CHANGES IN THE MARINE HABITAT AND BIOTA OF PELEKANE BAY, HAWAI'I OVER A 20-YEAR PERIOD

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SUMMARY

Pelekane Bay has been subjected to large-scale alterations in the Kawaihae watershed over the last 200 years and the construction of the Kawaihae Harbor in the 1950's and 1960's. The goal of this study was to examine long-term changes in the marine habitat and biota by comparing the present abundance, diversity and distribution of marine organisms to those described 20 years earlier in previous studies. Quantitative and qualitative surveys were conducted within Pelekane Bay in the same area as previous studies. A species list and the relative abundance of all species was compiled for all habitats within the bay. In addition, quantitative sampling was conducted on three 50 m transects on patch reefs.

Although the absolute areas of different habitat types within the bay appear to have been stable, there have been striking declines in the abundance of all plants and animals associated with major changes in species diversity and composition since the last surveys in 1976. Seaweeds declined from 13 species to one, invertebrates from 106 to 21, and fishes from 64 to 57 over the intervening 20-year period. Similar declines occurred in the percent cover of live corals, which declined over 84%, and fish density which declined 35%.

Although the causes of these changes cannot be ascertained directly from this study, it seems likely that the community is changing in response to long-term sedimentation stress due to chronic terrestrial run-off and reduced ocean circulation in Pelekane Bay associated with massive deforestation in the Kawaihae watershed and the construction of the Kawaihae Harbor revetment. Several suggestions are made to restore Pelekane Bay to a more productive condition.

INTRODUCTION

Pelekane Bay is located along the south Kohala Coast of the island of Hawai'i. The goal of this study was to examine long-term changes in the marine habitat and biota by comparing the present abundance, diversity and distribution of marine organisms to those described 20 years earlier on marine plants (Ball, 1977) and animals (Chaney et al., 1977). As mentioned in these earlier papers, changes in the marine community of Pelekane Bay over this 20-year period are likely due to modifications in the environment of the area surrounding this site. These include large-scale alterations in the Kawaihae watershed over the last 200 years and the construction of the Kawaihae Harbor in the 1950's and 1960's.

Early historical accounts indicate that the Kawaihae area was dense with hardwood forests which ran from the Kohala mountains (Langlas, 1994) almost to the shore in the late 1700's and early 1800's (Greene, 1993). Water also flowed continuously from the two major gulches, *Makehua* and *Makahuna*, which drained the majority of the Kawaihae watershed and entered the ocean near Pelekane Bay (Greene, 1993). However, beginning in the early 1800's, sandalwood was extensively harvested from the upper slopes of the watershed (*Kawaihae Uka*) and in the Waimea area. By 1845 the harvest had been so extensive that there were "…no trees left larger than mere saplings" (Willis 1845, cited in Kelly, 1974). In addition to the large-scale removal of upland forests, cattle were introduced by Captain George Vancouver in 1793. The cattle, saved from slaughter by a kapu, multiplied rapidly and by 1807 were running wild and grazing the land (Greene, 1993). As a result of deforestation and extensive cattle grazing the Kawaihae area was described as barren with little vegetation by 1830. Moreover, water in the gulches had ceased to flow (Greene, 1993).

During the late 1950's the large fringing reef adjacent to Pelekane Bay was dredged to create Kawaihae Harbor, which was completed in 1959. Coral rubble and sand fill from the dredging was used to build causeways, a dike and a revetment which adjoins the area next to Pelekane (Figures 1-3). In 1969, as part of Project Tugboat, the army's Nuclear Cratering Group used high explosives to excavate the small-boat harbor located 300 m north of Pelekane and to widen the harbor's entrance and basin (Greene, 1993). The net result of these activities was to scatter coral rubble throughout the northern part of Pelekane Bay and cause a considerable reduction in the degree of ocean circulation.

In response to these large-scale changes, increased erosion and the natural funneling of water by three gulches (*Makehua*, *Makahuna* and particularly *Pohaukole*) into Pelekane Bay resulted in chronic instances of high sediment runoff into the ocean. By 1976, turbidity in Pelekane was reported as low compared to offshore waters by Chaney et al. (1977), with visibility ranging from 10m at the mouth of the bay to less than 1m near the shore. Ball (1977) reported a visibility of a few cm in 1976. In addition, the area contains numerous warm freshwater springs, which were used by early Hawaiians for bathing (Kelly, 1974). In 1976 these springs discharged warm fresh water into Pelekane Bay along the shoreline to the south of the bay and up through sediments in several areas, causing a reduction of salinity to 25-32 °/°° (Chaney et al., 1977).

The goal of this study is to reexamine the study areas surveyed in 1976 by Ball (1977) and Chaney et al. (1977) in order to estimate any changes that may have occurred in the subtidal marine habitat and biota in the intervening 20-year period. Estimates will be made of the area of different habitat types and the abundance and diversity of the plants and animals in the bay. An additional goal of this study is make recommendations on ways to restore the marine environment of Pelekane Bay to the condition that existed prior to the construction of the Kawaihae harbor.

MATERIALS AND METHODS

The study site included the areas previously surveyed by Ball (1977) and Chaney et al. (1977) which includes Pelekane Bay and the areas immediately adjacent to the bay (Figure 1). The one exception is the intertidal zone, which was not surveyed during this study. Surveys were focused on estimating changes in the abundance and distribution of habitat types and the abundance of invertebrates and fishes in the study area relative to those estimated in earlier studies.

The relative abundance of different habitat types within the bay were estimated using both quantitative and qualitative methods. First, the area was examined by freely swimming the entire study site. Using the descriptions in Chaney et al. (1977) we searched for distinct habitat types primarily based on the composition of the substratum (silt, coral rubble, or live coral). Within each habitat type, species lists were compiled and the relative abundance of each species was noted. Infaunal macro-invertebrates were examined by manually taking samples of the sediment to 10 cm depth and visually identifying the species present. In addition, the shape, size and position of animal burrows were also noted.

In order to estimate the relative area of each habitat type, a transect line was extended across the bay in a NW-SE orientation. The distance on the transect where habitat type changed was noted and three-five 0.25 m^2 quadrats were placed within each habitat and the percent cover of substratum composition was estimated. In addition, aerial photographs were taken on July 31, 1996 from an altitude of 500-1500 m (Figures 2-3) in order to provide a visual estimate of habitat area and a reference for future studies.

In order to resurvey the areas quantitatively sampled by Chaney et al. (1977) we established three, parallel 50m transects in patch reefs located at the southern mouth of the bay (Figure 1). The transects were oriented in a NW-SE direction and were spaced approximately 20 m apart. The ends of each transect were marked by stainless steel pins cemented into holes drilled into dead coral heads.

Fishes were visually surveyed on these transects at the same time of day on three different days (mid-morning on 21 January, 8 March, and 28 April, 1996) by 2-3 different observers for a total of 24 separate transect-surveys. During each survey each observer surveyed all three transects. Fish abundance was estimated by slowly swimming the transect and counting fish occurring within 2 m of each side of the line. Data from each observer was pooled and averaged for each transect. Thus a total of 200 m^2 was surveyed on each transect for a total area of 600 m^2 , which was repeatedly sampled nine times. The total area previously surveyed by Chaney et al. (1977) was 1000 m2, which was sampled once.

The abundance of macro-invertebrates, corals, seaweeds and other bottom substrates were estimated by sampling 10 randomly placed 0.5 m^2 quadrats along each permanently marked transect line. Macro-invertebrate abundance was estimated by counting the number of individuals seen within the transect. Thus a total of 5 m^2 was surveyed on each transect for a total area of 15 m^2. Chaney et al. (1977) did not quantitatively survey macro-invertebrates.

The percent cover of corals, seaweeds and other substrates was estimated by recording the substrate type under nine points within each quadrat delineated by intersecting mono-filament lines. Thus, a total of 270 points were sampled. Corals were sampled by Chaney et al. (1977) using two 50 m line transects. Ball (1977) did not quantitatively sample marine plants.

RESULTS

A description of the five habitat types surveyed during the study is described in Table 1 and illustrated in figures 4-7. In general the area was composed of five different habitat types: a mixed rubble and sand bottom (type I), which graded into a coral and rubble area (type IV) on the north side of the bay; a sand and silt bottom (type II), which extended from the shore out to offshore patch reefs (type V) up the middle of the bay; and a basalt pavement and rubble area (type III) which also graded into a coral and rubble area (type IV) on the south side of the bay. An estimate of the area of each habitat type is listed in Table 2. The habitat types surveyed were very similar in description and area to those sampled by Chaney et al. (1977) and did not appear to have varied since the previous survey. However, since the previous study made no quantitative estimates of the area of each habitat type, no statistical comparisons were possible.

