Title: The Food and Feeding Habits of the Kumu, Parupeneus porphyreus.

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Degree: Master of Science (Zoology), Plan B. University of Hawaii

Pagination: Total - 54; 23 text, 31 Appendix including 3 Tables and 27 Figures.

Abstract

The kumu, Parupeneus porphyreus, is one of the most valuable reef fishes in Hawaii. It is a member of the goatfish family (Mullidae) and is endemic to Hawaii. One hundred and ninety-eight specimens, ranging in size from 31 to 306 mm, were collected from four areas around Oahu, Hawaii. Collections were made from July through November, 1968. The anatomy and the contents of the digestive systems were examined.

The digestive system is short. The stomach is V-shaped with a bulbiform pylorus. There are 20 pyloric caeca. The intestine has one siphonal loop. Transforming specimens differ in having a shorter, straight intestine. They also have sharper pharangeal teeth and longer gill rakers than do the adults.

Occurrence of food in the entire gastrointestinal tract was used in ranking relative fullness. These rankings, compared with time of capture, indicated feeding was nocturnal or crepuscular among larger fish (only very young kumu fed during the day) and that food passed through the alimentary canal within 19 hours. Twenty-three food items were identified; 12 of them occurred in >10% of the guts. Crabs were the most important food, followed by other crustaceans (copepods, isopods, other decapods) and other invertebrates. Sand occurred in 57% of the specimens. An extensive comparison of food items vs. fish size demonstrated various relationships. Although crabs were eaten by nearly all fish, only large kumu ate Stenopus and other fish, and only small kumu ate copepods and isopods.
THE FOOD AND FEEDING HABITS OF THE KUMU,
PARUPENEUS PORPHYREUS

DIRECTED RESEARCH REPORT
SUBMITTED TO THE GRADUATE SCHOOL OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

PLAN B

IN ZOOLOGY

FEBRUARY, 1969

BY

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INTRODUCTION

This paper presents a study of the stomach contents of kumu (Parupeneus porphyreus Jenkins) from a number of localities, habitats, and depths around Oahu, Hawaii; as well as a description of the gross anatomy of the digestive system.

The kumu is a member of the family Mullidae (goatfishes, surmullet and red mullets), which is widely distributed in tropical and subtropical waters with some species ranging into temperate seas. Mullids are valuable food fishes wherever they occur. Because of this, some species have been extensively studied, especially in the Mediterranean area. In Hawaii, goatfishes are captured by trap fishermen and by divers using spears and surround nets. Markets pay fishermen an average of $1.35 per lb. for average size (1 - 2 lb) kumu, making this species one of the most valuable reef fishes in Hawaii.

No author has directly investigated the ecology of goatfishes in the central Pacific area, despite the economic importance of the family. The other two genera of mullids in Hawaii, Upeneus and Mullloidichthys, have been thoroughly examined ecologically and anatomically in such areas as Japan and the Red Sea, but the Indopacific genus Parupeneus has not been studied anywhere. Fortunately broad ecological investigations, such as that of Hiatt and Strasburg (1960) in the Marshall Islands, have included members of the genus. The kumu is endemic to Hawaii and thus has been excluded.

The purpose of this study was to gain useful information about the food and feeding habits of the kumu in order to illuminate some aspects
of the biology of this extremely important reef fish. Hopefully, this information will some day lead to an improvement in the fishery.

**METHODS**

My husband and I (Henry and Cherrie Mahi) collected kumu from four general areas around Oahu: the North Shore, the Waianae coast, Kaneohe Bay, and Waikiki. Table 1 lists the collection localities and depths of capture in these four areas along with the numbers and average sizes of specimens from each locality. Depths of collection ranged from 1 to 95 feet, but the majority were about 30 feet. We collected fish at times varying from 6:00 AM to 7:00 PM, but we concentrated on the morning hours. Our collections were made between mid July and early November, 1968. In addition, I borrowed 18 transforming or very small kumu from a collection made in June by Mr. Gregg Stanton, and I received the largest specimen (306 mm) from Mr. Richard Wass who speared it at Niihau in late November. These borrowed fish are indicated in Table 1 by asterisks.

We used Hawaiian three-prong hand spears to collect the specimens in all but two cases. We used powdered rotenone to collect 36 small specimens at Kawailoa and Mr. Stanton used rotenone to capture the 18 juvenile fish that I borrowed.

Immediately after capturing the fish, we measured each one, removed its digestive tract, and tagged each tract for identification purposes. I preserved all of the digestive systems in 10% formalin with 15 cc of Ionol per gallon added as a color preservative. Three fish were preserved intact.

