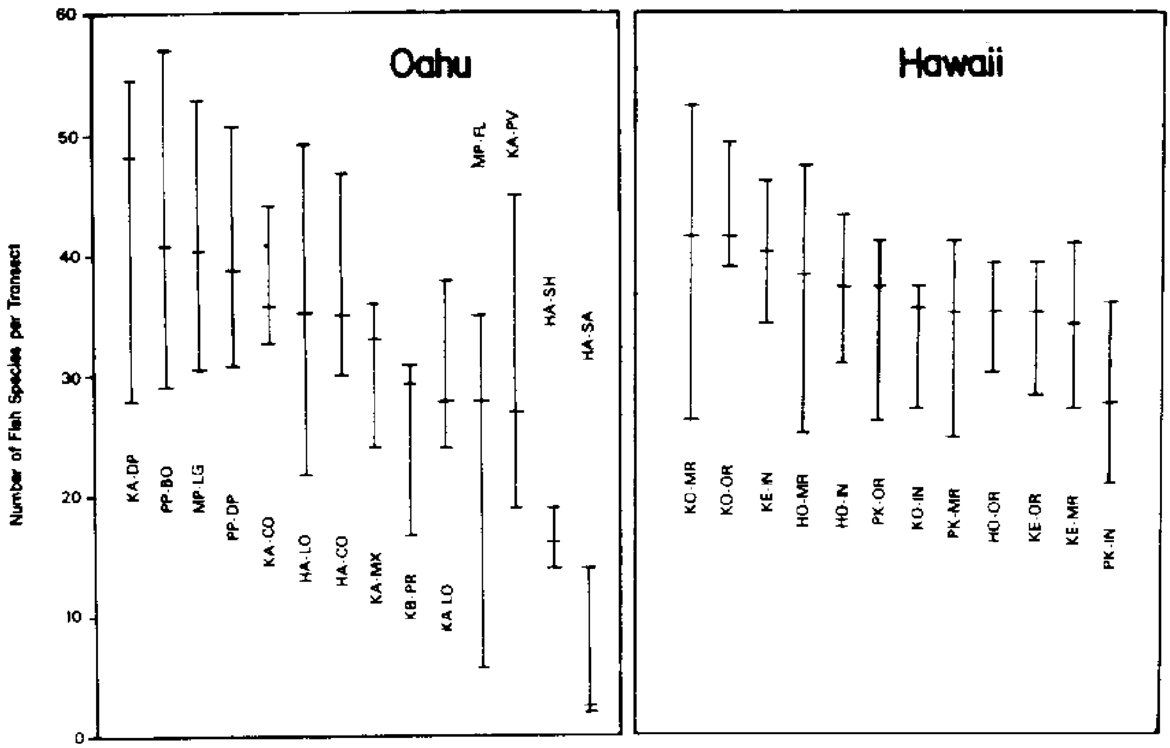


Figure 5. Medians and ranges for fish species per transect by habitat

Diversity index (see Table 10 and Figure 6). Fish diversity indices for the Oahu sites were highest in the Kahe deep zone. The two habitats at Pupukea were next, being significantly lower than the Kahe deep zone, and greater than all others. The Hanauma Bay sand area, with a very low fish abundance, had the lowest diversity, and the Hanauma Bay shallow area was again the lowest habitat of those ranked. Overall, the ranking of sites was similar to that determined for the number of species per transect.

As with the species counts, Hawaii diversity indices did not differ much from one site to the next. The highest and lowest both occurred at Puako, with the inshore habitat being much lower than the offshore reef areas. Fish diversity at Koaie Cove was high in the two offshore areas, but significantly lower inshore. At Honaunau Bay, the inshore area was more diverse than the habitats offshore. The species counts in all three habitats were about the same, so the lower diversity offshore probably reflects the more pronounced dominance of the top three species in the offshore areas. The same may be true at Kealakekua Bay, where the highest single transect was in the inshore area, but the sample size was too small to compare this habitat with other areas in the bay.

TABLE 10. COMPARISON OF HABITATS AND SITE RANKINGS FOR FISH DIVERSITY INDEX

Habitat Comparisons*

Oahu	HA	KA	MP	PP		Hawaii	KE	KO	PK	HO
HA		- + -	- = =	- - -	(LO)	KE		= - -	= - -	= = +
KA	+ - +		= - +	- - +	(DP)	KO	= + +		= = =	- + +
MP	+ = =	= + -		- - -	(LG)	PK	= + +	= = =		- + +
PP	+ + +	+ + -	+ + +		(BO)	HO	= = -	+ - -	+ - -	

Site Rankings*

Oahu		Hawaii	
Pupukea	4	Koaie Cove	3.5
Kahe	2.5	Puako	3.5
Makapuu	2.5	Kealakekua Bay	2
Hanauma Bay	1	Honaunau Bay	1

*See Table 8 for the key.

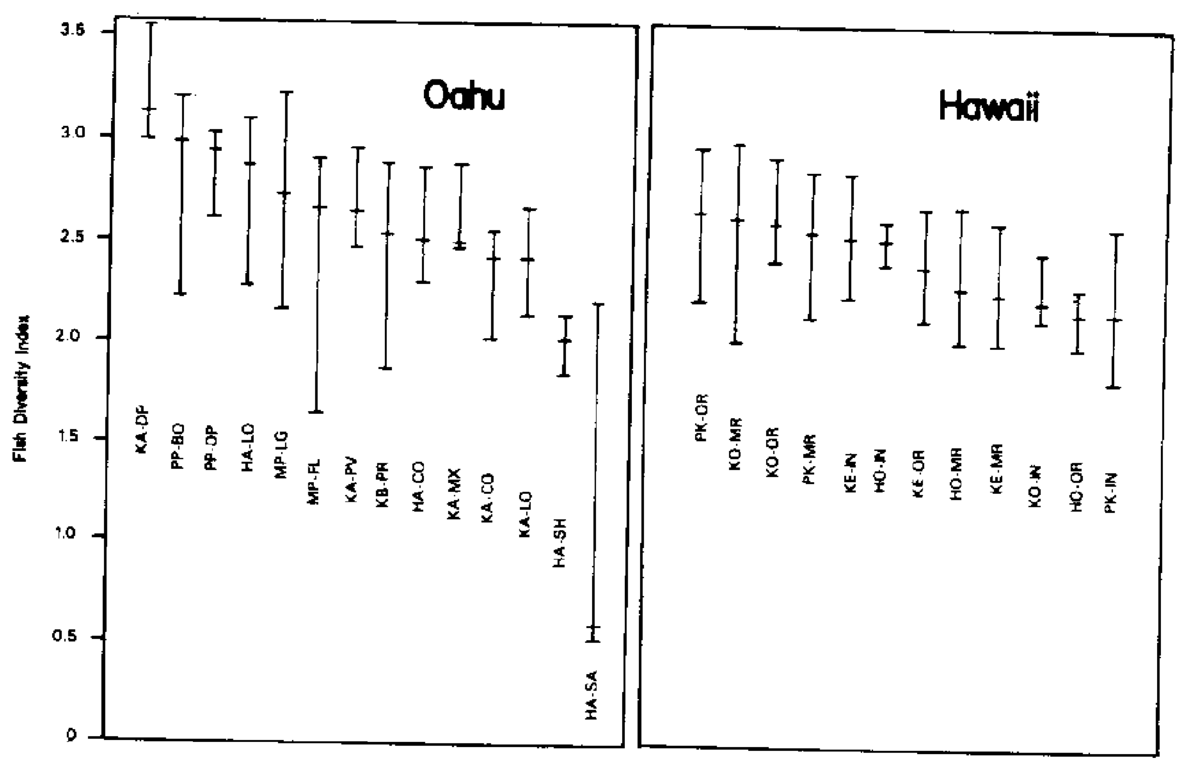


Figure 6. Medians and ranges for fish diversity index by habitat

Biomass (see Figure 7). The biomass of fish was not used for the ranking, but was calculated for each habitat. The outer reef at Koaie Cove had the highest median biomass for either island, but the highest single value recorded, 6718 kg/hectare, came from a transect in the *P. lobata* area of Hanauma Bay. This was the transect at which a school of pualu, *Acanthurus xanthopterus*, which accounted for 82 percent of the biomass on this transect, was counted. Such schools were seen several times on Hawaii, where they contributed substantially to the biomass figures. For most areas, biomass paralleled abundance fairly well, except that the deep habitats on Hawaii were relatively higher in biomass than in abundance.

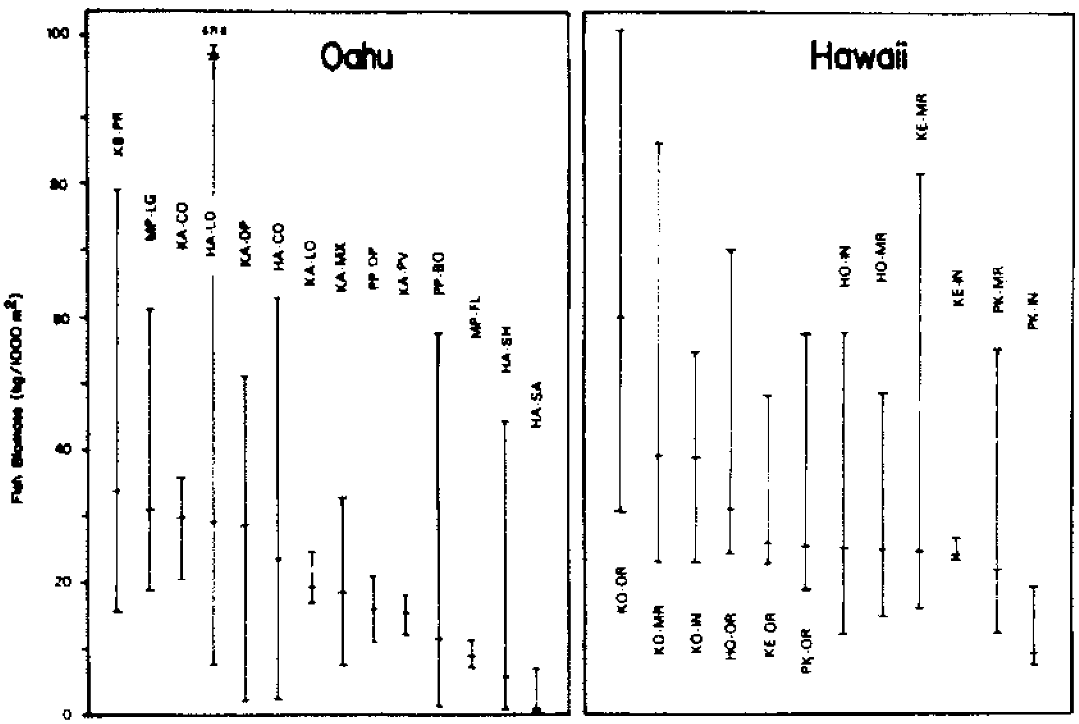


Figure 7. Medians and ranges for fish biomass by habitat

Species composition. See the site description section for the ten most abundant fish species in each habitat. The ten most abundant fish species for each island are listed on the following page. These were determined by adding the results of transects in each habitat and by taking the ten species with the highest total abundance. The Hanauma Bay sand habitat and the Kapapa Island area in Kaneohe Bay, where few fish were seen on each transect, were not included. In the following list, the number of habitats in which each species was among the ten most abundant is also given. Note that 15 Oahu habitats and 12 Hawaii habitats were included in the listing.

Species	Common, Hawaiian Name	Number of Habitats
OAHU		
Thalassoma duperreyi	Hinalea lauwili, saddleback wrasse	15
Ctenochaetus strigosus	Kole	8
Chromis vanderbilti	-----	9
Acanthurus nigrofuscus	Lavender tang	10
Stethojulis balteata	'Omaka	3
Plectroglyphidodon johnstonianus	Blue damselfish	4
Eupomacentrus jenkinsi	Jenkins' damselfish	9
Chromis ovalis	Olive damselfish	4
Chromis hanui	-----	5
Chromis verater	Black damselfish	6
HAWAII		
Ctenochaetus strigosus	Kole	12
Zebrasoma flavescens	Yellow tang	10
Chromis agilis	-----	9
Thalassoma duperreyi	Hinalea lauwili, saddleback wrasse	12
Acanthurus nigrofuscus	Lavender tang	7
Chaetodon multicinctus	Pebbled butterfly fish	11
Plectroglyphidodon johnstonianus	Blue damselfish	2
Chromis hanui	-----	6
Chromis vanderbilti	-----	4
Chromis verater	Black damselfish	6

Seven of the 10 fish species occurred in both of the above lists, showing the similarity between the two islands of the most abundant fish. The abundances of these species, however, is more regular at the Kona coast sites than on Oahu. The kole, *Ctenochaetus strigosus*, numbered among the top ten in all Kona coast habitats and made up at least 16 percent of the fish counts in all but one habitat. The saddleback wrasse, *Thalassoma duperreyi*, was among the top ten species in all habitats on both islands. Altogether, there were 31 species among the 10 most abundant in the 12 Kona coast habitats and 43 species in the 15 habitats on Oahu.

There are a few differences in the less common species between the two islands. Hawaii sites had a greater variety of carangids and scarids in most habitats than did Oahu sites. Whether this is a result of fishing pressure is unknown, but in the Oahu areas protected by regulation or by distance from shore, there were more species of these two families than at the other Oahu sites.

Several species were found only on one island. Those seen only on the Kona coast of Hawaii included three species of lutjanid or snapper, the surgeonfish *Ctenochaetus hawaiiensis*, the butterfly fish *Hemitaurichthys thompsoni*, and a rare boxfish, *Ostracion whitleyi*. Those found only on Oahu included the wrasses *Coris venusta*, *C. ballieui*, *Thalassoma purpureum*, *Chelio inermis*, *Cheilinus bimaculatus*, and *Macropharyngodon geoffroyi*. These were found most often in areas of low coral cover and, although not seen at the Kona coast sites, may inhabit other parts of the island of Hawaii. Several species which appeared to prefer coral-rich habitats were more common on Hawaii than on Oahu. These included the introduced grouper *Cephalopholis argus*, the nenue, *Kyphosus* *cinerascens*, the wrasses *Cheilinus rhodocrous* and *Thalassoma lutescens*, the tangs *Acanthurus achilles* and *A. glaucopareius*, the triggerfish *Xanthichthys mento*, the flame angelfish *Centropyge loriculus*, and eight species of butterfly fish. Species more common on Oahu than at Kona coast sites again were found in areas with low coral cover. These may be common elsewhere on the island of Hawaii but were not common on the Kona coast. They included the goatfishes *Parupeneus pleurostigma* (malu) and *P. multifasciatus* (moana), the olive damselfish *Chromis ovalis*, the wrasse *Coris flavovittata*, the surgeonfish *Acanthurus mata* (pualu), the triggerfish *Sufflamen frenatus*, and the filefishes *Pervagor epilosoma* and *P. melanocephalus*. In addition, the ala-'ihi *Adioryx spinifer* was slightly more abundant on Hawaii, while *A. xantherythrus* was seen more on Oahu; similarly, *Apogon menesemus* was the most common on Oahu. Also seen were two unnamed grouper species of the genus *Pseudanthias*--one species on each island.

See Appendix F for a complete list of species for each habitat.

Corals

Percentage of bottom cover (see Table 11 and Figure 8). The transect with the greatest live coral cover on Oahu was on a patch reef in Kaneohe Bay, where the coral is protected from wave damage. Other transects on these reefs had lower coral cover, the lowest being at the bottom of the leeward side of the reefs where coral does not appear as healthy. Of those habitats included in the ranking scheme, the Hanauma Bay *Porites compressa* reef had the highest median coral cover, with a maximum value of 67 percent on a single transect. The Kahe *P. compressa* reef was significantly lower in live coral cover, but total live and dead coral cover was greater than at Hanauma Bay, apparently as

TABLE 11. COMPARISON OF HABITATS AND SITE RANKINGS FOR PERCENTAGE OF LIVE CORAL COVER

Habitat Comparisons*

Oahu							Hawaii				
	HA	KA	MP	PP				KE	KO	PK	HO
HA		- - +	- + +	- + +	(CO)		KE		+ + =	+ = -	+ + +
KA	+ + -		+ + +	+ + +	(CO)		KO	- - =		= - -	= = =
MP	+ - -	- - -		- + +	(LG)		PK	- = +	= + +		= + +
PP	+ - -	- - -	+ - -		(BO)		HO	- - -	= = =	= - -	

Site Rankings*

Oahu		Hawaii	
Kahe	4	Kealakekua Bay	3.5
Hanauma Bay	3	Puako	3.5
Makapuu	2	Honaunau Bay	1.5
Pupukea	1	Koaie Cove	1.5

*See Table 8 for the key.

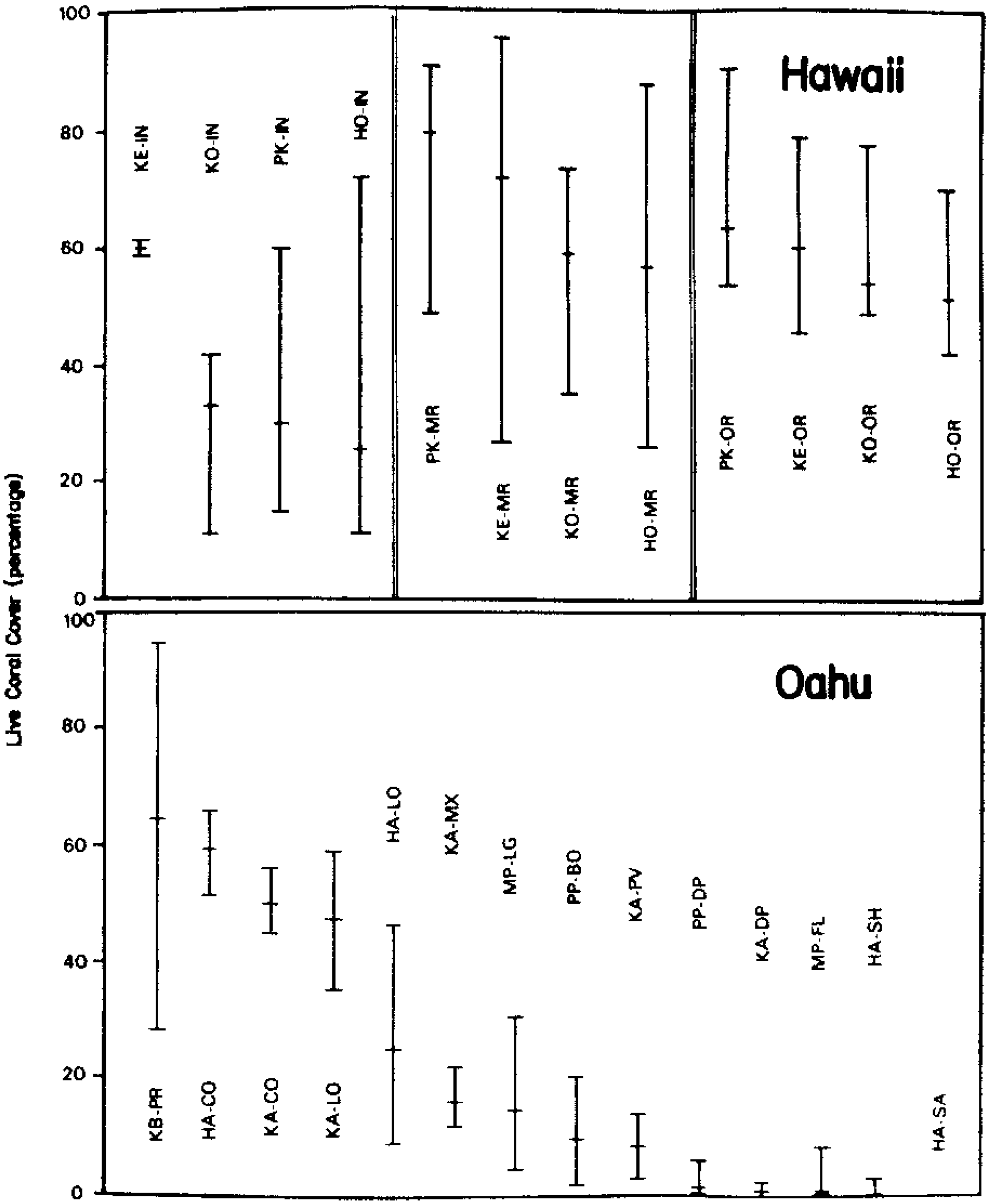


Figure 8. Medians and ranges for live coral cover by habitat

a result of damage by waves which had knocked over large areas of the delicate finger coral, exposing the dead coral beneath. The Kahe *P. lobata* area had about the same live coral cover as the *P. compressa* reef and more than the Hanauma Bay *P. lobata* area. The Kahe mixed zone, though also dominated by *P. lobata*, had a much lower coral cover than the *P. lobata* zone, as can be seen in Figure 7. The Makapuu and Pupukea habitats were all lower in coral cover than the Hanauma Bay and Kahe reefs, apparently because of scouring action by waves and currents.

Hawaii habitats, on the other hand, all had a fairly dense coral growth. Puako had the two highest median values, both in the outer reefs, while the Kealakekua Bay mid-reef zone had the highest individual transect, with 96 percent coral cover. At all sites, the mid-reef habitat had greater coral cover than the inshore zone and, at all but Kealakekua Bay, the outer reef had more coral than the inshore zone. At all sites except Honaunau Bay, the mid-reef exceeded the outer reef in coral cover. If the mid-reef habitat of Hawaii were exactly analogous to the Oahu *P. lobata* reef, and the outer reef to the *P. compressa* reefs of Oahu, the opposite would have been expected.

None of the Oahu sites receives the protection from surf that is afforded the Kona coast. It is therefore not surprising that the coral cover on Hawaii is higher. No Oahu habitat had significantly higher coral cover than any Hawaii mid-reef zone and only the Hanauma Bay *P. compressa* zone exceeded the Koaie Cove and Honaunau Bay outer reefs. Coral cover on the four Oahu *Porites* reefs exceeded that on three of the four Hawaii inshore habitats. All habitats on Oahu except the *Porites* reefs had significantly lower coral cover than even the inshore habitats of Hawaii.

<u>Coral diversity</u> (see Table 12 and Figure 9). The Pupukea boulder area had a significantly higher diversity index than any other habitat; the Makapuu

TABLE 12. COMPARISON OF HABITATS AND SITE RANKINGS FOR CORAL DIVERSITY INDEX

Habitat Comparisons*

Oahu	HA	KA	MP	PP	
HA		- = -	- - -	- + -	(LO)
KA	+ = +		+ - =	= + =	(MX)
MP	+ + +	- + =		- + -	(LG)
PP	+ - +	= - =	+ - +		(BO)

Hawaii	KE	KO	PK	HO
KE		= + +	- = +	= + +
KO	= - -		- - -	= - -
PK	+ = -	+ + +		+ + -
HO	= - -	= + +	- - +	

Site Rankings*

Oahu		Hawaii	
Kahe	3	Kealakekua Bay	3.5
Makapuu	3	Puako	3.5
Pupukea	3	Honaunau Bay	2
Hanauma Bay	1	Koaie Cove	1

*See Table 8 for the key.

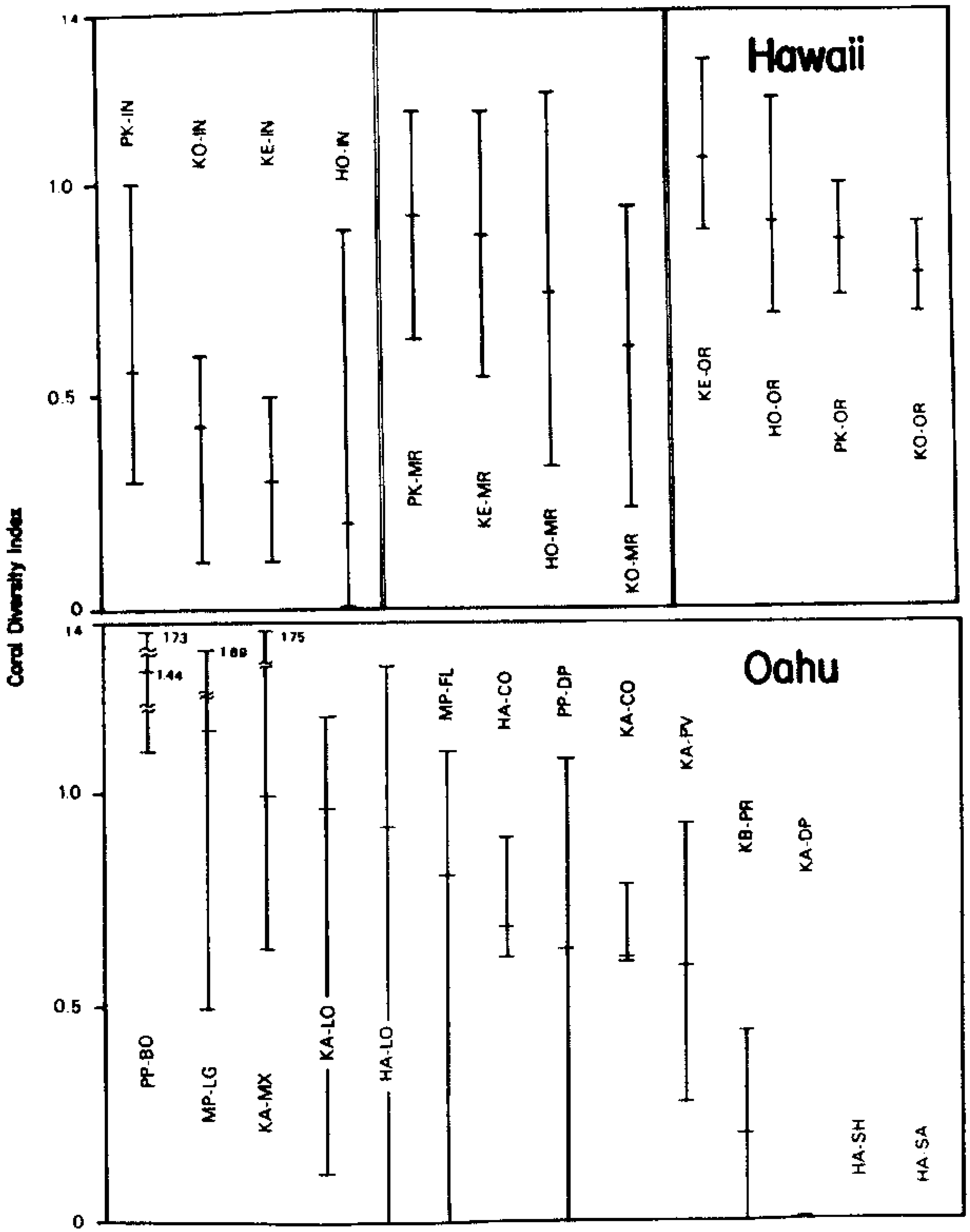


Figure 9. Medians and ranges for coral diversity index by habitat

ledge area was next, being higher than the other Oahu and Hawaii habitats. As with fish diversity, the diversity of coral had a wider range of values on Oahu than on Hawaii. Several Oahu transects had a diversity of 0, either because no corals fell under the quadrat points or because only one species, *P. lobata*, was found there. The *P. lobata* reefs at Kahe and Hanauma Bay both had higher diversity indices than either of the *P. compressa* reefs at those sites.

On Hawaii, the sites with high coral cover generally had a higher coral diversity than the other sites, but this relationship did not hold for each habitat. Within sites, the inshore habitat had the lowest diversity index and the outer reef was more diverse than the mid-reef except at Puako, where they were the same. As seen in the results for coral cover, the middle and outer reefs of the Kona coast are not truly analogous to the *P. lobata* and *P. compressa* habitats on Oahu.

Grigg and Maragos (J.E. Maragos, 1975: personal communication) found a significant inverse relationship between coral cover and diversity on lava flows on the island of Hawaii. This relationship was seen at only one of the sites of the present study, probably because of the relatively large sample size. Coral diversity did vary inversely with coral cover on the patch reefs of Kaneohe Bay, as had been previously reported by Maragos (1972). In those parts of the patch reefs where coral cover is high, the finger coral *P. compressa* is dominant and diversity as a result is low. No other coral-rich habitats on Oahu or Hawaii show such a relationship. Apparently, *P. compressa* and *P. lobata* share dominance of these reefs and all other species are relegated to a minor part of the total coral cover. The two habitats with the highest coral diversity indices, the Pupukea boulder zone and the Makapuu ledge zone, both have low to moderate coral cover. Conditions for coral growth in these areas appear optimum except for the stress of water motion--either waves or currents. Diversity may be high because this stress does not allow the more abundant species to achieve dominance. Other areas of low coral cover, however, do not exhibit a particularly high diversity. This may indicate some other limit to coral growth, such as a lack of a suitable substrate which would not inhibit dominance.