The relative abundance of all species in each habitat type is presented in Table 3. In general, the number of species of plants and invertebrates observed in each habitat type were greatly reduced compared to the earlier studies. Only one of the 13 subtidal plant species listed in Ball (1977), *Porolithon onkodes*, was seen. Moreover, almost all of the species of sponges, flatworms, sipunculans, echiurians, ectoprocts, annelids, arthropods, molluscs and echinoderms listed by Chaney et al. (1977) were not seen during this survey. Thus, the number of species of invertebrates declined from 106 species in 1976 to 21 species in 1996, a decline of over 80%. In contrast, the number of species of fishes experienced a small decline over the 20-year period: 64 species were seen in 1976 and 57 in 1996, a decline of 11%

Results of quantitative surveys of substratum types on patch reefs is presented in Table 4 and Figure 8. Although there were marked changes in substratum composition between the two surveys, most of these changes were not statistically significant due to low sample size (2) in the 1976 survey. Only two species of corals, *Cyphastrea ocellina* and *Pavona varians*, were significantly less abundant in 1996 relative to 1976 (Figure 9). Overall, however, there was a marked decrease in the diversity and percent cover of all species of coral.

Overall, the number of species of coral seen declined from 10 in 1976 to five in 1996, a 50% decline (Figure 9). Five coral species seen in 1976, *Cyphastrea ocellina*, *Leptastrea bottae*, *Montipora patula* and *Pavona varians*, were not observed on transects in 1996. Total percent coral cover declined from 44% in 1976 to 6.7% in 1996 and there was a concurrent increase in the percent cover of dead coral from 15.6% in 1976 to 54.2% in 1996, suggested high mortality of live corals between the two surveys. The percent cover of mud and sand declined from 41% cover in 1976 to 30.5% in 1996.

The dominant species of coral in 1976, finger coral (*Porites compressa*), declined from 16% to 1.3% cover. Similarly, the cover of lobe coral (*Porites lobata*) declined from 11% to 4%, rice coral (*Montipora verrucosa*) declined from 7% to 0.4%, and cauliflower cover (*Pocillopora meadrina*) declined from 3.5% to 0.4%. Other substrate types, such as encrusting coralline algae, turf algae, and the red coralline algae *Porolithon onkodes*, were not recorded on transects in 1976 but present in 1996 (Figure 9).

The abundance of fishes along transects on patch reefs is presented in Table 5 and Figure 10. Overall, the number of species of fish changed from 35 in 1976 to 39 in 1996, an 11% increase. The species composition of the fish community in 1976 was markedly different from that in 1976: the overall percent similarity between these two communities was 30.2% (Figure 10). There were a total of 31 species not common to either survey (Table 6). Fourteen of the 35 species counted on transects in 1976 were not recorded on transects in 1996. In particular, these included the abundant species *Chromis ovalis* and *Scarus sordidus*. Similarly, 17 species counted on transects in 1996 were not recorded on transects in 1976. These included the abundant species, *Lutjanus fulvus*, *Acanthurus leucopareius* and *Chaetodon auriga*. These differences are also reflected in changes in species diversity indices: the Shannon-Weiner diversity index changed from 1.07 in 1976 to 1.17 in 1996 and the evenness index changed from 0.69 in 1976 to 0.73 in 1996. Thus, the fish community in 1996 was both slightly more diverse and slightly more evenly distributed than the community in 1976. In contrast however, the mean abundance of all fish declined from 27.9 fish/100m^2 in 1976 to 18.1 fish/100m^2 in 1996, a 35% decline.

The five most abundant fishes seen on reefs in 1976 were, in rank order of abundance: *Mulloidichthys flavolineatus*, *Chromis ovalis*, *Scarus sordidus*, *Thallosoma duperrey*, and *Abudefduf abdominalis*. These species accounted for 72% of the fishes seen in 1976. In contrast, in 1996, the five most abundant fishes seen on reefs were, in rank order of abundance: juvenile *Scarus*, *Ctenochaetus strigosis*, *Gomphosus varius*, *Thallosoma duperrey* and *Acanthurus triostegus*. These species accounted for 61% of the fishes seen in 1996.

Overall, however, the only statistically significant change in abundance occurred in five species (Table 5). One species, *Thallosoma duperrey*, exhibited a significant decline in abundance from 2.9 fish/100m^2 in 1976 to 1.4 fish/100m^2 in 1996, a 51% decline in abundance. In contrast, five species, *Acanthurus nigroris*, *Acanthurus triostegus*, *Chaetodon lunula*, *Parupeneus cyclostomus*, and juvenile *Scarus*, exhibited significant increases in abundance. Lack of significance was mostly due to the small sample size (two transects in 1976 and three in 1996) associated with sampling fishes. Based on α=5% and a power of 0.90 (β =10%) the average minimum detectable difference for all species was ±1.8 fish/100m^2. Thus, although changes in many species were obvious, due to the small minimum detectable difference, these changes could not be detected statistically.

In order to examine ecological changes in the fish communities analyses were also conducted among fish families and feeding guilds (Figure 11). In general, the abundance of Damselfishes (Pomacentridae), Goatfishes (Mullidae), Wrasses (Labridae) and Parrotfish (Scaridae) declined from 1976 to 1996 while the abundance of Surgeonfishes (Acanthuridae) and Butterflyfishes (Chaetodontidae), increased over the same 20-year period. Overall, however, there were no significant changes in either fish families or feeding groups between the two surveys. These results were probably due to low statistical power as stated earlier. Similar changes were also noted in the abundance of fish feeding guilds. In general the abundance of carnivores and herbivores decreased between 1976 and 1996 while the abundance of corallivores, omnivores, and planktivores increased over the same 20-year period. However, none of these differences were statistically significant.

DISCUSSION

Results indicate that major changes have taken place in the marine biota of Pelekane Bay since 1976. Although the absolute areas of different habitat types within the bay appear to have been stable, there have been striking declines in the abundance of all plants and animals associated with major changes in species diversity and composition. Although the causes of these changes cannot be ascertained directly from this study, it seems likely that the community is changing in response to long-term sedimentation stress associated with chronic terrestrial run-off and reduced ocean circulation in Pelekane Bay.

Changes in marine biota

With the exception of the coralline algae *Porolithon onkodes* and *P. gardeneri*, the brown alga *Padina japonica*, and sparse patches of filementous "turf" algae, marine plants have largely disappeared from Pelekane Bay. Surveys by Ball (1977) in 1976 found 13 species present, only two of which were abundant. Ball (1977) concluded that the low plant diversity was due to high rates of sedimentation coupled with reduced water motion associated with the Kawaihae Harbor revetment. Based on the results of this study, it would appear that these factors have caused continued declines in algal abundance and diversity over the intervening 20-year period. The only marine plant present in 1996 and listed in Ball (1977) in 1976 was *Porolithon onkodes*, which was described as moderately abundant on coral rubble. In this study live *P. onkodes* was rare on coral rubble and accounted for only 0.6% of substratum cover. In addition, dead *P. onkodes* accounted for 0.8% of the substratum cover, suggesting that it has also experienced high mortality.

The abundance and diversity of invertebrates also experienced major declines between the two surveys. Chaney et al. (1977) described 106 species of invertebrates associated with the soft sediments, coral rubble and patch reefs of Pelekane Bay in 1976. In and amongst coral rubble they found numerous species of polychaete worms, crustaceans, gastropods, sea cucumbers and sea urchins. During surveys in 1996, these same coral rubble areas were largely bare, with occasional *Alpheus* shrimp burrows, vermetid gastropods, shore crabs, and several unidentifiable worm burrows. Moreover, the infauna, which consisted of several species of polychaetes, and *Alpheus* and Callinassid shrimp burrows in 1976, were greatly reduced in 1996. Although several unidentifiable worm burrows and *Alpheus* shrimp burrows were commonly seen during this study, repeated samples of sediment throughout the Bay contained few macroscopic organisms. Anoxic conditions were often encountered within several centimeters of the surface, perhaps in response to chronic accumulations of sediment. Thus, the overall diversity of invertebrates declined 82% between the 20 year period of the two studies.

On patch reefs the abundance and diversity of corals also experienced dramatic changes. Of the ten coral species surveyed in 1976, only five were seen in 1996. In contrast, 300 m north of Pelekane Bay near the Kawaihae small-boat harbor, 11 species of corals are found (US Fish and Wildlife Service, 1993). Moreover, the abundance of living corals declined from 44% to 6.7% cover and there was a corresponding increase in the abundance of dead coral. Interestingly, mortality appears to have been the highest in branched corals such as *Porites compressa* and *Pocillopora meandrina*, which experienced 82% and 89% percent declines in abundance, respectively. The more massive coral, *Porites lobata*, experienced a smaller 65% decline. This pattern is in contrast to that observed in several studies which have demonstrated lower mortality in branching species due to their natural ability to eliminate sediments (Rodgers, 1983, 1990). This pattern suggests that additional physical factors in Pelekane Bay, such as increased temperatures and lower salinities, may also be contributing to mortality.