I dissected these three average size fish (130 - 140 mm in standard
length) in order to compare the gross anatomy of the kumu's digestive system with that of *Mullloidichthys auriflamma* as described by Al-Hussaini (1946) and *Upeneus bensasi* as described by Suyehiro (1942). In addition, I examined two transforming newly benthic juvenile kumu (37-41 mm) for comparison with the benthic adults. Henceforth, I shall refer to these newly arrived kumu as "transforming" and those which have already achieved the appearance of miniature adults as "benthic."

I ranked the degree of fullness of each digestive system from 0 to 3. If the entire alimentary canal contained food, the rank was 3. If the stomach was empty but the intestine was full, the rank was 2. If food remained only in the last fold of the intestine or the rectum, the rank was 1. If completely empty, the digestive tract was ranked 0. I compared these ranks with the time of capture to obtain a degree of fullness for each collection time. I did this by multiplying the percentage of fish having each rank at any one time by the rank. I then added the rank times percent values for each time. Examples of these calculations are shown in Table II. These total rank times percent values provided a means for estimating the rate of digestion.

I examined stomach contents separately from intestinal contents so that I could determine whether there was a reduction in the variety of food organisms in posterior portions of the gut. I identified the food organisms as closely as their condition permitted. Useful references were Edmondson (1962), Barnes (1963), and Hiatt (unpublished lab manual). Each food organism was ranked from 1 to 7 according to its relative volumetric importance in each fish, with 7 being the most important.
RESULTS

The sample consisted of 198 specimens ranging in standard length from 31 to 306 mm. The median length was 130 mm. The mean was 132 mm with a standard deviation of 53 mm. Figure 1 shows the distribution of the lengths within the sample. The 198 specimens are divided into 28 size classes, each class having an interval of 10 mm.

Feeding and Digestive Anatomy

The anatomy of the digestive system of Parupeneus porphyreus proved to be very similar to that of Mullloidichthys auriflamma and Upeneus bensasi. Like Mullloidichthys, there are teeth on the premaxillary and dentary bones but none of the vomer or palatine bones. Upeneus differs in having rudimentary vomerine and palatine teeth. The kumu's teeth are small, conical and blunt. They are widely spaced in a single row in each jaw. The pharangeal teeth are fairly well developed. They are small, pebble-like structures found in dorsal and ventral pads on the branchial bones (Figure 3). Each pad is sectioned by tough ridges of flesh.

The gill rakers are 2/3 the length of the gill filaments (Figure 2). They are stiff structures with slightly toothed inner edges. There are 28 in all.

Figure 4 shows the intact digestive system of the kumu. The liver is fairly large on the left side, but the right lobe is very small. With the liver removed (Figure 5), the finger-like pyloric caeca can be seen. In some specimens, the pyloric caeca are completely encased in fat. This fatty tissue is rich in pancreatic cells according to
Al-Hussaini (1946). The pyloric caeca number about 20 and arise from a thickened portion of the duodenum just beyond the pyloric valve. They lie such that in the right view (Figure 6) they hide the stomach. The intestine has one siphonal loop. It arches dorsally across the esophagus, runs posteriorly to the tip of the stomach, then turns sharply anterior until it reaches the arch of the duodenum where it turns sharply posterior again. Like the pyloric caeca, the intestine is frequently encased in fat. About half-way between the duodenum and the tip of the stomach, the last fold of the ileum enters the rectum. The rectum has a larger diameter than the intestine and its wall is thicker and darker in color.

In Figure 7, the duodenum has been cut and the intestine removed to expose the large spleen, which fits into the "V" between the two parts of the stomach. After the intestine, pyloric caeca, and all fat are removed, the shape of the stomach can be determined (Figure 8). The esophagus is short and unmodified. The cardiac portion of the stomach ends in a blind pouch posteriorly. In *Mulloidichthys* this pouch is more elongate. The pyloric valve is clearly evident as a sharp constriction in the bulbiform pylorus before it enters the duodenum.

The division between the esophagus and the stomach can best be determined by examining the internal structure of the gut (Figure 9). According to Al-Hussaini (1946), the division is where the number of mucosal ridges is suddenly reduced. There are five mucosal ridges in the cardiac portion of the stomach. These are most pronounced in empty stomachs, but are always evident. There are only three in the pyloric portion of the stomach. Between the ridges in the pylorus there is a
spongy network of more minute ridges. According to Al-Hussaini, this network is lacking in Mulloidichthys. The wall of the stomach is so thick that in empty fish, it almost obliterates the cavity. The wall consists of three layers, the innermost mucosa, the submucosa, and the muscularis. Al-Hussaini (1946) detailed the histology of these layers for Mulloidichthys, which I assume is similar histologically to Parupeneus. The intestine has a few weak mucosal ridges in the anterior part of the duodenum, but the rest of the intestine is lined with a spongy network similar to that of the pylorus. A section of this network (small squares) is enlarged in Figure 9C. Neither I nor Al-Hussaini (1946) could determine the difference between the duodenum and the ileum. The anterior wall of the duodenum is only slightly thinner than that of the stomach, but it gradually becomes much thinner until it is almost membranous in the ileum, especially when it is full of food. It is very easy to distinguish the rectum by its thicker wall and different color. Internally the muscular ileorectal valve is evident. The spongy network is dark orange in color and more pronounced than in the intestine.

