INTERACTIONS OF NONINDIGENOUS BLUELINE SNAPPER (Taape) WITH NATIVE FISHERY SPECIES

by

James D. Parrish
Greta S. Aeby
Eric J. Conklin
Gayla L. Ivey

Hawaii Cooperative Fishery Research Unit
University of Hawaii
2538 The Mall
Honolulu, Hawaii 96822

31 August 2000

Final Report

submitted to

State of Hawaii
Department of Land and Natural Resources
Division of Aquatic Resources

TABLE OF CONTENTS

ABSTRACT

The blueline snapper or taape (*Lutjanus kasmira*) was intentionally introduced to Hawaii from French Polynesia some four decades ago. It has adapted quickly and successfully to the coastal waters of Hawaii, spread rapidly throughout the archipelago and over a large range of depths, and developed dense populations in some coastal waters of the high islands. Concern has been expressed that it may be producing negative effects on populations of native deep-water snappers or otherwise disrupting the existing valuable commercial/recreational handline fisheries for these species. The purpose of this project was to assess the potential for such negative effects.

Fish specimens and quantitative data on characteristics of the fishing process for taape and the native snappers were collected by employing methods essentially similar to standard commercial handline fishing. Catch and effort data from existing NMFS files were extracted. Fish density and habitat use were examined by dives with a manned submersible and remotely operated vehicle, and data were extracted from records of previous dives in the areas of interest. Gut contents of specimens of all target species were examined for evidence of predation or diet overlap among the snappers.

Our catch data indicated that taape were caught almost exclusively at significantly shallower depths than all the native snappers except opakapaka, and that taape fed considerably lower in the water column than opakapaka or kalekale (very close to the bottom) and primarily on benthos, while opakapaka and kalekale fed primarily on planktonic prey. The diel feeding schedule of taape was similar only to that of opakapaka. Taape were caught on the same line hauls and stations only with opakapaka. On almost all line hauls where taape were caught, with or without opakapaka, the catch did not saturate the available hooks on the line, and there was no evidence that an overabundance of taape was excluding native snappers by competition for hooks. There was considerable overlap in species caught on a common hook size, but some experimentation with a range of sizes suggested that careful selection of hooks could introduce some selectivity in catch. Underwater observations tended to confirm depth occupied, provided some information on habitats used, and revealed intimate association of taape with other benthic fishes, suggesting that they do not routinely display aggressive behavior or agonism.

Diet studies indicated that taape clearly separated trophically from opakapaka and kalekale (feeding above the bottom) and from ehu, onaga and gindai (feeding at the bottom). The diet of taape contained some planktonic crustaceans and some fish, but was dominated by benthic invertebrates. Taape shared some specific fish prey with some native species, and there was tentative evidence of cannibalism and of consumption of three native snapper species (one specimen each) by taape. Fish prey specimens were too infrequent to quantify these trophic interactions.

The overall impression is that the introduced taape shows little if any aggression toward native snappers, generally does not share the same depth and feeding habitat with most native species, overlaps little in diet, and is not a frequent predator or prey of the natives. This evidence does not imply strong negative effects of taape on adults of native fishery species in these habitats. It does not address the potential for interactions of taape with young stages of the native snappers or with native species in shallow-water coastal habitats.

INTERACTIONS OF NONINDIGENOUS BLUELINE SNAPPER (Taape) WITH NATIVE FISHERY SPECIES

I. INTRODUCTION

Many nonindigenous finfish species have been introduced, intentionally and accidentally, into fresh and brackish waters in much of the world. In many cases, such introductions have produced unexpected and/or undesirable effects on the native ecosystems, and significant attention has been focused on understanding and minimizing such effects through such management mechanisms as the ICES/EIFAC Code of Practice (Welcomme 1988). Introductions of fishes to marine waters have been less numerous, particularly in the tropics, and much less scientific effort has been applied to understanding the effects of such transfers on the receiving systems. The potential for further marine introductions is high, and there is a clear need to learn from experience about the present effects in order to assess the potential for future ecological hazards.

The blueline snapper or taape *(Lutjanus kasmira)* is a species of marine lutjanid intentionally introduced to Hawaii from French Polynesia some four decades ago (Oda and Parrish 1982; Randall 1987). It has adapted quickly and successfully to the coastal waters of Hawaii, spread rapidly throughout the archipelago and over a large range of depths (to at least a few hundred meters), and developed dense populations in some coastal waters of the high islands. The populations have been exploited for commercial and recreational purposes for decades, but the taape is not a popular fish, and the catches and market value remain low.

One incentive for initial introduction of the taape was that the lack of native, shallow-water, demersal snappers in Hawaii seemed to suggest a "vacant niche" that might be filled with minimal disturbance to the community. However, since the rapid and dramatic increase in numbers of taape, concern has been expressed (Tabata 1981; Maciolek 1984; Randall 1987) that it may be producing negative effects on populations of native food fishes or otherwise disrupting the existing fisheries for native species. Concern has been raised both for shallow, inshore waters with their native "reef fisheries" and for the handline fisheries of deeper waters.

Little hard scientific evidence has been available to address these questions. The Hawaii Cooperative Fishery Research Unit (HCFRU) conducted a preliminary study on the diet and habitat ecology of the taape and a native soldierfish (menpachi) in waters to about 30 m deep (Oda and Parrish 1982). However, no focused study has been made of the taape in deeper waters farther offshore that would assess its potential interactions with the several species of lutjanid snappers of the subfamily Etelinae (Anderson 1987) that support the valuable Hawaiian deep-water bottomfishery. This group, here referred to as the etelines, includes: *Aphareus furca* (wahanui), *Aphareus rutilans* (lehi), *Aprion virescens* (uku), *Etelis carbunculus* (ehu), *E. coruscans* (onaga), *Pristipomoides filamentosus* (opakapaka), *P. sieboldii* (kalekale), and *P. zonatus* (gindai).

Some information is available on basic life history characteristics (e.g., growth parameters, reproductive data, size data, and mortality rates) for some of the etelines (Ralston 1981; Everson 1984; Kikkawa 1984; Uchiyama et al. 1984; Uchiyama and Tagami 1984) and for taape (Rangarajan 1971, 1972; Suzuki and Hioki 1979; Mizenko 1984; Morales-Nin and Ralston 1990). However, little is known about the deep-water habitat or how it is used by either the etelines or taape. A single initial study of eteline diets and some general habitat characteristics has been done in Hawaii (Haight et al. 1993), and the meager diet results for elsewhere in the Pacific have been collected recently (Parrish 1987; Seki and Callahan 1988). Diets of taape have been studied in deep-water habitats only in Western Samoa (Mizenko 1984), and there are no studies of the ecology of deep-water taape and the Hawaiian eteline species occurring together. Therefore, with the current knowledge of the species involved, it has not been clear whether the taape produces significant negative effects on the etelines and should be treated as a pest in that fishery.

The Hawaiian bottomfishery has substantial economic and recreational value and affects many fishers as well as consumers. The retail market revenue from the 1995 catch of the entire archipelago is estimated at $3,600,000, about 4.6% of the total for all fisheries in the state. Over 750 licensed commercial bottom fishers are involved; the number of recreational fishers is unknown, but is believed to be much greater.

The Hawaii Division of Aquatic Resources (HDAR) has recently implemented a new management regime to prevent further overfishing of some of the deep-water Hawaiian eteline stocks in State waters. Since one factor that may affect these populations is the growth of taape stocks and further spread into the habitats of the etelines, it seems important to assess the potential interactions with taape at this time.

Major potential interactions between taape and etelines that could affect the fishery include: (1) predation by taape on etelines or vice versa, (2) competition for food between taape and etelines, and (3) co-occurrence and sharing of habitat. Predation by taape tends to reduce populations of etelines. Predation on taape improves nutrition of etelines and tends to increase their populations, while tending to control taape populations. Where there is much overlap between diets of taape and etelines, and limited food supply, competition for food may reduce nutrition and tend to restrain the populations of both groups. Wherever taape and etelines co-occur in a habitat, there is potential for competition for resources of the habitat (e.g. space, shelter, sites used for reproduction or other behavior), either by direct exploitation or behavioral interference with the other species. Such competition may restrain the populations of either or both species through reduced survival of present or potential spawners or reduced reproduction.

All the above mechanisms (predation, food competition, habitat competition) may result in exclusion or displacement of taape or etelines from particular patches of habitat where the other group dominates, so that reduction in population occurs locally in ways that may or may not be representative of the population effects overall (e.g. archipelago-wide).

The behavioral response to baited hooks by taape and etelines also affects their relative catch by the fishery and perceptions of their relative abundance (because line fishing is the most common way of sampling their populations, particularly in deep water). Experience fishing where taape occur suggests that they take bait very aggressively at times and may be superior competitors for hooks. This behavior may or may not reflect their competition with etelines for natural prey; and the relative catch of taape and etelines at a given location may not reflect their relative abundance there.

With funding from HDAR, the HCFRU performed a study between 1 Sep 97 and 31 Aug 00 to examine and evaluate factors in the ecology of taape and the eteline snappers in the fishery and characteristics of the fishing process that would help assess the nature and importance of these interactions between taape and these native species. This study had the following objectives:

Assess the magnitude of predation by taape on important native eteline snappers (and vice versa) by quantitative analysis of diet.

Assess the potential for competition for food resources between taape and important native eteline snappers by quantitative comparison of diets.

Assess the potential for competition for important habitat by sampling the use of habitat and co-occurrence of taape and important native eteline snappers.

These objectives were accomplished using the following basic approaches (see Materials and Methods sections for details):

(1) Carefully controlled experimental fishing protocols provided fish specimens and detailed information on the fishing process, along with data on catch and effort (including time of day, depth of water, distance caught above bottom, exact geographic position, and co-occurrence with other species).

(2) Results of experimental handline fishing by staff of the National Marine Fisheries Service (NMFS) and a fishing vessel chartered by the agency were extracted from their data base for comparison with our field results.

(3) Visual and photographic observations by project staff and collaborators from a manned submersible vessel by day and from a remotely operated submersible vehicle by day and night provided sightings and counts of the target species and habitat information in typical snapper habitats of the fishery.

(4) Records of similar relevant data from previous dives by other investigators using the manned submersible were examined and combined with results in item (2).

(5) Gut contents of specimens collected in item (1) were examined for evidence of predation by any of the species on any of the others and for comparison of diets to assess the potential for competition.

Results from all the diverse sources were synthesized to assess the nature and importance of interactions between the target species.

II. MATERIALS AND METHODS – General

Fish Collection and Handling and Data on the Fishing Process

All fish specimens and data on fishing were collected by handlining from small/medium-size vessels on the surface. Fishing was distributed over a wide range of the Main Hawaiian Islands, with considerable effort (especially in shallow depths) concentrated on windward (northeast) and leeward (southwest) sides of Oahu and Molokai (see Appendix A for maps). Since the project objectives were not primarily site specific, locations are reported only occasionally in Results where they may be of particular interest.

Handlining methods were designed to be generally similar to those in use in the local commercial fishery, with some modifications required to obtain the detailed data needed and explore the effects of certain variables such as hook size (see report Section III.5). One of the most frequently used vessels and its captain, Mr. Gary Dill, are participants in the regular commercial fishery. Other experienced bottom fishermen participated on some other trips.

A small number of different riggings of hooks on the line and combinations of lines were employed (see report Section III.4). All hooks were baited, almost always with cut squid. On some drops, palu (chum) was deployed when the lines were down, to attract fish from a greater distance. All lines were raised with haulers powered by either battery or hydraulics. Lines were lowered over the side of the vessel and the haulers allowed to free-spool until the lead touched bottom. The lines were then pulled up a short distance (see Section III.4) for fishing. Distance to the bottom was checked periodically while fishing the line by lowering to feel bottom with the lead and repositioning the height.

In fishing done on trips in Dr. Chris Kelley's project, two or three lines were fished together on a drop. Each line was fished for ~5 min, or less if a fish took the hook. The rate of hauling the lines was not closely controlled. In fishing done by Dill, either one or two lines were fished together on a drop. The duration of the drop varied widely, and the drop might be done by drifting or at anchor. In this mode, lines were hauled at a rate of about ½ m/sec – a speed that previous experience (Haight et al. 1993) had indicated tended to produce less barotrauma and eversion of the gut, with less attendant loss of gut contents.

The following data about the fishing process were recorded thoroughly under Protocol 1 (see Section III.2):

At both the beginning and end of each drop (or when each line was hauled): boat location by GPS; time; depth of bottom.

At the beginning of each drop: general geographic location; habitat/bottom information (if available); bait used; hook size and type at each position on the lines.

At the end of each line haul: time spent hauling to the surface; fate of each hook (present/absent, bait/no bait/bait bitten/fish caught); for each target fish caught, the species and the hook on which caught (non-target species identified and thrown overboard).

The following data were recorded for each target fish specimen caught:

State of regurgitation (the extent to which the gut was moved forward or everted at the mouth due to barotrauma), recorded as a simple numerical code (condition 1-5).

Unique identification code assigned to each specimen when removed from hook, and fish chilled at once.

At end of fishing (several hours – two days later), chilled fish processed to include:

Length measured to nearest 1 mm and weight by spring scale (typically to about 1%).

Complete digestive tract and gills removed by ventral incision, preserved with any loose gut contents Found in mouth or elsewhere.

Gonads collected (Protocol 1) or sex and gonad stage recorded (Protocol 2).

Collected fish parts and diet items stored at freezing temperatures until analysis.

Much of the same information was recorded on Protocol 2 collections, but because of time and logistic constraints of the major mission, the following items were often recorded incompletely or omitted:

Regurgitation code; time spent hauling to the surface (rate not closely controlled); fate of hooks; time, depth and position, when fishing was fast-paced.

Methods specific to individual parts of this study are reported separately under results for those individual sections.

III. RESULTS & DISCUSSION

III.1 GENERAL

Species Collected

Besides the main target eteline species that were sampled in sizable numbers and discussed in the rest of this report, several species of interest were taken and observed in very small total numbers in the complete study. Four specimens of *Aprion virescens* (uku) were collected. Uku are usually caught shallower than most of this fishing was done, and collecting substantial numbers would have required targeting areas and depths that would probably have been unproductive of the other important etelines (Haight et al. 1993). Catch of uku is typically seasonal and often highly variable from year to year. *Aphareus rutilans* (lehi) (three specimens collected) provide a small component of the local commercial fishery and are normally caught incidentally while targeting other species. The congeneric *Aphareus furca* (wahanui) (two specimens caught) also have some commercial value, but often occur shallower than the main target species and contribute little to the total catch of etelines. Six specimens of *Pristipomoides auricilla* (yellowtail kalekale) were taken in only one drop at Kaula Rock, Niihau. Two *Erythrocles scintillans* (golden kalekale) were also taken in the entire study. These species have commercial value, but are relatively rare in the local fishery. Directed fishing efforts to obtain samples of useful size of these lesser species would have caused an unacceptable reduction in catch of the main species of interest. These species and other, non-eteline species caught or seen in small numbers (e.g. the deep-water commercial grouper *Epinephelus quernus* [hapuupuu]) are referred to in this report only incidentally to information on taape and the main target species. For almost all these incidental species, no data were taken other than notation of their occurrence, and specimens were not always retained.

Organization of Results

The following sections (III.2 – III.8) report results in several major areas of this investigation. Where appropriate, individual sections contain description of methods and/or discussion specific to their particular results. Section IV draws upon all previous sections for an integrated assessment of interactions by the species of interest.

III.2 HANDLINE FISHING & CATCH PATTERNS

Material and Methods

Data on fish catch and effort, details of the fishing process, and specimens for analysis came from two experimental fishing protocols used more or less concurrently (see Section II, Methods). In one of these, data were taken either (1) by our project staff accompanying fishing trips of a deep-water snapper project conducted by Dr. C. Kelley for DLNR, or (2) by an experienced fisherman (Mr. G. Dill) trained and equipped to take the data per our standard protocol on trips that were appropriate to our data needs. By either means, we were able to insure full and consistent data details of the fishing process and specimen collecting, handling and data recording. Such collections are here termed "Protocol 1" collections.

Other data and specimens came incidentally from other fishing trips in Dr. Kelley's project, in which our staff did not participate. That fishing was focused on catching onaga and ehu, and often occurred much deeper than most of the fishing under Protocol 1 (Fig. 1) - below depths where taape would be expected. It was done almost entirely in daylight hours. It was based on much different objectives, e.g., collection of live specimens for experiments and fresh tissues for biochemical analysis. Specimens were available to our project only on an opportunistic basis.

These "Protocol 2" trips often provided useful specimens, and some of the basic catch data could usually be incorporated into some of our analyses. For other analyses where data were required on details such as specifics of fishing rigs, time of drops/hauls, exact fishing duration of each drop of each line, and fate of each hook in each drop, only the Protocol 1 data were suitable. The Protocol 2 trips were valuable for expanding the sample size for a number of analyses and for extending the geographic range covered. Reference will be made throughout this report to Protocol 1 and 2 data (also see Section II, Methods).

Results

Diel Patterns of Catch

Fishing under Protocol 1 was done around the clock, with an attempt to give some coverage to all parts of the day (Fig. 2). The patterns of CPUE for the various target species were diverse (Fig. 3 and 4). Taape showed the highest recorded CPUE values (Fig. 4), but CPUE varied widely, with high values between ~1600 and 0200 and very low values between 0400 and 1600. Opakapaka also reached its highest values of CPUE between ~1600 and 0200, with lows during much of the daytime, but also showed a minor peak between ~0600 and 1000. Other eteline species were more erratic (and sample sizes were smaller), but all showed lowest values near midnight (Fig. 3).

Depth of Catch

The best overall estimate of the depth distribution of these snappers probably comes from combining the data from Protocol 1 and 2. The median depths of capture of all the target species, based on such pooled data, are shown in Fig. 5. Effort was focused shallower in Protocol 1 fishing and deeper in Protocol 2 fishing; this is indicated in the overall vertical distribution of effort shown in Fig. 1. Effort was light shallower than 50 m, and trivial deeper than 350 m, but reasonably strong over the range 50-300 m.

Because many of the results in this report are based only on data from Dill's collections using Protocol 1, it is useful to consider the (rather different) depth distribution of that fishing effort (Fig. 1). A large majority of all fishing in the range 50-150 m (and thus a great deal of the effort in conventional taape depths) was done with this protocol. About half the total fishing at 150-200 m was done this way, and much less of the effort at greater depths.

In order to examine CPUE by depth, catches by the two protocols were pooled in much the same way as effort in each depth range, and CPUE's were calculated from these pooled catches and pooled efforts (Fig. 6). CPUE of taape was much the highest of all species at depths <100 m and declined to zero below 150 m. Opakapaka produced fairly high CPUE, peaking at about 100-150 m and declining rather steeply. Kalekale peaked broadly at 150-200 m with somewhat lower CPUE. Ehu built steadily to the highest peak of all etelines at 200-250 m and then declined rather sharply. Catches of onaga were very low shallower than 200 m and peaked at ~250-300 m. Similar calculations of CPUE using only Dill's Protocol 1 collections indicated similar trends with depth (Fig. 7 and 8) except that CPUE values for taape in the shallowest depths were even higher, and all CPUE values for eteline species were somewhat lower.

Because taape were essentially absent from catches and observations deeper than ~150 m, it seemed useful to compare CPUE of all the target species above and below 150 m. There was some difference in the pattern based on Protocol 1 data only (Fig 9) and the pattern based on all data pooled (Fig. 10). With both data sets, few opakapaka occurred deeper than 150 m, and the other four eteline species were much more abundant deeper than 150 m.

Diel changes in patterns of depth of capture are also of interest. Only the data from Dill's catches covered the hours of the day sufficiently for this breakout, and only taape and opakapaka at shallow depths produced sample sizes marginally large enough to be meaningful for examining 4-hr increments. For taape, the samples permitted division into three depth ranges (Fig. 11); for opakapaka, there was no catch <50 m, and only catches <150 m were used in this analysis for comparison with taape (Fig. 12). For both species, the general diel pattern was broadly similar in these different depth ranges. The very small total effort (particularly at 0-50 m) and the low total catches in the 0000-0400 period made the estimate of CPUE for these hours suspect. CPUE of taape was higher at shallower depths during the night and early morning hours, when nearly all catch occurred. The CPUE for 0000-0400 was actually the same as for 0000-0200, since no catch occurred during 0200-0400 (effort also approached zero). Examining the data for Fig. 11 and 12 using 25-m depth intervals showed little difference in pattern from the 50-m intervals shown here.