Marked declines in invertebrate abundance are not suprising considering the strong negative effects chronic sedimentation has on invertebrate growth and reproduction. Among corals, declines in both abundance and species diversity are common response to increased rates of sedimentation (e.g., Acevedo and Morelock, 1988). High sediment loads may kill corals by slowing growth rates (Chansang et al., 1992), or smothing, which causes corals to secrete large amounts of mucus to cleanse themselves (Rodgers, 1990). At low rates of sedimentation, this excess mucus secretion causes reduced growth and reproductive output. At higher levels of sedimentation, corals are eventually killed by a combination of smothering and reductions in available energy due to turbid waters. Bak (1979) described a similar response of corals to sediments associated with dredging activities which both increased the turbidity of the water and reduced the amount of circulation. A study by Tissot et al. (1998) also found reduced abundance and diversity of invertebrates and coral growth in dredge holes associated with increased turbidity and reduced circulation. Moreover, sediment cover on the bottom has been shown to prevent larval settlement and thus natural recovery of an area (Hodgson, 1990).

The fish community at Pelekane Bay was also remarkably different between 1976 and 1996. Overall, the abundance of fish declined 68% and there were additional, dramatic changes in fish community structure. Although the 1996 fish community was more diverse in both richness and evenness when compared to the community in 1976, the species composition of the two communities were markedly different. In 1976, the fish community was dominated by relatively few species of fish: goatfish, wrasses, adult parrotfish and several species of surgeonfishes. In 1996, the community was represented by a much more divers mix of juvenile parrotfish, surgeonfishes, snappers, and wrasses. Thus, the overall similarity of the communities between the two surveys was only 19.7%.

Changes in the fish community due not appear to be entirely associated with changes in the plant and invertebrate fish communities. Although there were no significant changes in fish feeding guilds, the incidence of both herbivorous and corallivorous fishes tended to increase despite major declines in seaweeds and corals. Thus, fish may be responding directly to the effects of sedimentation or to other factors which influence fish abundance and diversity such as recruitment, predation and additional human impacts such as fishing. Hypotheses on factors which influence coral reef fish community diversity are controversial but in general support the lottery hypothesis (Sale and Dybdahl, 1975). The lottery hypotheses maintains that coral reef communities are open, non-equilibrium system where chance recruitment events play a major role in structuring abundance patterns (Sale, 1991). As a result, fish communities display low temporal stability and thus display low temporal similarity, a pattern noticed in this study. Thus, the large changes noticed between the fish communities in Pelekane Bay in 1976 and 1996 could be due to a variety of factors.

Recommendations for restoration

It seems highly likely that changes in the marine biota at Pelekane Bay are associated with chronic, long-term sedimentation from the adjacent watershed combined with reduced water circulation in the bay due to the Kawaihae Harbor revetment. Both of these factors were also mentioned in the earlier studies of Ball (1977) and Chaney et al. (1977) as causing significant impacts in 1976. Consequently, a full restoration of Pelekane Bay would require the following changes:

1. Reduction in the amount of terrestrial sediment runoff. Because terrestrial runoff is associated with watershed degradation, this step would require reestablishing vegetation in the Kawaihae area or installing sediment basins upslope from the ocean.

2. Increase in ocean circulation. In order to flush naturally occurring sediments the circulation in the bay needs to be increased. It may possible to run a canal through the harbor landfill from the large-vessel harbor to Pelekane Bay to allow longshore currents to re-enter the bay and flush out suspended sediments.

3. Removal of accumulated sediments. To foster the re-establishment of corals through normal larval recruitment, the sediment accumulated since harbor construction needs to be removed. This step would require careful dredging of the sediment in the middle of Pelekane Bay. This habitat is completely covered with soft sediments and could be removed without damaging the patch reefs. Care must be taken with respect to the Hawaiian shark heiau (*Hale o Kapuni*), an important Hawaiian archeological site, which may be located in the middle of the Bay (Greene, 1993).

4. Coral transplantation. Based on several studies in Hawai'i (Grigg and Maragos, 1974; Maragos, 1991), natural recruitment, growth, and eventual reestablishment of the coral reef in Pelekane Bay could take 30-50 years. Therefore, in order to facilitate and accelerate this process transplantation of adult corals into this area would be warranted.

During the process of restoration in would be important to continue monitoring the marine biota in addition to the magtitude and frequency of sedimentation occurring in the area. Changes in the reef community associated with restoration of the Pelekane watershed and subsequent reductions in terrestrial run-off would present a unique and unprecedented opportunity to observe the coupled response of both marine and terrestrial systems to resource management in addition to restoring both an aesthetic, economic and culturally important area.

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Table 1. Physical descriptions of habitat types present at Pelekane Bay, Hawai'i and a summary of their major biological features. Habitat types follow those described in Chaney et al. (1977).

Habitat Type 1: Mixed rubble and silt bottom

Depth to 1 m. Substrate defined as loose small to medium-sized coral rubble or debris with coral fragments up to 20 cm in diameter. Alternating compositions of sand and silt mixed with coral rubble. Substrate was commonly covered with filimentous red algae and super-surface algal mats. Encrusting coralline algae was seen, but rare. Macro-invertebrates that were observed, but rare, include burrowing shrimp and isopods. Box crabs were commonly seen. *Chelonia midas* were commonly observed on sandy bottoms.

Habitat Type 2: Sand and silt bottom

Depth ranged from 1 - 3 m. Visibility was usually very poor—between 0.5-1.0 m. Substrate was primarily composed of silt and sand. Shrimp burrows were quite abundant, ranging from 0.5 cm - 4 cm in diameter. Distinct channeling of silt between shore and patch reef area. *Chelonia midas* were observed but rare.

Habitat Type 3: Basalt pavement with rubble

Depth was 0.5 - 3 m. Southern side of bay composed of basaltic pavement and large boulders. Visibility usually ranged between 1-3m. Macro-invertebrates commonly seen were *Echinometra mathaei, E. oblonga, Echinothrix diadema, E. calamaris*. Other invertebrates that were seen include *Anthelia edmondsoni, Zoanthus specificus*, and turf algae. Common fish were juvenile *Acanthurus triostegus* and *Mulloidichthys* spp., *Kuhlia sandvicensis* and *Mugil cephalus*.

Habitat Type 4: Coral in mixed rubble

Depth usually between 0-1m. Characterized by small dead coral heads on a silt-sand substrate (off Eastern point) and offshore. Some *Pocillopora damnicornis* and isolated patches of *Porites lobata* were observed. Filamentous algae and *Porolithon onkodes* were common.

Habitat Type 5: Patch reefs

Patch reefs were 1-4m in depth. Habitat Type 5 had the greatest visibility on all occasions ranging from 2-4m. Large vertical relief of coral formations that were up to 4m in diameter. Most coral formations were dead due to extensive sedimentation or coverage by dead coralline algal mats. Live corals were sparsely distributed patches of *Porites lobata* interspersed with *Pocillopora damnicornis, Porites compressa*, and *Pavona varians*. Large areas were abundantly covered with *Porolithon gardeneri* and *P. onkodes*. Few macro-invertebrates were found. Those that were included *Echinometra mathaei*.

Table 2. Areal estimates of habitat types present at Pelekane Bay, Hawai'i based on underwater surveys and aerial photographs.

Habitat type	**Area (m^2)**	**Percent of total**
I. Mixed rubble and silt bottom	7,593	16%
II. Sand and silt bottom	21,651	45%
III. Basalt pavement with rubble	2,758	6%
IV. Coral in mixed rubble	4,375	9%
V. Patch reefs	12,111	25%

Table 3. Qualitative observations marine organisms observed in habitat zones at Pelekane Bay in 1996. Relative abundance was estimated in five different habitat types: I. Mixed rubble and silt bottom, II. Sand and silt bottom, III. Basalt pavement with rubble, IV. Coral in mixed rubble, and V. Patch reefs. Organisms were noted as A = abundant, C = common or R = rare.

