Manual of Hawaiian Fish Remains Identification Based on the Skeletal Reference Collection of Alan C. Ziegler and Including Otoliths*

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1 Introduction

Hawai‘i lost a fine scientist and Hawaiian archaeologists a good friend when Alan C. Ziegler passed away at the age of 73 in September, 2003. Trained as a zoologist at the University of California at Berkeley, where he earned the Ph.D. degree, and for many years head of Bishop Museum's Vertebrate Zoology Division, Ziegler had an active and broad interest in archaeology. In 1973 he published *Inference From Prehistoric Faunal Remains* as an Addison-Wesley module in Anthropology, which provided a generation of archaeologists with a clear-headed appraisal of the information that might be gained from a study of the bones and shells recovered during excavation. His *magnum opus*, published by the University of Hawai‘i Press the year before he passed away, is *Hawaiian Natural History, Ecology, and Evolution*, a nearly 500 page overview of Hawai‘i's natural heritage.

After he left Bishop Museum in 1983, Ziegler established an independent zoological consultancy that, among other projects, served the archaeological community by identifying vertebrate faunal remains, including fish remains, from archaeological sites. Ziegler's identifications were carried out efficiently and with a level of competence that will be difficult to replace. His work over the years produced a database of faunal identifications that archaeologists can use with complete confidence to reconstruct the interactions of traditional Hawaiians with their animal world.

This handbook is intended both as a memoriam to Alan Ziegler and as a tool that Hawaiian archaeologists can use to promote his legacy of high-quality faunal identifications. At its core are high-resolution scanned images of the fish bones in Ziegler's reference collection, now held by Bishop Museum. These images are intended to serve as a guide to the identification of fish bones. In many cases, comparing a bone with the images will be sufficient to yield a confident identification, but in many others it will be necessary to go beyond the images and make comparisons with actual bones in a high-quality fish bone reference collection. Currently, there are at least two of these in Hawai‘i; Bishop Museum holds a large number of fish skeletons in addition to the Ziegler collection (`<url:http://www2.bishopmuseum.org/anthro/fauna/fishes_query.asp>`), and the Anthropology Department of the University of Hawai‘i also holds a useful and well-organized collection of fish bones from Hawai‘i and Fiji (`<url:http://www.archaeology.hawaii.edu/collections/fishbone.htm>`).

In addition, the manual contains an atlas of fish otoliths, or ear stones. An otolith is an extremely durable fish remain that is distinctive in many cases to species level. It is routinely used by paleontologists for taxonomic identification of fossils from geologic formations. A detailed descriptive terminology for otoliths, highlighting the distinctive differences among fish taxa, has been worked out and can be applied directly to the Hawaiian materials. Given this situation, the otolith atlas should be immediately useful to archaeologists and to biologists conducting dietary studies of animals that prey on fishes.

The manual was produced as a Portable Document Format (pdf) file using pdfLaTeX software. Hypertext links for the table of contents, lists of figures and tables, figure references, text citations, and a list of citation locations following each bibliographic entry were generated by the hyperref package created by Sebastian Rahtz. When this file is viewed with Adobe Acrobat Reader software in full page mode it is possible to move through the manual with relatively great speed and precision using the links. Hypertext links are indicated on the computer screen with a colored box around the link text; brown links lead to locations in the text and dark red links lead to the bibliography. The same file can be used to print out the manual on a printer capable of two-sided printing. The colored hypertext links will not appear on the printed manual; the only tell-tale sign of the document's hypertext capability will be the list of citation locations following each bibliographic entry.

2 Identification and Quantification of Fish Remains

The isolation of the Hawaiian Islands has led to a relatively impoverished fish fauna with a high degree of endemism (Ziegler 2002:144 ff.). There are approximately 530 species of native and alien bony fishes in Hawaiian waters and 51 species of cartilaginous fishes, about half the number found at islands in Micronesia, and one fifth that found in the Philippines. Still, the prospect of identifying a fish bone or otolith is somewhat daunting. The following sections provide some general guidelines for identification and discuss issues of quantification faced by archaeologists in their work with fish remains. Issues of identification specific to otoliths are discussed in section 4.2.

2.1 Taxonomic Level of Identifications

Given a collection of fish remains, how does the analyst produce useful identifications that maximize the potential information of the collection but clearly reflect the various uncertainties that are almost always present? It goes without saying that to be useful an identification must be correct, but it is also true that in most cases an identification to a low taxonomic level, such as genus or species, is preferable to one to a higher level, such as family or class. In practice, the analyst will usually want to identify the remains to the lowest taxonomic level possible. What are the limits of possibility? These are determined by the quality and completeness of the reference collection. A quality collection meets the following criteria:

- Remains are from fish that were identified correctly, preferably by a specialist, using an up-to-date and reliable taxonomic classification;

- Remains have been processed correctly so that distinguishing features are clearly expressed and not obscured by extraneous material, broken, or otherwise altered by processing;
- The collection is cataloged and stored in such a way that bones from different fish are not confused with one another; and
- The collection is held at a location or institution where it is available for scholarly use.

Identifications based on collections that don't meet these criteria are clearly open to question and analyses built upon them run the risk of having their foundations fail.

The completeness of a collection determines the lowest taxonomic level possible for identification. This is most easily illustrated with a hypothetical example, in which the analyst identifies a premaxilla of what appears to be a rudderfish from the family Kyphosidae using a hypothetical reference collection that contains the high quality remains of the two most common of the family's five species in Hawai‘i, *Kyphosus pacificus* and *K. vaigiensis*. The premaxilla, after comparison with premaxillae in the reference collection is found to resemble very closely the premaxilla of *K. pacificus*. Certainly, the analyst feels the urge to identify the bone as *K. pacificus*, but the best that can be done in this instance is identify the bone as belonging to the family Kyphosidae. An identification to species is impossible because the other three species of Kyphosidae known from Hawai‘i are not in the collection and the analyst cannot be certain that one of these would provide a better match for the premaxilla than *K. pacificus*. Likewise, a confident identification to the genus *Kyphosus* is impossible because the collection lacks a specimen of *Sectator ocyurus*, the sole representative of the other genus of Kyphosidae known from Hawai‘i, though only rarely collected and quite possibly a waif from elsewhere in the Pacific.

Alan Ziegler's skeletal reference collection, which is illustrated in section 3, supports identifications to the general levels set out in appendix A. Most of the taxa correspond to families of fish, with a few exceptions. The taxon Marine Eel lumps together the ten eel families known in Hawai‘i, and Fish was used for the very many skeletal elements, such as most vertebrae, that can't be readily identified to a lower taxonomic level.

Identifications to taxonomic levels lower than those listed in appendix A are undoubtedly desirable in many situations. For example, studies concerned with where fish were caught will want to identify genera or species within families that contain members found in a variety of habitats. Studies of this type will be based on identifications made with a more complete reference collection than the one illustrated here.

2.2 Quantification Issues for Archaeological Collections

The methods useful for estimating patterns of fishery resource exploitation involve deriving estimates of the relative abundance of taxa from the identified fish remains and determining whether they reflect the full diversity of the prehistoric catch. As it turns out, estimating the relative abundance of taxa from archaeological remains is often difficult and is intimately tied to the units used to quantify the remains. This is an issue that has generated a large, often contentious literature but no reporting standards, thus complicating and often compromising efforts to summarize and synthesize published data. Investigations into the diversity of the catch are often subsumed under the heading "niche breadth." They are important for determining the influence of size on the diversity of a collection. The goal here is to know how many bones are needed to characterize the diversity of the catch(es) from which a collection derived.

At the outset, it should be noted that remains recovered from an archaeological site are several steps removed from the catch, and that at each step of the way from catch to archaeological site potential biases are introduced that complicate inferences about the abundance of taxa. A useful way to look at this considers the various statistical populations from which a collection of fish remains might be considered a sample (Klein and Cruz-Uribe 1984:3):

Life assemblage The community of live fish in their natural proportions;

Death assemblage The catch, or fish available for deposition at the archaeological site;

Deposited assemblage The fish or portions of fish that come to rest at the archaeological site;

Fossil assemblage The fish parts that survive in a site until excavation or collection; and

Sample assemblage The part of the fossil assemblage that is in the collection.

This classification makes it easy to see that the archaeological collection, or sample assemblage, is usually only a partial reflection of the catch, separated from it by the vagaries of human deposition practices, the breakdown of faunal remains in the archaeological site over time, and the recovery efforts of the archaeologist.

There are a host of methods by which fish remains can be quantified and a large literature that summarizes the methods (see Klein and Cruz-Uribe 1984; Reitz and Wing 1999; Ringrose 1993). One review of zooarchaeology counted 122 unique definitions for quantification methods (Lyman 1994). Most commonly used in Hawai‘i are the number of identified specimens, often abbreviated NISP, the minimum number of individuals, or MNI, and weight. Each of these can be used to estimate relative abundance of taxa in the *sample assemblage* with varying degrees of reliability and difficulty. None of these measures directly estimates the relative abundance of taxa in the fossil, deposited, death, or life assemblage.[1] The following discussion attempts to point out the strengths and weaknesses of each measure as an estimator of the relative abundance of taxa in the sample assemblage.

NISP

MNI

The measure with the most intuitive attraction is MNI, which estimates the smallest number of individual animals in the catch that could have produced all the remains in an archaeological collection. Relative abundances calculated with MNI are used

[1] A statistic known as the Lincoln Index, applied to paired elements, yields estimates of the relative abundance of taxa in the death assemblage (Ringrose 1993:128 ff.), but to our knowledge this has not been applied to Hawaiian archaeological remains.

by Pacific archaeologists "to convey what the catch would have looked like when laid out on a mat after a fishing trip" (Leach 1997:6), a characterization that plays up the conceptual appeal of counting individual animals, but ignores the fact that MNI estimates characteristics of the sample assemblage and not the death assemblage. MNI can be calculated from individual elements, e.g. the distinctive first dorsal spine of a Triggerfish, paired elements, such as the dentary of a fish, or multiple elements where the elements cannot be told apart, such as vertebrae. The measure is straightforward when it uses individual elements, but becomes complicated when paired or multiple elements are used, as they typically are when calculating the MNI of fish. The problem here is that MNI estimates based on paired or multiple elements are not additive; for a given taxon, the sum of MNI from sub-units of a collection unit, e.g. the individual 1 m^2 excavation units of a 20 m^2 excavation block, will generally be greater than the MNI calculated for the larger unit because paired or multiple elements of an individual animal are counted separately if they are collected from different sub-units. This characteristic of MNI is discussed at length by Grayson (1984), who refers to it as the aggregation effect. In practical terms, a literature source must report the MNI of taxa identified by paired or multiple elements for the stratigraphic unit of interest if the data are to be used for comparison. If the report gives MNI for some other unit, then direct comparison will be impossible. The MNI statistic is known to over-estimate rare taxa, over-estimate taxa with many identifiable parts in highly fragmented collections, and under-estimate these same taxa in collections with little fragmentation (O'Connor 2001:706). MNI estimates are sensitive to stochastic factors and in this way are less robust than estimates made with NISP.

Less intuitively attractive is the NISP measure, which, in practice, counts every identifiable element and element fragment.[2] Taxa with a large number of identifiable elements—a good example, common in Pacific faunal collections, is the spiny puffer of the family Diodontidae, each individual of which has approximately 500 distinctive dermal spines (Leach 1997:11)—will yield high NISP values compared to taxa with a small number of identifiable elements. A correction for this divides the NISP for each taxon by the number of identifiable, or identified, elements of the taxon, although this is rarely accomplished in Hawai'i. Also, taxa with identifiable elements that fragment easily are likely to be over-represented relative to taxa with sturdier identifiable elements in collections with a high frequency of fragmentary remains. Despite these potential problems, many investigators find NISP a useful measure of relative taxonomic abundance. In an analysis of fish remains from the Cook Islands, Nagaoka (1994) found that MNI and NISP values for each taxon varied in a predictable fashion, indicating that they carried similar information on relative abundances. Thus, given the relative ease of obtaining NISP estimates and their mathematical manipulability, they appear to be superior to MNI for most purposes. Alan Ziegler recommended to his clients that they report the bones he identified as NISP, in a table similar to table 1.

Use of sample weights to estimate relative abundance of taxa is relatively rare among archaeologists (Reitz and Wing 1999:191), primarily because the weight of an animal's remains varies widely among taxa. A correction for this variability multiplies the weight of identified remains by a value for each taxon that describes the relationship

[2] An alternative designation for NISP is total number of fragments, or TNF.

Table 1. Example table of identified fish remains (NISP)

	Collection				
Taxon	**1**	**2**	**3**	**4**	**Total**
Carangid	12	8	22	17	59
Chaetodontid	2	4	1	6	13
Acanthurid	34	66	21	55	176
Balistid	7	23	4	1	35
Total	55	101	48	79	283

of meat weight to the weight of inedible remains that might be deposited in archaeological sites. Corrected in this way, bone weights provide estimates of the relative weight of meat contributed by each taxon to the sample assemblage. A problem with this procedure is that, for many taxa, the meat weight ratio is not constant over the life span of the animal (Casteel 1978), a fact that might or might not introduce significant errors into an analysis. In practice, weights are often used to quantify shellfish remains, where they provide "a simple and quite effective method for establishing the relative economic importance of different shellfish taxa" (Leach 1997:8), but only rarely for vertebrate remains, where the use of MNI and especially NISP are more common.

3 Atlas of Identifiable Fish Bones

3.1 About the Atlas

The images in this atlas of identifiable fish bones are high-resolution scans made with a flat-bed scanner. They are best viewed on a computer with display software for Portable Document Format (pdf) files. The advantage of this method is that one can zoom in on a particular bone or bones to view them at greater than life size. This simulates the effect of looking at the bones through a hand lens, revealing small details of shape and structure that might be useful for identification. The manual can also be printed on a printer capable of two-sided reproduction; such printers are typically found at copy shops. When printed in this way the photographs will generally show bones smaller than life size and small details of shape and structure might be lost in the printing process. Hard copies of the handbook should prove as useful as another atlas of fish bones that includes fishes found in Hawaiian waters (Barnett 1978).

The fish illustrated in the atlas were all identified by Alan Ziegler. Most of them were purchased in markets, but others were given to him by fishermen and scientists. As the images show, most of the identifiable bones were labeled in India ink with a catalog number and often the sex of the specimen. The bones most useful in Ziegler's work identifying archaeological materials were kept in a cabinet with divisible plastic drawers, ordered alphabetically by family; other bones were kept in black cardboard boxes, each with a label indicating the taxon, family name, catalog number, locality, date collected, sex, and occasionally a note.

The bones were scanned at 1,200 dots-per-inch against a black cloth background in both medial and lateral views. The tagged image file format files produced by the scanner ranged in size from 10–97 megabytes. Using Gnu Image Manipulation Program software, the image of each bone was cut out and pasted onto a uniform background of dark gray, following a standard layout, where possible. In the standard layout the bones are arranged with the lateral view on the right and the medial view on the left, with the maxilla at the top, followed by the premaxilla, dentary, angular, and quadrate at the bottom. The bones have generally been placed so that Ziegler's india ink labels are oriented correctly and to minimize the size of each plate, without regard to the orientation of the bone in the skeleton. Variations from the standard layout, e.g. for fish that have fused one or more of the identifiable bones with other bones or that have distinctive bones from other parts of the skeleton, are noted in the figure captions. A 1 cm scale bar has been placed on each plate.

The plates have been ordered alphabetically by family and alphabetically by species within each family, a compromise that steers clear of the treacherous shoals of phylogenetic arrangement. An idea of the flux that characterizes this branch of taxonomy can be had by comparing the phylogenetic arrangement of families used by Gosline and Brock (1960) with a more modern one, such as Randall (1996). Along with many small changes in the order of families are several large ones; the lefteye flounders of the family Bothidae are placed by Gosline and Brock (1960) at the primitive end of the list, near the squirrelfishes of the family Holocentridae, and by Randall (1996) near the advanced end of the list, separated from the Holocentridae by some 40 other families! Although a phylogenetic arrangement carries some information of potential use to the faunal analyst, it is beyond the scope of the manual to choose among competing phylogenetic arrangements and the interested analyst will have to refer to other publications for this information.

3.2 A Procedure for Identifying Fish Bones

A useful procedure for identifying fish bones has been set out in detail by Leach (1997).[3] The account here outlines Leach's procedure.

After the fish bones in a collection are laid out on a table, all the bones are assigned to one or another of eight categories, one bone at a time, focusing on distinctive bones of the skull. The categories are:

special bone An unusual bone that is distinctive to a particular taxon. Examples include the first dorsal spine of *Pervagor spilosoma*, which bears a row of prominent downcurved spines on each side (Randall 1985:58) and the two-rooted dermal spines of *Diodon hystrix*.

[3] Leach (1997) cites the preferential use of MNI as one reason to follow this identification procedure. As indicated in section 2.2, the use of MNI as a basic unit of quantification is not recommended. The identification procedure set out by Leach is still valid, however, because the bones it uses are among the most distinctive of the fish skeleton and were the bones used by Ziegler in his identifications. Leach's argument against the identification of bones other than those explicitly noted in the procedure, based on the use of MNI as a basic unit of quantification, should be ignored except in instances where identification of other bones yields redundant information, i.e. does not alter the relative abundances of identified taxa.

dentary The most distinctive bone of the fish skull (fig. 1). It is a paired dermal bone of the lower jaw that bears teeth in most bony fishes (Rojo 1991). The dentaries are fused together in the pufferfishes, forming a structure that resembles a parrot's beak. Landmarks on the dentary include the symphyseal margin, mental foramen, coronoid process, external wall, meckelian fossa, internal wall, and sensory canal (fig. 2).

premaxilla The second most distinctive bone of the fish skull (fig. 1), it is a paired dermal bone of the anterior part of the upper jaw (Rojo 1991). In most fish, the lower border of the premaxilla bears teeth. Landmarks on the premaxilla include the symphyseal margin, ascending process, articular process, maxillary process, and caudal process (fig. 3).

angular A paired bone directly posterior to and articulated with the dentary. It articulates posteriorly with the quadrate (fig. 1). Also known as the articular. Landmarks on the angular include the anterior process, coronoid process, quadrate facet, postarticular process, prearticular fossa, superior crest, and inferior crest (fig. 4).

maxilla A paired bone directly posterior to and articulated with the premaxilla (fig. 1). It bears teeth in some primitive fishes, but teeth are absent in more advanced forms (Rojo 1991). Landmarks on the maxilla include the premaxillary sulcus, internal process, palatine sulcus, maxillary process, caudal process, and external process (fig. 5).

quadrate The bone directly posterior to and articulated with the angular (fig. 1). Landmarks of the quadrate include the ectopterygoid margin, collus, and preopercular groove (fig.).

fish A bone that can be definitely identified as not belonging to one of the previous six categories. The great majority of bones in most collections will fall into this category.

problem A bone that cannot be assigned with confidence to any other category. Typically, these bones are re-examined at the end of the sort and classified, if possible. In some cases, the problem bones will be examined by a specialist.

It cannot be stressed too strongly that each of the assignments at this stage represents a positive statement about one fish bone.

The bones in the special bones category and the five distinctive bones of the skull are then identified to taxon by reference to the photographs in this manual and, if needed, by reference to actual bones in a reference collection. As it stands today, this is a task guided solely by experience and familiarity with the distinctive bones of Hawaiian fishes. No key for the identification of a particular skeletal element has been worked out. A key for each of the identifiable bones would be a great advance and a worthy project for the ambitious faunal analyst.

Once a bone has been identified to the lowest possible taxonomic level it is placed in a bag with a label for that taxon. In general, it is advisable to start with the most

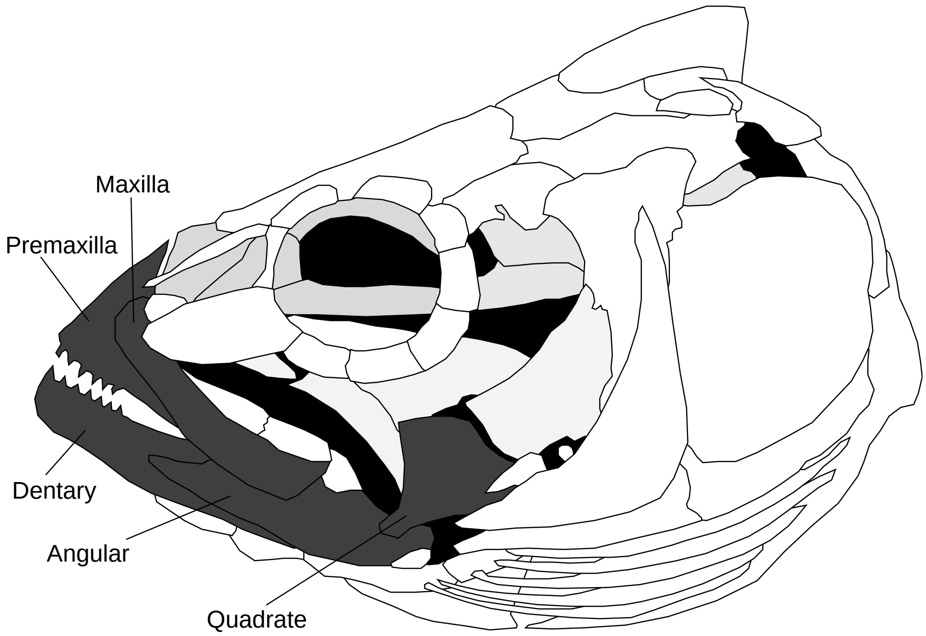

Figure 1. Distinctive skull bones of the fish. Adapted from Barnett (1978:fig. 7).

