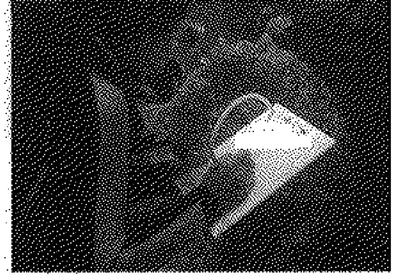

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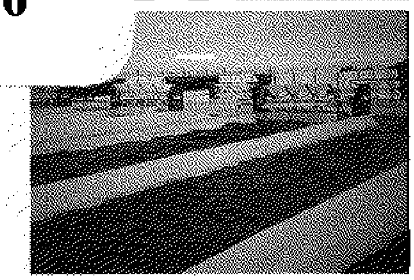

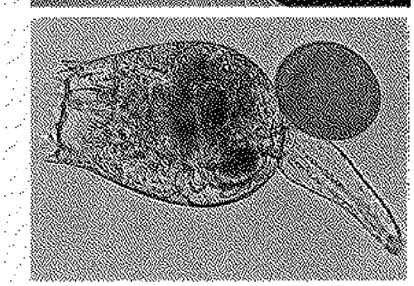

Sea Grant College Program
School of Ocean and Earth Science and Technology
University of Hawai'i

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Cover (from top to bottom): Student observing the propellar on the SS Kaua'i*; Lena Asano growing her rotifers at the Anuenue Fisheries Research Center; Raceways at Aquasearch Inc. Laboratory, NELHA, Kailua-Kona; Sara Peck and William Young in the culturing laboratory at Aquasearch Inc.; A basic rotifer that has eaten algae with eggs; and Lena Asano counting rotifers or algae at Anuenue Fisheries Research Center.*
Photos of Lena Asano and the rotifers are courtesy of Harry Ako. All other photos are courtesy of Marine Option Program.

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Abstract

Three undergraduate student research projects were jointly funded by the University of Hawaii Sea Grant College Program and the Hawaii Department of Land and Natural Resources during the summer of 1996. Project topics were selected to promote sustainable use of ocean resources: the biological impact of a shipwreck, aquaculture as a solution to overpopulation of an exotic aquatic snail, and site selection for an artificial reef to enhance surfing and fish populations. Each project produced a final written report; one also produced a videotape, and all students presented their results at a concluding symposium.

The *Kaua'i*, A Financial Loss ... An Ecological Gain: Biological Survey and Mapping of the Shipwreck *Kaua'i*, Mahukona, Hawaii

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Funding by:
University of Hawaii Sea Grant Fellowship
Department of Land and Natural Resources (DLNR)

Final Report
August 15, 1996

Abstract

We chose a wreck off Mahukona, on the north-western side of the Big Island of Hawaii, to study an artificial reef ecosystem and investigate the effect that such structures have on the nearby marine community. Although only the propeller, propeller shaft, engine and boiler remain, even small artificial reefs may show a difference in biomass densities in comparison to sand and natural reefs.

We studied the distribution and richness of the artificial reef to determine if biomass was being enhanced in comparison to the surrounding area. We found that certain sections of the wreck did enhance encrusting substrate and fish species abundance. However, stony corals and mobile invertebrates were not significantly influenced by the artificial environment. A study was also conducted on the abundance of living substrate on horizontal and vertical wreck pieces. We found that the stony corals and filamentous algae showed no preference for any one orientation, but that the crustose algae had a higher abundance on the horizontal surfaces. Overall, the wreck appears to have become a part of the reef and provides new habitat for the local flora and fauna.

Introduction

In recent years, ships have been sunk for the reef-like climate they produce and the biota they are thought to attract. Usually, the hope is that by sinking these new habitats, more biota will settle, and eventually growth will be stimulated in an area that has been either destroyed or that has low productivity (Spainer *et al.*, 1990). Most experimentation with artificial reefs is relatively recent, and many discoveries have been made as to what types of materials stimulate a good environment for coral growth (Harriott, 1992). However, there is still much to be learned on the broader effects these wrecks are having on the marine community.

Many ships have sunk all around the Hawaiian chain over the last 100-plus years and there are still a few pieces left in shallow waters that have not yet been claimed by the ocean. None of the vessels around the Big Island is there intentionally as an artificial reef (Hendricks, 1996), but, in theory, the amount of biological recruitment and growth should be the same on an intentional and an unintentional sunken ship.

In San Francisco in 1887, the steamer *Cosmopolis* was commissioned. In 1896, under the name *Kaua'i*, the steamer was brought to Hawaii to be a cargo transport between the islands. She was considered a second class steamer, 154 ft. long, 32 ft. beam, 10 ft. draft, 265 tons regulation, and her captain was William Mayne. On December 24, 1913 she was moored off the Mahukona area filled with railroad trucks and other small items. A heavy trade wind was blowing from the northeast and, without warning, switched to a southerly quarter. The *Kaua'i* broke from the mooring, and, before help could get to her, she washed up onto the reef. An attempt by the steamer *Maui* to pull her off the reef proved useless, and the *Kaua'i* was given up to the sea and rests there today in 20 feet of water (Anonymous, 1913). The wreck pieces have been at this site for eighty-three years, and the coral communities living in and on it have had time to climax stabilize and should show long term results that are comparable to the off-wreck community.

The objective of our study was to investigate the marine community associated with the shipwreck *Kaua'i*, located at Mahukona, Hawaii. We propose to show a comparison between an artificial reef and the immediate surrounding area. Our focus will be on the abundance of corals, invertebrates and fish in two locations on the wreck and on one off-wreck location. We will also compare species composition on the horizontal and vertical substrates to see if orientation plays a role in recruitment of species.

The questions asked in this study are:

(1) Does the wreck enhance species richness and abundance compared to the surrounding area?

(2) Does the orientation of the substrate (horizontal vs. vertical) have different effects on the marine community (Wendt *et al.*, 1989)?

Methods and Materials

The study site for this project lies approximately 100 meters offshore with a depth between 6.5 to 7 meters of water at Mahukona, Hawaii (N 20°11'15", W 155° 54'15") (Figure 1). The data were collected between June 22, 1996 and July 10, 1996 between 7:30 am and 3:30 pm.

Two transect lines were deployed in parallel at the site. One ran the length of the wreck pieces for 20m from the propeller, along the shaft, to the top of the engine then turned at a forty-five degree angle toward the boiler. The second ran off-wreck for the same 20m length, starting at a distance five meters out from the boiler, shoreside (Figure 2). The distance between transects was chosen to minimize differences in environmental factors, while still being far enough apart to avoid species interaction among the two sites.

To follow Wendt *et al.*, 1989, attention was also given to the orientation of the living substrates on the wreck. The wreck data were divided into horizontal and vertical categories and tested for differences in abundance and species present. Tests were run on corals, crustose and filamentous algae for variations in abundance due to differences in orientation. Horizontal pieces included the boiler top (Figure 4c.i.) and the horizontal surfaces of the engine (Figure 4b.ii.). The vertical pieces included the shore face of the boiler (Figure 4c.ii.), the right side of the boiler when facing boiler front, the left side of the boiler when facing boiler front, the seaward face of the boiler and the surfaces of the engine. The vertical surfaces of the engine were pooled due to very low sample sizes in this group (Figure 4b.i.).

A photographic substrate survey was completed utilizing a Nikonos camera with a 15 mm. lens mounted on a photoquadrate with predetermined settings to give consistency in the area being measured (Figure 3). All photographs were marked as to their location on a map of the wreck, in the event that any ground truthing was necessary for species identification. This method allowed an accurate measurement of the percentages of the bottom species and rock from the photographs, while still providing correct classification of the indistinguishable species in the photograph. Data on encrusting organisms were collected from the photographs using the random point intersect method and were later transformed into percent cover. Fifty random points were generated from a random number sheet and plotted on a 20.5 x 11 inch area for the off-wreck and engine/boiler quadrates and 8.5 x 39 inch height for the propeller and propeller shaft to keep the sample area unified while maximizing the narrower wreck pieces. These area sizes were chosen to facilitate species identification.

The crustose algae was not identified to species, due to the limited resources available to this study but instead was grouped into the following colors: white coralline algae, light purple crustose, light green crustose, green crustose, brown crustose, blue crustose and yellow crustose.

Large mobile invertebrates were sampled by counting all individuals on the same parallel transects of 20 random point locations using 0.25 m^2 quadrats. Invertebrates were also censused using a species count approximation during a free swim over the wreck pieces. These two methods were analyzed differently; the first used mean density counts across species and quadrate to establish a comparison of on- and off- wreck sites, and the second used to build a species list.

During a survey dive it became visually apparent, that the propeller/shaft and the engine/boiler pieces provided different environments for fish, so the fish data were collected in three areas: propeller/shaft for 10 meters, engine/boiler for 10 meters and off-wreck for 20 meters. To estimate the abundance and species richness of fish for each site, the strip transect method was used. Two divers swam along the transects and recorded the species and number of fish that were seen between the transect and three meters either side. All fish surveys were performed in the morning and repeated in the afternoon. In analysis, these data were transformed to density in no./100m^2.

Analysis of these fish data included tests for the Shannon-Wiener diversity index, totals, density and percent for each species as well as grand total and percent. Fish were also separated into feeding guilds with the categories of detritivores, herbivores, planktivores, coralivores, carnivores, cleaners, omnivores and unknowns (Randall, 1985).

Mapping of the wreck structures and their living substrate was performed, using photographs taken in the field and later projected in a small frame for tracing. Video footage for an underwater wreck documentary was taken using a low-8 mm, Sony 40 m Handycam Marine Pack.

All statistical tests were performed in Minitab ver. 11.1 using one-way ANOVA's or the General Linear Model for two-way analysis.

Results

Biological diagramming was done on the three wreck pieces. The propeller and shaft did not have much growth on them except for the crustose and filamentous algae. As evidenced by the rust patches, the propeller is slowly deteriorating. There are a few small patches of *Porites lobata* on the shaft as well as *Pocillopora meandrina* on the propeller itself (Figure 4ai, ii). The engine is covered in crustose algae as well as *Porites lobata,* so much so, that the original metallic pieces are hard to distinguish (Figure 4bi, ii). The boiler was heavily populated with *Porites lobata* as well as crustose algae. The are many holes in the boiler, the largest of which is located on the top section (Figure 4ci, ii).

The first series of statistical tests were performed on the living substrate data. All stony corals were pooled together for analysis on total coral cover across the three different locations, p-value registered at 0.005 for a significant difference. The coral remained relatively constant across all locations, but showed higher levels in the engine/boiler section and was less abundant on the propeller/shaft location (Figure 5). When a one-way ANOVA between coral species was tested, *Porites lobata* showed significantly higher mean average percent when compared to all other stony corals at all locations for mean percent cover (Figure 6).

Total algae was found to be higher in abundance than corals overall, but when total corals were compared to crustose algae, the corals show a significantly higher mean percent coral (31%) over crustose algae (24%). Crustose algae is more abundant at the on-wreck sections, especially in the propeller/shaft section where there is less coral (Figure 5).

For further analysis, the algae were split into separate groups (Figure 6). There was a significantly higher mean percent cover of coralline algae (45%) and filamentous algae in respect to all other types of algae recorded. The light purple crustose algae (20%), although very abundant, was only significantly higher than the brown crustose algae (6%). Results of a two-way analysis of variance revealed a significant interaction between types of crustose algae and their location on the wreck: high on the horizontal sections (max. 55%) and practically absent on the off-wreck transect (min. 5%) (Figures 5a-c, Figure 7b).

In testing the filamentous algae, the propeller/shaft and off-wreck sections showed a significantly higher amount of filamentous algae than the engine/boiler section, but they are not significantly different from each other (Figure 5). A comparison of coral and filamentous algae percent coverage showed an inverse relationship between the two across all locations. The filamentous algae ranged from 10-58% while the coral ranged from 2-45%.

Analysis of the influence of horizontal and vertical wreck pieces to the encrusting organisms (Figure 7) showed mixed results. Filamentous algae does not show any significant difference in the horizontal (10%) and vertical (15%) surfaces; however, these data show a significant and dramatic difference in abundance between the larger wreck pieces and the propeller/shaft (55%) and off-wreck (68%) sections. Similarly, the stony corals showed no significant difference ($p = 0.087$) among the two orientations of wreck pieces. In contrast, crustose algae did significantly better on the horizontal surfaces (52%) than on the vertical surfaces (22%).

A one-way ANOVA showed average total densities, (Figure 8), for invertebrates to be low in density, but the off-wreck transect (2.1) shows a significantly higher average density than the on-wreck section (0.75) (mean density (1/4 m2) and n=20). The on-wreck totaled six species observed showing *Spirobranchus giganteus* (68%) and *Echinometra mathaei* (21%)

making up over 80% of the whole. The off-wreck totaled eight species showing *Echinometra mathaei* making up 83% of the whole. For a comparison of invertebrates between sites, the four shared spices *Spirobranchus giganteus, Echinometra mathaei, Heterocentrotus mammillatus* and *Echinothrix diadema* were analyzed and tested using one-way ANOVA's. These tests resulted in a significant difference between *Echinometra mathaei* at both sites (p=0.000) being higher on the off-wreck section. There also appears to be a greater amount of *Spirobranchus giganteus* on the wreck and *Heterocentrotus mammillatus* and *Echinothrix diadema* appear to be similar at both locations.

The total fish density was significantly greater (p=0.000) in the engine and boiler environment than the propeller shaft and the off-wreck sections (Appendix 1, Figure 9). A two-way ANOVA was used for the three most abundant species *(Acanthurus nigrofuscus, Ctenochaetus strigosus, Chromis vanderbilti)* between species and between sites. The test was found not to be significantly different between species and sites (p-value = 0.110) (propeller/shaft, engine or boiler) or between each species (p-value = 0.492), but was significantly different between locations (on-/off-wreck) as mentioned earlier.

The most abundant fish species made up 65% of the total number of fish recorded. These species tended to be more numerous overall in the engine and boiler environment (Figure 9). The high numbers of *Chromis vanderbilti* were thought to be skewing the total counts toward the boiler and engine so the same total density test was run without the *Chromis vanderbilti.* The same results and p-values were achieved, so there is confidence that the *Chromis vanderbilti* was not skewing the data totals.

The Shannon-Wiener diversity index was calculated for fish at the three sites, (Table 1) and indicates that the off-wreck section had the highest species richness and species eveness (H' = 1.1686) followed by the engine/boiler section (H' = 1.1352) and the propeller/shaft section (H' = 1.1209). Overall, there was not much variation across the three locations.

Based on fish feeding guilds (Figure 10), the detritivores have a significant dominance over all other feeding guilds by 63%. Herbivores were second in rank with 13% of the total. There was no significant interaction between feeding guilds and location (p-value = 0.960).

There were many fish that were not high in numbers overall, but which showed a specific preference for the engine/boiler section. Five species of these fish with relatively high numbers in comparison to other locations are presented in Table 3. Values are given in mean density, with a cut-off at 1.

Discussion

Overall, the wreck was found to play an intricate role in the marine community as an artificial reef. Some species of encrusting organisms were enhanced by the wreck's presence while others were unaffected. Many mobile invertebrates were much less abundant or even absent from the wreck pieces. Fish habitat was enhanced by the wreck, shown in the higher densities of fish in the engine/boiler sections. Orientation of the wreck pieces seemed to further enhance the crustose algae, but did not have any effect on the filamentous algae and coral.

The first tests run were on the stony corals to compare the dynamics of these species between the two environments. There was no significant difference in coral cover between the on-wreck and off-wreck transects. This supports Spainer *et al.*, 1990 who found that the proximity to the nearest reef and the overall productivity of a given area played a large role in recruitment to the artificial reefs.

The presence of dominant *Porites lobata* coverage was expected, to some extent due to the somewhat shallow reef-flat zone, but such a large patch may tell something about the nature of the environmental conditions. The clarity of the water and, thereby, the amount of sediment that has settled on the wreck (Pamintuan and Rollon, 1994) could be influencing the settlement, position preferences and survivorship of some of the coral species. It is possible that *P. lobata is* a hardier species that is able to survive in the, what was seen as, silty and rather shallow environment of Mahukona with greater success.

The coral, *Pocillopora meandrina* that was second highest in abundance, was seen as being bleached and generally occurring in fist-sized clumps or in wreck-protected areas. These trends could be evidence of the very surgy conditions of the Mahukona area and the deterioration of the wreck pieces. In addition to the environmental impacts of the harbor, there are characteristics such as the size (Bohnsack *et al.*, 1994) and the age (Wendt *et al.*, 1989) of the wreck structure that can determine biota abundance and species richness. One of the main concerns with shipwrecks as opposed to other artificial substrates is the aging due to chemical reactions of metal with sea water and the eventual breakdown of the structure. Perhaps the taller standing and bulkier corals are not abundant because the surge tends to break them off the wreck once they reach a certain size, or part of the structure breaks off from the stress. A survey of overturned or dead coral pieces might lead to answers to these questions.

The overall abundance of coral was represented with a mean average of 31% coverage. Crustose algae made up 24% of the mean average cover and is significantly lower. Within the crustose algae, there is significant difference in relations between two of the forms. The coralline algae has significantly higher cover and the light purple crust was significantly higher than the brown crust. This is the area of most uncertainty in our results and needs to be interpreted with caution. The coralline algae represents all of the white "speckled" data points on the wreck surface, the light purple crust was of a similar color (depending on the lighting) and was found in thicker mats interwoven with light green, like lichens on a tree. These could be the same species of coralline algae in different growth morphs. Likewise, the brown crust often had green edges and vice versa. These, too, could be the same species that have different colors due to light availability or age. Other algae, which represent a very small percentage, are the blue and yellow crustose. These two crustose forms had very vivid colors like that of sponges. This brings out a low confidence level as to whether these crustose organisms are corallines, sponges or a combination of the two. However, after later observations of crustose algae in other locations, it is the authors' belief that these are in fact crustose algae. Even with the discrepancy in origin, these data are presented here because they appear to play a dynamic role in the environment.

Crustose algae has an extremely high presence on the horizontal surfaces relative to the other sites. Also, a very low abundance of crustose algae on the off-wreck transect was observed. This supports Bohnsack *et al.*, (1994), who observed that certain species, such as fast growing algae, may only be found on the wreck itself. In contrast, corals fluctuated slightly across locations. There is a discrepancy in the pattern in the crustose algae vs. coral. There is no straightforward pattern of corals being more abundant than algae or algae being more abundant than coral. This supports the idea that coralline algae and corals work together to build reefs and most likely can inhabit an environment with equal success. Although there is a visual difference between off-wreck and propeller/shaft, it was not significant statistically.

Filamentous algae consisted of a brown algal mat with a fine sediment cover. These algal mats were significantly higher in abundance in the low level areas that accumulate high siltation and in many instances lacked other substrates. It is possible that the higher pieces of the wreck are "washed clean" by the strong surge in this area. In comparison to filamentous algae, a negative correlation between the abundance of the algal mats and the abundance of coral was observed. This could be due to a non-compatible environment amongst species or some degree of competition. Only a long term study will show if either of these hypotheses is correct.

Corals showed no difference in abundance between vertical and horizontal surfaces. However, crustose algae showed a significantly higher mean percent cover on the horizontal pieces compared to the vertical ones. Filamentous algal mats, are practically absent from the engine/boiler section and showed no significant difference between orientations, supporting the theory that siltation and surge play a large role in site selection for these species.