PLANTS

DIVISION	SPECIES	RELATIVE ABUNDANCE IN HABITAT TYPES				
		I	II	III	IV	V
Phaeophyta	*Padina japonica*					R
Rhodophyta	*Porolithon gardeneri*					C
	Porolithon onkodes	R			C	C

INVERTEBRATES

PHYLUM	SPECIES	RELATIVE ABUNDANCE IN HABITAT TYPES				
		I	II	III	IV	V
Cnidaria	*Anthelia edmondsoni*			A		
	Montipora verrucosa					R
	Palythoa tuberculosa			R		
	Pavona varians					R
	Pocillopora damnicornis			C	C	R
	Pocillopora meadrina					R
	Porites lobata			C	C	C
	Porites compressa					R
	Zoanthus pacificus			R		
Mollusca	vermetid gastropods					C
Annelida	*Alpheus* burrows	R	C			
	Spirobranchus giganteus					R
Arthropoda	*Alphaeus spp.*	C	A			
	Callapa hepatica	C				
	Grapsus tenuicrustatus			C		
	burrowing *isopods*	R				
Echinodermata	*Actinopyga mauritiana*					
	Echinometra mathaei			C		R
	Echinometra oblonga			C		
	Echinothrix diadema			C		
	Echinothrix calamaris			C		

FISHES

FAMILY	SPECIES	RELATIVE ABUNDANCE IN HABITAT TYPES I	II	III	IV	V
Carcharhinidae	*Cacharhinus melanopterus*		C			R
Synodontidae	*Synotus* sp.			C		R
Kuhliidae	*Kuhlia sandvicensis*			C		
Apogonidae	*Apogon* spp.					R
Lutjanidae	*Lutjanus fulvus*					C
	Lutanus vaigiesis					
Mugilidae	*Mugil cephalus*			C		
Mullidae	*Mulloidichthys flavolineatus*			C		
	Mulloidichthys vanicolensis			C		R
	Parupeneus bifasciatus					
	Parupeneus cyclostomus					R
	Parupeneus multifasciatus					C
	Paracirrhites arcatus					
Chaetodontidae	*Chaetodon auriga*					R
	Chaetodon lunula					R
	Chaetodon miliaris					
	Chaetodon multicinctus					
	Chaetodon ornatissimus					R
	Chaetodon quadrimaculatus					
	Chaetodon trifasciatus					
	Chaetodon unimaculatus					C
Pomacentridae	*Abudefduf abdominalis*					
	Chromis hanui					R
	Chromis ovalis					
	Dascyllus albisella					
	Plectroglyphidodon imparipennis					R
	Plectroglyphidodon johnstonianus					R
	Stegastes fasciolatus					C
Labridae	*Coris flavovittata*					
	Coris gaimard					R
	Gomphosus varius					C
	Halichoeres ornatissimus					R
	Labrid spp.					
	Labroides phthirophagus					
	Stethojulis balteatus					
	Thallosoma ballieui					C
	Thallosoma duperrey					C

FAMILY SPECIES RELATIVE ABUNDANCE IN

		HABITAT TYPES				
		I	II	III	IV	V
Scaridae	*Calotomus sandvicensis*					
	Scarus dubius					
	Scarus sordidus					
	Scarus spp. (juveniles)					C
Zanclidae	*Zanclus canescens*					
	Zanclus cornutus					
Acanthuridae	*Acanthurus blochii*					R
	Acanthurus leucopareius					C
	Acanthurus. nigrofuscus					C
	Acanthurus. nigroris					C
	Acanthurus. triostegus			C		C
	Ctenochaetus strigosis					C
	Naso lituratus					
	Zebrasoma veliferum					
Monacanthidae	*Pervagor spilosoma*					
Ostraciidae	*Ostracion spp.*					
	Ostracion meleagris					R
Tetraodontidae	*Arothron meleagris*					
	Canthigaster jactator					

REPTILES

FAMILY	SPECIES	RELATIVE ABUNDANCE IN HABITAT TYPES				
		I	II	III	IV	V
Chelonidae	*Chelonia midas*	C	R			

Table 4. Abundance of substrate types on patch reefs in 1976 compared to 1996. Mean percent cover of plants, invertebrates and non-living substrates and standard error of surveys on transects (inner. middle, or outer) for each year are presented. The probability that samples are different among years is given for a two-sample t-test. Values indicated by an asterisk (*) are significant at $\alpha = 0.05$

	1976		1996			1976		1996		
Taxa	**Inner**	**Outer**	**Inner**	**Middle**	**Outer**	**Mean**	**SE**	**Mean**	**SE**	**P**
Plants										
Turf algae	0.0	0.0	0.0	8.3	0.0	0.0	0.0	2.8	2.8	0.42
Encrusting coralline algae	0.0	0.0	1.0	12.7	1.9	0.0	0.0	5.2	3.7	0.30
Porolithon onkedes - live	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.6	0.6	0.42
Porolithon onkedes - dead	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.8	0.8	0.42
Corals										
Cyphastrea ocellina	0.9	0.8	0.0	0.0	0.0	0.9	0.0	0.0	0.0	**0.04***
Lepastrea bottae	0.9	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.50
Montipora patula	0.0	3.8	0.0	0.0	0.0	1.9	1.9	0.0	0.0	0.50
Montipora verrucosa	5.5	8.8	0.3	0.9	0.0	7.2	1.7	0.4	0.3	0.14
Pavona varians	0.9	0.8	0.0	0.0	0.0	0.9	0.0	0.0	0.0	**0.04***
Pocillopora damnicornis	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.3	0.3	0.42
Pocillopora meandrina	2.3	4.6	0.0	0.1	1.3	3.5	1.2	0.4	0.4	0.20
Porites compressa	23.0	8.8	3.1	0.3	0.6	15.9	7.1	1.3	0.9	0.28
Porites lobata	8.7	13.4	1.3	8.8	1.6	11.1	2.4	3.9	2.4	0.13
Porites sp.	3.7	0.0	0.0	0.0	0.0	1.9	1.9	0.0	0.0	0.50
Non-living substratum										
Dead coral	8.1	23.0	59.1	56.4	47.2	15.6	7.5	54.2	3.6	0.07
Sand & Mud	46.0	36.0	31.1	12.8	47.5	41.0	5.0	30.5	10.0	0.42

Table 5. Abundance of fishes on patch reefs in 1976 compared to 1996. Mean number of fish per 100 m^2 and standard error of surveys on transects (inner, middle or outer) for each year are presented. The probability that samples are different among years is given for a two-sample t-test. Values indicated by an asterisk (*) are significant at $\alpha = 0.05$

	1976				1996					
	Inner	**Outer**	**Mean**	**SE**	**Inner**	**Middle**	**Outer**	**Mean**	**SE**	**P**
Carcharhinidae										
Carcharhinus melanopterus	0.000	0.000	0.000	0.000	0.083	0.083	0.000	0.056	0.028	0.184
Synodidae										
Synodus spp.	0.000	0.000	0.000	0.000	0.167	0.000	0.000	0.056	0.056	0.423
Apogonidae										
Apogon spp.	0.000	0.000	0.000	0.000	0.056	0.083	0.000	0.046	0.024	0.199
Lutjanidae										
Lutjanus fulvus	0.000	0.000	0.000	0.000	0.611	1.217	0.483	0.770	0.226	0.076
Lutanus vaigiesis	0.000	0.200	0.100	0.100	0.000	0.000	0.000	0.000	0.000	0.500
Mullidae										
Mulloidichthys flavolineatus	0.000	12.333	6.167	6.167	0.347	0.000	0.033	0.127	0.111	0.370
Mulloidichthys vanicolensis	0.000	0.000	0.000	0.000	0.444	0.083	0.000	0.176	0.136	0.326
Paracirrhites arcatus	0.067	0.000	0.033	0.033	0.000	0.000	0.000	0.000	0.000	0.500
Parupeneus bifasciatus	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.011	0.011	0.423
Parupeneus cyclostomus	0.000	0.000	0.000	0.000	0.111	0.167	0.167	0.148	0.019	0.015*
Parupeneus multifasciatus	0.267	0.200	0.233	0.033	0.333	0.233	0.350	0.306	0.036	0.246
Chaetodontidae										
Chaetodon auriga	0.000	0.000	0.000	0.000	0.306	0.167	0.150	0.207	0.049	0.052
Chaetodon lunula	0.000	0.000	0.000	0.000	0.153	0.167	0.167	0.162	0.005	0.001*
Chaetodon miliaris	0.000	0.200	0.100	0.100	0.139	0.000	0.383	0.174	0.112	0.657
Chaetodon multicinctus	0.000	0.200	0.100	0.100	0.000	0.000	0.000	0.000	0.000	0.500
Chaetodon ornatissimus	0.200	0.000	0.100	0.100	0.194	0.067	0.267	0.176	0.058	0.590
Chaetodon quadrimaculatus	0.000	0.200	0.100	0.100	0.000	0.000	0.150	0.050	0.050	0.710
Chaetodon trifasciatus	0.600	0.200	0.400	0.200	0.042	0.000	0.150	0.064	0.045	0.331