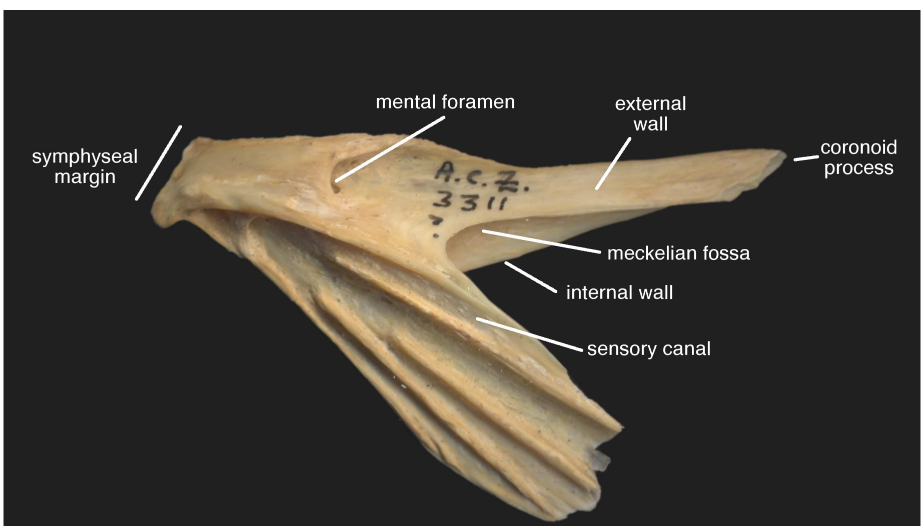

Figure 2. Dentary of *Beryx decadactylus*, showing landmarks. After Rojo (1991:fig. 17).

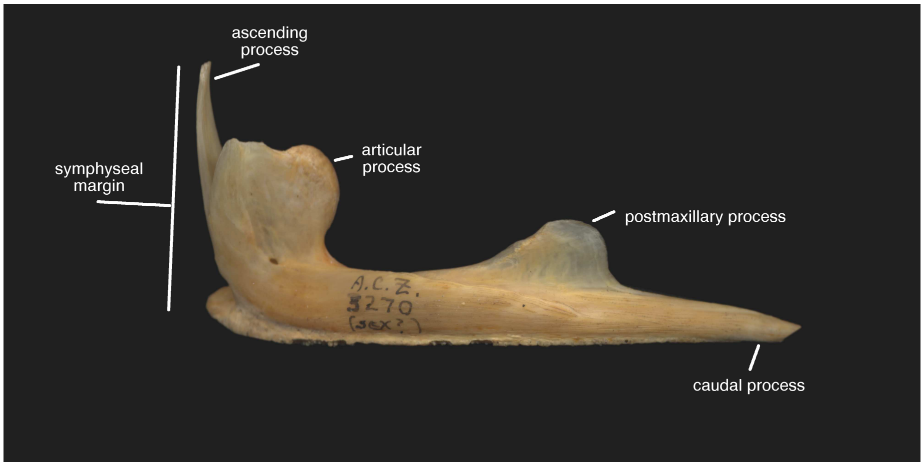

Figure 3. Premaxilla of *Seriola* cf. *dumerili*, showing landmarks. After Rojo (1991:fig. 15).

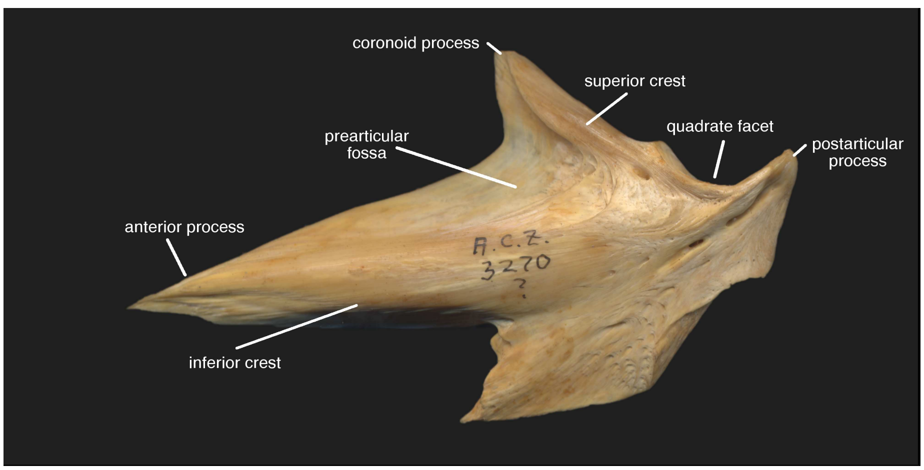

Figure 4. Angular of *Seriola* cf. *dumerili*, showing landmarks. After Rojo (1991:fig. 18).

distinctive bones and work toward the least distinctive. In this way, by the time the least distinctive of the identifiable bones—the quadrates—are being identified, the analyst has a reasonably good idea about the kinds of fish in the collection, which in many cases can speed identification of otherwise difficult bones.

At the end of this procedure there is one bag for each taxon identified in the collection, containing all of the identified bones for that taxon, plus one bag of fish remains not identified.

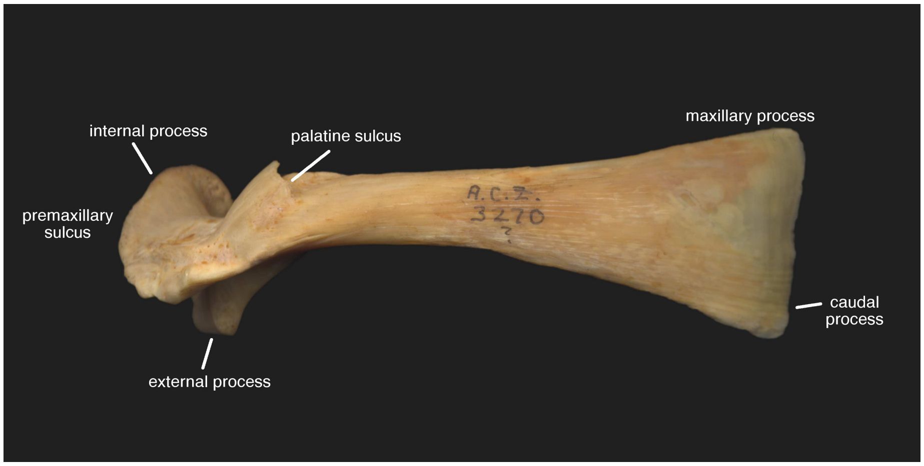

Figure 5. Maxilla of *Seriola* cf. *dumerili*, showing landmarks. After Rojo (1991:fig. 16).

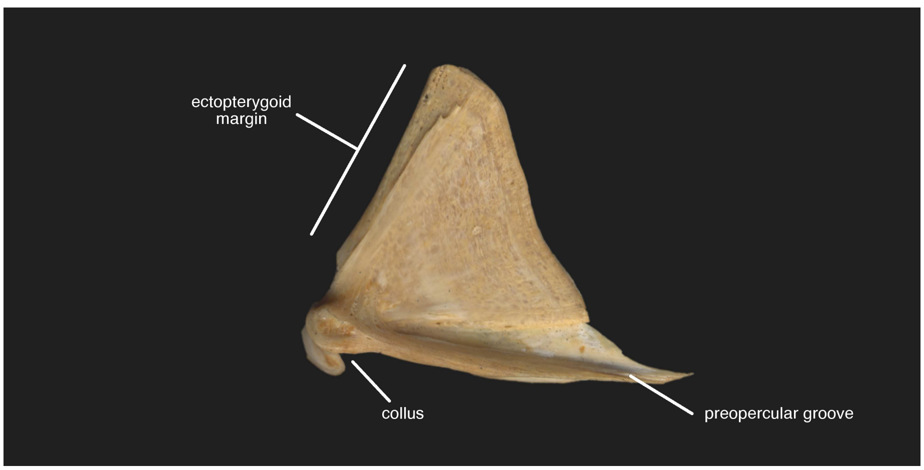

Figure 6. Quadrate of *Seriola* cf. *dumerili*, showing landmarks. After Rojo (1991:fig. 29).

3.3 Identifiable Bones of Hawaiian Fishes

3.3.1 Acanthuridae

Acanthurus olivaceus (fig. 7) is an herbivore that reaches 30 cm in length and is found over sand bottoms near reefs in waters 10 m to at least 45 m deep (Randall 1985:48, 49). It is known in Hawai‘i as *na‘ena‘e*.

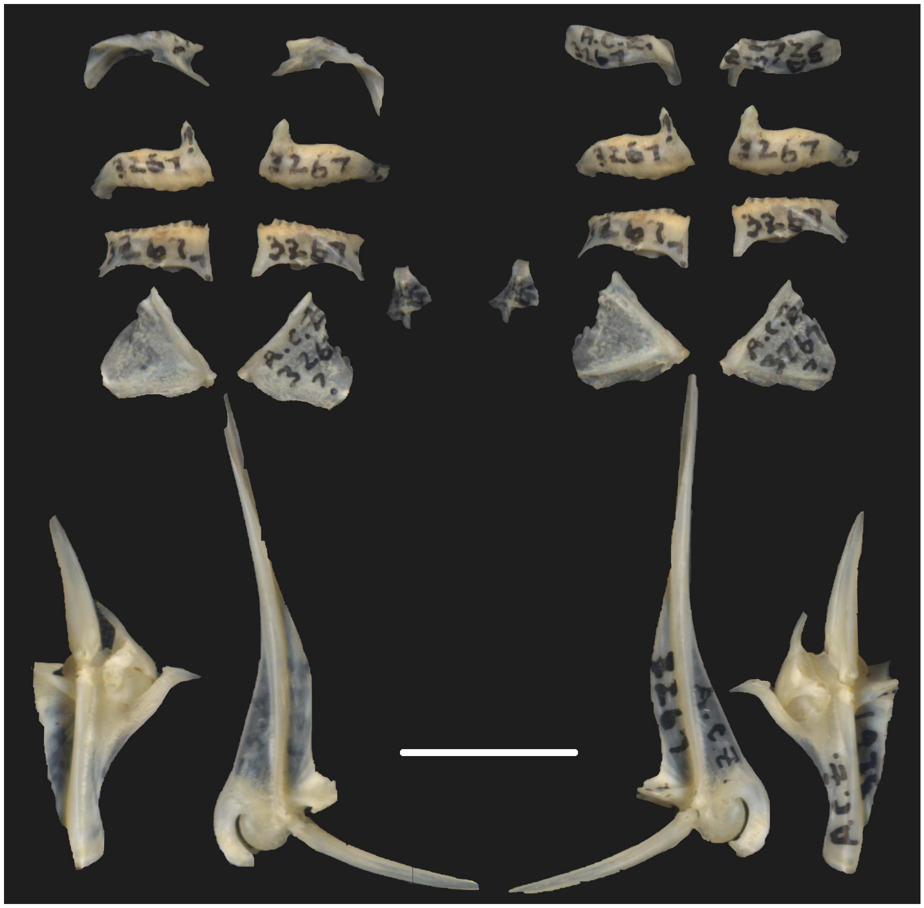

Figure 7. *Acanthurus olivaceus*, the orangeband surgeonfish, or *na‘ena‘e*, ACZ-3267. Original locality unknown; purchased at Honolulu, O‘ahu fish market. Scale bar = 1 cm.

Acanthurus xanthopterus (fig. 8) is a large surgeonfish that reaches 56 cm in length (Randall 1985:49). It lives on coral reefs but ranges widely to 90 m depths (Randall 1985:49, 50). It eats diatoms and detritus, which it ingests with sand (Randall 1985:49). Known in Hawai‘i as *pualu*, it is usually caught in a net, but sometimes takes a hook, as well (Hosaka 1973:137). The fish has a strong odor, but is eaten raw by some and broiled by others (Titcomb 1972:144).

Zebrasoma veliferum (fig. 9) grows to 38 cm on coral reefs and rocky shores, where it sometimes goes into the surge zone (Randall 1985:52). It browses on filamentous algae (Randall 1985:52). Known in Hawai‘i as *māne‘one‘o*, it is not particularly valued as a food fish (Titcomb 1972:88).

Naso unicornis (fig. 10) grows to a length of 69 cm browsing on coarse leafy algae in shallow water (Randall 1985:52). It travels in large schools but is also seen singly at

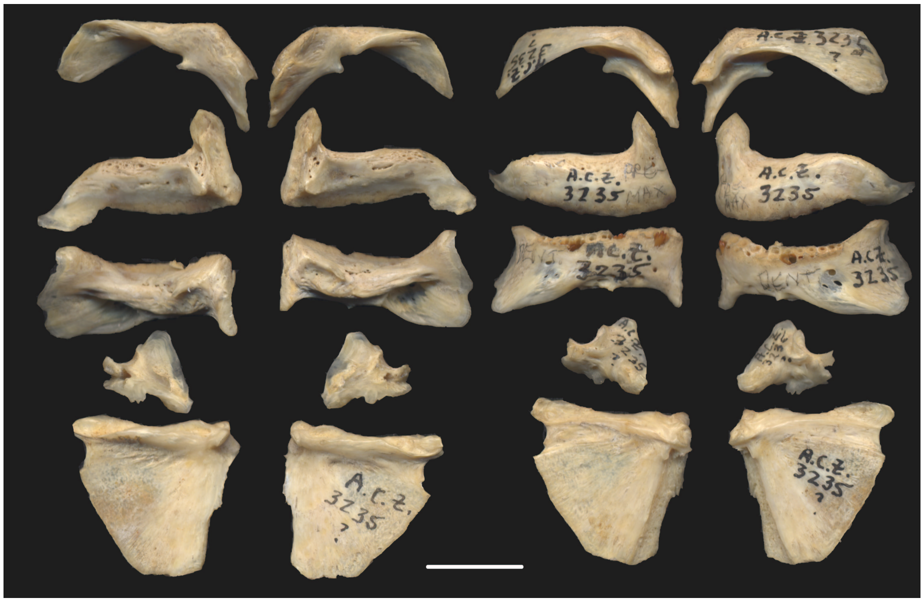

Figure 8. *Acanthurus xanthopterus*, the yellowfin surgeonfish, or *pualu*, ACZ-3235. Scale bar = 1 cm.

the edge of the reef. Known in Hawaiʻi as *kala*, it is caught in nets or with a spear; it never takes a hook (Hosaka 1973:142). Its flesh has a strong odor and is rarely eaten raw; it is best broiled or dried and broiled or baked (Titcomb 1972:85).

Naso brevirostris (fig. 11) travels in schools and can reach a length of 50-60 cm (Hosaka 1973:141–142). Younger fish browse benthic algae, but adults feed primarily on zooplankton (Randall 1985:53). Known in Hawaiʻi as *kala lōlō*, it is one of about a dozen varieties of *kala* recognized traditionally (Titcomb 1972:84). It is generally caught in nets or with a spear (Hosaka 1973:142). The flesh has a strong odor and is rarely eaten raw; it is often broiled or partially dried and broiled (Titcomb 1972:85).

3.3.2 Albulidae

Albula sp.[4] (fig. 12) is a fish of sandy bottoms that often runs in large schools (Hosaka 1973:73). It attains a maximum length of about 90 cm feeding on crustaceans in the sand (Gosline and Brock 1960:95). It is caught with a hook and line or in *hukilau* nets (Hosaka 1973:73). Known in Hawaiʻi as *ʻōiʻo*, it is an "exceedingly popular food fish, flesh is delicious, white; liked raw when its may fine bones are supple and slip down the throat without any trouble: often eaten 'lomied' with *limu kohu*" (Titcomb 1972:119).

[4]Alan Ziegler identified this fish as *Albula vulpes* at a time when it was believed there was a single circumtropical species of bonefish. Two species, difficult to distinguish, are now recognized in Hawaiʻi, *A. glossodonta* and *A. argentea* (Randall 1996:27).

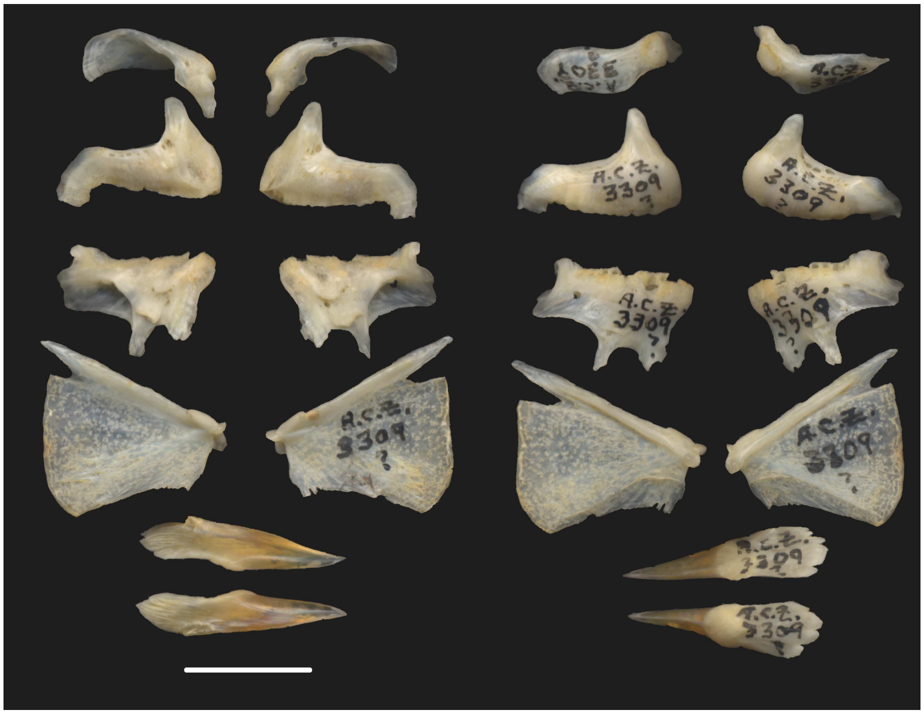

Figure 9. *Zebrasoma veliferum*, the sailfin tang, or *māne‘one‘o*, ACZ-3309. Original locality unknown; purchased at Honolulu, O‘ahu fish market. *Bottom*, peduncular spines. Note angular missing from collection. Scale bar = 1 cm.

3.3.3 Antennariidae

Antennarius sp. (fig. 13) is a bizarre-looking fish that sits on the bottom, where it lures small fish with an unusual first dorsal spine that resembles a fishing pole (Randall 1985:10). It grows to a length of 30 cm on a carnivorous diet of small fish. It is blends in very well with its surroundings and rarely moves, so that it is not often seen.

3.3.4 Apogonidae

Apogon menesemus[5] (fig. 14) is a carnivorous, nocturnal fish that feeds on zooplankton and reaches a length of about 18 cm (Randall 1985:17, 18). Known in Hawai‘i as *‘upāpalu*, it is an easy fish to hook (Hosaka 1973:120), primarily on moonlit nights (Titcomb 1972:158). Its “sweet, soft, and tender” flesh is good “raw, broiled, or wrapped in *ti* leaves and broiled” (Titcomb 1972:158). When fried, the bones become brittle and the fish can be eaten whole (Hosaka 1973:120).

[5]Ziegler identified this specimen as *A. taeniopterus*, which is found elsewhere in the Indo-Pacific and was, at the time of Ziegler’s identification, thought to occur in Hawai‘i, as well.

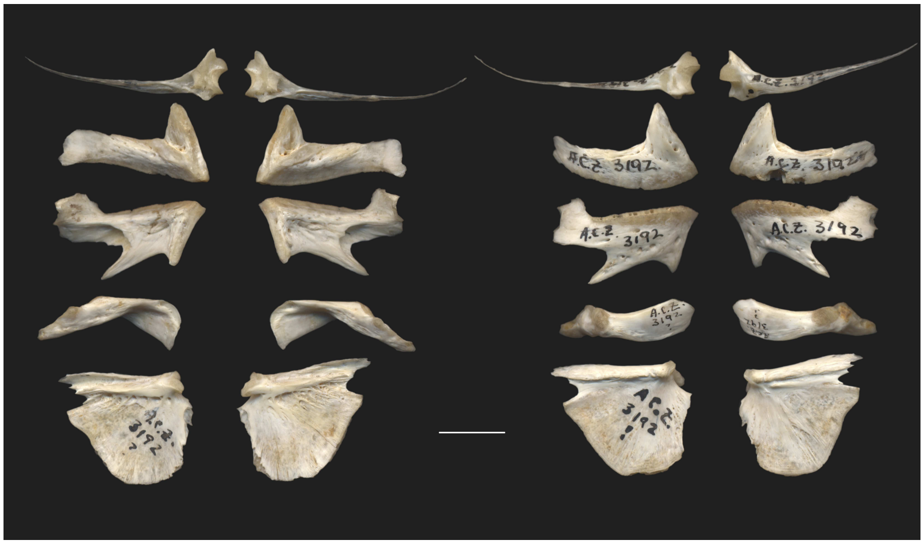

Figure 10. *Naso* cf. *unicornis*, the bluespine unicornfish, or *kala*, ACZ-3192. Collected at ʻĀpua Point, Hawaiʻi. Scale bar = 1 cm.

3.3.5 Aulostomidae

Aulostomus chinensis (fig. 15) ranges from shallow water to at least 113 m. It is often found swimming with herbivorous fishes, using them as cover to prey on small fish, which it sucks into its elongated snout (Randall 1985:9). Known in Hawaiʻi as *nūnū*, it is eaten either broiled or dried (Titcomb 1972:117).

3.3.6 Balistidae

Sufflamen fraenatus (fig. 16) grows to a length of about 38 cm on a primarily carnivorous diet that includes a wide variety of urchins, fish, crabs, shrimps, and other animals (Randall 1985:61). Known in Hawaiʻi as *humuhumu mimi*, it is one of about ten traditionally recognized varieties of *humuhumu* (Titcomb 1972:79, 80). Some *humuhumu* are caught with hook and line (Hosaka 1973:157) or with a baited basket (Titcomb 1972:81). They generally have a strong odor and are eaten broiled, or nowadays fried (Titcomb 1972:81).

3.3.7 Belonidae

Platybelone argalus platyura[6] (fig. 17) is the smallest of the three needlefish in Hawaiian waters, growing to a length of 38 cm. It is a carnivore that travels in schools in the surface layers of the ocean, often moving far from shore (Gosline and Brock

[6] Ziegler identified this specimen as *Belone platyura*. The name has changed since Ziegler's identification.

Figure 11. *Naso brevirostris*, the spotted unicornfish, or *kala lōlō*, ACZ-3306. Original locality unknown; purchased in Honolulu, O‘ahu fish market. Scale bar = 1 cm.

1960:129). Known in Hawai‘i as *‘aha* when full grown, or as *‘aha‘aha* when young (Titcomb 1972:57), it is caught with a hook and line or, occasionally, in surround nets (Hosaka 1973:80). It is eaten broiled (Titcomb 1972:58).

Tylosurus crocodilus[7] (fig. 18) grows to a length of 1 m on a carnivorous diet of shrimps and crabs (Hosaka 1973:79–80). Its habits, Hawaiian name, and methods of capture and cooking are identical to *Belone platyura* (pg. 21).