Total density for invertebrates was low for both locations but the off-wreck areas had a significantly higher density. The findings of this study support the ideas of Wendt *et al.*, (1989) and Pamintuan *et al.*, (1994) that certain species, such as mobile invertebrates, may be completely absent from the wreckage. When looking at the species abundance and densities for each transect, the on-wreck transect recorded six species, while the off-wreck transect identified eight. The on-wreck transect was dominated by *Spirobranchus giganteus*, but it should be noted that all of these worms were found in the *P. lobata* and were difficult to count. Nevertheless, these filter feeders may have an easier time filtering food higher up away from the silt layer. These data support Pamintuan *et al.*, (1994), who observed patterns in settlement of many invertebrate species possibly due to "phototactic preferences and silt susceptibility." *Echinometra mathaei* were also relatively abundant on the on-wreck section, boring into the *P. lobata*. However, the *E. mathaei* were far more dominant in the offwreck transect. Making up over 80% of the total density, *E. mathaei* may prefer the rocky substrate of the off-wreck section instead of the metal of the wreck.

When comparing the two locations, on- and off-wreck, we saw a significantly higher mean density of *Echinometra mathaei* on the off-wreck section. Conversely, there was a trend for the *Spirobranchus giganteus* to be more prominent on the wreck, as explained previously. Only *Heterocentrotus mammillatus* and *Echinothrix diadema* seemed to be equally distributed between the sites, and they were in very low numbers. Perhaps the strong surge or the exposure on the wreck pieces to predators prevents the macro-invertebrates from establishing a firm hold on this artificial habitat.

Fish are typically highly variable in abundance and distribution on reefs. In this study the species richness is somewhat similar for all three specified locations, with the propeller/ shaft being somewhat lower in richness. The smaller S-value in the propeller/shaft region further supports the hypothesis of a lower amount of diversified habitat. This drop could be due to a lower amount of habitats for fish without the coral heads of the off-wreck transect or the holes in the engine and boiler. These data lead to the conclusion that high mean density of fish for the engine/boiler section may be concentrated in the top five species as opposed to evenly distributed throughout all observed species.

Statistical results from an ANOVA comparing the three species of fish with the highest total percent showed that they were evenly distributed amongst each area. Possible trends to keep in mind are assemblages of fish that reflect a recruitment of species from the nearby reef studied and the overall fish densities observed on the wreck (Bohnsack *et al.*, 1994). There is a trend of the relative abundance to be constant across sites, probably reflecting the food and habitat availability. However, these data do show the general trend across all species to have a higher mean density in the engine/ boiler section. Two considerations must be taken when looking at these data. First, the *Chromis vanderbilti* are extremely high in number. Their numbers are high due to large schools in the engine/boiler and lower numbers in the off-wreck areas.

The second consideration involved the time of day that the studies were conducted. Although attempts were made to run fish transects during the early morning and the late afternoon, there were no night data taken. When lights were used to survey the boiler, many nocturnal species were observed in relatively high numbers. It is probable that a night survey would bring in higher numbers of some of the species recorded, and the top 50% of the total percent make-up of these three sections would be distributed across more species.

As it was, five species made up the top 65% of the total percent found at each site. Among these five species, two of them were herbivores *(Acanthurus nigrofuscus, Zebrasoma flavescens)*, one detritivore *(Ctenochaetus strigosus)*, one planktivore *(Chromis vanderbilti)* and one carnivore *(Thalassoma duperrey)* hinting at an even distribution of feeding specialization (Randall, 1985). However, when all of the species observed are pooled into eight feeding groups, the detritivores are significantly higher in abundance. The results of this test are somewhat surprising because there is only one representative detritivore *(Ctenochaetus strigosus)* and because this species ranked number two in overall abundance. As before, the power of the test concentrated on the average of all of the species considered in each grouping; therefore, since there are some high and some low amounts of representatives of herbivores, their standing would be somewhere in the middle. It also should be noted that most of the carnivores (ranking fifth) were invertebrate feeders and that most of the omnivores had a diet constituted mostly of algae. This chart (Figure 10) does support the earlier findings of a larger amount of algae when encrusting and filamentous are pooled as an abundant food source (most of the herbivores were filamentous algae feeders) over coral cover.

The feeding and habitat variation of the engine/boiler section is well represented by the fish in Table 3. The *Chromis vanderbilti* schooled in higher numbers, indicating either a higher amount of plankton in this area, or perhaps more likely, a greater amount of hiding places. The territorial *Abudefduf abdominalis* were all but absent from the other sites, probably due to a preferred habitat in the engine/boiler section. A couple of cleaner stations were also observed in and around the boiler, which brought in a variety of solitary species. The *Priacanthus* and *Myripristis* species represented in the Appendix show a small number of nocturnal species that were recorded; however, it is expected that more of these species are present and would be better represented in a night survey.

Conclusions

The presence of the wreck does enhance certain aspects of the surrounding community, such as in the greater abundance and species richness of crustose algae and fish species. In fact, there were many species observed that were only found on the bigger sections of the wreck. The greater abundance of fish can be explained by the increased habitat. However, for the coral species that were present, there were no significant trends to indicate that the wreck was enhancing their abundance or richness.

The presence of the metallic structures of the wreck does not seem to have a profound effect on the community, except perhaps in the case of the rock boring urchins *(Echinometra mathaei)*, which may find metal a little more resistant to boring than they are used to. The overall abundance of invertebrates for the on-wreck was lower, which indicates that the wreck was in some way inhibiting that form of habitat.

The orientation study presented mixed results, with the crustose algae being much more abundant on the horizontal surfaces and the stony corals and filamentous algae tending to have similar abundances on both orientations.

Acknowledgments

We would like to thank Dr. Brian Tissot for his advice, his patience and, most importantly, his time in helping us with this project. We also want to thank Pete Hendricks, who provided great insight and enthusiasm in the history of the *Kaua'i* and John Coney for his invaluable technical support and trust. Our thanks go out to the members of Sea Grant and the Department of Land and Natural Resources for funding this project and giving us a chance to get our feet wet.

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Tables

Appendix 1: Totals, percents and densities are presented in tabular form for all of the fish species recorded.

Table 1. Values for Shannon Wiener diversity index for fish at the three locations at Mahukona, Hawaii. H' values are fairly similar for all locations. S' values are slightly lower at propeller/shaft location.

Location	H'	S
Off-Wreck	1.1686	43
Prop/Shaft	1.1209	34
Engine-Boiler	1.1352	42

Table 2. Five species of fish found in relatively high abundance at the engine/boiler sections, in comparison to other locations at Mahukona, Hawaii. *Chromis vanderbilti, Abudefduf abdominalis, Labroides phthirophagus, Priacanthus* spp., *Myripristis* spp., and *Dascyllus albisella*. Values given in mean density (#/100m^2) with a cut-off at 1.

Fish Species	Engine/Boiler	Prop/Shaft	Off-Wreck
C. vanderbilti	31.3	0.0	10.9
A. abdominalis	9.5	0.3	0.07
L. phthirophagus	2.3	0.0	0.08
Priacanthus sp.	1.3	0.0	0.00
Myripristis sp.	1	0.2	0.00
D. Albesella	1	0.0	0.00

Figures

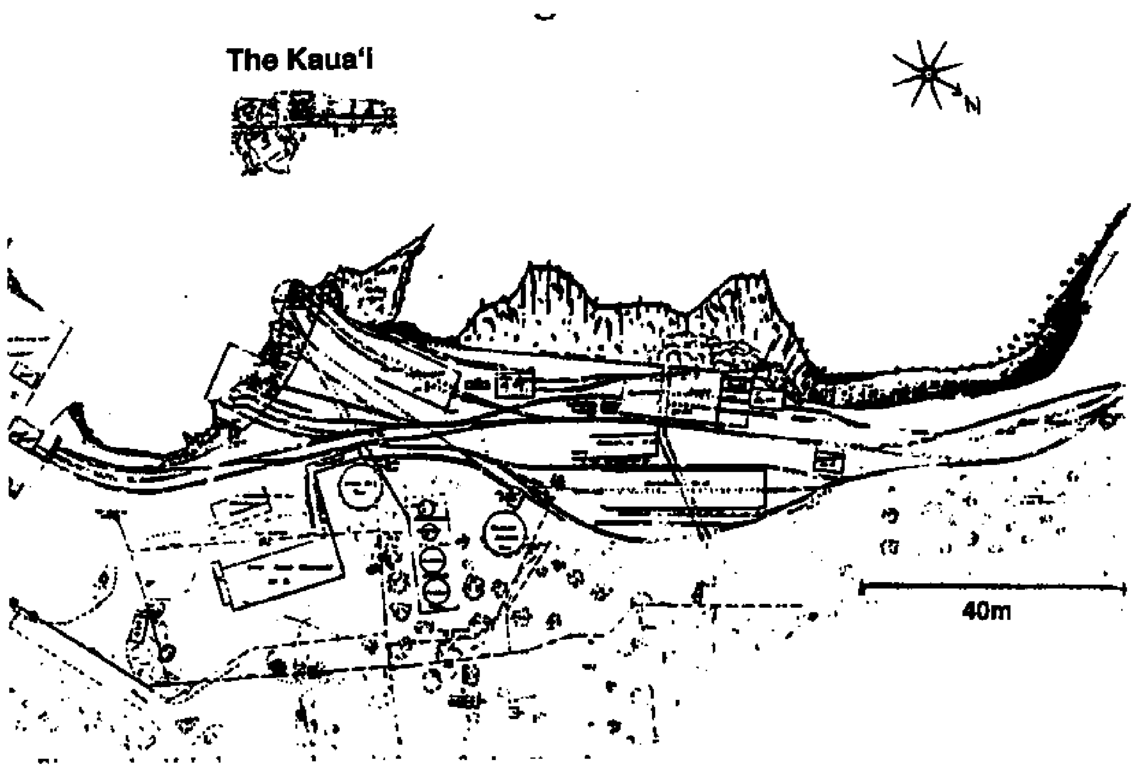

Figure 1. Location of the Kaua'i *off Mahukona, Hawaii, showing the coastline, some inshore structures, and the approximate location of the* Kaua'i.

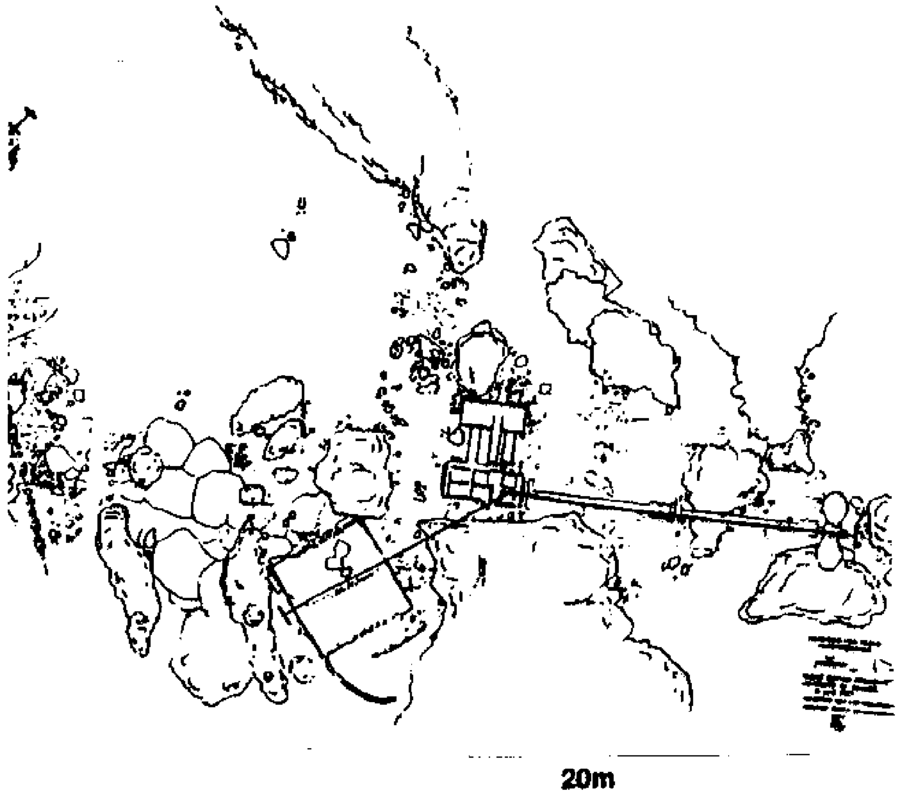

Figure 2. Detail of the shipwreck Kaua'i *at Mahukona, Hawaii. Diagram shows the locations of the two main transects, the on-wreck transect that jogs 45 degrees at the end of the engine and proceeded over the center of the boiler and the off-wrect transect that was placed five meters toward shore from the boiler.*

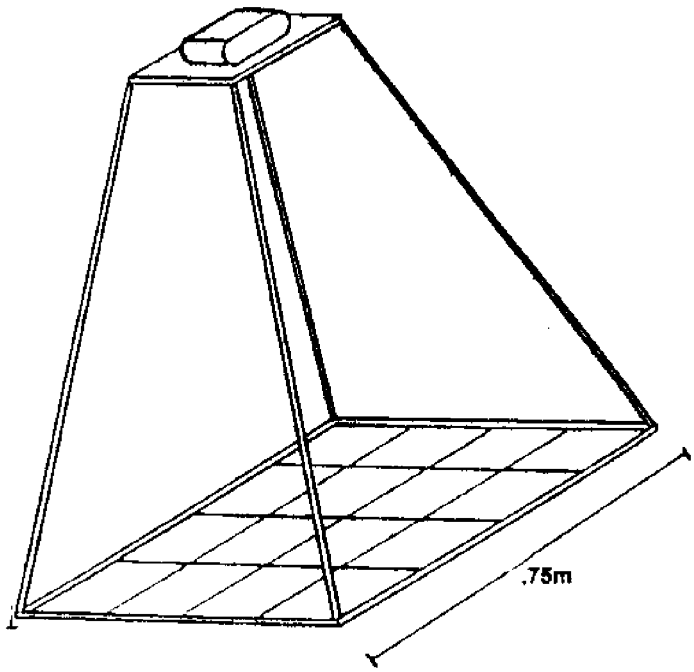

Figure 3. Diagram of photoquadrat from QUEST 96 *handbook. Similar to the one used in the study.*

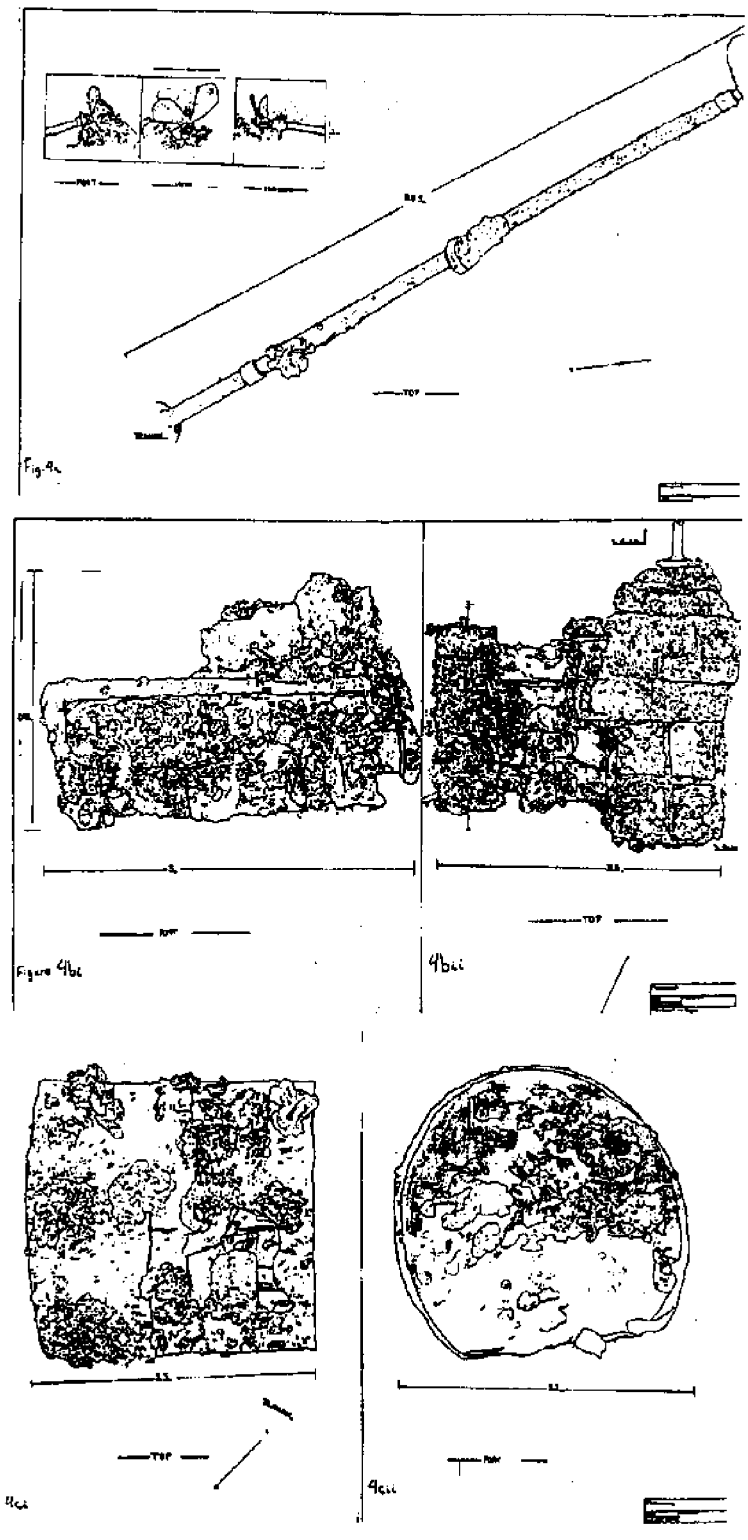

Figure 4. Diagrams of the three remaining large pieces of the wreck Kaua'i *at Mahukona, Hawaii and the encrusting organisms that are presently growing on them. a) The propeller and shaft top view also included the starboard, port and stern view of the propeller by itself. b) Engine top view and front view (port side) facing shore. c) The boiler surface and front view (port side) facing shore.*

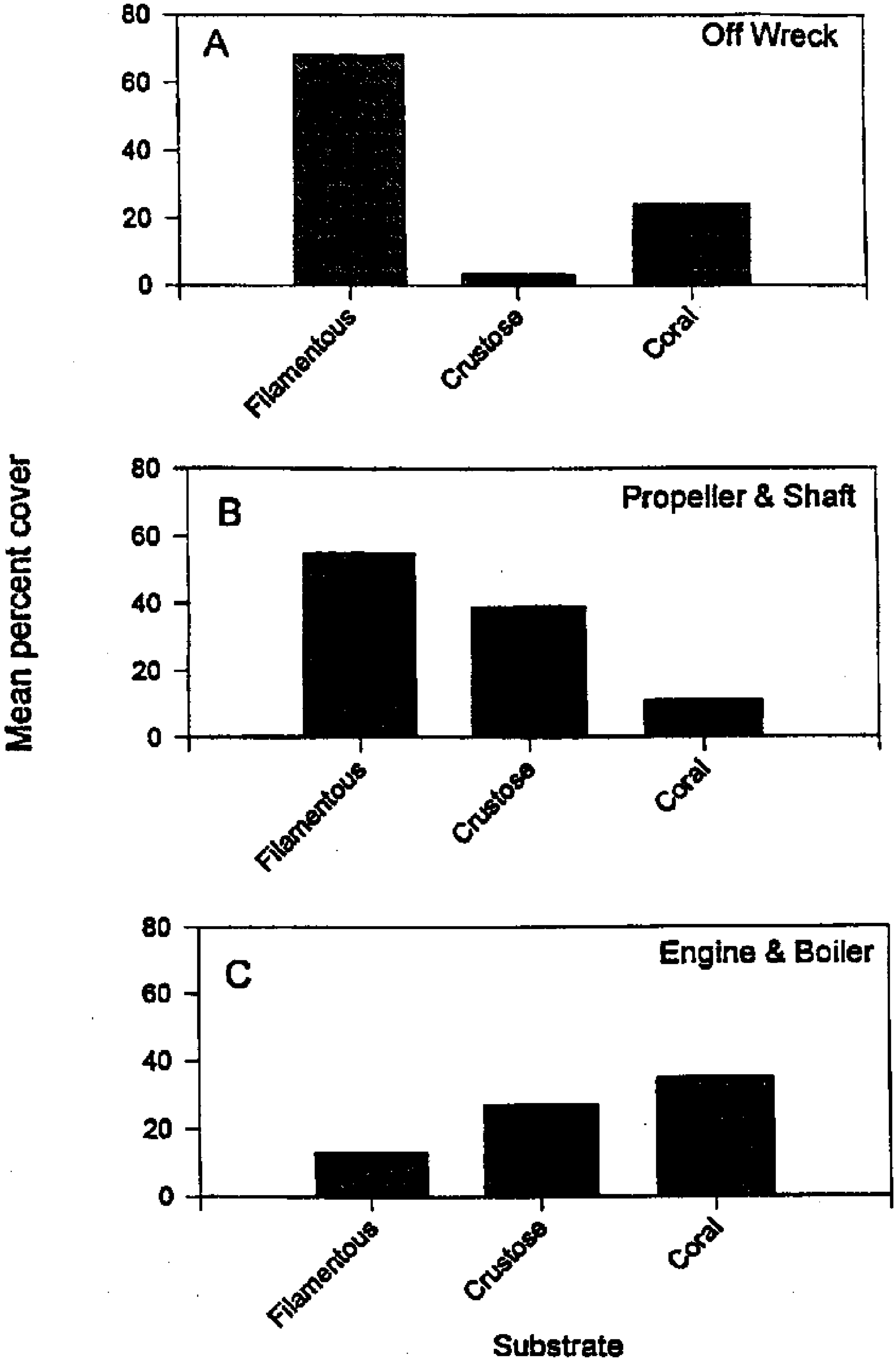

Figure 5. Mean percent cover of filamentous algae, crustose algae and stony corals across the off-wreck, propeller/shaft and engine/boiler sections.