	1976				1996					
	Inner	**Outer**	**Mean**	**SE**	**Inner**	**Middle**	**Outer**	**Mean**	**SE**	**P**
Chaetodon unimaculatus	0.000	0.333	0.167	0.167	0.042	0.300	0.133	0.158	0.076	0.969
Pomacentridae										
Abudefduf abdominalis	3.133	1.533	2.333	0.800	0.056	0.000	0.550	0.202	0.175	0.215
Chromis hanui	0.000	0.000	0.000	0.000	0.000	0.083	0.167	0.083	0.048	0.225
Chromis ovalis	4.800	6.933	5.867	1.067	0.000	0.000	0.000	0.000	0.000	0.114
Dascyllus albisella	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.028	0.028	0.423
Plectroglyphidodon imparipennis	0.000	0.000	0.000	0.000	0.236	0.100	0.000	0.112	0.068	0.243
Plectroglyphidodon johnstonianus	0.200	0.000	0.100	0.100	0.000	0.067	0.000	0.022	0.022	0.577
Stegastes fasciolatus	2.067	1.467	1.767	0.300	1.389	0.850	1.400	1.213	0.182	0.272
Labridae										
Coris gaimard	0.000	0.000	0.000	0.000	0.000	0.083	0.083	0.056	0.028	0.184
Coris flavovittata	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.028	0.028	0.423
Coris spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.067	0.022	0.022	0.423
Gomphosus varius	0.400	0.867	0.633	0.233	1.931	1.683	2.033	1.882	0.104	0.075
Halichoeres ornatissimus	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.028	0.028	0.423
Labroides phthirophagus	0.000	0.200	0.100	0.100	0.042	0.000	0.333	0.125	0.105	0.875
Stethojulis balteatus	0.000	0.133	0.067	0.067	0.000	0.000	0.000	0.000	0.000	0.500
Thallosoma ballieui	0.200	0.267	0.233	0.033	0.000	0.417	0.083	0.167	0.127	0.658
Thallosoma duperrey	2.800	2.933	2.867	0.067	1.125	1.483	1.617	1.408	0.147	0.004*
Unidentified labrid	0.000	0.200	0.100	0.100	0.000	0.000	0.000	0.000	0.000	0.500
Scaridae										
Calotomus sandvicensis	0.000	0.133	0.067	0.067	0.000	0.000	0.000	0.000	0.000	0.500
Scarus dubius	0.133	0.400	0.267	0.133	0.000	0.000	0.000	0.000	0.000	0.295
Scarus sordidus	1.200	4.667	2.933	1.733	0.000	0.000	0.000	0.000	0.000	0.340
Scarus spp. (juveniles)	0.000	0.200	0.100	0.100	5.361	3.617	3.767	4.248	0.558	0.015*
Zanclidae										
Zanclus canescens	0.000	0.200	0.100	0.100	0.000	0.000	0.000	0.000	0.000	0.500
Acanthuridae										
Acanthurus blochii	0.000	0.133	0.067	0.067	0.056	0.167	0.000	0.074	0.049	0.937
Acanthurus leucopareius	0.000	0.000	0.000	0.000	0.000	0.433	0.233	0.222	0.125	0.218
Acanthurus nigrofuscus	0.000	1.400	0.700	0.700	1.111	1.517	1.050	1.226	0.146	0.588

	1976				1996					P
	Inner	Outer	Mean	SE	Inner	Middle	Outer	Mean	SE	P
Acanthurus nigroris	0.000	0.133	0.067	0.067	0.556	0.417	0.717	0.563	0.087	0.020*
Acanthurus triostegus	0.200	0.000	0.100	0.100	1.139	0.967	1.667	1.257	0.211	0.020*
Ctenochaetus strigosis	0.667	1.933	1.300	0.633	2.222	2.883	1.783	2.296	0.320	0.329
Naso lituratus	0.200	0.000	0.100	0.100	0.000	0.000	0.000	0.000	0.000	0.500
Zebrasoma veliferum	0.200	0.000	0.100	0.100	0.000	0.000	0.000	0.000	0.000	0.500
Monacanthidae										
Pervagor spilosoma	0.000	0.200	0.100	0.100	0.000	0.000	0.000	0.000	0.000	0.500
Ostraciidae										
Ostracion meleagris	0.000	0.000	0.000	0.000	0.236	0.033	0.183	0.151	0.061	0.131
Ostracion spp.	0.200	0.000	0.100	0.100	0.000	0.000	0.000	0.000	0.000	0.500
Tetraodontidae										
Arothron meleagris	0.000	0.267	0.133	0.133	0.042	0.000	0.083	0.042	0.024	0.616
Canthigaster jactator	0.000	0.200	0.100	0.100	0.000	0.000	0.000	0.000	0.000	0.500

Table 6. Change in fish community structure on patch reefs in 1976 compared to 1996. Species of fish are listed that are unique to each survey.

A. Species recorded in 1976 but not recorded in 1996

Calotomus sandvicensis
Canthigaster jactator
Chaetodon multicinctus
Chromis ovalis
Lutanus vaigiesis
Naso lituratus
Ostracion spp.
Paracirrhites arcatus
Pervagor spilosoma
Scarus dubius
Scarus sordidus
Stethojulis balteatus
Zanclus canescens
Zebrasoma veliferum

B. Species recorded in 1996 but not recorded in 1976

Acanthurus leucopareius
Apogon spp.
Carcharhinus melanopterus
Chaetodon auriga
Chaetodon lunula
Chromis hanui
Coris flavovittata
Coris gaimard
Dascyllus albisella
Halichoeres ornatissimus
Lutjanus fulvus
Mulloidichthys vanicolensis
Ostracion meleagris
Parupeneus bifasciatus
Parupeneus cyclostomus
Plectroglyphidodon imparipennis
Synodus spp.

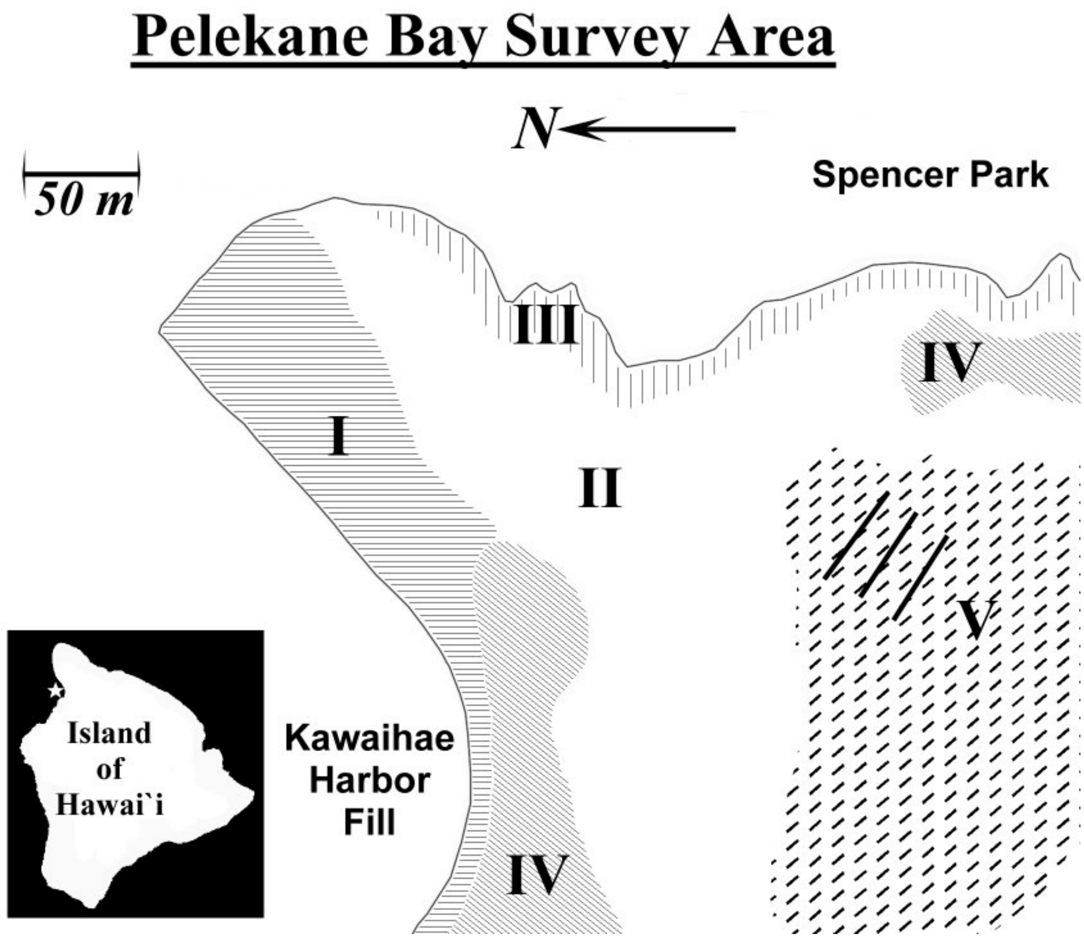

Figure 1. Map of Pelekane Bay study area indicating habitat types (I-V) and location of surveyed transects (three diagonal lines). Habitat types are: I. Mixed rubble and silt bottom; II. Sand and silt bottom; III. Basalt pavement with rubble; IV. Coral in mixed rubble; V. Patch reefs.

Figure 2. Aerial photographs of Pelekane Bay taken on July 31, 1996 showing the study area in relation to Kawaihae harbor and *Pohaukole* gulch (lower right).