Discussion

Indications of Abundance

Since no absolute measure of abundance or density of taape or eteline snappers is available, catch per unit effort (CPUE) has been used here as an index of abundance (more properly, density) to permit comparisons (e.g. Fig. 3, 4, 6, 7, 8, 11). The usual units here are number of individuals caught per hook-hour. The assumption is made that each hook has the same fishing power for each individual of all species in a given situation when the fish are in feeding condition (e.g. active and receptive to prey). Thus CPUE may be considered proportional to the density of fish exposed to the baited hooks at the time.

CPUE values for taape in Fig. 3-11 were in the range of ~0-6.5 individuals/hook-hr in this study, and were typically <1.0 averaged over larger ranges of time, depth, etc. For opakapaka, CPUE values were usually less in this study, in the range of 0-3.5 indiv./hook-hr, and typically <0.3 in similar situations. Overall values for these two species are best considered by major depth ranges, particularly since taape occurred only shallower than 150 m in this study. For taape (<150 m), the overall CPUE for the entire study was ~0.345 indiv./hook-hr (Fig 9 and 10). For opakapaka, in this depth range CPUE estimates were ~0.12 and ~0.22 indiv./hook-hr (Fig 9 and 10), and in the deep range the estimate was ~0.035 (Fig 10). In depths where taape occurred, the ratio of these values, $CPUE_{taape}/CPUE_{opakapaka}$, for the two species is estimated at 2.88-1.57.

Little information is available from the literature or other sources to compare with these results. Haight et al. (1993) made a study on Penguin Bank involving experimental fishing somewhat similar to ours in this study for eteline snappers, but taape were not collected and were recorded only incidentally. Based on original data from that study, 21 taape and 232 opakapaka were caught in 2164 hook-hr of overall handlining, with 856 hook-hr at depths of 0-150 m, providing CPUE's over all depths of 0.0097 indiv./hook-hr and 0.107 indiv./hook-hr for taape and opakapaka respectively: a ratio of 0.090. For the depth range 0-150 m (where nearly all taape seem to occur), 19 taape and 151 opakapaka were caught, and the CPUE values were 0.024 indiv./hook-hr for taape, 0.176 for opakapaka, and 0.136 for the ratio.

Based on NMFS experimental fishing on 22 cruises (see Section III.6), catches in the total study included 31 taape and 609 opakapaka caught in 7514 hook-hr of handlining, or 21 taape and 416 opakapaka with 2130 hook-hr at 0-150 m. These numbers would result in CPUE's overall of 0.0041 indiv./hook-hr for taape and 0.0810 for opakapaka (ratio 0.0506); for 0-150 m, the values would be 0.0099 for taape and 0.1953 for opakapaka (ratio 0.0506).

The CPUE values for opakapaka from these three sources show some similarity. Estimates based on Haight et al. (1993) and on the 22 NMFS cruises are reasonably close for opakapaka shallow (~0.18 indiv./hook-hr) and overall (~0.09). Our estimates range above and below these shallow values, and our overall values seem significantly lower; they may have some value as another rough estimate of a point index of density of opakapaka in local waters.

For taape, there is great diversity among the CPUE's from the various sources. The estimate from NMFS is less than half that of Haight et al. (1993) and less than ours by a factor of >30. Effort by Haight et al. (1993) was intended to sample habitats on the "fingers" of Penguin Bank and nearby randomly, without effort to catch or avoid taape. Although the 22 NMFS cruises no doubt had diverse missions and methods, the large number of cruises probably provides some randomization and may leave the overall estimate fairly representative. In our study, since many taape specimens were needed, some fishing areas were selected for the prospects of good catches of taape, and it seems less likely that our CPUE values provide unbiased estimates of abundance of taape. (Such estimates were not an objective of the study.) Comparison of all the above numbers seems to support the overall impression that distribution of taape abundance is very patchy (also see Discussion, Section III.7)

Diel Patterns and Depth of Catch

Good information is available on diel and depth distribution of catch for the five major eteline species plus uku, based on the experimental fishing on Penguin Bank by Haight et al. (1993). The trends of CPUE with depth are very similar in the two studies, although values for opakapaka and kalekale were higher, relative to the other etelines in the earlier study. The sample sizes of taape in the earlier study were inadequate for making quantitative diel or depth comparisons.

The diel CPUE patterns for the etelines in our study show some general similarity to results from the previous Penguin Bank study. Results of the two studies differ considerably in detail for some species. It seems likely that the differences reflect sample size and random variability. One of the major indications from our results is the strong tendency of taape to concentrate feeding at night (although our sampling was much less thorough in the middle hours of daylight [Fig. 2]). This research is the first on diel activity of taape in Hawaii. The results are consistent with unpublished taape data from the earlier Penguin Bank project in which catch times of 19 taape specimens taken on handlines were recorded. The full range of times was 0955–2345, with 12 specimens collected during evening twilight to dark (1900-1942 in winter), six specimens late at night (2108-2345), and one in full daylight. This pattern is consistent with limited evidence on the feeding schedule of taape in shallow water (Oda and Parrish 1982).

III.3 FREQUENCY OF CATCH OF SPECIES AND CO-OCCURRENCE IN CATCH

Materials and Methods

Records were kept of every individual line hauled and of the catch (number of individuals of each species) on each line, as well as the length of time the line was fished (a measure of effort). These data permitted determining the frequency of catch of each species in relation to the total number of line hauls or various subsets of line hauls, as well as the frequency of co-occurrence of a species on the lines with other species. Using the single line haul as the unit of sampling gave the most unequivocal measure and evidence of co-occurrence of fishes at a particular place and time. However, the size of the sample was severely limited (typically 4-8 hooks), and from an ecological and habitat perspective, co-occurrence of fishes over a somewhat larger space and time frame is certainly of interest. For this kind of sampling, such a more extended sample can best be taken by pooling lines that were closely adjacent in time and space. The most obvious and probably most reliable pooling would be of lines within the same "drop", i.e. lines deployed and hauled from the same boat at the same time and place. Our data contained some multi-line drops (usually only two or three lines), but many of the drops used only one line. Occasionally two or more drops were made in quick succession at very nearly the same location (e.g. within a few tens of meters based on GPS readings), especially when the boat was anchored. In such cases, when the measured depths were very nearly the same and all other information suggested that fishing was in the same habitat and easily within the immediate range of the same group of fish, the catches from these drops were pooled. These cases of pooled line hauls are referred to as fishing stations to distinguish them from individual line hauls (including individual hauls within the station).

Results

Of a total of 2823 line hauls in the complete study, 192 (<7%) caught taape. Taape were caught on 17.2% of all lines that caught fish, and on 24.4% of all lines that caught snappers (Table 1). Taape were never caught with the three deepest-living common native snappers: ehu, onaga and gindai. They were caught alone on 153 line hauls, on one line haul with kalekale, and 21 line hauls (10.9%) with opakapaka, as well as 17 line hauls with miscellaneous non-eteline species (~20 total individuals, four caught along with taape and opakapaka) (Table 2).

The eteline snappers in the fishery were also caught on lines alone or in a variety of combinations with other species (Table 3). Ehu were caught on line hauls with all the other main commercial bottomfish species (including the grouper hapuupuu) except the shallow-living uku. Onaga were caught with three other etelines, kalekale with four others and the hapuupuu, and opakapaka with three others (one haul each). Gindai were caught with two other etelines and hapuupuu. Some combinations occurred on a good many line hauls (12-14). The shallow uku did not occur on hauls with other etelines.

Taape and all the etelines except kalekale also occurred with a variety of non-snapper species, either caught with other snappers or alone. The "Miscellaneous only" column in Table 3 includes only cases where the only co-occurring fishes were non-snappers. For each species (row) in Table 3, percentages are of the figure in the "Total" column. Thus, they indicate what percent of all the hauls for the species are shared with each other species or group, or are not shared. Except for the shallow uku (with only four specimens), the range of shared hauls over the other six snapper species was about 19-26%. If interactions with the non-target species (in the "Miscellaneous only" column) are pooled with the "Alone" column, so that only co-occurrences of target species are involved, the range of shared hauls across the six species is ~12-25%, and taape shows the lowest co-occurrence. All together, ~27.8% of all hauls caught snapper, and ~ 70.4% of all hauls that caught fish caught snapper.

Co-occurrence of target species was examined in a similar way using the "station" (consisting of more than one line haul at a site) as the sampling unit (see "Methods" above). The results appear in Table 4. Because of the difficulty in assigning many line hauls to stations with Dill's data, this analysis included only the data from all Kelley's collections. The patterns are generally rather similar. Overall, more interactions occurred among target species as the station took a larger sample at a site. For a few species pairs, the number of interactions decreased. A striking case was taape, which continued to occur only with kalekale (once) and with opakapaka. The 21 line hauls with only taape and opakapaka grouped into only nine stations. Two new species pair combinations occurred with low frequency: gindai with onaga and opakapaka. The net increase in co-occurrence among species resulted in somewhat lower percentages of occurrences of all species "Alone" at a station (Table 4), and in a wider range of values. Thus, the range of shared stations over the six snapper species was ~26-46%. For taape it was ~44%. If interactions with the non-target ("Miscellaneous only") species are lumped with the "Alone" column so that only co-occurrences of target species are involved, the range of co-occurrence across the six target species is ~20-44%, and taape is ~40%.

For the above analysis by "stations", a subset (Kelley's collections) of the full data set was used that represented a relatively small amount of sampling at depths where taape are usually found, but a relatively large portion of the sampling at greater depths where most of the eteline species are taken. That subset of data was therefore divided into a block of all samples shallower than 150 m and a block deeper than 150 m. The shallow block included all the stations with taape present and most of the stations with opakapaka present. It seemed useful to examine the degree of co-occurrence of these two species within a depth habitat that they share, with the results "undiluted" by interactions with species that are relatively rarely caught in that habitat. Table 5 shows these results only. (The sample sizes for other etelines in this data block [Kelley's data <150 m deep] were probably too small to be representative.) The entries for taape are identical with Table 4. For opakapaka, the total number of interactions is less; it occurs only with kalekale (once), at nine stations with taape (~16% of its total occurrences), and at 12 stations with miscellaneous non-target species (about 21.1% of occurrences). Interactions represent ~39% of occurrences at stations for opakapaka and about 44% for taape. If interactions with non-target species are pooled with the "Alone" category (as above), interactions occur in only ~17.5% of stations for opakapaka and ~40% for taape.

To round out these comparisons of co-occurrence, the original data set with species grouped by line haul (as in Table 3) was examined again, but only the samples shallower than 150 m. The results appear in Table 6. For taape, these results were identical to the first analysis (see Table 3) because all taape collected occurred at depths <150 m. For opakapaka, the results were similar to the first analysis, including the frequency of interactions between taape and opakapaka and overall interactions of both species separately. Again, the sample sizes for the other etelines at these shallow depths were probably inadequate for interpretation.

A potential negative impact of taape on the fishery for eteline snappers would occur if taape were sufficiently abundant and aggressive toward baited hooks in areas where etelines were being targeted that the taape saturated the hooks and reduced the catch of the desired etelines. Our data were examined for any evidence of such hook saturation. Because the data indicated virtually no co-occurrence of taape in catches of any species other than opakapaka, this analysis was limited to occurrence of taape and opakapaka.

Of 153 taape and 148 opakapaka that were caught on line hauls without any other species, the breakdown of numbers caught and occurrence of remaining intact baited hooks appears in Table 7. These results indicate that in about 90% of all cases when a single fish of either species was caught on our lines, at least one intact baited hook remained (and on the average, 3.5 such hooks remained). Similarly, when 2 fish of the same species were caught together, at least one intact baited hook remained in 73% of the cases for taape and 57% for opakapaka (2.7 hooks and 2.1 hooks respectively). For larger multiple catches, hooks still remain, but the sample size may be too small for the numbers to be meaningful. Since for both species, only 9-12% of all hauls occurred with species other than taape (Table 3), the results in Table 7 are also fairly representative of all hauls other than those with taape and opakapaka co-occurring.

Since catches involving taape and opakapaka together are likely to be of greatest interest with regard to hook saturation, all such line hauls were identified and examined. As Table 3 indicates, 21 line hauls contained taape and opakapaka together; 14 of these hauls caught multiple taape and three hauls caught multiple opakapaka (Table 8). The three leftmost columns in each row of Table 8 together define a particular multi-species combination that occurred. The rightmost column indicates how many total line hauls produced this combination. The remaining columns indicate how many of these hauls ended with 1, 2, 3, 4, or 0 intact baited hooks remaining. Since the original number of hooks was not the same for every line haul, numbers in parentheses indicate the original number of baited hooks. In a few cases, competition by other species (all soldierfish/menpachi in these drops) reduced the number of intact hooks, and each of these effects is shown. The data set is small and there are no consistent overall trends. However, it is clear that in our collections, most hauls with both taape and opakapaka were not heavily overloaded with taape, and intact hooks usually remained except with the largest catches.

Discussion

Most of the 64 incidents of co-occurrence of target species on a line haul involved ehu, the species collected in largest numbers. Ehu were caught most often with gindai, kalekale and onaga in decreasing order of frequency; opakapaka and taape were much more abundant in the catch but co-occurred with ehu once and never, respectively. This may be largely a result of the relatively shallower distribution of opakapaka and taape. The co-occurrence of ehu with the deep-water benthic gindai and onaga seems reasonable; the high co-occurrence with the less bottom-oriented and more planktivorous kalekale seems less intuitive. The two shallowest snappers, opakapaka and taape, co-occurred most often with each other; for both species, about 11% of all catches were co-occurrences. These percentages were somewhat lower than the percentages of gindai and kalekale that co-occurred with ehu.

It is not clear whether grouping species occurrence by line haul or by station is more enlightening. Relatively high percentages of the onaga, kalekale and gindai on line hauls co-occurred with ehu, and these percentages increased when co-occurrence was assessed on a station basis. Gindai also co-occurred rather strongly with kalekale when compared by line haul and especially by station. Grouping by station brought out its co-occurrence with onaga and opakapaka. Kalekale and onaga co-occurred by both ways of grouping, more strongly by station. Co-occurrence of miscellaneous non-target species was not especially high or very different by the two ways of grouping except for opakapaka (where grouping increased its percentage considerably) and taape (where the number and percentage of co-occurrences both decreased substantially). Both taape and opakapaka, and possibly a mix of non-target species, were probably the groups most strongly affected in the change from the full data set for line haul analysis to the partial data set (Kelley only) for station analysis.

Some of these frequencies of co-occurrence seem rather high, e.g. ~11-19% by line haul and ~32-36% by station. The single shallow-water relationship – taape and opakapaka – was among the higher frequencies by both groupings, and these species show strong ecological differences (e.g. diet, position in the water column, overall range of depth). Both species showed relatively low co-occurrence with any other species. In fact, given the full depth ranges of opakapaka and kalekale and their ecological similarities (e.g. diet, position in the water column), their relatively low co-occurrence is a little surprising. The overall co-occurrence of opakapaka with all species is among the lowest of all target species. Overall frequencies for taape cover a rather wide range (11.5-44%) depending on the way of grouping and on whether miscellaneous non-target species are pooled. The other strongest co-occurrences are found among deep-water pairs, e.g. ehu and gindai (~19-34% by the two ways of grouping), ehu and onaga (~10-32% by the two methods). These pairs seem to show strong similarities in ecological characteristics such as those mentioned above. It is not entirely clear what factors led to these patterns of co-occurrence. They may be affected by subtleties of habitat that we did not detect.

The implications of the results relative to hook saturation will be discussed in the overall assessment in Section IV.

III.4 DISTANCE CAUGHT ABOVE BOTTOM

Material and Methods

The depth at which fish encountered the bait was of interest for several reasons. For each drop made under Protocol 1, records were kept of the distance that the lead was above the bottom when fish struck, and of which hook(s) in the vertical array on that line caught fish. The distance above the lead was known for each hook. So the distance above the bottom at which each fish caught had struck the bait could be closely estimated. Since a greater variety of distances above bottom were fished in Dill's fishing, those results are treated separately from results of fishing by Kelley under Protocol 1.

In Dill's fishing mode, there were typically 5-6 hooks in the vertical array spaced 1-2 m apart. The lead was fished at or just above the bottom while drifting and fished at the bottom or various known distances above the bottom while fishing at anchor. Kelley's fishing mode was used primarily in considerably greater depths of water than Dill's. The vertical array always consisted of one hook at each of four levels 2 m apart (the lowest hook just above the substrate), plus two hooks placed within the same general depth range for a few drops. This arrangement was less suitable for detecting fish higher above the bottom.

Results

Dill's fishing

Dill's rigging and its temporal deployment resulted in the vertical distribution of fishing effort shown in Fig. 13. For taape, the sample size was large enough to estimate vertical location in 1-m increments (Fig. 14). Clearly, CPUE was much greater within about 5 m above bottom and declined sharply for hooks higher on the line or when the entire string of hooks was higher above the bottom. CPUE was very low more than 9 m above the bottom. The greatest distance above bottom where catch was reported was 12-14 m.

For other snapper species, sample sizes were generally adequate to estimate vertical location in 2-m increments. For ehu, onaga and gindai, catches appeared concentrated very close to the bottom (Fig. 15), with CPUE generally greatly reduced above ~4 m, although occasional catches occurred as high as 16 m in the water column.

The distribution was considerably different for opakapaka and kalekale (Fig. 16). Catches of both species were rather widely distributed, relatively small near the bottom, and greatest at ~6-10 m up. For opakapaka, the peak was somewhat more pronounced.

Kelley's fishing

Using this vertical array of hooks and fishing always very near the bottom resulted in the vertical distribution of fishing effort shown in Fig. 17. The vertical distribution of CPUE for six snapper species based on this fishing mode is shown in Fig. 18 and 19. At these water depths, the sample size of taape was small (44 total individuals), and for all species, distance above bottom is shown only in 2-m increments. Despite the small sample size, the pattern for taape was similar to that in Dill's (shallower) fishing, with CPUE declining sharply more than 6 m above bottom (Fig. 18). CPUE for onaga and gindai also seemed to decline more or less continuously with increasing height above the bottom. (The apparent rise at 8-10 m may be an artifact of small absolute amount of catch [2-3 specimens] and effort.) For ehu, (Fig. 19), the steep decline in CPUE between 0-2 m and 6-8 m is consistent with results of Dill's fishing. The subsequent increase in CPUE between 8 and 12 m is unexplained; although effort was too small to make accurate estimates, the raw catch numbers were high, and the trend must be real for this data set. When data from Dill's and Kelley's fishing are pooled, this increase in CPUE higher above the bottom is insignificant. For opakapaka and kalekale (Fig. 18), the trends were generally similar to those with Dill's data. CPUE for opakapaka (Fig. 19) was low near the bottom, and increased from the 6-8 m level to the maximum height where data were usable (i.e. at least to 10-12 m). Kalekale (Fig. 11) showed an initial decrease in CPUE to ~2-4 m, then increased beginning at ~6-8 m to the maximum height where data were usable (i.e. at least 8-10 m). The height of maximum CPUE could not be determined for either species, but must be at least as high as that indicated by Dill's data.

III.5 HOOK SIZE

Materials and Methods

One question of interest was the relative effectiveness of various hook sizes and types for taape and the various eteline snappers. A limited investigation of this question was made in fishing by Dill with Protocol 1. The hooks tested are shown in Table 9. All are standard commercial hooks. Several are commonly used in the commercial handline bottom fishery in Hawaii, and these were used most frequently in this study. However, other hooks less commonly used commercially were also tried opportunistically and less often.