3.3.8 Berycidae

Beryx decadactylus (fig. 19) lives in the high seas at “presumably . . . moderate depths” (Gosline and Brock 1960:136).

[7] Ziegler identified this specimen as *Strongylura gigantea*. The name has changed since Ziegler’s identification.

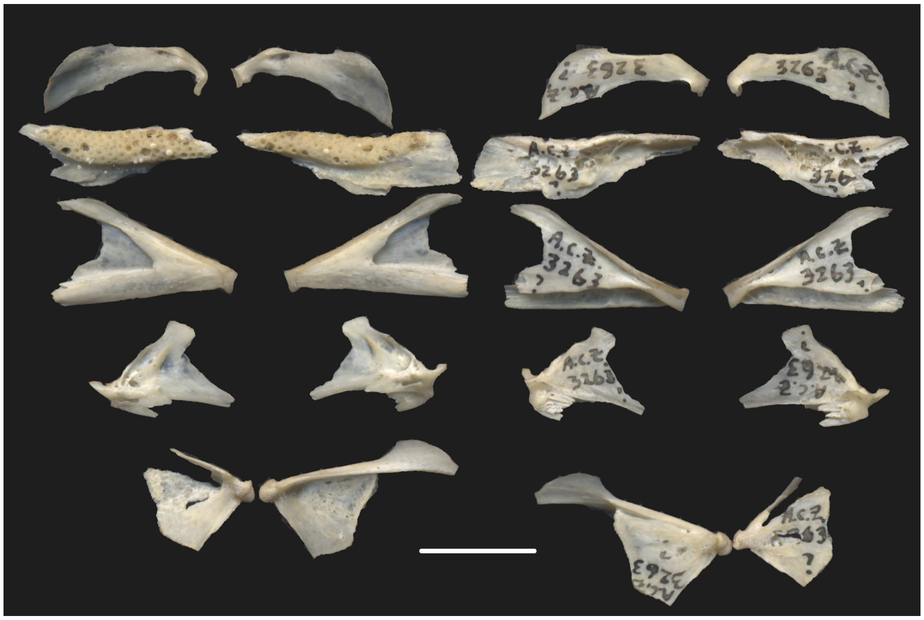

Figure 12. *Albula sp.*, the bonefish, or *‘ō‘io*, ACZ-3263. Original locality unknown; purchased at Honolulu, O‘ahu fish market. Scale bar = 1 cm.

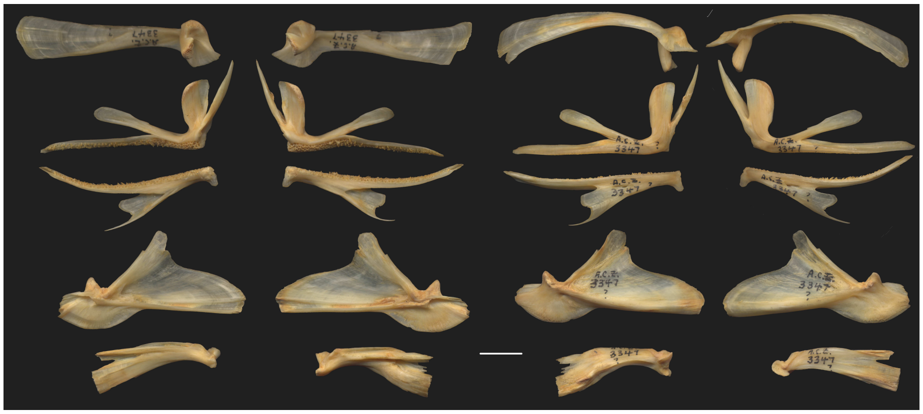

Figure 13. *Antennarius* sp., the frogfish, ACZ-3347. Original locality unknown; received from Kāne‘ohe, O‘ahu aquarium fish store. Scale bar = 1 cm.

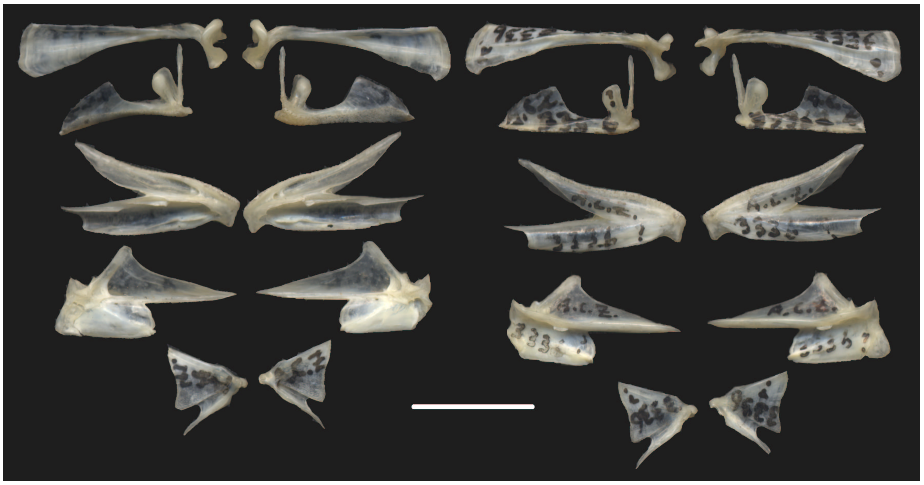

Figure 14. *Apogon menesemus*, the bandfin cardinalfish, or *‘upāpalu*, ACZ-3336. Collected at ‘Anini, Kaua‘i. Scale bar = 1 cm.

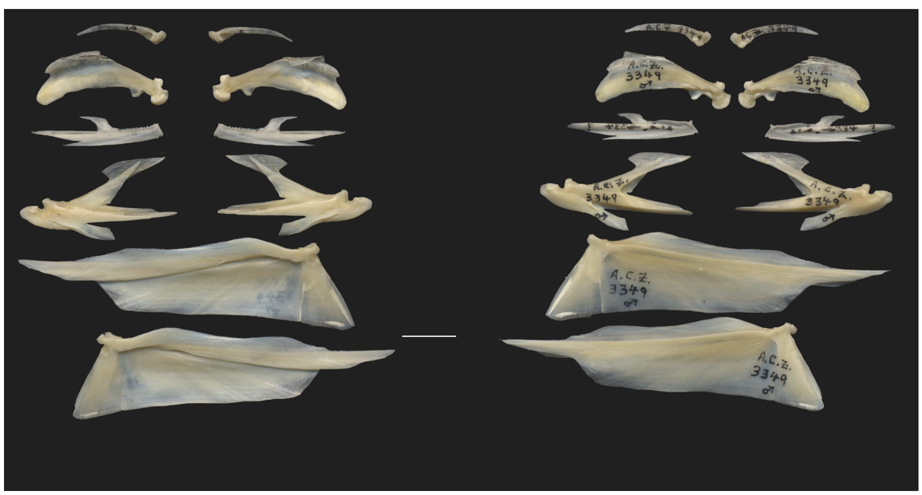

Figure 15. *Aulostomus chinensis*, the trumpetfish, or *nūnū*, ACZ-3349. Collected at Kāne‘ohe, O‘ahu. Scale bar = 1 cm.

3.3.9 Bleniidae

Entomacrodus marmoratus (fig. 20) is found along rocky coasts exposed to surf, often skipping from pool to pool in the intertidal zone (Randall 1996:153–155). It grows to a length of 15 cm on a diet of benthic algae. Known in Hawai‘i as *pāo‘o*, a general

Figure 16. *Sufflamen fraenatus*, the bridled triggerfish, or *humuhumu mimi*, ACZ-3193. Collected at Polihua, Lāna‘i. *Top to bottom*: maxilla, premaxilla, dentary, quadrate, 1st dorsal spine, 2nd dorsal spine, pterygial carina. Scale bar = 1 cm.

term for blennies, it is caught with a net, in the hands, or sometimes with a hook and line (Hosaka 1973:154). It is eaten dried or cooked with salt in *kī* leaves. It was used in sorcery to rid a person of infatuation (Titcomb 1972:126).

3.3.10 Bothidae

Bothus mancus (fig. 21) lives, like other flatfish, on sandy or sedimentary bottoms (Gosline and Brock 1960:147). It grows to about 48 cm. It is a carnivore, eating primarily fishes and some crabs and shrimp (Randall 1985:46). Known in Hawai‘i as *pāki‘i*, it is taken with a hook and line, spear, or by hand (Hosaka 1973:82). This fish is not eaten raw, but is broiled or partly dried and broiled (Titcomb 1972:137).

Figure 17. *Platybelone argalus platyura*, the needlefish, or *ʻaha*, ACZ-3274. Collected at North Island, Pearl and Hermes Reef. *Top to bottom*: dentary and premaxilla with maxilla, lower pharyngeal, angular, quadrate and pterygoids. Scale bar = 1 cm.

3.3.11 Carangidae

Pseudocaranx dentex[8] (fig. 22) lives in bays and coastal waters, but is not common around the main Hawaiian Islands, being more abundant in the Northwestern Hawaiian Islands (Gosline and Brock 1960:177). Like other jacks, it is a strong-swimming carnivorous fish. Known in Hawaiʻi as *ulua*, it is taken with a hook and line. They were eaten raw or cooked, the eyes considered a particular delicacy, and played an important role in certain traditional religious rites (see pg. 29).

Scomberoides lysan[9] (fig. 23) commonly reaches lengths of 30 cm and larger individuals can be 50 cm long (Hosaka 1973:105). It is found near the surface, where it moves constantly in search of the fish, shrimps, and crabs that are its food (Hosaka 1973:106). Known in Hawaiʻi as *lai*, it is most commonly caught with a hook and line

[8] Ziegler identified this specimen as *Caranx cheilio*. The name has changed since Ziegler's identification.

[9] Ziegler identified this specimen as *S. sancti-petri*; the taxonomy has changed since Ziegler's identification.

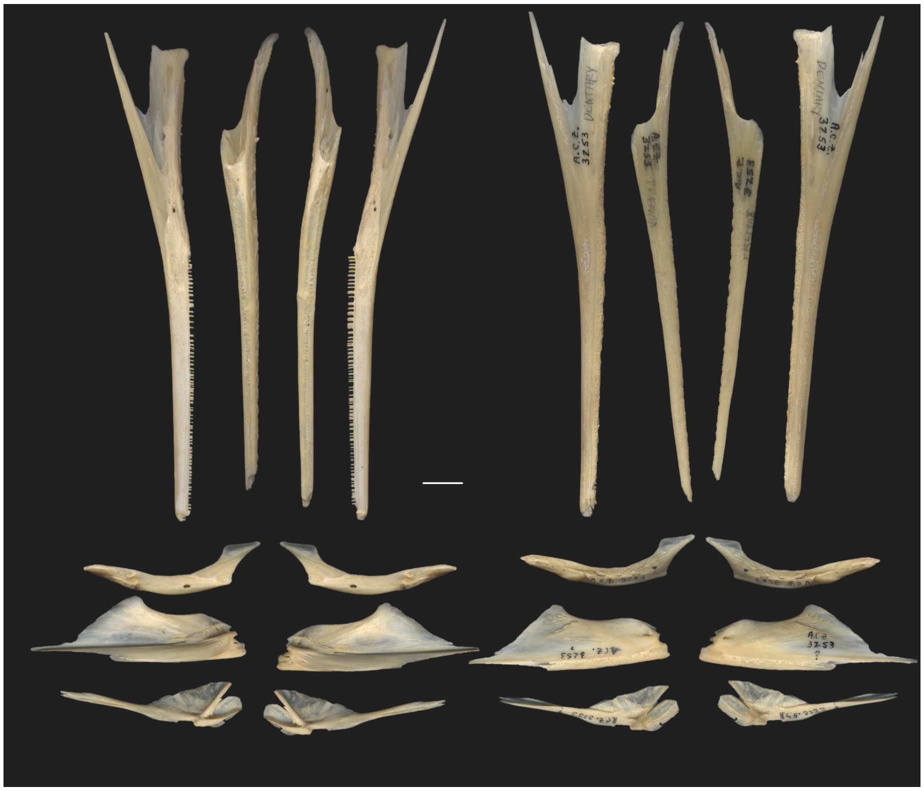

Figure 18. *Tylosurus crocodilus*, the needlefish, or *ʻaha*, ACZ-3253. Original locality unknown; purchased in Kāneʻohe, Oʻahu supermarket. *Top to bottom*: dentary and premaxilla, maxilla, angular, quadrate. Scale bar = 1 cm.

by dragging bait across the surface (Hosaka 1973:106). Titcomb (1972:95) reports that it is a "[d]elicious fish, broiled, dried, or baked in the *imu*."

Decapterus macarellus[10] (fig. 24) is commonly 25–30 cm long, but larger individuals are up to 45 cm long (Hosaka 1973:107). It is an open ocean fish that travels in large schools and feeds on plankton (Gosline and Brock 1960:172). Today, it is often taken in large nets set from a boat, but when schools run near shore they can be taken with a hook and line, as well (Hosaka 1973:107). Known in Hawaiʻi as *ʻōpelu*, it was caught in traditional Hawaiian times with a fine-mesh net called *kāʻili* (Malo 1951:209). This is a prized food fish that is eaten "raw, dried, sometimes broiled after drying, or broiled when fresh" (Titcomb 1972:133). The *ʻōpelu* is an *ʻaumakua* of the descendants of Pāʻao (Titcomb 1972:36–37), a priest from Kahiki. At the time of Contact, there was a *kapu* on fishing for *ʻōpelu* in the winter months of Hoʻoilo (Malo 1951:209). The *ʻōpelu* figured with the *aku* in yearly rites (Valeri 1985:231–232).

[10]Ziegler identified this specimen as *Decapterus pinnulatus*. The name has changed since Ziegler's iden-

Figure 19. *Beryx decadactylus*, ACZ-3311. Original locality unknown; purchased in Kāne‘ohe, O‘ahu supermarket. Scale bar = 1 cm.

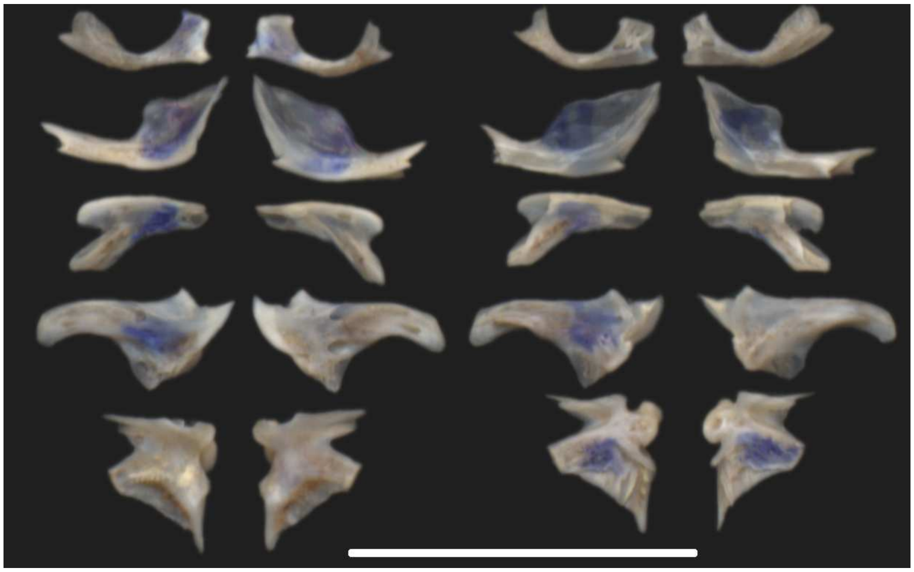

Figure 20. *Entomacrodus marmoratus*, the marbled blenny, or *pāo‘o*, ACZ-3346. Original locality unknown; received from Kāne‘ohe, O‘ahu aquarium fish store. Scale bar = 1 cm.

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tification.

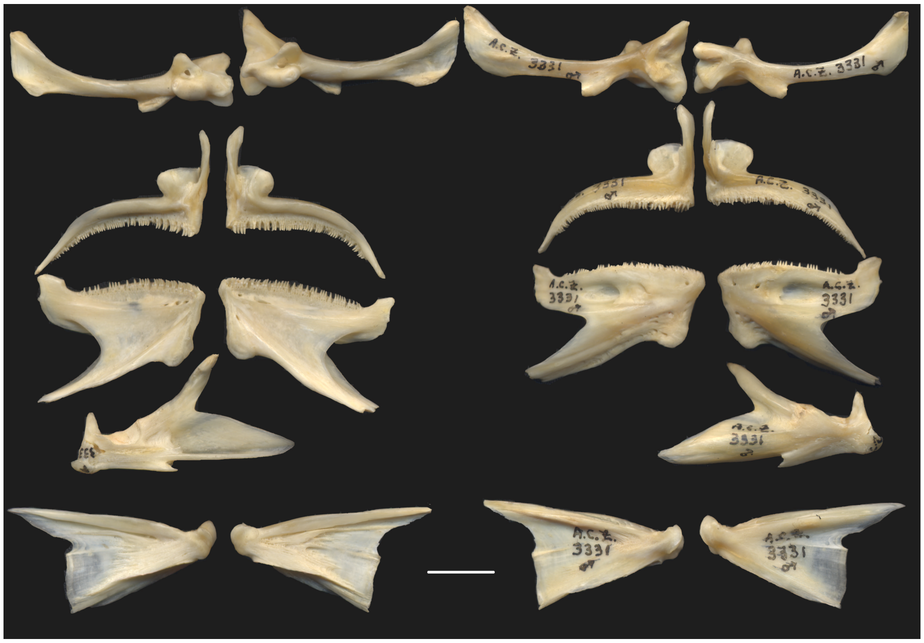

Figure 21. *Bothus mancus*, the flowery flounder, or *pāki‘i*, ACZ-3331. Collected at Waikīkī, O‘ahu. Scale bar = 1 cm.

Selar crumenopthalmus[11] (fig. 25) is a schooling fish of coastal waters throughout Hawai‘i. It feeds on plankton and grows to a length of about 38 cm (Gosline and Brock 1960:173). Known in Hawai‘i as *akule*, or *halalū* when young, it is caught with a hook and line, frequently at night with a light, and with surround nets (Hosaka 1973:108). It is eaten raw, broiled, or cooked in *ti* leaf bundles (Titcomb 1972:62).

Caranx ignobilis (fig. 26) is a common fish within the reef and close to shore. It grows to a length of about 90 cm on a carnivorous diet of crustaceans and fish (Gosline and Brock 1960:176, 177). Known in Hawai‘i as *pā‘ū‘ū* or *ulua*, it is caught day or night with a hook and line (Hosaka 1973:112). It is eaten raw, baked, or broiled; the eyeballs are a particular delicacy (Titcomb 1972:152 ff.). *Ulua* were offered during rites at sacrificial *heiau luakini*; if an *ulua* could not be caught for the rites, then a human was sacrificed instead (Valeri 1985:312–314). It was associated with the Hawaiian god, Kū (Valeri 1985:45).

Seriola dumerili (fig. 27) is an open-water, carnivorous fish that grows to a length of 1.9 m (Randall 1996:85). It is taken near the bottom in deeper coastal waters, from 75–185 m, with a hook and line (Gosline and Brock 1960:171). Known in Hawai‘i as *kāhala*, this once important commercial fish is now avoided because it frequently causes ciguatera (Randall 1996:85). Traditionally, it was cooked in the earth oven

[11] Ziegler identified this specimen as *Trachurops crumenopthalmus*. The name has changed since Ziegler's identification.

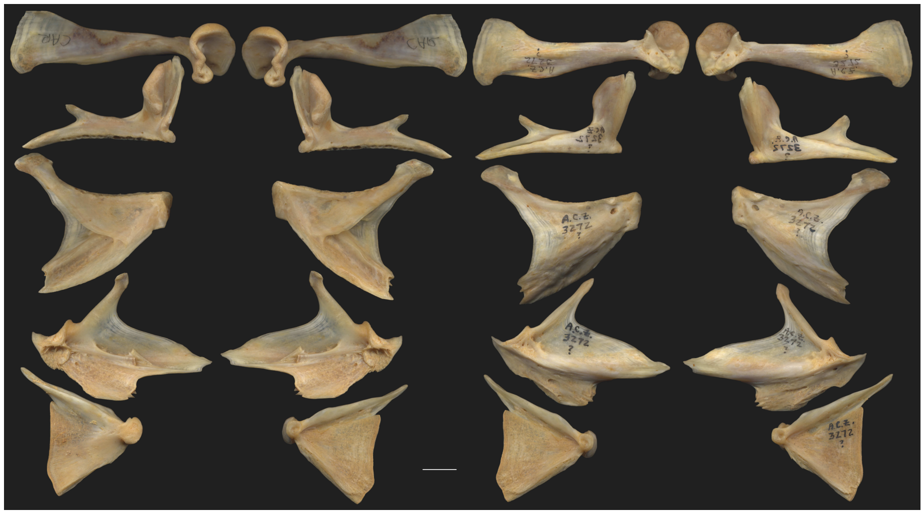

Figure 22. *Pseudocaranx dentex*, the thicklipped jack, or *ulua*, ACZ-3272. Collected off Southeast Island, Pearl and Hermes Reef. Scale bar = 1 cm.

Figure 23. *Scomberoides lysan*, the leatherback, or *lai*, ACZ-3356. Original locality unknown; purchased in Honolulu, O‘ahu fish market. Scale bar = 1 cm.

whole or sliced into steaks. It was also salted and eaten raw or wrapped in *kī* leaves and baked (Titcomb 1972:83).

3.3.12 Cichlidae

Fishes in Hawaii commonly referred to as tilapia (fig. 28) are in the genera *Oreochromis*, *Sarotherodon*, and *Tilapia*. They were introduced to Hawai‘i in 1957 to control the growth of weeds and algae in freshwater systems and for *aku* bait.