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Figure 3. Aerial photographs of Pelekane Bay taken on July 31, 1996 showing habitat types in relation to *Pohaukole* Gulch, which enters Pelekane Bay in the lower right-hand corner of the picture.

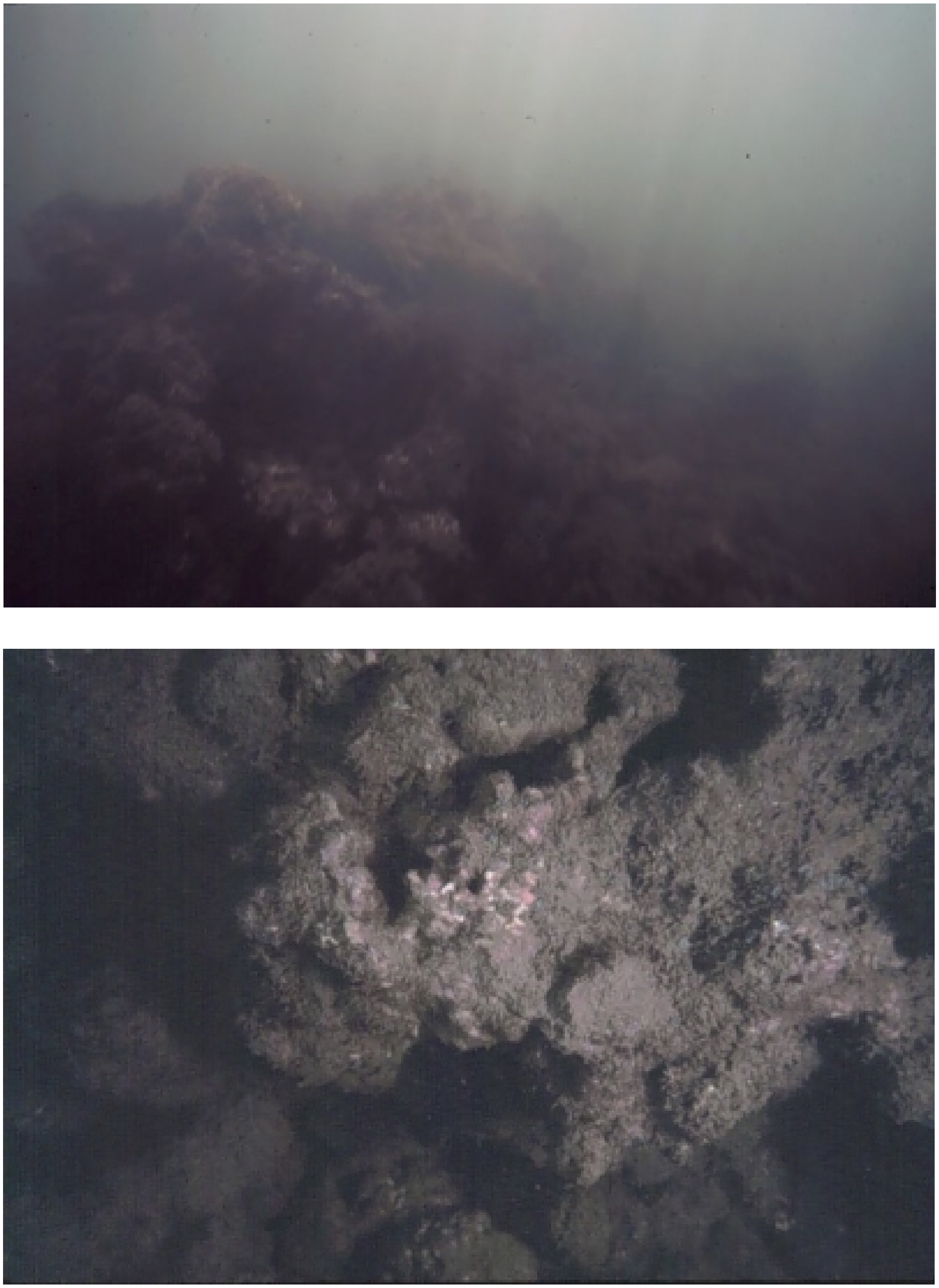

Figure 4. Underwater photographs illustrating habitat type I, mixed rubble and silt bottom, at Pelekane Bay taken during the summer of 1996. Silt covered rocks are noticeably bare of living organisms.

Figure 5. Underwater photographs illustrating habitat type II, sand and silt bottom, at Pelekane Bay taken during the summer of 1996. Animal burrows belong to *Alpheus* shrimp and unknown species of polychaete worms. Bottom photograph illustrates mucus sacks extruding from unknown animal burrows.

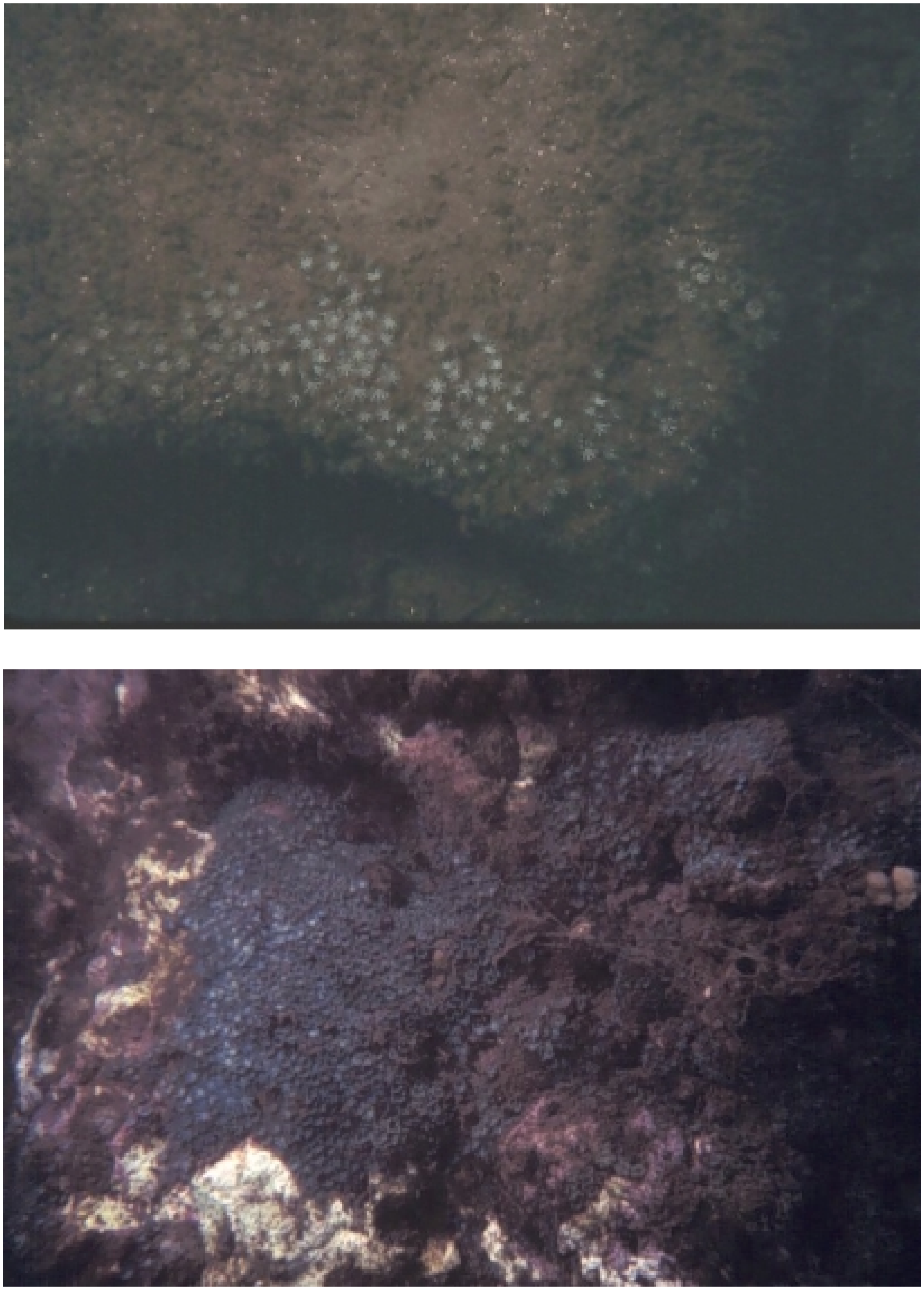

Figure 6. Underwater photographs illustrating habitat type III, basalt pavement with rubble bottom, at Pelekane Bay taken during the summer of 1996. Silt-covered rocks are encrusted with the octocoral, *Anthelia edmondsoni.*