Anatomy of Transforming Post-larvae

Transforming kumu which have just entered shallow water (Figure 10) look considerably different from the benthic form. At first glance, they look more like anchovies than goatfish. However, the barbels reveal their true identity as mullids. Even in the tiniest juveniles I have seen (31 mm), a bar through the eye and a white saddle behind the soft dorsal fin are present, which serve to distinguish these as well as adult kumu from all other Hawaiian goatfishes.
The pharyngeal teeth pads are shaped like those of the adults, but the teeth themselves are quite different. Instead of being pebble-like, they have sharp, recurved points somewhat resembling cat claws.

The gill rakers (Figure 11) of the transforming fish are relatively longer than those of the benthic form. They are slightly longer than the gill filaments. At the lower angle of the opercular opening there is a fringe on the gill cover that meets the poorly developed gill rakers of that region. The teeth on the inner edges of the gill rakers are more pronounced than in the benthic form.

The heart and liver are relatively larger in transforming kumu (Figure 12). The digestive tract is bound into a compact mass by mesentery. When the liver, fat, and mesenteries are removed from the digestive system (Figure 13), it resembles that of the adult with one very striking exception; the intestine is short and straight without the siphonal loop of the adult intestine. Also the pyloric caeca are shorter so that in the right view, the tip of the cardiac stomach protrudes. In the left view (Figure 14), the esophagus seems much longer than in benthic fish because there is no indication of where it ends and the stomach begins. When the pyloric caeca on the left side are removed and the esophagus is lifted slightly, the spleen is revealed. It is smaller than that of the adult and does not fit so tightly into the "V" of the stomach. The cardiac portion of the stomach is poorly defined and the pylorus is not so bulbous as that of the benthic form. Internally the digestive system is very similar to that of the adult.
Food Habits

About one fourth (1 out of 198) of the digestive tracts examined were completely empty. Only those fish caught before 9:30 in the morning had food in their stomachs. The only exceptions were fish less than 80 mm long. Fish with empty stomachs but full intestines were most common from 9:30 until noon. Fish with small amounts of food remaining in the last fold of the intestine and the rectum were found for only a short time between 11:00 AM and 1:30 PM. The first completely empty fish appeared at 9:30 AM and the percentage rose steadily until practically all fish were empty by 1:30 PM. Figure 16 shows how the degree of fullness (total rank times percent) decreases rapidly with time. A point at 10:00 AM is excluded because I borrowed the fish from a collection made earlier in the year and because the fish were very small. Also a point at 1900 (7:00 PM) was excluded because the collection consisted of one small specimen. Irregularities occur because small fish tend to continue eating throughout the day and large fish retain food in their intestines longer than average size fish.

Twenty-three different kinds of organisms were identified in the gut contents of the kumu (Table III). Crabs were by far the most important having an average rank of 5.3 out of a maximum rank of 7.0. The next most important organisms were isopods and alpheid shrimps each ranking only 2.2. Following in decreasing order, foraminiferans, gammarids, Stenopus hispida and stomatopods were also important. The vast majority of the organisms were crustaceans, but foraminiferans, fish and fish eggs, mollusks, polychaetes, a tunicate, and even a caterpillar were found.
57% of the fish contained sand. Although the quantity of the sand varied, it was generally small compared with the rest of the contents.