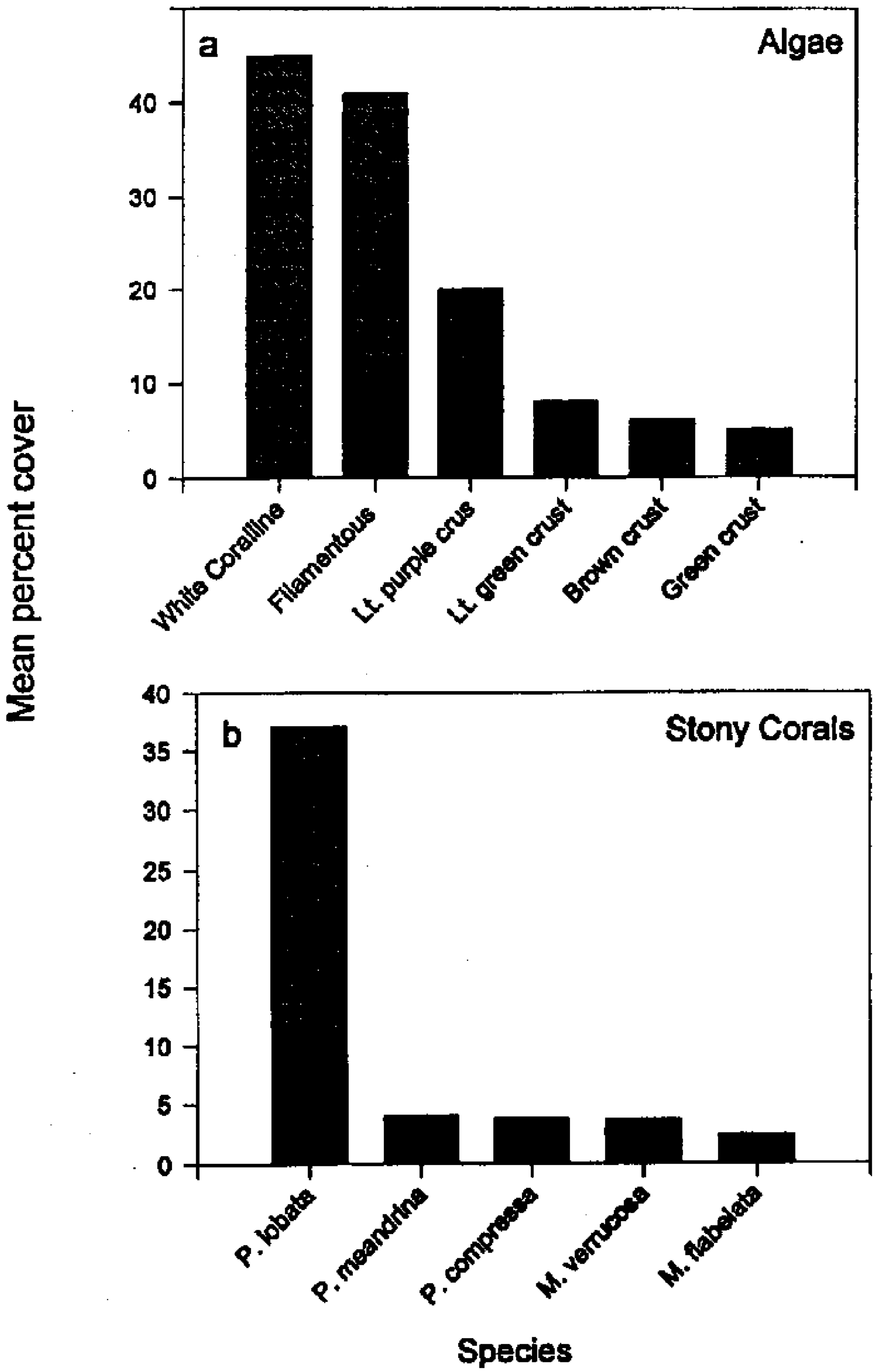

Figure 6. Mean percent cover breakdown os species for two living substrate groups across both locations. a) Algae: white coralline algae, filamentous algae, light purple crustose, light green crustose, brown crustose and green crustose. b) Stony Corals: Porites lobata, Pocillopora meandrina, Porites compressa, Montipora verrucosa *and* Montipora flabellata.

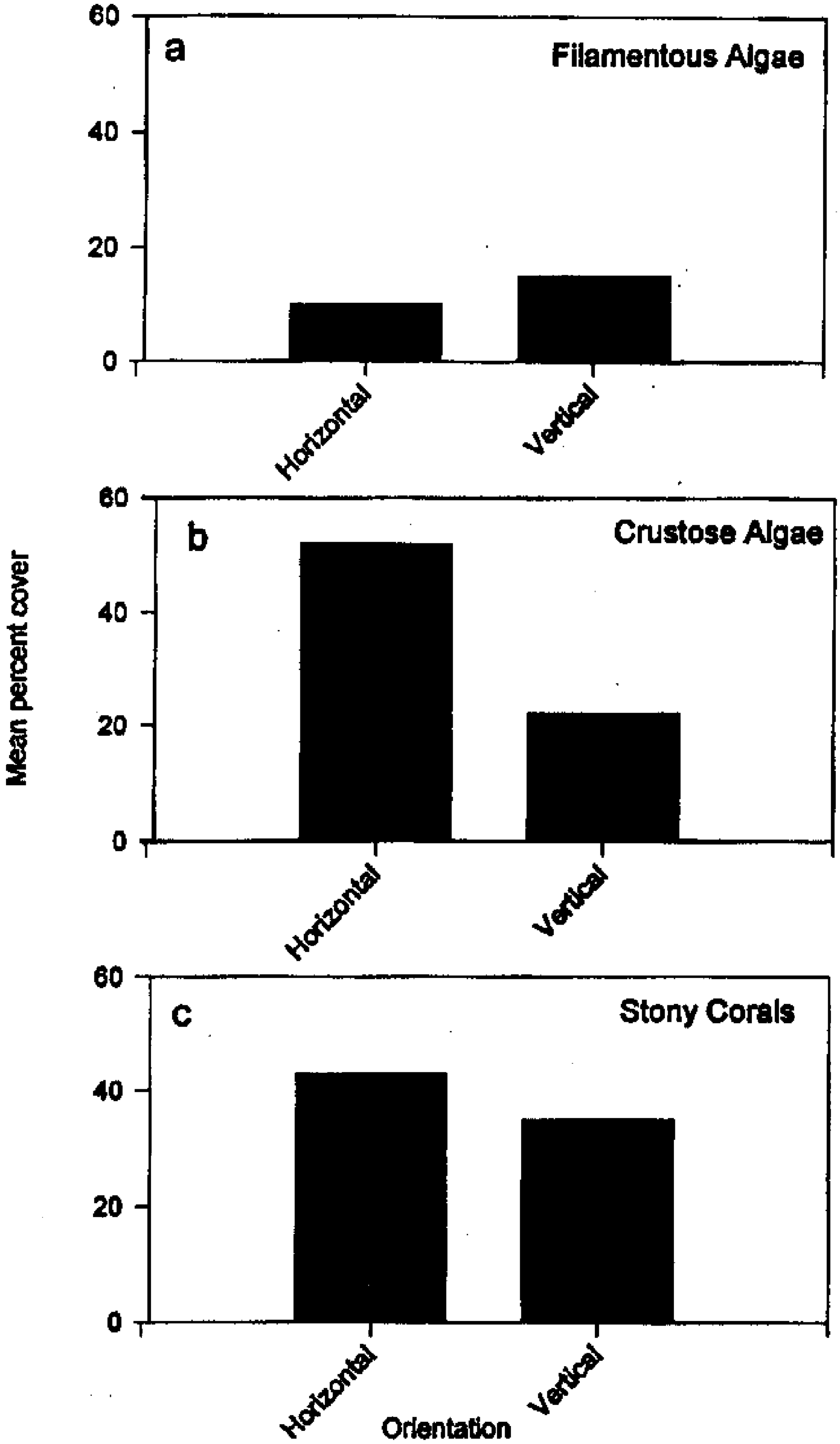

Figure 7. Mean percent cover of filamentous algae, crustose algae, and stony corals among horizontal and vertical orientations.

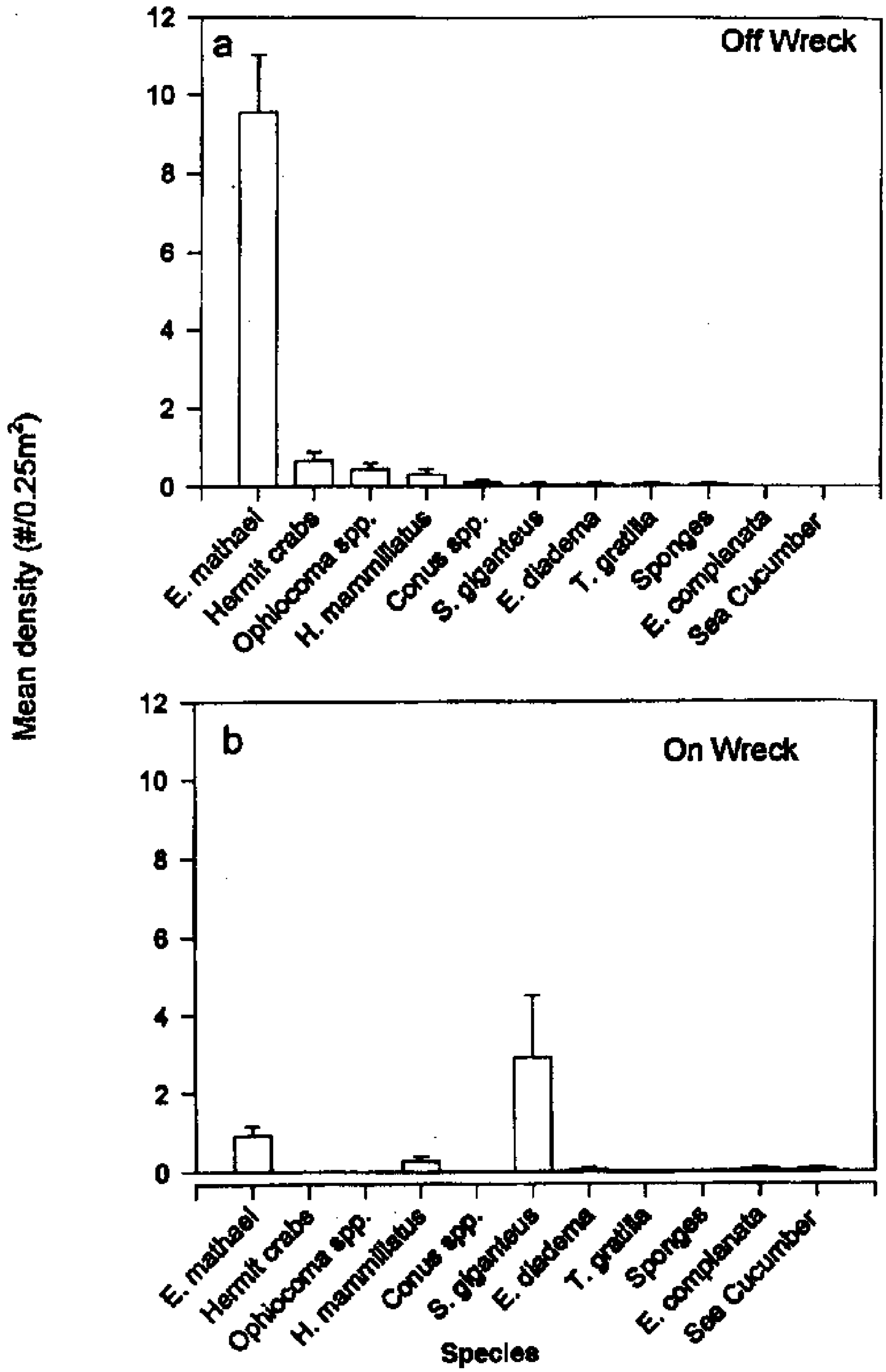

Figure 8. Mean density (#/0.25m^2) of mobile invertebrate species at Mahukona, Hawaii. Echinometra mathaei *(rock boring urchin), hermit crabs,* Ophiocoma *spp (Brittlestar),* Heterocentrotus mammillatus *(pencil slate urchin),* Conus *spp. (cone shell snail),* Spirobranchus giganteus *(Christmas tree worm), sponge,* Echinothris diadema *(black spine urchin),* Tripneustes gratilla *(collector urchin), Sponges,* Eurythoe complanata *(fire worm), and* Holocanthus atratus *(Sea cucumber). a) Off-wreck species distribution. b) On-wreck species distribution.*

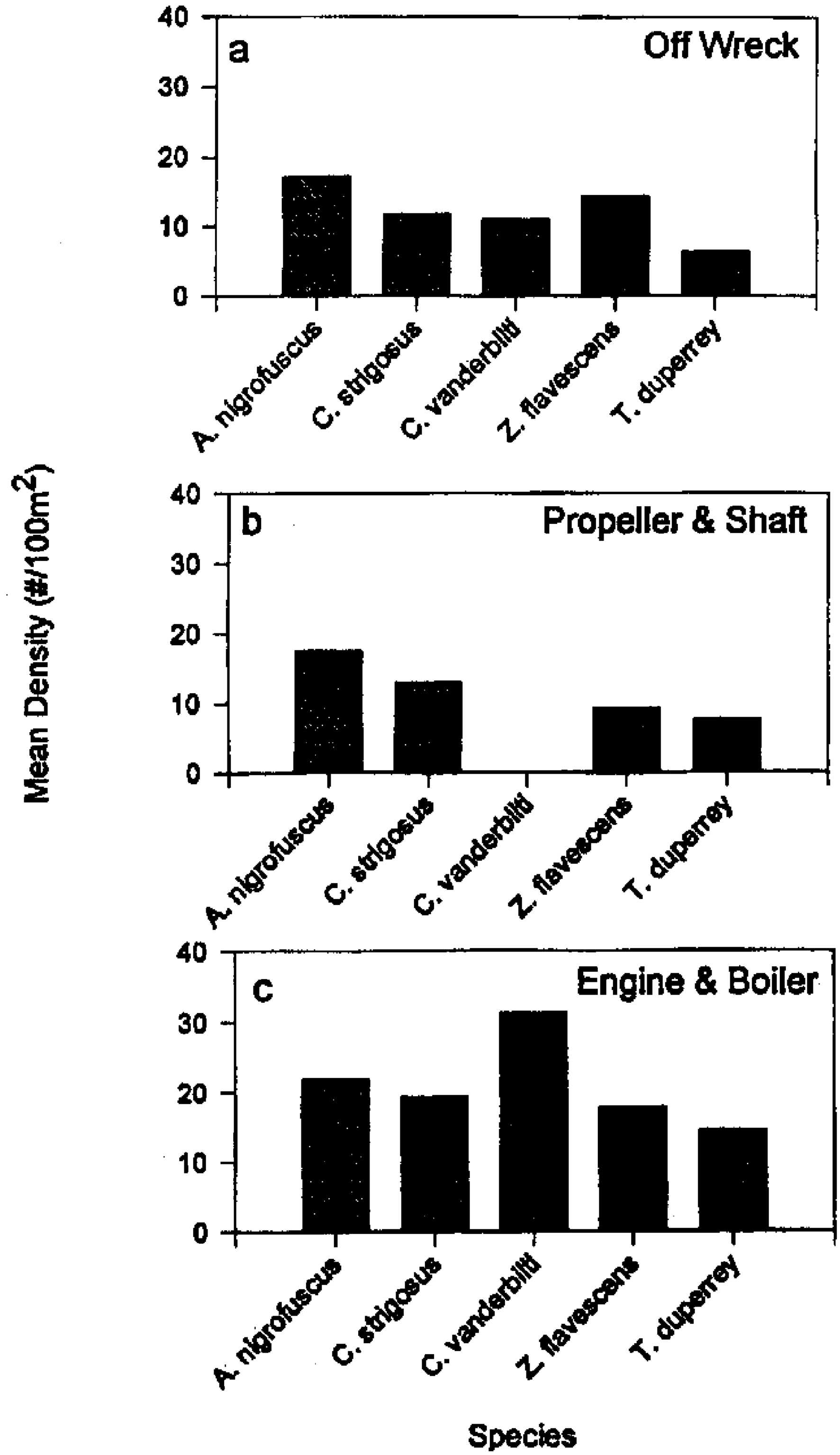

Figure 9. Mean density (#/100m^2) of fish surveyed at Mahukona, Hawaii: Acanthurus nigrofuscus, Ctenochaetus strigosus, Chromis vanderbilti, Zebrasoma flavescens, *and* Thalassoma duperrey *for off-wreck, propeller/shaft and engine/boiler locations.*

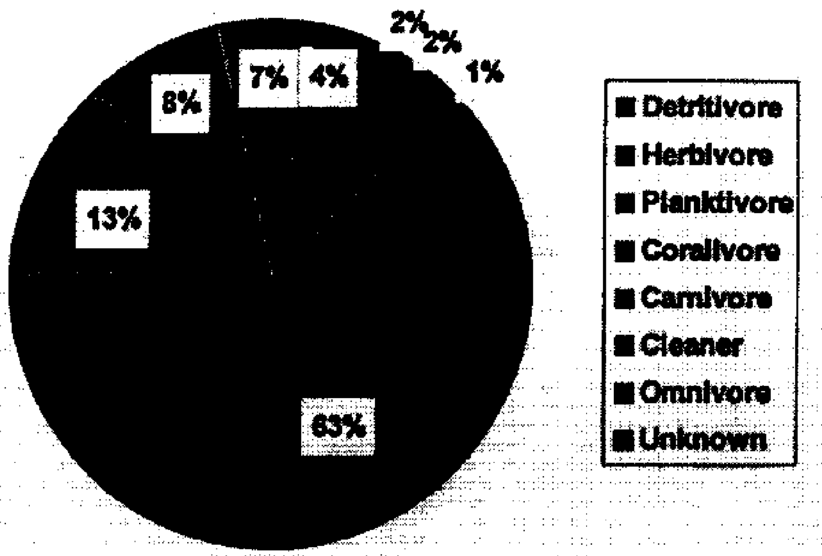

Figure 10. Distribution of feeding guilds for total fish including all locations. Values shown in percent of the overall totals.