Results

Figure 20 indicates the amount of fishing effort with each size class of hook (Table 9). All fishing with size classes 2, 3 and 6 and almost all fishing with size class 1 occurred at depths <150 m (depths where taape were caught) (Fig. 21). Hook size classes 5, 7, 8 and 9 were fished over a wide range of depths (Fig. 22), covering the habitat range of taape and of the deepest etelines.

Although the effort with some size classes was too small to provide reliable results (e.g. classes 2, 4 and 9), it is clear that some sizes of hook were more productive for some species than others (Fig. 23). Size class 3 (mtc 6/0) was highly effective for taape only. Class 5 was also highly effective for taape and for opakapaka and was the hook used most often (Fig. 20). Classes 6, 7 and 8 were more productive for the other eteline snappers, and fairly good for opakapaka, but CPUE of taape reduced rapidly with hooks progressively larger than size 5. The apparent high CPUE of kalekale with the Class 6 hook, shown in Fig. 23, is somewhat suspect; the total effort involved was very small, applied at one location over a period of ~3 hr.

III.6 CATCHES OF TAAPE BY NMFS EXPERIMENTAL FISHING

Materials and Methods

The Honolulu Laboratory of the National Marine Fisheries Service has done considerable experimental handline fishing over a period of several years. This fishing may have had a variety of objectives related to commercial bottomfish, but the taape was probably never targeted, and the data may not have been examined from the perspective of the present study. The Honolulu Laboratory provided data from two different sources for our examination: (1) fishing by the laboratory staff, primarily from the NOAA vessel assigned to the laboratory, and (2) fishing by a commercial fisherman chartered by the laboratory.

The laboratory's standard catch data bank provided fishing data for 22 research cruises by NMFS staff in the Main Hawaiian Islands, carried out between June 1983 and September 1993. Collectively these cruises applied a total fishing effort of 7514 hook-hours, typically in the form of four lines fished simultaneously with four hooks per line. Data available for each commercial species and some incidental species included date, start and end time and start and end depth and location for each drop or drift, the specific fishing rig used, fishing effort (convertible to hook-hr), and for each fish caught, the species and size, depth and time caught. From these data, we calculated catch in number of individuals, corresponding effort, and CPUE for taape and each of the major eteline species. Detailed data were extracted on each taape caught and each eteline specimen caught on the same drop with a taape.

The charter fishing was performed using the vessel Kaimi in October 1982 in the waters around Niihau and Penguin Bank. All fishing was done drifting using three lines, each with four Mustad #5 hooks. The data taken were much the same as collected in fishing by NMFS staff (above). From the Kaimi data, we calculated catch in number of individuals, corresponding effort, and CPUE for each of the major eteline species.

Results from these two NMFS sources provided a supplement to our own fishing data and that from Kelley's project and covered an earlier time period.

Results

NMFS Laboratory Fishing

Of the 22 cruises from which data were used, 20 provided data on catches of snapper. Five of these included catches of taape. A total of 31 taape individuals was reported as part of a total catch of 1931 fish (see Table 10), i.e. ~1.6% of the total. The catch of taape at depths <150 m was 21 individuals from a total catch of 725 fish (~2.4%). However, the data for taape are not entirely credible. The six specimens reported caught at 150-200 m, the two specimens at 200-250 m, and the specimen reported at 300-350 m are possible but highly unusual compared to data from other sources. Catches of opakapaka at depths <150 m were high, and catches of gindai, ehu and kalekale were substantial (Table 10, Fig. 24). Effort in these depths was not high except in the 100-150 m range (Fig. 25). The result was a higher dominance of CPUE by opakapaka in this shallow range, with the other three etelines lower and similar (Fig. 26). CPUE of taape was relatively higher compared to all these etelines than in comparisons of catch alone, but except in the 0-50 m depth range, taape CPUE was low (e.g. ≤6% of opakapaka CPUE). By a depth of 150 m, CPUE of taape was near zero and remained so at greater depths. Effort peaked by 200 m as CPUE of opakapaka declined and CPUE of gindai, kalekale and ehu increased, then declined until CPUE of all species was near zero by depths of 350 m.

The cruise data contain almost no information on habitat of capture. As with other handline data, aggregation of individuals and association between species can only be inferred by proximity of catches, so the data were examined for groupings of catches. On one evening drift of about 20 min, two taape and one opakapaka were caught on the same line at 73 m depth at 1955, and 5 min later 2 more taape were caught at a depth of 26 m on the same line (usually inferred from data on time of catch). On a particularly long drift (>2 hr), 8 taape were reported caught at depths between 150 and 203 m. Apparently all were on separate lines, with catches spaced apart from 1 min to 1½ h. In this drift, one opakapaka was caught shortly after a taape catch (but separately) at 207 m depth, and two opakapaka were caught on the same line with one of the eight taape just at the end of the drift at 2115 at a depth of 150 m. Several of these reported depths are surprisingly great. In two other cases, two taape were caught very close together on the same drift, once apparently on the same line (at ~1500 at depth 84 m), and once two catches within a minute (at 2130 at depth 95 m). In one other case, three taape were reported on the same line (at 2035 at depth 44 m). Another case of closely spaced catches of one taape and one opakapaka (within 3 min) occurred at 2345 at depth 157 m. Two taape were reported taken at 2100 on the same line at 57 m depth, and nine minutes later, an opakapaka was taken at the same depth. Five taape were taken in individual drifts with no other taape or etelines reported.

Charter Fishing

The total fishing effort of the Kaimi charter was ~109 hook-hours, distributed as shown in Table 11. Effort was focused in the depth range of ~100-150 m, a range in which taape are often encountered. The commercial species caught were ehu, gindai, opakapaka, kalekale, and the grouper hapuupuu. Total CPUE was much higher between 100 and 200 m (Fig. 27). Surprisingly, hapuupuu showed the highest values of CPUE, but only around 100 m depth. No taape were caught in this effort of 109 hook-hours applied strongly at depths where catch rates of taape in our recent project were sizable.

III.7 UNDERWATER OBSERVATIONS

Materials and Methods

Direct observations of taape and their habitat, with incidental observations of eteline snappers and other fish species present, were made on two cruises during the periods 16 Aug-7 Sep 98 and 15-27 Sep 99 using submersible vehicles of the Hawaii Undersea Research Laboratory (HURL), Pisces V and RCV-150, and the surface support vessel Kaimikai-o-Kanaloa.

Pisces V is a manned submersible carrying a pilot and 2 observers, each observing the surroundings through an individual view port using external floodlights as needed at depth and recording data using still flash camera, digital video, and conventional video with simultaneous recording of observers' voices. Time, depth and position of the submersible (based on GPS positions for the tending vessel and sonar fixes of the submersible's position relative to the vessel) were available continuously or at frequent intervals. (See Appendix B for description, specifications and capabilities of Pisces V.)

All diving with Pisces V was done in collaboration with other projects studying deep-water snappers. These projects were concerned with specific locations related to areas closed to fishing and corresponding control areas, or they required observations at greater depths than taape usually occur. However, taape were a target species of opportunity in all Pisces V dives, and all sightings were recorded with camera images and commentary. All Pisces V dives were made during daylight hours (~0800-1700).

The RCV-150 is a remotely operated vehicle (ROV), connected to the support vessel by an umbilical cable with fiber optics for data signal transmission. Its attitude in the water and small-scale movements are adjusted by thrusters controlled from the tending vessel. It carries floodlights for operation at depth and provides signals of depth and video images, with simultaneous voice recording by an observer in the control room. Position can be constantly estimated from GPS position of the tending vessel, providing a record of the vehicle's track with position, time and depth. (See Appendix B for description, specifications and capabilities of the RCV-150.)

Diving with the RCV-150 was almost entirely devoted to the taape project, and except where noted in Results, was all done during hours of darkness. The general localities observed were mostly near those where Pisces V submersible diving was done, and were somewhat constrained by distance feasible to travel from the locations of daytime Pisces V dives. However, RCV-150 dives were concentrated in shallower waters to include the depths where taape occur most commonly. The entire period when the vehicle was submerged was recorded with videotape and commentary, including all sightings of taape and eteline snappers, with data on their depth, habitat and behavior. The RCV-150 and Pisces V have almost no capability for measuring objects in the water, and estimates of size and distance were based mostly on comparison with other objects in the field of view and (for fish) on general familiarity with the species morphology.

Reports of observations of taape were also retrieved from submersible dives made previous to this project. The data archives at HURL were scanned to identify those dives most likely to provide accurate sightings of taape. Dives were screened on the basis of location and depth, mission objectives, and observers' backgrounds, familiarity with taape and eteline snappers, and level of professional interest in these fish that would have led to reporting such sightings. A relatively small fraction of all previous dives met these criteria; all these dives employed the 2-person submersible Makalii, predecessor of Pisces V. Makalii provided generally similar capabilities for observation and identification of fish in the depths of interest. Project staff examined the full transcript of the audiotapes and the logs of still photos from the most promising dives (made in 1981-1987) found in the archives. The data of interest for taape are reported in Results.

Results

Project Dives (1998-1999)

On the 1998 cruise, the submersible Pisces V made 19 dives for a total of ~123 hours of underwater observation. Taape were observed on only one dive at ~0900 31 Aug 98 at a depth of ~110 m. A school of 100 or more ~15 cm long were seen on the southern face near the east end of the "Third Finger" of Penguin Bank (off the southwest tip of Molokai), a little below the top of the feature. The habitat consisted of a rocky sloping wall with a dusting of sand. Several balistids were sighted in the area at the same time.

On this 1998 cruise, a total of 22 dives (37.7 hr) of underwater observation were made with the RCV-150: 5 dives (4.8 hr) at depths <160 m and 21 dives (32.9 hr) at depths >160m. No taape was ever seen or caught using any equipment at depths >160m in the entire study. In 1998, the only sightings of taape from the ROV were also on "Third Finger" of Penguin Bank, on a track run diagonally across the top of the feature near the middle at ~2015 on 29 Aug 98. The substrate at a depth of 96 m was mostly flat, hard sand with small depressions (<1 m across) scattered rather closely and containing knobby rock/rubble encrusted with algae and sessile invertebrates, with perhaps 15 cm of relief. One taape was motionless under a small ledge, and two were seen immediately afterwards resting on bottom against a rock face. Several "reef fish" species were seen relatively motionless close to the taape, including two *Heniochus diphreutes,* one *Chaetodon fremblii*, and two *Myripristis chryseres* – the latter sheltering within centimeters of the two taape against the same rock. In all the 1998 ROV diving, no eteline snapper was seen at depths <160 m. Deeper than 160 m, three total individuals of ehu (*Etelis carbunculus*) were seen on two dives at depths of 199 and 300 m, and one onaga was seen at 200 m (see Table 12).

The only sightings of taape from Pisces V on the 1999 cruise were in the same general area on "Third Finger" of Penguin Bank near the east end of the southern face, near the shoulder of the steep drop from the top of the feature at ~110 m depth. The first sighting, at ~0900 15 Sep 99, was of one taape ~18 cm long, near the shoulder, with a relatively flat sandy top and a slope with about half the surface made of exposed rock, with ~15-30 cm relief. Other species seen in the same area at the time were a school of ~25 *Naso* sp. 30-45 cm long, *Chaetodon modestus, C. miliaris, Desmoholacanthus arcuatus*, and possibly the snapper *Aprion virescens* (which usually occurs at shallower depths). The other Pisces V sighting in 1999 was made close to this location five days later at ~1500 at a depth of ~115 m. Two taape were seen swimming with *Symphysanodon typus* about ½ m above the bottom in a habitat that was ~95% rock with relief to ~1/2 m, and many ledges and caves. Other species seen in the same immediate area at the time were the deep-living snapper *Aphareus furca* (and possibly also opakapaka)*,* the jacks *Caranx melampygus* and *Seriola dumerili, Naso* sp., *Chromis struhsakeri, Holanthias fuscipinnis, Pseudanthias fucinus,* and *Myripristis chryseres.*

In total, 3 taape individuals were sighted in only two of the 13 Pisces V dives in 1999 and only in the 110-115 m depth range. The available observation time for these dives was 72 hr; only 3 hr were spent at depths shallower than 160 m. Over the same observation periods, many more sightings were made of native eteline snappers (Table 13). All except 23 of the estimated number of fish observed were seen at depths >160 m, probably reflecting a preference of most of these species for deeper habitat, as well as the much greater observation time >160 m. Opakapaka and kalekale are generally considered to have the shallowest distributions of these five eteline species, and only these two species were reported at depths <160 m. The low number of total sightings and individuals of opakapaka was somewhat unexpected and may reflect a behavioral avoidance of the submersible as well as the higher position above the bottom that this species is believed to occupy commonly (see Section III.4).

On this 1999 cruise, a total of 31 dives (38 hr) of underwater observation were made with the ROV: 25 dives (21.1 hr) at depths < 160 m and 24 dives (16.9 hr) at depths >160 m. Many more sightings of all species occurred during these dives in 1999 than in the 1998 dives (see Table 14). Of these, all taape and opakapaka and over half the kalekale were seen shallower than 160 m; all except two ehu and all the onaga were seen at greater depths (~165-325 m).

Taape were seen from the ROV in 1999 in six general areas: east tip of "Third Finger" (Penguin Bank), west end of "Third Finger", between "Second Finger" and "Third Finger" on the edge of the Bank, top of "Second Finger", southernmost tip of Penguin Bank, and an area northeast of Mokapu Point on the windward coast of Oahu. Considerable ROV surveying was also done in an area on Oahu east of the Mokulua Islands (mostly in somewhat deeper water), but no taape was seen.

A track was run 17 Sep 99 ~0200 northeasterly across a small pinnacle situated just east of the tip of "Third Finger" (Penguin Bank). Near the base, at 153 m depth, two taape ~15 cm and 22 cm long rested motionless ~30 cm apart on a flat sand bottom, with occasional rocks, but no substantial shelter or bottom relief. No other species was seen. On 18 Sep 99 at ~2000, a track was run northeasterly from the northwest corner where "Third Finger" joins Penguin Bank, roughly at the top of the feature along the edge of the Bank. Two taape ~25 cm or smaller were seen at ~100m depth at the edge of a steep drop from the edge of the feature in a rocky habitat with relief of ~1/3-1 m. They were under a ledge, very close to (possibly touching) a goatfish and two unidentified fishes. Three taape (lengths ~15, 22, 22 cm) were seen later at a depth of 71 m in an area of mostly sandy bottom with rocky outcrops and ~5-10 cm relief (no obvious ledges or caves).

On 15 Sep 99, between ~1900 and 2300, two tracks were run end-to-end in a generally easterly direction along a portion of the rim near the top of the southward facing slope of Penguin Bank roughly halfway between the bases of "Third Finger" and "Second Finger". A total of eight taape were seen in six separate sightings; one individual was estimated at about 30 cm long and the others at <25 cm long. All were seen between 91 and 94 m. depth in broadly similar habitat with mostly hard substrate and a dusting of sand cover. Much of the substrate was rocky, often with knobby rock encrusted with benthic invertebrates and algae and several centimeters of relief. Occasionally boulders up to 2-3 m in size were present. Three taape (three sightings) were within several centimeters of the bottom and very close to small ledges that could provide some shelter. Two taape (two sightings) were on the bottom very close to small caves or holes in rocks. Two taape (two sightings) were swimming within several centimeters of the bottom in similar habitat, but not near any features that appeared to offer shelter. At two sightings, a pair of taape were 2-3 m apart. At one sighting, 2 *Myripristis chryseres* and one *Sargocentron* or *Neoniphon* species sheltered under the same ledge, and at another sighting, an *Acanthurus dussumieri* swam near a taape at the same ledge. At another, a *M. chryseres* was under a small ledge just below a taape. At another, *Neoniphon aurolineolatus* was close to a potential shelter hole in the ~1-m high feature that a taape swam close over; a *Dardanus brachiops* was also nearby. At another sighting, an *Arothron hispidus* swam in the water column ~2 m from a taape at the opening of a cave, and two *Myripristis chryseres* sheltered 6-7 m away in another hole.

On 19 Sep 99 between about 0100 and 0200, a track was run starting on the top of "Second Finger" near the west end and running northeast diagonally across the top of the feature and part way down over the north facing slope. The substrate and benthic habitat were much like that described above for the 15 Sep 99 dive. Five taape were observed in 3 sightings within a period of about 7 min on or near the top of the feature at depths of 107-113 m. Sizes were probably in the middle of the range of others reported here. One taape was sighted along with three *Myripristis chryseres* in a cave with an opening of about 30 cm in an area of knobby, encrusted rocky bottom with up to ~30 cm relief. Three other taape were seen in similar habitat, swimming together several centimeters above the bottom, next to a ledge about 30 cm high. A single taape was reported "low down in algae" on the bottom. Ten minutes after the last taape sighting, an ehu was sighted at a depth of 160 m.

Two dives were made at the southernmost tip of Penguin Bank on 17-18 Sep 99. A dive from ~2200 17 Sep through ~0100 18 Sep explored the southeastern corner of this tip on tracks that ran roughly northeasterly, sometimes above or near the top of the steep slope of the bank and sometimes on or far down that slope. Two onaga were seen far down the slope (210 m), but all the taape were seen at the top of the slope on a relatively flat, sand/rubble substrate that in most places provided little relief or cover. Seven taape were observed in five separate sightings over about 1½ hr. One taape was resting on the bottom in an area with no relief or cover; another was resting on bottom in a rubble patch with a few centimeters of relief but no real shelter. One taape swam a few centimeters above the bottom close to one of several scattered carbonate ledges that occasionally emerged half a meter or more from the sand bottom. Three taape were seen together a few centimeters above the substrate in one of several scattered rocky patches, each patch ~2 m in radius, that provided ~15 cm of relief; this patch also contained (in close proximity) *Desmoholacanthus arcuatus* and *Myripristis* sp.

The other dive on this southernmost tip of Penguin Bank was at the southwestern corner, where tracks were run in a northerly direction up the slope and for some distance across the relatively flat top of the bank. Taape were seen only on top of the bank at depths of 45-50 m on substrate that was basically rock and hard sand, much of it with knobby cobbles encrusted with sessile invertebrates and algae, providing several centimeters of relief. Five taape were observed in 3 separate sightings within about 6 min on a dive between ~2000 and 2200 17 Sep 99. Two sightings were of individual taape resting openly in this knobby bottom, not sheltering. In one of these cases, an acanthurid and four *Myripristis* species were sheltering under a small ledge near the taape. At the other sighting, three taape swam just above the bottom, meters apart, with no recognizable shelter in sight.

At Mokapu Point on the windward coast of Oahu, taape were seen on three of the nine ROV dives made. A dive was made at dusk (~1730-1830) 24 Sep 99 in depths a little over 100 m over a hard sand slope. At one location at a depth of 113 m, emergent rock created a deeply undercut ledge with a vertical opening of ~2 m. A large group of taape, estimated to number ~250 fish, schooled near the ledge. Large schools of the small deep-water snapper, *Symphysanodon typus* were also present nearby. Some 13 min later on the same track, a single kalekale was seen at a depth of 122 m.

In a daylight dive the same afternoon, a track was run between ~1600 and 1700 at slightly shallower depths nearby, over the same kind of hard sand with little relief. At 105 m and 103 m depths, rather large groups of opakapaka were sighted about 3 min apart. Later in the track, a series of large boulders (some 3 m or more in height) was encountered at depths of 99-101 m. The boulders provided high relief, with caves, cracks, crevices and ledges for shelter. Within a period of 4 min, three apparently separate groups of taape were sighted with numbers estimated at 27, 15 and 100. They schooled at the edge of the group of boulders and among them. Throughout much of this boulder area, large clouds of *Luzonichthys* sp. were also present. A school of 30 *Naso* sp. was present ~5 m from where the first taape school was encountered, as well as a school of carangids. *Chaetodon miliaris* was also common throughout the immediate vicinity. *Heniochus* sp. and some wrasses were also present.

On 23 Sep 99 at about 0230-0400, a night dive was made nearby, beginning in what seemed a generally similar habitat (i.e. hard, relatively flat sand with little relief). During the track, the topography became more rough, uneven and rocky, and taape and etelines were sighted: three taape at a depth of 107 m, one opakapaka each at depths of 90 and 121 m, one kalekale at 107 m, and one ehu each at 200 and

228 m. The taape and kalekale were seen at the same depth and within 1 min; one of the opakapaka was seen 2 min later and 14 m deeper.