The corals in the Makapuu ledge zone, and particularly in the Pupukea habitats, have apparently adapted to the continual stress of water motion. *Porites compressa*, a form especially susceptible to breakage by surge or currents, is not very abundant at Makapuu and is wholly absent at Pupukea. Corals which do grow in these areas are either difficult to break like *Pocillopora meandrina*, or occur in a low-profile encrusting growth form. This growth form occurs in *Porites lobata* and several species of *Montipora*.

The number of species per transect, while a good indicator of diversity for fish, does not serve as well for corals because the point quadrat transect method misses many of the rare species and the number of species per transect is therefore small. These data are presented in Figure 10 for rough relative comparison only.

On Hawaii, the species counts of the offshore habitats are higher than inshore, but the difference is not as pronounced as with diversity indices. On Oahu there is only slight correspondence between diversity index and number of species, at least for the habitats at which coral cover is not extremely low. Evidently, the unevenness of species composition is playing a larger role in determining the diversity than is the number of species present.

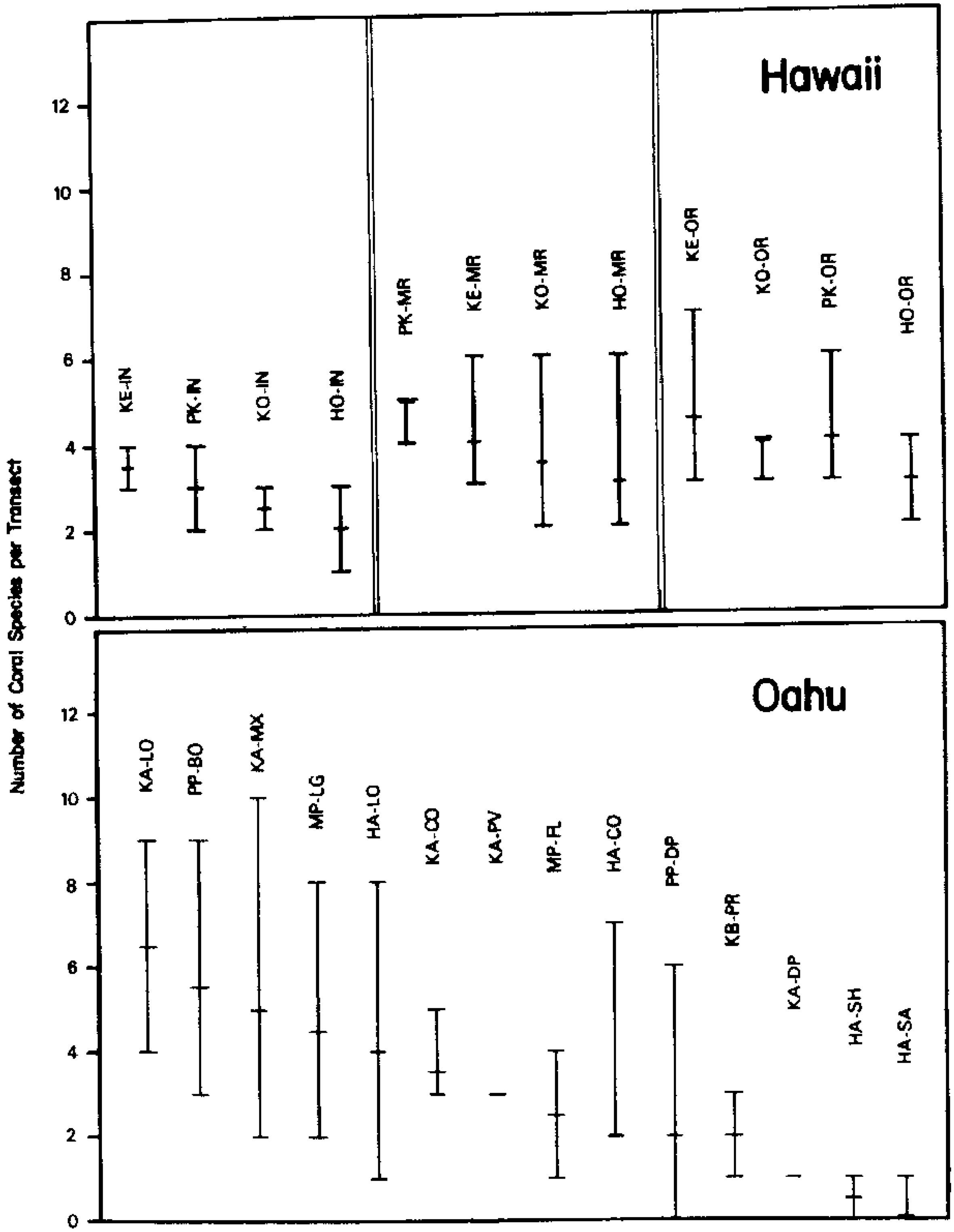


Figure 10. Medians and ranges for number of coral species per transect

A comparison of Oahu and Hawaii coral species composition reveals that there is a greater dominance by the two *Porites* species on Hawaii than on Oahu. The Oahu *P. lobata* reefs, especially, permit the growth of numerous other species, most notably *Pocillopora meandrina*, *Montipora verrucosa*, and *M. verrilli*. *Psammocora verrilli*, although highly abundant on Hawaii transects, was rare on Oahu.

See Appendix G for a complete species list for each habitat.

Macroinvertebrates

Abundance (see Table 13 and Figure 11). The abundance of motile invertebrates on Oahu was extremely variable. Single transect values ranged from 0 to 815 individuals per 100 square meters. The Kahe *P. compressa* zone exceeded all but the Makapuu flat zone, but Makapuu was ranked higher because the two major habitats there had a high abundance of macroinvertebrates.

Hawaii macroinvertebrate abundance was in general higher than that of Oahu, with a maximum value of 1830 per 100 square meters on a single transect. Variability between sites was not as great as on Oahu. Puako greatly exceeded the other sites in the inshore zone and Kealakekua Bay had the most macroinvertebrates in the mid-reef zone. Except at Kealakekua Bay, the inshore habitats exceeded the offshore habitats and at Puako and Honaunau Bay macroinvertebrate abundance in the inshore area was greater than in the mid-reef zone.

TABLE 13. COMPARISON OF HABITATS AND SITE RANKINGS FOR INVERTEBRATE ABUNDANCE

Habitat Comparisons*										
Oahu						Hawaii				
	HA	KA	MP	PP			KE	KO	PK	HO
HA		- + -	- - =	- = +	(CO)	KE		= + =	- + +	= + +
KA	+ - +		- - =	- = +	(CO)	KO	= - =		- = +	= = +
MP	+ + =	+ + =		+ + +	(FL)	PK	+ - -	+ = -		+ = =
PP	+ = -	+ = -	- - -		(DP)	HO	= - -	= = -	- = =	

Site Rankings*			
Oahu		Hawaii	
Makapuu	4	Kealakekua Bay	4
Hanauma Bay	2	Koaie Cove	2.5
Kahe	2	Puako	2.5
Pupukea	2	Honaunau Bay	1

*See Table 8 for the key.

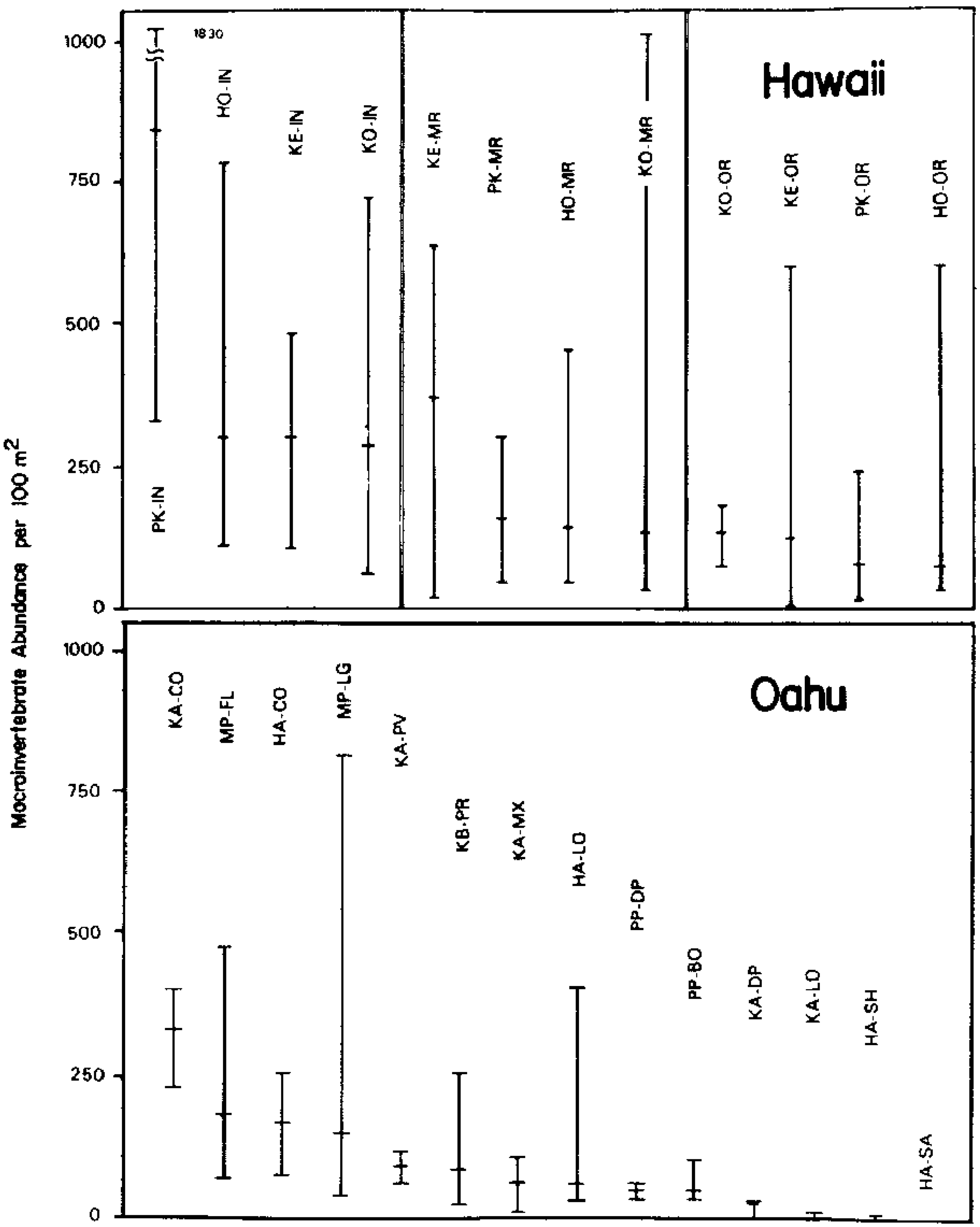


Figure 11. Medians and ranges for abundance of macroinvertebrates by habitat

All of the Hawaii inshore habitats exceeded the Oahu habitats except for the Kahe *P. compressa* zone, which had a macroinvertebrate abundance equal to three of the Hawaii inshore habitats. The five Oahu habitats with the fewest macroinvertebrates were significantly lower than all Hawaii habitats.

Diversity index (see Table 14 and Figure 12). Overall, the ranking of Oahu sites for echinoderm diversity was the reverse of that for abundance, but this relationship did not hold in each habitat category. As with other diversity indices, the echinoderm diversity had a wide range of values. The Kahe pavement area had the highest diversity index, with the Hanauma Bay *P. lobata* zone next. Besides these areas and the three least diverse habitats, there was little difference among the Oahu habitats.

A somewhat greater difference was discernible at the Hawaii sites, particularly in the mid-reef and outer reef habitats. In the inshore habitat, only Puako differed significantly from the other sites. Except at Kealakekua Bay, the mid-reef exceeded the inshore area in echinoderm diversity and the mid-reef exceeded the outer reef at all but Honaunau Bay.

Echinoderm diversity was generally higher on Hawaii than on Oahu. The Kahe pavement area was the only Oahu habitat equal to the Koaie Cove and Honaunau Bay reef zones, which were the most diverse Hawaii habitats.

No significant relationship existed between the abundance and diversity of echinoderms. There was, however, a significant (P = .05) negative correlation at most sites between abundance and species evenness. The latter is equal to the diversity index divided by the maximum possible diversity index with the same number of species. The species evenness therefore indicates how evenly

TABLE 14. COMPARISON OF HABITATS AND SITE RANKINGS FOR ECHINODERM DIVERSITY INDEX

Habitat Comparisons*

Oahu	HA	KA	MP	PP		Hawaii	KE	KO	PK	HO
HA		- + -	- + +	- + +	(LO)	KE		= - -	+ - -	= - -
KA	+ - +		= = +	= + +	(PV)	KO	= + +		+ + +	= = +
MP	+ - -	= = -		= + =	(LG)	PK	- + +	- - -		- - -
PP	+ - -	= - -	= - =		(BO)	HO	= + +	= = -	+ + +	

Site Rankings*

Oahu		Hawaii	
Hanauma Bay	3	Koaie Cove	4
Kahe	3	Honaunau Bay	3
Makapuu	2	Puako	2
Pupukea	1	Kealakekua Bay	1

*See Table 8 for the key.

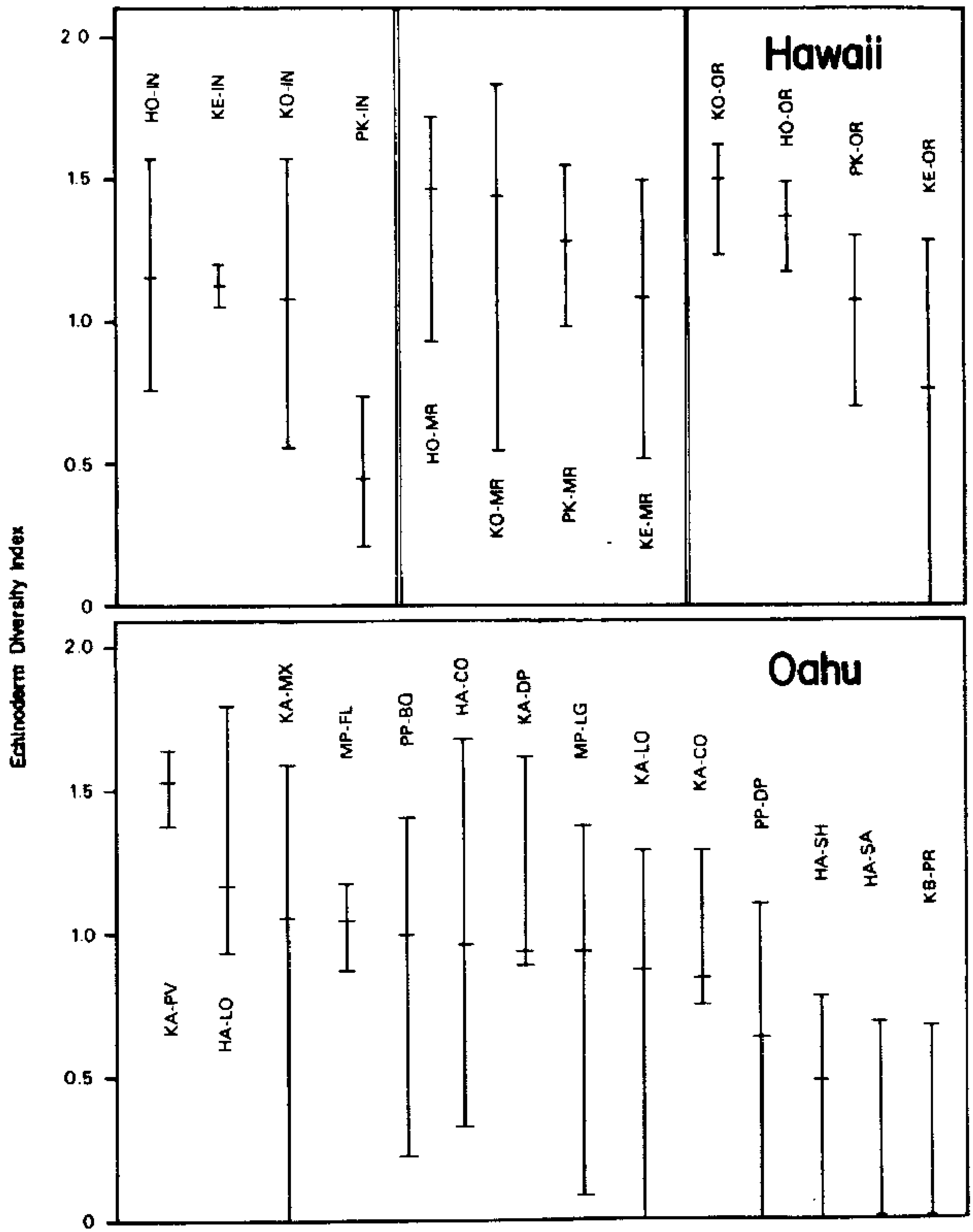


Figure 12. Medians and ranges for echinoderm diversity index by habitat

the abundance is divided among all species present and can take a value between 0 (complete dominance) and 1 (all species equally abundant). It generally decreases as total abundance increases because of increased dominance by one or a few species. On Oahu, the dominant species was often the sea urchin *Tripneustes gratilla*, which occurred in patches of up to 469 per 100 square meters. The sea urchins *Echinometra mathaei* and *Echinothrix* sp. (wana) were also frequently dominant. Such dominance occurred less often in Hawaii, where several species appeared to be about equally abundant. Where dominance occurred, *Echinometra mathaei* was most often the dominant species at Puako and Koaie Cove and the slate pencil urchin *Heterocentrotus mammillatus* was most often dominant at Kealakekua Bay. At Honaunau Bay, *E. mathaei*, *T. gratilla*, and *H. mammillatus* were all very abundant. For all of the Hawaii sites, the maximum values of abundance for these three species were 1760 per 100 square meters for *E. mathaei*, 698 for *H. mammillatus*, and 415 for *T. gratilla*.

For a complete species list for each habitat, see Appendix G.

Algae (see Figure 13)

Algal data were not used to compare sites, partly because most algae were not identified down to species and because quantitative measurements of standing crop were not made. Besides, the presence of a large quantity or a great diversity of algae is not necessarily an asset for a potential marine park site; in fact, algae may be abundant where coral cover and fish standing crop are low. Therefore, the presence of each species or genus of algae was merely noted and a species list is presented in Appendix I.

Oahu sites appeared to have more macroscopic algae than did the Hawaii sites. On both islands the most abundant algae appeared to be the encrusting forms such as *Porolithon*. On Oahu, other common algae were the red alga *Amansia glomerata* and the brown alga *Dictyota*.

SITE DESCRIPTIONS

Each of the following general descriptions of the sites include a map, a photograph showing the site and surroundings, and a photograph showing a representative underwater scene in the area. In each site description, a table lists the ten most common fish species found in each habitat at that site. Fish with well-known common or Hawaiian names are listed by those names; all others are listed by scientific name. Table 15 lists the common and scientific names for all fish listed in the site descriptions by common name.

The descriptions for Hawaii sites are considerably shorter than for Oahu sites because there is less difference among them. All of the sites studied on Hawaii are on the Kona coast and are therefore subjected to similar environmental conditions. As a result, the reefs which have developed at these sites are very similar within the constraints imposed by bottom topography.

Dollar (1975) described the zonation pattern for Kona coast corals. The habitats described in the present study are essentially the same as three of his four zones. The shallow inshore zone, referred to by Dollar as the boulder zone, is dominated by the corals *Pocillopora meandrina* and *Porites lobata*; the mid-reef, which Dollar called the "reef-building zone," is dominated by *P. lobata*; and the outer reef, Dollar's "*P. compressa* slope zone," is

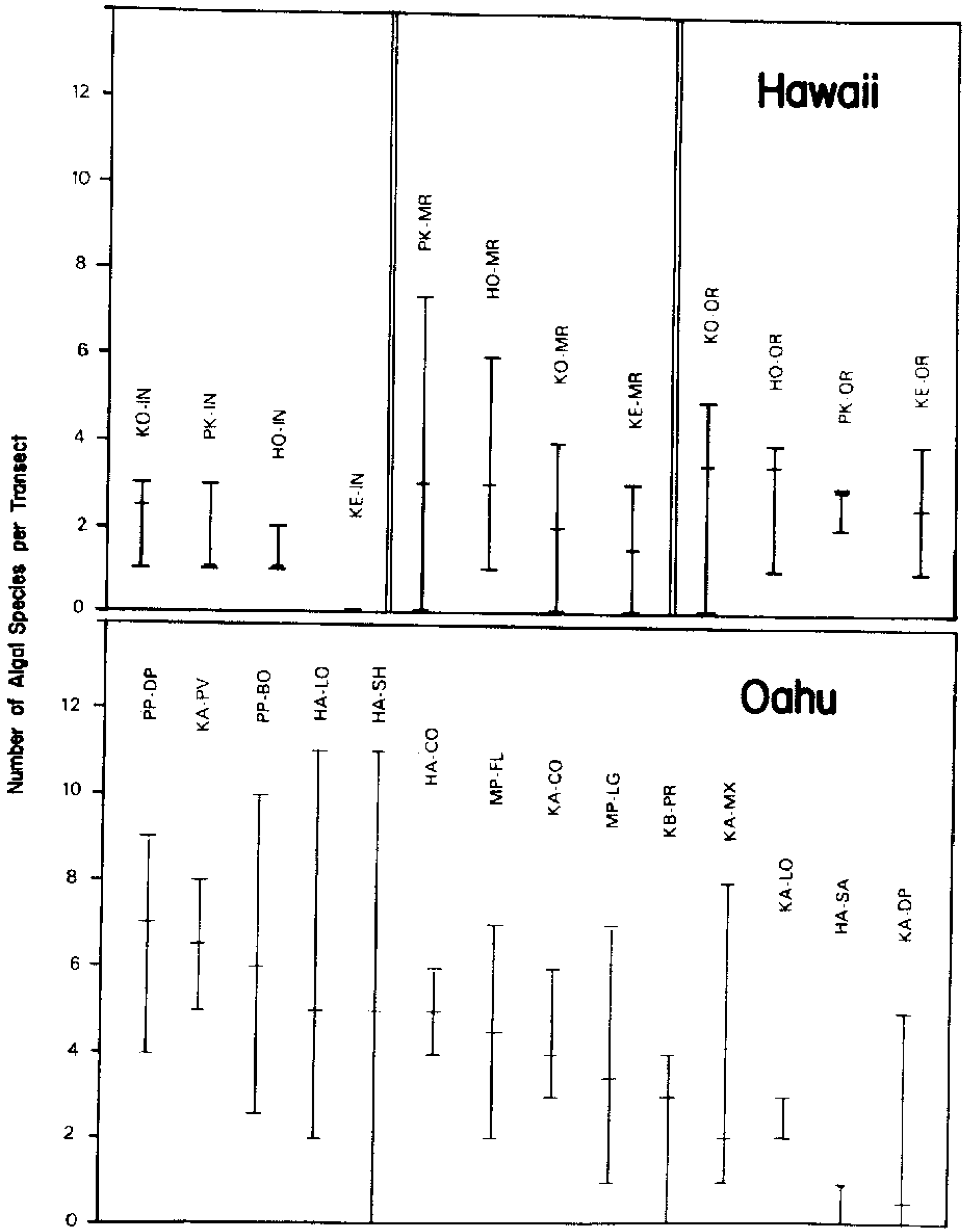


Figure 13. Medians and ranges for number of algal species per transect by habitat

TABLE 15. SCIENTIFIC, COMMON, AND HAWAIIAN NAMES OF COMMON FISH SPECIES LISTED BY FAMILY

Scientific Name	Common and/or Hawaiian Name
Acanthuridae	Surgeonfish, tangs
Ctenochaetus strigosus	kole
Zebrasoma flavescens	yellow tang
Acanthurus nigrofuscus	lavender tang
A. nigroris	maiko
A. achilles	Achilles tang, paku'iku'i
A. olivaceus	olive tang, na'ena'e
A. thompsoni	-----
A. mata	pualu
A. xanthopterus	pualu
A. triostegus	manini
Naso lituratus	kala
Lauridae	Wrasses, hinaleas
Thalassoma duperreyi	saddleback wrasse, hinalea lauwili
Stethojulis balteata	'omaka
Gomphosus varius	bird wrasse, hinalea i'iwi
Coris venusta	-----
Macropharyngodon geoffroyi	hinalea 'aki-lolo
Mullidae	Goatfishes
Mulloidichthys flavolineata	weke
M. vanicolensis	weke-'ula
Parupeneus pleurostigma	malu
P. multifasciatus	moana
Pomacentridae	Damselfishes
Eupomacentrus jenkinsi	Jenkins' damsel
Pleatroglyphidodon johnstonianus	blue damsel
P. imparipennis	-----
Abudefduf abdominalis	sergeant major, mamo
A. sordidus	kupipi
Chromis verater	black damsel
C. ovalis	olive damsel
C. agilis	-----
C. hanui	-----
C. vanderbilti	-----
Chaetodontidae	Butterfly fishes
Forcipiger flavissimus	long-nosed butterfly fish, lau wiliwili nukunuku 'oi'oi
Chaetodon miliaris	lemon butterfly fish
C. multicinctus	pebbled butterfly fish
C. fremblii	blue stripe butterfly fish
C. ornatissimus	ornated butterfly fish
C. kleini	-----
Hemitaurichthys polylepis	pyramid butterfly fish
Pomacanthidae	Angelfishes
Centropyge potteri	Potter's angelfish
Cirrhitidae	Hawkfishes
Paracirrhites arcatus	pili ko'a
Cirrhitops fasciatus	pili ko'a
Holocentridae	Squirrelfishes
Adioryx xantherythrus	'ala'ihi
Myripristis murdjan	menpachi, u'u
Scaridae	Parrotfishes, uhus
Scarus sordidus	uhu
Carangidae	Jacks, uluas
Other common fish species	
Sufflamen bursa	trigger fish, humuhumu umauma lei
Pervagor spilosoma	fantail filefish
Canthigaster jactator	spotted puffer, Hawaiian puffer
Kuhlia sandvicensis	aholehole
Apogon snyderi	cardinal fish, upapalu
Scorpaena coniorta	scorpionfish
Pseudanthias thompsoni	grouper
Eleotris microlepis	goby

dominated by that coral species, but with *P. lobata* also very abundant in spots. The zone which Dollar called the *P. lobata* rubble zone was not wider than a few meters at any of the sites of this study, so this zone was not considered as a separate habitat.

Besides the corals, fish and macroinvertebrate species lists are also very similar from one Kona coast site to another. Discussions of fish, macroinvertebrate, and coral species found at these sites are therefore limited in the site descriptions to particularly abundant species and to rare or unusual species.

Habitat boundaries shown in the maps are only approximations because they were not precisely surveyed in all cases and because most of the habitats blend into each other without a well-defined boundary.

Where features are described as being on the right or left, it means to the right or left while facing the water from shore.

Hanauma Bay, Oahu

Hanauma Bay, located on the southeast shore of Oahu, encompasses about 40 hectares (101 acres) of water (Figure 14). The marine life conservation district comprises the area shoreward from a line connecting the outermost points on either side of the bay mouth. A city beach park extends along the periphery of the bay, with rest room, shower, and snack bar facilities beside the sandy beach at the west end.

Hanauma Bay receives about 20,000 visitors per month (J. Lee, City and County of Honolulu Department of Recreation, 1975: personal communication) It is a popular picnic and recreational spot for residents and visitors and is frequented by a sizable number of snorkelers and SCUBA divers.

About 80 m from the beach at the west end, a shallow limestone reef extends across the bay, cutting off access to the outer bay except through a series of natural channels at the left end, and a channel cut to accommodate submarine cables near the right end of the reef. Access to the outer bay can also be attained by walking around the perimeter of the bay or over the reef. Between the beach and the reef lies a protected area suitable for beginning snorkelers. Water depth here does not exceed 4 m and in much of the area it is not over 1 m. Visibility is usually quite poor due to sediment carried from the shore by freshwater runoff. The southern end of this area is often full of debris blown there by the trade winds.