The Development of Criteria for the Site Selection for an Artificial Reef, to Enhance Surfing Waves and Nearshore Fisheries

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Abstract

New technologies in artificial reef designs are now focused on modifying the beach slope to enhance the quality of surfing waves and to increase and enhance fishing opportunities. The Big Island of Hawaii's recent lava flows and rugged coastline have created unsafe and overcrowded conditions at existing surfing areas. Even more so, Hawaii's increasing human population has put pressure on the limited nearshore fishery resource. Installing an artificial reef will provide a new surf site and may increase habitat for aggregating fish populations. This project developed criteria on the physical, biological and geological components of each site and uses these criteria to select an optimal site for an artificial reef. In East Hawaii, along Keaukaha's shoreline, Chocks, James Kealoha and Richardson's were each surveyed to determine a site suitable for the artificial reef.

Methodologies divided the study into two parts, where wave-enhancement and fishenhancement would be beneficial by installing the artificial reef. The criterion developed for wave-enhancement by the artificial reef consist of surveying: 1) placement of the artificial reef relative to prevailing swells, 2) effect on preexisting waves from the artificial reef, and 3) each site's perimeters. The criterion to test fish-enhancement consisted of: 1) surface topography, 2) coral and seaweed abundance 3) herbivorous fish abundance, and 4) juvenile and adult fish abundance.

Of the three sites surveyed, Chocks proved to be the most favorable for the artificial reef. Wave-enhancement would be most optimal at Chocks because the artificial reef would have a 45° angle to prevailing swells, a non-obstructed preexisting wave and a safe surfing perimeter. The artificial reef could enhance fish abundance at Chocks, which has a high percent cover of filamentous algae, low abundance of herbivore fish species and a high abundance of juvenile parrotfish.

Introduction

Due to recent lava flows on the island of Hawaii, many surf spots have been destroyed. The deficit in surfing reefs has resulted in overcrowding of surf spots along the east side of the island. The Big Island has more than 306 miles of coastline with only 185 surf sites, or a very low 0.6 surf sites per mile of coastline (Walker, 1974). Out of a total of six surf spots along Hilo and Keaukaha, only two are considered safe. The other four spots have basalt outcroppings that interfere with the peeling wave, making them less desirable to ride. A good safe surfing wave, described in Figure 1, is usually dependent on where the surfer rides the wave and the skill of that surfer (Walker, 1974). Installation of an artificial reef would provide safer wave riding conditions by dispersing crowds and avoiding hazardous outcroppings.

The recent lava flows have also destroyed many reefs that were once used for traditional fishing activities. The Keaukaha and Hilo shorelines have become more populated, increasing stress on local fish populations. Keoki Keanu III, a local fisherman, claims fish catch amount and fish size has decreased 50% in the last five years due to human population increase in Keaukaha. Although this observation is anecdotal, the experience of fishermen who have worked for generations in this area lends credibility to the observation that fish populations may be declining.

To partially accommodate the increased demand on existing marine resources, artificial reefs provide shelter and may aggregate fish where they are more easily caught. Spatial arrangement of surface types is an important factor governing the abundance patterns of many marine organisms (McCormick, 1994 and Grigg, 1993). By increasing the topography of marine habitats, available fish habitat will be enhanced, potentially providing greater opportunity for recruitment and retention of fish populations.

In the late 1950s, the state of Hawaii started artificial reef projects to enhance fishing opportunities for its fishermen. Artificial reefs have been created by deploying derelict car bodies, damaged concrete pipes, barges, fish aggregating devices (Onizuka, 1984) and automobile tires. These artificial reefs succeeded in attracting and sustaining large numbers of fish to bottom areas that were barren and without substantial vertical relief (Kanenaka, 1991). Kanayama and Onizuka (1973) reported that the artificial reefs appeared to increase fish resources and provided alternatives to traditional fishing grounds that were being heavily fished.

Along Keaukaha, low shoreline basalt extends into the ocean creating a benthic shelf between 5 m and 10 m depths. Three sites, Chocks, James Kealoha and Richardson's were chosen because they offer easy public beach access and are frequently subjected to prevailing North Pacific swells and Northeast tradewind swells. Chocks and Richardson's are similar, as waves break on rocks outside the bay, then reform into a surfable wave inside the bay. James Kealoha has waves breaking onto rocks far offshore, dissipating wave energy into the bay area.

Herbivorous fish (parrotfish, tangs and surgeonfish) are common in these areas and were the target species for this study. These species were chosen because they are a common, popular catch of nearshore fishermen and they graze on algae, preventing coral overgrowths that can potentially smother coral reefs. With the current concerns of reducing detrimental environmental impacts, the inert artificial reef is one system available that will create vertical habitat and internal spaces for fish assemblages. This could benefit traditional fisheries by increasing fish abundance locally without harming the environment.

Artificial reefs are now being designed to create perfect surfing waves. These artificial reefs are added to the existing beach slope, improving the bottom contour that the wave 'feels.' Prevailing swells are triggered to break by decreasing the beach slope depth with installing the artificial reef. Currently there are several projects under way in California, Florida and Australia (Marcus, 1996). In Hilo, Hawaii, a non-profit organization, Quantum Reef, has adopted an artificial reef design, shown in Figure 2, from High Wave Inc. in California (Montana, 1996). This design has been tested in wave tanks and it creates perfect peeling waves.

Quantum Reef plans to anchor the structure to existing basalt substratum. The artificial reef structure is made from fourteen polyethylene pipes with a 0.75 m diameter. Pipes are stacked in a pyramidal formation with a bottom layer of five pipes and a top layer of two pipes. The structure is assembled using 5/8" by 6" stainless steel bolts to fasten the pipes to one another. Quantum Reef's artificial reef structure dimensions are 45 m by 4.16 m by 2.8 m. Three pipes on the bottom layer and two pipes on the second to bottom layer are filled with concrete to lower the structure's center of gravity and act as a ballast. Anchoring of the structure to basalt substrate is based on work done by John Halas on mooring systems at Florida's Key Largo Marine Sanctuary (Wilkins and Tabata, 1989). Stainless steel threaded bolts eighteen inches long will be cemented into four-inch diameter holes, with 12 inches inserted into the substrate. Holes are drilled into the substrate by two scuba divers using an underwater air-powered drill. The six inches of threaded bolt protruding from the substrate will fit into holes drilled into the bottom of the pipes, where a washer and nut will secure the structure. For every 3 m of artificial reef structure, four bolts will anchor it down with one at each corner of a 3 m by 4.16 m section. Artificial reefs have been proven to increase fish habitat, so therefore holes of different diameter will be drilled into the pipes providing shelter for both juvenile and adult fishes (Kanayama and Onizuka, 1973). These holes providing refuges will be no larger than 4 inches in diameter, so they cannot weaken the structure or affect its wave-making ability. At a 7 m isobath, this artificial reef structure can create a nearshore fish haven and a wave for surfing.

The purpose of this project was to select an optimal site for an artificial reef based on the following criteria.

A. Surfing wave

1) suitable habitat at 7m depth for artificial reef placement

2) no interference with preexisting surfing waves

3) no hazardous obstacles (rocks) within 30 m of structure

B. Fish enhancement

1) low surface topography that would be increased by the artificial reef, providing shelter

2) low coral abundance in the area of the structure placement and a high seaweed abundance, which is food for herbivore species

3) low fish abundance that could be enhanced by aggregation and retention by the artificial reef

4) high juvenile abundance that would benefit from increased shelter to avoid predation

Methods

Preliminary observations during winter swells were used to select three sites for study. Chocks (N 19°4'42", W 155°0'28"), Richardson's (N 19°4'40", W 155°0'08"), and James Kealoha (N 19°4'44", W 155°0' 19") were all observed as having swell energy but unrideable surfing conditions (Figure 3). Each site was field surveyed for the possibility of artificial reef installation. Scuba divers deployed four, 20-m transect lines at the perimeter of the site for the artificial reef structure, each at the 7 m isobath. This depth was chosen so that the 2.8 m- high structure would cause a wave (avg. 4 ft. height) to break. Two transects were placed parallel with a 4.16 m distance between them. Then two more parallel transects were placed 5m laterally to the previous pair of transects. The transects outline a 45 m by 4.16 m rectangular area, approximately the size of the artificial reef structure. This transect layout was replicated at each site.

Wave-enhancing Methods

To determine the artificial reef angle, compass bearings of the deployed transects were recorded with the direction of travel directed toward the open ocean. Point of origins where the transects were placed were obtained by surface bearings fixed on permanent landmarks. These measurements were recorded on waterproof paper. Charts were then used to plot locations of the artificial reef structure. Angles of reef structures were then evaluated relative to prevailing swell directions, and each site was mapped to describe preexisting surfing waves, which break from north swells, and hazardous basalt outcroppings.

The following criteria were evaluated with respect to the purpose of causing waves to break, by the artificial reef.

1) The relation of the artificial reef angle to approaching swells. The artificial reef should be placed at a 45° angle to direct north. A wave prevailing from direct north will propagate onto the reef structure creating a shoaling effect where part of the wave will break from the decrease in depth caused by the structure. A remainder of the wave will continue shoaling in the northerly direction providing a wave face to surf. The 45° angle is ideal to form a perfect point-break wave (Figure 4). Due to the artificial reef needing 7 m of depth for placement, with a 45 m length for installation, some sites might not be suitable for placement at a 45° angle to direct north. Therefore, preexisting bathymetry will determine the suitability of an artificial reef at the desired angle to prevailing swell.

2) The second part of the evaluation was to assess the effects the artificial reef would have on preexisting surfing waves. The artificial reef's main purpose is to create a new surfing wave. Where preexisting waves are in the vicinity of the artificial reef site, it was hypothesized that a new breaking wave could possibly enhance or destroy its wave riding potential. So therefore, a site where the artificial reef destroys preexisting waves would have to be rejected.

3) Examination of site for any hazardous basalt outcroppings where a wave rider might be in danger. We required a minimum distance of 30m from the artificial reef to any basalt outcroppings. A site would be rejected if rocks would be any closer then 30 m to the artificial reef structure.

Fish-enhancing Methods

Each site was preliminarily surveyed using the following methods: Diving conditions were observed during low-, medium-, and high-tide levels considering the variable currents at each site. While free diving, salinity and temperature samples were taken three times at both baseline (0.0 in/24hr) and precipitation (avg. 0.56 in/24hr) periods. Salinity samples were obtained with 10ml water bottles at the surface and at the bottom of the water columns.

Surface topography was measured by contour topography versus linear length. This is the 'chain-and-tape' method of Risk (1972), and was calculated as a ratio of moulded surface topography to the linear distance of 20 m. This technique is used to quantify three-dimensional surfaces. Four samples were collected per site.

Benthic substratum was measured at ten randomly picked 1-m^2 quadrat locations on each transect. The sample size was 40 for each site. All taxa present were identified, and densities were calculated as mean percent cover per 1-m^2 quadrat. Abundances of rock, coral? and filamentous algae were tested for significant differences between sites using a twosample T-test.

The strip transect method was utilized to measure the abundance of targeted fish species (Brock, 1982). Using the same transects, two divers swam for 10 minutes on either side of each transect, recording the total number of parrotfish, tangs, and surgeonfish. Parrotfish size was estimated to the nearest inch to determine their sexual maturity. Parrotfish ranging from 2 to 8 inches were classified as juveniles and those greater than 8 inches were considered adults (Bellwood and Choat, 1989). For the more common fish, divers counted in a 2m width of the transect. The larger, more mobile, and popular fish hunted by fishermen were counted at a 5m width from the divers. Those species are usually adult parrotfish, *Naso literatus, Acanthurus leucopareius, Acanthurus olivaceus,* and *Acanthurus blochii,* which are wise toward humans in the water and tend to keep their distance. Each transect was considered as one sample totaling 32 samples taken at each site (n=32). Sampling took place in the afternoon during the rising tide on consecutive days. The total abundances from each site were measured for significant differences among sites.

Fish-enhancing Criteria

The criterion tested has been adopted from many studies on previous artificial reef projects (Risk, 1972; McCormick, 1984; Luckhurst & Luckhurst, 1978).

1) Habitat heterogeneity. This is a measurement of the complex vertical habitat at each site. This tested which site favored the herbivorous fishes habitat of rock rubble or coral reef shelters. Luckhurst & Luckhurst (1978) found fish abundance and substratum complexity were correlated. A site with low heterogeneity could be improved by adding the artificial reef to enhance its fish population.

2) Abundances of corals and seaweeds between sites. Hacker & Steneck (1990) found that the availability of food is often correlated with specific fish organisms. Three substratum types were compared to observe the abundance of food for herbivorous fish: rock, *Porites lobata,* and filamentous algae. Rock was measured because algae are most likely to grow on its surfaces. *P. lobata* was tested because parrotfish were observed grazing on the coral polyps during fish counts, and it was the most abundant coral species. Filamentous algae was tested because it is primarily consumed by herbivorous fish. A site with high coral cover should be rejected because the artificial reef should not be placed over coral. The site with a high percent cover of rock and filamentous algae favors the preferred ecological requirements of the herbivorous fish species.

3) The abundance of herbivorous fish. Lower abundances imply that one site may be lacking in fish habitat and can be enhanced by installing the artificial reef. Increases in fish abundances around artificial reefs have been observed almost immediately after installation (Kanenaka, 1991).

4) By documenting parrotfish size, a quantitative estimate of the ratio of juveniles to adults was obtained. Juveniles can benefit from the artificial reef structure, which provides

prey refuges (Hixon & Beets, 1993). By increasing the number of refuges for juvenile fish, the fish population at that site may be enhanced by installing the artificial reef.

Sites were compared for significant differences within the tested criterion, focusing on the question: Which site is in need of increased habitat to enhance herbivorous fish abundance? Data were analyzed using a two-sample T-test. All samples were set at alpha=0.05. The data were examined for the normal distribution, and log transformation were made where necessary.

Results

Wave-enhancement Results

All sites had a 7 m isobath where the artificial reef structure could be installed. The artificial reef structure angle at Chocks was 45° to prevailing direct North Pacific swells, Richardson's angle was 90°, and James Kealoha's was 315°, which in actuality is 45° to the North Pacific swells, causing the wave to break in the opposite direction of Chocks.

Pre-existing surfing waves were observed at both Chocks and Richardson's (Figures 5 & 6). The surfing wave at Chocks is inside the bay and would not be affected by the artificial reef wave. At Richardson's, the preexisting wave also breaks inside the bay, but would no longer exist because the artificial reef wave would dissipate the wave energy moving into the bay. At James Kealoha, there are no pre-existing rideable waves around the surveyed area.

For surf site perimeters, Chocks would have easy access to the artificial reef wave from a deep channel exiting the bay. Hypothesized wave-induced currents could push into the bay or to an outside channel past the breaking wave (Figure 5). Basalt outcroppings were present 35 m away from the artificial reef. A large, submerged lava pillar marks the beginning of the takeoff zone and the ride ends at the mouth of the bay or could be ridden to the preexisting wave inside the bay. The artificial reef at Richardson's would not have an easy access to the artificial reef because the wave would break in front of the bay, creating a breaker zone the width of the bay. Wave-induced currents would push into the bay or out to sea parallel to the artificial reef (Figure 6). The end of the ride would deposit surfers in front of large outcroppings of basalt rocks less than 10m from the artificial reef. James Kealoha would have easy access to the artificial reef wave by several channels coming from deep inside the bay (Figure 7). There are several rock formations more than 40m from the artificial reef site. Field surveys at James Kealoha observed strong rip currents and longshore currents (Figure 7).

Fish-enhancement Results

Salinity samples at all sites recorded an average of 34 ppt. on the surface and 35 ppt. at the bottom. Temperature recordings at all sites averaged 29°C at the surface and 26°C at the bottom of the water column. These sample averages were the same during baseline and precipitation periods. Precipitation measurements were recorded at an average of 0.56 inches of rainfall in the last 24 hours. Rip or ebb currents were not noticed at Richardson's or Chocks. James Kealoha had tremendous rip and ebb currents passing through the study area. This was discovered during preliminary free dives. As a result, James Kealoha was not subjected to further surveys.

Heterogeneity of surface topography was not significantly different between the sites (Figure 8). A two-sample T-test revealed that mean surface topographies from both sites were not significantly different (Table 1).

The composition of benthic substratum varied between Chocks and Richardson's (Table 2, Figure 9). The following benthic substratum categories were compared between sites: the percent cover of rock, *P. lobata*, and filamentous algae. Rock and *P. lobata* cover were not significantly different between sites (Table 3). Filamentous algae was significantly different between sites, with Chocks having the higher mean percent cover of 16.4% while Richardson's had a mean of 6.53%.

Richardson's had the higher density of total fish abundance at 118 per $100m^2$, while Chocks total fish abundance was 75 per $100m^2$ (Table 4, Figure 10). However, mean fish abundances were not significantly different between sites (two-sample T-test, Table 5). The five most abundant fish species at Richardson's were *Ctenochaetus strigosus, Acanthurus triostegus, Acanthurus nigrofuscus, Zebrasoma lavescens,* and *Acanthurus olivaceus.* The most abundant fish species at Chocks were *Acanthurus nigrofuscus, Scarus sordidus, Naso literatus, Ctenochaetus strigosus,* and *Acanthurus leucoparius.*

Species abundance at each site is described in Figure 11. Parrotfish species were more diverse and more abundant at Richardson's (Figure 12). All parrotfish species counted in this study were seen at Richardson's while only five of the six species were seen at Chocks.*Scarus sordidus* was the most common parrotfish seen at both sites. Chocks had the highest abundance of juvenile parrotfish (Figure 12). Out of the total parrotfish abundance, Chocks was 64% juveniles and 36% adults. Richardson's was 59% juvenile and 41% adult parrotfish.

Discussion

Wave-enhancement

The 45° angle of the artificial reef at Chocks would create a 'right point break.' Richardson's 90° angle would cause the wave to break, but not produce a rideable wave face to surf. The 315° angle of the artificial reef at James Kealoha would create a 'left point break.' Both directions of breaking waves at Chocks and James Kealoha are equally desired by surfers.

Creating a rideable wave to break farther outside the bay at Chocks would enhance the surfer's length of ride if they can connect the ride to the preexisting wave. If that is not possible, the artificial wave would still create a new surfing wave at Chocks. However, at Richardson's, the artificial wave would actually destroy the preexisting wave by dissipating the wave energy outside of the bay. The artificial reef would create a new wave for surfing at James Kealoha.

Hazardous basalt formations were only observed at Richardson's, where surfers could be injured. At James Kealoha, very strong currents were observed. These currents were observed without the presence of waves during field studies. Rip currents flowing out to sea were caused by tidal movement. A longshore current moving parallel to the coastline is the result of the ebb current coming off the Hilo Breakwall. These currents have the possibility of becoming intensified by swells, creating unsafe surfing conditions. Field survey observations and the evaluation of the wave-enhancement criteria for each site favor Chocks to be the site selected for the artificial reef. Richardson's and James Kealoha contain unsafe surfing conditions. At Chocks, wave enhancement by the artificial reef will create a safe new pointbreak wave for surfing.

Fish-enhancement

Chocks and Richardson's had similar results within the tested criterion. Heterogeneity was not significantly different between the two sites and the low vertical topography at both sites could be improved by installation of the artificial reef. Of the substratum measured, the percent cover of rock and *P. lobata* was not significantly different between sites. However, on average, Richardson's had more coral cover while Chocks had more cover of rock (mostly boulders) and seaweed. The mean cover of filamentous algae was three times as abundant at Chocks compared to Richardson's. This shows that the availability of food for herbivorous fish is more favorable at Chocks. Fish abundances were not significantly different between sites, but the mean fish abundance at Chocks was less than that of Richardson's. Parrotfish size differed between sites. Richardson's parrotfish were mostly adults and Chocks parrotfish were mostly juveniles. These juveniles could benefit the most from improved shelter by avoiding predation.