The above account includes all sightings of taape in both years with both underwater vehicles.

Previous Dives (from HURL archives)

All the most promising records found were from dives on Penguin Bank by the submersible Makalii. Useful data were examined from a total of 51 dives (Table 15); 29 dives were classified as deep (significant time at depths >160 m), and 23 dives were classified as shallow (significant time at depth <160 m). No sighting of taape was reported >160 m. Twenty-one of the 29 deep dives (72%) reported sightings of etelines. Of the shallow dives, 19 of 23 (83%) reported etelines and seven (30%) reported taape. In only one dive, taape were explicitly reported once in the same sighting with an eteline species (uku). From the 7 dives with taape observed, a total of 19 individual reports of taape occurred. Each may have represented a separate sighting, but the information on location and time suggests (but does not confirm) that some may have occurred at essentially the same place at very nearly the same time, and may have been multiple counts of some of the same individuals. Records from this group of 23 shallow dives contained 80 individual reports of sightings of snappers (including taape and etelines). The fraction of sightings of taape (19/80 = 24%) is similar to the fraction of all shallow dives (7/23 = 30%) that provided sightings of taape.

Of the dives on which taape were reported, four dives (including 13 sightings) were made on the extensive, relatively flat, sandy top of Penguin Bank at a few sites where artificial reefs had been placed within the previous few years. A few of the sightings could have occurred on the open sand between these reefs, but the available records and discussions with scientists involved in these dives strongly suggest that all or nearly all these taape were in fact seen at the artificial reefs.

All these dives were made at depths of 58-61 m and in full daytime between 1025 and 1224. As suggested above, the relevant substrate and habitat are probably the reef materials and structure. For example, at one sighting, the taape (reported as ~6 individuals) were described as hiding in holes in the pipes of the reef structure. That was the only sighting for that dive and the only sighting where even an approximate count was available. Another dive in this series reported four sightings; based on time and depth, at least two were very likely the same reef and group of fish. Apparently at least two other artificial reefs were visited and taape reported in that dive. Another dive provided taape sightings from at least two (probably three) reefs. At one sighting they were described as "several good size". The last dive apparently made sightings on at least four reefs, without record of numbers or sizes of taape or habitat.

The remaining three dives (including 6 sightings) retrieved from the archives were made at two or more general locations away from the artificial reefs. These dives were apparently independent of the artificial reef program and of each other. These sightings were also made in late morning (1102-1200). One dive on the "First Finger" of Penguin Bank at a depth of 76 m sighted a "big school" of taape <10 in. long over rubble and sand bottom. "Lots of fish" of other species were reported present, including *Chromis* sp., *Pseudanthias* sp. and other anthiids. Opakapaka and/or uku may also have been seen elsewhere on this dive. Another dive on Penguin Bank, probably near the west end, at 107 m depth reported a "few" taape over hard bottom. The third dive also occurred near the west end of Penguin Bank at depths of 107-110 m and produced four sightings, each with "many" taape. The first sighting also reported the co-occurrence with 2 uku individuals, without further details. Many opakapaka and uku were also reported elsewhere on this dive (not with taape present). Depth and time data suggest that at least the last three of the reported sightings (and very possibly all) from this dive may have been of the same school of taape.

If the total number of taape sightings is adjusted for the probable duplications (multiple reportings of the same individuals) suggested above, the actual total is probably about 15 or 16 sightings. This amounts to an average of a little over two sightings of taape on each of the seven dives where they were sighted, i.e. two sightings over the course of a dive of several hours at depths of 58-107 m. Based on all dives within the "shallow" range, this amounts to roughly 0.65-0.70 sightings per dive of several hours.

Discussion

The greater number of sightings/effort with the ROV in 1999 than in 1998 was due partly to improvement in technology and increased operating experience with the vehicle (first put into service in 1998). Results may also have been affected by differences in areas surveyed. Both cruises involved major effort on the "fingers" of Penguin Bank (Molokai) and at stations east of the Mokulua Islands on the windward coast of Oahu. However, the 1999 cruise included dives northeast of Mokapu Point on windward Oahu. These included five daylight dives with 2 hr 10 min total at depths <160 m and 2 hr 50 min total at depths >160 m. A few of the dives in this area encountered some rather large schools of taape (estimated at 20-250 individuals) that accounted for most of the individuals counted in 1999 surveys. The tracks in the Mokapu area ran through some terrain with high relief that seemed to be prime habitat, and in fact was obviously used as shelter by many fish. However, other areas surveyed (e.g. the Penguin Bank "fingers") also included high relief substrate that appeared to be very attractive fish habitat, and a school of ~100 taape was sighted in this area also. Large schools may be infrequent enough that this limited sampling cannot give a useful estimate of their frequency. What is known about the distribution of taape suggests that they are extremely patchy. For example, in a large series of shallow-water visual censuses in Hanalei Bay, Kauai, taape was the second most abundant species by number of individuals and biomass, but occurred in only 22% of all censuses (Friedlander et al. 1997).

III.8 DIET INTERACTIONS

Materials and Methods

For fish specimens collected under Protocol 1 and many of those collected under Protocol 2, the complete alimentary tract plus any associated food material found was preserved under refrigeration beginning very shortly after collection (see general "Materials and Methods" section). For most of this time, this material was fully frozen until analysis in the laboratory. Guts were thawed and dissected to remove the contents. Procedures for analysis of the diets were generally similar to those described by Hyslop (1980), Harrison et al. (1983), Parrish et al. (1985), and Haight et al. 1993). Material from the gills, stomach, pyloric caeca and the entire intestinal tract was rinsed in 8% saline solution and examined under a dissecting microscope. Potentially recognizable items were removed, cleaned, described, counted and measured as appropriate (using an ocular micrometer where needed), and stored in labeled vials. Fish otoliths were stored dry, cephalopod beaks were stored in 70% ethanol, and the remainder of the items were stored in 10% formalin solution. Prey items were visually identified under magnification to the lowest feasible taxon, using an extensive taxonomic literature and reference specimens of potential prey items or their parts. In particular, fish otoliths, scales and other fish parts were compared to reference specimens of local deep-water species and related fishes obtained by our own fishing and by loan from colleagues, museums and other collections. Whole prey organisms and parts were counted and used to estimate the total number of prey individuals represented by the contents of each gut.

Diet composition was expressed in terms of number of prey items (individuals) and frequency of occurrence of predator guts containing the prey category. Also, an index of prey importance (IPI) for each prey category in the diet was calculated as:

$$IPI = F \times N$$

where:

F = percentage of all predator individuals that contained that prey category, and

N = percentage of total prey individuals that were of that category .

These variables (F, N, and IPI) were compared for taape and the eteline species as a means of assessing the similarities and differences of their diets. These diet comparisons were also quantified by doing pairwise analyses using the following measures of overlap (Krebs 1999):

(a) Pianka's measure, O_{jk} :

$$O_{jk} = \frac{\sum_{i=1}^{n} p_{ij}\, p_{ik}}{\sqrt{\sum_{i=1}^{n} p_{ij}^2 \sum_{i=1}^{n} p_{ik}^2}} \qquad (1)$$

(b) Percentage overlap, P_{jk}:

$$P_{jk} = \left[\sum_{i=1}^{n} (\text{minimum } p_{ij}, p_{ik}) \right] 100 \qquad (2)$$

(c) Simplified Morisita-Horn index, C_H:

$$C_H = \frac{2 \sum_{i=1}^{n} p_{ij} p_{ik}}{\sum_{i=1}^{n} p_{ij}^2 + \sum_{i=1}^{n} p_{ik}^2} \qquad (3)$$

(d) Horn's index, R_o :

$$R_o = \frac{\sum_{i=1}^{n}(p_{ij} + p_{ik})\log(p_{ij} + p_{ik}) - \sum_{i=1}^{n} p_{ij} \log p_{ij} - \sum_{i=1}^{n} p_{ik} \log p_{ik}}{2 \log 2} \qquad (4)$$

where:

p_{ij} = proportion that prey category i is of the total prey eaten by species j.

p_{ik} = proportion that prey category i is of the total prey eaten by species k.

n = total number of prey categories .

These overlap analyses (1) through (4) were implemented using the software package Ecological Methodology, Version 5 (for IBM PC running Windows) by Exeter Software, 47 Route 25A, Suite 2, Setauket, NY 11733.

Results

For the purposes of this study, trophic analysis is focused on the diet of taape and the diets of the eteline snappers in the fishery. These diets are characterized and compared in an attempt to estimate the nature and general magnitude of ecological effects of any of these species on any other. For comparisons and analyses of fish diets, prey items could be pooled at a wide variety of levels into systematic and/or ecological groups. Pooling was done at several levels that seemed potentially interesting, and those that seemed to produce best insight into questions of diet interactions between taape and the eteline species are presented and discussed here. Table 16 provides the most complete and detailed form of diet data presented. It contains much information on specific prey types for each of the above target predators and is organized to facilitate comparisons on the basis of frequency of occurrence in predator diet, numbers of prey individuals, or IPI. For each predator species, the value of %N at each level in Table 16 is the actual number of prey individuals of that level (category) as a percentage of all prey individuals (i.e. N in the IPI equation in the Methods section). The value of %F at any level is simply the number of individuals of the predator that ate prey of that category as a percentage of the number of predator individuals examined (i.e. F in Methods).

Sample sizes of all species except onaga appear to be adequate for broad comparisons of the overall diet, and their results in Table 16 are generally credible (see Discussion section). The small sample size of onaga appears to have been inadequate and produced results that are believed to be non-representative of the population; our onaga data were replaced for subsequent analysis (e.g. Table 17 and 18) with the data from Haight et al. (1993).

For more rigorous and quantitative comparisons of the diets of these species, attention focuses on specific levels of aggregation (pooling) of the prey. In Table 17, prey are aggregated into 12 groups at very high systematic/ecological levels (not necessarily closely related to traditional "trophic" levels). These are the levels indicated in bold print in Table 16. The general pattern for the six species is conspicuous in Table 17, particularly with %IPI. Diets of opakapaka and kalekale were heavily dominated by planktonic animals, especially crustaceans, but also molluscs and urochordates. Some fish were eaten by most individuals, but they were quantitatively much less important. In contrast, ehu, gindai and onaga (the latter based on data from Haight et al 1993) were heavily dependent on fish as prey, in terms of large numbers of piscivorous individuals and heavy consumption (%IPI). Each of the three species had a second, much less important food source in benthic crustaceans, in terms of %F and %IPI, and a third minor but significant source was cephalopods. Planktonic urochordates were of some importance to onaga, and pelagic crustacean were significant for gindai. Taape were more or less intermediate between these planktivorous and piscivorous groups, overlapping most of these major categories to some extent, but they were clearly most dependent on benthic invertebrates, primarily crustaceans and mollusks. Many taape ate fish and a good many ate planktonic crustaceans, but the contributions of both categories to the total diet were much less.

Quantitatively, pairwise comparisons between diet compositions of predator species by four common overlap indices (see Methods section) produced the index values of Table 18 for %IPI. (Computations using %F and %N produced generally similar patterns.) The same trends appear with all four indices in Table 18. Absolute values are not especially meaningful or directly comparable across the four indices. It is clear that taape has very low and similar overlaps with opakapaka and kalekale, and has moderate and similar overlaps with ehu, onaga and gindai. Opakapaka and kalekale show very high overlap with each other and low overlaps with the other four species (highest with gindai). Ehu, onaga and gindai show high overlaps with each other. These overall results are consistent with the results for specific groups discussed in the previous and following paragraphs.

The data permit comparisons for specific diet overlap at some lower systematic levels (Table 16). Large benthic crustaceans are clearly the dominant category for taape. The most important benthic crustacean category for taape was crabs, which are a much smaller component of the benthic crustacean diet and the total diet of all the etelines. The same is true for the anomuran and brachyuran divisions within the crab category. Benthic mollusks were very significant in the diet of taape and trivial in the diets of all the etelines. This was true of both gastropods and bivalves. Taape also ate planktonic molluscs (mostly pteropods), including several of the same species as opakapaka and kalekale, but much less abundantly (more nearly as the other three etelines did). All the snappers ate pelagic urochordates, including larvaceans and especially thaliaceans. It seems that these groups may be fairly important prey for opakapaka , kalekale, and even onaga, but they were relatively minor groups for taape.

All the snappers ate some planktonic crustaceans, but the quantities were trivial for ehu and onaga (when an adequate sample is used as in Haight et al. 1993). For taape, this group was somewhat more important, but a clearly minor component by comparison. Gindai in our study ate many more pelagic crustaceans than the *Etelis* species and taape, and consumption by the opakapaka and kalekale was much greater. The taape diet seemed to contain several of the common planktonic crustacean subgroups, and no major qualitative separations are obvious between the fish predators' diets at these levels.

Cephalopods were a minor component of the taape diet. They were trivial in the diets of opakapaka and kalekale, somewhat more important for onaga, and provided several percent of the diet for gindai and ehu. Based on this comparison, taape could hardly compete strongly for the available cephalopod resources. Of the six squid species identified, taape ate three species (probably four individuals); one of these species was also eaten by ehu and opakapaka. These limited data at the species level do not suggest much commonality in cephalopod diets of these predators. Further species identifications may be feasible and may provide a clearer pattern.

The second most important prey category for taape was fish. Although fish were clearly more important to ehu, onaga, and gindai by all available measures, it seems useful to compare diets of the snappers at the lowest systematic levels feasible. Table 19 shows all fish species that were at least tentatively identified in the diets. A total of 93 fish prey individuals are included (of 446 prey individuals with possible potential for identification). Of immediate qualitative interest is occurrence of any of the snappers in the gut of any other. Only in guts of taape were tentative identifications of snapper prey made, based on scales found in the guts that appear similar to scale reference material for snappers (4 prey species, 6 predator individuals, 6 prey individuals, each prey identified based on a single scale). Three of the prey individuals (scales) appeared most like taape, the other three most like wahanui, lehi and opakapaka (one each). Six of the 30 identified individuals in this sample of taape guts (and six of the 93 identified individuals in this sample of all snapper guts) may have been snappers eaten by taape.

Based on the tentative prey identifications to date, diet overlap on fish at these low systematic levels appears between:

Taape and ehu - 2 prey species, once each
Taape and gindai - 2 prey species/genera, once each
Taape and opakapaka - 1 prey species, once
Ehu and gindai - 1 prey species, several times
Opakapaka and kalekale - 1 prey family, once

In this sample of 93 prey individuals, of 31 taxa identified, 7 are shared between some pair of snapper predators and 24 are not.

Discussion

Although the sample sizes for diets are not large for some species, they are probably at least minimally adequate for high-level comparisons for all species except onaga. Certainly the sample would be expected to give representative results for taape, the species of greatest interest and the one for which least data existed in these habitats previously. For opakapaka (arguably the next most critical species in this study), the sample is clearly adequate, and it seems to be so for ehu and kalekale. For these last three species, the diet compositions are credible and compare favorably with results from reasonable sample sizes in the trophic study on Penguin Bank by Haight et al. (1993). The sample size for gindai is less impressive, but the results are in good agreement with the only six specimens reported in Hawaii previously (Haight et al. 1993) and with a more extensive sample in the Mariana Islands (Seki and Callahan 1988). The sample of 9 specimens of onaga in the present study is clearly inadequate, particularly when no good measure of food bulk consumed is available, and the results (as presented in Table 16) are inconsistent with the results of Haight et al. (1993, based on a much larger sample) and with our total knowledge of ecology of onaga (Parrish 1987). Because these results are believed to be non-representative, data for onaga from Haight et al. (1993) are used in subsequent reporting (Table 17 and 18). For the other strictly deep-water species (etelines), the diet results in this study are generally consistent with the existing (limited) published information. For taape, these results are concordant with available information on its diet in shallow waters (Rangarajan 1972b, Oda and Parrish 1982, Parrish 1987, J.D. Parrish, unpublished data).

For evaluating the importance of predation or the co-occurrence of particular prey taxa (relative to the potential for food competition) at low systematic levels, much larger sample sizes are typically required. This is partly the result of the relatively low yield of identifiable prey organisms (or parts) and difficulty of identification at low systematic levels. For some important questions, e.g. quantitative co-occurrence of prey species or comparison of predation among two or more predators, sample sizes of the predator species should be approximately balanced where feasible as well as large. Neither the size nor the balance required was feasible with the resources of this study, and its objectives were limited to detecting co-occurrence qualitatively and obtaining a general idea of the magnitude of predation on key species. Comparison of numbers in Table 19 among the snappers is not meaningful unless considered in relation to the very different sample sizes of the snapper species involved. Clearly if 180 specimens of taape are examined, occurrence of a specimen of prey species x (or any arbitrary number of species x) is more likely than if 32 specimens of kalekale are examined, even if the actual rate of consumption of prey species x is the same by both predator species. Comparing variables such as the number of individual predators with a particular prey and the number of individuals of a particular prey eaten are probably better compared on a "per predator sampled" basis (e.g. dividing the variable values by the sample sizes in parentheses in Table 19. It is less clear how variables such as the number of prey taxa can be normalized since (like the "species area curve") this relationship is unknown but probably nonlinear. When these variables in Table 19 are compared on a "per predator sampled" basis, the order of the resulting numbers for these predator species is much the same as the order of importance of fish as a whole in their diets. Kalekale is the exception (with normalized numbers placing it in the order above taape and similar to onaga). Notably, kalekale has a rather low sample size (32). Clearly none of the normalized variable values for taape are out of line (high) relative to the other predator species

These considerations apply directly to the issue of co-occurrence. With the raw numbers in Table 19, it appears that taape share considerably more prey taxa with other snappers than do the other etelines. The number of prey taxa adjusted to a "per predator sampled" basis for the five snappers with usable data are: ehu = 5/42 = 0.119, taape = 19/180 = 0.106, opakapaka = 0.075, kalekale = 0.187, gindai = 0.130. On this basis, taape would take the second lowest number of prey taxa and almost certainly would share fewer prey taxa with other snappers. (As noted above, this particular adjustment is probably unrealistic because the relationship is probably nonlinear, but the exercise demonstrates that the co-occurrence of taape is exaggerated by its large sample size.) The key point is that these data give little reason to believe that taape is likely to share more prey species (with other snappers) than any other snapper, and that (large) samples of comparable size of all the snapper species would show this directly.

Obtaining a large sample size of taape was a priority because (1) almost nothing was known about its diet in this environment and (2) any information about shared prey taxa (and potential for competition) or about prey taxa of particular interest (such as eteline snappers) was viewed as important. Now that some level of prey species/genus overlap has been shown by this (feasible) unbalanced sampling program, it is important to bear the limitations of this result in mind and not make interpretations beyond what the data support.

These considerations are also highly relevant to the finding of some scales in a few taape that resemble snapper scales and may represent as many as four species of interest. If taken at face value, this finding is a first and is certainly qualitatively interesting. If it can be fully confirmed, it will be meaningful (although not particularly surprising) to know that there is strong physical evidence that taape do sometimes eat other snappers. These few scales are a very recent find, coming after examining many scales from many fish. The sample size of scales identified as snappers is very small, the basis for comparison not optimum, and further confirmation (either way) seems likely to be feasible eventually. There may also be opportunity to examine other specimens. An important characteristic of this particular study is that relatively little fish prey material has been found in really good condition, and a large fraction of identifications have been based on otoliths and scales. These parts can be very useful, but especially with fish species as poorly known as most of these prey, better prey specimens would lead to higher confidence in identifications. Interpretation of the taape scales in the taape predator is particularly troublesome (although it would not be surprising to find that the taape is cannibalistic). There are a number of ways in which a diet sample can become contaminated by scales from the predator. Although our staff was aware of the potential problems and took precautions, a finding of scales of the predator's own species tends to undermine confidence in identifications. In particular, where regurgitation is a problem (as in this study) and every effort is made to recover food items that may be found outside the fish, the risk of contamination with the predator's scales is probably higher.