The importance of numerous organisms varied with the size of the kumu. Figures 17 A-N illustrate these relationships. Crabs are very important in all but the smallest kumu (Figure 17B). The broad size range helps account for their overall high rank. Isopods are important in small to medium kumu, but not in the very tiniest nor the larger specimens (Figure 17A). Alpheid shrimps (Figure 17E) resemble crabs in that their importance is uniform over a broad size range excluding very small fish. Stomatopods (Figure 17C) and ostracods (Figure 17D) have irregular distributions which don't seem to be closely related to size of fish. Fish (Figure 17F) and copepods (Figure 17G) are just the opposite showing close relationships to size. Copepods are found only in very small specimens, and fish bones are found only in very large specimens with no overlap of size ranges. Gammarids (Figure 17H) and Stenopus (Figure 17I) are also size related but the differences between them are not so extreme so that there is overlap in size ranges. Gammarids are important in small to medium fish whereas Stenopus is important in medium to large fish. Gastropods and foraminiferans are shown together (Figures 17J and 17K) because they both seem to be related to a third factor — sand. In only a few cases were they present when sand was absent. Most of the gastropods were even smaller than the sand grains. One notable exception is a ½-inch Cyprea fimbriata which was in the stomach of a 140 mm fish. Foraminiferans occurred mostly in small numbers except in small fish. Caprellids and megalops crab larvae (Figures 17L
and 17N) were more important in small fishes.

In general, when less than 60 mm in standard length, kumu eat mostly copepods, gammarids, megalops and cannellids. From 60 to 110 mm, the same organisms occur, but isopods are more important, and crabs are beginning to appear more frequently. From 110 to 180 mm, crabs are dominant with stomatopods, isopods, and alpheid shrimps often included. In kumu greater than 180 mm, fish share dominance with crabs. Stenopus and alpheids also make major contributions.

Food organisms exhibited variations with locality in addition to size of fish. Crabs ranked greater than 6 in all localities except Kawailoa on the North shore where they ranked only 5. One collection of large fish from Kawailoa was dominated by Stenopus and another collection of small fish from Kawailoa was dominated by isopods. At Waikiki, Stenopus was almost absent whereas stomatopods and foraminiferans were disproportionately important. At Kaneohe, Stenopus and fish were more abundant than usual, but this may be because most of the Kaneohe specimens containing food were large.

DISCUSSION

The Sample

Although my sample was small (198 specimens), it did bear a resemblance to the population of kumu at the time of collection. At the time I did most of my collecting, the greatest numbers of fish in the environment were between 100 and 150 mm in standard length. These are the largest classes in Figure 1. If I had begun collecting earlier, I would
have had greater numbers of specimens in the smaller size ranges. Since each successive year class is smaller, one can expect to find progressively smaller numbers of larger fish. The 31 mm specimen probably approaches the minimum size for benthic kumu since all specimens between 31 and 40 mm were transforming from the pelagic type. On the other hand, 306 mm is by no means the maximum size for kumu since they reach at least 600 mm.

The season of collection is not the only factor that biased the sample. Spearing was the primary technique for capturing the fish and this technique is inherently selective. Slower more sluggish fish are most easily speared. Perhaps these fish have fed best or are ill. Also larger fish are generally more wary, especially in areas such as Waikiki that are frequented by spear fishermen. This last factor, as well as the general scarcity of large fish around Oahu, explains the relatively small size of the largest fish in the sample.

It didn't take me long to find that the later the fish were caught, the emptier they were; therefore, I began doing most of my collecting in the early morning hours. A night collection would have been very valuable, but we were unable to find the fish even in areas where they were abundant during the day.

Anatomy of the Digestive System

Varley (1964) was unable to make many generalizations concerning the relationship between the anatomy of a fish's digestive system and its diet. One generalization that does apply to goatfishes is "Carnivores have a shorter intestine often with fingerlike pyloric
The general anatomy of the digestive systems of Upeneus bengasi (Suyehiro, 1942), Hulioichthys auriflamma (Al-Hussaini, 1946 and 1947) and Parupeneus perphyreus (present study) compares very well. In all cases the total length of the digestive system is about the same length as the standard length of the fish. Hulioichthys differs from Parupeneus in having heavy mucosal ridges in the intestine. Al-Hussaini (1946) concluded that these ridges and the heavy mucous that they secrete protect the lining of the digestive system from abrasion by the large amounts of sand included in the diet. According to Randall (personal communication), Hulioichthys feeds by blowing through the sand or silt swallowing anything edible and extruding the excess sand through the gills. In the process, considerable sand is swallowed. Parupeneus is evidently more selective in its feeding because it swallows only small quantities of sand. For this reason, heavy mucosal ridges in the intestine are not necessary.

One puzzling aspect of the anatomy of the kumu concerns the length of the intestine in transforming kumu compared with benthic kumu. The intestine is nearly three times longer in benthic specimens than in transforming juveniles. Randall (1961) reports a similar lengthening of the intestine in transforming manini (Acanthurus sandvicensis), but he relates the change to a transition from a zooplankton to herbivorous diet. Such a drastic alteration in basic diet does not occur in the kumu. Perhaps the longer intestine is an adaptation for handling bulkier foods such as heavily armored crabs.