The surveyed fish-enhancement criteria at Richardson's included low vertical topography, high percent cover of coral, high total fish abundance, and the majority of parrotfish being adults. Meanwhile, at Chocks the fish-enhancement criteria indicated a low vertical topography, high percent cover of seaweed and rock, a low total fish abundance, and the majority of parrotfish being juveniles. Therefore, according to the tested criteria, Chocks is the site more suitable for increased habitat for fish enhancement. The installation of the artificial reef at Chocks will be beneficial for fish aggregating purposes, and provide increased habitat and shelter for targeted herbivorous fish species.

Conclusions

Quantum Reef's artificial reef design has yet to be installed. Currently the non-profit organization has been recognized by Hawaii's County Council and is being considered for private sector funding. This is yielding the permit process for nearshore development. Permits are in the process of being filed with the Department of Land and Natural Resources and the Army Corps of Engineers.

Although the sites surveyed in this project did not completely fulfill the requirements for an ideal site for the artificial reef, Chocks would be a good site for the first artificial reef installed by Quantum Reef. The criteria introduced in this project could be employed to survey new sites for this specific artificial reef structure, or be modified to survey sites for other artificial reef structures.

Acknowledgments

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Tables

TABLE 1. Data analysis from test of significant differences in heterogeneity between Chocks and Richardson's. The sites were not significantly different at a=0.05.

Two Sample T-Testfor Chocks vs. Richardson's

	N	*Mean*	*Std. deviation*	*SE Mean*
Chocks	4	1.2700	0.0606	0.030
Richardson's	4	1.2000	0.0796	0.040

95% C.I. for mu Chocks - mu Richardson's: (-0.052, 0.192)

T-Test mu Chocks = mu Richardson's (vs not =): T=1.40 P=0.21 DF=6

TABLE 2. Benthic substratum taxa and mean percent cover per 1-m^2 quadrat (n=40).

	Chocks	*Richardson's*
Rock	30.38	28.69
Porites lobata	14.78	17.97
Porites compressa	0.00	0.47
Porites rus	0.78	0.00
Pocillopora meandrina	3.03	1.56
Pocillopora damicornis	1.16	0.31
Leptastrea pupurea	0.91	0.03
Leptastrea biottia	1.28	0.25
Montipora flabellata	4.91	7.25
Montipora patula	1.91	2.69
Montipora verrucosa	1.03	1.34
Palythoa tuberculosa	0.09	0.00
Pavona varians	1.03	0.50
Cyphastrea ocellina	0.47	0.06
Spirastrella coccinea	0.16	0.00
Filamentous algae	16.38	6.53
Dictyosphaeria cavernosa	0.03	0.00
Lyngbya majuscula	0.53	0.00
Halimeda opuntia	0.03	0.00
Crustose coralline algae	13.97	15.00
Sand	5.81	17.31

TABLE 3. Data analysis of significant differences in benthic substratum between Chocks and Richardson's.

Variable	*df*	*T*	*P*
Rock	78	0.49	0.63
Porites lobata	78	-1.06	0.29
Filamentous algae	78	4.28	0.0001*

* significant difference at $p<0.05$

TABLE 4. Herbivore fish species densities and data analysis from test of significant differences in total fish abundance between Chocks and Richardson's. The sites were not significantly different at a=0.05. Density calculated for number of fish per 100 m^2.

	Chocks	*Richardson's*
Acanthurus nigrofuscus	53.98	33.79
Acanthurus leucopareius	2.42	1.21
Acanthurus olivaceus	1.21	4.29
Acanthurus blochii	0.63	1.84
Acanthurus triostegus	0.59	5.08
Naso literatus	4.41	3.09
Ctenochaetus strigosus	3.09	45.04
Ctenochaetus hawaiiensis	0.16	0.23
Zebrasoma flavescens	1.68	16.60
Zebrasoma veliferum	0.31	0.16
Calatomus carolinus	0.12	0.20
Scarus sordidus	5.00	3.98
Scarus dubius	0.08	0.51
Scarus psittacus	0.00	0.43
Scarus rubroviolaceus	0.12	0.78
Scarus perspicillatus	1.45	0.82

TABLE 5. Data analysis for significant differences of total fish abundance between Chocks and Richardson's.

Two Sample T-Test for Chocks vs. Richardson's

	N	*Mean*	*Std. deviation*	*SE Mean*
Chocks	16	0.90	1.02	0.25
Richardson's	16	1.32	1.19	0.30

95% C.I. for mu Chocks - mu Richardson's: (-1.22, 0.38)

T-Test mu Chocks = mu Richardson's (vs not =): T=-1.07 P=0.29 DF=29

FIGURES

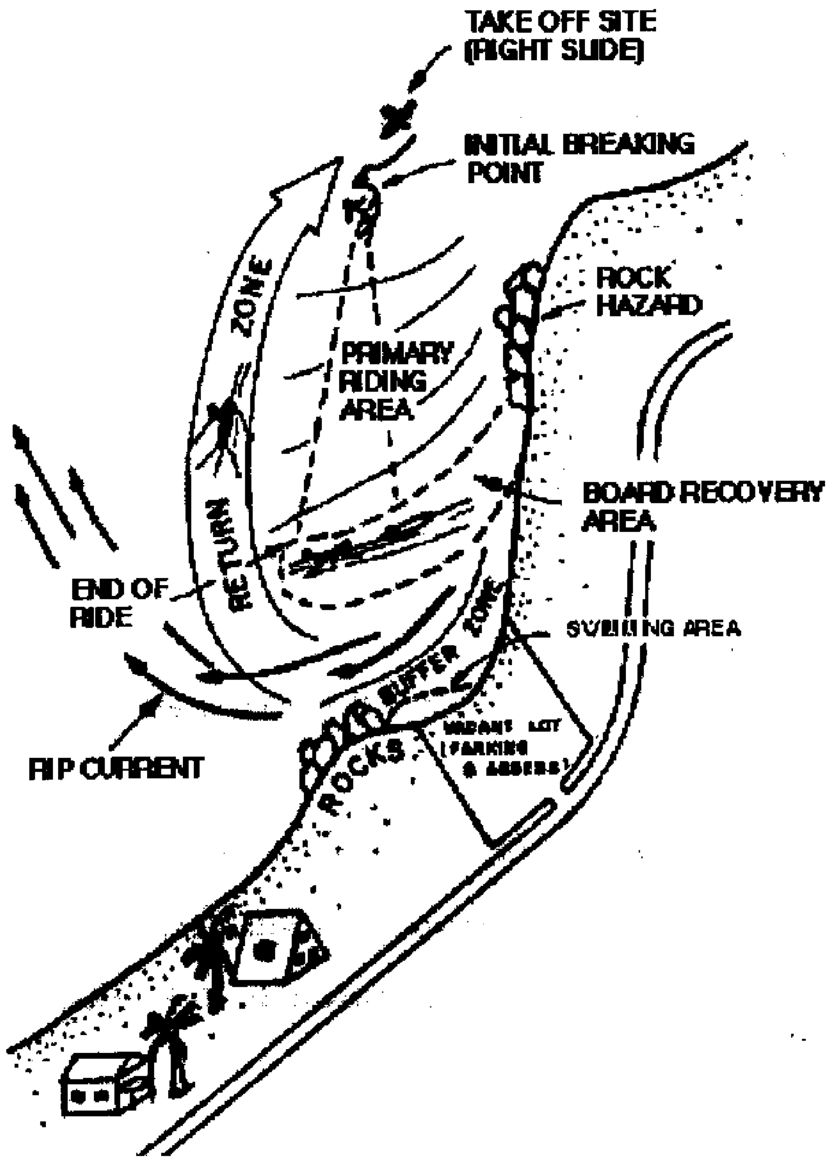


Figure 1. Typical surfing area where, in this case, a right 'point-break' wave peels at approximately a 45° angle to the beach (Walker, 1974). A good safe surfing wave usually has a takeoff site, primary riding area, board recovery or swimming area, and a channel for returning to the takeoff site. Wave-riding area and rip currents should steer surfers away from hazardous rocks.

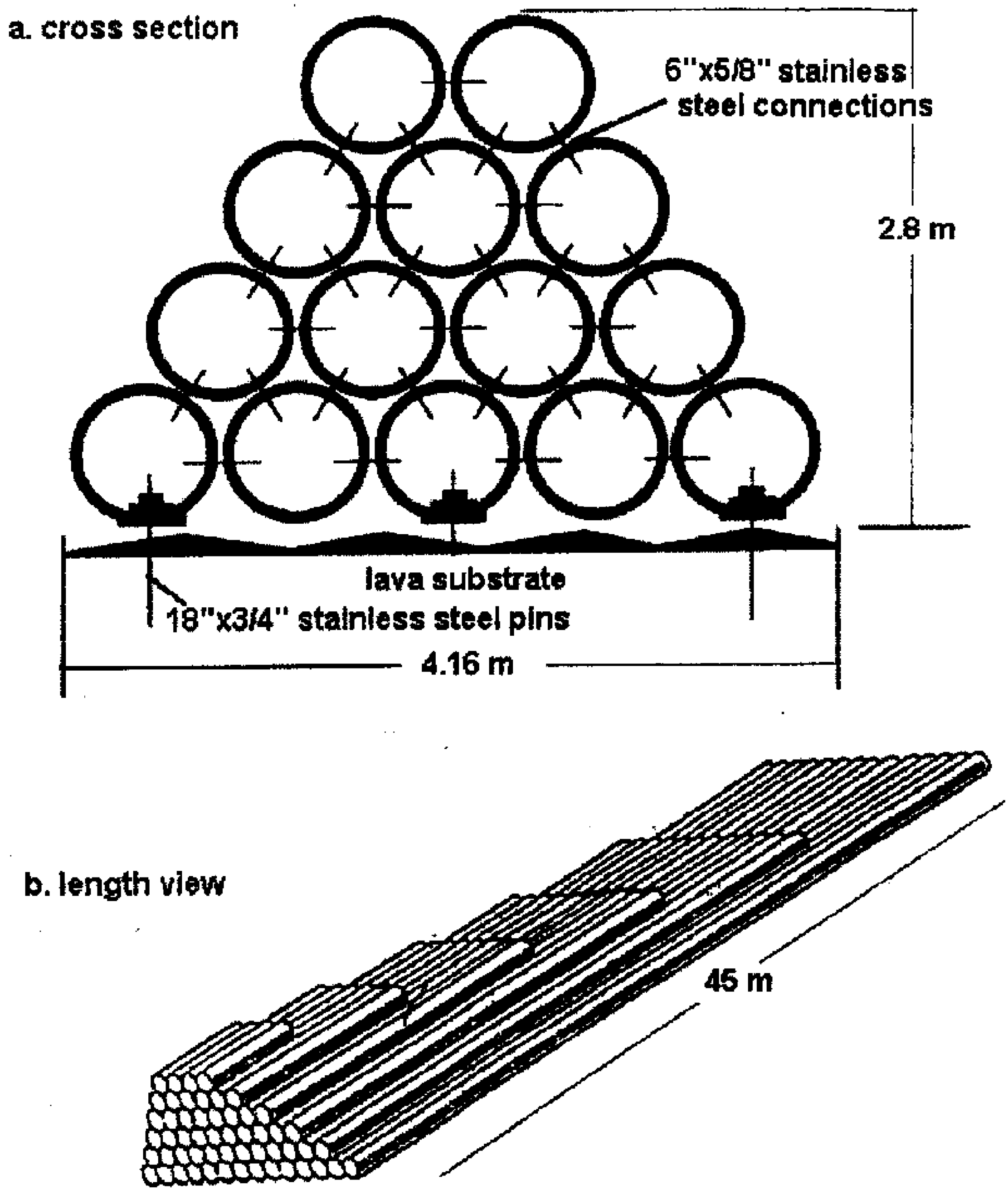


Figure 2. Quantum Reef's artificial reef structure (Montana, 1996). Consisting of 14 polyethylene pipes stacked in a pyramidal formation. Dimensions: 45m by 4.16m by 2.8m. a) Cross section, displays anchoring into lava substrate and fastening of pipes in actual pyramidal formation. b) Length view, displays three-dimensional view of structure but not with proper amount of pipes.

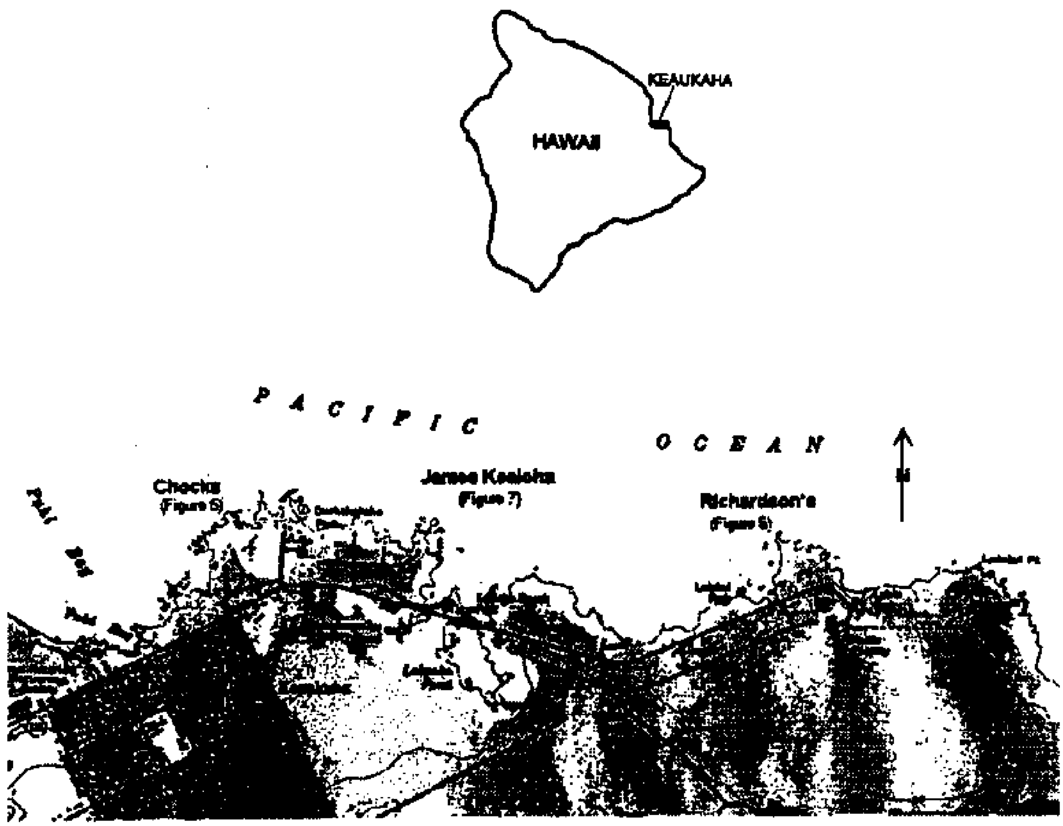


Figure 3. Artificial reef study sites, located offshore Keaukaha (USGS, 1961).

Chocks	*N 19° 4' 42", W 155° 0' 28"*
James Kealoha	*N 19° 4' 44", W 155° 0' 19"*
Richardson's	*N 19° 4' 40", W 155° 0' 08"*

Scale = 1:28,800

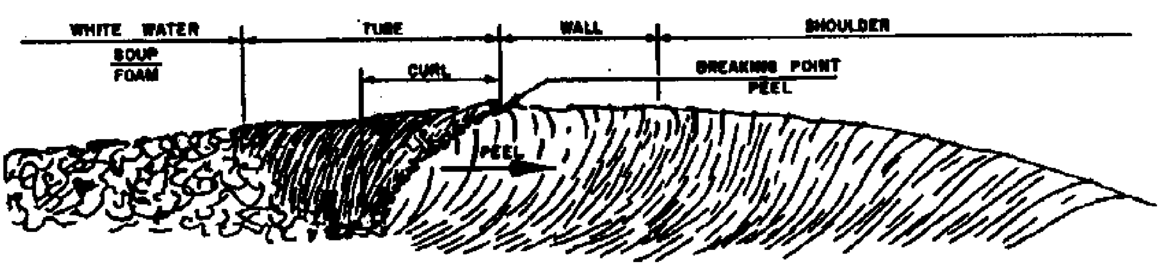


Figure 4. Left breaking 'point-break' surfing wave (Walker, 1974). A right 'point-break' surfing wave peels in the opposite direction.

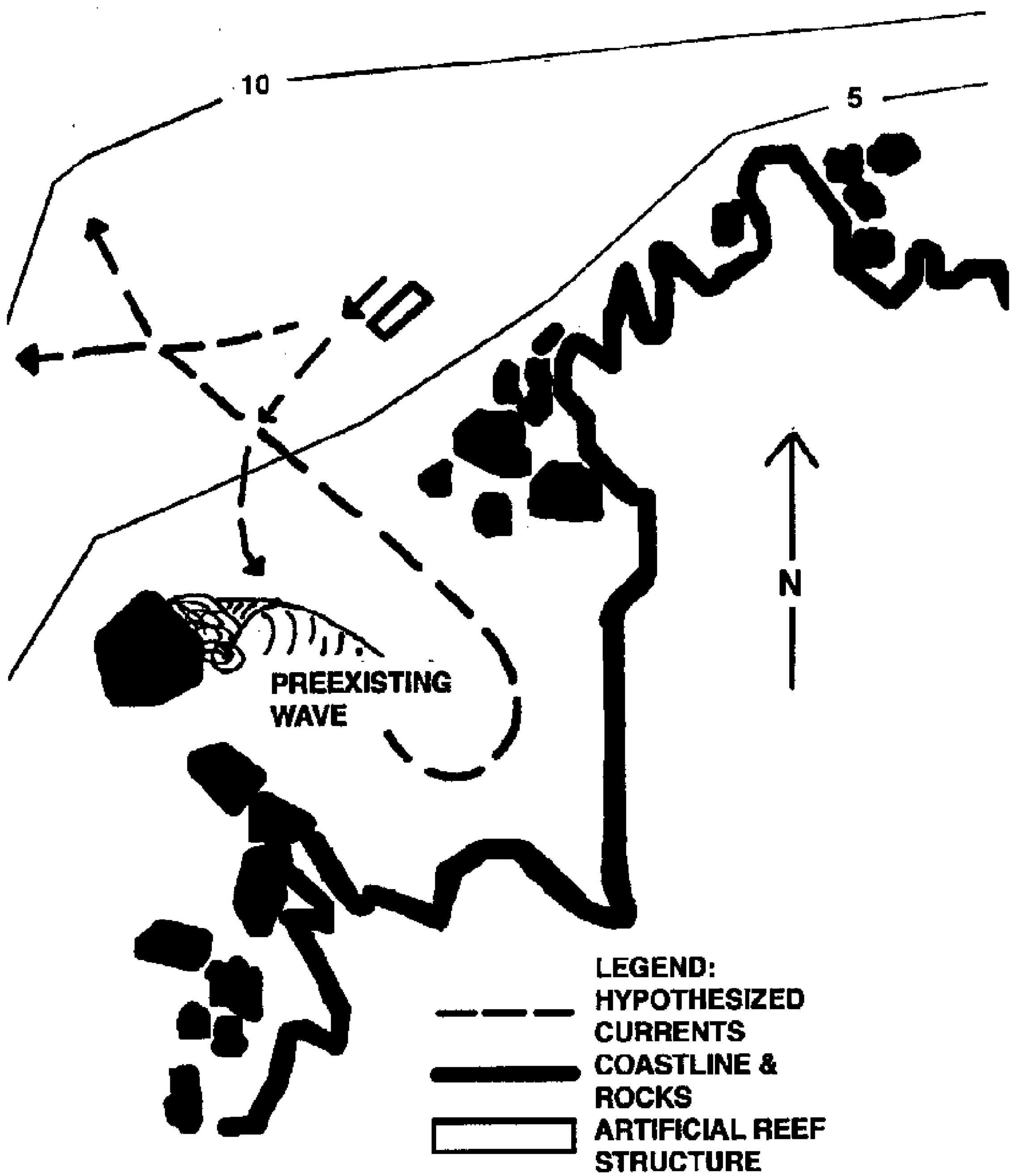


Figure 5. Chocks study site favors the installation requirements of the artificial reef. The artificial reef wave would peel as a 'right point-break' and would not obstruct the preexisting wave. Map obtained from USGS Chart no. 4103 (1981).
Bathymetry in meters, scale = 1:3,000