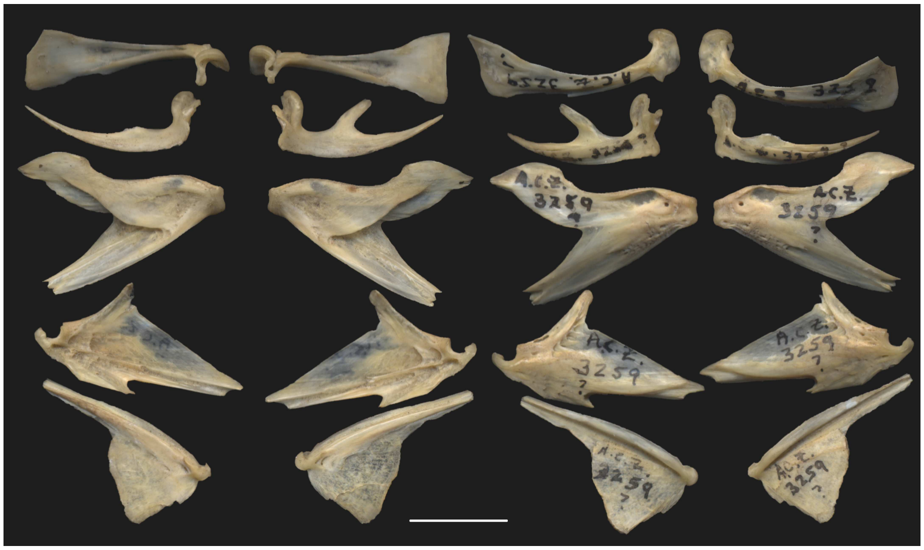

Figure 24. *Decapterus macarellus*, the mackerel scad, or *‘ōpelu*, ACZ-3259. Original locality unknown; purchased in Honolulu, O‘ahu fish market. Scale bar = 1 cm.

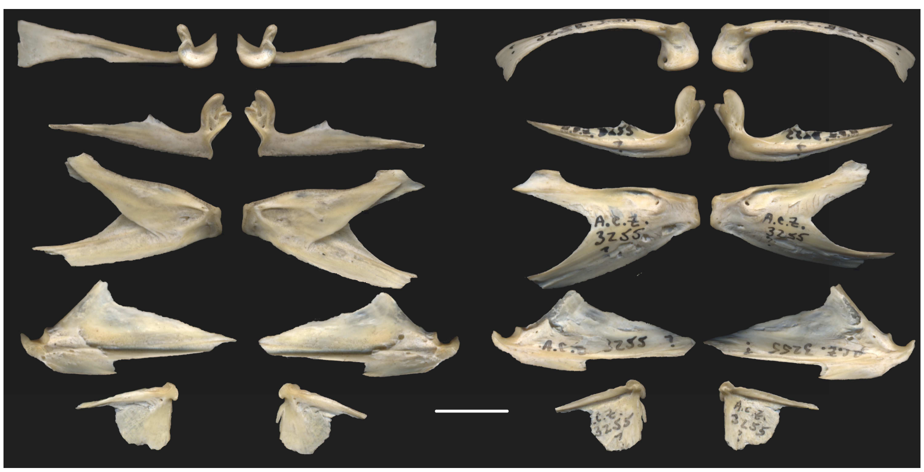

Figure 25. *Selar crumenopthalmus*, the bigeye scad, or *akule*, ACZ-3255. Original locality unknown; purchased in Kāne‘ohe, O‘ahu supermarket. Scale bar = 1 cm.

3.3.13 Chaetodontidae

Chaetodon miliaris (figs. 29 and 30) grows to a length of about 16 cm and feeds mainly on zooplankton (Randall 1985:26). It is diurnal and usually found on shallow water

Figure 26. *Caranx ignobilis*, the crevally, or *pāʻūʻū*, ACZ-3149. Original locality unknown; received from Waikīkī Aquarium, Honolulu, Oʻahu. Scale bar = 1 cm.

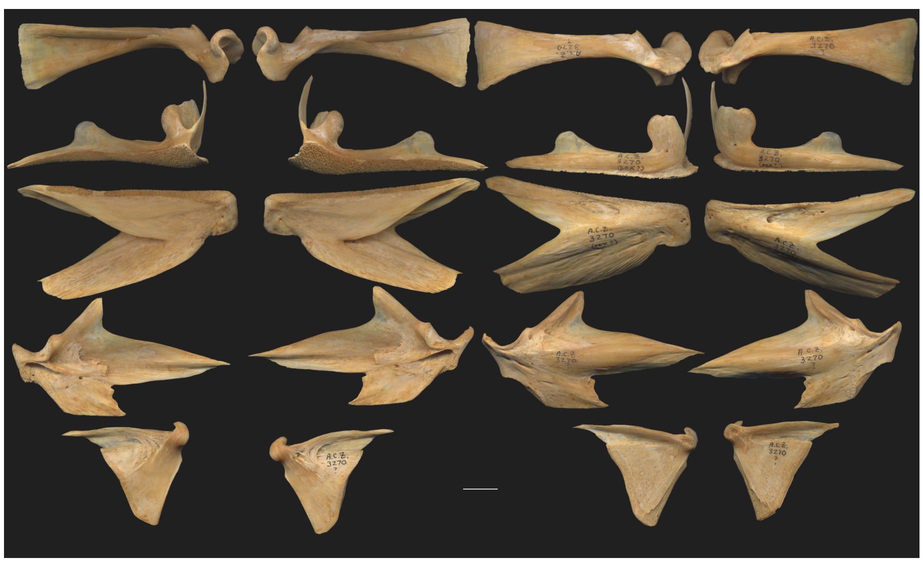

Figure 27. *Seriola* cf. *dumerili*, the greater amberjack, or *kāhala*, ACZ-3270. Scale bar = 1 cm.

reefs (Randall 1985:25). Known in Hawaiʻi as *lau wiliwili*, it has relatively little value

Figure 28. Cf. *Tilapia* sp., the tilapia, ACZ-3321. Original locality unknown; purchased in Honolulu, Oʻahu fish market. Scale bar = 1 cm.

as a food fish and is “[e]aten when better cannot be had” (Titcomb 1972:98).

Forcipiger sp. (fig. 31) is a reef fish that grows to a length of 18–22 cm on a primarily carnivorous diet of worms, small crustaceans, sea urchins, and fish eggs (Randall 1996:105–106). It has limited value as a food fish.

3.3.14 Chanidae

Chanos chanos (fig. 32) is found in bays, inlets, and the mouths of harbors, usually near the surface but occasionally deeper. It grows to a length of about 1.5 m on a vegetarian diet primarily of seaweed (Hosaka 1973:74). Known in Hawaiʻi as *awa*, it was a favorite food fish, grown in fishponds. Chiefs would reserve the fish for themselves if they were in short supply (Titcomb 1972:70).

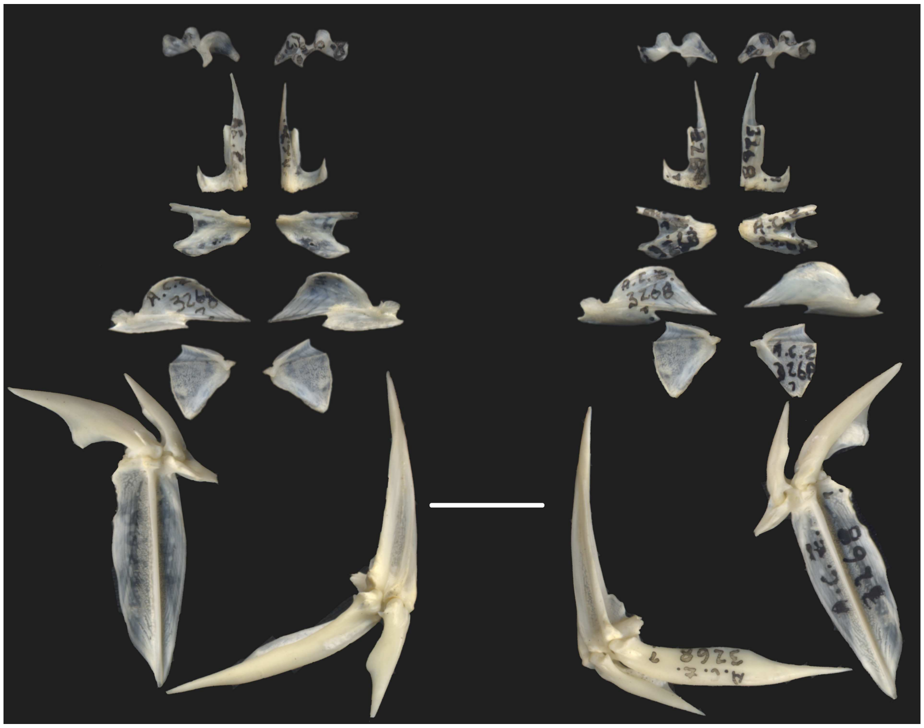

Figure 29. *Chaetodon miliaris*, the milletseed butterflyfish, or *lau wiliwili*, ACZ-3268. Original locality unknown; purchased in Honolulu, Oʻahu fish market. *Bottom*, dorsal and anal fin pterygiophores and spines. Scale bar = 1 cm.

3.3.15 Cheilodactylidae

Goniistius vittatus[12] (fig. 33) is a relatively deep water fish, not usually seen at depths less than about 20 m. It has a carnivorous diet of small invertebrates (Randall 1985:19). It grows to a length of about 40 cm. In Hawaiʻi it is known as *kikākapu*, a name also given to several of the butterflyfishes, with which it appears to have been classified. *Kikākapu* in general were not regarded as good eating because they have so little flesh (Titcomb 1972:88-90).

3.3.16 Cirrhitidae

Cirrhitus pinnulatus (fig. 34) is a bottom-dweller found on hard substrates in the surge zone (Randall 1985:19). It grows to a length of about 28 cm on a carnivorous diet primarily of crabs. Known in Hawaiʻi as *poʻopaʻa*, it is easily caught with a hook and

[12] Ziegler identified this specimen as *Cheilodactylus vittatus*. The name has changed since Ziegler's identification.

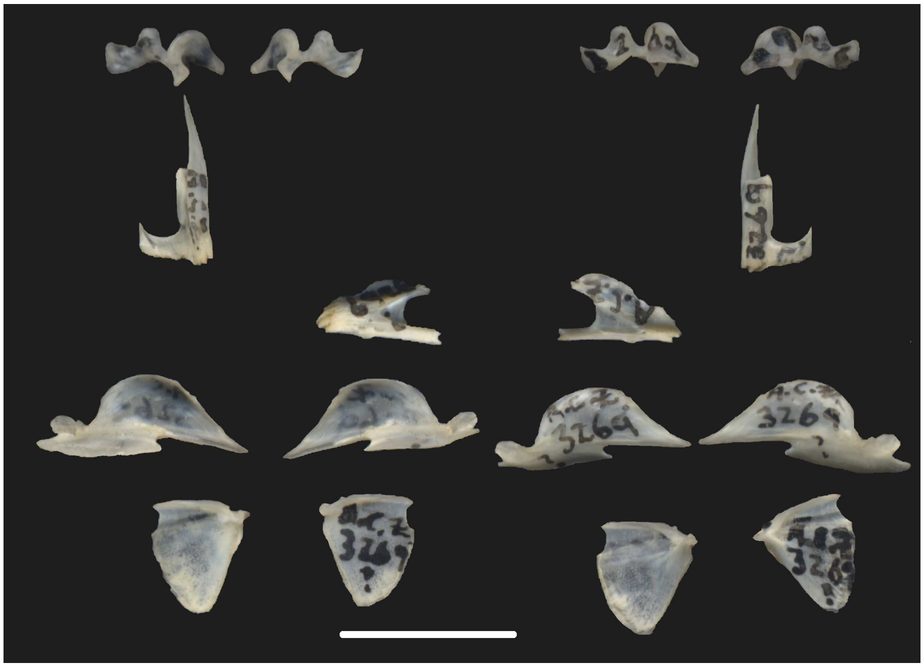

Figure 30. *Chaetodon miliaris*, the milletseed butterflyfish, or *lau wiliwili*, ACZ-3269. Original locality unknown; purchased in Honolulu, Oʻahu fish market. Scale bar = 1 cm.

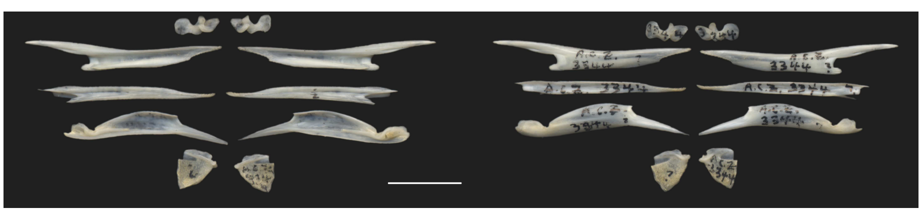

Figure 31. *Forcipiger* sp., a butterflyfish, or *lau wiliwili nukunuku ʻoiʻoi*, ACZ-3344. Original locality unknown; received from Kāneʻohe, Oʻahu aquarium fish store. Scale bar = 1 cm.

line (Hosaka 1973:133). Although its reputation as a food fish is mixed, it is eaten raw, broiled, or salted and dried (Titcomb 1972:142).

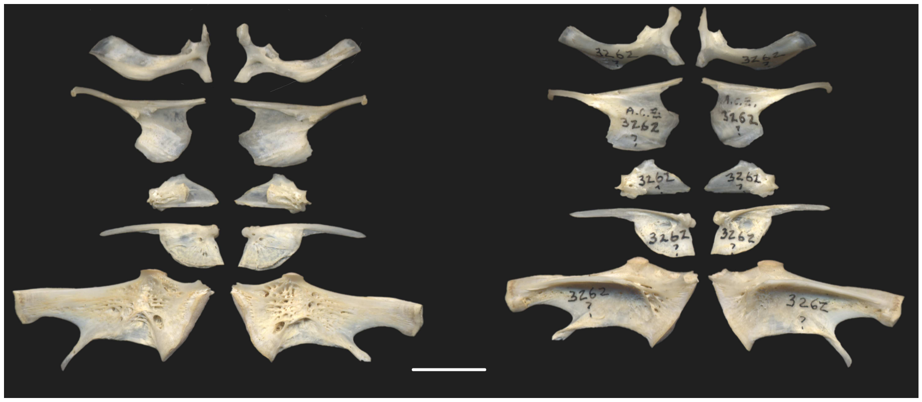

Figure 32. *Chanos chanos*, the milkfish, or *awa*, ACZ-3262. Original locality unknown; purchased in Honolulu, O‘ahu fish market. Scale bar = 1 cm.

Figure 33. *Goniistius vittatus*, the Hawaiian morwong, or *kīkākapu*, ACZ-3264. Original locality unknown; purchased in Honolulu, O‘ahu fish market. Scale bar = 1 cm.

Figure 34. *Cirrhitus pinnulatus*, the stocky hawkfish, or *po'opa'a*, ACZ-3145. Original locality unknown; received from Waikiki Aquarium, Honolulu, O'ahu. Scale bar = 1 cm.

3.3.17 Congridae

Conger cinereus marginatus[13] (fig. 35) is a nocturnal reef-dweller that grows to a length of 1.15 m on a carnivorous diet of fish, shrimps, and crabs (Randall 1985:6). Known as *puhi ūhā* in Hawai'i, it is caught with a hook and line, or with a hand net or a spear while torch fishing at night (Hosaka 1973:77). It is considered a good food fish.

3.3.18 Coryphaenidae

There are two Hawaiian species of the genus *Coryphaena* (fig. 36) in Hawai'i. Both are open-water fish that have a carnivorous diet of smaller fishes. The more common of the two species is *C. hippurus*, which grows to a length of at least 1.5–2 m; *C. equisetis* reaches a length of about 75 cm. They are taken by hook and line, typically while trolling (Gosline and Brock 1960:181). *Mahimahi* are not eaten raw; slices are broiled over coals or the fish is dried and then cooked (Titcomb 1972:100).

3.3.19 Diodontidae

Diodon holocanthus (fig. 37) grows to a length of about 38 cm on a carnivorous diet of gastropods, echinoids, and crabs, which it crushes with its strong beak-like jaws (Randall 1985:65–66). It is found primarily around coral reefs. Known in Hawai'i

[13] Ziegler identified this specimen only to species; the Hawaiian representative is an endemic subspecies.

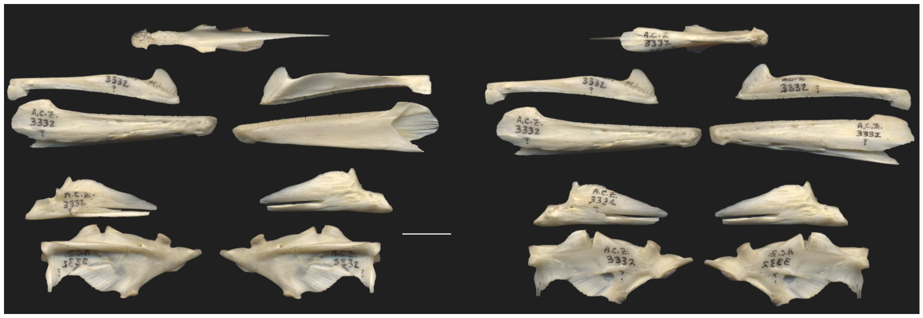

Figure 35. *Conger cinereus marginatus*, the mustache conger, or *puhi ūhā*, ACZ-3332. Hilo, Hawai‘i harbor. *Top*, premaxillo-ethmo-vomer; *bottom*, articulated quadrate and hyomandibular. Scale bar = 1 cm.

Figure 36. *Coryphaena* sp., the dolphin, or *mahimahi*, ACZ-3308. Original locality unknown; purchased at Honolulu, O‘ahu fish market. Scale bar = 1 cm.

as *‘o‘opu okala* or *kōkala* it is often regarded as poisonous. The fish is an *‘aumakua* associated with the sea god, Kāne ko kala (Titcomb 1972:91).

3.3.20 Elopidae

Elops hawaiensis (fig. 38) is found in small schools along sandy shores and in brackish areas and fishponds. It grows to a length of up to 1.05 m on a carnivorous diet of small fish and crustaceans (Randall 1996:26). Known in Hawai‘i as *awa‘aua*, the fish is caught with a hook and line (Hosaka 1973:72) or in nets (Titcomb 1972:70). Its soft flesh can be dry and bony, but when raised in a fishpond it takes on better eating qualities. It is eaten raw (Titcomb 1972:70).

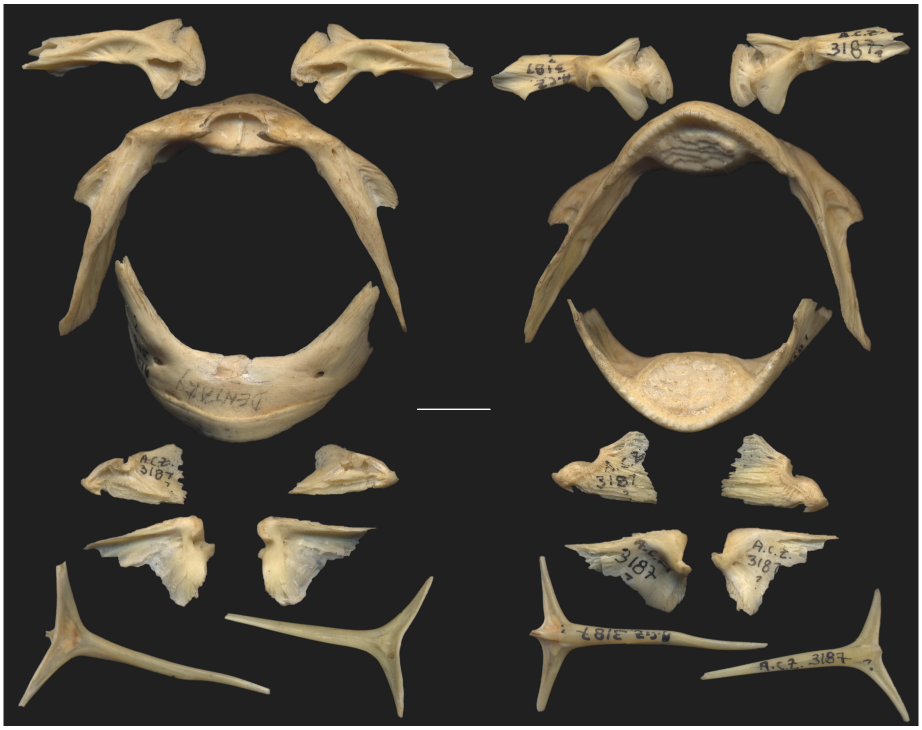

Figure 37. *Diodon* cf. *holocanthus*, the spiny puffer, or *‘o‘opu okala*, ACZ-3187. Original locality unknown; discarded by Bishop Museum, Honolulu. Scale bar = 1 cm.

3.3.21 Exocoetidae

Exocoetus volitans (fig. 39) is one of the smaller species of flyingfish in the waters around Hawai‘i, reaching a length of about 25 cm (Gosline and Brock 1960:131). Known as *mālolo* in Hawai‘i, the flyingfish was caught with surround nets. It was sought after for food and eaten raw or cooked in *ti* leaves (Titcomb 1972:104).

The exocoetid specimen (fig. 40) represents an unknown member of a family that is poorly classified (Gosline and Brock 1960:130).

3.3.22 Fistulariidae

Fistularia sp. (fig. 41) grows to a length of 1.2 m on a diet that includes shrimps. It is caught with a hook and line (Gosline and Brock 1960:133). The inshore species of this genus is known in Hawai‘i as *nūnū peke* (Randall 1996:56).

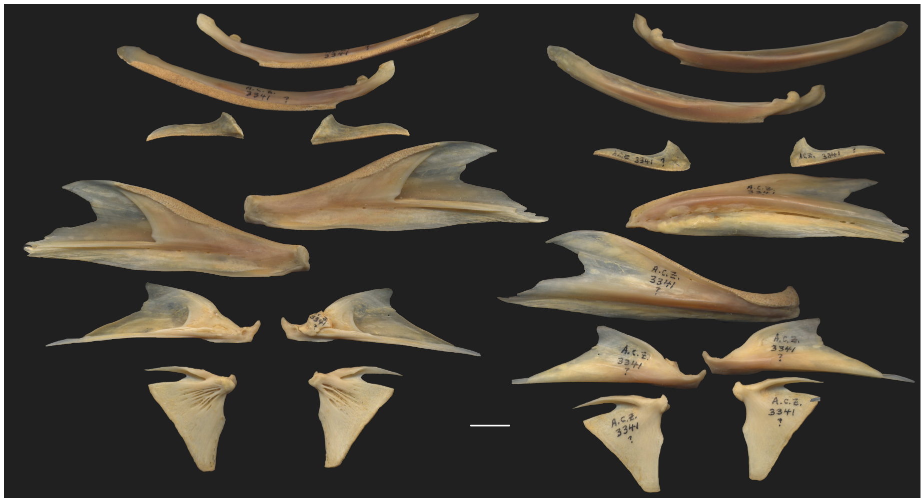

Figure 38. *Elops hawaiensis*, the Hawaiian tenpounder, or *awa‘aua*, ACZ-3341. Original locality unknown; purchased at Honolulu, O‘ahu fish market. Scale bar = 1 cm.