Outside of the reef, water depth slopes gradually from 2 to about 25 m in the middle of the bay mouth. This area is subjected to trade wind waves most of the year and to southerly swells in the summer. Wave patterns in the bay are confused and irregular because of reflections off the shore; on the right side a fairly persistent seiche, or standing wave, has led that area to be named "Witches' Brew." This is also a collecting point for debris during trade wind periods. Visibility is clearest near the outer edges of the bay and poorest on the left side just beyond the limestone reef where surf combines with a sandy bottom to produce visibility values as low as 2 m at times. Bottom currents are not particularly bothersome except in two places: at the trench cut through the reef for the cables, where a strong current sometimes

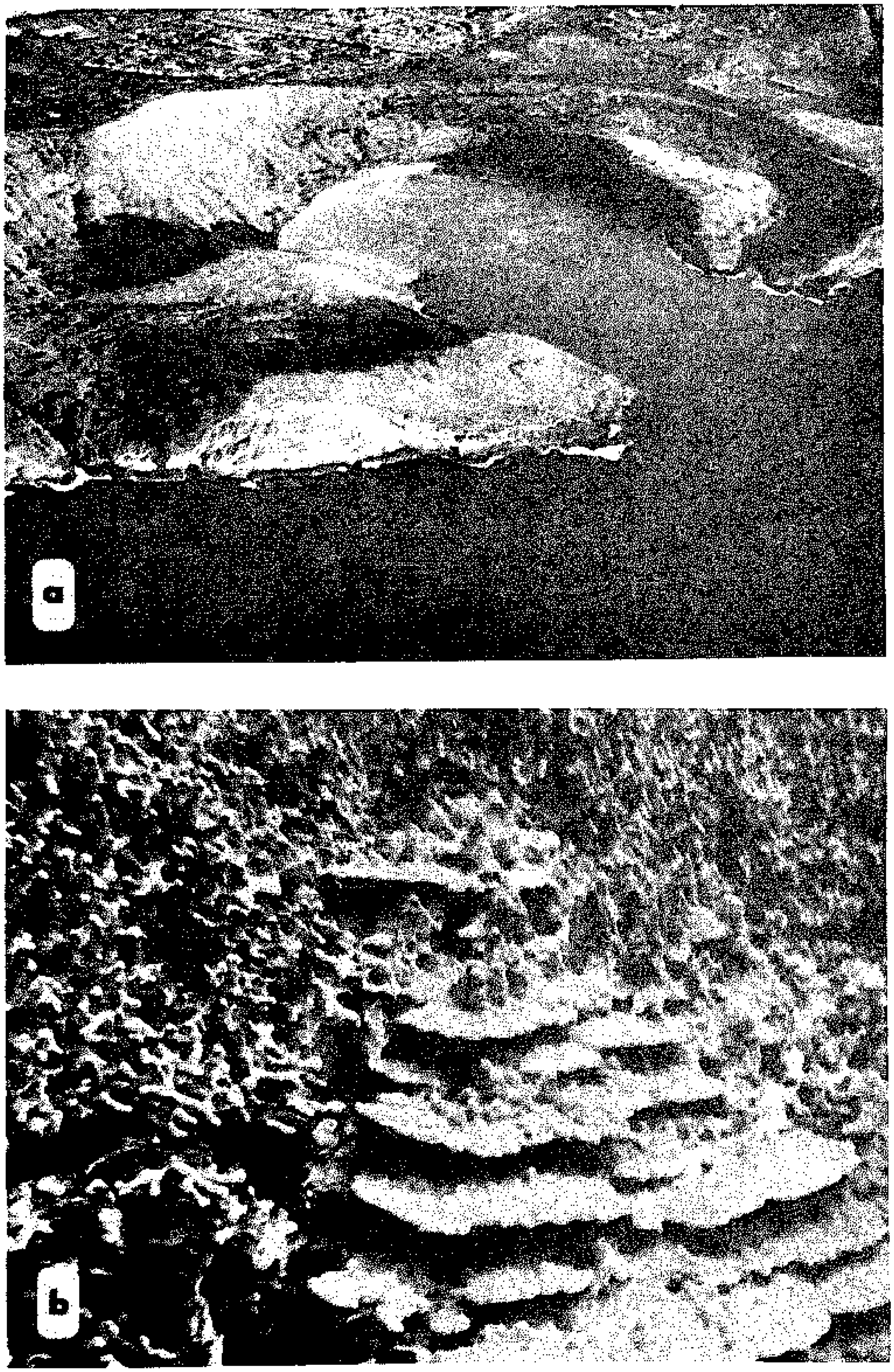


Figure 14. Hanauma Bay: *a*, aerial view; *b*, underwater view of coral ledge

makes swimming back into the shallow water difficult; and at the outer boundary of the bay where a strong tidal current known as the "Molokai Express" can sweep an unwary diver past the mouth of the bay.

Four major bottom habitats can be distinguished within the bay (Figure 15). One is the shallow zone inside the reef. The other three include a zone composed mostly of sandy bottom and two coral zones--one dominated by the massive coral *Porites lobata* and the other by the finger coral *Porites compressa* (Table 16).

Benches and outcrops of limestone are interspersed with sand patches to form the substrate in the shallow zone. Coral cover was extremely low, as were the abundance and diversity of fish and macroinvertebrates. The manini, *Acanthurus triostegus*, accounted for nearly a third of all the fishes counted within this zone. The mullet *Neomyxus chaptalii* was also seen frequently in the area, although it was not counted on a transect. This may have been because all counts in this area were done at low tide, which also apparently contributed to the large difference in biomass between these counts and those conducted by the State Division of Fish and Game. The Division of Fish and Game (1972) data indicated a biomass inside the reef which was higher than outside. Another possible cause of this discrepancy is that the transects in this study were placed well inside the reef (Figure 15). The deeper pockets just inside the reef are frequented by many large fish, which would contribute substantially to biomass figures of a transect run there.

Large sand patches outside of the shallow reef constitute the second zone. A few small outcrops of limestone provide the only vertical relief in these patches. Of the few fish counted in this zone, most were associated with nearby coral areas. A few species, such as one species of razorfish, *Hemipteronotus*, the weke, *Mulloidichthys flavolineata*, and the malu, *Parupeneus pleurostigma*, seemed to be associated at least part of the time with the pure sand habitat.

The *Porites lobata* zone is a diverse and plentiful habitat. Heads of *P. lobata* with diameters of up to 3 m stand out from substrates of sand and limestone, with some basalt on the cliffs on the right side of the bay. Coral cover was variable, being generally higher further out in the bay. Fish abundance also varied widely; the transect with the highest fish count in the Oahu survey (2320 per 1000 square meters) was in this zone. This transect included a large school of pualu, *Acanthurus xanthopterus*, which also boosted the biomass figure by 82 percent to 6718 kg/hectare. Many species of fish were common here, with no dominance by any one species: the most abundant, *Thalassoma duperreyi*, comprised only 11 percent of the total fish count for this habitat. There were several species of fish frequently seen here that are not particularly common in most other areas of Oahu. These included the colorful wrasses *Thalassoma purpureum* and *T. fuscum*, the nenue, *Kyphosus cinerascens*, the butterfly fish *Chaetodon trifasciatus*, and the surgeonfish *Acanthurus guttatus*, all of which inhabit the portions of this habitat along the limestone reef. Several carangid (ulua) species were also seen in the *P. lobata* zone, including *Scomberoides lysan*, *Elagatis bipinnulatus*, *Gnathonodon speciosus*, and *Caranx melampygus*. Invertebrates were moderately abundant, with a large number of taxa represented. Vermetid snails were common, as was the tubeworm *Spirobranchus*, which often builds its tube in live *Porites lobata* heads.

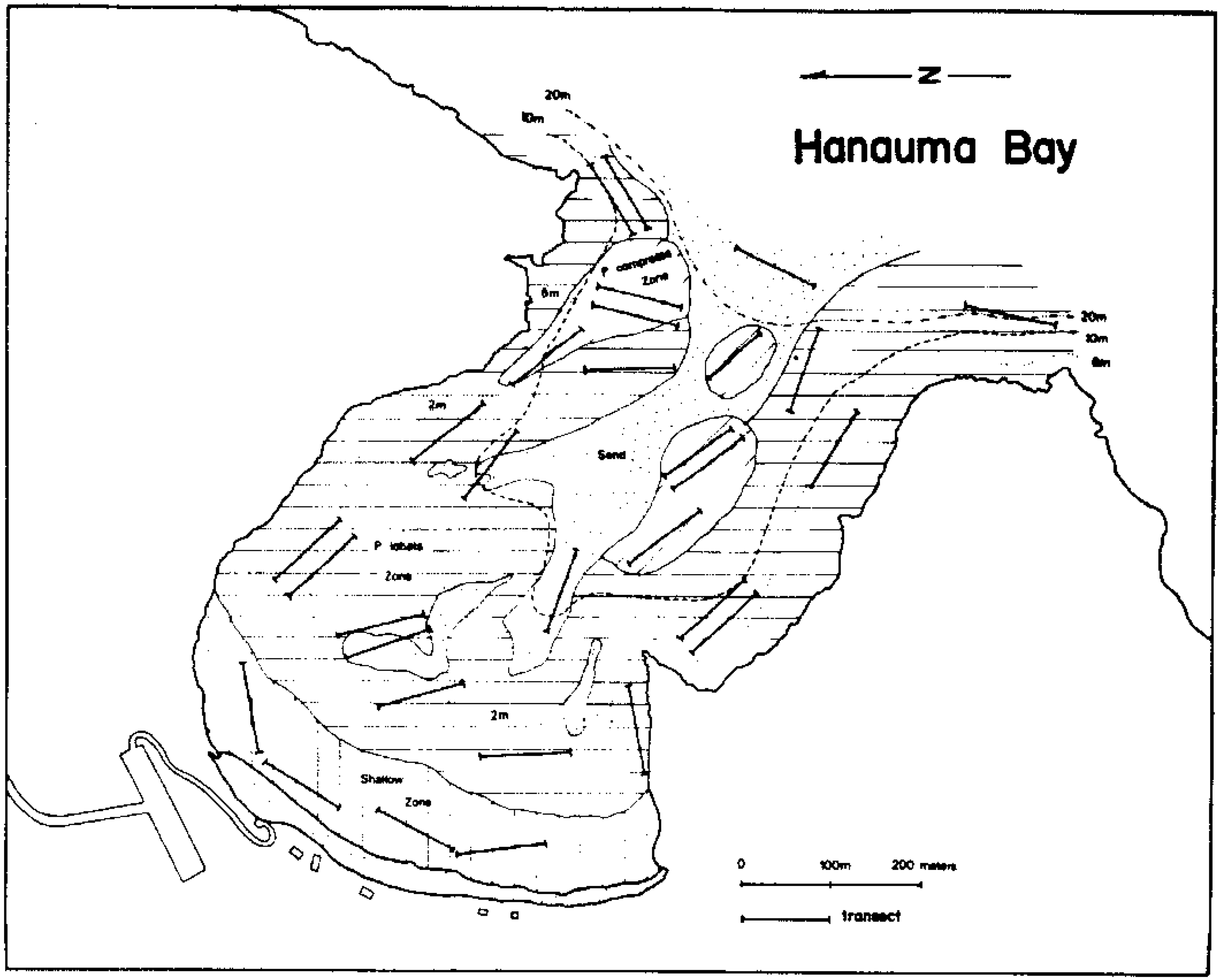


Figure 15. Map of Hanauma Bay showing transect locations and habitats

TABLE 16. PERCENTAGE OF RELATIVE ABUNDANCE OF THE TEN MOST COMMON FISH SPECIES* FOUND IN HABITATS AT HANAUMA BAY

Porites lobata Reef		*Porites compressa* Reef		Shallow Zone	
Species	Relative abundance (%)	Species	Relative abundance (%)	Species	Relative abundance (%)
Hinalea lauwili	11.2	Kole	25.5	Manini	31.3
Kole	7.3	*Chromis hanui*	12.6	'Omaka	16.7
Lavender tang	7.0	Hinalea lauwili	10.3	Hinalea lauwili	11.8
Jenkins' damsel	6.4	Jenkins' damsel	8.1	Jenkins' damsel	10.3
Black damsel	4.9	Potter's angel	5.4	Aholehole	7.9
Manini	4.6	Blue damsel	4.5	Weke	4.1
Lemon butterfly	4.4	Yellow tang	4.5	Lavender tang	3.4
Weke	4.2	Lavender tang	3.7	*Acanthurus mata* (pualu)	2.8
Hamo	3.8	Black damsel	3.5	Kupipi	1.5
Acanthurus xanthopterus (pualu)	3.3	Spotted puffer	2.4	*Chaetodon fremblii*	1.3

*Common or Hawaiian names are given where possible. See Table 15 for scientific names of these species.

The *Porites compressa* zone actually consists of several isolated reefs at depths between 9 and 18 m. This was the habitat which contained the greatest coral cover and the highest median fish counts in the bay. The fish fauna were composed mainly of small animals that can hide among the coral fingers, such as the kole, *Ctenochaetus strigosus*, which comprised 25 percent of the fish present, and the damselfish *Chromis hanui*. The macroinvertebrates were heavily dominated by the sea urchin *Tripneustes gratilla*, with *Eucidaris metularia* and *Echinothrix* sp. also common.

The fish throughout the bay, even in the shallowest waters, were unafraid of humans. It was possible to approach many of them quite closely, more so than in any other area studied. Even the wary parrotfish, or uhu, could be approached to within a few meters.

Several large pelagic fish were occasionally seen within the bay. The awa, *Chanos chanos*, was a frequent visitor near the center and the bonefish, *Albula vulpes*, was occasionally seen. Both species of barracuda appeared here, as well as several carangid (ulua) species. The green sea turtle, *Chelonia mydas*, was also seen in deeper parts of the bay.

Improvements could be made to enhance Hanauma Bay's value as a marine park. These include reducing erosion from the beach and its surroundings, clearing the accumulating debris from the southwest corner of the bay, and posting more specific information on the hazards of diving and snorkeling in the bay. The latter is an important point, as divers and swimmers are occasionally lost there.

Kahe, Oahu

The site referred to here as Kahe is located south of Kahe Beach Park on the west coast of Oahu (Figure 16). Boundaries of the area were set to the

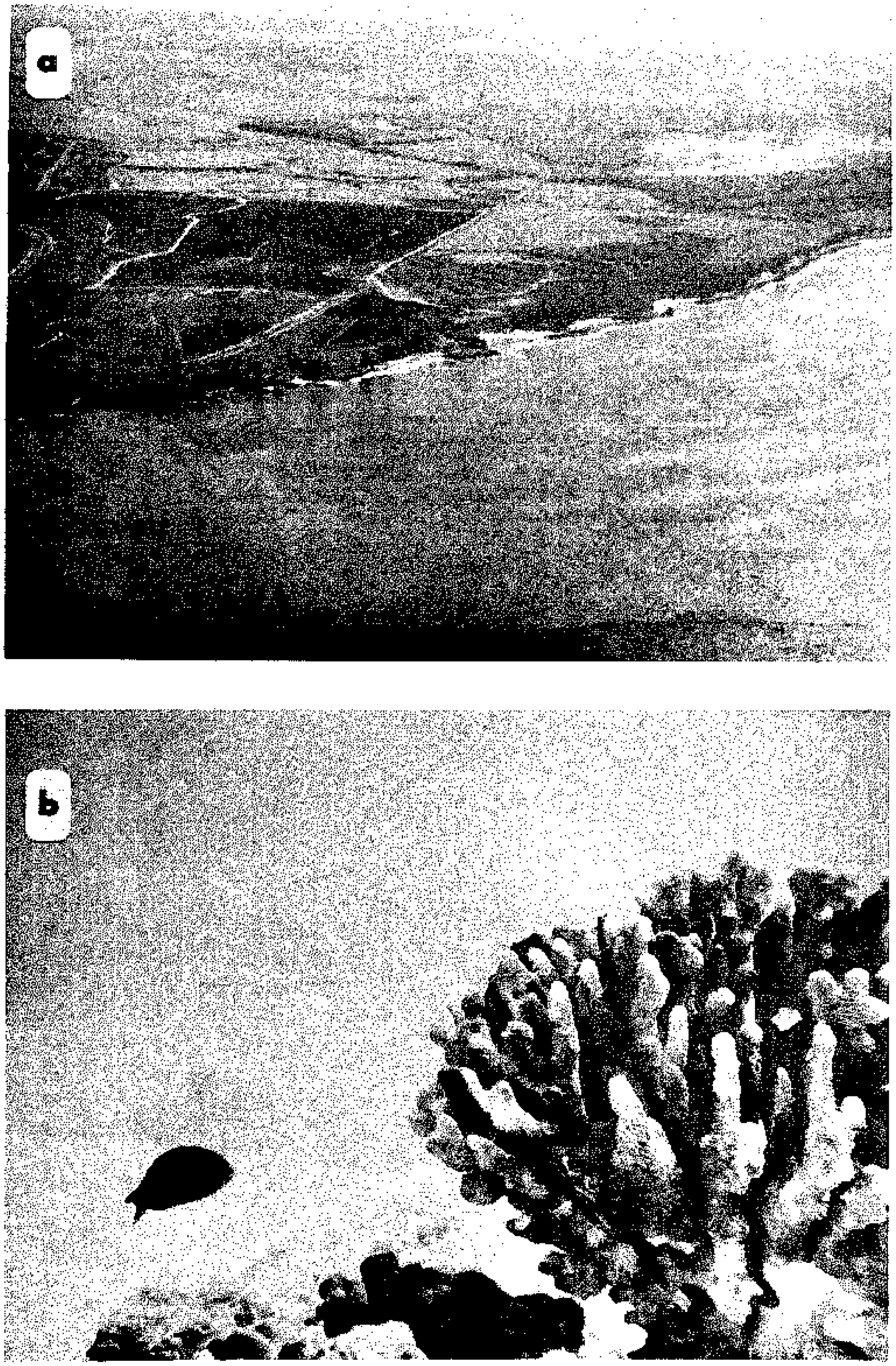


Figure 16. Kahe: *a*, aerial view; *b*, underwater view of a *Pocillopora* head in deep water

north by the beginning of a large sand patch off Kahe Beach Park and to the south by a gradual decrease in coral cover. The seaward limit is somewhat arbitrary, but can be set at the 30-m depth contour, which runs about 1500 m offshore. These boundaries enclose approximately 380 hectares.

The land adjacent to this area is presently owned by Campbell Estates, but the City and County of Honolulu has been negotiating with Campbell Estates officials for acquisition of the site as a beach park.

The rocky shoreline is broken up by three sandy beaches which border on well-protected lagoons. Access to the water can be readily gained from these beaches, but access from Kahe Beach Park is difficult. A rocky cliff runs from the beach park almost to the fence (Figure 17), where there is a small pebble beach suitable for entry into the water. Fishermen use the cliff area, especially at the beach park, for pole fishing. Their use of this area would be unaffected by the establishment of a marine conservation district, as the northern limit of the district would be established south of the existing beach park.

Water depth just offshore is about 3 m. The bottom slopes very gradually to 15 m between 600 and 1400 m offshore, at which point it descends at a steeper angle to 20 to 25 m. This dropoff marks the outer limit of the coral reef and the beginning of a deep area with a sandy bottom broken up by outcrops of coral and rock.

Diving conditions are excellent at Kahe for most of the year. Adverse conditions do occur when a southwest or northwest swell is running and during Kona storms. Currents are predominantly tidal and can be quite strong in the deeper waters, so novice divers should avoid these areas. Visibility appears to depend on currents and surge strength. It is occasionally reduced by fallout from sugar cane fires, which emit large, fine pieces of ash that settle slowly to the bottom. The major impediment to visibility, however, is silt from construction at the Kahe power plant. This source of silt can be expected to continue for several years until the construction of a deep thermal diffuser is completed. Another potential source of silt is the Campbell Barge Harbor to the south; it may be enlarged in the near future.

Five habitats were distinguished in this area (Figure 17), but boundaries between them are quite indistinct. Immediately in front of the sandy beaches begins a zone of dense coral cover, with *Porites lobata* predominating. This is flanked by two areas of lower coral cover, referred to together as the "mixed" zone. To seaward, there is an area of *P. compressa*, or finger coral, which is replaced to the south by an area of limestone pavement with scattered pockets of coral and rubble. Beyond these two zones is the dropoff, followed by the outer sandy region.

The *P. lobata* area is characterized by large heads of this massive coral near shore, grading to smaller heads further seaward. Coral cover here was significantly higher than in the comparable area in Hanauma Bay. Fish fauna were dominated by the lavender tang, *Acanthurus nigrofuscus*, and the kole, *Ctenochaetus strigosus* (Table 17). Two rare butterfly fish species were seen in this area: the saddleback butterfly fish, *Chaetodon ephippium*, and one pair of *Chaetodon reticulatus*, which was seen nowhere else on Oahu. No macroinvertebrates were seen in greater abundance than a few individuals in this zone.

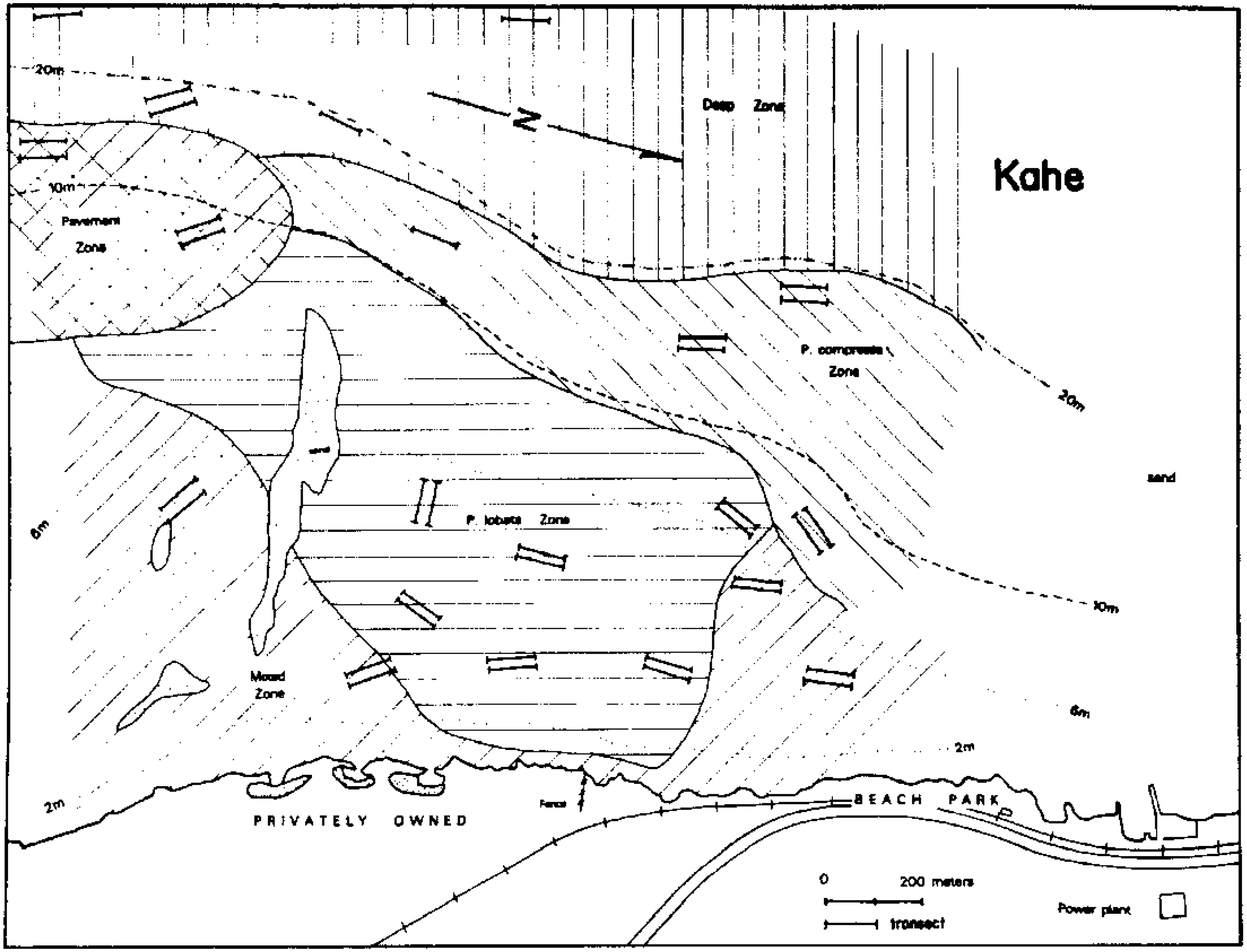


Figure 17. Map of Kahe site showing transect locations and habitats

TABLE 17. PERCENTAGE OF RELATIVE ABUNDANCE OF THE TEN MOST COMMON FISH SPECIES* FOUND IN HABITATS AT KAHE

Porites lobata Reef		*Porites compressa* Reef		Mixed Zone	
Species	Relative abundance (%)	Species	Relative abundance (%)	Species	Relative abundance (%)
Lavender tang	23.8	Kole	34.2	Lavender tang	17.7
Kole	21.7	Yellow tang	12.0	Kole	16.5
Hinalea lauwili	13.3	Black damsel	7.6	Hinalea lauwili	13.5
Jenkins' damsel	8.4	*Chromis hanui*	7.0	Jenkins' damsel	6.7
Blue damsel	4.9	Olive damsel	6.3	*Chromis vanderbilti*	6.2
Spotted puffer	4.5	Potter's angel	4.6	Olive tang	4.0
Pebbled butterfly	2.6	Hinalea lauwili	4.0	Spotted puffer	3.9
Bird wrasse	2.3	*Chromis vanderbilti*	3.0	Yellow tang	3.0
Chromis vanderbilti	2.2	Pebbled butterfly	2.9	Menpachi	2.4
Menpachi	1.6	Menpachi	2.2	Potter's angel	1.8

Pavement Zone		Deep Zone	
Species	Relative abundance (%)	Species	Relative abundance (%)
Hinalea lauwili	13.2	*Chaetodon kleini*	10.7
Chromis vanderbilti	11.5	*Chromis hanui*	10.3
Kole	11.3	Ala-'ihi	4.5
Lavender tang	8.5	*Chromis vanderbilti*	4.3
Paracirrhites arcatus	6.5	Moana	4.2
Chromis hanui	5.4	Hinalea lauwili	4.2
Chaetodon kleini	4.5	Ulua (unident.)	4.1
Lemon butterfly	4.1	Lemon butterfly	4.0
Yellow tang	3.8	Menpachi	3.7
Pebbled butterfly	3.4	Black damsel	3.5

*Common or Hawaiian names are given where possible. See Table 15 for scientific names of these species.

The area referred to as the "mixed" zone also has *Porites lobata* as the dominant coral, but total coral cover is only about half that of the first zone. Coral is gradually replaced by sand to the north and by limestone with the coralline alga *Porolithon* to the south. The two fish species that dominated the *Porites lobata* zone fish counts, *Acanthurus nigrofuscus* and *Ctenochaetus strigosus*, were dominant in the mixed zone, but to a lesser degree. *Chaetodon ephippium* was also seen in this area. Macroinvertebrates were somewhat more abundant than in the *P. lobata* zone; the most common were the sea urchins *Tripneustes gratilla* and *Echinometra mathaei* and the tubeworm *Spirobranchus*.

The finger coral *Porites compressa* was the dominant coral species in the next habitat, with *P. lobata* also very abundant. Live coral cover here was lower than in similar areas of Hanauma Bay, apparently because of extensive damage to the reef by storms. The total substrate coverage by coral was actually higher in the Kahe *P. compressa* reefs than at Hanauma Bay, but much of this had been knocked over, exposing the dead coral beneath. Fish were very abundant with the kole comprising over one-third of the fish counted. Other common fish were small species which normally remain near the shelter of the reef, such as the yellow tang, *Zebrasoma flavescens*, the angelfish *Centropyge potteri*, and several small damselfish. The larger damselfish *Chromis verater* and *C. ovalis*, which normally swim in the water column well off the reef, were also common here. This habitat was the only area where the rarer species of long-nosed butterfly fish, *Forcipiger longirostris*, was seen on Oahu; this species is common on Hawaii island reefs. Also seen in this area was the flame angelfish *Centropyge loriculus*. Macroinvertebrate abundance was higher in this area than on any other coral reef on Oahu. The most common species were the sea urchins *Tripneustes gratilla*, *Eucidaris metularia*, and *Echinometra mathaei*.

The pavement area had low coral cover, mostly *P. lobata*, and moderate numbers of invertebrates dominated by the starfish *Linckia*. Fish abundance was moderate, with most of the fish, along with the corals and many of the invertebrates, concentrated around small pockets or depressions in the limestone substrate. Dominance of the fish was shared by the wrasse *Thalassoma duperreyi*, the small damselfish *Chromis vanderbilti*, and the kole.