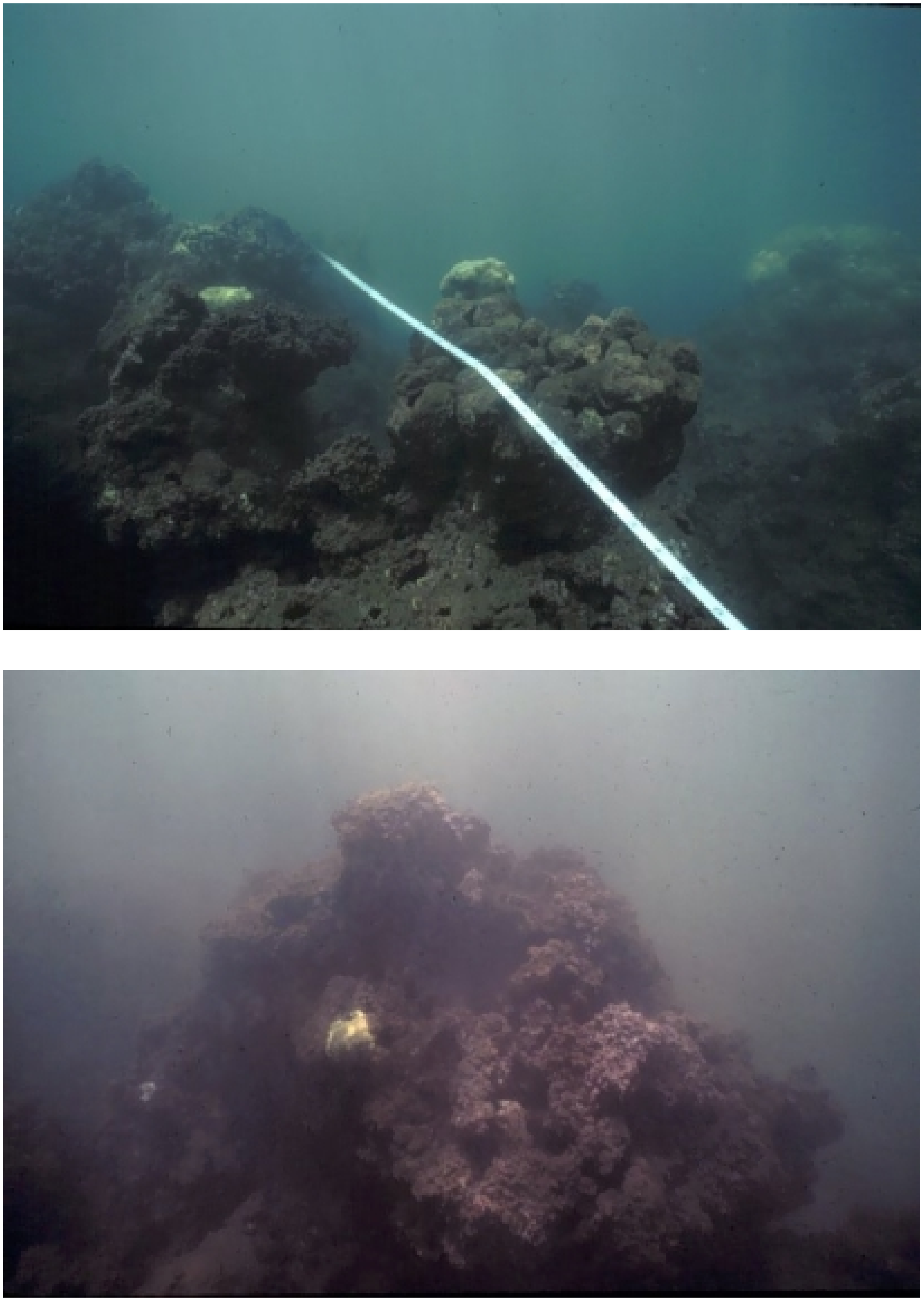

Figure 7. Underwater photographs illustrating habitat type V, patch reefs, at Pelekane Bay taken during the summer of 1996. Small patches of live coral are *Porites lobata*; also present is a small patch of *Porolithon gardineri* (bottom right).

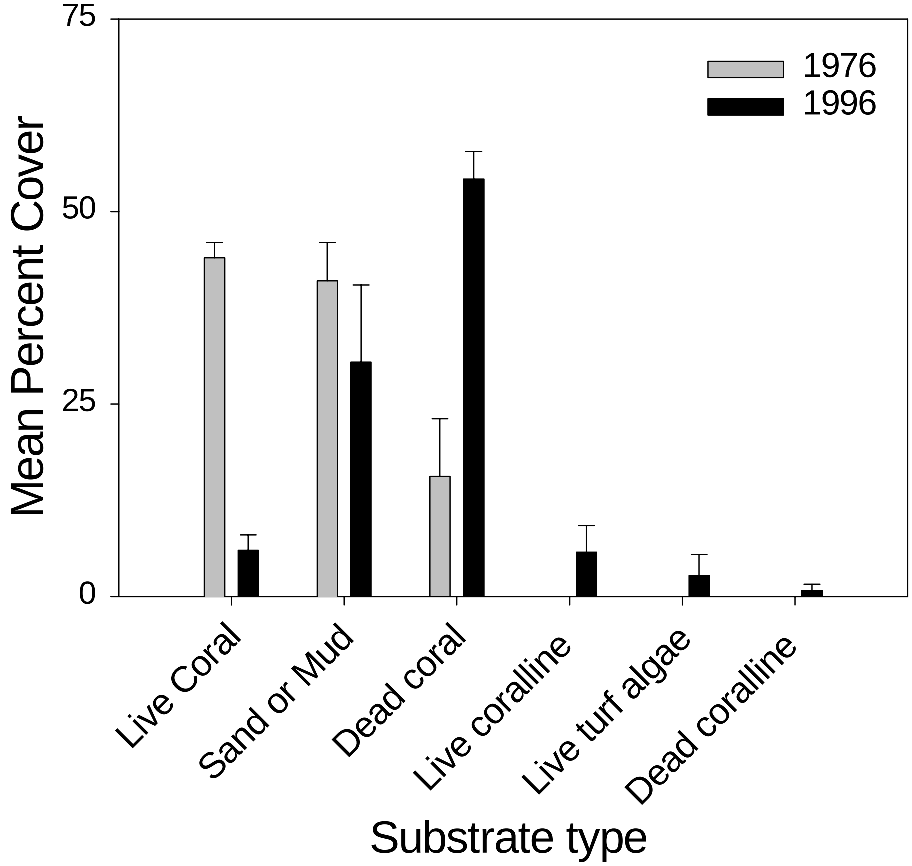

Figure 8. Mean percent cover (±1 SE) of major substrate types on patch reefs at Pelekane Bay, Hawai'i in 1996 relative to surveys by Chaney et al. (1977) conducted in 1976.

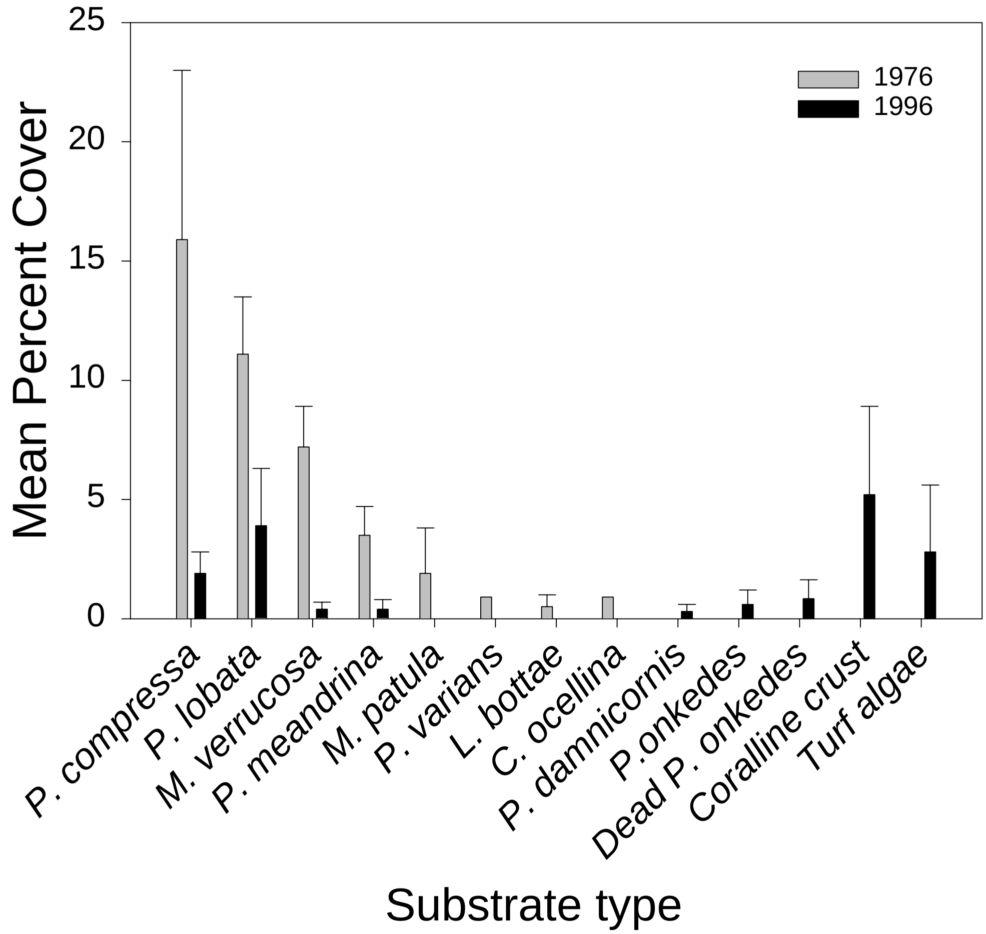

Figure 9. Mean percent cover (±1 SE) of corals and seaweeds on patch reefs at Pelekane Bay, Hawai'i in 1996 relative to surveys by Chaney et al. (1977) conducted in 1976.