3.3.23 Gadidae

Theragra chalcogramma (fig. 42) is a fish of the northern ocean commercially harvested off the west coast of Canada and Alaska. It is a popular fish for fish and chips and is used to make imitation crab meat. It is not found in Hawaiian waters.

3.3.24 Holocentridae

Myripristis kuntee (fig. 43) is a small soldierfish that grows to a length of about 19 cm. Like other fish in this family, it hides in caves and holes during the day and forages for food, mainly crustaceans, at night (Randall 1985:11, 12). Known in Hawai‘i as *‘ū‘ū*, it is taken with hook and line, net, or spear (Hosaka 1973:85). It is considered an excellent food fish and is eaten raw or broiled (Titcomb 1972:158). Some *‘ū‘ū* were considered *‘aumakua* (Pukui and Elbert 1986).

The Ziegler collection contains another specimen of *Myripristis* (fig. 44) that was not identified to species.

Pristilepis oligolepis (fig. 45) is a deep-water fish (Randall 1996:49). The Hawaiian name for this fish is not known; it was likely a rare catch while fishing with a hook and line in traditional Hawaiian times.

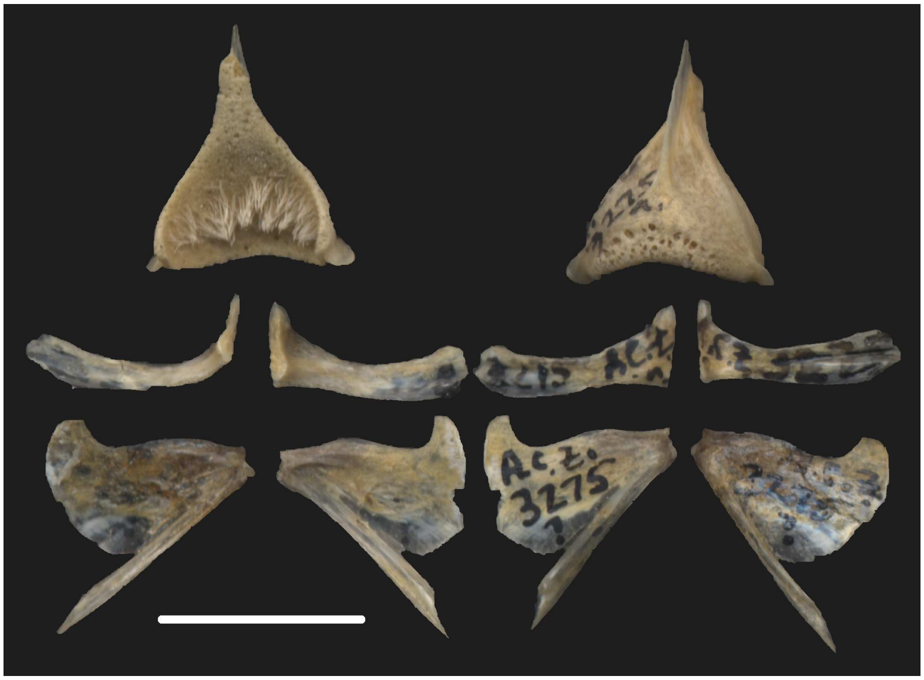

Figure 39. *Exocoetus volitans*, a flyingfish, or *mālolo*, ACZ-3275. Found dead on deck of Townsend Cromwell. *Top to bottom*: Lower pharyngeal, premaxilla, dentary. Scale bar = 1 cm.

3.3.25 Kuhliidae

Kuhlia sp.[14] (figs. 46 and 47) is a primarily nocturnal omnivore that is found in schools in marine, brackish, and freshwater environments. It grows to about 30 cm in length (Randall 1985:16). Known in Hawai‘i as *āholehole*, it is taken by hook and line and throw net (Hosaka 1973:121). It is also raised in fishponds. Considered a fine eating fish, it is eaten "raw, dried, or broiled on hot coals, also salted or *ho‘omelumelu*" (Titcomb 1972:59). The *āholehole* was considered a "sea pig" associated with the demigod Kamapua‘a (Valeri 1985:11). It was traditionally used in birth rites and is associated with the Hawaiian god, Lono (Valeri 1985:45).

3.3.26 Kyphosidae

Kyphosus sp. (fig. 48) is a shore fish that lives on rocky bottoms and coral reefs, where it grows to a length of about 60 cm on an herbivorous diet of primarily benthic algae. There are three species of *Kyphosus* in Hawai‘i (Randall 1985:22), all known as

[14] Ziegler identified these specimens as *K. sandvicensis*; the taxonomy of the genus has been revised since Ziegler's identification.

Figure 40. Exocoetid, a flyingfish, or *mālolo*, ACZ-3286. Found dead on Lisianski Island. Scale bar = 1 cm.

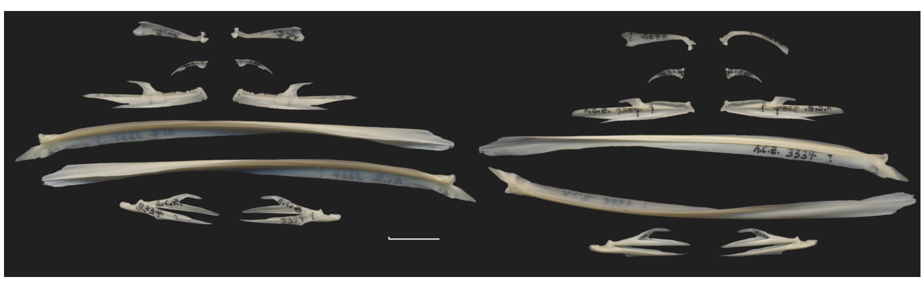

Figure 41. *Fistularia* sp., cornetfish, ACZ-3334. Collected at ‘Anini Beach, Kaua‘i. Scale bar = 1 cm.

nenue. It is occasionally caught by hook and line (Hosaka 1973:126) or in nets (Titcomb 1972:113). It has a strong odor, but is considered a delicious fish raw, or wrapped in *ti* leaves and broiled (Titcomb 1972:114).

Figure 42. *Theragra chalcogramma*, Alaskan pollack, ACZ-3318. Original locality unknown; purchased in Honolulu, Oʻahu. Scale bar = 1 cm.

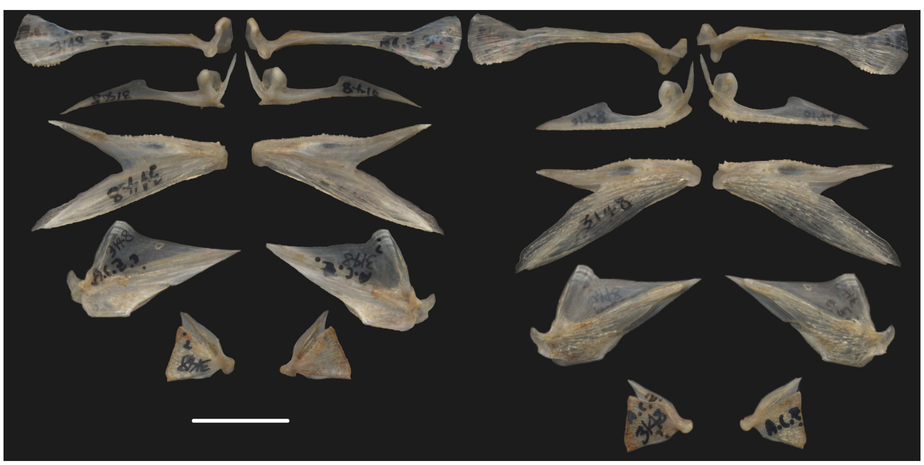

Figure 43. *Myripristis kuntee*, the shoulderbar soldierfish, or *ʻūʻū*, ACZ-3148. Original locality unknown; received from Waikiki Aquarium, Honolulu, Oʻahu. Scale bar = 1 cm.

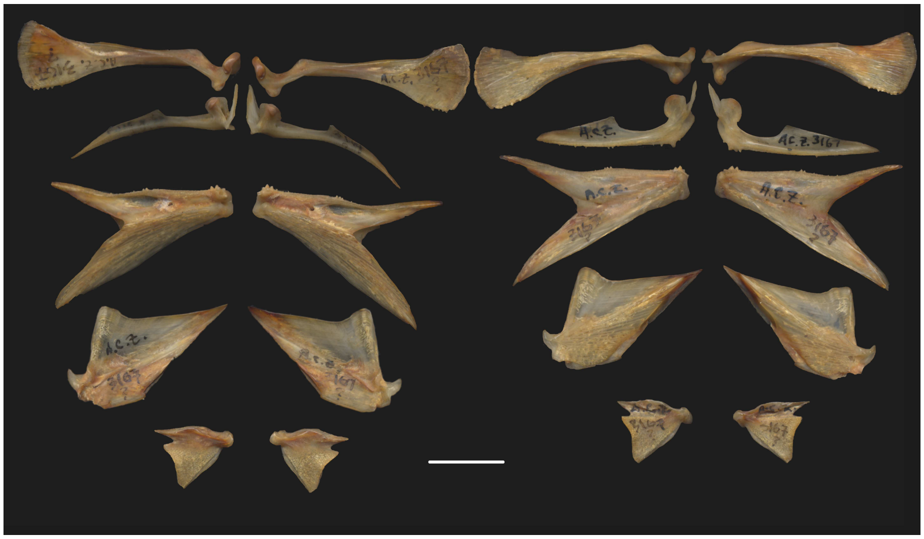

Figure 44. *Myripristis* sp., a squirrelfish, or ‘ū‘ū, ACZ-3167. Collected in the vicinity of Ka‘ena Point, O‘ahu. Scale bar = 1 cm.

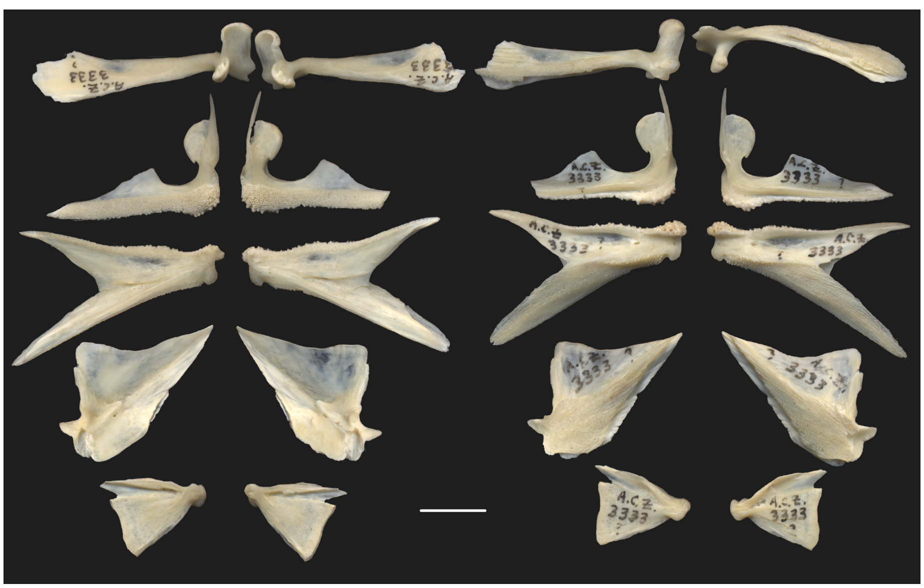

Figure 45. Cf. *Pristilepis oligolepis*, a squirrelfish, ACZ-3333. Hawai‘i Island; purchased at Honolulu, O‘ahu fish market. Scale bar = 1 cm.

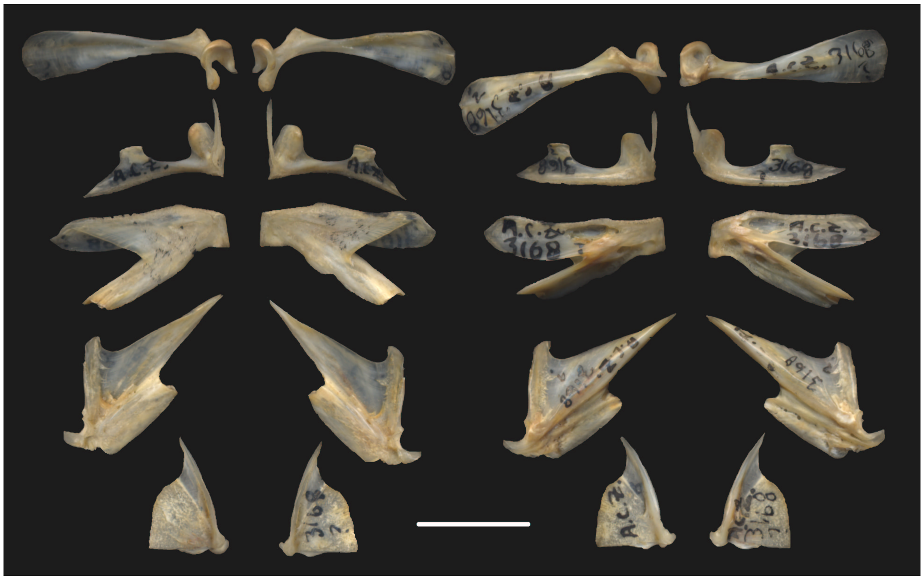

Figure 46. *Kuhlia sp.*, the Hawaiian flagtail, or *āholehole*, ACZ-3168. Collected in the vicinity of Ka‘ena Point, O‘ahu. Scale bar = 1 cm.

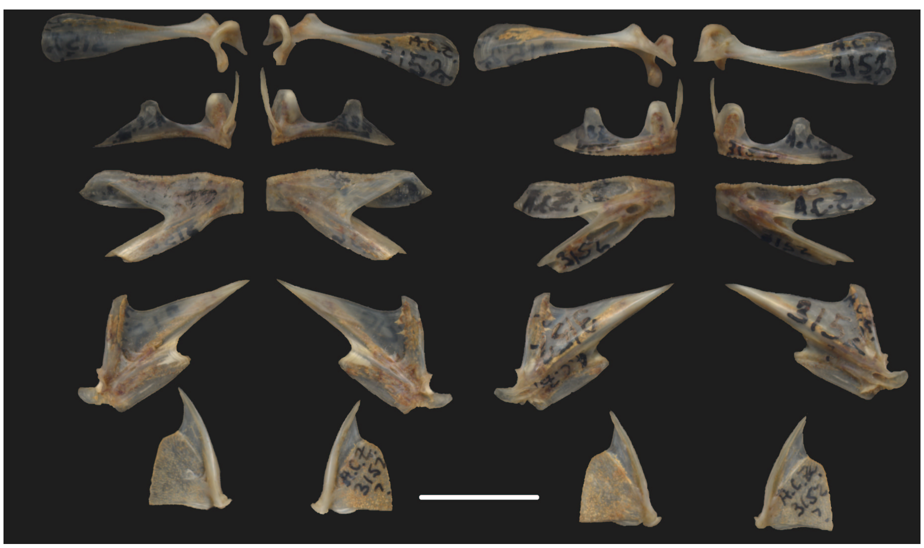

Figure 47. *Kuhlia sp.*, the Hawaiian flagtail, or *āholehole*, ACZ-3152. Original locality unknown; received from Waikiki Aquarium, Honolulu, O‘ahu. Scale bar = 1 cm.

Figure 48. *Kyphosus* sp., the rudderfish, or *nenue*, ACZ-3340. Original locality unknown; purchased at Honolulu, O‘ahu fish market. Scale bar = 1 cm.

3.3.27 Labridae

Oxycheilinus unifasciatus[15] (fig. 49) grows to a length of 46 cm on a carnivorous diet of fish, crabs, brittle stars, and urchins (Randall 1985:36). It ranges in depth from 9–161 m. Known in Hawai‘i as *po‘ou*, it is eaten raw or broiled, among other ways (Titcomb 1972:143).

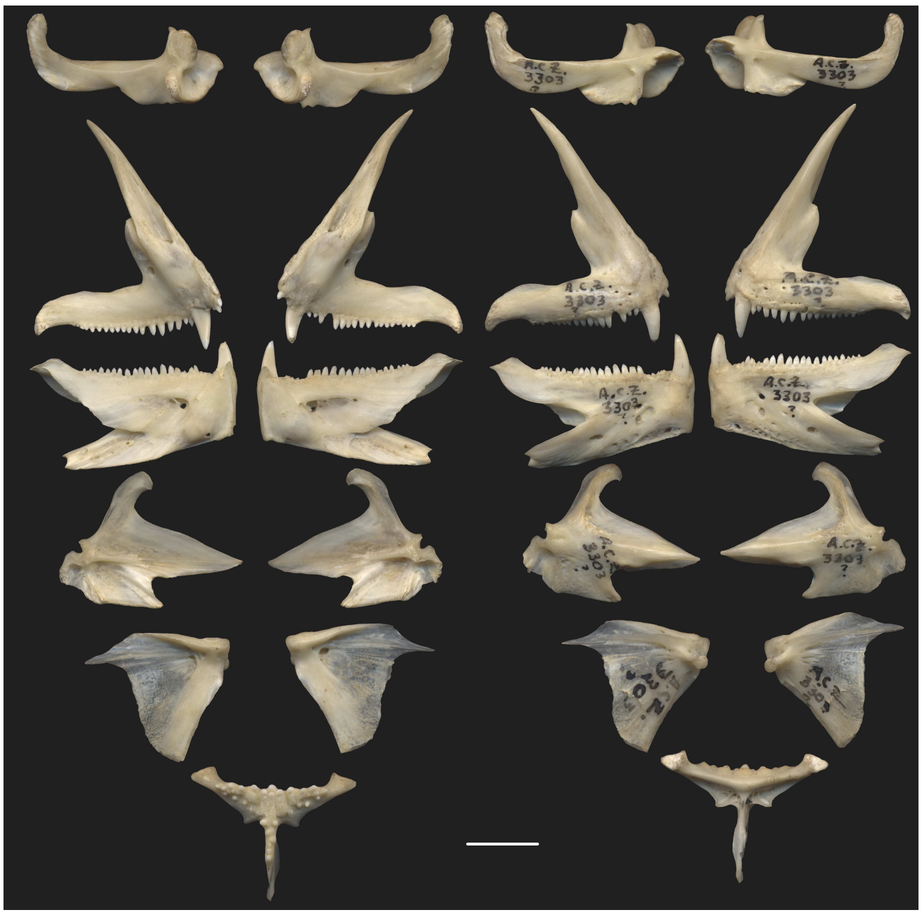

Figure 49. *Oxycheilinus unifasciatus*, the ringtail wrasse, or *po‘ou*, ACZ-3303. Original locality unknown; purchased in Kāne‘ohe, O‘ahu supermarket. *Bottom*, lower pharyngeal. Scale bar = 1 cm.

Bodianus bilunulatus (fig. 50) is found on shallow-water reefs into deeper water up to 110 m (Randall 1985:38). It grows to a length of 50 cm on a carnivorous diet of mollusks, sea urchins, and crabs. Known in Hawai‘i as *‘a‘awa*, it is usually caught on

[15] Ziegler identified this specimen as *Cheilinus unifasciatus*. The name has changed since Ziegler's identification.

a hook and line (Hosaka 1973:147). Its white flesh is eaten broiled or dried (Titcomb 1972:57).

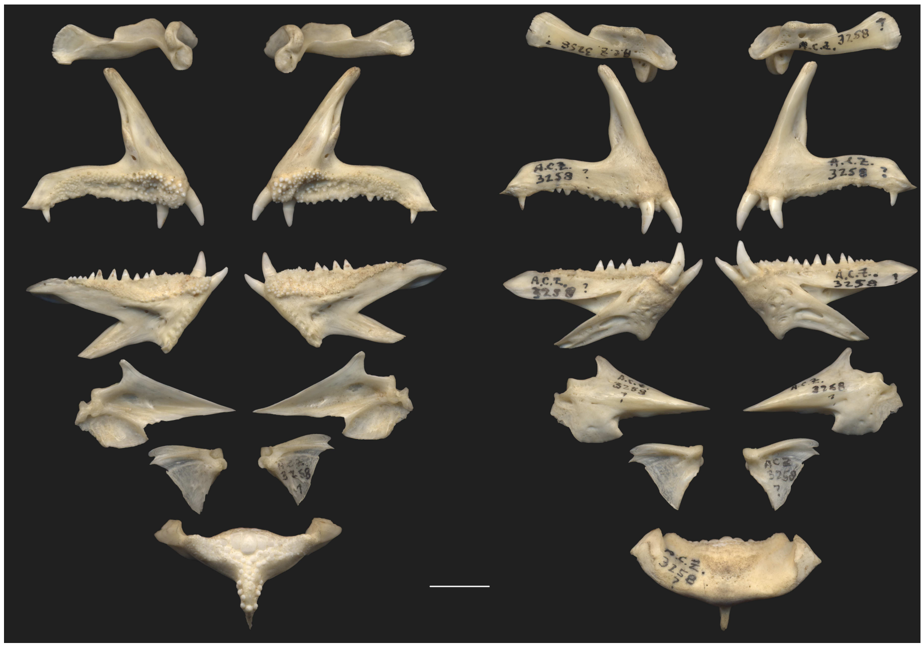

Figure 50. *Bodianus bilunulatus*, the Hawaiian hogfish, or *ʻaʻawa*, ACZ-3258. Original locality unknown; purchased in Honolulu, Oʻahu fish market. *Bottom*, lower pharyngeal. Scale bar = 1 cm.

Coris flavovittata (fig. 51) reaches 45 cm in length (Gosline and Brock 1960:229). It is found "in crevices of the reef, under large projecting *limu*-covered rocks, or asleep in the sandy bottom, completely hidden" (Titcomb 1972:75) where it feeds on sea urchins, pelecypods, gastropods, brittle stars, crabs, hermit crabs, and polychaetes (Randall 1985:39). Known in Hawaiʻi as *hilu*, it is caught in nets and eaten "raw, dried and salted, baked or broiled" (Titcomb 1972:75).