Examination of 180 taape specimens has produced six scales in six fish of four species that may be useful in establishing the qualitative fact of these predatory interactions for taape. In accordance with the discussion above, since less than a third of this sample size has been examined for any of the other five snapper species, the fact that no snapper material has been identified in their guts probably gives little indication about whether any of these species consume snappers.

The particular interactions that these scales imply are interesting for several reasons. Certainly our results suggest that sizable populations of opakapaka occupy more or less the same habitat as taape routinely as adults. Adult opakapaka are too large to be prey for taape. Provided that appropriate sizes of (younger) opakapaka are present where adult taape are present, such predation seems feasible. There may be no evidence of such sharing of habitat (see Section IV, final segment). Wahanui seem to frequent depths appropriate for interacting with taape as adults, although they are not known to be especially abundant in the habitats we studied. Probably little or nothing is known about their juvenile habitats (at sizes when they would seem to be vulnerable). Adult lehi are taken mostly at considerable depths and are not commonly caught or observed from submersibles. Opportunities for interaction between adult taape and adult lehi would seem minimal because of the difference in depth of habitat and probable low abundance of lehi. Again, knowledge of juvenile lehi habitat must be very scarce. Although the habitat of juvenile taape in these areas has probably never been studied, experience with taape elsewhere suggests that juveniles can often be found in the same general areas as adults. There are no known barriers against cannibalism.

IV. OVERALL ASSESSMENT OF INTERACTIONS

All relevant factors in the preceding results were considered together to reach an overall evaluation of the interactions between taape and the native eteline species in terms of what interactions occur and the probable general magnitude of their effects. If these effects can be rigorously demonstrated quantitatively, it would almost certainly require a very large-scale and intensive experimental program that is far beyond the scope of the present study. The conclusions reached here are based on trends and extrapolation from limited data, but the accumulation of evidence from a variety of sources is convincing.

Abundance and Depth Range of Taape

Indications of the abundance and depth distribution of taape over a rather wide range of locations in the Main Hawaiian Islands came from (1) underwater observations (several hundred hours) in our project and previous submersible missions in the archives of HURL, and (2) handline fishing (>9000 hook-hr) in our project (and Kelley's collaborating project) and previous cruises by NMFS vessels and a NMFS charter (see Sections III.2, III.3, III.6, III.7). These observations and collections involved sufficient effort distributed over a wide enough range of area, depth, season and time of day to provide a reasonable picture of the depth range occupied routinely by adults of the target species. In all the handlining performed or reviewed, only 11 taape were reported taken at depths greater than ~150 m. (None were reported deeper in fishing or submersible observations in this project). Although taape have occasionally been reported anecdotally at greater depths, it seems clear that in these waters, the adult taape population occurs almost entirely at depths <150 m.

Our methods did not permit any direct estimates of abundance or density of any fish species. As is commonly assumed in fisheries biology, catch or sightings per unit effort may provide a reasonable index of density for some purposes, particularly for comparison between species in a location/habitat. Fig. 9 and 10 show these indices from handlining for each target species, and Fig. 5 shows the median depth of catch for each. It is clear that the abundance of all the major etelines in the fishery except opakapaka (and uku) is concentrated at depths greater than where taape are common. Of the others, only kalekale and ehu were taken in any quantity shallower than 150 m (Fig. 6, 9 and 10), and they were caught in much greater numbers at greater depths. On the other hand, a very large fraction of the opakapaka occur in depths <150 m. The relative CPUE values in these figures suggest that in depths <150 m, taape may be about 1½ to 3 times as abundant as opakapaka – the only eteline with which it overlaps significantly in depth. Underwater observations from submersible vehicles (e.g. Table 12, 13 and 14) are not easily reconciled with these catch results nor among themselves; i.e. the results from Pisces V in these depths (only ~3 hr of observations) in 1999 are not very comparable with the results from the ROV in 1998, and both are considerably different from the results of the ROV in 1999. The main conclusion from Table 12 and 13 would be that taape are seldom seen from these vehicles. The ROV results in 1999 (Table 14) may be the best controlled for comparisons, and they also suggest that taape are at least several times as abundant as opakapaka at depths <150 m. (For example, the number of sightings of taape from the ROV in 1999 was about three times the number of opakapaka sightings.) However, all results confirm that the spatial distribution of taape is patchy, varying between widely dispersed individuals and occasional widely scattered groups with numbers from dozens to hundreds. In summary, adult taape occur almost entirely at depths <150 m, where they co-occur primarily with adult opakapaka, and seem to be considerably more abundant than opakapaka in this core depth range of both species.

Activity/Feeding/Catch with Depth and Time

Catch data (Section III.2, Fig. 3 and 4) indicate that the diel pattern of CPUE is considerably different among the target species, implying that their diel cycles of feeding – and probably activity generally

– are different. Although the results for the etelines are somewhat different from those based on larger samples in earlier work (Haight et al. 1993), it appears that taape and opakapaka both tend to be highly active in the late hours of the night and much less so during much of the daytime. In our data, the other etelines tend to have a generally opposite trend, with low activity late at night and higher CPUE between early morning and late evening. This low overlap in activity period between these etelines and taape could tend to reduce interactions between these species, e.g. competition (especially interference competition) for food. However, there appears to be rather strong temporal overlap with the only eteline species that also shows high overlap in general depth range, i.e. opakapaka (Fig. 4). Interestingly (although sample sizes are somewhat small in some time and depth groups), at the extreme hours in the middle of the night when the activity of both species seems to increase greatly, the increase for opakapaka is primarily in the depth range of 100-150 m (Fig. 12), and for taape it is primarily in the depth range of 0-50 m (Fig. 11). This may suggest that these two species seek different habitats at key times of intense foraging. In any case, it implies that the most intense feeding by these two species does not occur at the same time and depth.

Visual underwater observations provided little evidence regarding the diel cycle of activity and foraging (Section III.7). Very few sightings of taape were made from the submersible (all in daylight), and almost all sightings from the ROV were made at night. The daytime sightings of taape showed cases of schooling in sizable numbers and cases of one or two individuals moving together. The several nighttime observations and one dive at dusk showed taape alone or in groups of 2-3, sometimes swimming in the open near the bottom, often resting motionless on the bottom or under ledges or other cover. Individual observations were very brief; no behavior could be characterized as either torpor (sleep) or active foraging.

Our results about distance above the bottom at which the various species feed (Section III.4, Fig. 13 – Fig. 19) may be relevant to the degree of interaction between the target species, particularly when they are feeding. These results clearly showed higher CPUE (thus probably higher feeding activity) for taape, gindai and the *Etelis* species in the 3-5 meters immediately above the substrate; in contrast, they indicated an increase in CPUE for the other two *Pristipomoides* species, especially opakapaka, beginning several meters above the substrate and extending to at least 10 m above it. This strongly suggests a vertical partitioning of the feeding habitat, and probably of the available assortment of prey types. (See following section on "Trophic Interactions"). The two species that show strongest overlap in depth of habitat – taape and opakapaka – show a large displacement in the their distance of feeding above the bottom.

Co-occurrence of Taape with other Species

Co-occurrence relates to issues of interaction among species in a number of ways. One issue is whether one species is sufficiently aggressive, dangerous or disagreeable to neighboring species that they avoid it, i.e. give it a wide berth and are not found together with it in close proximity or in a resting situation. This kind of avoidance might be characteristic of behavior toward a generalized piscivorous predator. Such behavior toward taape might suggest that it has some sort of negative effect on other fishes. Our only source of evidence regarding this possibility is underwater observations (Section III.7, text description of observations). Although such observations were not very numerous, taape were usually seen either schooling rather calmly (often relatively close to a variety of fish species), or as individuals moving slowly or resting on the bottom, sometimes quite close to other demersal fishes. These observations of co-occurrence with other species gave no evidence of interactions or effects (positive or negative) between taape and other species, but they can be interpreted as limited behavioral evidence against agonistic relations. We made essentially no observations of taape and etelines remaining close together. The closest spacings were one nighttime observation of three taape and then of one kalekale, all at depths of ~107 m, within 1 minute, followed by one opakapaka 2 min later and 14 m deeper. All other sightings of taape were considerably more widely spaced from eteline sightings.

The fairly frequent observations on some dives and frequent collection of some of the eteline species without taape present suggest that taape are neither extremely abundant nor obligate users of the same habitat or set of resources. If taape co-occurred almost always with an eteline species or were very abundant and highly competitive for bait on handlines, a likely result would be catch of taape on a very large fraction of all fishing drops that caught the eteline species, and perhaps many more taape than etelines on these drops. Such co-occurrence was not observed in this study. The results of analyzing all lines hauled for co-occurrence (Section III.3), showed no case where a taape was caught on the same line as ehu, onaga, gindai, or uku (Table 1, 3 and 4). (This must be at least partly because taape seem to be almost absent from the main depth ranges of these species.) A taape was caught only once on a line that caught kalekale (1.1% of all lines with kalekale), and taape were caught on 21 lines (10.9%) that caught opakapaka. Twelve cases (line hauls) were found where two or more taape were caught on a line with one opakapaka, as well as two cases where two or more taape were caught with two opakapaka. There were seven cases of one taape with one or two opakapaka (Table 2). Usually four or more hooks were fished on a drop, and there were few if any cases where all hooks on a line were filled with opakapaka and taape. On most line hauls, even with multiple taape and/or opakapaka caught, intact baited hooks remained on the line (Table 7 and 8). On the basis of co-occurrence on "stations", taape co-occurred with opakapaka in 36% of the stations where it occurred and in ~12% of the stations where opakapaka occurred. This incidence of co-occurrence of taape on lines and at stations with the etelines and multiple occurrences on a line does not indicate a great abundance of taape where the etelines were fished or extreme bait competition. Considering co-occurrence both at the level of the line haul and of the "station", with and without including co-occurrence with non-target species, the overall frequencies for taape (with all other species combined) were in the range of 11.5%-44%. Compared with frequencies of the main eteline target species, taape was within the overall range, from near the low end to near the high end (Section III.3). Therefore, based on data from handline catches, particularly when grouped by line haul, taape may be no more "interactive" with other species on lines than are the main eteline target species.

The degree of co-occurrence of different species on handlines may be influenced by the vulnerability of the various species to the hook, its presentation, and the bait. The number and location of hooks was largely standardized in this study, and cut squid was used as bait almost uniformly. Palu was used occasionally and not confined to any particular depth range, habitat or situation. Experience fishing for all the target species indicates that squid is an effective bait (e.g. Haight et al. 1993), and all the species seem to respond positively to use of palu. It does not seem likely that the type of bait caused a major bias for or against any of the target species. Results of Section III.5 indicate that hook size (and possibly design) can create bias in the catch, and that careful selection of hooks can reduce the incidental catch of taape. However, the above results on co-occurrence of the main target species on lines are based heavily on the use of hooks that were productive for both etelines and taape, so the occurrence of taape in these catches is not less than would be expected in commercial fishing.

Trophic Interactions

The most obvious kind of interaction to be considered is predation by any of the target species on any other. Our findings about the diet composition of taape (Table 16, 17, and 19) indicate that the species is significantly piscivorous (although apparently less strongly than onaga, ehu and gindai), but that benthic invertebrates are the dominant prey, and pelagic invertebrates are of some importance. Therefore, predation by taape on etelines small enough to be consumed is possible, although a wide range of alternative fish and invertebrate prey is certainly consumed.

As mentioned above, the strong tendency toward separation of habitat depth between several of the species reduces the opportunity for realized diet overlap and potential food competition. Opakapaka was the only eteline that seemed to overlap strongly in depth with taape in this study. Differences in height of feeding above the bottom may also reduce the realized diet overlap even for species that occur in the same general depth habitat (e.g. taape and opakapaka).

Results of diet studies in this project (Section III.8) indicated some qualitative differences and large quantitative differences between the diets of some of the target species. Diets of opakapaka and kalekale were dominated by plankton and were rather similar, but they were clearly different enough from the more demersal species – ehu, gindai and taape - to make serious diet competition unlikely. They were also markedly different from the heavily piscivorous diet of onaga in a previous study with an adequate sample size (Haight 1993). The diet of taape, heavily dominated by benthic invertebrates and to a lesser extent by fish, was radically different from that of the opakapaka with which it overlaps heavily in depth distribution, and also from that of the kalekale with which it overlaps slightly in depth distribution. These diet differences are clearly demonstrated quantitatively by the small overlap indices of taape with opakapaka and kalekale (Table 18). Diet overlap indices with taape are moderate and similar for gindai (the largest), ehu, and onaga (using onaga data from the adequate sample of Haight et al. [1993]).

Pairwise examination of diets for shared use of particular prey items produced diverse results. Overall, for invertebrate prey groups at intermediate systematic levels, taape did not appear to overlap strongly with other snappers for groups that were important in its diet. Identification of invertebrates at the lowest systematic levels generally did not permit comparison. Some squid could be identified to low systematic levels, but cephalopods were a minor diet item for taape. Relatively few fish (~21%) could be identified to low systematic levels (as usual). Of those, diet overlap among the six snappers was found for taape with ehu, gindai and opakapaka (one or two prey species or genera, once each), for opakapaka with kalekale (one prey family, once), and for ehu with gindai (one prey species, several times). The relative incidence, numbers, etc. among the snapper species have little meaning because of widely different predator sample sizes. For a total sample of prey composed of 30 identified low level taxa, the degree of overlap of the snappers as a whole seemed moderate.

The finding, in the guts of six taape, of six fish scales that look like snapper scales (possibly taape, wahanui, lehi and opakapaka) may turn out to provide the first solid evidence of. predation by taape on snappers. The most salient points regarding this result are: (1) the evidence is strongly suggestive but wants confirmation; (2) if confirmed, it is the first known evidence of these trophic interactions, but not inconsistent with what is known generally about feeding of the species; (3) the identified sample size of this prey is very small, drawn from a rather large sample of predators; (4) it provides almost no quantitative clue to the frequency of such predation; (5) obtaining useful estimates of such frequency or magnitude or other details on this interaction will probably require extraordinary efforts; (6) there is still no information to put this finding in perspective with other predation (if any) between snappers.

Missing Evidence on Early Life Stages

As expected, this study produced little or no evidence about interactions of younger life stages of any of the target species with any life stage of other target species. It is possible that young stages of some of the target species are represented in the gut contents examined, but if so, they could not be identified as such. No young juveniles were caught nor recognized in underwater observations. The locations and habitats used by young stages of the etelines are very poorly known. For opakapaka, there is information from elsewhere (Parrish et al. 1997) that the nursery grounds for juveniles well beyond the postlarval pelagic stage are rather far removed from the known habitat and traditional fishing grounds of the adults and provide much different environments (e.g. shallower, open, sandy, relatively featureless bottoms). Unpublished submersible observations by Kelley of HURL and R. Moffitt of NMFS have produced some preliminary information about the habitat of juvenile ehu, which may be more similar to that of adults. The habitat of adult taape studied here does not appear to include either of these kinds of juvenile nurseries. No larvae of taape or etelines were recognized in the present study. Although eggs that may have been fish eggs were found in the guts of a good many taape and some opakapaka, kalekale and a gindai, identification of the eggs does not seem feasible. The possibility that interactions involving young stages occur between the species cannot be eliminated by results of this study. If studies that are developing now on culture of some of the etelines begin to produce good reference material for identification of young stages, and knowledge of the habitats that they use accumulates, an assessment of such interactions may become feasible.

Summary Assessment

The overall impression is that the introduced taape shows little if any aggression toward native snappers, generally does not share the same depth and feeding habitat with most native species, overlaps little in diet, and is not a frequent predator or prey of the natives. This evidence does not imply strong negative effects of taape on adults of native fishery species in these habitats. It does not address the potential for interactions of taape with young stages of the native snappers or with native species in shallow-water coastal habitats.

ACKNOWLEDGMENTS

This work was funded by the Hawaii Department of Land and Natural Resources (DLNR) as a research project to the Hawaii Cooperative Fishery Research Unit (HCFRU). Major administrative and logistic support was provided by HCFRU, which is supported by the U. S. Geological Survey, University of Hawaii and DLNR.

Dr. Chris Kelley collaborated throughout the life of this project as it ran concurrently with his own deep-water snapper project funded by DLNR. His willingness to share personnel, equipment, data and sea time on vessels permitted this project to accomplish much more than would otherwise have been possible. Gary Dill was indispensable to the project, providing fish specimens and high quality fishing data with his vessel for much of the project's needs, as well as valuable practical advice and "know-how". Equipment, facilities and technical personnel support for the deep diving was provided by Hawaii Undersea Research Laboratory (HURL). The highly dedicated and professional performance of the vehicle operators and support staff, as well as the ship's crew, are greatly appreciated. Support in the laboratory, processing data and specimens, was provided by Ryan Fu, Lucy Kida and Kualani Richardson.

Many people contributed to identification of animals, alive, fresh, preserved, or retrieved from fish guts. This assistance included loan of literature, specimens, and other reference materials, and personal examination of some of our specimens. Some important contributors included C. E. Birkeland, D. Catania, C. D. Kelley, J. M. Leis, R. B. Moffitt, B. C. Mundy, M. Parry, R. L. Pyle, M. P. Seki, A. Suzimoto, and R. E. Young.

Data from their archives of research cruises were generously provided by the National Marine Fisheries Service Honolulu Laboratory and HURL.

LITERATURE CITED

Anderson, W. D., Jr. 1987. Systematics of the fishes of the family Lutjanidae (Perciformes: Percoidei), the snappers. pp. 1-31 In: J.J. Polovina and S. Ralston (Eds.) Tropical Snappers and Groupers: Biology and Fisheries Management. Westview Press, Inc., Boulder, CO. 659 pp.

DeMartini, E. E., F. A. Parrish, and D. M. Ellis. 1996. Barotrauma-associated regurgitation of food: implications for diet studies of Hawaiian pink snapper, *Pristipomoides filamentosus* (family Lutjanidae). Fishery Bulletin 94:250-256.

Everson, A. R. 1984. Spawning and gonadal maturation of the ehu, *Etelis carbunculus*, in the Northwestern Hawaiian Islands. pp.128-148 In: R. W. Grigg and K.Y. Tanoue (Eds). Proceedings of the 2nd Symposium on Resource Investigations in the Northwestern Hawaiian Islands Vol. 2. University of Hawaii Sea Grant Misc. Report UNIHI-SEAGRANT-MR-84-01. Honolulu.

Friedlander, A. M., R. C. DeFelice, J. D. Parrish, and J. L. Frederick. 1997. Habitat resources and recreational fish populations at Hanalei Bay, Kauai. Final project report to Hawaii Department of Land and Natural Resources by Hawaii Cooperative Fishery Research Unit. 320 pp.

Haight, W. R., J. D. Parrish, and T. A. Hayes. 1993. Feeding ecology of deepwater lutjanid snappers at Penguin Bank, Hawaii. Transactions American Fisheries Society 122:328-347.

Harrison, C. S., T. S. Hida, and M. P. Seki. 1983. Hawaiian seabird feeding ecology. Wildlife Monographs 85:71.

Hyslop, E. J. 1980. Stomach contents analysis: a review of methods and their application. Journal of Fish Biology. 17:411-429.

Kikkawa, B. S. 1984. Maturation, spawning, and fecundity of opakapaka, *Pristipomoides filamentosus*, in the Northwestern Hawaiian Islands. pp.149-160 In: R.W. Grigg and K.Y. Tanoue (Eds.) Proceedings of the 2nd Symposium on Resource Investigations in the Northwestern Hawaiian Islands Vol. 2. University of Hawaii Sea Grant Misc. Report UNIHI-SEAGRANT- MR-84-01. Honolulu.

Krebs, C. J. 1999. Ecological methodology. Second Edn., Addison Wesley Longman, Menlo Park, CA. 620 pp.

Maciolek, J. A. 1984. Exotic fishes in Hawaii and other islands of Oceania. pp. 131-161 In: W. R. Courtenay, Jr. and J. R. Stauffer, Jr. (Eds.) Distribution, Biology and Management of Exotic Fishes. Johns Hopkins Univ. Press, Baltimore. 446 pp.