Immediately seaward of the pavement area and the *P. compressa* reef, there is a dropoff where numerous fish and some invertebrates were concentrated. Beyond this region the bottom consisted of sand with scattered patches of rubble and some coral. These areas were combined into the deep zone. The only common coral was *P. lobata* and the total coral cover was very low. As in the pavement area, fish and invertebrates were distributed very unevenly. Invertebrates were not abundant, but the starfish *Linckia multifora* was seen frequently. The lobster, *Panulirus* sp., and the octopus, *Polypus marmoratus*, although not counted on a transect, were present in moderate abundance near the dropoff. Fish diversity was very high, as there was little dominance by any one species. The most common fishes were the butterfly fish *Chaetodon kleini* and the damselfish *Chromis hanui*. Several unusual species were seen here, including two grouper species, *Pseudanthias thompsoni* and an as yet unnamed species of *Pseudanthias*, and the maka'a, *Malacanthus hoedtii*. A school of about 80 small carangids or ulua was seen on one transect, contributing to the high relative abundance of that family. Owing to the distance at which they were sighted, further identification could not be made.

Makapuu, Oahu

Makapuu Point, which marks the southern tip of the windward coast of Oahu, forms the western boundary of the third location studied (Figure 18a). The seaward limits of this area lie approximately along a line from the point to the outer edge of Manana (Rabbit) Island and from there to the Makai Range pier. The rest of the shoreline comprises Makapuu Beach Park, which includes a popular bodysurfing beach as well as fishing and camping areas.

Bottom topography is relatively flat from the shoreline to about 700 to 1500 m out--the area between Manana Island and Makapuu Point. Here the bottom drops away in a series of ledges and cliffs to about 25 m. Along the outer face of Manana Island and near the tip of Makapuu Point, the bottom descends in a spectacular dropoff from the surface to about 20 m (Figure 18b).

Wind and water conditions can be quite harsh at Makapuu. Except for the areas behind the two islands, there is little protection from trade winds and swells from the northeast. When strong trade winds are blowing, the combination of wind and waves can make this area dangerous for a small boat. A strong tidal current sweeps through the area inside of and between the two islands and can be hazardous to divers. Visibility, however, is highly favorable for diving, being typically over 25 m near the dropoff.

Three habitats can be defined at Makapuu (Figure 19 and Table 18). One is the area of ledges and cliffs running from the outer face of Manana Island around both sides of Kaohikaipu Island (Black Rock) and over to the point. Another is the wide, relatively flat-bottomed area shoreward of the ledge zone. The third is a deep zone to seaward.

The bottom in the flat zone varies from a hard pavement to rubble and sand, with very low coral cover. *Porites lobata* is again the most common coral. Fish abundance was very low, but increased with distance away from shore. The wrasses *Coris venusta* and *Thalassoma duperreyi* together made up about one-third of the fishes present. Two species more common here than elsewhere were the wrasse *Macropharyngodon geoffroyi* and the scorpionfish *Scorpaena coniorta*. The carangids *Caranx melampygus* ('omilu) and *Scomberoides lysan* (lae) were also common near the outer boundary of this area. Invertebrates were abundant here, with *Tripneustes gratilla* and *Echinometra mathaei* being the most frequently seen.

The ledge area with its steep topography offered a sharp contrast to the flat region. Fish abundance and diversity here were very high. The small damselfish *Chromis vanderbilti*, the saddleback wrasse, and the lavender tang, *A. nigrofuscus*, together comprised nearly half of the fish counts. The less abundant fish, however, are sometimes more striking. These included the butterfly fishes *Hemitaurichthys polylepis* and *Chaetodon ephippium* and six species of adult parrotfish or uhu. The eagle ray, *Aetobatus narinari*, was also a common sight in this area. Coral cover was variable, with *P. lobata* again the most common species, but with *Pocillopora meandrina*, which forms smaller, branching colonies, also common and quite conspicuous. The fairly rich invertebrate fauna were dominated by the sea urchins *Echinothrix* sp., *Tripneustes gratilla*, and *Echinostrephus aciculatus*, with a great many less common forms present.

The deep zone was transected only once. It is an area of flat rock, rubble, and sand, with a few outcrops of coral. Invertebrates were not

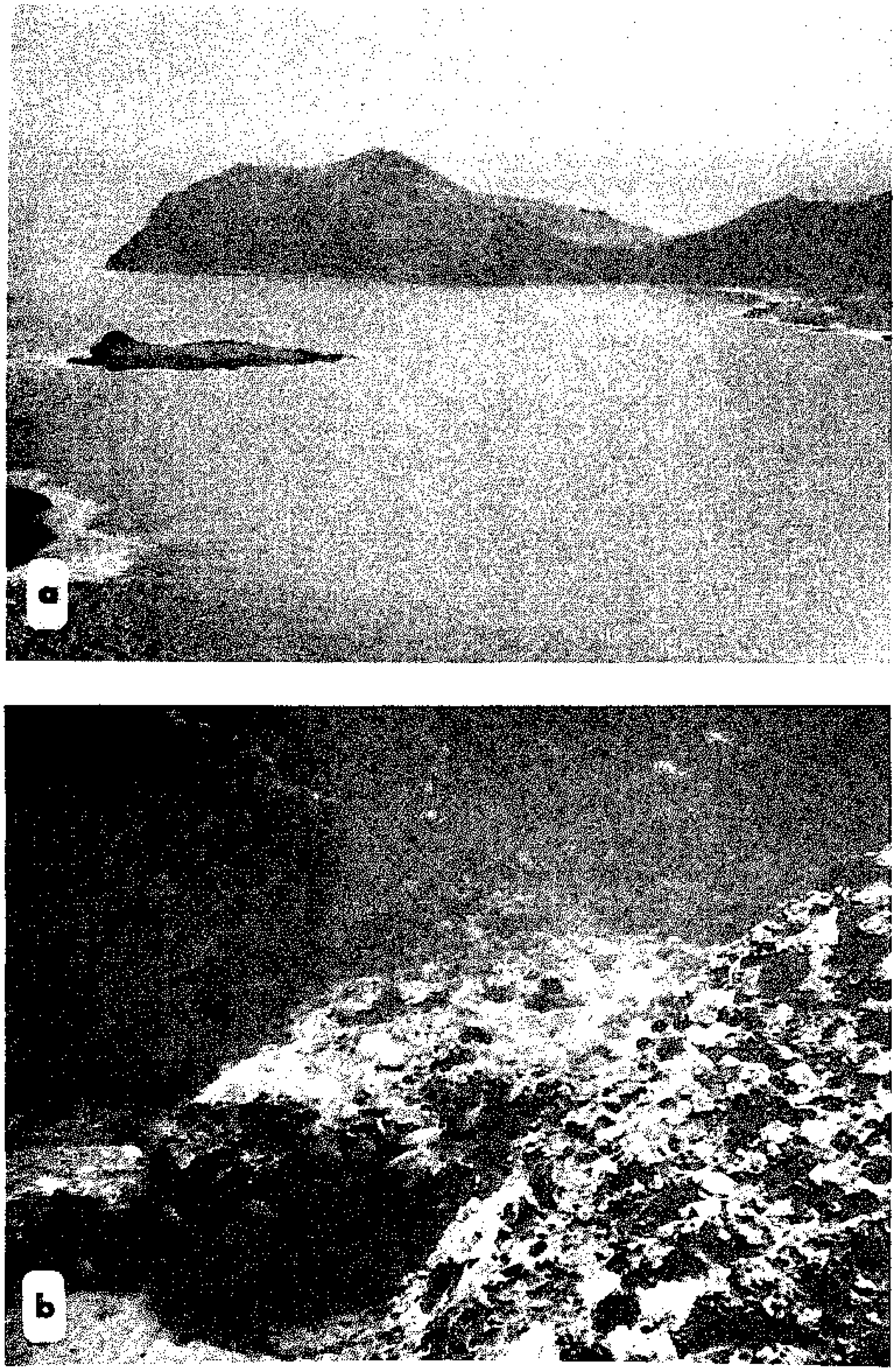


Figure 18. Makapuu: *a*, aerial view; *b*, underwater view of boulders near the dropoff

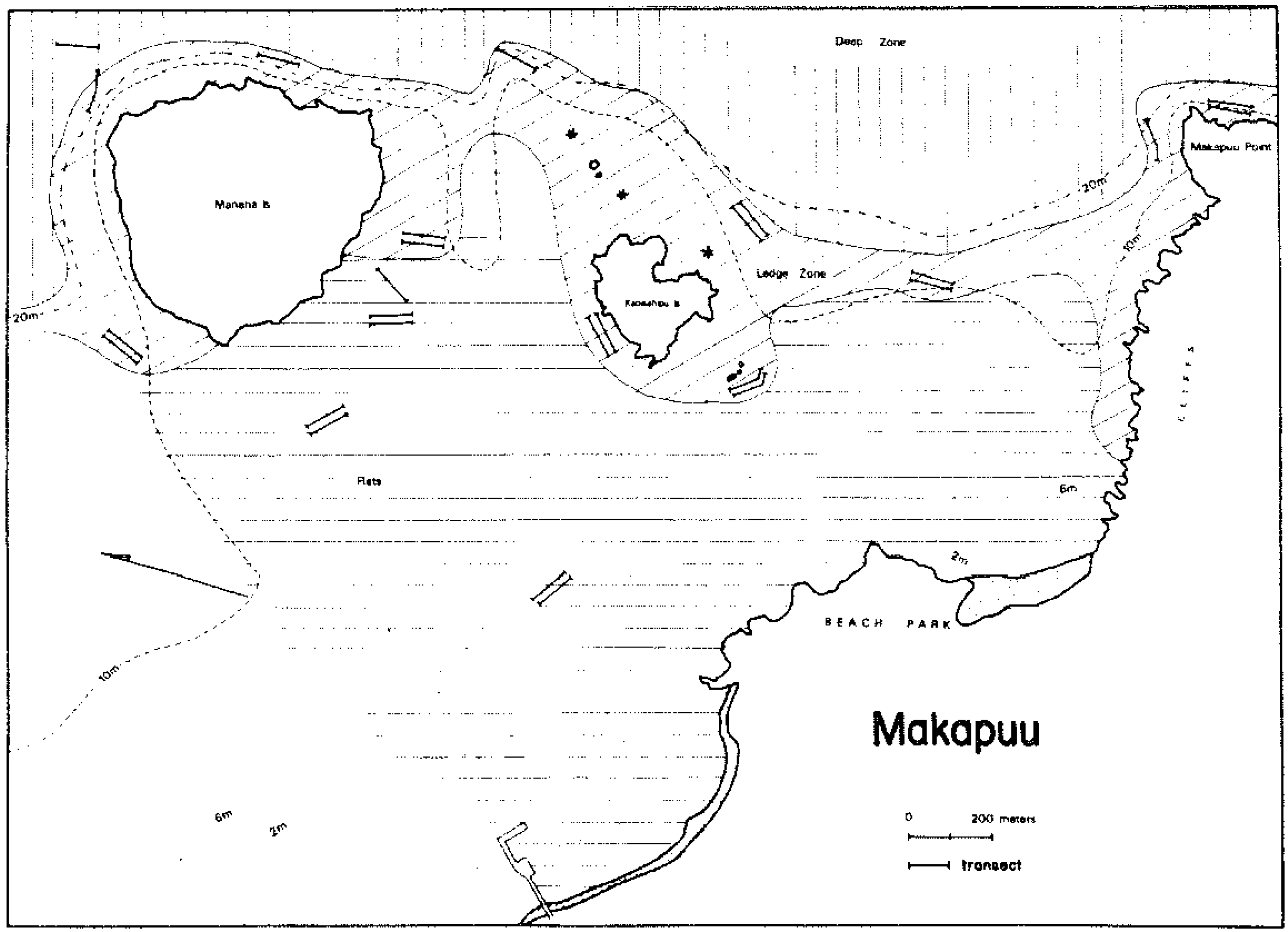


Figure 19. Map of Makapuu area showing transect locations and habitats

TABLE 18. PERCENTAGE OF RELATIVE ABUNDANCE OF THE TEN MOST ABUNDANT FISH SPECIES* FOUND IN HABITATS AT MAKAPUU

Flat Zone		Ledge Zone		Deep Zone	
Species	Relative abundance (%)	Species	Relative abundance (%)	Species	Relative abundance (%)
Coris venusta	18.1	*Chromis vanderbilti*	24.6	*Pseudanthias thompsoni*	19.7
Hinalea lauwili	15.3	Hinalea lauwili	11.4	*Chaetodon kleini*	9.2
Chromis vanderbilti	9.7	Lavender tang	11.1	*Chromis hanui*	9.2
Macropharyngodon geoffroyi	9.2	Olive damsel	3.5	Lemon butterfly	4.8
'Omaka	6.0	'Omaka	3.1	*Chromis vanderbilti*	4.4
Scorpaena coniorta	4.7	Kole	3.1	*Paracirrhites arcatus*	4.4
Blue damsel	3.5	Black damsel	2.6	Fantail filefish	4.4
Lavender tang	2.8	Juvenile uhu**	2.5	Hinalea lauwili	4.0
Jenkins' damsel	2.6	Jenkins' damsel	2.4	*Ptereleotris microlepis*	3.5
Manini	2.3	Lemon butterfly	2.2	Cardinal fish	3.1

*Common or Hawaiian names are given where possible. See Table 15 for the scientific names of these species.
**Juvenile scarids (uhu) of different species have similar habits, frequently school together, and are extremely difficult to distinguish in the water. These have therefore been lumped into one group.

common, but there was an abundance of the bryozoan *Triphyllozoon hirsutum*, or "lace coral." Although fish were not very abundant, diversity was high and there were a number of unusual species. The most abundant fish species listed from this transect was *Pseudanthias thompsoni*, with the deep-water butterfly fish *Chaetodon kleini* and the damselfish *Chromis hanui* common as well.

Human influence is not very noticeable at Makapuu. In the deeper waters little fishing occurs and the only fish collecting of any consequence is apparently that done by Sea Life Park and Oceanic Institute aquarists. The effect of these activities is not noticeable, as those species which are being caught for aquarium use are abundant. Apparently the inaccessibility of the more interesting diving areas at the dropoff has deterred large-scale spearfishing and collecting. Also contributing to the low level of use of this area are the hazardous conditions for boating and the distance to the nearest boat ramp, which is in Kailua.

Pupukea, Oahu

Pupukea Beach Park, just east of Waimea Bay on the north shore, is one of the most popular summer diving spots on Oahu. Although it is unsafe for diving about eight months out of the year because of heavy surf, during the summer the waters at Pupukea are calm (Figure 20a).

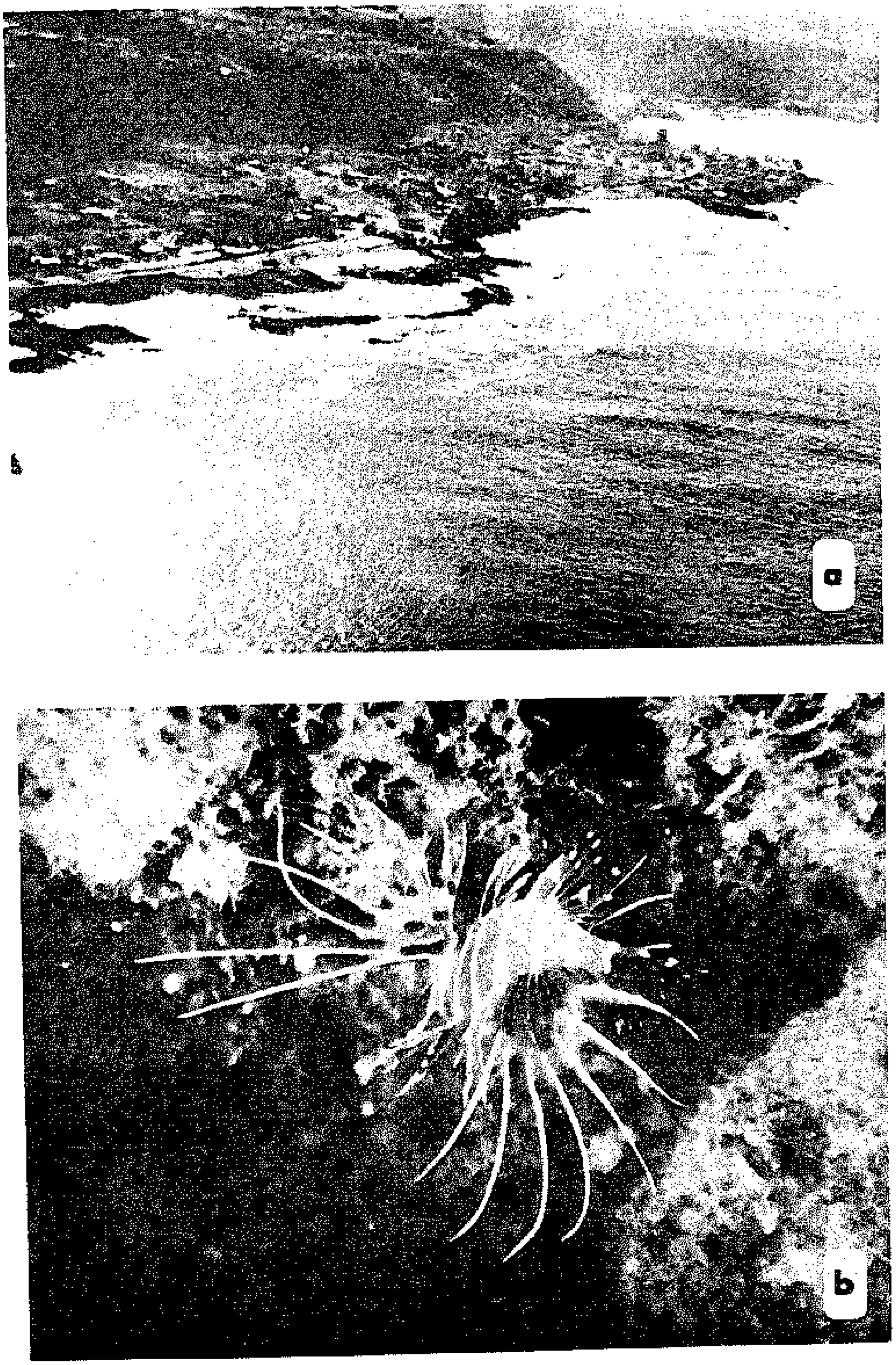


Figure 20. Pupukea: *a*, aerial view; *b*, underwater view of a lionfish (*Pterois sphex*) in a cave

The beach park is broken up into two parts. On the left is the so-called "Three Tables" area, with a wide sandy beach in front of a shallow lagoon separated from the sea by the three flat rocks which give the beach its name. On the right is "Shark's Cove," a narrow rocky cove with a small beach. Connected to Shark's Cove is a large, shallow brackish water pool supplied with water from springs and from tunnels connecting the pools to the ocean. These tunnels penetrate a barrier of limestone which separates the pools from the ocean; on the seaward side of this barrier is a limestone bench which is just covered at high tide. Between the pools and the Three Tables beach, the Sunset Beach fire station stands in front of a stretch of rocky shoreline. The lateral boundaries of the study area are a point jutting out between Waimea Bay and Three Tables and another rocky point to the right of Shark's Cove.

Summer diving conditions at Pupukea are benign, with very slight currents, calm waters, and protection from trade winds. In winter, of course, diving is impossible due to the swells which pound the north shore almost continuously. Survey results for Pupukea can therefore apply only for the summer.

Bottom topography is very irregular. Inside Shark's Cove and the Three Tables lagoon, the bottom is covered with medium-sized boulders and sand. Outside of these protected areas and beneath the cliffs on the seaward side of the pools, the bottom consists of sand patches and huge boulders up to 12 m high. Under the boulders and under some of the cliffs lie caves of various shapes and dimensions. Further seaward the boulders become smaller and the sand areas larger until the bottom becomes mainly sand with scattered outcrops of rock. Visibility is fair in most areas, but is highly dependent upon silt runoff and mixing by surge.

Division of this area into habitats was made difficult by the extreme heterogeneity of the bottom. There are basically two zones--the boulder zone closer to shore and the "deep" zone characterized by smaller boulders, lower relief, and different fish fauna (Figure 21). In addition, the caves form a distinct habitat, as do the brackish water pools and the limestone bench area surrounding the pools. The last three habitats were too small and irregularly shaped to be transected by the methods used in this project, but these areas were inspected and lists prepared of the species seen in each one (Table 19).

In the boulder area, coral cover was low, with the highest value on a transect being only 20 percent. The coral species most abundant here were *Porites lobata* and *Montipora verrilli*. Most of the corals in this area occurred in an encrusting form, an adaptation to the wave-stressed environment. Calcareous algae of the genus *Porolithon* were also found encrusting the rocks. Macroinvertebrate abundance was moderate, but a large number of different forms were seen. The most abundant of the motile invertebrates was the bandana prawn, *Stenopus hispidus*.

Fish were plentiful in the boulder zone, with a consistently high index of diversity. The highest number of species per transect, 57, was in this habitat. Fish biomass, however, was quite low. This agrees with the observation that there was a large number of juvenile fish in the area and relatively few adults. Whether this was a product of mortality due to winter surf or spearfishing is not known. It was observed, however, that fish in this area are not easy to approach. Adult scarids (uhu or parrotfish) were particularly wary: although they were seen frequently in the morning, by the time transect lines had been laid they had left and no adult uhu was ever counted on a transect. The most common species counted was the damselfish *Chromis vanderbilti*, with *C. ovalis*

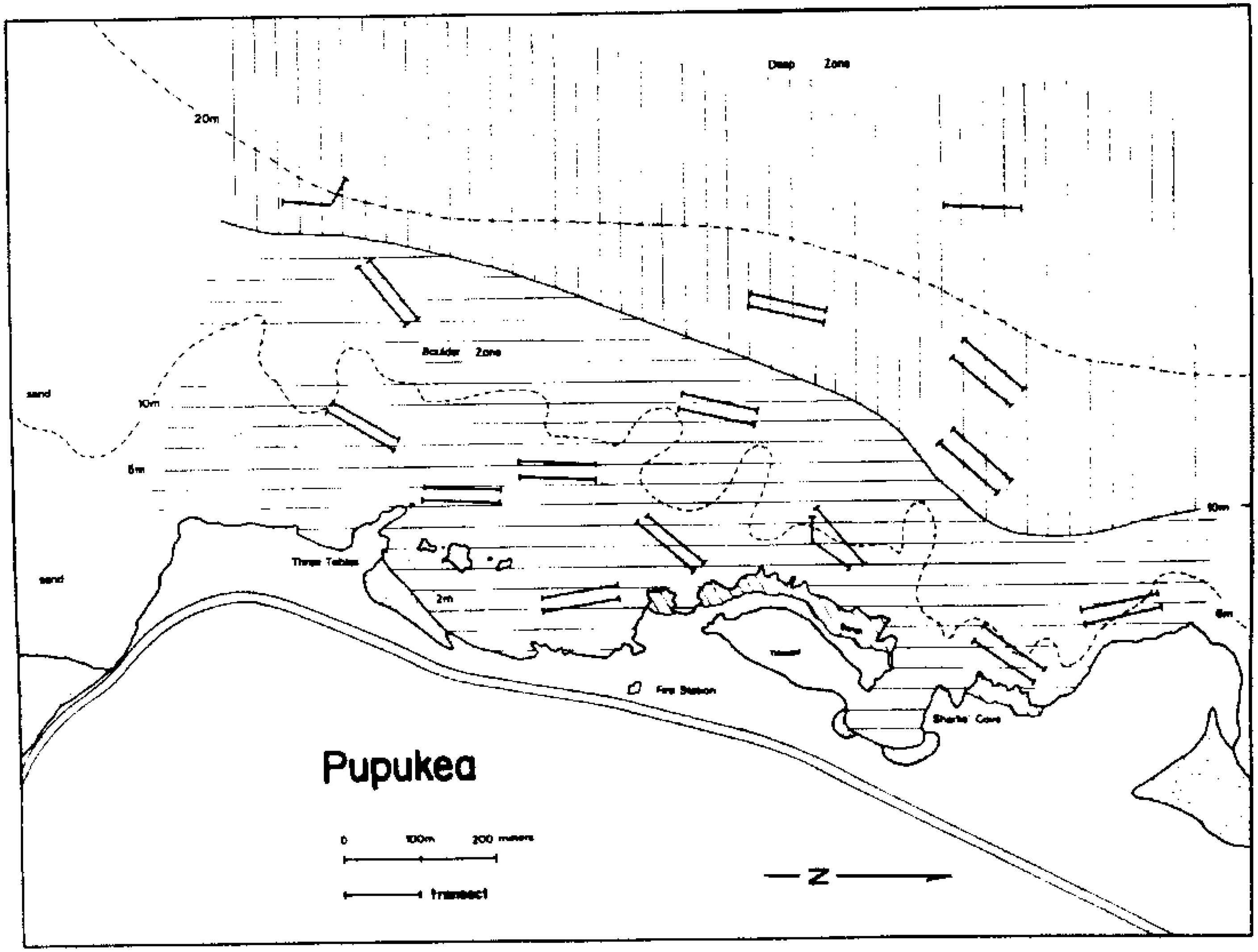


Figure 21. Map of Pupukea area showing transect locations and habitats

TABLE 19. PERCENTAGE OF RELATIVE ABUNDANCE OF THE TEN MOST ABUNDANT FISH SPECIES* FOUND IN HABITATS AT PUPUKEA

Boulder Zone		Deep Zone	
Species	Relative abundance (%)	Species	Relative abundance (%)
Olive damsel	22.3	*Chromis vanderbilti*	15.1
Black damsel	8.7	Olive damsel	12.0
Lemon butterfly fish	7.4	Hinalea lauwili	11.9
Malu	6.2	Lavender tang	7.7
Moana	6.1	Jenkins' damsel	6.0
Lavender tang	5.1	Moana	3.3
Hinalea lauwili	4.9	*Paracirrhites arcatus*	3.2
Fantail filefish	3.7	*Cirrhitops fasciatus*	2.7
Humuhumu umauma lei	2.9	*Apogon snyderi*	2.6
Coris venusta	2.7	*Coris venusta*	2.0

*Common or Hawaiian names are given where possible. See Table 15 for the scientific names of these species.

and the wrasse *Thalassoma duperreyi* also very abundant. The barracuda, *Sphyraena barracuda*, was seen in this area, as were several awa, *Chanos chanos*, and the green sea turtle, *Chelonia mydas*.

From a depth of about 15 m to the outer limits of the study area at around 21 m lies the area referred to as the deep zone. This area differs from the boulder zone in its topography, which is considerably less abrupt. Coral cover in the deep zone was even lower than in the boulder zone, as was the abundance of coralline algae. The reduced amount of shelter has resulted in a lower fish abundance, but fish diversity was nearly as high. The most common fish species were two damselfish, *Chromis ovalis* and *Chromis verater*, which normally stay up in the water column, and the lemon butterfly fish *Chaetodon miliaris*. Invertebrate fauna were similar to those found in the shallower zone.

The caves which lie beneath the boulder zone contain an interesting assemblage of organisms. Although transects were not run in the caves, estimates were made of the relative abundance of the more common species. Few corals were found, the most common species being *Leptoseris incrustans* and the orange corals *Tubastrea aurea* and *Balanophyllia*. Some coralline algae were also found in the caves. Various sponges were abundant, as was the "lace coral," *Triphylozoon hirsutum*, a bryozoan. Common crustacea included the bandana prawn, the spiny lobster *Panulirus* sp., and hermit crabs. The fish were mostly typical cave-dwelling or nocturnal species (Figure 20b), such as the menpachi *Myripristis murdjan*, the ala-'ihi *Adioryx xantherythrus*, and three species of cardinal fish, only two of which were common. The aholehole, *Kuhlia sandvicensis*, appeared to be common only in the shallower caves.

The wave-swept bench outside of the tidepools, while very small, is a distinct habitat from the others. The bench is pockmarked with holes made by the sea urchins *Echinometra mathaei* and *Echinometra mathaei oblonga*, while the shing urchin *Colobocentrotus atratus* occupied spaces further down into the water. The most abundant fish species appeared to be two blennies, *Entomacrodus marmoratus* and *Istiblennius zebra*, the rockskipper.

Within the tidepool area, salinities were found to range as low as 21 parts per thousand (ppt) and as high as 36 ppt. Despite this wide range, numerous fish species manage to survive here. The most common species found were the aholehole, which is euryhaline, and the manini, *Acanthurus triostegus*. Altogether 37 fish species were recorded from this zone. This tidepool, along with the other unusual habitats discussed above, added a certain unique value to the Pupukea area.

Kaneohe Bay, Oahu

Kaneohe Bay, located on the windward coast of Oahu, is the largest protected body of water in the Hawaiian Islands (Figure 22a). A barrier reef across the mouth of the bay has protected the inner bay from much of the effects of trade wind waves and has allowed the growth of numerous patch reefs within the bay (Figure 23). In the Hawaiian Islands, these reefs are unique to Kaneohe Bay.