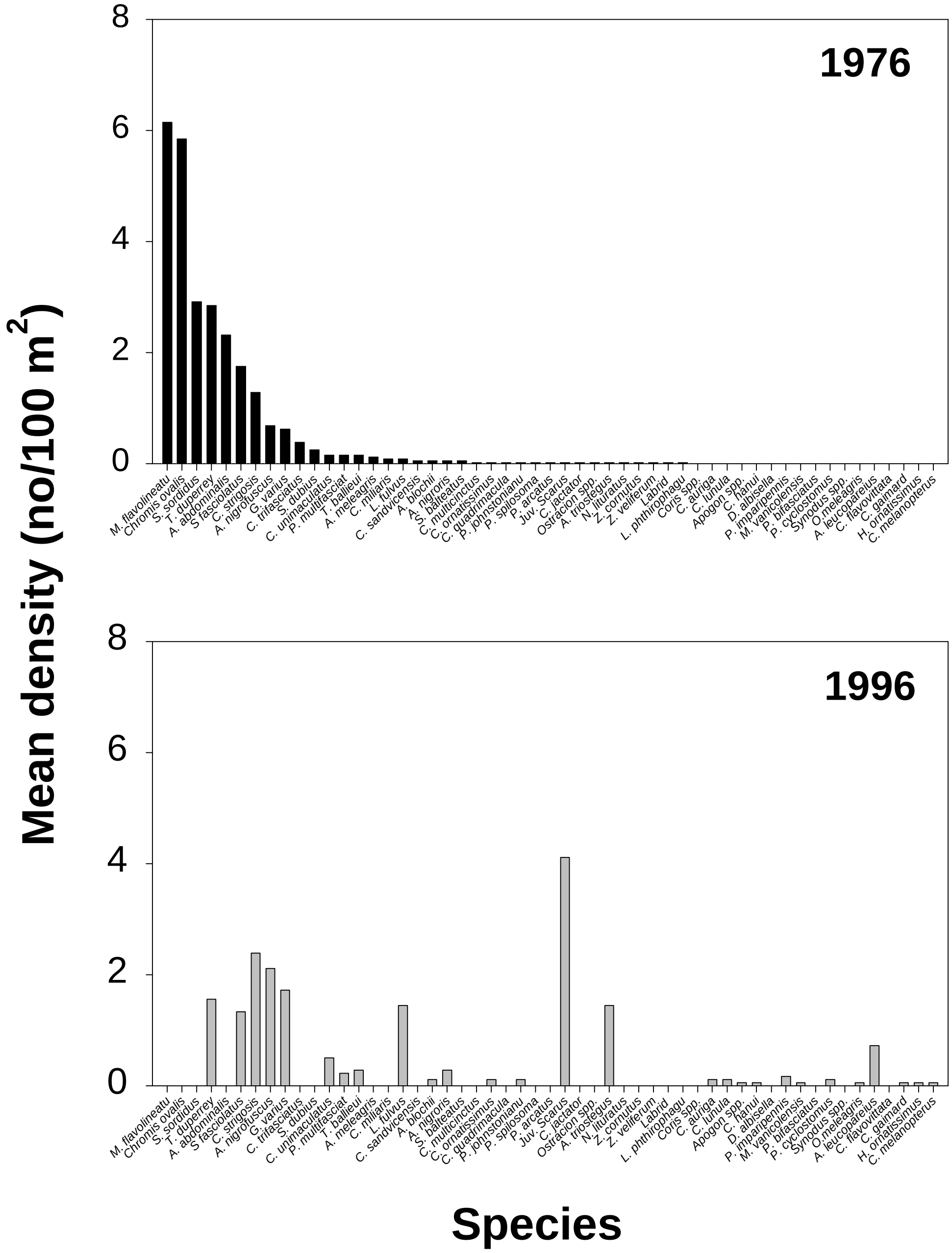

Figure 10. Mean density of fishes per 100 m^2 (±1 SE) on patch reefs at Pelekane Bay, Hawai'i in 1996 relative to surveys by Chaney et al. (1977) conducted in 1976.

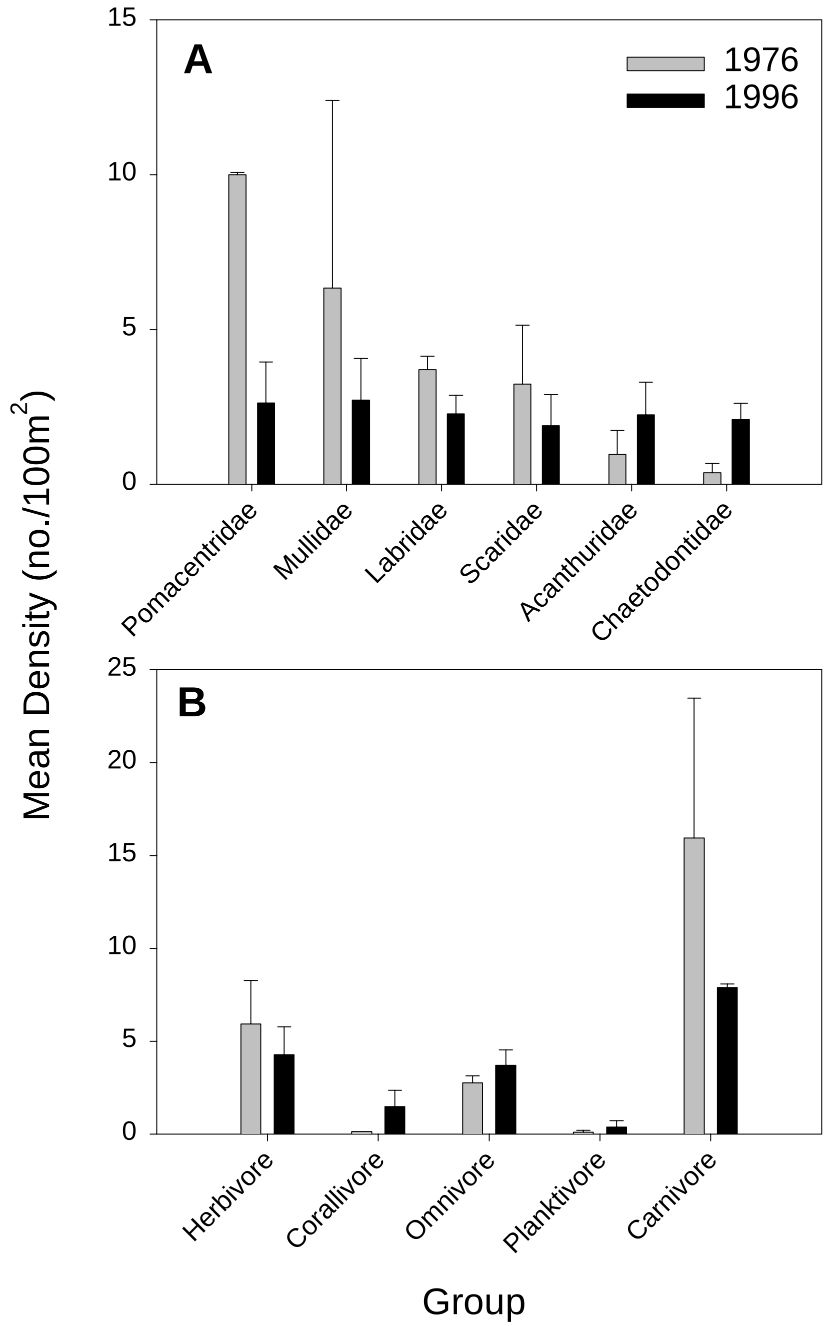

Figure 11. Mean density of fishes per 100 m^2 (±1 SE) on patch reefs at Pelekane Bay, Hawai'i in 1996 relative to surveys by Chaney et al. (1977) conducted in 1976. **A**. Fish families. **B**. Fish feeding guilds.