Cheilio inermis (fig. 52) is found commonly on open bottoms with rich plant growth (Randall 1985:39) and may sleep on the sand at night (Titcomb 1972:94). It reaches a length of 50 cm (Randall 1985:39). It is a carnivore, feeding on gastropods, pelecypods, crabs, sea urchins, and shrimps (Randall 1985:39). In Hawaiʻi it is known as *kuūpoupou*, and is considered "a good food fish, eaten raw or cooked in *ti* leaves" (Titcomb 1972:94).

Anampses cuvier (fig. 53) is found inshore on rocky bottoms to a depth of about 80 ft. (Randall 1985:40). A carnivore, it feeds on a variety of small invertebrates and reaches a length of about 35 cm (Randall 1985:40). Known in Hawaiʻi as *ʻōpule*, it is a "greedy feeder easily caught with a hook and line" (Hosaka 1973:148). This fish is not eaten raw, but is good for broiling and baking (Titcomb 1972:135).

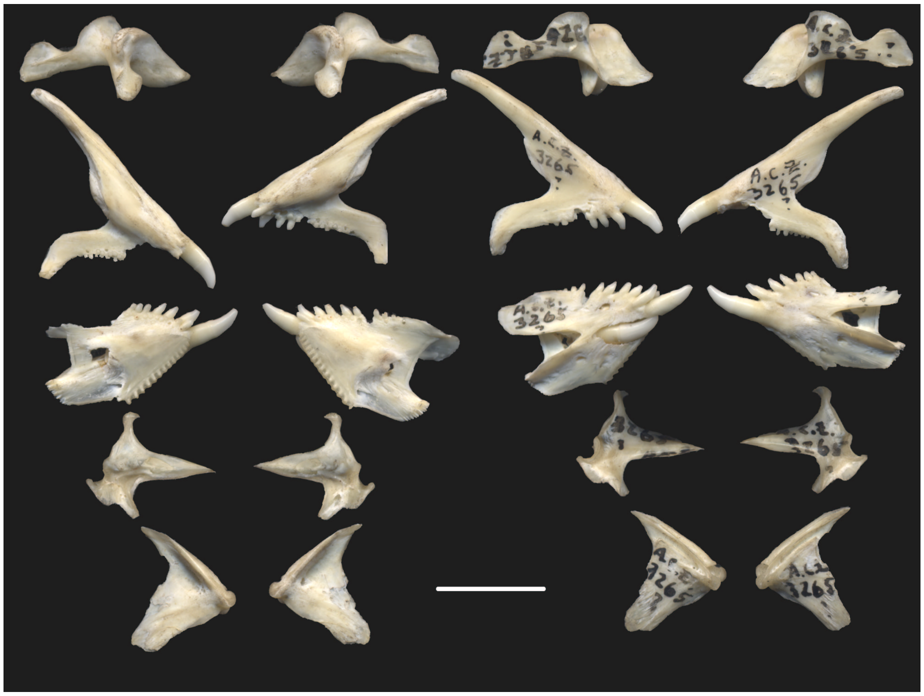

Figure 51. *Coris flavovittata*, the yellowstripe coris, or *hilu*, ACZ-3265. Original locality unknown; purchased in Honolulu, O‘ahu fish market. Scale bar = 1 cm.

Figure 52. *Cheilio inermis*, the cigar wrasse, or *kūpoupou*, ACZ-3261. Original locality unknown; purchased in Honolulu, O‘ahu fish market. Scale bar = 1 cm.

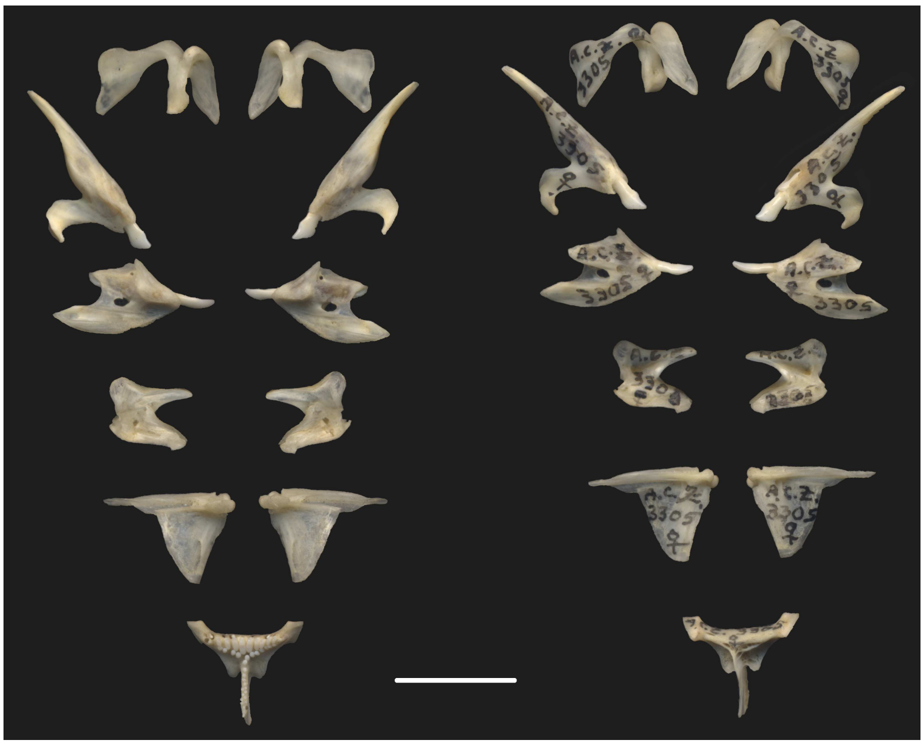

Figure 53. *Anampses cuvier*, the pearl wrasse, *ʻōpule*, ACZ-3305. Original locality unknown; purchased in Honolulu, Oʻahu fish market. *Bottom*, lower pharyngeal. Scale bar = 1 cm.

3.3.28 Lethrinidae

Monotaxis grandoculis (fig. 54) is a primarily nocturnal carnivore that feeds on mollusks, crabs, and urchins, which it crushes with its large molars. It grows to a length of 60 cm (Randall 1985:21). Known in Hawai‘i as *mū*, it is caught at night with a hook and line (Hosaka 1973:125). It is an excellent food fish that isn’t eaten raw, but is broiled or cooked in the *imu* (Titcomb 1972:112).

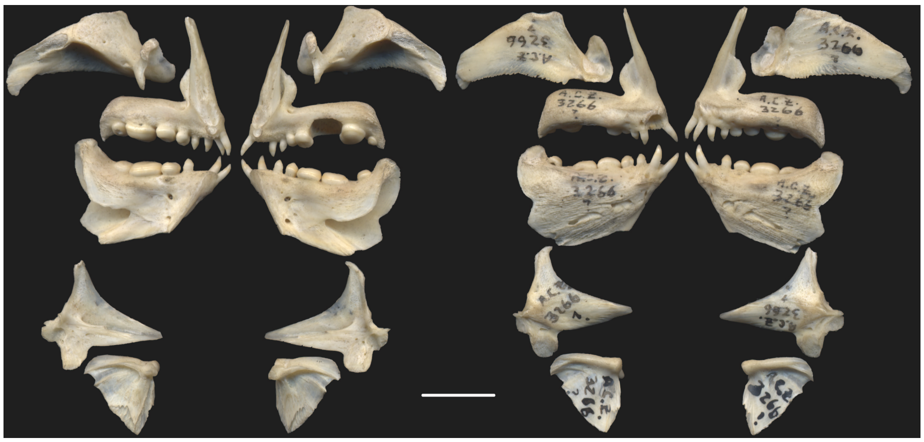

Figure 54. *Monotaxis grandoculis*, the bigeye emperor, or *mū*, ACZ-3266. Original locality unknown; purchased at Honolulu, O‘ahu fish market. Scale bar = 1 cm.

3.3.29 Lutjanidae

Aprion virescens (fig. 55) is an open-water predator that grows to a length of 1 m on a carnivorous diet of primarily reef fish (Randall 1996:86). It is found on rocky bottoms off the reef and in deep areas near shore (Hosaka 1973:123). Known in Hawai‘i as *uku*, it is caught with a hook and line.

Pristipomoides sieboldii (fig. 56) is a commercially important deep sea snapper that reaches about 60 cm in length (Gosline and Brock 1960:186). It is taken by hook and line. One of about four species known in Hawai‘i as *‘ōpakapaka* (Pukui and Elbert 1986), *P. sieboldii* was eaten raw, dried, or cooked, but appears not to have been particularly prized in traditional Hawai‘i, as it is in restaurants today (Titcomb 1972:133).

Etelis carbunculus (fig. 57) is a commercially important bottomfish that grows to a length of 90 cm (Gosline and Brock 1960:186). It is taken with a hook and line. Known in Hawai‘i as *‘ula‘ula*, it is considered a delicious fish eaten raw, dried, or broiled. “It was sometimes used in sacrifice when a red fish was required” (Titcomb 1972:152).

Lutjanus kasmira (fig. 58) is a shallow-water snapper that grows to a typical length of 25 cm on a carnivorous diet of crustaceans and small fish. Known in Hawai‘i by its Tahitian name, *ta‘ape*, this fish was introduced to Hawaiian waters in 1956 (Randall 1985:21).

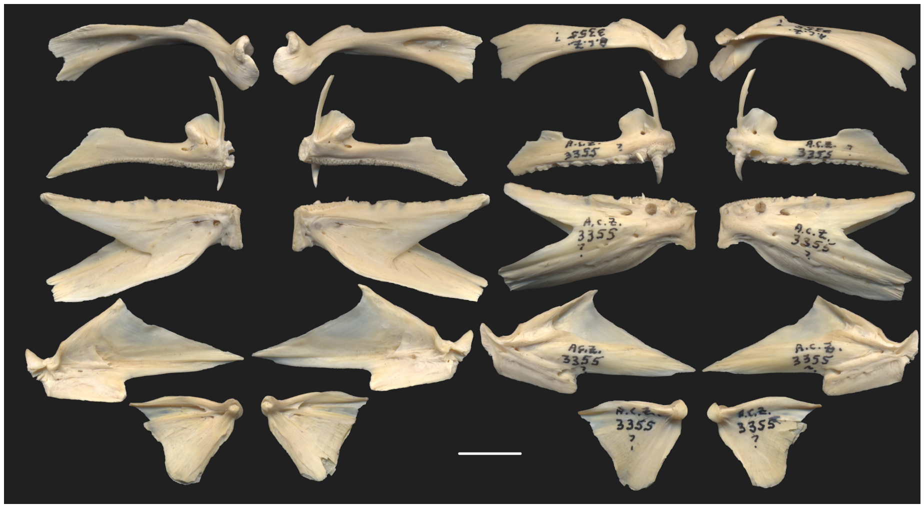

Figure 55. *Aprion virescens*, the green jobfish, or *uku*, ACZ-3355. Original locality unknown; purchased at Honolulu, Oʻahu fish market. Scale bar = 1 cm.

3.3.30 Monacanthidae

Pervagor spilosoma (fig. 59) grows to a length of about 18 cm on an omnivorous diet of algae and benthic invertebrates (Randall 1996:192). Its abundance varies considerably; some years it washes ashore dead in great numbers and others it is scarce. Known in Hawaiʻi as *ʻōʻili ʻuwīʻuwī*, it is eaten by some people and not by others. Its appearance in great numbers was believed to prophesy the death of a great person or chief. It was used in "idol worship" in traditional Hawaiian times (Titcomb 1972:119).

3.3.31 Mugilidae

Mugil cephalus (fig. 60) is found along open coasts and in areas of brackish water, where it reaches a length of 45 cm. It is an herbivore that grazes on diatoms and other plants dredged from the bottom (Gosline and Brock 1960:154). Known in Hawaiʻi as *ʻamaʻama* or *ʻanae*, it is caught with a hook and line, throw net, and surround net (Hosaka 1973:87). It was the primary fish grown in fishponds and is raised commercially in this way today. It is highly prized for food, eaten either raw, broiled, or baked in a wrapping of *ti* or ginger leaves (Titcomb 1972:64). The *ʻamaʻama* was traditionally used in birth rites and is associated with the Hawaiian god, Lono (Valeri 1985:45).

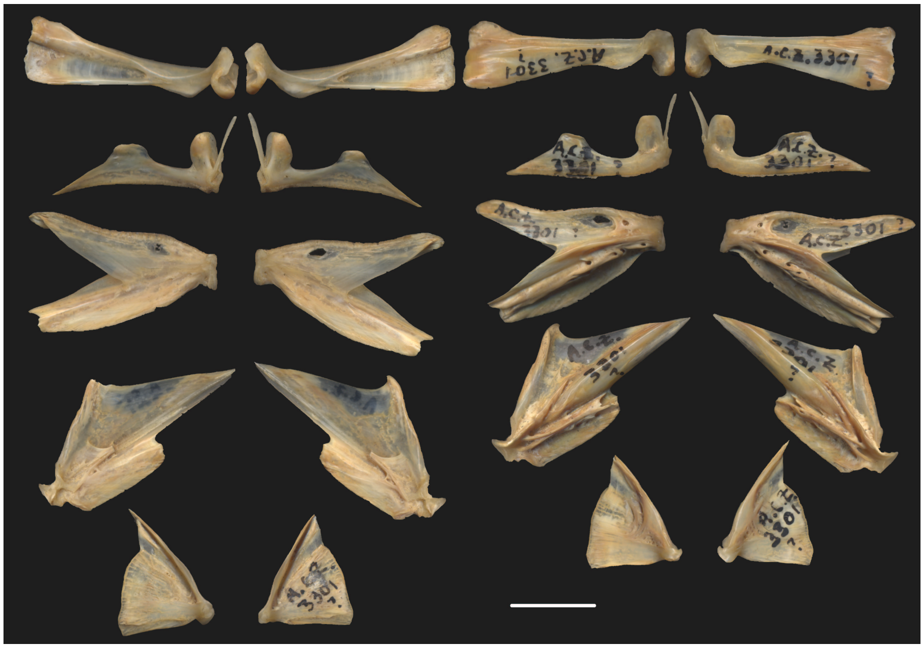

Figure 56. *Pristipomoides sieboldii*, the *ʻōpakapaka*, ACZ-3301. Original locality unknown; purchased in Kāneʻohe, Oʻahu supermarket. Scale bar = 1 cm.

Figure 57. *Etelis* cf. *carbunculus*, the red snapper, or *ʻulaʻula*, ACZ-3310. Original locality unknown; purchased in Kāneʻohe, Oʻahu supermarket. Scale bar = 1 cm.

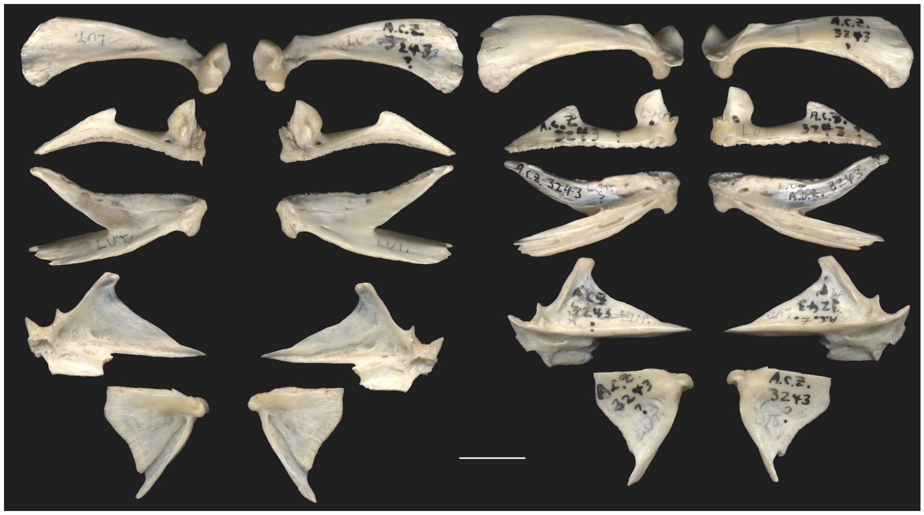

Figure 58. *Lutjanus kasmira*, the bluestripe snapper, or *ta'ape*, ACZ-3243. Original locality unknown; purchased in Kāne'ohe, O'ahu supermarket. Scale bar = 1 cm.

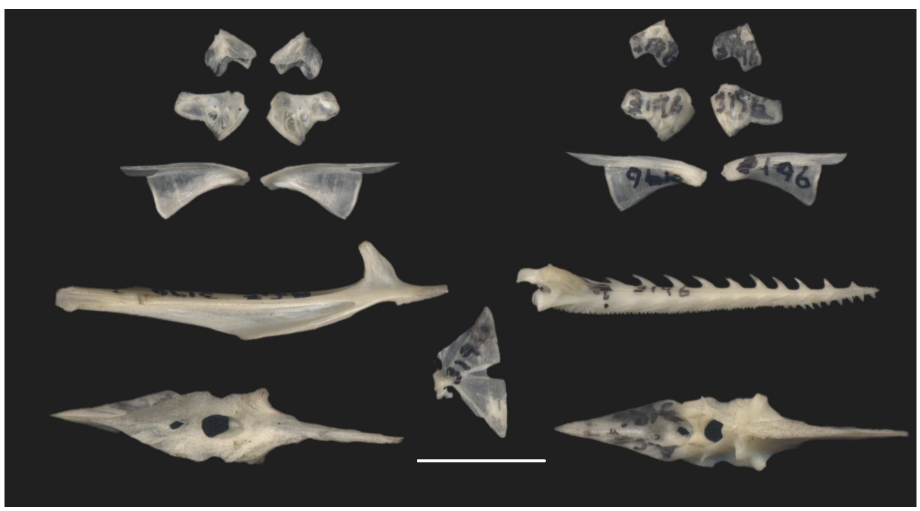

Figure 59. *Pervagor spilosoma*, the fantail filefish, or *'ō'ili 'uwī'uwī*, ACZ-3196. Kailua Bay, O'ahu; found dead on beach. *Top to bottom*: dentary, premaxilla, quadrate, pelvis (*left*), dorsal fin spine (*right*), terminal vertebra (*middle*), pterygial carina. Scale bar = 1 cm.

Figure 60. *Mugil cephalus*, the striped mullet, or *‘ama‘ama*, ACZ-3361. Collected at Punalu‘u, O‘ahu. Scale bar = 1 cm.

3.3.32 Mullidae

Mulloidichthys vanicolensis[16] (fig. 61) aggregates at specific places on the reef by day but forages individually at night (Gosline and Brock 1960:191). It grows to a length of about 38 cm (Randall 1985:23). It is a carnivore that feeds on shrimp, crabs, and shellfish. Known in Hawai‘i as *weke ‘ula*, it is caught today with a hook and line or at night with a scoop net on the reef (Hosaka 1973:127). It is considered the best eating fish among the goatfishes, and is often broiled in a *ti* leaf wrapping (Titcomb 1972:160).

Parupeneus multifasciatus (fig. 62) ranges from the nearshore to depths up to 450 ft. It grows to a length of about 28 cm on a diet of primarily crabs and shrimps (Randall 1985:24). Known in Hawai‘i as *moano*, it is caught by hook and line during the day, or in surround nets or traps (Hosaka 1973:128). It is eaten raw or broiled in *ti* leaves (Titcomb 1972:110).

3.3.33 Muraenidae

Gymnothorax flavimarginatus (fig. 63) is a large, bold eel that grows to a length of 1.2 m (Randall 1985:7–8). It lives in moderately deep rocky areas near shore where it eats fish, octopi, and crabs (Hosaka 1973:77–78). Known as *puhi paka* in Hawai‘i, it is easily caught with a hook and line. These eels have an oily flesh that is highly prized as food (Titcomb 1972:146).

[16] Ziegler identified this specimen as *Mulloides vanicolensis*; taxonomic revisions since that time have changed the name of the genus.

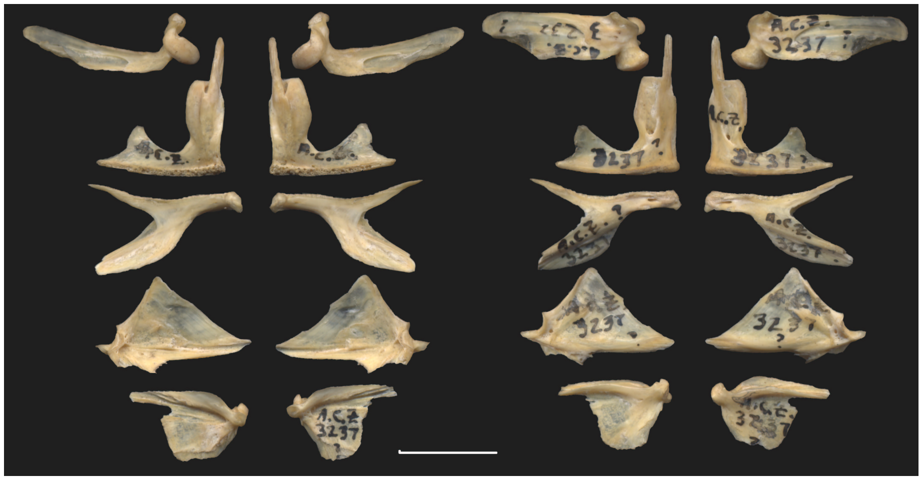

Figure 61. *Mulloidichthys vanicolensis*, the yellowfin goatfish, or *weke ʻula*, ACZ-3237. Original locality unknown; purchased in Kāneʻohe, Oʻahu supermarket. Scale bar = 1 cm.

Figure 62. *Parupeneus multifasciatus*, the manybar goatfish, or *moano*, ACZ-3256. Original locality unknown; purchased at Honolulu, Oʻahu fish market. Scale bar = 1 cm.

Figure 63. *Gymnothorax flavimarginatus*, the yellowmargin moray, or *puhi paka*, ACZ-3194. Collected at Kaunolū Bay, Lānaʻi. *Top, middle*, premaxillo-ethmo-vomer. Scale bar = 1 cm.

3.3.34 Ostraciidae

Ostracion meleagris (fig. 64) lives in shallow water, where it grows to a length of about 16 cm (Randall 1996:192 ff.). Known in Hawaiʻi as *moa*, a general name for members of this family, it was not eaten by Hawaiians and is sometimes poisonous (Titcomb 1972:136).