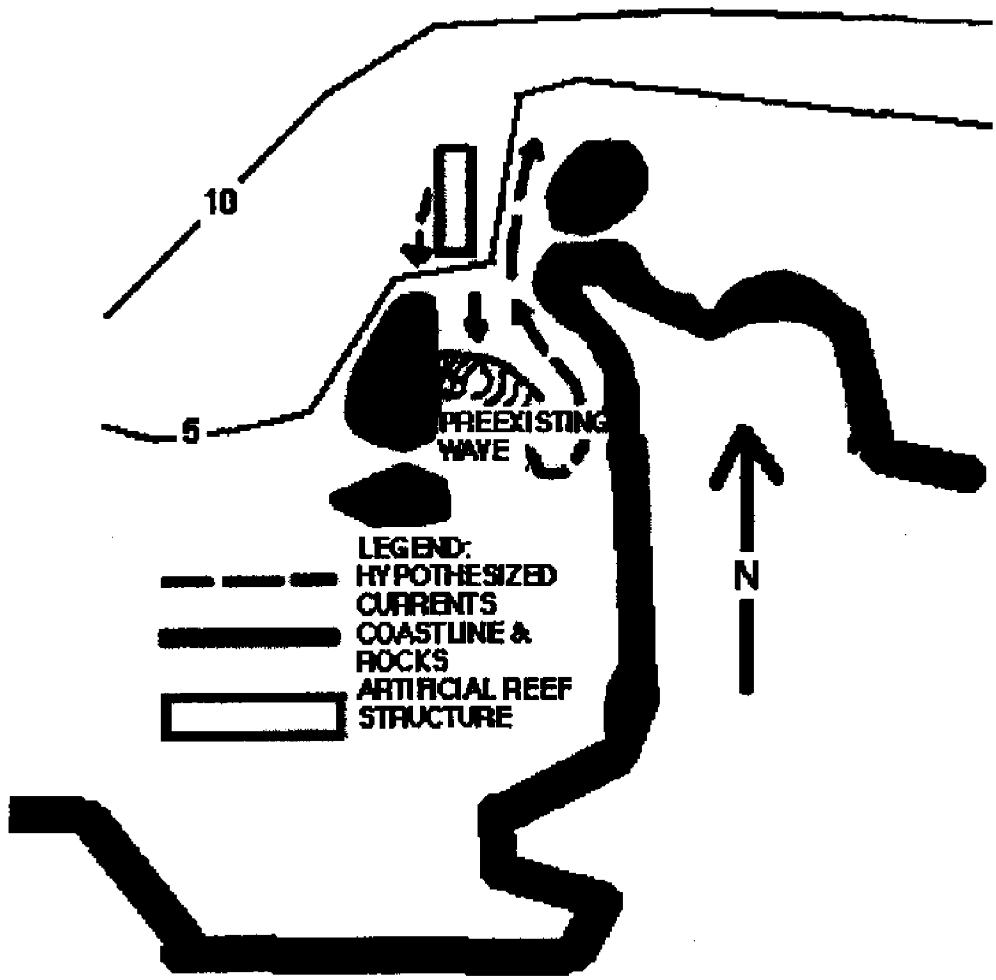


Figure 6. Richardson's study site has rock outcroppings that would be dangerous for surfers and the preexisting wave would be destroyed from dissipation of wave energy. The artificial reef angle would not create a surfing wave. Map obtained from USGS Chart no. 4103 (1981).
Bathymetry in meters, scale = 1:3,000

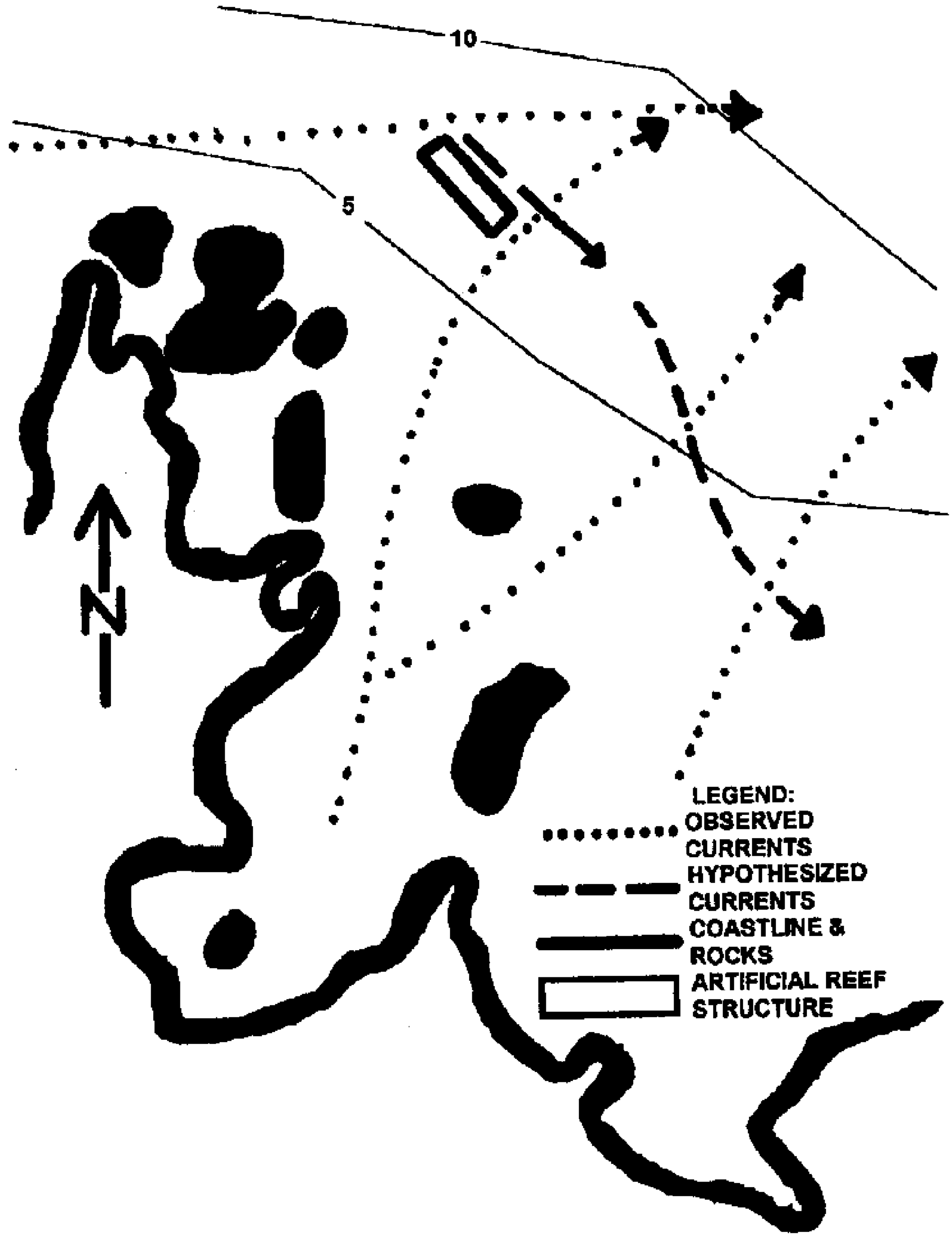


Figure 7. James Kealoha study site was observed with strong rip and longshore currents, creating unsafe diving conditions. The artificial reef would peel as a 'left point-break.' Map obtained from USGS Chart no. 4103 (1981).
Bathymetry in meters, scale = 1:4,000

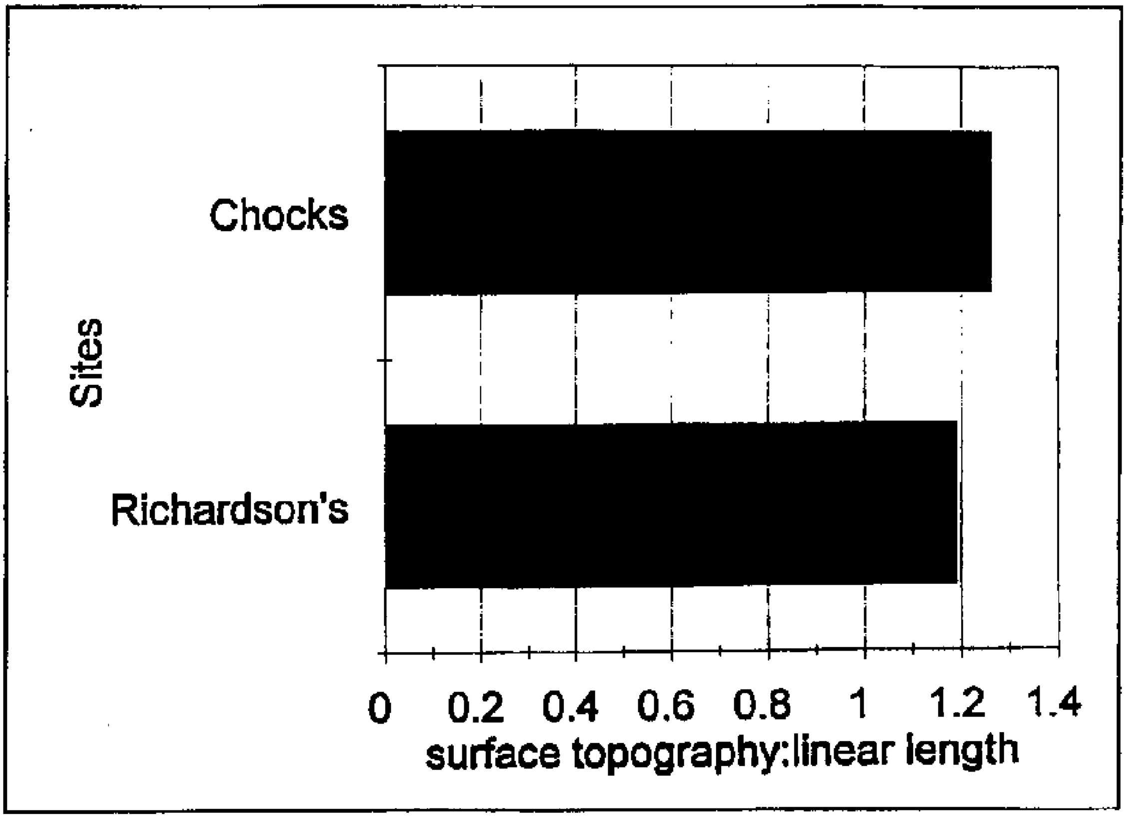
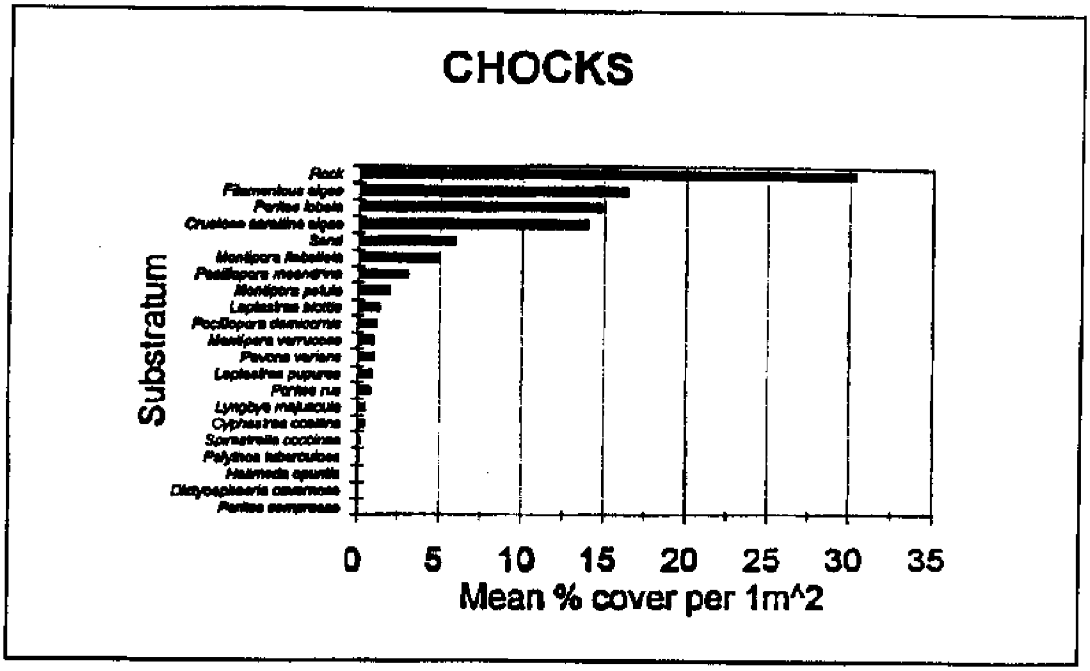


Figure 8. Mean heterogeneity index at the two study sites. Heterogeneities from both sites were not significantly different.



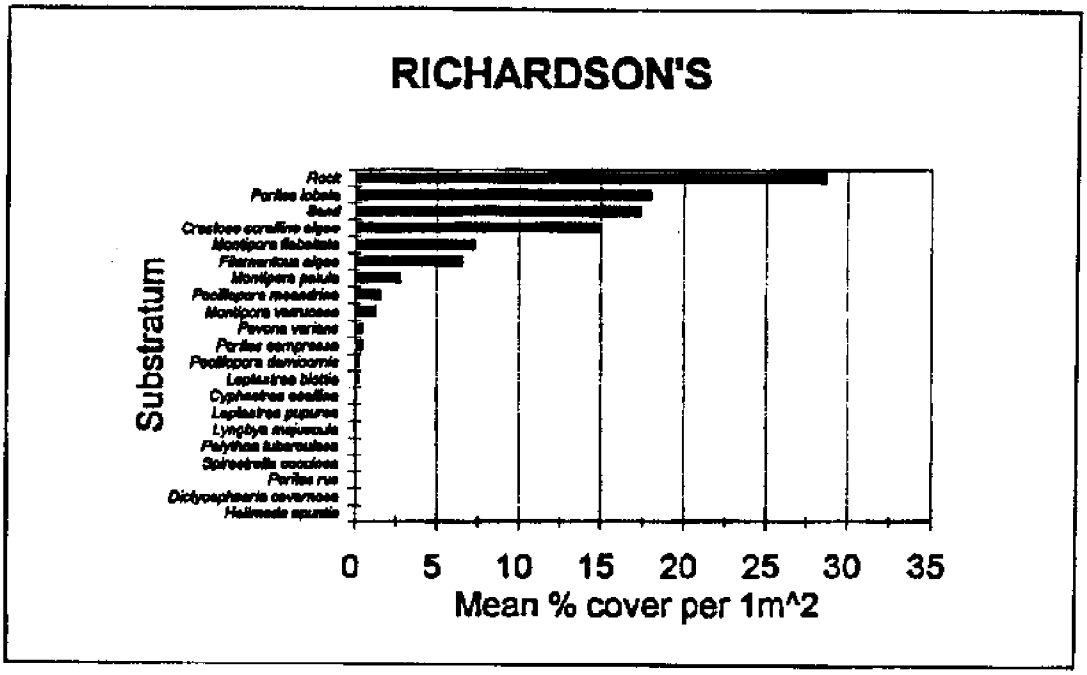


Figure 9. Benthic substratum taxa abundance for Chocks and Richardson's within 40 samples per site (n=40). Given are mean percent cover per 1-m² quadrat. Taxa are sorted by greatest density per site.

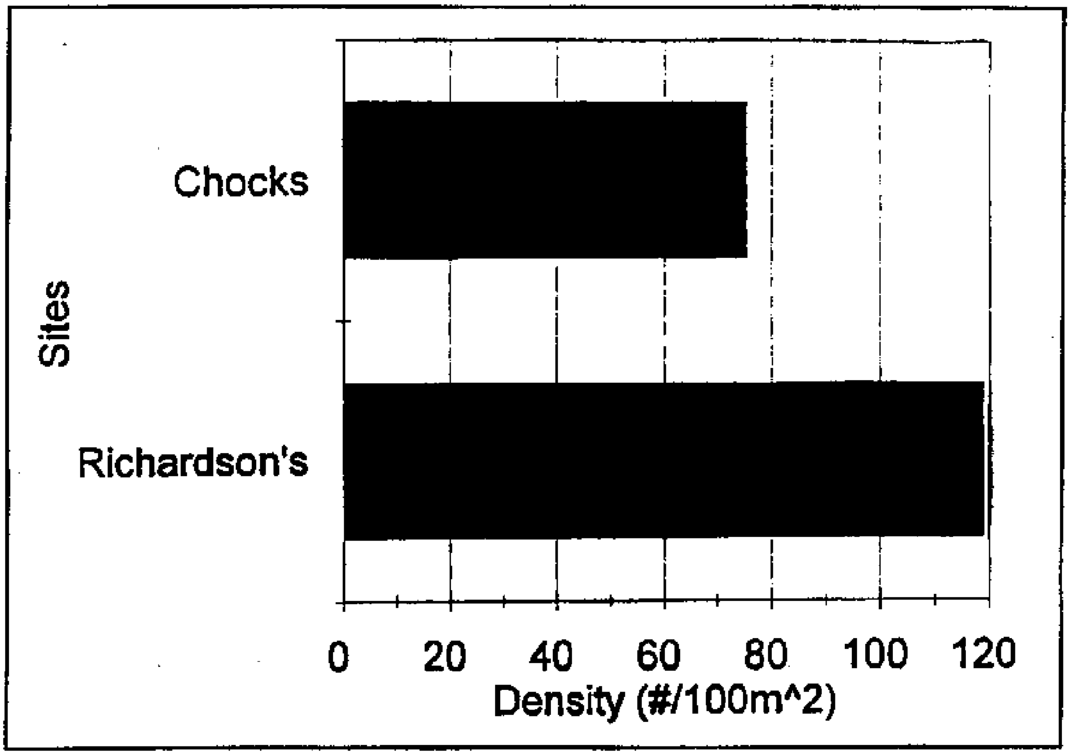


Figure 10. Total fish abundance compared between sites. 16 herbivore species recorded within 32 samples (n=32). Densities computed by number of fish per 100m². Fish abundances from both sites were not significantly different.