The Hawaii Institute of Marine Biology is located within the bay. Because of this and because of the apparent deterioration of conditions within the bay, it has been the subject of a number of studies. One of these, the *Atlas of Kaneohe Bay: A Reef Ecosystem Under Stress* (Smith et al., 1973), compares the coral cover on reefs at the north end of the bay, where the water is still relatively clean, with those at the south end, where sewage and silt from overdevelopment near the bay have killed nearly all of the coral.

Several locations in the northern part of the bay have been suggested as potential marine park sites. These are the Kapapa Island area; several patch reefs near the north end of the bay; an area off Kualoa Park; Mokumanu Island; and an area outside the bay near the sampan channel. The last two are actually located outside the bay and do not enjoy the advantages of protection by the barrier reef. Access to Mokumanu, an island off the Mokapu Peninsula, is limited to relatively calm days. This area is also subjected to a very strong current at times. It seemed preferable to select a site with more protection, so this area was dropped from the list. The water just outside the sampan channel is not as rough as in the Mokumanu Island area, but this area has no natural limits in any direction, except for Kapapa Island and the channel buoys. Furthermore, preliminary dives in this area indicated a low coral and fairly low fish abundance, which were substantiated by the Smith et al. (1973) study. Therefore this area was also dropped from the list as unsuitable for use as a marine park. In the Kualoa Park region there are only a few coral reefs, most of which are choked with silt. According to the atlas, this region is low in coral cover and also in fish abundance and diversity. The Kualoa area was therefore also deleted from the list of potential marine park sites.

The Kapapa Island area has been suggested as a marine park site because of its central location within the bay and because the island provides a shelter for boat anchorage. At present, the island is used by fishermen, boaters, and campers for a recreational site. As a beach park, it could serve these users well, particularly if rubbish were removed periodically. The area does not, however, show any promise as a marine park. Smith et al. (1973) found that live coral cover in this region was very low, in nearly every case less than 10 percent and often under 1 percent, while sand covered 5 to 100 percent of the bottom. Fish abundance, while not extremely low at all stations in this region, was not as high as in other areas of the bay. Finally, algal biomass was higher in this area than at most other stations in the bay.

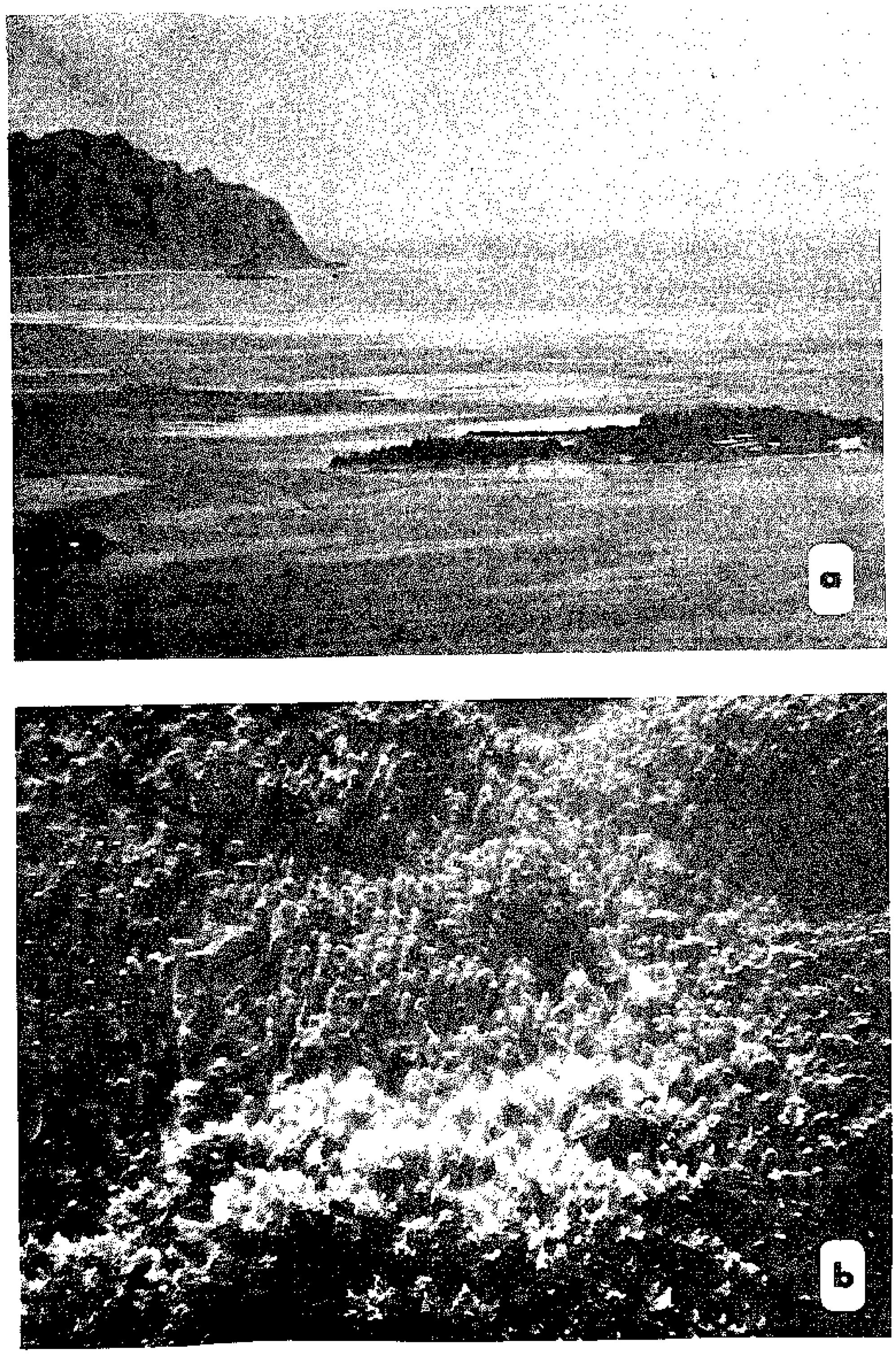


Figure 22. Kaneohe Bay: *a*, view of Coconut Island (foreground) and several patch reefs; *b*, underwater view of coral growth on a patch reef

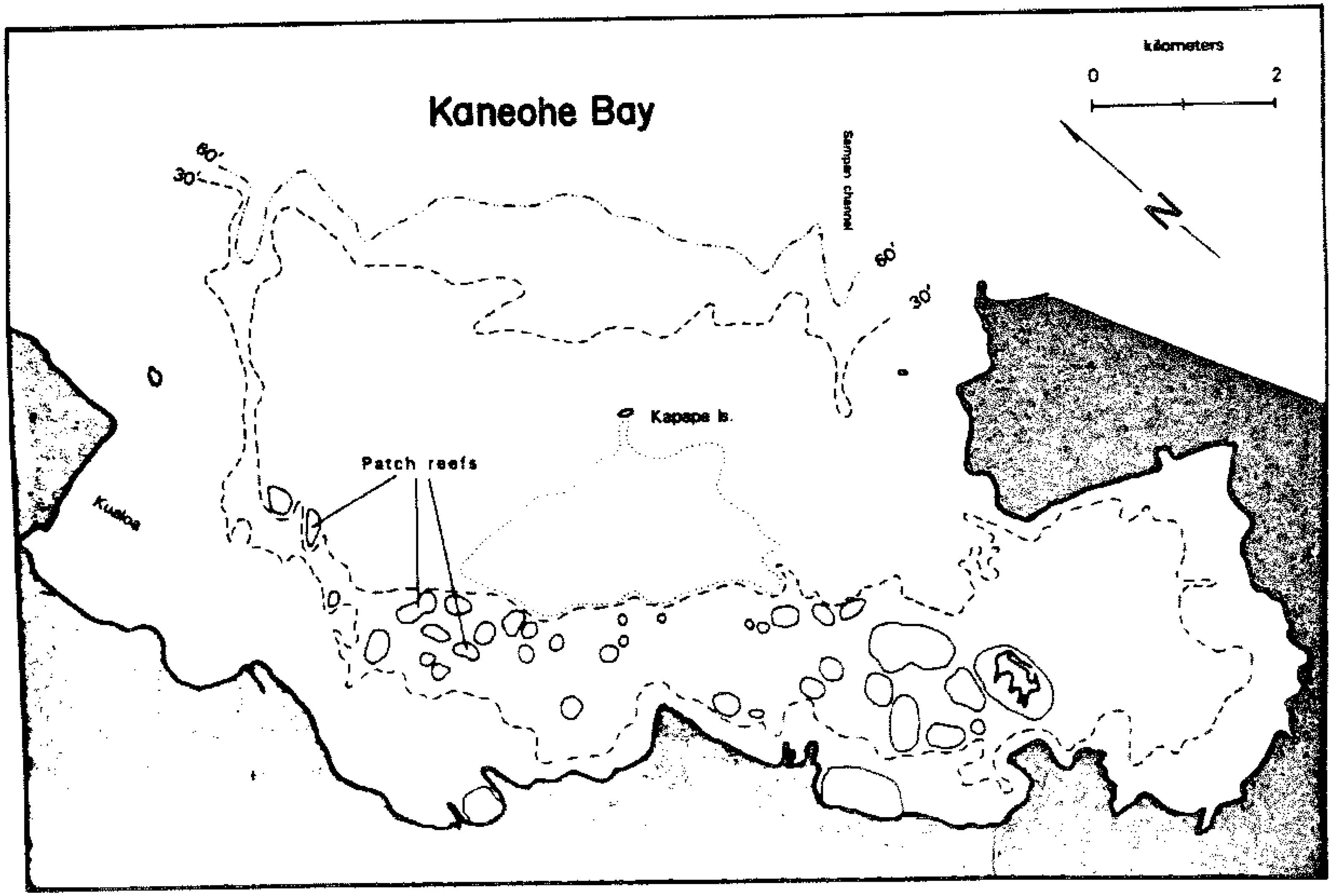


Figure 23. Map of Kaneohe Bay showing patch reefs surveyed. Transect run in the Kapapa Island area was located in the center of the shallow area inshore from the island.

In the present study, only one pair of transects was conducted in the Kapapa Island area (Figure 23). These transects revealed very little live coral, with about half of the bottom covered with sand. Fish abundance was only 158 individuals per 1000 square meters, with but 11 species represented (Table 20). This is lower than even the Hanauma Bay shallow zone. Sixty-five percent of the fish seen were of two wrasse species, *Stethojulis balteata* and *Thalassoma duperreyi*. Invertebrate abundance was high, 475 individuals per 100 square meters, but diversity was low because of heavy dominance by the sea cucumber *Holothuria cinerascens*. Algae appeared to flourish here, with 17 algal species recorded, more than at any other station on Oahu.

TABLE 20. PERCENTAGE OF RELATIVE ABUNDANCE OF FISH SPECIES* FOUND IN HABITATS AT KANEOHE BAY

Patch Reef Edge		Patch Reef Flat		Kapapa Island Area	
Species	Relative abundance (%)	Species	Relative abundance (%)	Species	Relative abundance (%)
Juvenile uhu	25.6	Hinalea lauwili	77.1	'Omaka	43.7
Kole	11.8	'Omaka	6.6	Hinalea lauwili	22.8
Hinalea lauwili	10.5	Manini	2.9	*Thalassoma fuscum*	11.4
Scarus sordidus	9.0	Jenkins' damsel	2.1	Manini	8.9
Yellow tang	5.4			Juvenile uhu	2.0
Jenkins' damsel	5.1				
Bird wrasse	3.8				
Lemon butterfly	3.5				
Blue damsel	3.0				
Mamo	2.8				

*For habitats in which few fish were counted, only those species with five or more individuals are listed. Common or Hawaiian names are given where possible. See Table 15 for the scientific names of these species.

On the whole, the Kapapa Island area can be characterized as a flat, shallow area of very low relief, with a bottom composed primarily of sand and coral rubble and with a high algal standing crop. Although invertebrate abundance was high, diversity was very low, with only 5 species present. Fish abundance and diversity were also low.

The patch reefs, on the other hand, offer an abundance of coral and fish. Well protected from ocean swells by the barrier reef, these patch reefs have grown in a roughly circular form, with extremely dense coral on the outer edge (Figure 22b). The inner reef flats have less coral and more sand and rubble.

Although the entire bay is dotted with patch reefs, three reefs toward the northern end of the bay were selected for study; these reefs were along the main channel next to buoys 11, 13, and 15. This selection was made because these reefs are far enough north to be only slightly affected by the sewage in the southern sector, but not so far that they come under the influence of ocean swells through the northern channel.

The patch reefs are, of course, accessible only by boat, but water conditions are such that boating in the bay usually presents no hazard. Also, there is a launching ramp only 4 km away at Heeia. The reef tops are shallow enough for snorkeling, but a SCUBA diver has an advantage in being able to go further down the reef slope.

The reef flats and the slope are two entirely separate habitats. In the present study, only two transects were run in the reef flat area. Coral cover was found to be low, with most of the bottom covered with dead coral and coral rubble. Macroinvertebrates were moderately abundant, with the sea urchins *Echinometra mathaei*, *Echinothrix* sp. (wana), and *Tripneustes gratilla* being the most common. Fish abundance and diversity were low, reflecting the lack of shelter. The saddleback wrasse, *Thalassoma duperreyi*, made up 77 percent of the fish seen. This contrasts with the 1973 study in which a high relative abundance of juvenile scarids (uhu) occurred. These fish were seen off the transect line in large schools and it is likely that a larger number of samples in this zone would have indicated a higher relative abundance of juvenile scarids.

The reef face presents an interesting contrast to the reef flat. This narrow belt, which is the zone of the active coral growth, rings the patch reef with dense coral dominated by *Porites compressa*, the finger coral. The slope is quite steep from 2 to 3 m down to about 10 m, where this live coral gives way to dead coral covered with a thick layer of silt. According to Maragos (1972), this zone has an average live coral cover of about 75 percent. Smith et al. (1973) reported a fish abundance greater than 100 per station, which equates to over 830 individuals per 1000 square meters. They also reported that the algae were dominated by *Dictyosphaeria cavernosa*, the "bubble alga." In the present study, the same conditions were observed. Coral cover varied from 28 percent on the relatively impoverished deeper portions of the leeward slopes to 95 percent on the windward slopes higher up on the reef. This was by far the highest coral cover on Oahu. Coral was heavily dominated by *P. compressa*, with *Montipora verrucosa* and *M. verrilli* present in low quantities. The solitary coral *Fungia scutaria* was found in large numbers predominantly in the upper portions of the reef slope. Macroinvertebrates were not overly common in this habitat. The fish fauna, however, were quite rich, with a median value of 1065 fish per 1000 square meters. Diversity was not particularly high. The fish most commonly seen were juvenile scarids, with the kole and the saddleback wrasse, *T. duperreyi*, also abundant. Fish in this zone appeared quite colorful; common species included the yellow tang, *Zebrasoma flavescens*, the moorish idol, *Zanclus cornutus*, and several species of butterfly fish. *Chaetodon trifasciatus* was seen in greater abundance here than in any other Oahu habitats and this was the only place on Oahu where the rare species *C. lineolatus* was seen.

Visibility on the patch reefs was poor, never exceeding 9 m; this made the fish transects difficult because the fish were continually moving and were not easy to identify. The turbidity is caused by sewage, which stimulates phytoplankton growth to the point where the water has a greenish hue, and by suspended silt. Although the sewage outfall is scheduled to be moved outside of the bay, sedimentation is likely to continue increasing. The watershed around Kaneohe Bay is an area of high rainfall, up to 175 inches per year at the base of the Koolau mountain range. Where residential development has occurred, exposed ground and channelized streams produce a huge silt load during rainstorms. This is especially noticeable at the more heavily developed southern end of the bay; however, much more development of the northern end is expected to follow the completion of the third trans-Koolau highway in the late 1970's. As previously noted, even the relatively robust patch reefs are suffering from sediments on their lower slopes. (See Maragos, 1972 for a discussion of the effects of sediment on reef corals.) The future survival of these reefs therefore appears uncertain.

Kealakekua Bay, Hawaii

Kealakekua Bay, Hawaii's marine conservation district, is located in the South Kona District of the island of Hawaii (Figure 24a). The marine conservation district is divided into two zones. The removal of marine organisms is prohibited in the first zone, which is that area north of a line connecting a benchmark near the parking lot at Napoopoo with a point near the Captain Cook monument. This area includes most of the reef, which lies along the north edge of the bay. Much of the rest of the bay has a sandy bottom, including the second zone, which is open to limited consumptive uses such as pole and throw-net fishing.

The study area was restricted to the northern part of the bay along the reef. A steep cliff runs along the shore in this area, preventing access to the reef directly from shore. A swim of about 200 m is required to reach the reef from the closest accessible point on the shore. To reach the spectacular reef area near the monument would require a swim of about 1600 m. As a result, few go there except by boat. The area is ideally suited for boating, however, as the water is nearly always calm and there is a small pier near the Captain Cook monument. Divers and snorkelers frequently tie their small boats there and explore the reef in the vicinity of the pier. The small cove near the pier is also visited daily by glass-bottom boats, which transport tourists from Kailua-Kona to view the marine life.

All three habitats at Kealakekua Bay are narrow (Figure 25), especially the inshore habitat, which all but disappears at some points along the shore. The outer reef area slopes very steeply, as much as 45 degrees in places, down to about 33 m, at which point there is a fairly abrupt transition to sandy bottom.

The biota of Kealakekua Bay (Table 21) showed greater similarity between habitats than the other Hawaii sites, probably because the habitats are so narrow. The macroinvertebrates of all three habitats were dominated by the slate pencil urchin, *Heterocentrotus mammillatus*. Two species of surgeonfish, the kole, *Ctenochaetus strigosus*, and the yellow tang, *Zebrasoma flavescens*, together accounted for over 40 percent of the fish in all three habitats (Figure 24b). Many other species that were common in one habitat were also common in the other two.

Fish more common in the inshore area included the raccoon butterfly fish, *Chaetodon lunula*, the lavender tang, *Acanthurus nigrofuscus*, and the damselfish, *Eupomacentrus jenkinsi*. The black damselfish, *Chromis verater*, common in deeper waters, was not seen here.

The mid-reef zone included most of the area just off the Captain Cook monument. Here the fish appeared very tame, probably because of feeding by visitors on the glass-bottom boats. Large schools of nenue, *Kyphosus cinerascens*, were seen in this area.

The portion of the outer reef just off the monument is the part with the steepest slope. Along this slope are numerous plates of the coral *Psammocora*

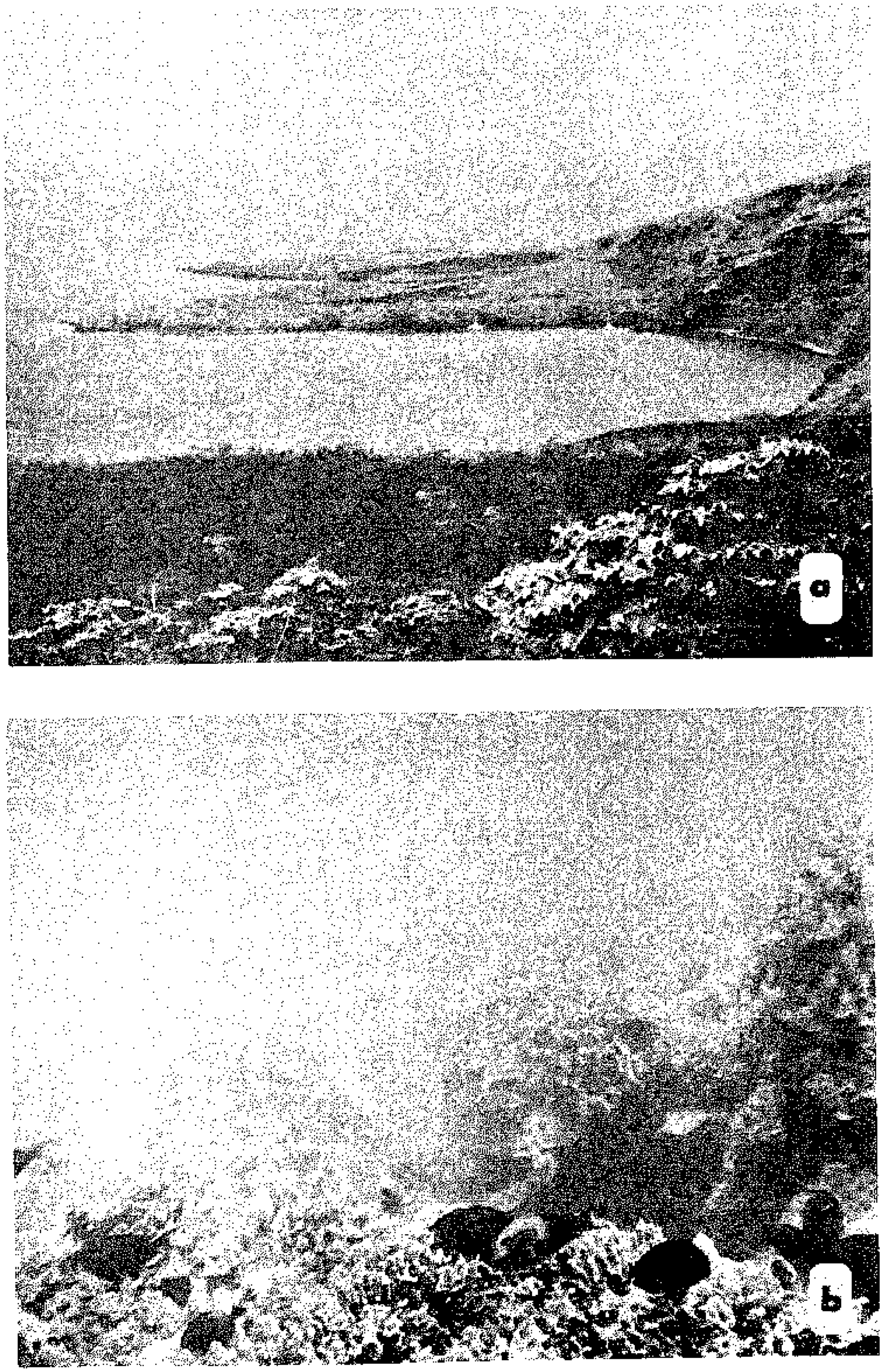


Figure 24. Kealakekua Bay: *a*, view of shoreline; *b*, underwater view of surgeonfishes swimming among coral

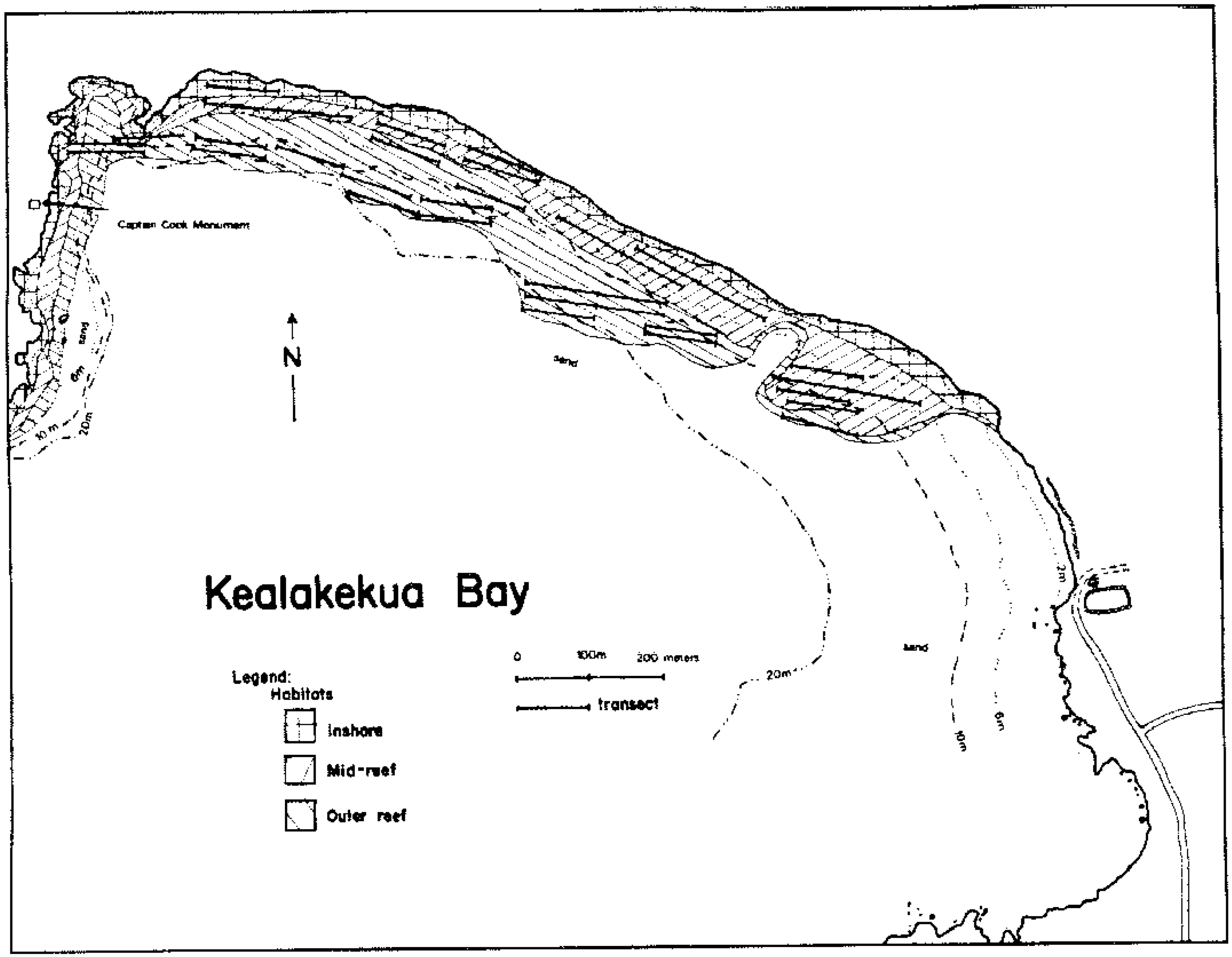


Figure 25. Map of Kealakekua Bay showing transect locations and the inshore, mid-reef, and outer reef habitats

TABLE 21. PERCENTAGE OF RELATIVE ABUNDANCE OF THE TEN MOST COMMON FISH SPECIES* FOUND IN HABITATS AT KEALAKEKUA BAY

Inshore Zone		Mid-reef		Outer Reef	
Species	Relative abundance (%)	Species	Relative abundance (%)	Species	Relative abundance (%)
Kole	24.1	Kole	28.6	Kole	22.7
Yellow tang	19.9	Yellow tang	18.0	Yellow tang	19.4
Lavender tang	10.5	*Chromis agilis*	11.9	*Chromis agilis*	16.3
Hinalea lauwili	8.4	Pebbled butterfly	7.9	Black damsel	6.7
Jenkins' damsel	7.3	Hinalea lauwili	6.7	Pebbled butterfly	5.5
Pebbled butterfly	6.1	*Chromis hanui*	2.8	Hinalea lauwili	5.0
Chromis agilis	2.4	Potter's angel	2.2	Potter's angel	2.2
Maiko	2.3	Black damsel	1.9	Weke-'ula	1.8
Paracirrhites arcatus	1.4	Lavender tang	1.9	Kala	1.6
Achilles tang	1.4	Ornated butterfly	1.5	Long-nosed butterfly	1.6

*Common or Hawaiian names are given where possible. See Table 15 for the scientific names of these species.

verrilli, which was seen here in greater abundance than at any other site. This region is also apparently the home range for a large school of the barracuda *Sphyraena helleri*. The moorish idol, *Zanclus cornutus*, and the uhu, *Scarus taeniourus*, were seen in greater abundance in the outer reef habitat at Kealakekua Bay than elsewhere.

Schools of pualu, *Acanthurus xanthopterus*, were seen in all three zones. Porpoises frequented the open waters of the bay and garden eels of the genus *Gorgasia* were found in the sandy area at a depth of 15 m.

Koaie Cove, Hawaii

Koaie Cove, in the North Kohala District of Hawaii, is located offshore from Lapakahi State Park just south of Mahukona (Figure 26a). In this park is an ancient Hawaiian fishing village which is being restored as a historical site. The study area extends from the shoreline within the cove to the edge of the reef at about 30-m depth. The shoreline here consists of pahoehoe and a'a lava with a few small pebble beaches; there are no sandy beaches at Koaie Cove. The bottom in this area slopes gently from the shore to the outer edge of the reef.

Koaie Cove had the highest fish abundance of all sites studied, with a median value of 1624 per 1000 square meters in the mid-reef habitat (Figure 27 and Table 22). Even the inshore habitat (Figure 27), typically the least prolific, had more fish than any habitat at any other site, although diversity was low. The lavender tang, *Acanthurus nigrofuscus*, the damselfish *Chromis vanderbilti*, and the kole were the three most abundant fish species. The rare butterfly fish *Chaetodon reticulatus* was seen in this zone, but not on a transect.