Mizenko, D. 1984. The biology of Western Samoan reef-slope snapper (Pisces: Lutjanidae) populations of : *Lutjanus kasmira, Lutjanus rufolineatus,* and *Pristipomoides multidens.* M.S. Thesis. University of Rhode Island, Kingston, RI. 66 pp.

Morales-Nin, B. and S. Ralston. 1990. Age and growth of *Lutjanus kasmira* (Forskal) in Hawaiian waters. Journal of Fish Biology 36:191-203.

Oda, D. K. and J. D. Parrish. 1982. Ecology of commercial snappers and groupers introduced to Hawaiian reefs. Proceedings of the 4th International Coral Reef Symposium. 1:59-67.

Parrish, F. A., E. E. DeMartini, and D. M. Ellis. 1997. Nursery habitat in relation to production of juvenile pink snapper, *Pristipomoides filamentosus*, in the Hawaiian archipelago. Fishery Bulletin 95:137-148.

Parrish, J. D. 1987. The trophic biology of snappers and groupers. pp. 405-463 In: J.J. Polovina and S. Ralston (Eds.) Tropical Snappers and Groupers: Biology and Fisheries Management. Westview Press, Inc., Boulder, CO. 659 pp.

Parrish, J. D., M. W. Callahan, and J. E. Norris. 1985. Fish trophic relationships that structure reef communities. Proceedings 5th International Coral Reef Congress 4:73-78.

Ralston, S. V. D. 1981. A study of the Hawaiian deep sea hand line fishery with special reference to the population dynamics of opakapaka, *Pristipomoides filamentosus* (Pisces: Lutjanidae). PhD Thesis, University of Washington, Seattle.

Randall, J. E. 1987. Introductions of marine fishes to the Hawaii Islands. Bulletin of Marine Science 41:490-502.

Rangarajan, K. 1971. Maturity and spawning of the snapper, *Lutjanus kasmira* (Forskal), from the Andaman Sea. Indian Journal of Fisheries 18:114-125.

Rangarajan, K. 1972. Food and feeding habits of the snapper, *Lutjanus kasmira* (Forskal), from the Andaman Sea. Indian Journal of Fisheries 17:43-52.

Seki, M. P. and M. W. Callahan. 1988. The feeding habits of two deep slope snappers, *Pristipomoides zonatus* and *P. auricilla*, at Pathfinder Reef, Mariana Archipelago. Fishery Bulletin 86(4):807-811.

Suzuki, K. and S. Hioki. 1979. Spawning behavior, eggs, and larvae of the lutjanid fish, *Lutijanus kasmira*, in an aquarium. Japanese Journal of Ichthyology 26:161-165.

Tabata, R. S. 1981. Taape: What needs to be done? Transcripts of a workshop. University of Hawaii Sea Grant College Program Working Paper 46.

Uchiyama, J. H., S. M. Kuba and D. T. Tagami. 1984. Length-weight and standard length-fork length relationships of deep sea handline fishes of the Northwestern Hawaiian Islands. pp. 209-225 In: R. W. Grigg and K. Y. Tanoue (Eds.) Proceedings of the 2nd Symposium on Resource Investigations in the Northwestern Hawaiian Islands Vol. 2. University of Hawaii Sea Grant Misc. Report UNIHI-SEAGRANT-MR-84-01. Honolulu.

Uchiyama, J. H. and D. T. Tagami. 1984. Life history, distribution and abundance of bottomfishes in the Northwestern Hawaiian Islands. pp. 229-247 In: R. W. Grigg and K. Y. Tanoue (Eds.) Proceedings of the 2nd Symposium on Resource Investigations in the Northwestern Hawaiian Islands Vol. 1. University of Hawaii Sea Grant Misc. Report UNIHI-SEAGRANT-MR-84-01. Honolulu.

Welcomme, R. L. (comp.). 1988. International introductions of inland aquatic species. FAO Fisheries Technical Paper 294. 318 pp.

Table 1. Occurrences of taape in the catch overall and with other target eteline snappers. Numbers based on all line hauls in the entire project (Protocol 1 and 2)

Target Species	**Total no. line hauls that caught target species**	**Total no. line hauls that caught target species and taape together**	**Column 3 as a percent of Column 2**
Ehu	246	0	0
Onaga	74	0	0
Gindai	66	0	0
Uku	4	0	0
Sum of ehu, onaga, and gindai	~372*	0	0
Opakapaka	193**	21	~10.9%
Kalekale	85**	1	~1.2%
Total line hauls with snapper	787		~24.4%
Total line hauls with fish	1118	Total line hauls with taape: 192	~17.2%
Total line hauls	2823		~6.8%

*Corrected for overlap among line hauls summed. (In some cases two of the species were caught on the same line haul.)

**One line haul caught an opakapaka and a kalekale together.

Table 2. Catch on each line haul where taape were caught in the entire project (including all fishing by Protocol 1 and 2).

No. fish of various types caught on line				No. lines with this catch	Percent of lines with this catch
No. taape	No.opakapaka	No. kalekale	Miscellaneous non-snappers*		
1				80	41.7%
1		1		1	0.5%
1	1			6	3.1%
1	2			1	0.5%
2				44	22.9%
2	1			6	3.1%
2	2			1	0.5%
3				15	7.8%
3	1			5	2.6%
3	2			1	0.5%
4				9	4.7%
4	1			1	0.5%
5				3	1.6%
6				2	1.0%
1			present	11	5.7%
2			present	6	3.1%
			Total =	192	

* Includes some species of low commercial value in this quantity (~20 total individuals), e.g.: soldierfish (Holocentridae), bigeyes (Priacanthidae), amberjack (*Seriola dumerili*), mackerel scads (*Decapterus macarellus* and *Selar crumenophthalmus*), unidentified jack.

Table 3. Fish caught with each target species and the number of line hauls and percent of all hauls for the species where each combination occurred. Numbers based on all line hauls in the entire project (Protocol 1 and 2). See Table 1 and 2 for details for taape.

	Alone	Ehu	Onaga	Opakapaka	Kalekale	Gindai	Taape	Hapuupuu	Misc. only	Total
Ehu	182	--	7	1	12	14	0	1	10	224
	81.2%		3.1%	0.4%	(*3 with kalekale & gindai on same line)			0.4%	4.5%	(Corrected for *)
					5.40%	6.20%				
Onaga	58	7	--	1	3	0	0	0	5	74
	78.4%	9.5%		1.3%	4.0%				6.8%	
Opakapaka	148	1	1	--	1	0	21	0	21	193
	76.7%	0.5%	0.5%		0.5%		10.9%		10.9%	
Kalekale	67	12	3	1	--	3	1	2	0	89
	75.3%	13.4%	3.4%	1.1%		3.4%	1.1%	2.2%		
Gindai	54	14	0	0	3	--	0	1	1	73
	73.8%	19.2%			4.1%			1.4%	incl. *P. auricilla*	
Uku	1	0	0	0	0	0	0	0	3	4
	25.0%								75.0%	
Taape	153	0	0	21	1	0	--	0	17	192
	79.7%			10.9%	0.5%				8.8%	

Table 4. Fish caught with each target species and the number of stations and percent of all stations for the species where each combination occurred. Numbers based on all stations by Kelley in the entire project (Protocol 1 and 2).

	Alone	Ehu	Onaga	Opakapaka	Kalekale	Gindai	Taape	Hapuupuu	Misc. only	Total
Ehu	108		13	1	8	14	0	4	8	146
	74.0%	--	8.9%	0.68%	5.5%	9.6%		2.7%	5.5%	
					.					
Onaga	23	13		1	5	1	0	0	1	40
	57.5%	32.5%	--	2.5%	12.5%	2.5%			2.5%	
Opakapaka	43	1	1		4	2	9	2	13	73
	58.9%	1.4%	1.4%	--	5.5%	2.7%	12.3%	2.7%	17.8%	
Kalekale	31	8	5	4		6	1	3	1	51
	60.8%	15.7%	9.8%	7.8%	--	11.8%	2.0%	5.9%	2.0%	
Gindai	22	14	1	2	6		0	2	1	41
	53.7%	34.1%	2.4%	4.9%	14.6%	--		4.9%	incl. *P. auricilla*	
Taape	14	0	0	9	1	0		0	1	25
	56.0%			36.0%	4.0%		--		4.0%	

Table 5. Fish caught with taape and opakapaka and the number of stations and percent of all stations for the species where each combination occurred. Numbers based on all stations by Kelley shallower than 150 m (Protocol 1 and 2).

	Alone	Ehu	Onaga	Opakapaka	Kalekale	Gindai	Taape	Hapuupuu	Misc. only	Total
Opakapaka	35	0	0		1	0	9	0	12	57
	61.4%			--	1.8%		15.8%		21.1%	
Taape	14	0	0	9	1	0		0	1	25
	56.0%			36.0%	4.0%		--		4.0%	

Table 6. Fish caught with each target species and the number of line hauls and percent of all hauls for the species where each combination occurred. Numbers based on all line hauls in the project shallower than 150 m (Protocol 1 and 2).

	Alone	Ehu	Onaga	Opakapaka	Kalekale	Gindai	Taape	Hapuupuu	Misc. only	Total
Ehu	9	--	0	1	4	3	0	0	2	18
	50.0%			5.6%	(*1 with kalekale & gindai on same line)				11.1%	(Corrected for *)
					22.2%	16.7%				
Onaga	7	0	--	0	0	0	0	0	0	7
	100.0%									
Opakapaka	131	1	0	--	1	0	21	0	21	175
	74.9%	0.57%			0.57%		12.0%		12.0%	
Kalekale	6	4	0	1	--	1	1	1	0	14
	42.8%	28.6%		7.1%		7.1%	7.1%	7.1%		
Gindai	13	3	0	0	1	--	0	0	0	17
	76.5%	17.6%			5.9%					
Uku	1	0	0	0	0	0	0	0	3	4
	25.0%								75.0%	
Taape	153	0	0	21	1	0	--	0	17	192
	79.7%			10.9%	0.5%				8.8%	

Table 7. Percentage of all line hauls that caught only taape or only opakapaka that retained intact baited hooks when retrieved. Mean number of intact hooks is shown in parentheses.

Species	Number caught on a line haul			
	1	2	3	4
Taape	89% (3.5)	73% (2.7)	50% (1.8)	50% (1.2)
Opakapaka	90% (3.0)	57% (2.1)	100% (1.0) [Only 5 line hauls]	0%

Table 8. Catch and remaining intact baited hooks for all line hauls where taape and opakapaka co-occurred. Only the three taxa shown occurred on these hauls.

Catch			Number of line hauls with remaining baited hooks. (In parentheses: original no. baited hooks deployed)					Total line hauls
No. Taape	No. Opaka-paka	No. soldier-fish*	0 hook	1 hook	2 hooks	3 hooks	4 hooks	
1	1	2 ----	2 (4 , 5) -----------	1 (6) --→		2 (5 , 6)	1 (6)	6
1	2		1 (6)					1
2	1	1 ---- 1 ----	2 (6 , 6) --→ -----------	2 (6 , 4) --→		2 (6 , 6)		6
2	2		1 (6)					1
3	1	1----	2 (6 , 4) --→	1 (6)	2 (6)			5
3	2		1 (6)					1
4	1		1 (6)					1
Totals			10	4	2	4	1	21

**Myripristis* sp.

Table 9. Hooks compared in fishing by Dill under Protocol 1. Size class designations are arbitrary and indicate increasing hook size with size class numbers.

Manufacturer's designation	Size Class
Limmirick #5	1
Limmirick #3	2
mtc 6/0	3
mtc 7/0	4
mtc 8/0	5
maruto #18	5
maruto #22	6
mtc 10/0	7
mtc 11/0	8
mtc 12/0	9

Table 10. Total catches and catches shallower than 150 m for taape and five species of eteline snappers taken in experimental handline collections by the NMFS Honolulu Laboratory in waters of the Main Hawaiian Islands between June 1983 and Sept 1993.

	Taape	Opakapaka	Kalekale	Gindai	Ehu	Onaga
Catch at depths <150 m	21	416	76	111	99	0
Total Catch (0-550 m)	31	609	288	426	541	34

Table 11. Fishing effort by depth for experimental handline fishing by the NMFS charter vessel, Kaimi, in waters of the Main Hawaiian Islands in October of 1982.

Depth strata (m)	Effort (hook-hours)
0-50	8.8
50-100	4.4
100-150	58.2
150-200	36.2
200-250	1.4
Total	109

Table 12. Summary of snapper sightings from remotely operated vehicle dives conducted in 1998. "No. dives" = total no. of dives on which a given species was seen; "No. sightings" = total no. of separate incidents when individuals of a species were seen; "Total no. of ind." = total no. of individuals of a given species seen, across all sightings.

	Taape	Opakapaka	Kalekale	Gindai	Ehu	Onaga
No. dives	1	0	0	0	2	1
No. sightings	1	0	0	0	3	1
Total no. of ind.	1	0	0	0	3	1
Depths (m)	96	na	na	na	199-300	200

Table 13. Snappers observed from the Pisces V research submersible in 1999. Numbers in the table are derived by assigning each fish sighting to a standard abundance group and summing within species over all sightings. Sums are broken down into depth categories, with the amount of submersible observation time within depth categories noted in parentheses.

	Taape	Opakapaka	Kalekale	Gindai	Ehu	Onaga
> 160m (69 hours)	0	9	292	81	634	277
< 160m (3 hours)	3	12	11	0	0	0

Table 14. Summary of snapper sightings from remotely operated vehicle dives conducted in 1999. "No. dives" = total no. of dives on which a given species was seen; "No. sightings" = total no. of separate incidents when individuals of a species were seen; "Total no. of ind." = total no. of individuals of a given species seen, across all sightings.

	Taape	Opakapaka	Kalekale	Gindai	Ehu	Onaga
ROV Observations at >160m depth						
No. dives	0	0	5	0	8	6
No. sightings	0	0	5	0	17	10
Total no. of ind.	0	0	~ 14	0	25	29
Depths (m)	na	na	162-170	na	165-325	165-300
ROV observations at <160m depth						
No. dives	10	6	4	0	2	0
No. sightings	24	8	6	0	2	0
Total no. of ind.	~ 425	~ 26	7	0	2	0
Depths (m)	45-153	86-152	113-159	na	150,160	na

Table 15. Breakdown of previous (1981-1987) dives by HURL submersible Makalii examined for sightings of taape and eteline snappers.

Total no. dives	51
No. dives with snapper sightings	34

	Depths	
	>160 m	<160 m
Dives with snapper sightings	21	20
Dives with eteline sightings	21	14
Dives with taape sightings	0	7
Dives with eteline and taape sightings	0	2

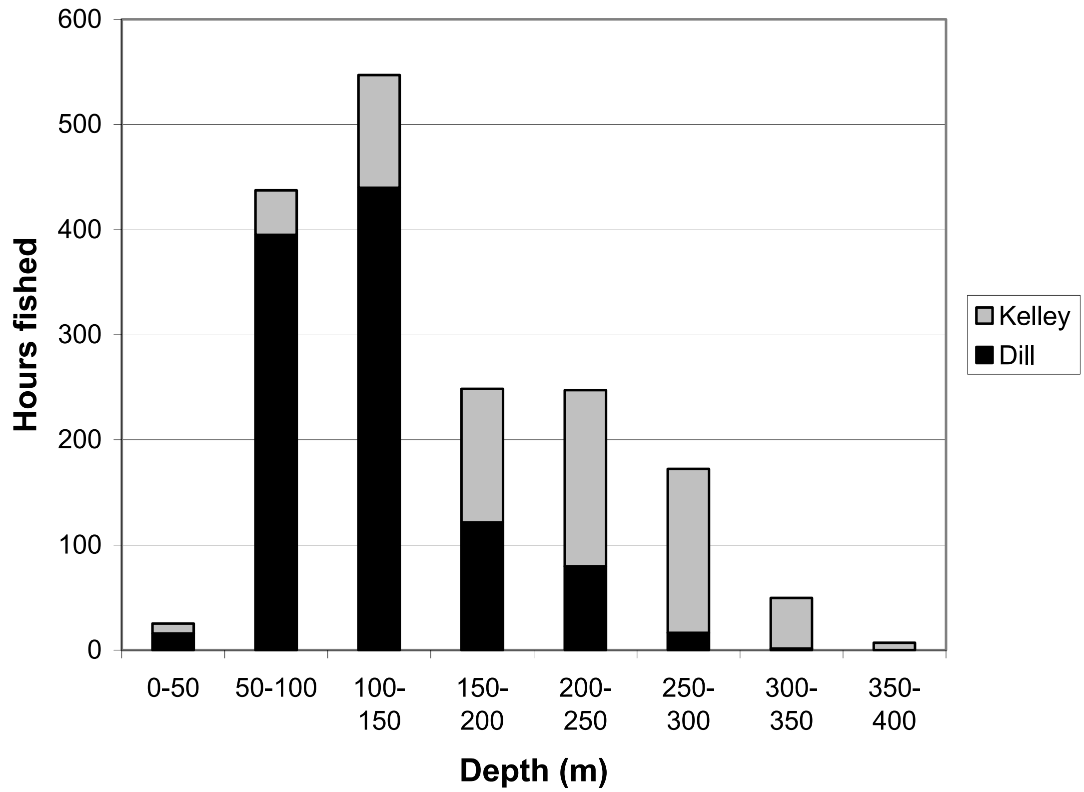

Figure 1. Fishing effort by depth for all project fishing under Protocols 1 and 2.

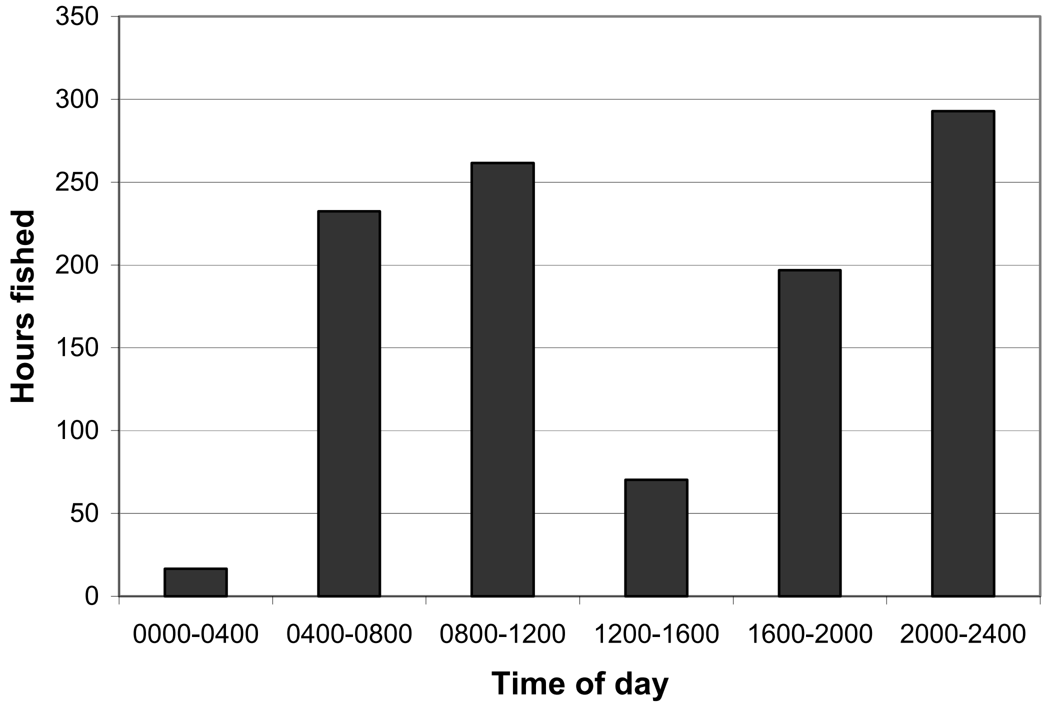

Figure 2. Fishing effort by time of day for all project fishing by Dill under Protocol 1.