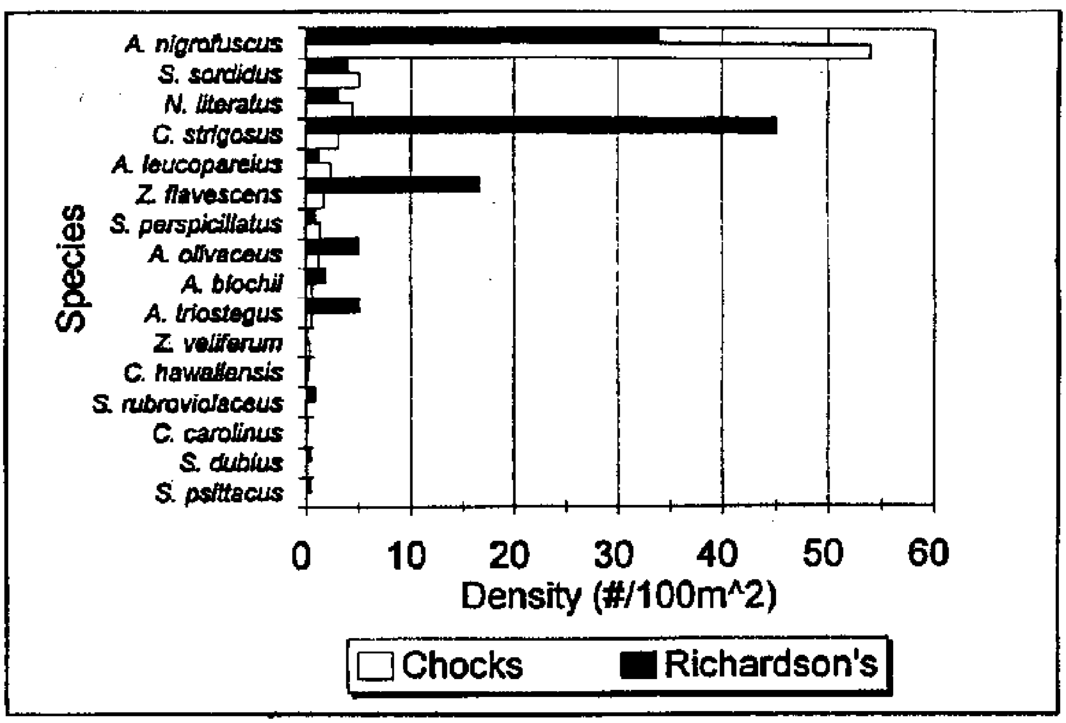


Figure 11. Herbivore species abundance for both sites. 16 species counted within 32 samples (n=32). Mean densities computed by number of fish per 100m².

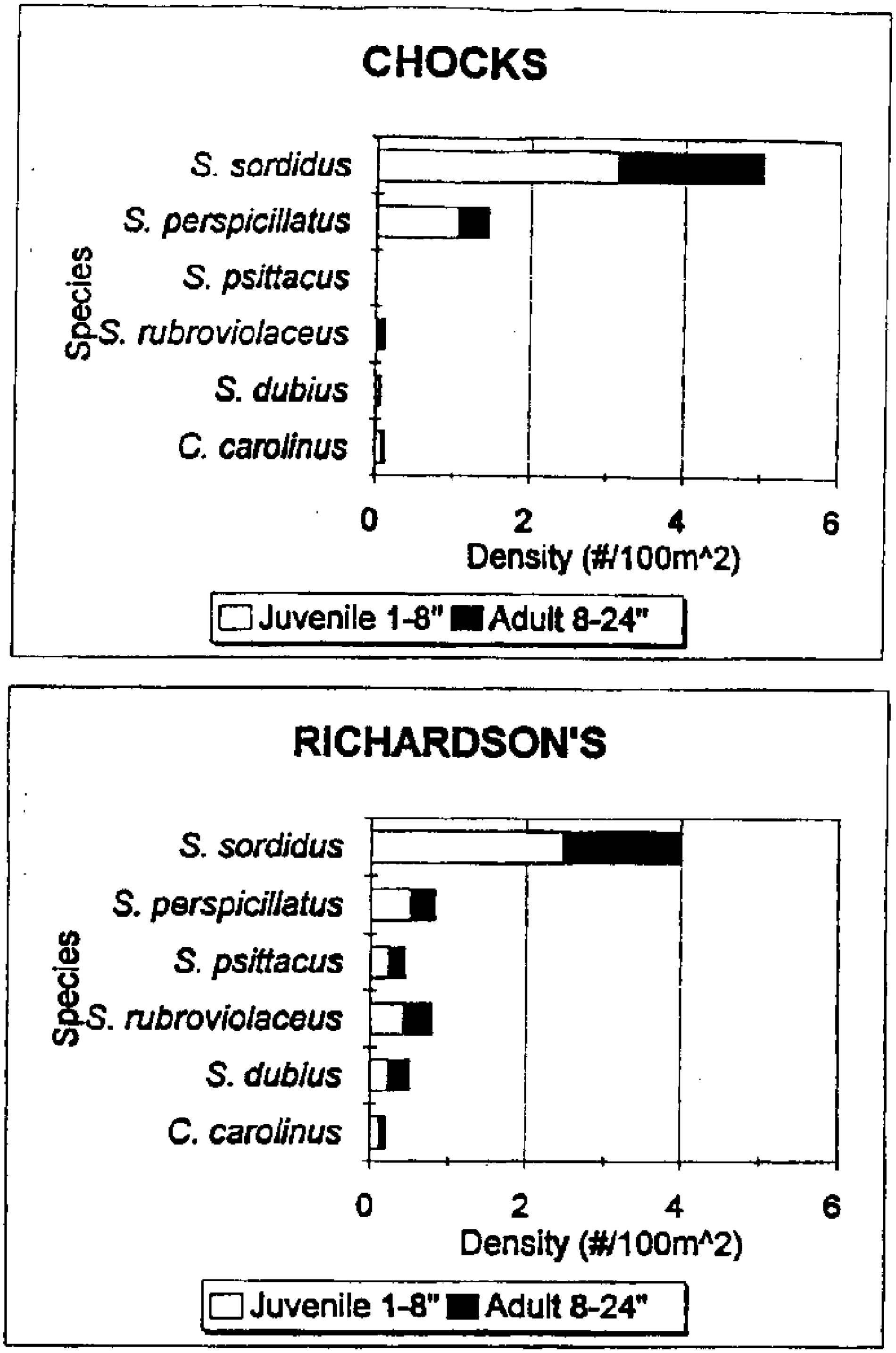


Figure 12. Parrotfish abundance at both sites with juvenile and adult abundance combined. Juvenile body length 2-8", adult body length 8-24".

Feedlot for the Hawaiian Escargot, *Pomacea canaliculata*

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Final Report
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Abstract

Introduced in the late 1980s, the apple snail is now destroying many of Hawaii's aquatic crops. The most noticeable being the state's two- to three-million-dollar taro industry. Pesticides and biological controls have been tried and have been found to be wanting. Hence, an aquaculture scheme was worked out for the apple snail. A trapping experiment in the *lo'i* suggested that 300 snails can be collected when baited with a small mound of feed. Large amounts of fresh water are needed for culture of the apple snails. Feeds should be chosen that do not pollute the water and are easy to see. Several formulations were found to be acceptable but, for management purposes, the feed chosen should be a floating aquaculture feed. Between 4.4 to 5.0 grams per individual per month growth rates should be possible with a production of between 31 and 35 kilograms per 379 liter tank per month. Each restaurant would require about 9,000 snails a month. Aquacultured snails are chewy, have healthy fat, and are sweet.

Introduction

The apple snail, *Pomacea canaliculata*, is considered to be the most damaging pest to ever hit neotropical areas (Halwart, 1994). They have a relatively high fertility rate (200-700 eggs/female), large egg size (about 2mm), short hatching time (12 days), and a high hatching rate (about 50%; Kobayashi and Fujio, 1993). In a heavily infested *lo'i*, they are known to destroy one ha in a night, produce 15,000 offspring a year, and move day and night in search of new food to satisfy their appetites. They thrive in stagnant pools of water at a concentration of 1,000 mature snails per square meter (Anderson, 1993). Combine these factors with their ability to mature in 60-85 days after hatching, and spawn at weekly intervals, and they are a nearly unstoppable pest (Halwart, 1994).

In the late 1980's, the apple snail was introduced to Hawaii and began ravaging local Hawaiian crops (Gordon, 1995). Originally brought to the islands from South America as aquarium pets, the apple snail now destroys taro, watercress, ung choi, and other aquatic crops (Wong, 1995). They are especially dangerous to the state's taro industry, which generates two to three million dollars a year (Statistics in Hawaii Agriculture, 1993). According to Wong (1995): "the apple snail is now well established in many of our wetlands and innovative approaches are needed to contain the apple snail."

One strategy for control of the apple snail was initiated by BoKe' Farms of Hawaii in 1993. It started to develop a market for the apple snails. They are sold as escargot. In a little over two years, they have set up an apple snail culture system based on ancient Hawaiian agricultural philosophies and techniques (Chung, 1995). Although trials and tests are still being performed on the apple snail, there are several benefits that can arise from the success of this project. Not only is BoKe' Farms turning an agricultural pest into local income, they are also teaching the community about hard work and Hawaiian culture (Chung, 1995). The result is not just escargot, but a true Hawaiian product that can be sold to executive chefs in Hawaii and around the world.

While there has been much success with the development of the apple snail as escargot, as with any new product, there is room for improvement. The growth and cultivation of the apple snail has not been investigated systematically. Moreover, apple snails in the *lo'i* (ponds) are small and must be grown to market size. One goal of this research is to help provide answers on how to best raise these snails.

Preliminary studies suggest the growth rate and tenderness, as well as docosahexanoate (DHA) content can be influenced by diet. In January of this year, fatty acid analyses were run on apple snails found at different locations statewide (Table 1; Paguirigan, R., Tamaru, C., Ako, H., preliminary observations). The highest fatty acids as well as DHA content came from the snails collected at Mokuleia, Oahu. It was found that the Mokuleia snails were located near a fish farm and were eating fish food run-off. This suggests tenderness and DHA content can increase with diet. Other mollusks have also been found to have higher fatty acid and DHA contents (Table 2; Thomas, F., Ako, H., and Paguirigan, R., preliminary observations). This is important for another reason. Comparison of marine snail fatty acid profiles with apple snail fatty acid profiles suggests growth rates can be enhanced by improving the feed lot ration, since their low fatty acid content indicates apple snails are probably growing at sub-optimal rates. Tenderness is a function of age; an apple snail that can be grown to restaurant size in a shorter period of time should be more tender because it will be younger. Mouth feel or texture, is influenced by fat content, producing a more palatable snail. Maintaining a high DHA content also benefits health, since it has been found to be an important factor in stress tolerance and nervous tissue composition (Ako, *et al.*, 1994).

In this experiment we hope to increase the growth rate of the apple snail and to find the optimal parameters in which to grow the snails.

Methods

Feeds. Five feeds with different presumed nutritional contents were tested. Lettuce was obtained from a produce wholesaler. All feeds were then tested for amino acid and fatty acid content according to the method of Tamaru *et al.*(1992).

Trial 1 and 2. In Trials 1 and 2, a ten-tank system was implemented, each tank being given one of the five feeds with or without lettuce. Two were reserved as controls. While there were no replicates in Trial 1, replicates were made in Trial 2. Each tank was a ten gallon (20x10x12-inch) glass aquarium equipped with an aerator system to help circulate the water (snails are air breathers and thus have no need for high levels of dissolved oxygen; Perera and Walls, 1996). Plastic screens were laid on top of the tanks to prevent escape. Eggs were collected and destroyed.

A thousand snails were collected. The snails collected were about 3 cm in length. These snails were chosen since this is the size BoKe' Farms collects from Keanae. The three main types of snails at BoKe' Farms were *Pomacea canaliculata, P. paludosa*, and a hybrid of the two. About 80% of the stock are hybrids. *P. canaliculata* is mainly a gold color and *P. paludosa* is a black color. BoKe' Farms harvest about 40% gold and 60% black. A random mixture of all three snails was collected for the feed trial. The tanks were then stocked with 103 and 100 snails for Trial 1 and 2, respectively.

For Trials 1 and 2, except as noted, the tanks were fed to satiation with as much lettuce and/or feed as would be consumed in a 6-hr and 18-hr feeding period. In keeping with the lengths of the feeding periods, the day's ration was divided into a 1:3 ratio. Thus the morning feeding would be fed 1/3 the afternoon feeding or as specified by the hours between meals. Satiation is defined as follows. If at the end of the feeding period, all the feed was gone, an additional gram was added to the next feeding period's ration. If feed remained, a gram was decreased from their ration. The lettuce used in Trial 1 was also fed to satiation and changed on a daily basis.

All trials were carried out for 31 days. Weight measurements were taken at the beginning and end of each trial. Egg clusters and mortalities were noted every day. Length versus weight measurements were noted at the end of Trial 1. In addition, snails were sexed at the end of Trial 2. This was determined by looking at the operculum of each snail. A concave operculum indicates a male while a convex operculum indicates a female (Halwart, 1994).

A fatty acid analysis was performed at the end of Trial 2. One male and one female snail were tested from each of the different feed groups (5 tanks total were then tested for fatty acid content according to the method of Tamaru *et al.*(1992).

At the end of Trial 1, all snails greater than 12g in weight were returned to BoKe' Farms and new size 4 snails replaced them for Trial 2.

Keanae Field Trial. For the Keanae trial, existing 100-gallon tanks with snails that had been collected from the *lo'i kalo* were used. These were nearly exclusively the gold, *P. canaliculata*. Estimates were 7,000 snails per tank. Four level scoops (1 scoop = 200g) of either catfish feed or a mixture of trout feed and chicken feed were used. Beakers (250ml) were used to scoop the feeds. Rates were increased to six scoops per day as the trial progressed, the strategy being that the snails should finish their meal within an eight-hour period after morning feedings.

Trials were carried out for 31 days. Weight measurements were taken at the beginning and end of each trial.

Attractant. To find the best way to attract the snails in the *lo'i*, three different attractants and several methods were tried. Fourteen *lo'i* were tested, varying in the presence and/or maturity of taro and wetness or dryness of the *lo'i*. Three feeds per *lo'i* were used. The three types of feed used were chicken feed, trout feed and mahimahi feed. All the *lo'i* contained a water inlet and a water outlet. All the feeds were placed near the water inlet. Each feed was alternated within the *lo'i* according to distance from the water inlet. Thus if the chicken feed was the closest to the water inlet in the first *lo'i*, the trout feed would be placed near the water inlet in the second *lo'i*. The feeds were tested by placing 150g of feed in a pile, waiting 2 hours, and then coming back to count the individual snails at the pile of feed.

Taste Test. At the end of Trial 2, a taste test was performed on the snails by Alan Wong and his staff of Alan Wong's Restaurant. A dozen snails were collected from each of the treatment tanks. They were then steamed for two minutes to facilitate removal of the meat from the shells. After this, the snails were gutted and then grilled. The snails were tested for texture, tenderness and taste.

Results

Pre-trial Observations. The first main problem encountered was pollution. At the rates the snails were being fed, they produced so much waste matter that by the end of the day the water was extremely cloudy. The airstone could not be seen in about six inches of water. During the first few days of Honolulu trials the tanks became severely polluted. Hence 100% water changes were implemented once a day with cleaning by siphoning. Tanks remained clear during the Keanae trial where water turnover was approximately 12 tank volumes per day.

Feeds. The feeds varied widely in nutrient density. Table 3 shows chicken feed to contain the least amounts of fatty acids, 2.8mg per 100mg of dry matter. Lettuce came next at 3.6%, followed by catfish at 5.9%, trout at 11%, and mahimahi at 12%. The chicken feed was very low in the omega-3 family of essential fatty acids. It had low amounts of linolenate (18:3n-3) and negligible amounts of eicosapentanoate (EPA) (20:5n-3) and DHA (22:6n-3).

The amino acid analysis of the feeds in Table 4 showed that lettuce and chicken were the lowest at 13mg amino acids per 100mg feed each. Catfish followed with 29%, trout with 35%, and mahimahi with 44%.

Trial 1. The feeding scheme is shown in Table 5. The first two tanks were intended to mimic on-farm feeding schemes. In the third, fifth, seventh and ninth tanks, amounts of lettuce and artificial feed provided show that the snails ate preferred ratios of lettuce and feed and that this ratio depended on the feed. Mahimahi feed seemed to be the least palatable and hence snails offered mahimahi feed and lettuce ate a relatively large proportion of lettuce.

It is also noted (but not shown) that the 6- hour and 18-hour rations seemed to be consumed in a 1:3 ratio, consistent with a notion that snails eat 24 hours per day at a more or less constant rate.

Table 6 shows snail performance on the various feeding schemes. It may be seen that snail weight gain seemed to correlate with the amounts of food consumed on a dry matter basis. The tanks provided lettuce seemed to consume more dry matter and gained more weight. Among tanks provided with lettuce, the snails also given chicken and trout feed did well and did better than the tank provided lettuce and mahimahi feed. In tanks not provided with lettuce, catfish and trout feed tanks did well and did better than the tank provided mahimahi feed. Statistics were done by doing a natural log transform of the weights and then a one-way analysis of variance (ANOVA) was performed.

Feed conversion ratios (feed provided/weight gained) seemed similar between treatments. Feed prices are also shown in Table 6. Except for the mahimahi feed, prices are for walk-in purchases of small quantities of feed.

Length versus weight measurements were taken at the end of Trial 1. The results are shown in Figure 1. The fed snails of a certain length were heavier than the Keanae *lo'i* snails of the same length. This says that although the snails may have been the same length, the fed snails were much heavier than the Keanae *lo'i* snails.

The mortalities and egg clusters observed in Trial 1 are shown in Table 7. There seemed to be more egg clusters when the snails were growing faster. A typical egg cluster contained 82 eggs. More often than not, mortalities seemed to be the lowest in fastest growing tanks. Mortalities were almost exclusively small snails with severely rasped shells. Sometimes the shells had holes in them and sometimes the flesh of the snails had been cannibalized. Often, when one snail was on top of another, the bottom snail was seen spinning and the other snail would get off. Figure 2 illustrates the effect of size on rasping and shows that larger snails tended not to have rasped shells.

Trial 2. Results of satiation feeding for Trial 2 can be seen in Table 8. The first two tanks mimicked on-farm feeding schemes. The mahimahi feed was eaten in the lowest quantity of all the other feeds.

Again the 6- hour and 18-hour rations seemed to be consumed in a 1:3 ratio.

Table 9 shows the effect of sex on size at the end of the trial. All tanks except for the catfish tanks and one of the mahimahi tanks had a significant difference of weight gain between snails of different sex. Females in general weighed more than the males at the end of the trial.

In consequence, results were corrected back to a 50% female, 50% male sex ratio. This was done by selecting males using a random number generator so that there was a 1:1 ratio. Sex-corrected feed trial results are shown in Table 10. Catfish, trout, and mahimahi feed tanks did well with the exception of one trout feed tank. The controls and one of the chicken feed tanks did less well. An ANOVA test was performed for the statistics.

The mortalities and egg clusters observed in Trial 2 are shown in Table 11. Mortalities were high in Trial 2. In addition, many of the mortalities this time were larger and unrasped snails.

The fatty acid profiles of the male and female snails fed the different feeds are in Table 13. The results reveal that the control tanks did better than the BoKe' Farm or Mokuleia snails. Other diets also tended to do better than previously analyzed or control diet snails. It may be seen that feeds containing DHA transferred their DHA to the snail flesh. Further conclusions are avoided due to limited sampling.

Keanae Field Trial. The results of the Keanae feed trial can be seen in Table 12. Statistics were done by doing a natural log transform of weights and then a one-way analysis of variance. Initial weights of the snails were not significantly different ($P>0.05$). The control tank did not grow a significant amount in a month ($P>0.05$). Snails in the fed tanks grew significantly ($P<0.001$) compared with the control tanks but did not differ from one another.

Attractant. The total number of snails collected was 2,998. It appeared that the most snails were captured if the bait was in very slowly flowing water. A representative yield was 300 snails per well-placed bait. The types of feed used as the attractant, the presence and/or maturity of the taro in the *lo'i*, and the distance of the bait from the water inlet were not effectively tested.

Taste test. The snails were taste tested *au natural*. All were on the bland side and all were chewy like abalone. The catfish tank was liked best and was described as "sweet."