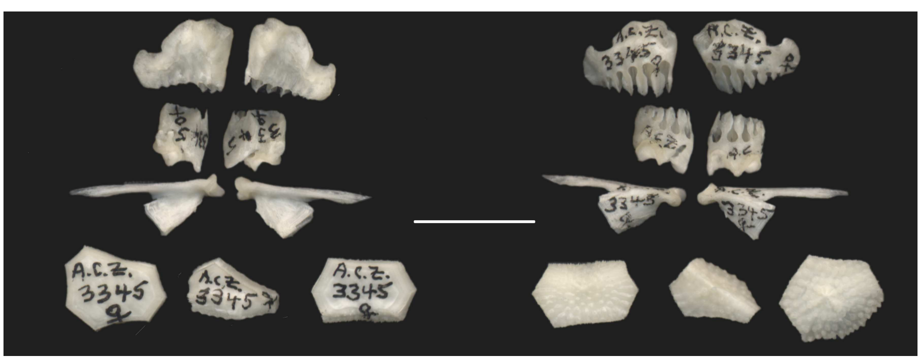

Figure 64. *Ostracion meleagris*, the spotted boxfish, or *moa*, ACZ-3345. Original locality unknown; received from Kāneʻohe, Oʻahu aquarium fish store. *Top to bottom:* premaxilla, dentary, quadrate, armor plates. Scale bar = 1 cm.

3.3.35 Pangasiidae

Pangasius sp. (fig. 65) is a shark catfish not found naturally in Hawai‘i.

Figure 65. *Pangasius* sp., a shark catfish, ACZ-3354. Locality unknown, but probably Southeast Asia; illegally brought to Hawai‘i for aquacultural purposes. *Top left*, parasphenoid; *top right*, vomer; *second row*, palatine. Scale bar = 1 cm.

3.3.36 Pleuronectidae

There are two species of righteye flounders of the Samaridae family (once thought to be a subfamily of the Pleuronectidae) in Hawai‘i. All of them are small, about 13 cm long. No Hawaiian name is known. The single specimen in Ziegler's collection (fig. 66) did not derive from Hawai‘i and was not identified to genus or species.

3.3.37 Polynemidae

Polydactylus sexfilis (fig. 67) is found in schools along sandy shores and at sandy holes in rocky shores, where it reaches a length of 45 cm (Hosaka 1973:91). It feeds both day and night on crabs and shrimp (Hosaka 1973:92). Known in Hawai‘i as *moi*, it is caught with a hook and line and with nets (Hosaka 1973:92). *Moi* is a delicious food fish and was reportedly reserved for chiefs, the commoners prohibited from eating it (Titcomb 1972:111). It is eaten raw, salted, dried, or cooked in *ti* leaves or in the *imu* (Titcomb 1972:111). In traditional Hawaiian times, their appearance in large numbers was an omen of disaster to the chiefs (Titcomb 1972:111).

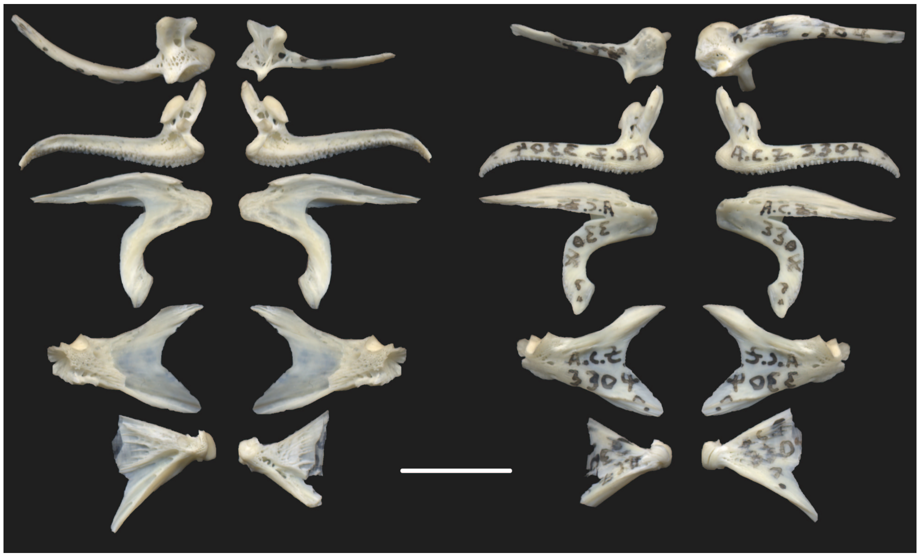

Figure 66. A righteye flounder in the Pleuronectidae family. Original locality "New Zealand"; purchased in Kāneʻohe, Oʻahu supermarket. Scale bar = 1 cm.

Figure 67. *Polydactylus sexfilis*, the six-fingered threadfin, or *moi*, ACZ-3251. Original locality unknown; purchased in Kāneʻohe, Oʻahu supermarket. Scale bar = 1 cm.

3.3.38 Pomacentridae

Abudefduf abdominalis (fig. 68) lives in protected waters, where it grows to a length of about 25 cm on an omnivorous diet of zooplankton and algae (Randall 1985:32). It is often seen in large schools feeding near the bottom. Known in Hawaiʻi as *mamo* or *maʻomaʻo*, it is caught on a hook and line, often with the aid of chum (Hosaka

1973:144, 145). It is a good food fish and a favorite of Hawaiian chiefs; "for softness, *ma'oma'o* was best, good to eat raw or broiled" (Titcomb 1972:104).

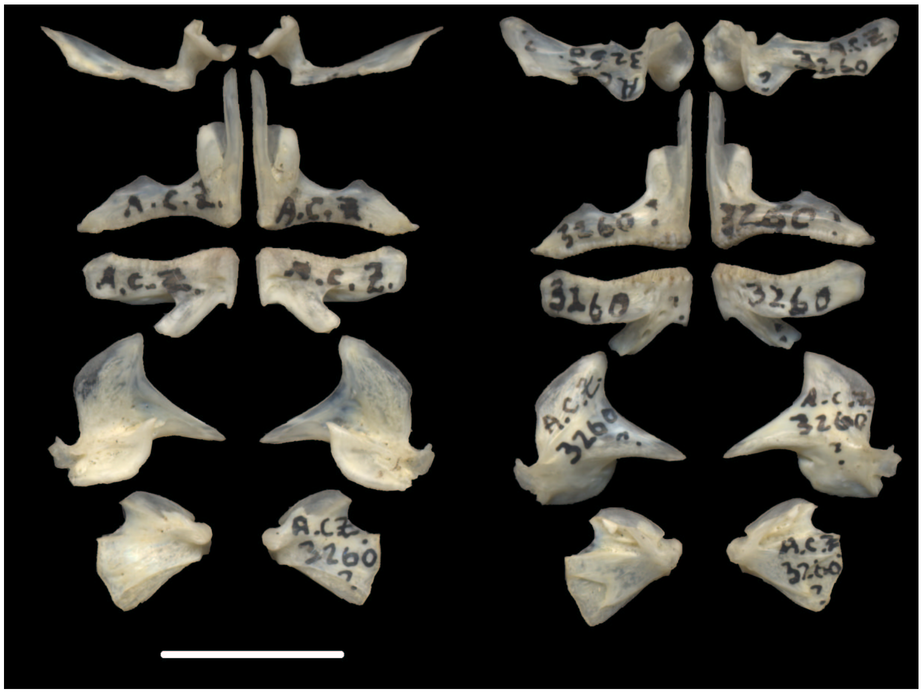

Figure 68. *Abudefduf abdominalis*, the Hawaiian sergeant, or *mamo*, ACZ-3260. Collected at Punalu'u, O'ahu. Scale bar = 1 cm.

Chromis verater (fig. 69) is a relatively deep water fish found most commonly at depths greater than 20 m. It grows to a length of about 20 cm (Randall 1985:34). The Hawaiian name for this fish isn't known.

3.3.39 Priacanthidae

Heteropriacanthus cruentatus[17] (fig. 70) is active at night and is generally found in caves or other holes by day (Hosaka 1973:122). It grows to a length of about 30 cm on a carnivorous diet composed principally of the larger elements of the zooplankton (Randall 1985:17). Known in Hawai'i as *'āweoweo*, it is taken by spear during the day and hook and line at night (Hosaka 1973:122). The white flesh is good when broiled or dried, but is only sometimes eaten raw (Titcomb 1972:71). It sometimes appears in large schools, which in traditional times were thought to portend the death of a chief (Titcomb 1972:71).

[17] Ziegler identified this specimen as *Priacanthus cruentatus*; the taxonomy has changed since Ziegler's identification.

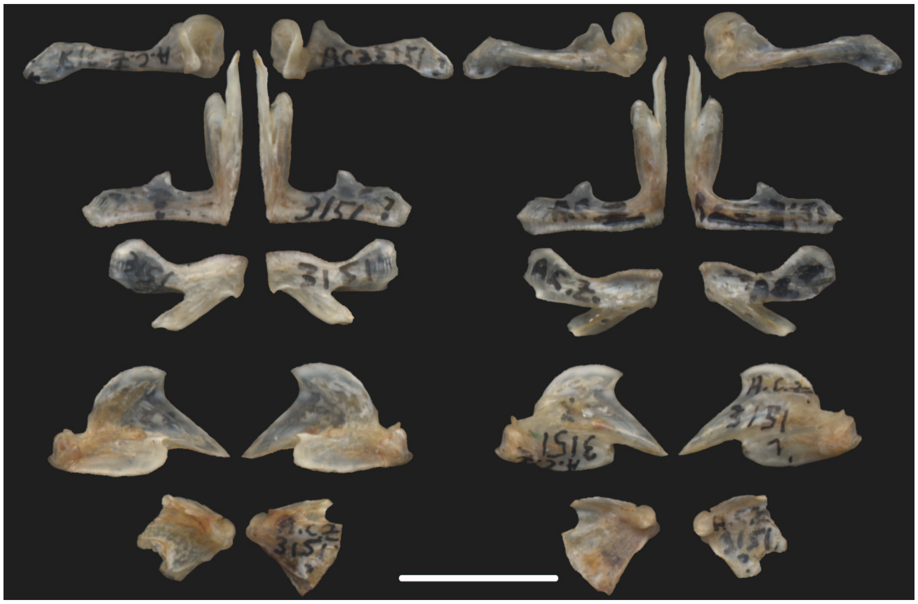

Figure 69. *Chromis verater*, the threespot chromis, ACZ-3151. Original locality unknown; received from Waikiki Aquarium, Honolulu, Oʻahu. Scale bar = 1 cm.

3.3.40 Scaridae

There are seven species of the family Scaridae (fig. 71) recognized in the Hawaiian Islands (Randall 1996). They all feed on an herbivorous diet of algae, which they generally graze from rock surfaces with their prominent dental plates. The pharyngeal plates of these fishes are used to grind coral, and they are believed to be responsible for creating much of the sand found today on beaches. They grow to lengths of 30–70 cm. Known by several names in Hawaiʻi, perhaps most commonly as *uhu*, they are caught with a spear or in nets and only rarely with a hook and line (Hosaka 1973:153). They are a fine eating fish and were preferred raw but also eaten dried or broiled. The liver is thought to be especially delicious (Titcomb 1972:148). The *uhu* figures prominently in Hawaiian legends (Titcomb 1972:149–150).

3.3.41 Scombridae

Katsuwonus pelamis (fig. 72) is a pelagic fish that grows to a length of 1 m. It is a carnivore that travels in large schools feeding on fish and squid (Gosline and Brock 1960:257–258). They come close to shore in Hawaiʻi during the summer months (Hosaka 1973:94). Known in Hawaiʻi as *aku*, they are taken with a barbless hook, often in great numbers. An important food fish, the *aku* is eaten raw, dried, or broiled; the eyeballs are considered especially good eating (Titcomb 1972:61). The *aku* was an important fish in traditional Hawaiian religion. It was *kapu* to fish for them in the

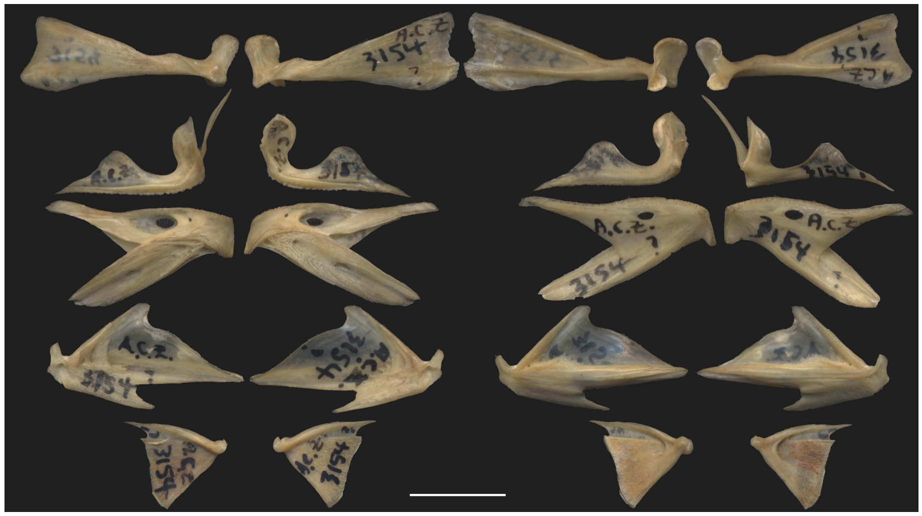

Figure 70. *Heteropriacanthus cruentatus*, the glasseye, or *ʻāweoweo*, ACZ-3154. Original locality unknown; received from Waikiki Aquarium, Honolulu, Oʻahu. Scale bar = 1 cm.

summer months when the *ʻōpelu* were in season (Valeri 1985:199). With the *ʻōpelu* it was an *ʻaumakua* of the descendants of Paʻao (Valeri 1985:28). Kahōaliʻi, the king's "divine double" (Valeri 1985:260), eats the eye of both an *aku* and a human victim during New Year's rites (Valeri 1985:228).

3.3.42 Scorpaenidae

Scorpaenopsis cacopsis (fig. 73) is a nocturnal bottom-dweller that ranges from 5–60+ m. It grows to a length of 50 cm on a carnivorous diet of fishes (Randall 1985:14). Known in Hawaiʻi as *nohu* it is most usually caught with a spear but sometimes with a hook and line (Hosaka 1973:143). It is a good eating fish that is always cooked (Titcomb 1972:116).

3.3.43 Serranidae

Caprodon schlegelii (fig. 74) is a grouper about 40 cm long occasionally taken by hook and line in about 150 m of water (Gosline and Brock 1960:157). It is not known if this fish has a Hawaiian name.

Epinephelus quernus (fig. 75) is a bottom-dweller that grows to a length of 90 cm (Gosline and Brock 1960:157). It is a deep water fish found at depths of 275–365 m (Titcomb 1972:73) caught with a hook and line. Known in Hawaiʻi as *hāpuʻu*, or *hāpuʻupuʻu* when young, it is eaten any way except raw (Titcomb 1972:73).

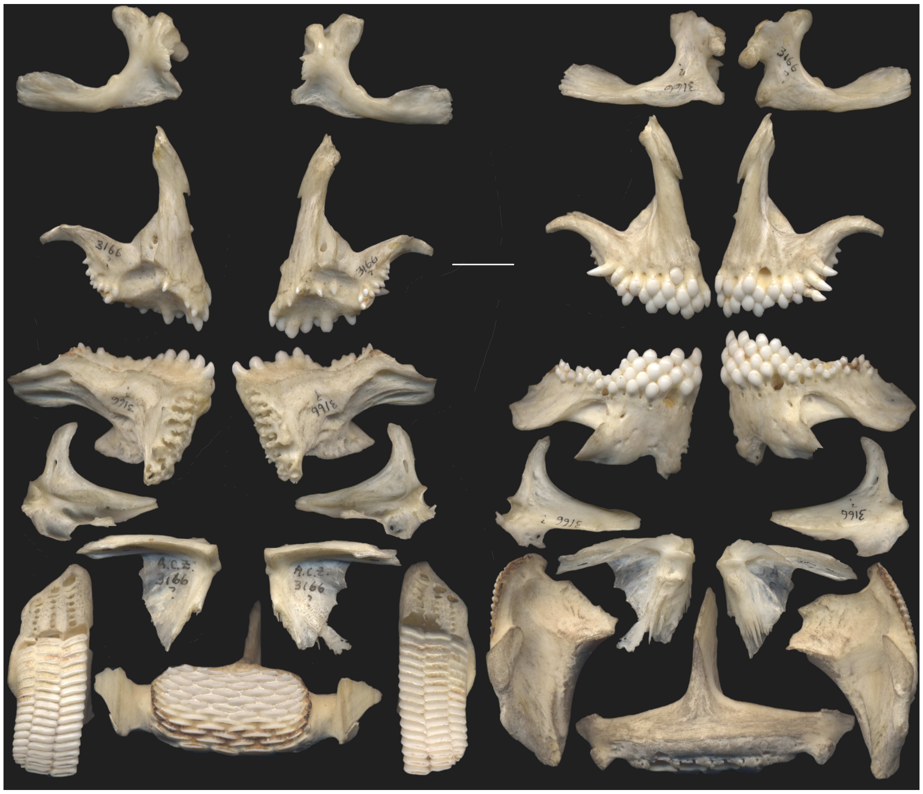

Figure 71. Scaridae sp., the parrotfish, ACZ-3166. Collected at Kailua, O‘ahu. *Bottom*, upper and lower (*middle*) pharyngeal plates. Scale bar = 1 cm.

3.3.44 Sphyraenidae

Sphyraena barracuda (fig. 76) is a carnivore that reaches 1.8 m in length. The young are frequently found in brackish waters and the fish can grow to a large size in fishponds, where it is destructive (Gosline and Brock 1960:153). It is often seen singly close to shore and traveling in schools farther offshore (Hosaka 1973:90). Known in Hawai‘i as *kākū*, it is caught with a hook and line. Apparently, it was not often eaten, though it has a fine white flesh (Titcomb 1972:84).

Sphyraena helleri (fig.77) is an inshore fish believed to enter fishponds (Gosline and Brock 1960:153). It is smaller than *S. barracuda*, reaching a length of about 65 cm. Known in Hawai‘i as *kawele‘ā* it is usually caught at night (Titcomb 1972:88). It is considered a delicious white-fleshed fish that is good broiled or cooked any other way, and is eaten raw when it is fat (Titcomb 1972:88).

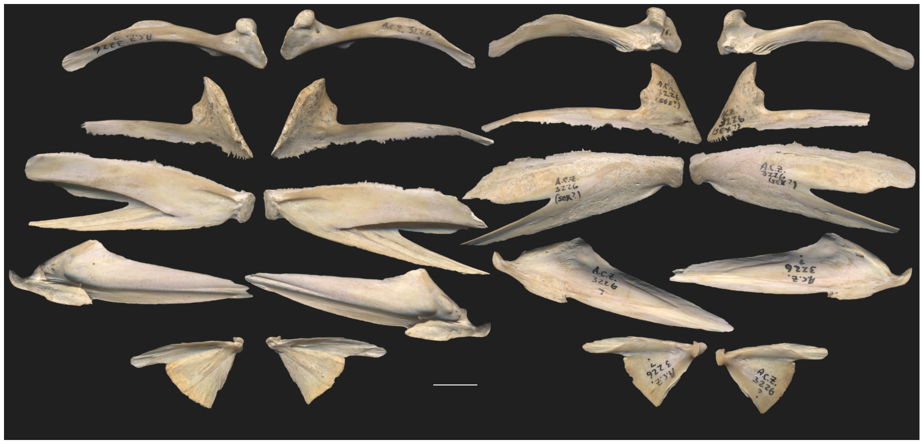

Figure 72. *Katsuwonus pelamis*, the skipjack, or *aku*, ACZ-3226. Original locality unknown; purchased at ‘Ewa Beach, O‘ahu supermarket. Scale bar = 1 cm.

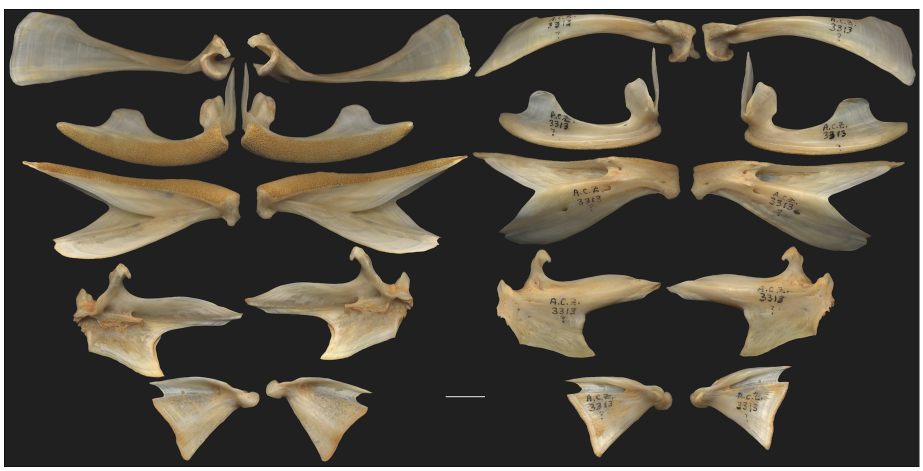

Figure 73. *Scorpaenopsis cacopsis*, the titan scorpionfish, or *nohu*, ACZ-3313. Original location unknown; purchased in Honolulu fish market. Scale bar = 1 cm.

3.3.45 Synodontidae

Saurida cf. *gracilis* (fig. 78) lives in shallow water with mud or silty sand bottoms; it may also be found in brackish water (Randall 1985:6). It is a carnivorous fish that grows to a length of 28 cm on a diet of small fishes, shrimps, and squid (Randall 1996:39). Known in Hawai‘i as *‘ulae*, these fish were “usually broiled, with or without a wrapping of *ti* leaves” (Titcomb 1972:151).

Figure 74. *Caprodon schlegelii*, a grouper, ACZ-3146. Original locality unknown; received from Waikīkī Aquarium, Honolulu, Oʻahu. Scale bar = 1 cm.