An even more puzzling difference is in the sharply-pointed pharangeal
teeth of the pelagic juvenile. Perhaps they help to prevent zooplankton from swimming back out of the mouth of the fish while it swims with its mouth open catching other prey. The pharangeal teeth of the benthic form appear to be fully capable of crushing prey, but I could find no evidence that the fish actually use them for this. Fish caught soon after feeding had intact food organisms in their stomachs, including hard-shelled gastropods. A question therefore exists as to the function of the pharangeal teeth in the adult.

**Feeding Habits**

My results strongly indicate that only very small kumu feed during the daylight hours, at least during the fall season. The obvious conclusion from my results is that most kumu feed at night. However, several commercial fishermen said that kumu sleep at night. These men make their living by knowing where kumu are at all times and what they are doing. They move off the reef to sleep either in sargassum or on flat sand next to, but not under rocks. Since they don't feed during the day and fishermen say they sleep at night, about all that remains is crepuscular feeding. Full stomachs in the morning indicate that they certainly feed at dawn, and full intestines at dawn seem to indicate that they also feed at dusk. If they begin feeding at dusk (say 6:00 PM), digestion must take a maximum of 19 hours since they are completely empty by 1:00 PM the next day (Figure 16).

I can only speculate as to where kumu feed. A number of the more important food organisms such as snapping shrimps, stomatopods, foraminiferans, and gammarids are sand dwellers. Most of the gastropods
Found in kumu were also sand-dwelling species. On the other hand, parrotfish live on rocks and *Chaplopa* lives in holes in rocks. Crabs are neutral since they occupy a wide variety of habitats according to Edmondson (1962), and since each fish generally contained many different species of crabs. Apparently kumu feed on both rocky and sandy substrates, but especially the latter. The presence of sand in 57% of the fish containing food further supports this conclusion.

Numerous authors have observed goatfishes probing the sand with their barbels (Devanesan and Chidambaram, 1949; Herre and Montalban, 1923; and Smith, 1949). Hiatt and Strasburg (1960) concluded from their observations that goatfishes eat both burrowing and surface benthic forms. The barbels appear very early in the pelagic lives of goatfishes, and are derived from the first branchiostegal ray (Caldwell, 1962). Sato (1937a, b) studied the histology and function of the barbels of a Japanese goatfish, *Upeneus bensasi*. He compared the histology of these barbels with those of numerous other kinds of fishes (Sato 1937c). Of all the different kinds of barbels studied, the barbels of *Upeneus* had the most cutaneous taste buds. He determined the function of the barbels in feeding by eliminating various senses and observing the behavior of the operated and unoperated fish. He concluded that although other senses contribute to finding food, the barbels are most important, especially in finding and recognizing buried food. He also determined that the barbels are more sensitive to gustatory stimuli than to tactile stimuli (Sato, 1937 a, b). Unfortunately the papers are rather old and the behavioral experiments were not controlled very well. *Upeneus bensasi* characteristically inhabits turbid waters with mud bottoms and very poor visibility.
Parapercis porphyreus has a very different habitat. The kumu lives on reefs where the water is relatively clear. The barbels of the kumu are shorter than those of any other Hawaiian goatfish except P. bifasciatus. Perhaps the barbels are not as important to the kumu as to the Japanese goatfish.

**Food Habits**

The food organisms in the gut of each fish were ranked according to volumetric importance. Some bias could easily arise by this procedure. In many cases identification of food organisms depended entirely on certain almost indigestible hard parts such as chelipeds and bones. Soft-bodied organisms such as polychaetes probably don't last very long in the digestive system. Although this almost certainly introduced some error, I don't think the error is very great, because stomach contents were no more varied than intestinal contents. If this factor were important, I should expect a rapid reduction in variety from the stomach to the mid-intestine. The bias was greatest for contents that were ranked on the basis of a few fragments in the rectum.

Since I was not able to determine where kumu feed, it is difficult to relate the food of kumu to the abundance of the food organisms. According to Edmondson (1962), Xanthid crabs form the largest group of brachyurans in Hawaii. The fact that they are also the most important food item for the kumu would seem to indicate that kumu tend to eat most of what is most available.

I was unable to identify any of the fish eaten by large kumu. One set of jaws might have belonged to a wrass, but I can't be certain.
There was absolutely no positive or negative correlation between the abundance of sand and the abundance of fish bones, so I cannot safely say that the fish were fossorial. I would guess that they were either fossorial or closely associated with the bottom. Perhaps they include fish that sleep buried in the sand.

Foraminiferans had a rather high rank as kumu food, but I doubt their actual importance in most of the specimens. Only in very small fish were they found in large numbers and in only two cases out of 55 were they present when sand was absent. The same seems to be true of gastropods, except for two cases. In one case a 3/4-inch Cypraea fimbriata filled the stomach. I believe that foraminiferans and gastropods are mostly incidental and are taken along with sand during the capture of larger sand-dwelling organisms.