Discussion

The Keanae area is home to a traditional Hawaiian community located on the remote north shore of Maui. Ancient Hawaiians filled the peninsula with soil, hand carried from the mountains. The people there are 50-100% Hawaiian. The land is a mixture of Hawaiian homestead and leased land. Shared work and shared resources are the foundation of this community. The taro flourished under the pristine conditions found at the peninsula. In the late 1980s, the apple snail was introduced to Keanae. The apple snails have since destroyed the taro crops and have infected the streams. They are an ecological nightmare, the result being small corms and no keikis. Many of the *lo'i* lay fallow or are only half filled with taro plants. If the snails can be marketed as escargot, the Keanae community hopes to employ their unemployed and to generate enough income to pay the liability insurance if DLNR (Department of Land and Natural Resources) agrees to lease them their land. In doing so, they may be able to preserve their traditional lifestyle.

The recommendations in this report are tentative. Three months is not enough time to generate an entire production scheme. The findings have not been replicated. One need only compare the duration of this project with the durations of *mo'i*, mahimahi, mullet, milkfish, or Chinese catfish projects that have lasted 2-4 years.

The use of attractants to trap the snails was one of the objectives of this report. On average, a good snail attraction was 300 snails per bait per 2-hour period. Water flow was found to be the main consideration when attracting the snails with the different feeds. However, new factors arose that left the details unclear. We need to return to finish this objective.

There were several main things learned about snail cultivation in this experiment. First, there must be good water flow. The snails are very dirty animals and at least one complete water change is needed per day for the suggested feed rates. A flat tank bottom tank is probably the best and most economical holding system to use. About 7,000 snails per 100 gallon tank is sufficient. A stand pipe is recommended as the easiest way to set up and control water level. However, a screen is needed to protect the feed and snails from being washed away. The Keanae field trial showed this most clearly. The water for the tanks is pulled directly from a nearby stream. The water in the tanks remained crystal-clear throughout the trial. The snails were fed 1/3 the maximum feeding rate and grew half as fast as the Honolulu trials. The projection if the snails were fed 2/3 the maximum would be between 4.4-5.0g of growth per individual per month. At this feeding rate, each 100 gallon tank will be able to produce about 68-77 pounds per month.

In the wild and at BoKe' Farms, the snail sex ratio is 1:1. However, this was not so in Trial 2. It seems as if the majority of the females were removed at the end of Trial 1. This led to problems in interpreting the data for Trial 2, which were later solved by fixing the sex ratio. The size differences in cultured snails as a function of sex has never before been reported.

The 24-hour per day feeding observed in this work contradicts a statement in the literature (Halwart, 1994).

Nutritional requirements of the snails seemed low since there was no correlation between growth and amounts of fatty acids and amino acids in the feeds. The positive control was the mahimahi feed which was intended to represent an extremely nutrient rich feed. It did not out-perform the other feeds. There was one exception to the low nutrient requirement observation. The data seemed to suggest that there was a fatty acid deficiency in the chicken feed tanks. Complementing the chicken feed with lettuce may have overcome this deficiency (or in Keanae, trout feed combined with chicken feed).

Lettuce in the amounts used in this work seemed, on hindsight, to be a poor choice. The lettuce obtained was nutrient dense because it is an active, photosynthetic tissue. Leafy vegetable materials are not available on any farm in the amounts used in the Honolulu experiments.

The recommendation for feed would relate to management, not nutrition. It should be an aquatic feed, not susceptible to breaking apart in the water. It should be floating, making it easier to monitor food consumption. The scheme taught to the snail culturist in Keanae (Awapuhi Carmichael) is to feed an amount of feed in the morning that will be gone at *pau hana* (at the end of the day). (This will be expanded to two feedings a day.) A feed with the nutrient composition of the catfish feed would be adequate based on the results of these tests.

The Keanae feed trial served as a proof of concept. Keanae used their water resources for 12 tank volumes of changes per day. The catfish feed fed at 1/3 the Honolulu rate yielded approximately 1/2 the Honolulu growth rate. A floating trout and chicken feed mix did well as did the floating catfish feed.

Fatty acid results of the snails after Trial 2 showed several things. Fatty acid contents of the snails can be influenced by diet. The catfish, trout and mahimahi snails had moderate amounts of fatty acids and DHA and this was transferred from the diet. These are likely to be more nutritious to the human consumers as DHA induces stress resistance (Ako, 1994). The control tanks seemed to be a poor control in that the snails seemed to do better than the BoKe' Farm snails. However, the fed tanks did better than the control tanks. A high total fatty acid content was one of the goals of the project. This was reflected in the results of the taste test which described the cultured snails as "chewy" rather than "crunchy."

The snails fed the catfish food also seemed to have a sweet taste that was enjoyed by Alan Wong and his staff. This was probably due to the snails' glycogen storage since these tanks also did the best in the feed trials. Possibly more significantly, the chefs asked for more snails and asked where they could be purchased. One restaurant would require collection and growout of about 9,000 snails (about 300 pounds) from the *lo'i* per month.

The market for the apple snails as escargot seems optimistic. BoKe' Farms is trying to develop a high end market for the snails by selling them to chefs. The apple snails are also sold on the open market as "bisokol." There are also some international interests. However, apple snail farmers must be very careful because some of these ideas have failed in the past. Once thought of as a food commodity in countries like the Philippines, Taiwan, and Japan, they have become an expense costing millions of dollars to control. Their once positive growth rate and hardiness are now the main threat to attempts to try and control these animals.

Both chemical and biological agents have been used to control these animals. Apple snails are important food items for many vertebrates like birds, fishes, turtles, and crocodiles (Donnay and Beissinger, 1993). Ducks and carp have helped to control the apple snail to some degree in the Philippines, but they only control the smaller snails (Halwart, 1994). Pesticides such as Brestan and copper sulfate have been used with harmful side-effects to the people and the environment, including blindness and even death (Anderson, 1993). Pesticides are also very expensive. From 1987 to 1990, Filipino farmers alone spent $10 million on molluscides, which was absorbing about 20% of the farmers' income by 1990 (Anderson, 1993). Instead of ignoring the failed apple snail culture efforts in the Philippines, Taiwan, and Japan, we must learn from them and a pursue a Hawaiian alternative.

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Tables

TABLE 1: Fatty acid profiles of apple snails (mg/100mg sample dry weight).

Location	docosahexanoate	total fatty acids
Keanae	trace	1.3
BoKe'	0.00	1.3
Mokule'ia #1	0.06	1.8
Mokule'ia #2	0.08	2.2
Wailua	trace	1.1
Haleiwa	trace	1.3
Kealia	0.04	1.2

TABLE 2: Fatty acid profiles of some mollusks collected in Kiribati (mg/100mg sample dry weight).

mollusk	type	docosahexanoate	total fatty acids
Cowrie	CAR/DET	0.02	1.3
Oyster	FF	0.23	2.2
Triton	CAR	0.03	1.8
Conch	DET	0.06	1.3
Venus	FF	1.1	5.4
Clam	FF	0.11	2.0

FF = lives in the sand, filter feeder
CAR/DET = carnivore; eats detritus
CAR = carnivore
DET = eats detritus

TABLE 3: Fatty acid composition of different feeds (mg/100mg dry weight).

fatty acid	lettuce	chicken	catfish	trout	mahimahi
14:0	0.01 ± 0.00 d	0.01 ± 0.00 d	0.35 ± 0.03 c	0.77 ± 0.04 b	1.3 ± 0.05 a
16:0	0.39 ± 0.00 d	0.5 ± 0.03 d	1.2 ± 0.07 c	2.4 ± 0.13 b	2.7 ± 0.13 a
16:1n-7	0.00 ± 0.00 d	0.01 ± 0.00 d	0.35 ± 0.04 c	0.71 ± 0.04 b	1.2 ± 0.05 a
18:0	0.06 ± 0.00 d	0.14 ± 0.00 c	0.24 ± 0.03 b	0.54 ± 0.03 a	0.20 ± 0.00 b
18:1n-9	0.03 ± 0.00 e	0.69 ± 0.00 c	0.76 ± 0.04 bc	1.2 ± 0.07 a	0.51 ± 0.00 d
18:2n-6*	0.57 ± 0.00 d	1.3 ± 0.00 b	1.4 ± 0.16 b	1.7 ± 0.09 a	0.90 ± 0.00 c
18:3n-3*	2.5 ± 0.00 a	0.14 ± 0.00 f	0.27 ± 0.03 d	0.42 ± 0.02 b	0.33 ± 0.00 c
18:4n-3	0.00 ± 0.00 d	0.00 ± 0.00 d	0.11 ± 0.01 c	0.31 ± 0.02 b	0.33 ± 0.00 a
20:1n-9	0.00 ± 0.00 c	0.01 ± 0.00 c	0.06 ± 0.01 b	0.12 ± 0.00 a	0.11 ± 0.00 a
20:4n-6*	0.00 ± 0.00 d	0.00 ± 0.00 d	0.05 ± 0.00 c	0.10 ± 0.00 b	0.21 ± 0.00 a
20:5n-3*	0.02 ± 0.00 d	0.01 ± 0.00 d	0.59 ± 0.05 c	1.3 ± 0.12 b	2.5 ± 0.00 a
22:1n-11	0.00 ± 0.00 c	0.01 ± 0.00 c	0.01 ± 0.00 c	0.03 ± 0.00 b	0.08 ± 0.00 a
22:6n-3*	0.00 ± 0.00 d	0.00 ± 0.00 d	0.51 ± 0.03 c	1.3 ± 0.06 b	1.6 ± 0.00 a
total fatty acids	3.6 ± 0.29 d	2.8 ± 0.02 d	5.9 ± 0.49 c	11 ± 0.60 b	12 ± 0.04 a

suffixes that are different indicate differences that are significant (P<0.05)
*essential fatty acids

TABLE 4: Essential amino acid composition of different feeds (mg/100mg dry weight).

amino acid	lettuce	chicken	catfish	trout	mahimahi
threonine	0.69 ± 0.09 d	0.53 ± 0.01 e	1.3 ± 0.03 c	1.8 ± 0.12 b	2.4 ± 0.12 a
valine	0.67 ± 0.11 c	0.57 ± 0.05 c	1.1 ± 0.06 b	1.8 ± 0.34 a	1.5 ± 0.18 a
methionine	0.18 ± 0.07 b	0.21 ± 0.08 b	0.35 ± 0.25 b	0.59 ± 0.27 ab	0.85 ± 0.16 a
isoleucine	0.67 ± 0.02 d	0.45 ± 0.01 e	1.1 ± 0.07 c	1.4 ± 0.06 b	2.1 ± 0.14 a
leucine	1.3 ± 0.04 c	1.3 ± 0.04 c	2.4 ± 0.03 b	3.5 ± 0.25 a	3.6 ± 0.24 a
phenylalanine	0.75 ± 0.08 c	0.59 ± 0.02 d	1.4 ± 0.05 b	1.7 ± 0.13 a	1.8 ± 0.30 a
histidine	0.30 ± 0.01 d	0.32 ± 0.03 d	0.64 ± 0.02 c	1.1 ± 0.11 a	0.84 ± 0.09 b
lysine	1.0 ± 0.11 c	0.93 ± 0.27 c	1.9 ± 0.06 b	3.3 ± 0.33 a	3.6 ± 0.34 a
arginine	0.78 ± 0.02 d	0.80 ± 0.04 d	1.9 ± 0.05 c	2.2 ± 0.07 b	2.7 ± 0.17 a
total amino acids	13 ± 0.94 d	13 ± 0.40 d	27 ± 1.6 b	35 ± 1.6 b	44 ± 2.8 a

suffixes that are different indicate differences that are significant (P<0.05)

TABLE 5: Total dry matter (DM) eaten in Trial 1. Lettuce was 7.71% dry matter.

type of feed	lettuce DM (g)	feed DM (g)	total DM (g)
lettuce + chicken (control)	175	151	326
lettuce + chicken (control)	79	148	227
chicken + lettuce	131	380	511
chicken + lettuce (sm.amt.)	38	396	434
catfish + lettuce	124	412	536
catfish		415	415
trout + lettuce	132	331	463
trout		359	359
mahimahi + lettuce	147	287	434
mahimahi		293	293

TABLE 6: Total dry matter consumed, weight gained per snail, feed conversion ratios and price per pound of feed for Trial 1.

Type of feed	total DM (g)	weight gained (g)	FCR	feed price/lb
lettuce + chicken (control)	326	3.6 cd	1.04	
lettuce + chicken (control)	227	2.2 e	1.15	
chicken + lettuce	511	5.6 ab	0.97	
chicken + lettuce (sm.amt.)	434	4.4 bc	1.04	$0.20
catfish + lettuce	536	6.6 a	0.84	
catfish	415	5.2 b	0.81	$0.39
trout + lettuce	463	5.8 ab	0.90	
trout	359	5.1 bc	0.82	$0.46
mahimahi + lettuce	434	5.5 b	0.86	
mahimahi	293	3.5 d	0.98	$1.00

suffixes that are different indicate differences that are significant ($P<0.05$)

TABLE 7: Mortalities and egg clusters produced for Trial 1.

type of feed	mortalities	egg clusters
lettuce + chicken (control)	12	14
lettuce + chicken (control)	12	8
chicken + lettuce	2	33
chicken + lettuce (sm.amt.)	5	33
catfish + lettuce	3	34
catfish	2	20
trout + lettuce	12	18
trout	15	34
mahimahi + lettuce	8	18
mahimahi	13	12

TABLE 8: Total dry matter (DM) eaten for Trial 2. Lettuce was 7.71% dry matter.

type of feed	lettuce DM (g)	feed DM (g)	total DM (g)
lettuce + chicken (control)	127	93	220
lettuce + chicken (control)	127	93	220
chicken		431	431
chicken		402	402
catfish		395	395
catfish		374	374
trout		368	368
trout		346	346
mahimahi		253	253
mahimahi		256	256

TABLE 9: Effects of sex on snail weights for various feeds for Trial 2.

Type of feed	mean weight females	mean weight males	P values
lettuce + chicken (control)	12.5	10.9	<0.05
lettuce + chicken (control)	11.8	9.90	<0.01
chicken	13.1	11.5	<0.05
chicken	12.4	11.0	<0.1
catfish	13.6	14.0	>0.2
catfish	13.9	14.3	>0.2
trout	14.0	11.8	<0.01
trout	14.2	12.8	<0.2
mahimahi	13.4	12.2	<0.2
mahimahi	13.2	12.3	>0.2

TABLE 10: Weight gain corrected to 50:50 sex ratio for Trial 2.

Type of feed	total DM (g)	weight gained (g)	FCR
lettuce + chicken (control)	220	2.6 b	1.16
lettuce + chicken (control)	220	2.6 b	1.04
chicken	431	3.5 ab	1.47
chicken	402	2.7 b	2.01
catfish	395	4.6 a	0.96
catfish	374	4.8 a	0.97
trout	368	3.2 ab	1.46
trout	346	4.7 a	1.04
mahimahi	253	4.1 a	0.91
mahimahi	256	4.3 a	0.90

suffixes that are different indicate differences that are significant (P<0.05)

TABLE 11: Mortalities and egg clusters produced for Trial 2.

type of feed	mortalities	egg clusters
lettuce + chicken (control)	27	12
lettuce + chicken (control)	19	7
chicken	16	58
chicken	26	41
catfish	11	20
catfish	20	17
trout	21	11
trout	29	5
mahimahi	32	18
mahimahi	34	24

TABLE 12: Initial and final weights of the Keanae snails

type of feed	initial weight (g)	final weight (g)	weight gained (g)
taro tops (control)	8.0 ± 2.9 a	8.6 ± 2.7 a	0.6 a
catfish	8.1 ± 3.8 a	10 ± 3.8 b	2.2 b
trout + chicken	8.5 ± 4.0 a	11 ± 4.4 b	2.5 b

suffixes that are different indicate differences that are significant ($P<0.001$)

TABLE 13: Fatty acids of cultured apple snails.

type of feed	total fatty acids (DHA) female	total fatty acids (DHA) male
BoKe' Farms	1.31 (0.00)	
Mokule'ia	2.16 (0.08)	
lettuce + chicken (control)	1.7 (0.00)	2.5 (0.00)
chicken	4.0 (0.00)	3.4 (0.00)
catfish	2.7 (0.18)	2.2 (0.08)
trout	2.5 (0.16)	3.2 (0.35)
mahimahi	2.2 (0.15)	2.6 (0.29)

Figures

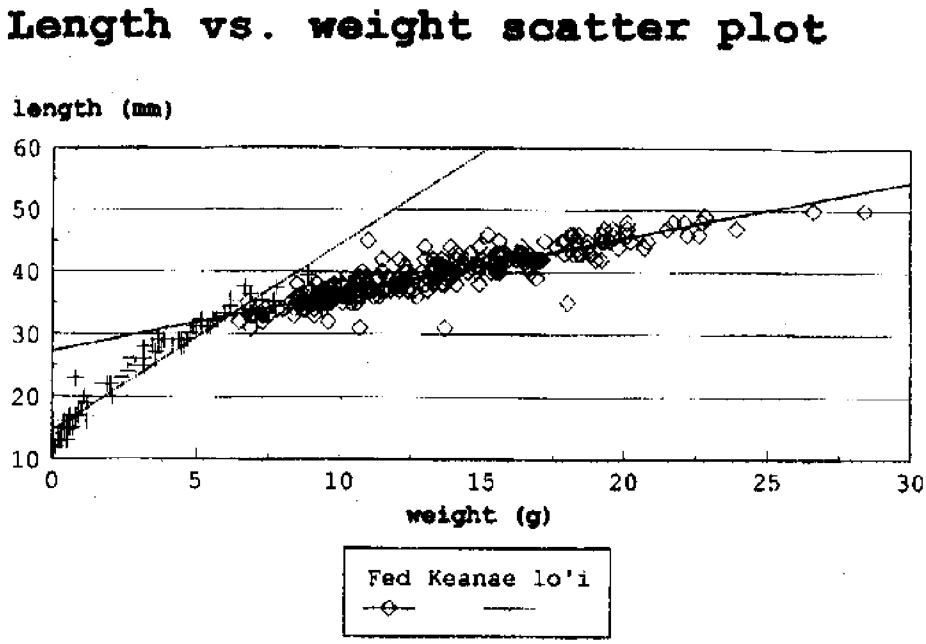

Figure 1. Length versus weight of wild snails collected in Keanae and fed snails aquacultured in Honolulu.

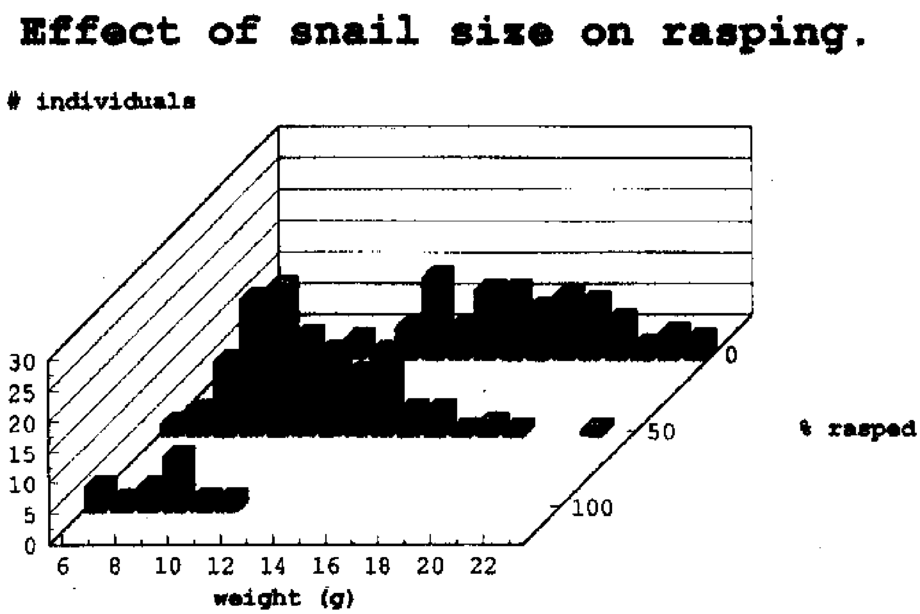

Figure 2. Sizes of snails scored for rasping.