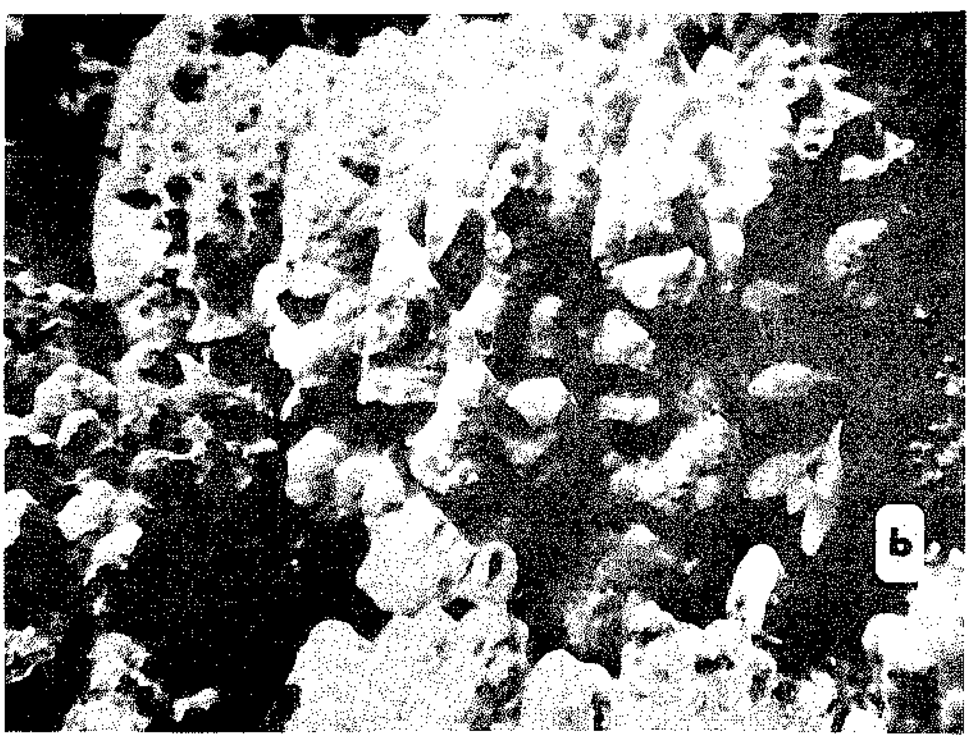


Figure 26. Koaie Cove: *a*, shoreline area looking south from the lighthouse; *b*, underwater view of *Porites* coral and butterfly fish

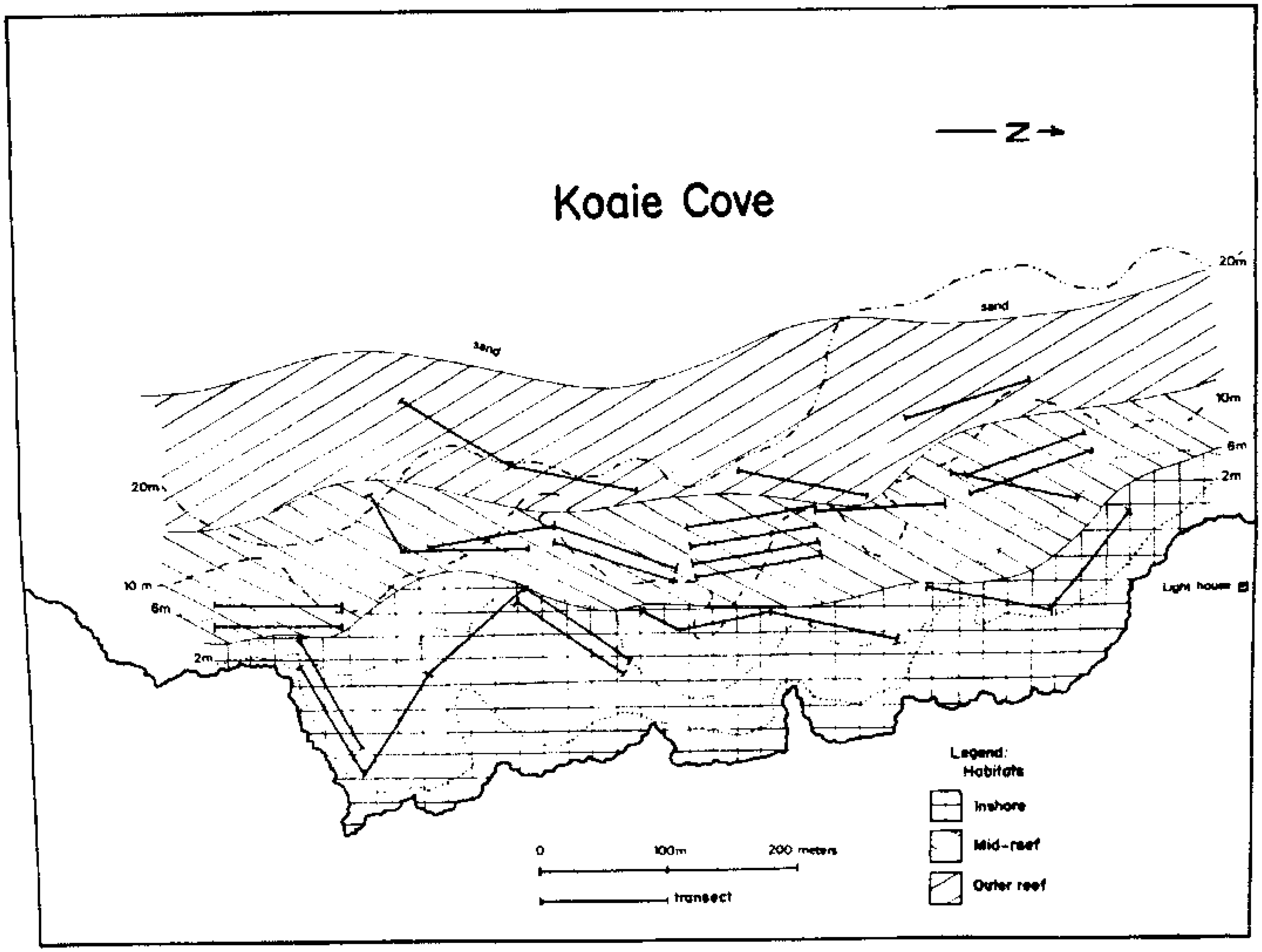


Figure 27. Map of Koaie Cove showing transect locations and the inshore, mid-reef, and outer reef habitats

TABLE 22. PERCENTAGE OF RELATIVE ABUNDANCE OF THE TEN MOST COMMON FISH SPECIES* FOUND IN HABITATS AT KOAIE COVE

Inshore Zone		Mid-reef		Outer Reef	
Species	Relative abundance (%)	Species	Relative abundance (%)	Species	Relative abundance (%)
Lavender tang	27.6	Kole	19.9	*Chromis agilis*	22.3
Chromis vanderbilti	18.9	*Chromis vanderbilti*	12.9	Kole	17.1
Kole	14.2	Lavender tang	8.9	*Chromis hanui*	10.3
Hinalea lauwili	8.8	Yellow tang	8.8	Hinalea lauwili	7.5
Yellow tang	8.1	*Chromis hanui*	8.0	Black damsel	7.5
Jenkins' damsel	4.0	*Chromis agilis*	5.9	Pyramid butterfly	4.0
Pebbled butterfly	2.4	Hinalea lauwili	4.7	Pebbled butterfly	3.6
Humuhumu umauma lei	1.9	Pebbled butterfly	4.3	Potter's angel	2.7
Olive tang	1.3	Black damsel	3.4	Weke-'ula	2.5
Moana	1.1	Jenkins' damsel	2.5	Menpachi	2.5

*Common or Hawaiian names are given where possible. See Table 15 for the scientific names of these species.

In the mid-reef habitat the three most abundant fish species were the same as in the inshore area, but fish abundance and diversity were both higher than inshore. The eagle ray, *Aetobatus narinari*, was seen on a transect in this zone, as were 14 species of butterfly fish (Figure 26b).

The outer reef habitat (Figure 27) was close to the mid-reef in fish abundance and had the highest median fish biomass of all of the habitats surveyed. This was due in part to the high abundance of the weke-'ula, *Mulloidichthys vanicolensis*, and three species of kala, *Naso lituratus*, *N. brevirostris*, and *N. hexacanthus* (opelu kala). This area also had large schools of the butterfly fish *Hemitaurichthys polylepis*.

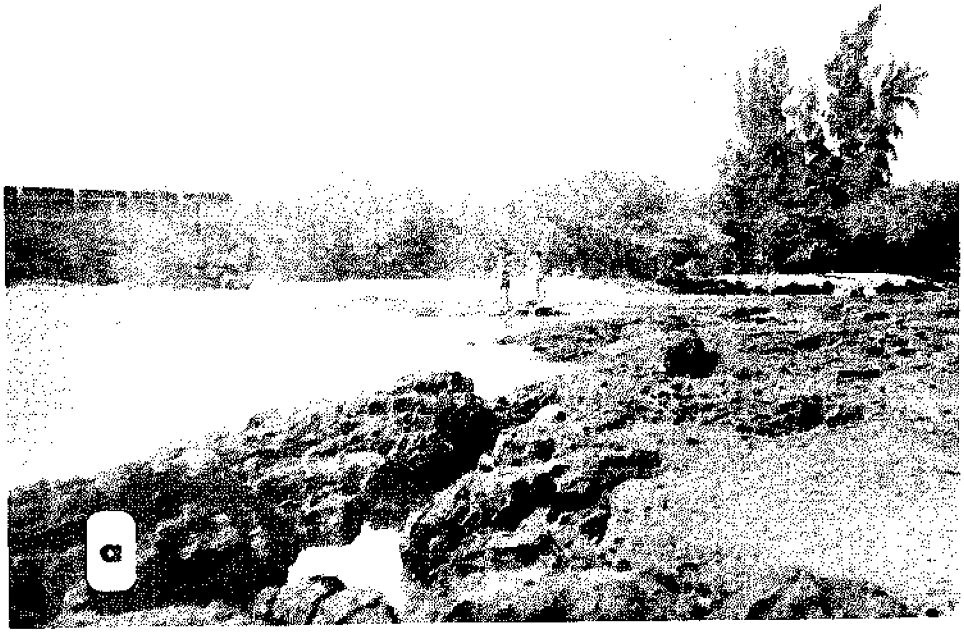
In the sand beyond the outer reef at a depth of about 40 m, numerous garden eels were seen. The manta ray, *Mobula japonica*, was seen in the reef area, as was the awa, *Chanos chanos*.

Puako, Hawaii

The Puako area (Figure 28 and 29), located south of Kawaihae, is a popular site among snorkelers and divers. The area included in the study extends from Puako Point south about 1.4 km. This portion of the shoreline adjoins a residential district and there are no public parks or facilities on the shoreline. The only public access to the shore is through four rights-of-way. The shoreline in this area consists of pahoehoe lava with several tide-pools and a few small sand beaches.

Bottom topography at Puako differs somewhat from the other Hawaii sites, in that the inshore area is shallower and ends in a sharp break or cliff which drops to 10 m. Beyond this point the slope of the reef is more gradual.

Visibility was fairly low in the inshore area, mainly because of a fresh-water lens on the surface. Coral cover in this zone was relatively low, as



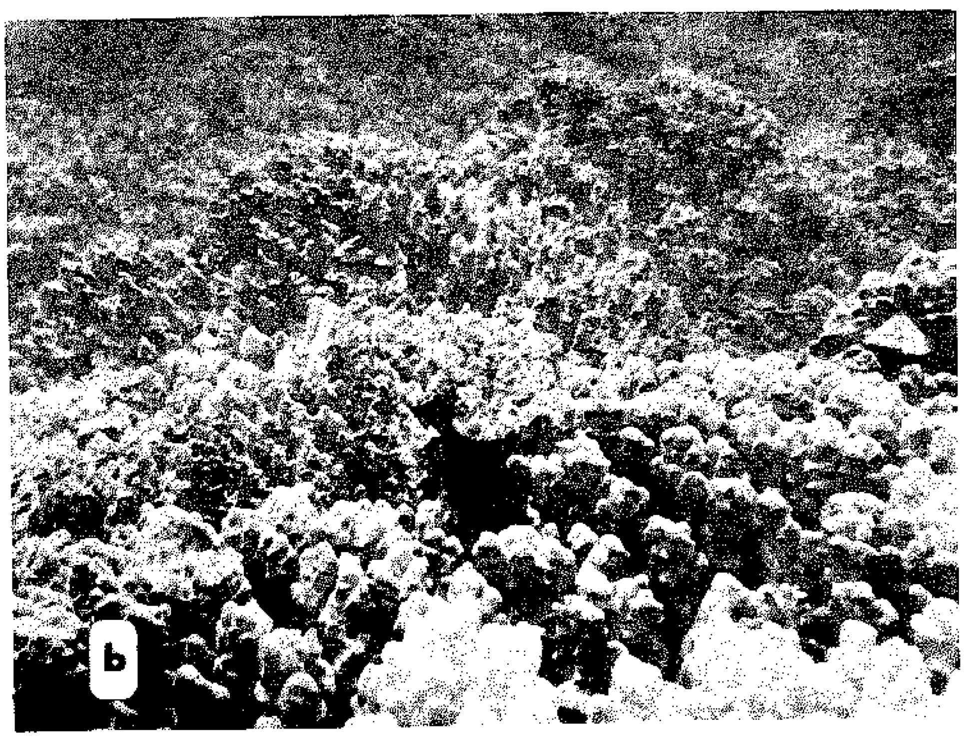


Figure 28. Puako: *a*, part of shoreline area; *b*, underwater view of triggerfish (*Melichthys niger*) entering nest among coral

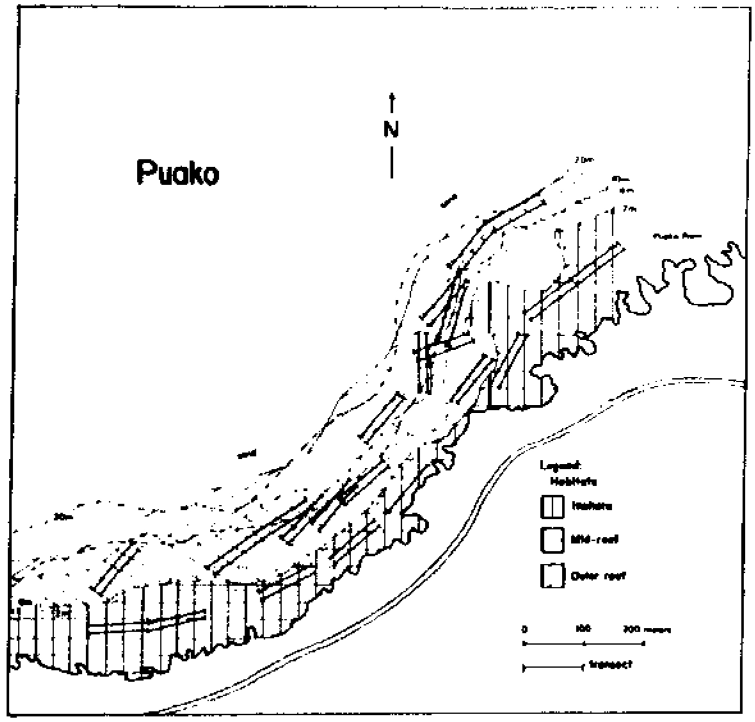


Figure 29. Map of Puako area showing transect locations and the inshore, mid-reef, and outer reef habitats

were fish abundance and diversity (Table 23). The species composition of fish seen in this area was somewhat different from that of the other inshore areas. The saddleback wrasse, *Thalassoma duperreyi*, was nearly twice as abundant as the next most common fish, *Acanthurus nigrofuscus*. The 'omaka or wrasse, *Stethojulis balteata*, was very common here as well. The inshore habitat had the greatest number of macroinvertebrates of any habitat; 78 percent of these were the urchin *Echinometra mathaei*.

Between the inshore and mid-reef zones are numerous cliffs about 5 to 10 m high, with large caves and arches which can be quite spectacular. Lobsters were often seen here, as were cave-dwelling fish such as the menpachi, *Myripristis murdjan*, and the aweoweo, *Priacanthus cruentatus*.

The mid-reef zone had the highest median coral cover of any of the habitats studied. Fish abundance was about the same as in the inshore zone, but the diversity was greater. The five most abundant fish were the same as in the Kealakekua Bay mid-reef zone. In this area, seven species of adult scarid (uhu) were seen, some of which were moderately abundant. The file fish *Alutera scripta* was also seen in this zone.

The fish seen in the outer reef area were very similar to those in the mid-reef zone. The five most abundant species were the same and were present in both zones in nearly the same numbers. Thirteen species of butterfly fish were found in this habitat. Also seen here were eagle rays, *Aetobatus narinari*, and green sea turtles, *Chelonia mydas*.

TABLE 23. PERCENTAGE OF RELATIVE ABUNDANCE OF THE TEN MOST COMMON FISH SPECIES* FOUND IN HABITATS AT PUAKO

Inshore Zone		Mid-reef		Outer Reef	
Species	Relative abundance (%)	Species	Relative abundance (%)	Species	Relative abundance (%)
Hinalea lauwili	31.6	Kole	24.8	Kole	24.1
Lavender tang	17.2	Yellow tang	12.7	Yellow tang	10.1
'Omaka	13.8	*Chromis agilis*	6.6	*Chromis agilis*	8.0
Jenkins' damsel	8.1	Hinalea lauwili	5.5	Hinalea lauwili	3.6
Bird wrasse	6.1	Pebbled butterfly	3.8	Pebbled butterfly	3.2
Paracirrhites arcatus	3.3	Bird wrasse	3.6	Kala	2.9
Manini	1.9	Kala	2.9	Potter's angel	2.6
Kole	1.7	Potter's angel	2.8	*Chromis hanui*	2.5
Achilles tang	1.6	*Chromis hanui*	2.1	Menpachi	2.4
Chromis vanderbilti	1.3	Blue damsel	2.0	Achilles tang	2.1

*Common or Hawaiian names are given where possible. See Table 15 for the scientific names of these species.

The sandy area beyond the reef at Puako is also populated by numerous garden eels, *Gorgasia* sp.

Honaunau Bay, Hawaii

Honaunau Bay is located 6 km south of Kealakekua Bay in the South Kona District of Hawaii (Figures 30 and 31). Adjacent to the bay is the City of Refuge National Park, a restored Hawaiian historical site which receives about 30,000 visitors per month. The park is on the left side of the bay, while on the right there is a small residential area. Between this area and the park is a boat ramp which is used by local residents for fishing and boating.

The shoreline is composed of pahoehoe lava, with one small sand beach within the park boundaries. Access to the water is excellent in the boat ramp area and from a low ledge on the left side of the bay. The reef extends approximately 100 m from shore, sloping gradually to a depth of 25 m on the left side. On the right, the reef is approximately 40 m wide and ends in a near-vertical drop to 25 m.

The biota of Honaunau Bay (Table 24) were very similar to those of nearby Kealakekua Bay. The kole and the yellow tang were abundant in all three habitats. The five most abundant fish in the inshore and mid-reef zones were the same as at Kealakekua Bay, with only a slight difference in the order. The three most abundant fish in the outer reef were the same as at Kealakekua Bay, but at Honaunau Bay the damselfish *Chromis agilis*, comprising over 30 percent of the total fish seen in that habitat, was the most abundant of the three.

The coral *Psammocora verrilli* was found in moderate abundance in the outer reef habitat. As at Kealakekua Bay, it occurred in a plate-like form on the steeper slopes under which were caves with large schools of menpachi, *Myripristis murdjan*.

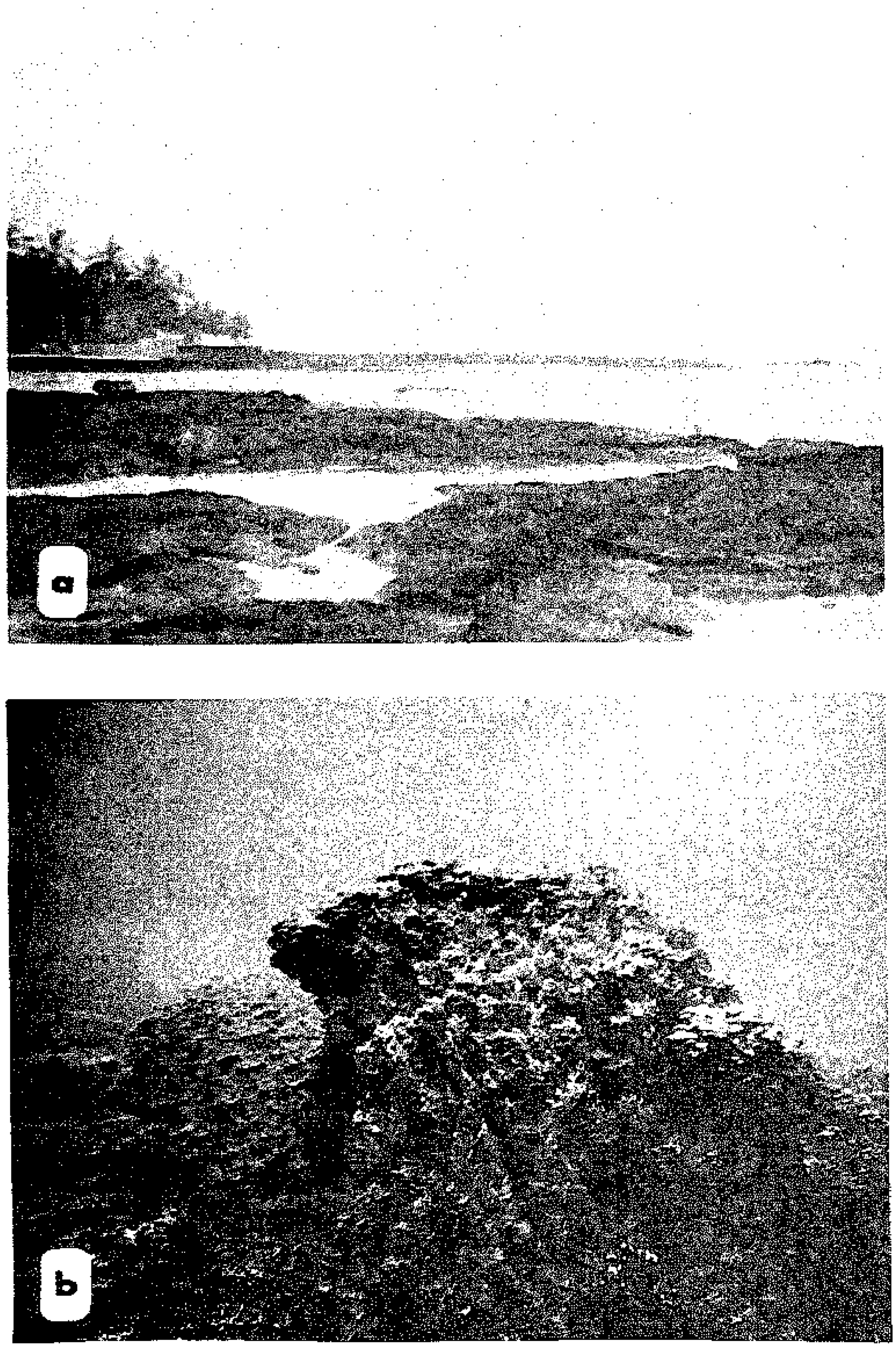


Figure 30. Honaunau Bay: *a*, shoreline area looking south; *b*, underwater view of coral head

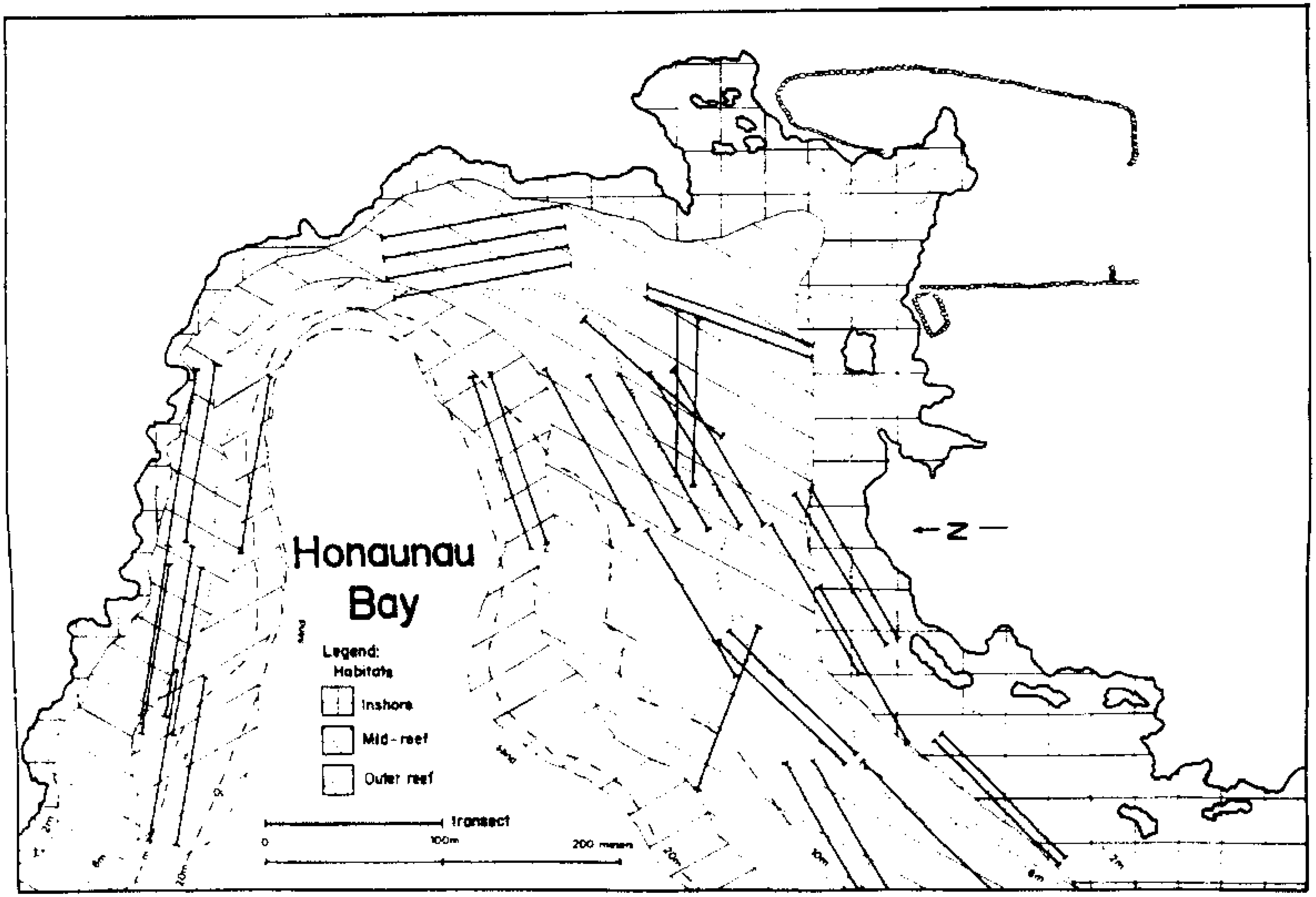


Figure 31. Map of Honaunau Bay showing transect locations and the inshore, mid-reef, and outer reef habitats

TABLE 24. PERCENTAGE OF RELATIVE ABUNDANCE OF THE TEN MOST COMMON FISH SPECIES* FOUND IN HABITATS AT HONAUNAU BAY

Inshore Zone		Mid-reef		Outer Reef	
Species	Relative abundance (%)	Species	Relative abundance (%)	Species	Relative abundance (%)
Lavender tang	19.3	Kole	25.2	*Chromis agilis*	30.7
Kole	16.1	*Chromis agilis*	19.9	Kole	19.3
Yellow tang	11.7	Yellow tang	18.0	Yellow tang	18.1
Hinalea lauwili	9.9	Pebbled butterfly	6.6	*Acanthurus thompsoni*	5.6
Jenkins' damsel	6.6	Hinalea lauwili	3.3	Pebbled butterfly	4.1
'Omaka	5.0	Blue damsel	2.3	Black damsel	3.2
Pebbled butterfly	3.5	Potter's angel	2.3	Hinalea lauwili	2.6
Chromis vanderbilti	3.2	*Chromis hanui*	2.2	Kala	2.4
Achilles tang	2.6	Lavender tang	1.8	*Scarus sordidus*	1.7
P. imparipennis	2.6	Black damsel	1.7	Potter's angel	1.5

*Common or Hawaiian names are given where possible. See Table 15 for the scientific names of these species.