There were many variations from locality to locality and from individual to individual. For example, one individual had eaten practically nothing but chitons, I didn't find chitons in a single other individual. This agrees with the findings of Wirszubski (1953) for the red mullet, Mullus barbatus.

The food habits of the kumu generally compare well with those of other species of mullids studied by other authors. In practically all cases, crustaceans were dominant, but in no case were crabs as important as in the kumu. With this exception, central Pacific members of the genus Parupeneus feed very similarly to Parupeneus porphyreus (Hiatt and Strasburg, 1960 and Randall, 1955). Suyehiro (1942) found that the Japanese goatfish Upeneus bensaci feeds on benthic shrimps, polychaetes
and amphipods, quite different from the kumu. Checko (1942) noted a large number of bivalves in _Urenerus tragula_. Bivalves were very rare in kumu. _Mullus barbatus_ is similar to _U. tragula_ in this respect. Bivalves are important dietary items for _mullus_ both in Israel waters (Wirszubski, 1953) and in the Mediterranean, Adriatic and Black Seas (Lipskaya, 1964). _M. barbatus_ also eats considerable quantities of polychaetes. The West African goatfish _Urenerus prayensis_ feeds very similarly to the kumu (Cadenat, 1954). In the tropical West Atlantic, _Mullloidichthys martinicus_ and _Pseudurenerus maculatus_ eat annelids, crabs, and small fish (Beebe and Tew-Van, 1928 and Longley and Hildebrand, 1941). Like the kumu, _M. martinicus_ is empty in the afternoon.

**Life History**

Little is known of the life history of the kumu. Gosline and Brock (1960) state that the young first appear in shallow water in March and apparently come in from a pelagic existence since young goatfishes are often found in tuna stomachs. My observations allow me to make a few guarded statements about the life history. From July to November when I was collecting kumu, I never found any ripe fish. If the young first appear in shallow water in March, the pelagic life must be less than four months (late November through February). Since I could not find newly benthic kumu after June, the breeding season must be about four months long also. I must qualify these statements because my observations are for less than one year and are limited. Yearly variations are possible. Usually kumu live at all depths from one foot to at least 200 feet, but larger kumu generally live in deeper water. Commercial fishermen say
that larger kumu move into shallower water during the winter; perhaps
this movement is associated with breeding. Wirszubski (1953) concluded
that _Buillus barbatus_ has a larval period of 10 months. Gottlieb (1976)
disagreed with this conclusion. On the basis of information from
otoliths, he decided that the pelagic stage extended from the spring
spawning time until the end of the same summer. Caldwell (1962) de-
scribes the pelagic juveniles of three Western Atlantic species, but
does not speculate as to the length of larval life. He believes that
metamorphosis from the pelagic type occurs after the juveniles enter
shallow water and not at a specific time after spawning.

I know of only one possible observation of actual spawning in any
gofish. Randall (personal communication) believes he saw one Atlantic
species spawning in mid afternoon. Spawning was accomplished by an up-
ward rush with ejection of gametes at the apex of the rush.

Several points warrant further study. The time of feeding can be
fixed more accurately by observing fish at dusk and at various hours of
the night. Both extremes of the size scale need further sampling. All
of my fish were benthic when captured. I would like to examine gut con-
tents of night light or trawl specimens. Also I would like to capture
large (greater than 200 mm) specimens early enough in the morning to find
intact fish in their stomachs. This way I could determine the types of
fish eaten. My study was not long enough to determine if there are any
seasonal effects on food habits. Suyehiro (1942) reports that _Upeneus
bensasi_ scarcely eats during the spawning season. Linskaya (1964) found
considerable seasonal variation in the relative importance of crustaceans,
polychaetes, and mollusks in Lullus barbatus. Perhaps there are similar variations with kumu.

**SUMMARY AND CONCLUSIONS**

The anatomy of the digestive system of the kumu is very similar to that of other goatfishes. The greatest difference is the presence of a spongy network lining the intestine instead of heavy mucosal ridges. The stomach is of the caecal type with a gizzard-like pylorus and the intestine has one siphonal loop. Juvenile kumu differ from adults in having longer gill rakers, sharply pointed pharyngeal teeth, and a short, straight intestine.