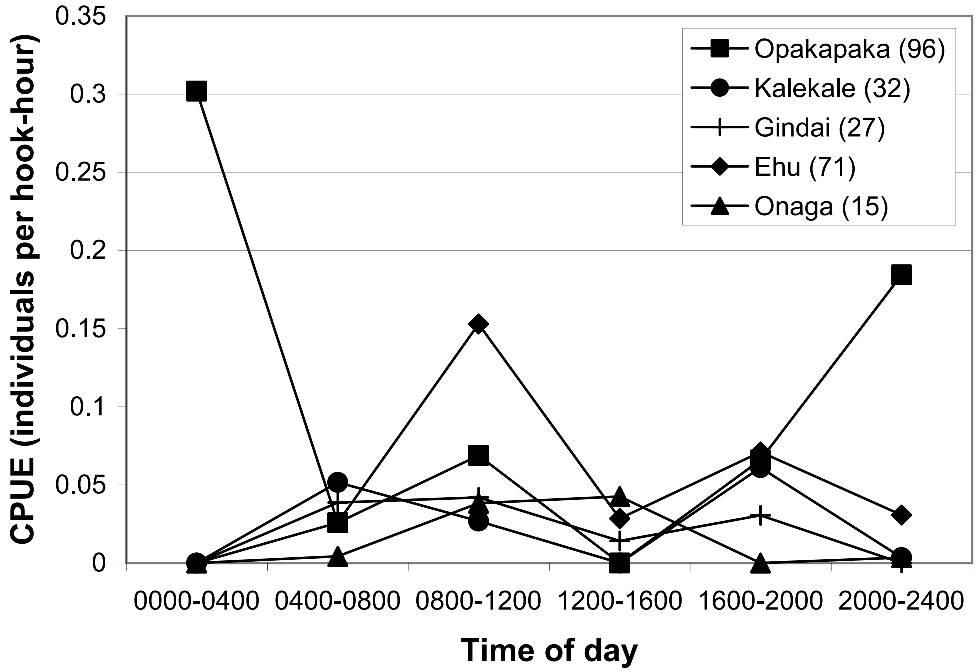

Figure 3. CPUE of five eteline snappers by time of day, for all project fishing by Dill under Protocol 1. Sample sizes are shown in species legend in parentheses.

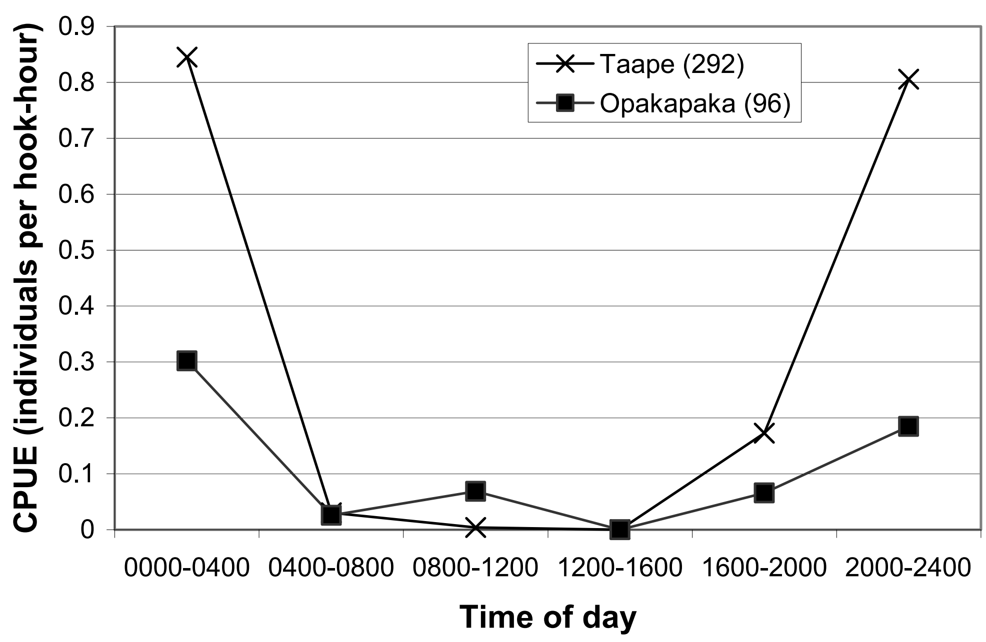

Figure 4. CPUE of taape and opakapaka by time of day, for all project fishing by Dill under Protocol 1. Sample sizes are shown in species legend in parentheses.

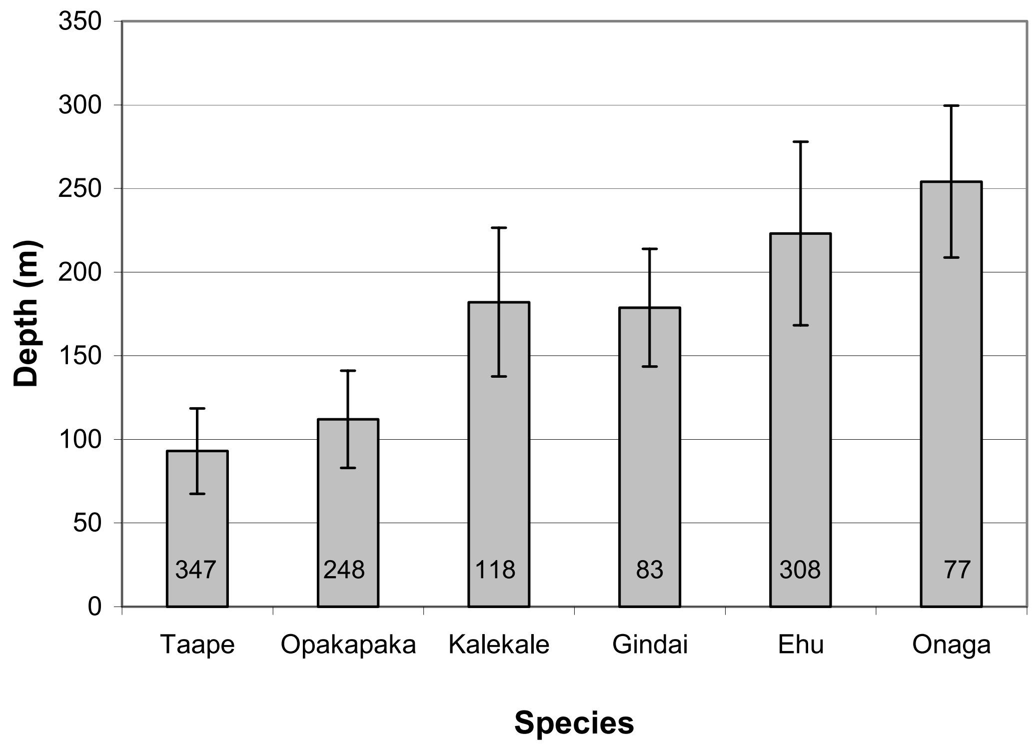

Figure 5. Median depth of capture of all target species for all project fishing under Protocols 1 and 2. Error bars indicate 1 std. dev; sample sizes are shown within the bar for each species.

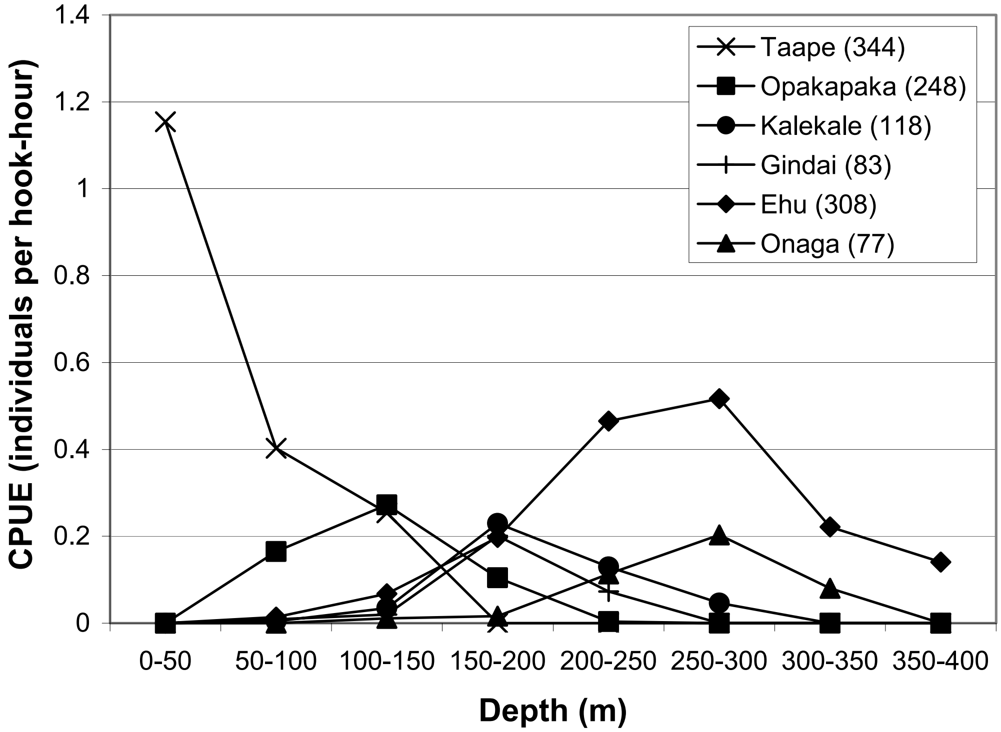

Figure 6. CPUE by depth for all project fishing under Protocols 1 and 2. Sample sizes are shown in species legend in parentheses.

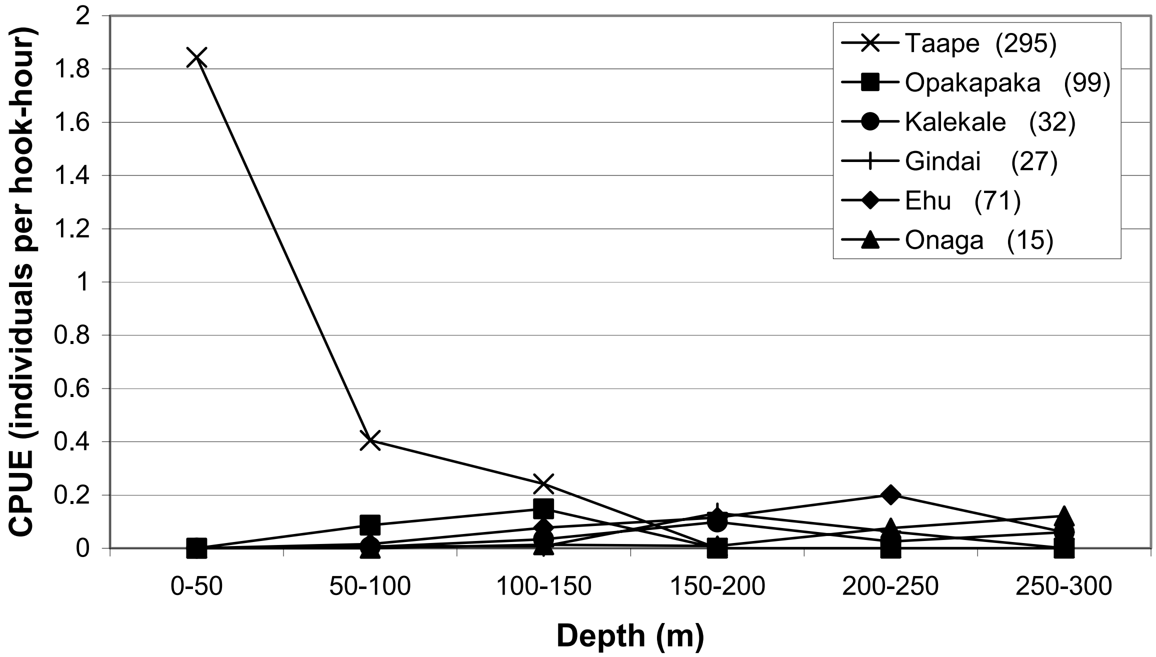

Figure 7. CPUE by depth for all project fishing by Dill under Protocol 1. Sample sizes are shown in species legend in parentheses.

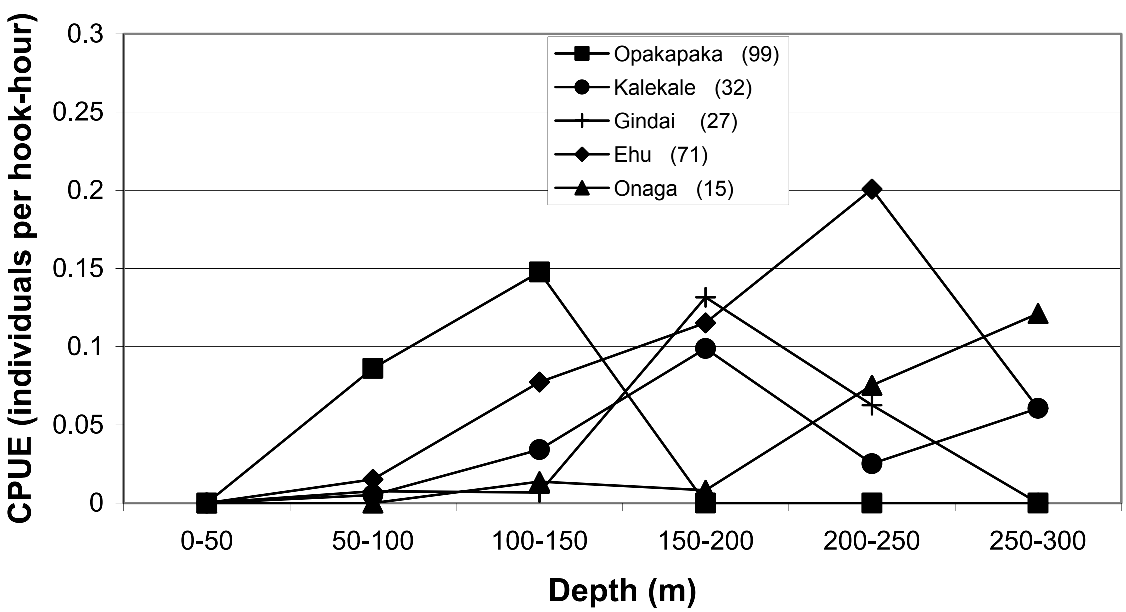

Figure 8. CPUE by depth for eteline snappers for all project fishing by Dill under Protocol 1. Sample sizes are shown in species legend in parentheses.

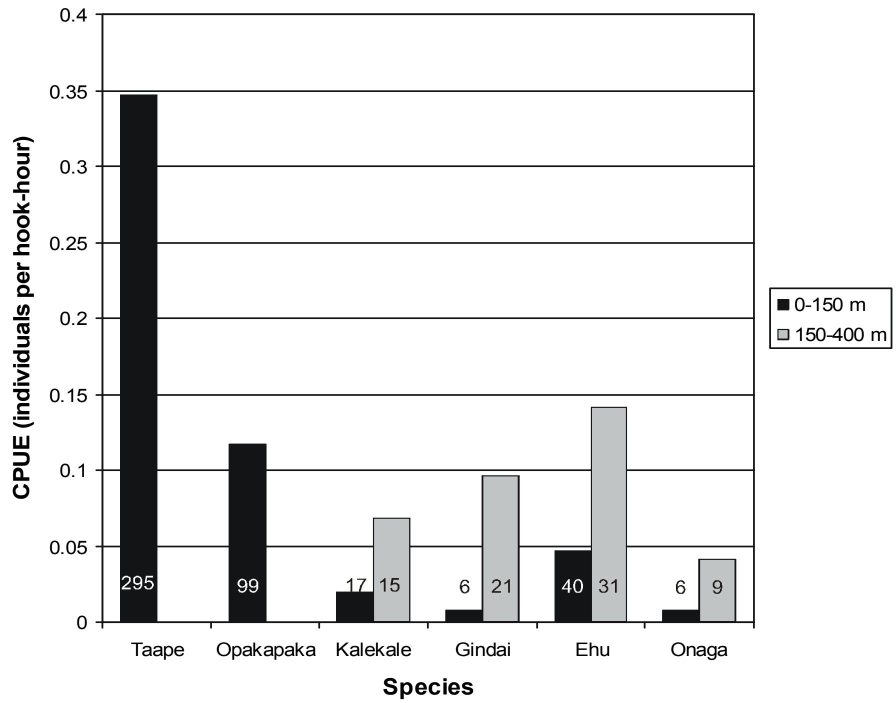

Figure 9. CPUE for snapper species in shallow and deep ranges for all project fishing by Dill under Protocol 1. Sample sizes are shown in the bars for each species.

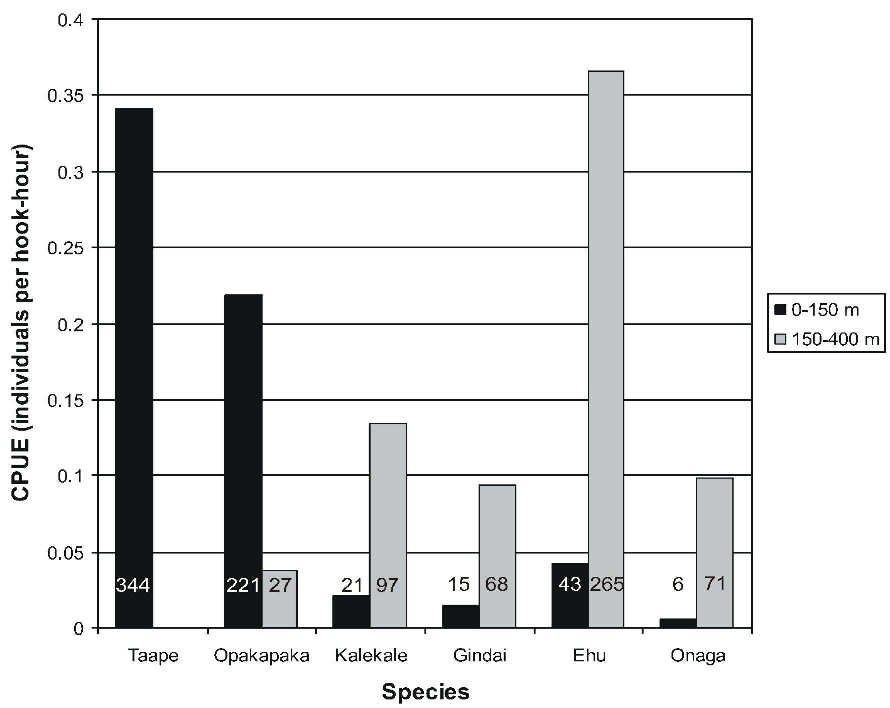

Figure 10. CPUE for snapper species in shallow and depth ranges for all project fishing under Protocols 1 and 2. Sample sizes are shown in the bars for each species.

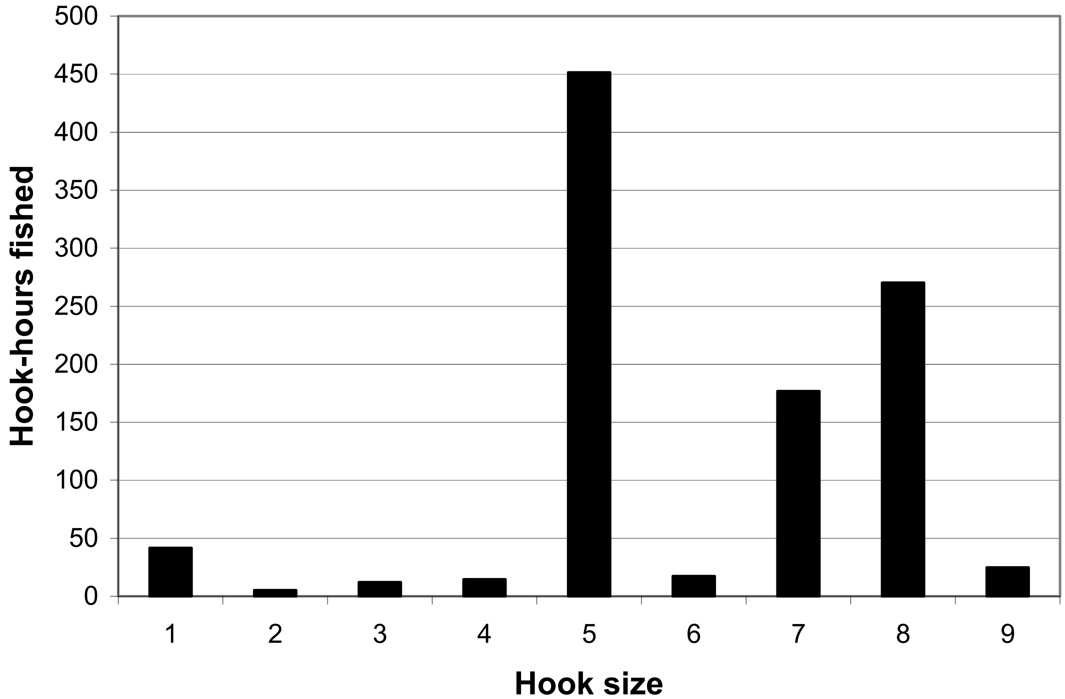

Figure 20. Total fishing effort with each hook size class (Table 9) used in this study, based on fishing by Dill under Protocol 1.