The invertebrates of Honaunau Bay were similar to those found at Kealakekua Bay except that the slate pencil urchin, *Heterocentrotus mammillatus*, was not as abundant.

DISCUSSION

A significant positive correlation (r = .56) was found between coral cover and fish abundance only in the Kahe data. At other sites, the coral reef habitats generally had more fish than the habitats with lower coral cover, but the data scatter obscured any relationship between transects. It seems likely that, in the Kahe data, coral cover is a dummy variable for habitat complexity or shelter availability. This would explain why the Oahu *P. compressa* reefs had higher fish abundances than most other areas since the interlocking fingers of coral provide shelter for a large standing stock of fish. The increase of fish standing stock with an increase in habitat complexity has been well documented for artificial reefs (e.g., McVey, 1971).

A few indications of the effects of fishing pressure on fish populations were observed. The wary behavior of the adult scarids at Pupukea is one example; another is the greater abundance of scarids and carangids at Hanauma Bay and Makapuu than at the more heavily fished areas. However, the Kahe *P. compressa* reef and the Kaneohe Bay patch reefs, which are subjected to some fishing pressure, had as many fish as the most densely populated habitats at Makapuu or Hanauma Bay. It therefore appears that the total removal of such pressure may not increase the abundance of fish at these sites, although it may shift the species composition somewhat.

At Puako, the most heavily fished site on Hawaii, the fish populations were smaller than at the other sites on that island. The species composition, however, was not much different than at the other sites. In fact, those species most likely to be removed by human predation, such as carangids, scarids, and butterfly fish, were fairly abundant in the reef habitats at Puako. Only in the inshore habitat did the species composition differ greatly from the other sites. The cause of the reduced fish abundance at Puako is thus a matter of speculation and it is impossible to predict what will happen to the fish populations of areas in which consumptive use is halted.

Table 25 summarizes the ranks assigned to each site for each criterion. For the biological criteria, it also gives site rankings for the inshore, mid-reef, and outer reef habitats of Hawaii, and the inshore, largest offshore and "best" habitats on Oahu. No attempt is made to obtain an overall ranking of the sites because of the subjective differences in importance of the various criteria.

TABLE 25. SUMMARY OF SITE RANKINGS* WITH RESPECT TO EACH CRITERION AND FOR THE COMBINED BIOLOGICAL CRITERIA IN EACH HABITAT CATEGORY

Criterion	Oahu Sites				Hawaii Sites			
	Hanauma Bay	Kahe	Makapuu	Pupukea	Kealakekua Bay	Koaie Cove	Puako	Honaunau Bay
Geographic								
Definability	4	1	3	2	2	3	1	4
Access to shoreline	2.5 (1.5)**	1 (3.5)	2.5 (1.5)	4 (3.5)	3	1	2	4
Access to dive sites	2.5	2.5	1	4	1	3	3	3
Adjacent land use	3.5	1 (1.5)	3.5	2 (1.5)	2.5	4	1	2.5
Oceanographic								
Exposure to seasonal surf	3.5	3.5	2	1	2.5	2.5	2.5	2.5
Exposure to trade winds	2	4	1	3	3.5	1.5	1.5	3.5
Current strength	3	2	1	4	3.5	1.5	1.5	3.5
Underwater visibility	1.5	1.5	4	3	1.5	3	1.5	4
Biologic								
Fish abundance	1.5	3.5	3.5	1.5	2	3.5	1	3.5
Fish species counts	1	3	2	4	2	4	1	3
Fish diversity index	1	2.5	2.5	4	2	3.5	3.5	1
Percentage of coral cover	3	4	2	1	3.5	1.5	3.5	1.5
Coral diversity index	1	3	3	3	3.5	1	3.5	2
Macroinvertebrate abundance	2	2	4	2	4	2.5	2.5	1
Macroinvertebrate diversity index	3	3	2	1	1	4	2	3
Habitat Category								
Inshore	1	3	2	4	3	3	1	3
Mid-reef					2	4	2	2
Outer reef					2	4	2	2
Largest offshore	2.5	2.5	4	1				
"Best"	2.5	4	2.5	1				

*A rank index of 4 is assigned the best or most suitable site and 1 to the least suitable.
**Ranking in parenthesis would apply if the Kahe site were made into a beach park.

On Oahu, Hanauma Bay emerged surprisingly low in the biological category. Even in fish abundance, Oahu's existing marine conservation district did not fare well, although Hanauma Bay's fish population has probably increased since the marine conservation district was established. The impoverished inshore zone, coupled with some areas of low fish abundance offshore, gives Hanauma Bay an overall low rating in this category. The other sites are roughly equal, although the habitat with the highest fish abundance at Pupukea has fewer fish than the best habitats at the other sites. In fish diversity and number of species per transect, Kahe had the habitat with the highest values, but this was in the deep zone which is far from shore. If this habitat were excluded from the ranking, then Kahe would be ranked equal with Hanauma Bay in diversity index and fish species per transect. The Pupukea boulder zone is the most diverse of the habitats readily accessible from shore. The ranking of Hanauma Bay for coral cover is also low due to the low coral cover in the inshore zone. Kahe has much more live coral in those areas closest to shore, although coral cover in the offshore finger coral reefs is higher at Hanauma Bay. Coral cover at Makapuu and Pupukea is much less than at Hanauma Bay, but diversity is higher. It is a matter of individual judgment whether an area of dense coral growth is more attractive than an area of many different kinds of coral. From a conservation standpoint, both would appear to be valuable. Invertebrate abundance and diversity did not show much variation between sites and furthermore may be misleading. The areas which had high numbers of macroinvertebrates showed a fairly high degree of dominance by a few sea urchins, most notably *Tripneustes gratilla*, which is not a particularly attractive species. Pupukea, where invertebrate abundance was fairly low, had large numbers of the bandana prawn, *Stenopus hispidus*, which seems more interesting for viewing than most sea urchins. This site had a unique assortment of invertebrate animals, but uniqueness is not readily measurable and was not included in the list of criteria.

Overall, it appears that all of the Oahu sites were superior to Hanauma Bay with respect to at least some of the biological criteria. The same was true on Hawaii. Both Koaie Cove and Honaunau Bay had a higher fish abundance than Kealakekua Bay, in spite of the ban on fishing along the reef in the marine conservation district. Puako was ranked equal with Kealakekua Bay in coral cover and diversity, but coral cover in the Puako outer reef zone was higher than in any Kealakekua habitat.

For the geographic criteria, Hanauma Bay, Makapuu, and Pupukea are not much different overall. Although Hanauma Bay is far superior in definability, the access into this site is more tedious than at Makapuu or Pupukea. As shown in Table 25, these rankings would change if Kahe were to become a beach park. In this case, Kahe would not lag much behind the other sites.

On Hawaii, Koaie Cove and Honaunau Bay both ranked higher than Kealakekua Bay with respect to some of the geographic criteria. Only Puako, with its poor definability and with the residential area adjacent to the shore, appears to be less suitable than the other sites from a geographic standpoint.

The suitability of the sites from the standpoint of diving comfort and safety was approached using the four oceanographic criteria. Oahu sites showed considerable variation. Makapuu had an overall poor rating except in visibility, while Pupukea was ranked consistently high except for exposure to seasonal surf. In other words, this site affords excellent diving conditions during the summer only. Hanauma Bay and Kahe could be ranked somewhere in the middle overall, but these sites can be used for recreational diving nearly the entire year.

Although the ranking for Hawaii sites shows some differences in their physical oceanography, these differences are in fact slight. Currents, wind, and waves, while more noticeable at Koaie Cove and Puako, do not present the hazard that they do at Makapuu or even Hanauma Bay. Visibility values did show significant variation, but in all cases provided sufficient water clarity for comfortable viewing of marine life.

CONCLUSIONS AND RECOMMENDATIONS

The recommendations made here are based upon the criteria listed in the site selection section. As discussed in that section, this list is obtained subjectively and is not quite complete. Furthermore, these criteria emphasize both the conservation and recreational aspects of the sites and are not really suited for a choice of sites for a natural area reserve in which recreational use is not desired. The acceptance of these conclusions must therefore be based upon the premise that these criteria are essentially the correct ones to apply.

The public opinion surveys showed that many more people favored than opposed the establishment of more marine conservation districts. Although there was some bias inherent in the methods used in the surveys, the results of the two different approaches--questionnaire and interview--corroborated each other remarkably well. It is probably safe to assume that these results approximate the opinions of Oahu and Hawaii residents reasonably well. The site preferences listed by respondents to the questionnaires and interviews were not as useful and were not used in the final choice of sites.

The on-site studies of geographic, oceanographic, and biological factors showed that all of the sites possess qualities that would make them useful as marine conservation districts or parks. There are, however, enough differences among sites to allow a choice of the most desirable locations.

On Oahu, Pupukea, Makapuu, and Kahe all surpassed Hanauma Bay in a comparison of biological characteristics. All three were ranked higher than Hanauma Bay in fish abundance and fish and coral diversity. These three sites were not much different from each other overall. Kahe had the greatest coral cover, but Pupukea had the highest diversity of fish. In fish abundance and coral diversity, all three were ranked the same. In order to make a selection, then, it was necessary to use the other criteria.

Makapuu was rated poorly from the standpoint of accessibility and diving safety. It is difficult to reach the ledge area except by boat and boating in this area can be hazardous. Also, there are no good snorkeling areas. This site apparently suffers little predation by humans for the reasons listed above. It is therefore recommended that this site be left as is, at least until it becomes apparent that the fishing pressure on the area is increasing. If this happens, it would be more appropriate to designate Makapuu as a natural area reserve because of its unsuitability for recreational use.

There are several drawbacks to the establishment of marine conservation districts at Kahe and Pupukea. Kahe is a safe place to dive most of the year, but its accessibility will remain poor unless the adjacent land is acquired by the City and County of Honolulu for a beach park. It is recommended that, if this happens, Kahe be designated a marine conservation district and markers or buoys be erected to delineate the area. Pupukea is also recommended as a marine conservation district, but should be considered second to Kahe because of its short diving season. If the Kahe beach park plans fail to materialize, Pupukea should be considered first for Oahu.

The Kaneohe Bay patch reefs would make excellent parks for those with boats because of their high coral cover, plentiful fish, and calm, safe waters. The main problems of Kaneohe Bay are not, however, a result of excess fishing or collecting. Designating these reefs as a marine conservation district would do nothing to enhance the visibility in the area or to insure the continued survival of the reefs. It is therefore recommended that the Kaneohe Bay patch reefs not be designated as a marine conservation district unless, in the future, nutrient and silt loads in the bay are reduced to a level which will not pose a threat to coral growth and survival.

On Hawaii, Koaie Cove surpassed all other sites from a biological standpoint. This site was also ranked high in all but one of the geographic criteria. Koaie Cove is therefore recommended as having the highest potential of all sites on Hawaii for designation as a marine conservation district.

Honaunau Bay received high rankings with respect to three of the geographic criteria, but in the biological criteria did not rank as high as Koaie Cove. Fish abundance here was higher than at Kealakekua Bay, but coral cover and diversity were lower. Honaunau Bay is located very close to Kealakekua Bay and the biota of the two sites are similar. It might therefore be appropriate to designate Honaunau Bay a marine conservation district as an alternative to Kealakekua Bay for those who do not have boats. Honaunau Bay should be considered a second choice to Koaie Cove.

Puako has a low fish abundance, but from other biological standpoints it would make an excellent marine conservation district. Coral cover is very high in the reef habitats, as is fish diversity. Furthermore, the caves and arches just beyond the inshore habitat are unique and add scenic value to the area. The main drawback of Puako is that it ranked last in three of the four geographic criteria. This site is therefore recommended as a third choice behind Koaie Cove and Honaunau Bay.

Summary of Recommendations

	Oahu	Hawaii
First choice for new marine conservation district	Kahe (if new beach park is established)	Koaie Cove
Second choice	Pupukea	Honaunau Bay

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Robert Myers took all underwater photographs except that of Honaunau Bay. That photograph and the view of Kaneohe Bay were taken by S. Arthur Reed.

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APPENDICES

UNIVERSITY OF HAWAII

Department of Zoology

APPENDIX A. MARINE PARK QUESTIONNAIRE - 1974

1. We have divided the island of Oahu into 10 general shoreline areas. Please indicate how often you go to each area.

	Very Often	Often	Sometimes	Never
a. Barbers Point to Maili Point...	( )	( )	( )	( )
b. Maili Point to Kaena Point.....	( )	( )	( )	( )
c. Kaena Point to Waimea Bay......	( )	( )	( )	( )
d. Waimea Bay to Kahuku...........	( )	( )	( )	( )
e. Kahuku to Chinaman's Hat.......	( )	( )	( )	( )
f. Kaneohe Bay....................	( )	( )	( )	( )
g. Kailua to Blowhole.............	( )	( )	( )	( )
h. Hanauma Bay....................	( )	( )	( )	( )
i. Koko Head to Sand Island.......	( )	( )	( )	( )
j. Pearl Harbor to Barbers Point..	( )	( )	( )	( )

2. A marine conservation area, like Hanauma Bay, is an area for the preservation of reef plants and animals. Fishing, spearing, collecting of shells and coral would be prohibited.

   Would you be in favor of additional marine conservation areas on Oahu?

   ( ) Yes

   ( ) No

   ( ) Don't know

   If "yes": Please check the areas where you think a marine park should be established.

   a. Kahe Point................( )
   b. Maili.....................( )
   c. Makua.....................( )
   d. Shark's Cove (Pupukea)....( )
   e. Laie Point................( )
   f. Kapapa Island Area of Kaneohe Bay................( )
   g. Blowhole..................( )
   h. Black Point...............( )
   i. Others (please specify)...
   ______________________ ( )
   ______________________ ( )

Background Information

3. Age:

   ( ) Under 20
   ( ) 20 to 29
   ( ) 30 to 39
   ( ) 40 to 49
   ( ) 50 to 59
   ( ) 60 or over

4. Sex:

   ( ) Male

   ( ) Female

5. Length of residence:

   ( ) 1 year or less
   ( ) 2 years to less than 5 years
   ( ) 5 years to less than 10 years
   ( ) 10 years or more

6. What is your zipcode number?

   (If you are unsure of your number please write in the general area where you live)

   ____

7. Are you registered to vote?

   ( ) Yes

   ( ) No

APPENDIX B. QUESTIONNAIRE RESULTS BY AGE, SEX, MAILING (OAHU), AND KNOWLEDGE OF EXISTING MARINE PARKS (HAWAII)

	OAHU				HAWAII			
	Favor	Oppose	No Opinion	Total	Favor	Oppose	No Opinion	Total
SEX:								
Male	223 71.7%	25 8.0%	63 20.3%	311	107 65.6%	42 25.8%	14 8.6%	163
Female	160 71.7%	5 2.2%	58 26.0%	223	152 75.2%	38 18.8%	12 5.9%	202
AGE:								
Under 20	7 77.8%	1 11.1%	1 11.1%	9	6 100.0%	0	0	6
20 - 29	84 75.0%	6 5.4%	22 19.6%	112	57 87.7%	6 9.2%	2 3.1%	65
30 - 39	95 80.5%	6 5.1%	17 14.4%	118	37 64.9%	14 24.6%	6 10.5%	57
40 - 49	81 69.2%	6 5.1%	30 25.6%	117	62 69.6%	22 24.7%	5 5.6%	89
50 - 59	78 68.4%	7 6.1%	29 25.4%	114	70 74.5%	15 16.0%	9 9.6%	94
60 and over	39 59.1%	4 6.1%	23 34.8%	66	35 54.7%	25 39.1%	4 6.3%	64
MAILING OF QUESTIONNAIRE								
First	232 79.5%	14 4.8%	46 15.8%	292				
Second	157 61.8%	15 5.9%	82 32.3%	254				
KNOWLEDGE OF EXISTING MARINE PARKS:								
Know					151 74.4%	37 18.2%	15 7.4%	203
Don't Know					118 68.2%	45 26.0%	10 5.8%	173
TOTAL:	395 71.2%	31 5.6%	129 23.2%	555	272 70.6%	83 21.6%	30 7.8%	385

APPENDIX C. SAMPLE OF COMMENTS RECEIVED ON THE QUESTIONNAIRE

"Areas should be made kapu to net fishing and spearing for 2-3 year periods! Kaneohe Bay--Kailua, Waimanalo etc.--imperative if reef fishes etc. to be restored to previous condition! Wardens must enforce and courts convict violators!"

"I don't care for collecting live shells and coral but I think people should be able to shore fish for supplementing their food budget; and part of childhood is being able to catch sand fish and crabs which you're not allowed to do at Hanauma."

"Could conservation areas be rotated on 3 or 5 year periods? Give the areas a recouperative period then reopen them for limited use. I think collecting of live shells should be prohibited."

"You should have the state pass a law to prohibit commercial gathering of coral, shells and other life forms." (accompanied by drawing of car covered with coral to be sold)

"Instead of a conservation area I would like to suggest instead:

1. Netting of fishes be prohibited within one mile from the shoreline.
2. A kapu system where areas would be closed for a period of time then reopened to public when fish become plentiful."

"I live in Punaluu and there is a daily invasion of skin divers with spears and 'gear'. They come by car load and park between Kahana Bay and the start of residential area of Punaluu. They net and spear - bring up coral and generally clean out miles of area between the reef and shore. They are like human 'vacuum cleaners'".

"I fully agree there should be marine conservation but it should be set to a certain length of time. Like say 10 or 15 years."

"(Chose Kahe Point and Laie Point) so that conservation areas will be located within reach of all residents."

"There are many factors to be considered before we go 'hog wild' and end up designating all Oahu shoreline as conservation areas. We cannot be overzealous in our efforts for future generations and forget our present youngsters."

"I strongly feel that this island (Oahu) is in desperate need of conservation. Stop development, thus stopping silt runoff. That way the reefs will not die from their pores being clogged. Kaneohe Bay is a prime example of this. I think that there is definitely a lot more involved in conserving the ocean than just making a conservation area. But it's a darn good start. Good luck!"

APPENDIX D. QUESTIONS ASKED DURING OAHU INTERVIEW

The location and the sex and activity of the person to be interviewed were first noted by the interviewer.

1. How often do you come here?
2. How long have you been coming here?
3. How long does it take you to get here?
4. Who do you usually come with?
5. Do you come to do other things besides your present activity? If "yes", what else do you do?
6. Why do you like this place?
7. What other areas do you go to?
8. Do you know what a marine conservation district is? (If the person did not know, or if he had a concept which differed from that used in this report, the interviewer explained his own concept before continuing with the interview.)
9. Would you be in favor of more marine conservation districts on Oahu?
10. If you are in favor, where do you think a marine park should be established?
11. How would you be affected if this area were to become a marine conservation district? Would you be affected favorably or unfavorably?
12. How long have you been living here?
13. Are you registered to vote in Hawaii?
14. How old are you?

APPENDIX E. RESULTS OF OAHU INTERVIEWS

Responses are listed by number of responses in each category, and percentage of the total responses. Question numbers are given in parentheses, and refer to the numbers in Appendix D.

	Favor	Oppose	No Opinion	Total
Opinions on new marine conservation districts (Question 9)				
Male	322 67.9%	92 19.4%	60 12.7%	474
Female	145 68.7%	38 18.0%	28 13.3%	211
Age (Question 14)				
Under 20	53 81.5%	3 4.6%	9 13.8%	65
20 - 29	222 75.8%	40 13.7%	31 10.6%	293
30 - 39	98 65.3%	34 22.7%	18 12.0%	150
40 - 49	53 54.1%	25 25.5%	20 20.4%	98
50 - 59	33 55.0%	20 33.3%	7 11.7%	60
60 and over	7 50.0%	5 35.7%	2 14.3%	14
Activity (based on observation and on Question 5, includes all those who were fishing, diving, or snorkeling, or said that they did)				
Fishermen	125 57.1%	73 33.3%	21 9.6%	219
Divers/snorkelers	130 75.6%	29 16.9%	13 7.6%	172
Knowledge of marine parks (Question 8)				
Knew	283 70.6%	79 19.7%	39 9.7%	401
Did not know	145 64.4%	44 19.6%	36 16.0%	225
Had different concept	36 64.3%	7 12.5%	13 23.2%	56
Voting status (Question 13)				
Registered	313 65.3%	102 21.3%	64 13.4%	479
Not registered	149 74.9%	27 13.6%	23 11.6%	199

	Favor	Oppose	No Opinion	Total
Frequency of site use (Question 1)				
Twice per week or more	124 67.8%	39 21.3%	20 10.9%	183
Weekly to monthly	130 64.7%	43 21.4%	28 13.9%	201
Every five weeks to two months	52 70.3%	8 10.8%	14 18.9%	74
Every three months or less often	145 72.1%	36 17.9%	20 10.0%	201
Length of residence in Hawaii (Question 12)				
Less than one year	43 78.2%	2 3.6%	10 18.2%	55
Two to five years	68 81.0%	7 8.3%	9 10.7%	84
Five to ten years	49 70.0%	6 8.6%	15 21.4%	70
Over ten years (not born here)	44 71.0%	11 17.7%	7 11.3%	62
Born and raised in Hawaii	261 63.5%	104 25.3%	46 11.2%	411

Response	Number Giving That Response	Percentage of Total Responses
Answers to question, "How would you be affected if this area were to become a marine park?" (Question 11)		
Favorably	223	32.4
More marine life	107	15.6
Better fishing in adjacent areas	68	9.9
Better snorkeling or diving	80	11.6
Unfavorably	195	28.4
Cannot fish	150	21.8
Cannot collect shells	42	5.1
Cannot collect coral	10	1.5
Not affected	246	35.8
Don't know	28	4.1

APPENDIX E. RESULTS OF OAHU INTERVIEWS (continued)

Response	Number Giving That Response	Percentage of Total Responses
Answers to question, "Why do you like this place?" (Question 6)		
Good beach	292	42.9
Far from crowds	242	35.5
Good fishing	149	21.9
Close to home	148	21.7
Good weather	138	20.3
Good swimming	133	19.5
Facilities that are available	84	12.3
Good surfing	76	11.2
Abundance of marine life	43	6.3
Good place for children	41	6.0
Other responses	205	30.1

APPENDIX F. LIST OF FISH SPECIES BY SITE AND HABITAT. (For site and habitat abbreviations refer to pages 23 and 24.)

Relative abundance indices are as follows:

4: Dominant--over 5 percent of the fish in that habitat
3: Common--0.5 percent to 5 percent of the fish in that habitat
2: Present on transects but less than 0.5 percent of the fish in that habitat
1: Seen in the habitat but not counted on any transect

	KE-IN	KE-MR	KE-OR	KO-IN	KO-MR	KO-OR	PK-IN	PK-MR	PK-OR	HO-IN	HO-MR	HO-OR	HA-LO	HA-CO	HA-SA	HA-SK	LA-LO	LA-CO	LA-MR	LA-PV	LA-BP	WP-FL	WP-LG	WP-OR	PP-CA*	PP-TP*	PP-BE*	PP-BO	PP-DP	KB-PR	SB-RF	LAG-RP*
Family Acanthuridae																																
Acanthurus achilles	3	2		2	3	2	3	2	3	3	2		2	2			2	2	2				2			1						
A. dussumieri		1	2		1			2	2		1		2			2												2	2			
A. glaucopareius	1			1	2		2				2	2							2													
A. guttatus	1			1			1			1			2																			
A. leucopareius	2	2		2	2	2	2	2	2	2	2		2			2	2		2			2	3			3			3		2	
A. mata						1		2					3	2	4	3	2	3	3		3	2	3			1		2	2	2		
A. nigrofuscus	4	3		4	4	3	4	2	2	4	3		4	3	4	3	4	3	4	4	3	3	4	3		3		4	4		3	2
A. nigroris	3	3	2	2	2	2	2	2	2	2	3	2	2			2	2	2			2		2						2			
A. olivaceus	2	2	3	3	2	2	2	3	3	2	2		3	2				2	3	3	3	3	2			2		2	2			
A. thompsoni		2	2		2	2			2		2	4						2		3	3											
A. triostegus		2	2		2		3		2	3	2		3	2	4	4	2						3			4	2	2	3	3	2	4
A. xanthopterus	2	2	2		1			3	2				3					2		3	2								2	2		
A. sps.																		2			3							2				
Ctenochaetus hawaiiensis	2	2	3	2	2	2			2	2	2	2																				
C. strigosus	4	4	4	4	4	4	3	4	4	4	4	4	4	4		2	4	4	4	4	3	3	3	2	1	1		2	3	4		
Naso brevirostris		2	2		2	3		2	2		2	2	2	2						2	2	2	2						2	2		
N. hexacanthus		2	2		2	3		2	3		2	2	2	2							2		3									
N. lituratus	2	3	3	3	3	3	2	3	3	3	3	3	2	2	4	2	2	2	2		2	2	3						2	2		
N. unicornis		2	2	1	2	2	2	2	3		2	2	2	2		2					2	2		2		1			2			
Zebrasoma flavescens	4	4	4	4	4	3	3	4	4	4	4	4	3	3			3	4	3	3	2		2					2	2	4		
Z. veliferum		1			2		3	2								1														2		
Family Albulidae																																
Albula vulpes														2																		
Family Antennariidae																																
Antennarius sp.																			1													
Family Apogonidae																																
Apogon maculiferus																									4			2	2			
A. menesemus		2	2		1			2	2	2	2	2	2																			
A. snyderi													2	2			2	2	2	2	3	4	2	3	4			2	3			
A. sp.																													2			
Family Aulostomidae																																
Aulostomus chinensis	2	2	2		2	2	2	2	2	2	2	3	2	3			2	2	2	2	2	2	2	2	2			2	2	3		
Family Balistidae																																
Melichthys niger	3	2		2	2	2	2	3	2	2	2						2	2	2		2		2									
M. vidua	2	2		2	2	2	2	2	2	2	2							2	2	2	2		2					2				
Rhinecanthus rectangulus		1			2		3			2									2			3	2									
Sufflamen bursa	3	3	3	3	3	3	2	3	3	2		2	2	2			2	3	2	3	3		3	2	1			3	3			
S. frenatus			2																2	1	2	2	3					2				
Xanthichthys mento		2	2	2	3	3		3	3	2		2									1											
Family Belonidae																																
unidentified sp.		1			1								2													1						
Family Blenniidae																																
Cirripectus obscurus					2																					1	1					

*In the Pupukea cave (CA), tidepool (TP), and bench (BE) habitats, the relative abundance indices are merely estimates.

APPENDIX F. LIST OF FISH SPECIES BY SITE AND HABITAT (continued).

	KE-IN	KE-MR	KE-OR	KO-IN	KO-MR	KO-OR	PK-IN	PK-MR	PK-OR	HO-IN	HO-MR	HO-OR	HA-LO	HA-CO	HA-SA	HA-SH	KA-LO	KA-CO	KA-NO	KA-FV	KA-DP	MP-FL	MP-LC	MP-DP	PP-CA*	PP-TP*	PP-BF*	PP-BO	PP-DP	KB-PR	KB-RF	Kapapa
Family Blenniidae (continued)																																
C. variolosus		2		2	2		2		2	2	2		2				2	2	3	2			2			3	4		2			
Exallias brevis	2	2	2		1	1	2	2	2	2	2		2	2			2	2	2				2						2			
Entomacrodus marmoratus					2	2		3	3																	3	4					
Istiblennius zebra																										1						
Plagiotremus goslinei							2	2	2										2			2	2						2	2		
P. rhinorhynchos					2	2	2		2	2				2							2		2						2			
unidentified sp.																																
Family Bothidae																																
Bothus sp.		1			1														2							2						
Family Brotulidae																																
Brotula multibarbata																									1							
Family Canthigasteridae																																
Canthigaster amboinensis							2			2	2		2	2		2		2					2		2	1		2	2		3	
C. coronatus													2							3	3	2	3					3				
C. epilampra		2	2								2										2			3				2	2			
C. jactator	2	2		2	2	2	2	2		3	2		3	3	3		3	2	3	3	3	3	3	2	1	1		3		3	3	
Family Caracanthidae																																
Caracanthus maculatus																						2							2			
Family Carangidae																																
Carangoides ajax								2																								
C. ferdau		1			1			2	2		1																					
Caranx melampygus		1		2	1	1						2	2									3	2						2			
Decapterus pinnulatus			2																													
Elagatis bipinnulatus													2																			
Gnathanodon speciosus		2		2				3	3				2																			
Scomberoides lysan									2				2						2			3	3									
Seriola rivoliana													1	1									2									
Carangidae spp.																					3											
Family Chaetodontidae																																
Chaetodon auriga	1	2								2	2		2			1							2							2		
C. ephippium										1							2		2													
C. fremblii	2	2	2	4	2	2	2		2		2		3	2		3	2	2	2		2	3	2	1	1			3	3			
C. kleini		2			2	2		2	3			1	2					2		3	4		2	4								
C. lineolatus		1			1			1		1																						
C. lunula	3	2	2	2	2	2	2	2	2	2	2	2	3	2		1	2	2					2	1	2			2	2	2		
C. miliaris			3		2		2		3	2			3	3					2	3	3	2	3	3	1			4	3			
C. multicinctus	4	4	4	3	3	3	3	3	3		4	3	3	3			3	3	3	3	3		3	3				3	3			
C. ornatissimus		3	5	2	2	2	2	3	3	3	3	3	2	2			2		2				2						2	2		
C. quadrimaculatus		2		2	2		2	3	3	3	2		2			2	2		2	2		2	3					2	2			
C. reticulatus				1						1									1													
C. trifasciatus	2	2			2		2		2				2																	3		
C. unimaculatus	2	2	2	2	2	2	2	2	2	2	2		2				3	2	2				2						2	3	2	
Forcipiger flavissimus	3	3	3	2	3	3	3	3	3	2	3	3	3	2			2	3	2	2	3	2	2					3	2		2	
F. longirostris	2	2	3		2	2		2	3	2	2	2						2														
Hemitaurichthys polylepis					2	3		2	3														2									
H. thompsoni					1	1				1		1																				
Heniochus acuminatus		3							1			1									3		2	2								
Family Chanidae																																
Chanos chanos	1		2		1						2		2	2														2	2			
Family Cheilodactylidae																																
Goniistius vittatus																									1			2				
Family Cirrhitidae																																
Amblycirrhitus bimacula																													2			
Cirrhitops fasciatus	2	2		2	2	2	3	2	2	2	2		3	3	3		2	2	3	3	3	3	3	3	1	1		3				
Cirrhitus pinnulatus		2			2		2	2	2				2			1	2		2				2						2		2	

APPENDIX F. LIST OF FISH SPECIES BY SITE AND HABITAT (continued).