Crabs are the most important food item in the diet for the size range collected and at least for the fall season. Alpheid shrimps and isopods are also quite important. A wide variety of other crustaceans are eaten in smaller quantities as well as other invertebrates and small fish. Generally, very small fish eat mostly minute crustaceans such as copepods and amphipods. Crabs become important very early and are dominant by the time the kumu reach 100 mm in standard length. Isopods are important in small and medium size fish. Larger crustaceans such as alpheids and stomatopods are relatively important in medium and large fish. Stenopus is eaten primarily by large specimens. Only large kumu eat other fish.

There is considerable individual and some local variations in food habits.

At least from July through November, all but the smallest kumu are crepuscular or possibly nocturnal feeders.

Digestion probably takes less than 19 hours.
The breeding season and pelagic larval stage appear to last less than four months each.


APPENDIX

Tables 1 through 3

and

Figures 1 through 17m
Table I. Localities and depth of capture of sample of A. muu.

<table>
<thead>
<tr>
<th>Area</th>
<th>Locality</th>
<th>Depth (ft.)</th>
<th>No.</th>
<th>Ave. Length (cm)</th>
</tr>
</thead>
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<td>North Shore</td>
<td>Hawailca 1</td>
<td>50</td>
<td>16</td>
<td>181</td>
</tr>
<tr>
<td></td>
<td>Hawailon 2</td>
<td>25</td>
<td>36</td>
<td>104</td>
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<td>Shark Cove</td>
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<td>7</td>
<td>95</td>
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<td>18</td>
<td>3</td>
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<td>Malamae</td>
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<td>80</td>
<td>12</td>
<td>148</td>
</tr>
<tr>
<td></td>
<td>Artificial Reef</td>
<td>50</td>
<td>9</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>Nahua</td>
<td>50</td>
<td>3</td>
<td>117</td>
</tr>
<tr>
<td>Kaneohe</td>
<td>Off Marine Base</td>
<td>70</td>
<td>12</td>
<td>198</td>
</tr>
<tr>
<td></td>
<td>Sampan Channel</td>
<td>50</td>
<td>2</td>
<td>134</td>
</tr>
<tr>
<td>Waikiki</td>
<td>Off Ilikai</td>
<td>25</td>
<td>20</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>Large</td>
<td>15</td>
<td>5</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td>Ft. DeRussey</td>
<td>25</td>
<td>42</td>
<td>137</td>
</tr>
<tr>
<td></td>
<td>Kapic Island</td>
<td>85</td>
<td>4</td>
<td>137</td>
</tr>
<tr>
<td></td>
<td>Kewalo Basin</td>
<td>25</td>
<td>1</td>
<td>245</td>
</tr>
<tr>
<td>Niihau</td>
<td>* South side</td>
<td>45</td>
<td>1</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Total 173 tons. 25 kg
Table II. Examples of calculations to determine the degree of fullness of the digestive tracts at each time.

<table>
<thead>
<tr>
<th>Time</th>
<th>0-6.30</th>
<th>2-8.45</th>
<th>12.00</th>
<th>16.00</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rank x %</td>
<td>rank x %</td>
<td>rank x %</td>
<td>rank x %</td>
</tr>
<tr>
<td>06:30</td>
<td>100 300</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>08:45</td>
<td>34 103</td>
<td>57 114</td>
<td>6 0</td>
<td>3 0</td>
</tr>
<tr>
<td>12:00</td>
<td>0 0</td>
<td>30 60</td>
<td>40 40</td>
<td>30 0</td>
</tr>
<tr>
<td>16:00</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
<td>100 0</td>
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</tbody>
</table>
Table III. Organisms found in the gut contents of kumu.

<table>
<thead>
<tr>
<th>Organism</th>
<th>% of fish with organism</th>
<th>average rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crabs</td>
<td>31.1</td>
<td>5.3</td>
</tr>
<tr>
<td>Isopods</td>
<td>39.9</td>
<td>2.2</td>
</tr>
<tr>
<td>Alpheid shrimps</td>
<td>47.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Foraminiferans</td>
<td>37.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Gammarids</td>
<td>27.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Stenopus hispidus</td>
<td>18.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Stomatopods</td>
<td>21.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Copepods</td>
<td>14.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Megalops</td>
<td>14.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Fish bones</td>
<td>11.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Gastropods</td>
<td>17.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Ostracods</td>
<td>12.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Caprellids</td>
<td>7.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Fish eggs</td>
<td>6.1 (9)</td>
<td>0.3</td>
</tr>
<tr>
<td>Polychaetes</td>
<td>4.1 (6)</td>
<td>0.2</td>
</tr>
<tr>
<td>Kona crabs</td>
<td>3.4 (5)</td>
<td>0.2</td>
</tr>
<tr>
<td>Mysids</td>
<td>1.4 (2)</td>
<td>0.1</td>
</tr>
<tr>
<td>Chitons</td>
<td>0.7 (1)</td>
<td>0.1</td>
</tr>
<tr>
<td>Spider crabs</td>
<td>1.4 (2)</td>
<td>0.04</td>
</tr>
<tr>
<td>Octopus</td>
<td>0.7 (1)</td>
<td>0.04</td>
</tr>
<tr>
<td>Tunicate</td>
<td>0.7 (1)</td>
<td>0.03</td>
</tr>
<tr>
<td>Caterpillar</td>
<td>0.7 (1)</td>
<td>0.03</td>
</tr>
<tr>
<td>Cucumacean</td>
<td>0.7 (1)</td>
<td>0.02</td>
</tr>
</tbody>
</table>