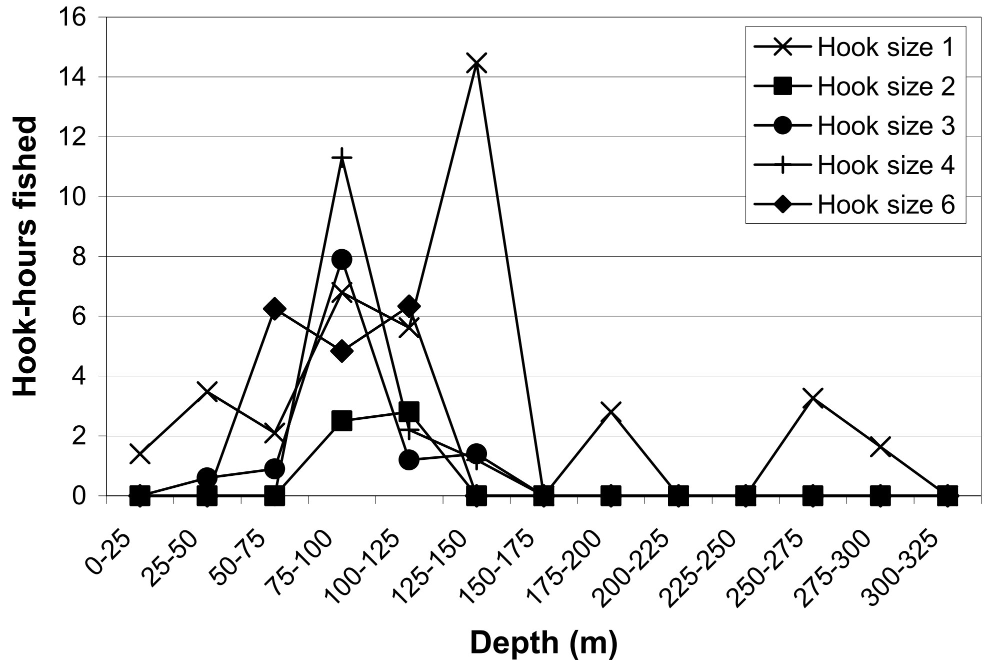

Figure 21. Fishing effort by depth and hook size for hooks used mostly at depths <150 m (fishing by Dill under Protocol 1).

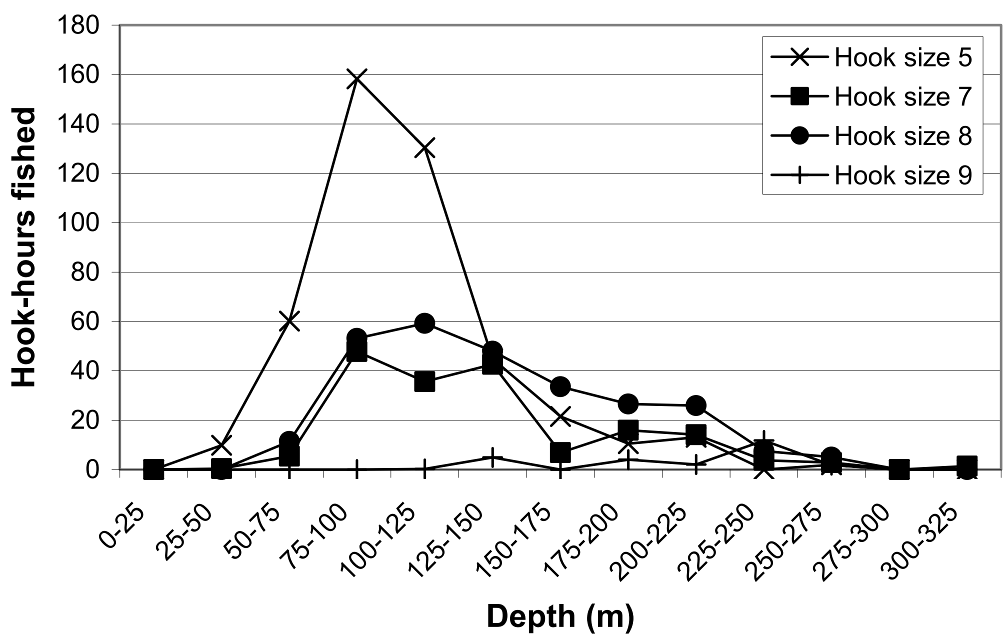

Figure 22. Fishing effort by depth and hook size for hooks used over a wide range of depths (fishing by Dill under Protocol 1).

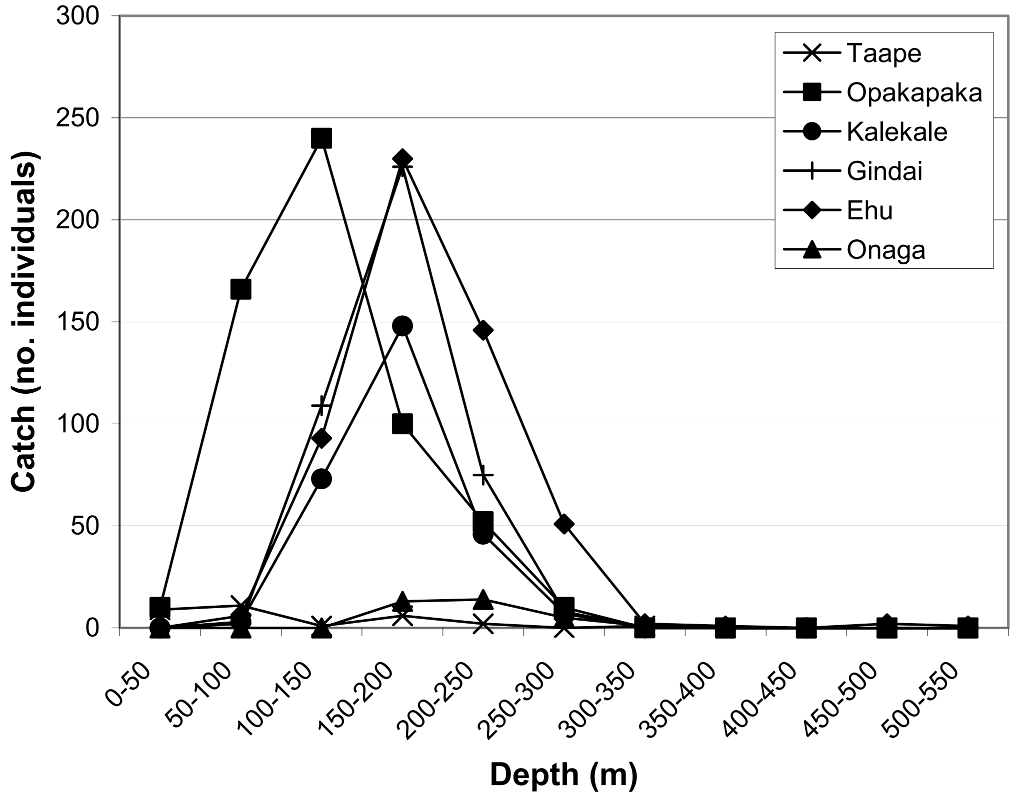

Figure 24. Catch of snappers by depth from experimental handline fishing on 22 cruises in the Main Hawaiian Islands by NMFS Honolulu Laboratory.

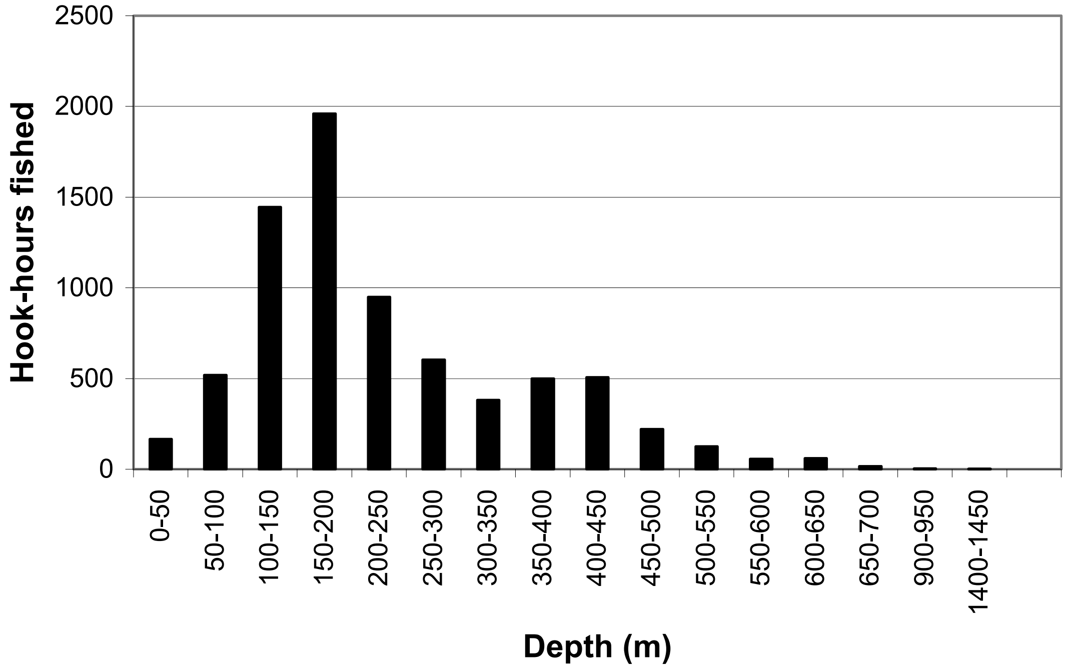

Figure 25. Fishing effort for all snappers by depth in experimental handline fishing on 22 cruises in the Main Hawaiian Islands by NMFS Honolulu Laboratory.

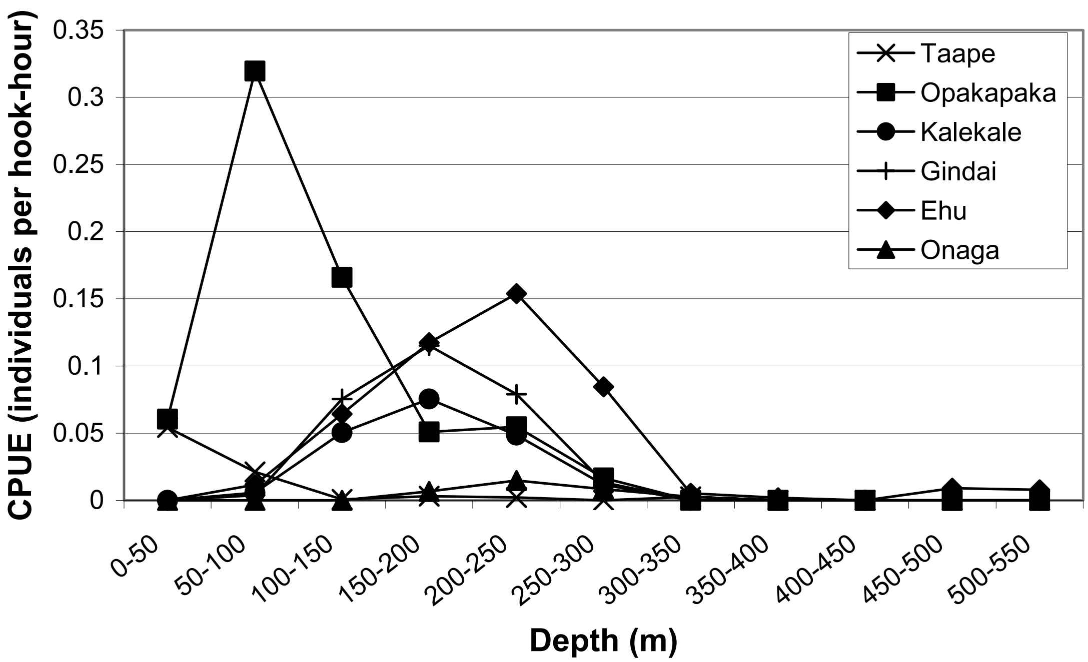

Figure 26. Catch per unit effort (CPUE) by depth for snappers calculated from experimental handline fishing on 22 cruises in the Main Hawaiian Islands by NMFS Honolulu Laboratory.

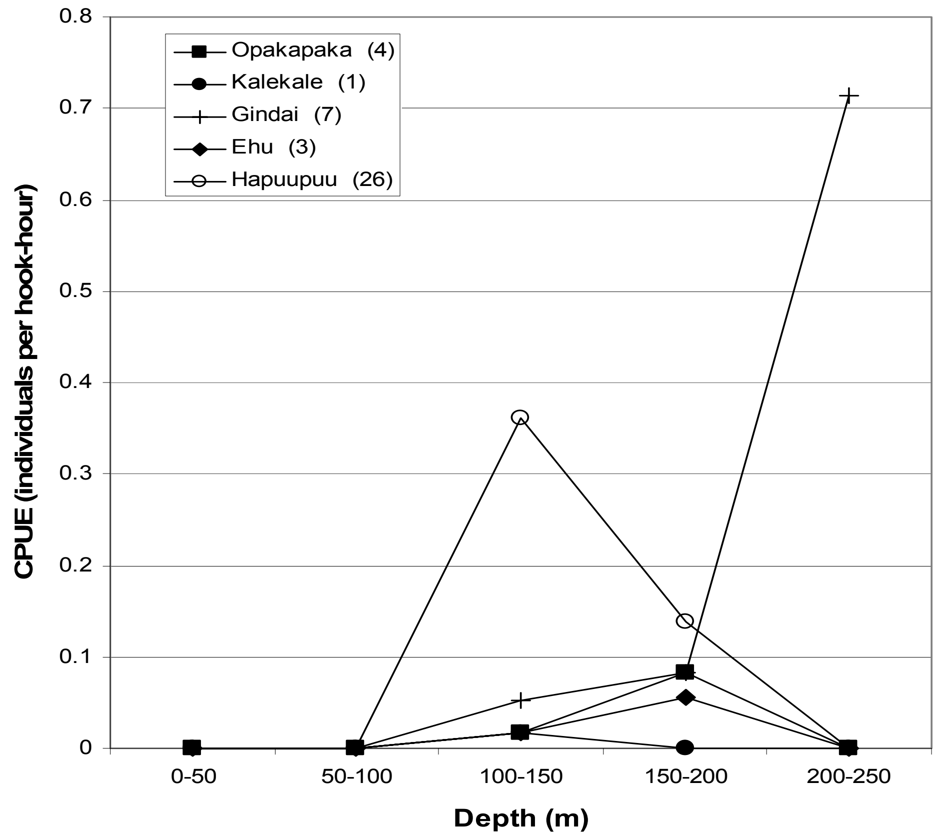

Figure 27. CPUE by depth for snappers and hapuupuu calculated from experimental handline fishing in the Main Hawaiian Islands by the NMFS charter vessel, Kaimi. Sample sizes are shown in species legend in parentheses.

APPENDIX A

Locations of handline fishing in the Main Hawaiian Islands that produced data for this project. Each black dot indicates the location of a fishing drop (occasionally more than one drop at about the same time and location). All fishing under both protocols by Dill (our project) and Kelley's project are included. Fish specimens were available from all the main islands (few from Maui). The depth contour shown is 100 fathoms (~183 m).

APPENDIX B

Description of deep diving vehicles and support equipment/facilities of Hawaii Undersea Research Laboratory (HURL) used in this project. (Extracted from HURL information packet for principal investigators).

1.3 EQUIPMENT AND FACILITIES

Center Facilities

The HURL operations center is located on the Makai Research Pier at Makapuu Point on the east coast of the island of Oahu. The center is approximately 15 miles from the city of Honolulu. A submersible shed is located on the pier, which also houses the operations office, diving locker, machine and electronic shops. Ship operations are managed by the UH Marine Center at Snug Harbor, on Sand Island Access Road in Honolulu. The ROV facility also operates at this location. The HURL administrative offices, data processing center, and labs are located on the University of Hawai'i at Manoa campus in Honolulu.

***Pisces V* Submersible**

Pisces V is a 3-person, 1-atmosphere submersible that has a depth capability of 2,000m (6,560 ft.). *Pisces V* usually operates with one pilot and two observers, although there are two pilots and one observer for Loihi dives and certain other dives. The pressure hull is 2.13m (7 ft.) in diameter. The submersible is equipped with two hydraulic manipulators and a sonar ranging device. Dive duration is 6 to 8 hours with emergency life support for 72 hours. **Dives occur during daylight hours.**

Equipment carried by or used in conjunction with the submersible includes:

- sample storage baskets
- color 8mm and digital video cameras, monitors, and recorders
- flood and video camera lights
- 35mm still camera and strobes
- sediment grab samplers
- temperature probes
- rotating Niskin water samplers (18)
- directional antenna for site relocation

- titanium water samplers
- dictaphone tape recorder
- CTD recorder for salinity, temperature density and depth
- Mini-Ranger navigation system
- short-baseline submersible tracking system
- suction sampler with rotating specimen containers

Additional equipment must be supplied by the scientist or may be fabricated by HURL, provided the request is made at least 3 months prior to use. Weight in air must not exceed 100 lbs. There are also size constraints, determined on a case-by-case basis by the Submersible Operations Director. Contact the Science Director for further information.

***RCV-150* Remotely Operated Vehicle**

The *RCV-150* system consists of the vehicle and launching garage, a transportable winch/A-frame unit, and associated power and control consoles. The vehicle's compact hydrodynamic design and neutrally buoyant tether cable permit close-up inspections and a high degree of maneuverability at speeds up to 3 knots. The vehicle can operate to depths of 800 m (2,625 ft.) and in currents up to 1.5 knots. Color video and a single manipulator are standard equipment on the *RCV-150*. A standard VHS record, including vehicle data (depth, heading, etc.), is made continuously during each dive, verbally annotated by the investigator in real time. A two-hour S-VHS cassette is available for higher quality real-time recording of highlights at the investigator's discretion. Other equipment and sensors may be adapted for use on the ROV, as well as sample baskets installed on the tethered garage. Small instrument packages can be carried to the ocean floor aboard the vehicle garage. ***RCV-150* operates day and night, but not during submersible dives.**

R/V *Ka'imikai-o-Kanaloa*

The R/V *Ka'imikai-o-Kanaloa* is the University of Hawai'i mother-ship for *Pisces V* and the *RCV-150*. The vessel is 222 feet in length. There are facilities for 18-20 scientists and technicians (including the submersible and ROV crews) and a ship crew of 14. The ship has A-frame launch capability, wet and dry labs, and photographic processing facilities. It is equipped with a CTD winch and rosette system for water column sampling. The ship can remain at sea for up to 50 days. In addition, it has a hull-mounted SeaBeam™ 210 (hybrid) multibeam bathymetric mapping system which consists of the original 16 hardware-former narrow beams capable of ensonifying a swath roughly 70% of water depth. SeaBeam™ 210 uses the modern SeaBeam™ 2100 projectors and receivers and Silicon Graphics-based (UNIX/IRIX) shipboard post-processing software packages including the standard "GMT-System" and "MB-System". Large and small format color plotters are available for map generation at-sea. SeaBeam™ 210 does not presently have sidescan backscatter capability.