	KE-IN	KE-MR	KE-OR	KO-IN	KO-MR	KO-OR	PK-IN	PK-MR	PK-OR	HO-IN	HO-MR	HO-OR	HA-LO	HA-CO	HA-SA	HA-SH	KA-LO	KA-CO	KA-MX	KA-PV	KA-DP	MP-FL	MP-LG	MP-DP	PP-CA*	PP-TP*	PP-RE*	PP-MO	PP-DP	KB-PR	KB-RF	Lapapa
Family Cirrhitidae (continued)																																
Paracirrhites arcatus	3	3	2	3	3	2	3	2	2	3	3		2	2			3	2	3	4	3	2	3	3				3				
P. forsteri	2	2	2	2	2	2	2	3	3	2	2		2	2			2	2	2	3	2		2	2								
Family Diodontidae																																
Diodon holocanthus																					2		2					2	2			
D. hystrix					1		2	1				1										2						2				
Family Fistulariidae																																
Fistularia petimba		2		2	2		2	2		2	2		2	2	3			2			2	2	2			1			2			
Family Gobiidae																																
Asterropteryx semipunctatus																2																
Bathygobius fuscus																										3	3					
unidentified sp.																					2				2	2						
Family Holocentridae																																
Adioryx ensifer													2																			
A. lacteoguttatus													2				2						2		3				2			
A. spinifer		2		2	2			3	3			1	2				2		2									2		2		
A. xantherythrus		2			2	2			2		1		2	2			2	2	2		3	2	2	3	4			3	3			
Flammeo sammara		2	2		1	1		1	3	2		2	2				2		2													
Myripristis amaenus													2	2			2		2				2						2			
M. chryseres													2																			
M. murdjan	2	2	2		3	3		2	3	3		2	3	3			3	3	3		3	2	3		4				2			
Family Kuhliidae																																
Kuhlia sandvicensis							1	2								4			2				2		4	4			2			
Family Kyphosidae																																
Kyphosus cinerascens	2	2		1	1				2				2			1			2											2		
Family Labridae																																
Anampses chrysocephalus		2						2		2	2		2	2				2		2	3	2	2					3	2			
A. cuvieri					2	2	2		2	2			2			2	2		2			2	2					2	2			
Bodianus bilunulatus		2	2		2	2		2	2		2		2					2		2	3	2		3				2	2	3		
Cheilinus bimaculatus																					2	2	2	3								
C. rhodochrous	2	3	3	2	2	2	2	3	3	2	2	2		2			2	2	2				2							2		
Cheilio inermis													2	2				2				2	2			1				2		
Coris ballieui																	2	2											2			
C. flavovittata					2	2							2	2							2	2	2	3		2		2	2			
C. gaimardi	2	2	2	2	2	2	2	3	2	2	2		2	2			2	2	2	2	2	2	2			2		2				
C. venusta													2	2			2		2	3	3	4	3	2				3	3	2		3
Gomphosus varius	3	3	2	3	3	2	4	3	2	3	3	2	2	2		2	3	2	3	2	2		2*						2	3	2	
Halichoeres ornatissimus	3	2	2	3	3	2	2	2	2	3	2	2	3	3			2	2	3	2		3	3	2	1			2	3			
Hemipteronotus leclusei			1			1		1														2										
H. pavo															3								2	2				2	2			
H. pavoninus		1	1		1			1	1														2					2	2			
H. taeniourus		1			2					2			2								1	1							2			
H. sp.					1																											
Labroides phthirophagus	2	2	2	2	2	2	2	2	3	2	2	2	3	3			2	3	2	2	3	2	2	3	2			2	2	3		
Leptojulis cerasinus								2	2		2		2	2				2	2	2	3	2	2	3				2	2			
Macropharyngodon geoffroyi													3	2	3		2	2	2	3	3	4	3	2	1				3			
Pseudocheilinus evanidus		2	3	1	1			2	2		2	3						2	2	2	3		2	2					2			
P. octotaenia	2	3	2	2	3	3		3		2	3	2	2	3				2	2	2	2	2	2					2	2	2		
P. tetrataenia		2	2	2	2	2		2	2	2	2	2	2	2			2	2	2	2	2	2	2						2	2		
Stethojulis balteata	2	3		3	2		4	3	3	4	3	2	3	3	4	4	3	2	3	2		4	3	3		2		3	3	3	4	4
Thalassoma ballieui		2	2		2	2	2	3	2		2		2	3	3		2	3	2	2		2	2					2	2	2	2	
T. duperreyi	4	4	4	4	4	3	4	4	3	4	3	3	4	4	4	4	4	3	4	4	3	4	4	3		1		3	4	4	4	4
T. fuscum					1			2	2		2	1			2		2		2				2			2	3				3	4
T. lunare					3	2		2																								
T. lutescens		2		1	2			2			2		2																			

APPENDIX F. LIST OF FISH SPECIES BY SITE AND HABITAT (continued).

	KE-IN	KE-MR	KE-OR	KO-IN	KO-MR	KO-OR	PK-IN	PK-MR	PK-OR	HO-IN	HO-MR	HO-OR	HA-LG	HA-CO	HA-SA	HA-SH	KA-LG	KA-CO	KA-MR	KA-PV	KA-DP	MP-FL	MP-LG	MP-DP	PP-CA*	PP-TT*	PP-BE*	PP-BO	PP-DP	KB-PR	KB-RF	Kapapa
Family Labridae (continued)																																
T. purpureum													2			2																
T. quinquevittata																							2									
Family Lutjanidae																																
Aphareus furcatus		1			1			2	2		2																					
Aprion virescens	2	2			2	2		1			1																					
Lutjanus kasmira		1			1						1	1																				
Family Malacanthidae																																
Malacanthus hoedtii					1																2	2		4				2				
Family Microdesmidae																																
Gunnellichthys curiosus																								1								
Family Mobulidae																																
Mobula japonica						1																										
Family Monacanthidae																																
Aluterus monoceros					1						1																					
A. scripta								2															2									
Cantherhines dumerili	2	2			2				2		2	2	2	2																		
C. sandwichiensis	2	2	2	2	2		2	2	2	2	2		2	2			2	2	2		1	2	2					2	2			
Pervagor melanocephalus											2		2					2	2	2	2		2						2			
P. spilosoma	2	3		2	2	2	2		2	2	2	2	3	3			3	3	3	3	3	3	3	3		1				3		
Family Mugilidae																																
Neomyxus chaptalii					1			1					1			1											2					
Family Mullidae																																
Mulloidichthys flavolineata	2	2	2	1	2	3		2	2		2		3		4	3	2		2							1		2	2	2		
M. vanicolensis		2	3		3	2			2	2	2		2	2	1	1	2	2	2				3					2	3	3		
Parupeneus bifasciatus	2	2			2	2	2		2	2	2		2				2		2				2					2	2			
P. chryserydros		2			2			3	2		2	2	2	2		2	2	2	2		2		2	1					3			
P. multifasciatus	2	2	2	3	3	3	2	2	3	2	2	2	3	3		3	2	3	3	3	3	3	3	3				4	3	2		
P. pleurostigma	2	2			2	2		2	2		2		3	2	3	2	2	2	2	3	3	3	2					4	3			
P. porphyreus					1			3	2		2	2	2				2				2	2	2	2		2			2			
Family Muraenidae																																
Echidna nebulosa													2								2	2							2			
Gymnomuraena zebra														1			2					2	2					2				
Gymnothorax eurostus														2			2	2			2	2						2	2	2		2
G. flavimarginatus							2				2			2			2	2	2	2	2	2	2			1		2	2		2	
G. melatremus																					2							2	2			
G. meleagris	2	2			2		2	2	2				2	2			2	2			2	2						2	2	2		
G. nudivomer																					1											
G. petelli							2		2																				2			
G. undulatus								2	2				2			1				2	2								2			2
G. sp.								2																								
Family Myliobatidae																																
Aetobatus narinari				1	2				2														2									
Family Ostraciontidae																																
Lactoria fornasini																		2											2			
Ostracion meleagris	2	2	2	2	2	2	2	2		2	2	2	2	2		2	2	2	2		2	2	2					2	2	2		
O. whitleyi		1								2	2																					
Family Parapercidae																																
Parapercis schauinslandi																					3	2										
Family Pomacanthidae																																
Apolemichthys arcuatus		2	2			1		2				1									2					1						
Centropyge loriculus		2				2		2	2		2			1				2														
C. potteri	3	3	3	2	3	3		3	3	2	3	3	3	4			2	3	3	3	3		3	3				3	2	2		
Family Pomacentridae																																
Abudefduf abdominalis	2	3	3		1	2	3	3	3	2	2		3	2		2	2	2	3		2	2	3			3			2	3	2	

APPENDIX F. LIST OF FISH SPECIES BY SITE AND HABITAT (continued).

	KE-IN	KE-MR	KE-OR	KO-IN	KO-MR	KO-OR	PK-IN	PK-MR	PK-OR	HO-IN	HO-MR	HO-OR	HA-LO	HA-CO	HA-SA	HA-SH'	KA-LO	KA-CO	KA-MR	KA-PV	KA-DF	MP-FL	MP-LG	MP-DP	PP-CA*	PP-TP*	PP-BE*	PP-BO	PP-DP	KB-PR	KB-RF	Kapapa
Family Pomacentridae (continued)																																
A. sordidus				1			2	2		2			2	2		3										1						
Chromis agilis	3	4	4		4	4		4	4	3	4	4	2	2			2	3	2	2	2		2					2	2			
C. hanui	5	3	3	2	4	4		3	3	2	3	2	3	4			3	4	3	4	4	2	3	4				3	3	3		
C. ovalis			2		2	2		2			2	3	3	3				4	3				3					4	4	2		
C. vanderbilti	3	2	2	4	4	2	3	2	2	3	3		3	3			3	3	4	4	3	4	4	3				2	4			
C. verater		3	4		3	4		2	3		3	3	3	3			2	4	3	2	3		3					3		4		
Dascyllus albisella		2	3		2	3			2		2			2				2			3	3		3			2		2	3		
Eupomacentrus jenkensi	4	3		3	3	2	4	3	3	4	5		4	4	4	4	4	2	4	2	2	3	3			2		3	4	4	3	
Plectroglyphidodon imparipennis				3	2		3	2	2	3			2			2		2	2	2	2	3	3				4					
P. johnstonianus	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	2				2	3	3	3	3
Family Priacanthidae																																
Priacanthus cruentatus		1			1	1		2	2		2		2				2		2						3				2			
Family Scaridae																																
Calotomus spinidens		2	2					2		2	2	2				1						2	2									
Scaridea zonarcha			2	2	2	2	2	2	2	2	2	2		1		1							2									
Scarops rubroviolaceus	2	2	2	2	2		2	3	2	2	2	2	2	2																		
Scarus dubius		2		2	2	2	2	2	2			2	2	2									2									
S. forsteni		2			2			3				2	2										2									
S. perspicillatus			2	2	2	2	2	2	2				2	2		3							2							2		
S. sordidus					2	2	2						2	2					2				2							4		
S. taeniourus	2		3					3	2	2	5	3																				
unidentified Juvenile	2	2	2		2		3	3	3	3	2	2	3	3		3		2	2			3	3					2	2	4	2	4
Family Scorpaenidae																																
Dendrochirus brachypterus																								1								
Pterois sphex		1			1			2																	1							
Scorpaena ballieui																													2			
S. coniorta																						3	2					2			2	2
S. sp.																	2			2					1							
Scorpaenopsis cacopsis																							2						2			
S. gibbosa		2							2												1							2				
Taenianotus triacanthus																			1		2											
unidentified sp.																												2	2			
Family Serranidae																																
Cephalopholis argus					2	2		2			2																					
Pseudanthias thompsoni																					3			4								
P. sp. nov. A(Oahu)																					1											
P. sp. nov. B(Hawaii)												2																				
Family Sparidae																																
Monotaxis grandoculis			2		2	2		2			2			1				1					2	1								
Family Sphyrnidae																																
Sphyrna lewini																							1									
Family Sphyraenidae																																
Sphyraena barracuda					1																								1			
S. helleri			3					1																								
Family Synodontidae																																
Synodus sp.		2	2		2		2	2	2	2	2	2	2			2	2		2	2		2	2	2		2		2	2			
Family Tetraodontidae																																
Arothron hispidus					1			2		2	2	1	2															2				
A. meleagris		2		2	2					2	2	2	1				2		2													
Family Triakidae																																
Triaenodon obesus												1																				
Family Zanclidae																																
Zanclus cornutus	2	2	3		2	2	2	2	2	2	2	2	2	2			2	2	2	2	3	2	2	3	1			3	3	3		

APPENDIX G. LIST OF CORAL SPECIES BY SITE AND HABITAT. (For site and habitat abbreviations, refer to pages 23 and 24.)

Relative abundance indices are as follows:

4: Dominant--over 25 percent of the bottom cover
3: Common--5 percent to 25 percent of the bottom cover
2: Counted on transects, but less than 5 percent of the bottom cover
1: Seen in the habitat but not counted on any transect

	KE-IN	KE-MR	KE-OR	KO-IN	KO-MR	KO-OR	PK-IN	PK-MR	PK-OR	HO-IN	HO-MR	HO-OR
Sarcothelia edmondsoni		2								1	1	1
Cirripathes sp.												
Psammocora verrilli		2	3		2						2	1
P. stellata		1	2		2							
Pocillopora damicornis		1	2					1	1			1
P. ligulata												
P. modumanensis												
P. meandrina	2	2	2	2	2	2	3	2	2	2	2	2
Montipora dilatata								2				
M. verrucosa	2	2	2	2	2	2	1	3	2	2	2	
M. patula					1			2				
M. flabellata												
M. verrilli		2	2	2	2	2	2	2	2		2	1
Pavona varians	2	3	3		2		2	2	2	2	2	2
P. explanulata	1	1	2				2	2		1		
P. pollicata												
Leptoseris incrustans		2										1
L. digitata												
L. tubifera												
Coscinaraea ostreaeformis												
Fungia scutaria		1						1	1		1	
Porites lobata	4	4	4	4	4	4	4	4	4	4	4	3
P. compressa	[illegible]	4	4	4	3	3	2	4	4	3	3	4
P. lichen												
P. brighami					2			2			2	
P. duerdeni												
Leptastrea bottae							2					
L. purpurea		1	1		1	1	2	1	1			
Cyphastrea ocellina		1	1		1	1	1	1			1	1
Tubastrea aurea							1	1			2	
Palythoa tuberculosa												
Palythoa sp.		2	2		1	1	1	1	1		2	
Balanophyllia sp.												
Cycloseris vaughani		1			1			1	1			
C. fragilis					1							

	HA-LO	HA-CO	HA-SA	HA-SK	KA-LO	KA-CO	KA-MR	KA-PV	KA-DP	MP-FL	MP-LC	MP-DP	PP-CA*	PP-TP*	PP-BE*	PP-BO	PP-DP	KB-PR	KB-RF	Kapapa
Sarcothelia edmondsoni	1				1		1	1			1			2		2	1			
Cirripathes sp.	1								1								1			
Psammocora verrilli											1					1	1	1	1	
P. stellata						1				1	1	1						1	1	1
Pocillopora damicornis											1	1		2				1	2	1
P. ligulata					2		2			1						1	1	1		1
P. modumanensis					1	1		1		1	1	1				1	1			
P. meandrina	3	2		1	3	2	3	1		1	3	1	2	2	2	2	1		2	
Montipora dilatata																				
M. verrucosa	3	1		2	2	2	2	2	1	2	3			2		2	2	2	1	
M. patula	2				1	1	1	2	1	1	2					2	1			
M. flabellata	2				1		1			1	1					2	1	1		
M. verrilli	3	1			3	2	3	1	1	2	2			2		3	3	2		
Pavona varians	2	1			2	2	2			1	1					1	1	1	1	
P. explanulata	3	1			2	1	1		1	2							1			
P. pollicata						1							1							
Leptoseris incrustans						2			1		1	1	3			1	1			
L. digitata						1			1			1					1			
L. tubifera						1														
Coscinaraea ostreaeformis													1			1	1			
Fungia scutaria	1				1		1				1							1	1	
Porites lobata	4	4	1	1	4	4	4	4	3	3	4	3				3	3	3	1	1
P. compressa	3	4			3	4	3	1	1		2							4	2	1
P. lichen					1		1			1	1					1		1		
P. brighami	1			1	1		1	1			1	1				1				
P. duerdeni											1									
Leptastrea bottae																1		1	1	1
L. purpurea	1	1			2		1	1	1	1	1		2			2	2			
Cyphastrea ocellina	1			1			1	1										1	1	
Tubastrea aurea													3			1				
Palythoa tuberculosa	2				3	1	2			1	1	1		2		1	1	1		
Palythoa sp.					1									2		1	1			
Balanophyllia sp.													3			1				
Cycloseris vaughani																				
C. fragilis																				

*In the Pupukea cave (CA), tidepool (TP), and beach (BE) habitats, the relative abundance indices are merely estimates.

APPENDIX H. LIST OF MACROINVERTEBRATE SPECIES BY SITE AND HABITAT. (For site and habitat abbreviations, refer to pages 23 and 24.)

Relative abundance indices are as follows:

4: Dominant--over 100 per 100 square meters
3: Common--10 to 100 per 100 square meters
2: Uncommon--less than 10 per 100 square meters
1: Seen in the habitat but not counted on any transect

	KE-IN	KE-MR	KE-OR	KO-IN	KO-MR	KO-OR	PK-IN	PK-MR	PK-OR	HO-IN	HO-MR	HO-OR	HA-LG	HA-CO	HA-SA	HA-SH	KA-LG	KA-CO	KA-MR	KA-PV	KA-OR	WP-FR	WP-LG	WP-DP	PP-CA*	PP-TP*	PP-BF*	PP-BO	PP-DP	LB-FR	LB-RF	Lsp-MA
Phylum Porifera																																
Demospongia sps.	1			1			1				1														3	1						
Phylum Cnidaria																																
Pennaria tiarella													2							2	2		2		3							
Phylum Platyhelminthes																																
Polycladida sps.	1			1			1						2							1		2	2					2	2			
Phylum Annelida																																
Errantia sps.																												2	2			
Terebellidae sps.				1			1			1			1			1		2			2					1						
Serpulidae sps.													2																	2		
Spirobranchus sp.	2	2	2	2	2		2	3	3	2	2	2	2	2			3	2		1		2	2	2				3	3	2		
Phylum Arthropoda																																
Stenopus hispidus				1																2	2		2		3	1		3	3			
Stenopus sp.																									1			2	2			
Panulirus sp.											1		2					2			1		2		3			2	2			
Scyllarides squamosus																									1							
Anomura sp.	2	2							2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	2	2	2		
Brachyura sp.																										1		2				
Xanthidae sp.																							2					2				
Trapezia sp.																									2			2	2			
Phylum Mollusca																																
Turbinidae sp.													2															2				
Nerita sp.																										2	2					
Patella sp.																										2	2					
Vermetidae sp.	2	2	2	2	2		2	2	2				4				2		2			3						3		3	3	
Cypraea sp.					1												2								2						2	
Charonia tritonis													2																			
Drupa sp.													2	2											1	2						
Laterius nodus																					2											
Terebra crenulata																						2	2									
Nudibranchia sps.		2						2					2				2	2		2		2	2		2	2		2		2		
Dollabella variegata											1																					
Pinna sp.																				2												
Ostrea sp.																										2						
Polypus sp.				1											2					1	1		1					2	2			
Conus sp.													2			2	2	2	2	2			2		1			2	2	2		
Phylum Ectoprocta																																
Triphylozoon hirsutum					1												2			3			2	3	3			2	2			
Phylum Echinodermata																																
Astropyga radiata																												1				
Dactylosaster cylindricus				2	2	2		2	2																						3	
Culcita novaeguineae		1			1								2	2																		
Leiaster callipeplus		1																														
Linckia multifora	2	2	2		2	2							2	2			2	2	2	3	2											
L. guildingi																					2											

*In the Pupukea cave (CA), tidepool (TP), and bench (BF) habitats, the relative abundance indices are merely estimates.

APPENDIX H. LIST OF MACROINVERTEBRATE SPECIES BY SITE AND HABITAT (continued).

	KE-IN	KE-MR	KE-OR	KO-IN	KO-MR	KO-OR	PK-IN	PK-MR	PK-OR	MO-IN	MO-MR	MO-OR	HA-LO	HA-CO	HA-SA	HA-SH	KA-LO	KA-CO	KA-MX	KA-PV	KA-DP	NP-FL	NP-LG	NP-DP	PP-CA*	PP-TP*	PP-BE*	PP-BO	PP-DP	KB-PR	KB-RF	Kapap
Phylum Echinodermata (continued)																																
Mithrodia bradleyi													2										2						2			
Acanthaster planci		2	2	2	2	2	2	2	2		2	2	2	2				2	2		2		2									
Ophiomora sp.					1		2	1					2	2						2	2	2	[illegible]		2	1		2				
Echinothrix sp.	3	3	3	3	3	3	3	2	2	3	3	2	3	3		2	2	2	2	2	2	3	3	2	3			2	2		3	
Diadema paucispinum		2	2	2	2		2	2		2	2		2					2				2	2									
Pseudoboletia indiana													2				2	2		2		2							2	2		
Eucidaris metularia	2	2	2	2	2	2	2	3	3	2	3	2	2	3			2	4		2			2	3								
Chondrocidaris gigantea		1	2			2		2			3							2					2		1							
Tripneustes gratilla	3	3	3	3	3	3	3	3	3	4	3	3	2	4	2		3	4	2		2	4	3			1		2	2	2	2	
Colobocentrotus atratus																										3	3					
Echinometra mathaei	4	3	3	4	4	3	4	3	3	4	3	3	3	2		2	3	3	2	2		3	3	[illegible]		3	3	2		2	3	3
E. mathaei oblonga	2			2	2					3	2			2		2		2		2		2	2			3	3				3	3
Heterocentrotus mammillatus	3	4	4	3	3	3	3	3	3	3	3	3	2	2			2	2	2				2									
Echinostrephus aciculatus		2		2	2	2	2	2		2	2		3	2			2	2		2	2	2	3	2				2	2	2		
Lytechinus sp.		1			1						1																					
Stichopus sp.																		2						2								
Holothuria atra					2		2	2	2	2	2		2	2	2	2	2		2		2		2			2		2	2		2	
H. cinerascens																										2						4
H. fuscorubra					2	2		2	2		2																					
Actinopyga obesa			2				2	2	2	2	2		2													2						
A. mauritiana					2	2																										2

APPENDIX I. LIST OF ALGAL SPECIES BY SITE AND HABITAT. (For site and habitat abbreviations, refer to pages 23 and 24.)

Relative abundance indices are as follows:

4: Abundant
3: Common
2: Uncommon
1: Seen in the habitat but not counted on any transect

	KE-IN	KE-MR	KE-OR	KO-IN	KO-MR	KO-OR	PK-IN	PK-MR	PK-OR	HO-IN	HO-MR	HO-OR	MA-LO	MA-CO	MA-SA	MA-SH	LA-LO	LA-CO	LA-MR	LA-PK	LA-DP	SP-FL	SP-LG	SP-DP	PP-CA	PP-PR	PP-MR	PP-BO	PP-DP	ER-PR	ER-BR	Lagoon
Phylum Chlorophyta																																
Boodlea composita													1					2						3			1					
Bornetella sp.																2																
Caulerpa sp.	1	1						1	1		2						1															
Cladophora sp.													1			2																
Cladophoropsis sp.																				1												
Codium arabicum													1															1	1			
C. edule																								3					1		3	
Dictyosphaeria cavernosa		1	1	1	1	1		2	2		1	1	1	3		2		1	1				1				1		1	4	3	
D. versluysii														1				1	1	1			1			2	2	3		3	4	
Enteromorpha sp.													1														1					
Halimeda discoidea													3	3				2	1	3	1	1	2	3				3	3	2	3	
H. opuntia		1	2		1	1	1	2	2		2	2																				
Microdictyon sp.		2						1	1		1																					
Neomeris sp.									1				3			1			1		1	2	1	3								
Ulva lactuca																										3	3					
U. reticulata																												1				
U. sp.							1																									
Valonia ventricosa		1	1		1	1		1	1		1	1																				
Phylum Phaeophyta																																
Chnoospora sp.																											3					
Colpomenia sinuosa																											3					
Dictyopteris australis		2			1						2		1		2							3	3									
Dictyota sp.					1								3	1	2	3		2		2	2	2	4				3	2	1		3	
Ectocarpus sp.													2			3						2										
Padina crassa																											3					
P. japonica																1				1	1	1					3	1	2			
Sargassum sp.								1			2																3					
Turbinaria ornata				2	1	1	1				1	1				3						1	3					3			3	
Zonaria hawaiiensis													1														2					
Phylum Rhodophyta																																
Acanthophora spicifera																										3	3					
A. sp.							2																				2					
Ahnfeltia sp.												1	4	4		3	3		3	3			3					4	3			
Amansia glomerata													3	2										3								
Asparagopsis sp.														3																		
Ceramium sp.					1		1				1		3	3				3	2		1		1					3	1	2		
Chondrococcus sp.																2												2			3	
Corallina sp.																															2	
Dasya sp.																																
Desmia hornemanni						1		1	1		2		2			3		3	2		2			3		3		3	3			
Galaxaura sp.		1	2		1		1	1	1		1	1															3					
Gelidium sp.																			1			1						2	1			
Halymenia sp.																2				3			1	3				3	2			
Hemitrema sp.		1									1	1																				

APPENDIX I. LIST OF ALGAL SPECIES BY SITE AND HABITAT (continued).

	KE-IN	KE-NR	KE-OR	KO-IN	KO-NR	KO-OR	PK-IN	PK-NR	PK-OR	HO-IN	HO-NR	HO-OR	HA-LO	HA-CO	HA-SA	HA-SK	KA-LO	KA-CO	KA-MK	KA-PV	KA-OP	NP-FL	NP-LG	NP-OP	PP-CA	PP-TP	PP-BE	PP-BO	PP-OP	KB-PR	KB-RF	Kapapa
Phylum Rhodophyta (continued)																																
Hypnea sp.													1										1									
Jania sp.		2	3		2			1		2	3	2		2		2	2	2														
Laurencia sp.											[illegible]	1	1	2						1							1	3	3			
Liagora sp.													1			2				1		1		3								
Porolithon sp.													4			2	4	2	4	2		3	4	3			3	4		3	3	
Spyridia sp.																												1				
Trichoglosa sp.																			1													
unspecified encrusting		2	3	2	3	3	3	3	4	4	3	3	2									3	3		3		3	3		3	3	
Phylum Cyanophyta																																
Lyngbya sp.				1	2	1	2	2	2		2																					
unidentified filamentous																			1							4						