(numbers in parenthesis are numbers of fish containing organisms.)
Figure 1

Distribution of sample of 108 fish according to standard length. Shaded areas represent numbers of fish with food in stomachs.
FIGURE 1

NUMBER OF FISH vs STANDARD LENGTH MM
Figure 2
First gill arch from the left side of a 140 mm kumu. Gill rakers number 28.

Figure 3
Pharanreal teeth of 140 mm kumu. Teeth are pebble-like. Patches of teeth are separated by ridges of tough flesh. Space between upper pads is concave, and space between lower pads is convex.
FIGURE 2

Gill filaments

Gill arch

Gill rakers

Upper pharangeal teeth

Ridges of tough flesh

 Teeth

Lower pharangeal teeth

4th gill arch

FIGURE 3
Figure 4

Average size kumu (140 mm) with left side of peritoneal and cardiac cavities opened to expose the gross internal anatomy. Gonads are in inactive state. The dashed line shows the position of the operculum. The body color is generally pink, but some small specimens are gray-green and some very large adults are purplish.
Figure 5
Digestive system of a 140 mm kumu viewed from the left after removal from fish. The liver has been removed.

Figure 6
A right view of the digestive system of a 140 mm kumu. The liver has been removed. This particular fish has relatively small quantities of fat surrounding the intestine and pyloric caeca.
Figure 7
A right view of the digestive system with the intestine removed. The darkened pyloric caeca below the spleen are in a notch which is usually occupied by the intestine.

Figure 8
A right view of the digestive system with the liver, intestine, pyloric caeca, and spleen removed. The pyloric valve is the constriction between the pylorus and the duodenum.
Figure 9

Internal view of the digestive system showing linings.

A. The stomach of a 140 mm specimen cut open from the left side and the sides folded back.

B. The intestine and rectum of the same specimen cut open longitudinally from the right and the sides folded back.

C. An enlarged section of the spongy network lining the pylorus and the intestine. Small squares in A and B represent the approximate relative size of the section.
Figure 9

A

Mucosal ridges

Pyloric valve

B

Ileopectal valve

C
A transforming kumu. Apparently it had just entered shallow water and become benthic at the time of capture. It measured 37 mm in standard length. The pattern is made up of large, widely-spaced melanophores.

The right opercular opening of a 37 mm transforming kumu with the gill cover lifted up and folded forward to expose the gill arches. Gill rakers are elongate on the first arch but rudimentary on the other arches.
Figure 12

A 37 mm transforming kumu with the right side of the peritoneal and cardiac cavities opened to expose the gross internal anatomy. The digestive system is tightly bound by mesenteries.

Figure 13

A right view of the digestive system of a transforming kumu after removal from the fish. The right lobe of the liver and the fat and mesenteries surrounding the digestive system have been removed. Note the short, straight intestine.
Figure 14
A left view of the digestive system of a transforming kumu. The dashed line shows the position of the large left lobe of the liver, which has been removed.

Figure 15
A left view of the digestive system of a transforming kumu with the liver and pyloric caecæ of the left side removed and the esophagus lifted slightly to expose the spleen. Note the poor development of the cardiac stomach.
Figure 16

The relationship between time of capture and fullness of the digestive system in kumu. The degree of fullness is the total rank times percent value for each time (see text and Table II for explanation).
Figures 17 A through H

The relationship between size of kumu and average ranks of the 13 most important organisms in the diet of kumu. The small cross above 131 mm on each graph represents the mean rank for the entire sample.
FIGURE 17

A

ISOPods

STANDARD LENGTH MM

B

CRABS

STANDARD LENGTH MM
FIGURE 17

STOMATOPODS

OSTRACODS

ALPHEIDS
FIGURE 17

GASTROPODS

FORAMINIFERANS

AVERAGE RANK

STANDARD LENGTH MM
FIGURE 17

CAPRELLIDS

STANDARD LENGTH MM

MEGALOPS

STANDARD LENGTH MM