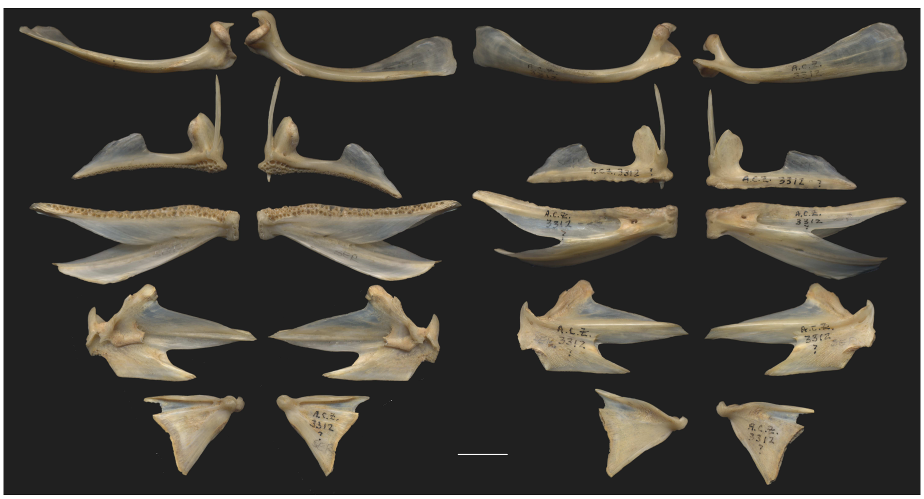

Figure 75. *Epinephelus quernus*, the Hawaiian grouper, or *hāpuʻu*, ACZ-3312. Original locality unknown; purchased in Kāneʻohe, Oʻahu supermarket. Scale bar = 1 cm.

3.3.46 Tetraodontidae

Arothron hispidus (fig. 79) is found from estuaries out to coral reefs (Randall 1996:196). It grows to a length of 48 cm on an omnivorous diet of algae and benthic invertebrates. Known in Hawaiʻi as *ʻoʻopu hue*, it is caught with a hook and line fitted with a steel

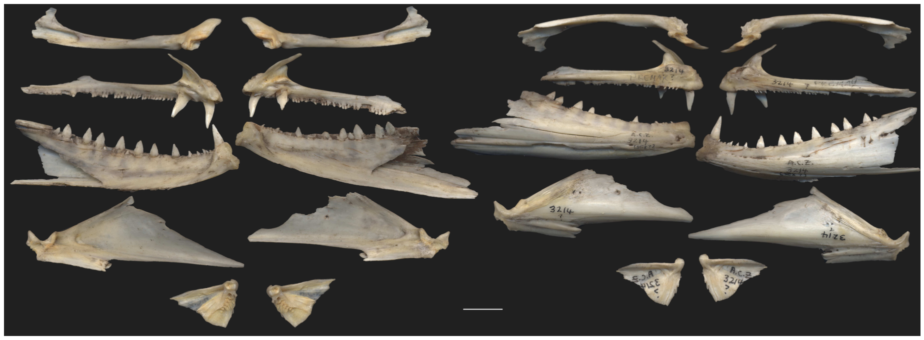

Figure 76. *Sphyraena barracuda*, the great barracuda, or *kākū*, ACZ-3214. Collected at Hulopoʻe Bay, Lānaʻi. Scale bar = 1 cm.

Figure 77. *Sphyraena helleri*, Heller's barracuda, or *kaweleʻā*, ACZ-3320. Original locality unknown; purchased at Honolulu, Oʻahu fish market. Scale bar = 1 cm.

leader and in nets (Hosaka 1973:158). It is sometimes speared in ponds (Titcomb 1972:132). The dental apparatus of this fish is sharp and powerful, able to bite through ordinary fishing line or a human finger. The flesh is considered a delicacy by many, but is often poisonous. It is thought to have been rarely eaten in traditional Hawaiʻi (Titcomb 1972:131).

3.3.47 Zanclidae

Zanclus cornutus (fig. 80) is an omnivore that grows to a length of 20 cm. It is found at a wide range of depths (Randall 1985:47). Known in Hawaiʻi as *kihikihi*, it has little flesh, but can be broiled and eaten if better fish can't be had (Titcomb 1972:88).

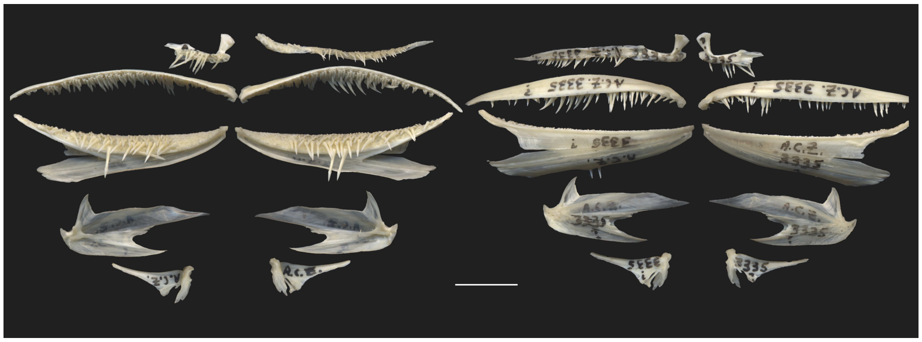

Figure 78. *Saurida* cf. *gracilis*, the slender lizardfish, *ʻulae*, ACZ-3335. Collected at ʻAnini, Kauaʻi. Scale bar = 1 cm.

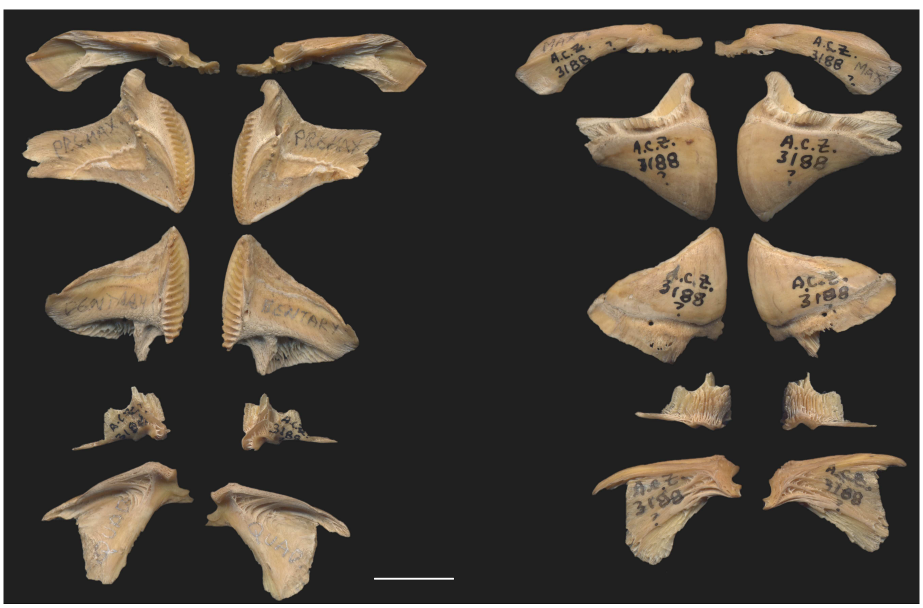

Figure 79. *Arothron hispidus*, the stripebelly puffer, or *ʻoʻopu hue*, ACZ-3188. Original locality unknown; discarded by Bishop Museum, Honolulu, Oʻahu. Scale bar = 1 cm.

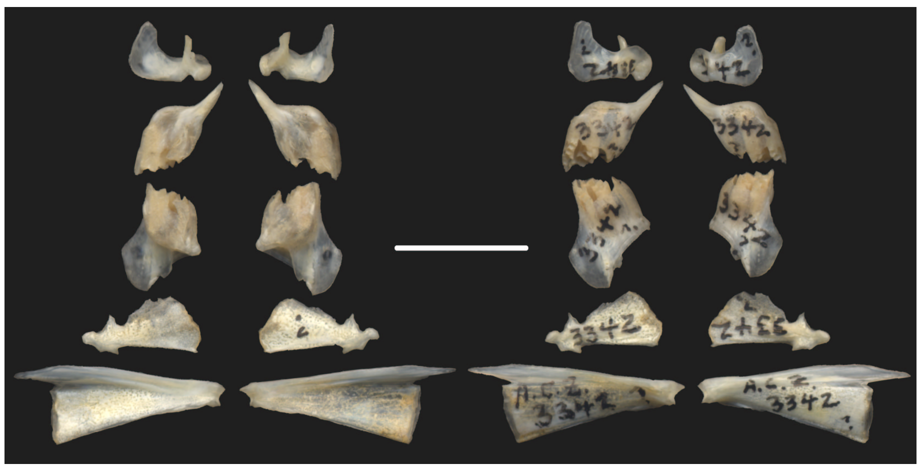

Figure 80. *Zanclus cornutus*, the moorish idol, or *kihikihi*, ACZ-3342. Original locality unknown; purchased in Honolulu, Oʻahu fish market. Scale bar = 1 cm.

4 Atlas of Fish Otoliths

Otoliths, or ear stones, are another type of anatomical structure that can be used as taxonomic indicators. These calcareous crystals are not skeletal elements (Nolf 1985; Maisey 1987), but form part of the acoustico-lateralis system and are housed in the auditory capsules of all Osteichthyes, or bony fishes (Nolf 1985). Their composition (aragonite inserted within a network of protein) makes them harder and more durable than skeletal components and, as such, they are often the only identifiable remains found in geological strata, archaeological sites or the digestive tracts of predators (Rivaton and Bourret 1999).

In paleolontological studies, complete skeletons are normally scarce; however, otoliths are common fossils throughout broad geographic and stratigraphic ranges from the late Cenozoic to the present (Hecht 1990). The most common Tertiary osteichthyan fossils, otoliths are found in nearly all marine deposits, often in tremendous quantities (Nolf 1985). These fossils are the basis of many studies of Oligocene and Miocene ichthyofaunal assemblages (Wheeler and Jones 1989). In reconstructing fish assemblages, these otoliths play much the same role as teeth in the reconstruction of shark or mammal assemblages (Nolf 1985).

Weisler (2002) argues that not considering otoliths in Pacific archaeofaunal studies virtually guarantees that some fishes will rarely, if ever, be inventoried. For instance, despite long-term studies that identified 21,051 bones from 126 sites on 24 island groups throughout Oceania, neither bonefish (*Albula glossodonta*) nor whiting (*Sillago ciliata*) were identified until otoliths were considered (Weisler 2002). In Hawai‘i, mullet (*Mugil cephalus*) were raised in thousands in more than 200 fishponds during late prehistory. Despite more than three decades of systematic excavations, mullet were not identified in Hawaiian archaeological sites until otoliths were examined (Weisler 1993). Weisler et al. (1999) included otoliths in a study of an archaic midden in New Zealand and identified 14 fish species *never* before found in New Zealand middens. Species richness in this study increased five-fold as a result of including otoliths. Likewise, the number of individuals and the proportion identified increased when otoliths were considered. At one site with a minimum number of individuals (MNI) of 414, only 18.5 percent were accounted for by bones; overall, the number of identified specimens (NISP) increased 27 percent when otoliths were added to the fish bone identifications (Weisler et al. 1999).

Otoliths are often the only identifiable fish remains found in the stomachs or feces of predators (Hecht 1990). Fitch and Brownell (1968) analyzed the stomach contents of 17 cetaceans and identified 51 fish species, only two of which were identifiable without otoliths. Their chemical composition and crystalline structure make otoliths remarkably more resistant to digestion than fish bones. Also, because they are housed in the skull and thus protected from digestion, otoliths are one of the last species-specific structures to be digested (Smale et al. 1995). Nolf (1985) argues that digestion by fishes has little influence on otolith appearance. He suggests that most fossil otoliths passed through the digestive system of fishes before entering the sediment, and observes that specimens found in non-decalcified and non-turbulent deposits are usually in perfect condition. Nolf (1985) further reports that well preserved otoliths are found in the regurgitation pellets of birds and otter, but warns that strongly altered otoliths have been found in pinniped stomachs.

Most actinopterygians, or ray-finned fishes (the only subclass of bony fishes found in Hawaiian waters), have three otoliths on each side of the head: a sagitta (saccular otolith or sacculith), a lapillus (utricular otolith or utriculith), and an astericus (lagenar otolith or lagenalith) (Smale et al. 1995). In most fishes, the sagitta is the largest of the three otolith types; the lapillus and astericus are smaller and thus rarely found in stomach contents or middens (Smale et al. 1995). Exceptions to this rule are the Cypriniformes (carps and minnows) and Siluriformes (catfishes) in which the lapillus is largest. None of the latter fishes are native to Hawai‘i, and thus should not be important in archaeological deposits.

In addition to being larger, the sagitta has more characteristic features that can be used as taxonomic indicators (Smale et al. 1995). The morphological elements of sagittae are so consistent among taxa that a rich vocabulary applicable to all actinopterygian fishes (except Ostariophysans) has been created (Nolf 1985). All Hawaiian fishes are actinopterygian, or ray-finned. Some common features of the medial side of the sagitta are illustrated in figure 81. Generally, the lateral side does not have features useful for taxonomic work; most are smooth or amorphous.

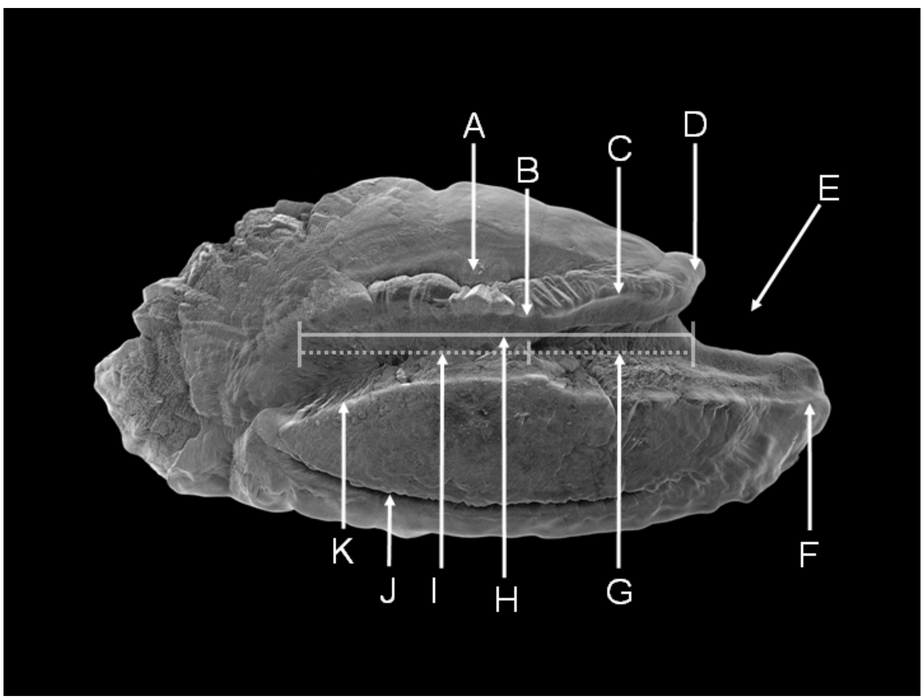

Figure 81. Some common features of the medial surface of the sagitta (from *Sebastapistes galactacma*): *A*, dorsal depression; *B*, neck; *C*, crista superior; *D*, antirostrum; *E*, excisura; *F*, rostrum; *G*, ostium; *H*, sulcus; *I*, cauda; *J*, ventral groove; *K*, crista inferior. Dorsal surface at top, anterior at right. See page 136 for definitions of terms.

The geometric shape, or outline, of otoliths is most useful for family- and order-level identifications (Hecht 1990). Smale et al. (1995) list the shapes illustrated in figure 82, plus the following types not found in this handbook: circular, kidney-shaped, maize-kernel, pyriform, tear-drop, and trilobate.

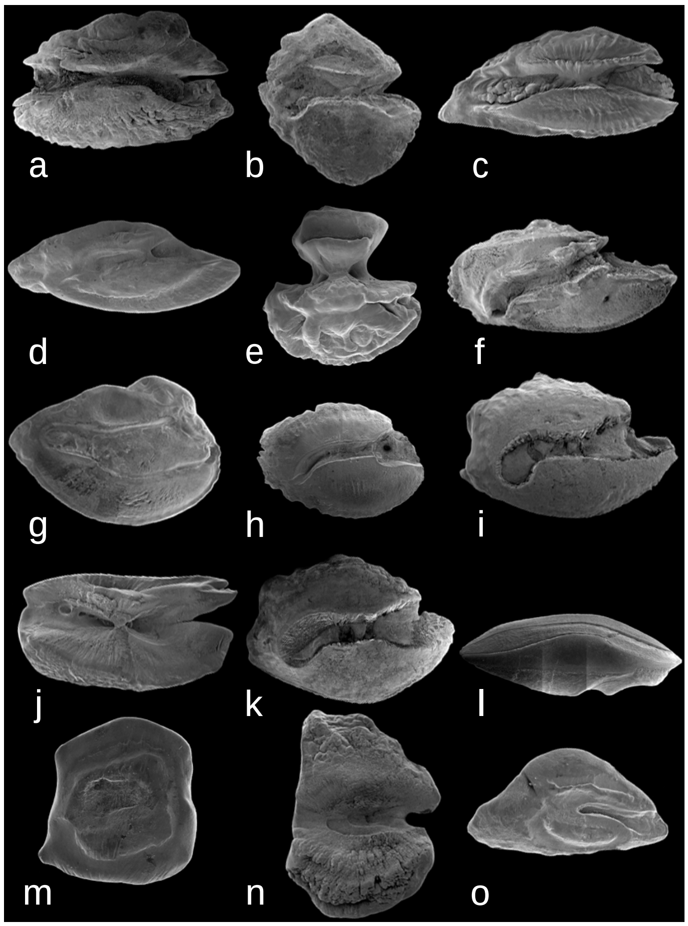

Figure 82. Outline shapes: *a*, anvil-shaped, *Thalassoma ballieui*; *b*, discoid, *Zebrasoma flavescens*; *c*, elliptic, *Bodianus bilunulatus*; *d*, fusiform, *Scorpaenodes kelloggi*; *e*, hourglass, *Pervagor aspricaudus*; *f*, oblong, *Chaetodon lunulatus*; *g*, obovate, *Apogon erythrinus*; *h*, oval, *Lutjanus kasmira*; *i*, ovate, *Acanthurus nigrofuscus*; *j*, rectangular, *Aulostomus chinensis*; *k*, rhomboidal, *Ctenochaetus strigosus*; *l*, spindle-shaped, *Brotula multibarbata*; *m*, square, *Eviota rubra*; *n*, tall, *Ostracion meleagris*; *o*, triangular, *Synchiropus rubrovinctus*.

Sculpturing on the medial side can be diagnostic at the genus and species level Hecht (1990). Characters used to describe otoliths include margin sculpturing (fig. 83), sulcus

the sulcus shape (fig. 84), how the sulcus opens onto the margins (fig. 85), and the condition of the sulcus floor (fig. 86).

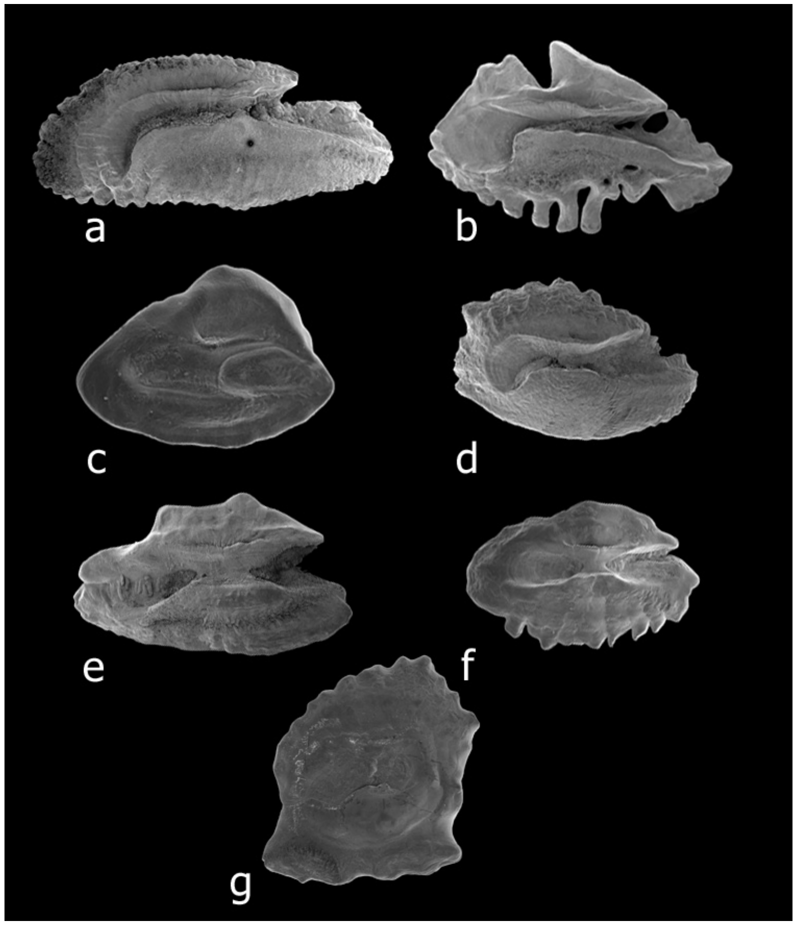

Figure 83. Margin sculpturing: *a*, crenate, on posteroventral margin of *Kyphosus bigibbus*; *b*, dentate, on ventral margin of *Parupeneus porphyreus*; *c*, entire, on ventral margin of *Pseudaminops diaphanes*; *d*, irregular, on dorsal margin of *Acanthurus olivaceus*; *e*, lobed, on dorsal margin of *Thalassoma duperrey*; *f*, serrate, on ventral margin of *Oxycheilinus bimaculatus*; *g*, sinuate, on dorsal and ventral margins of *Gnatholepis cuarensis*.

Intraspecific variation in the appearance of sagittae is generally moderate to insignificant in most species. For instance in Southern Ocean fishes, 80 percent showed negligible variation, 17 percent marginal and only 3 percent showed a relatively high level of intraspecific variation. On the other hand, ontogenetic changes follow a constant pattern in most species: the otoliths of all larval fishes are virtually identical, with an increase in size an order can be assigned, followed to being recognizable at the family level and so on, until species can be assigned (Hecht 1990).

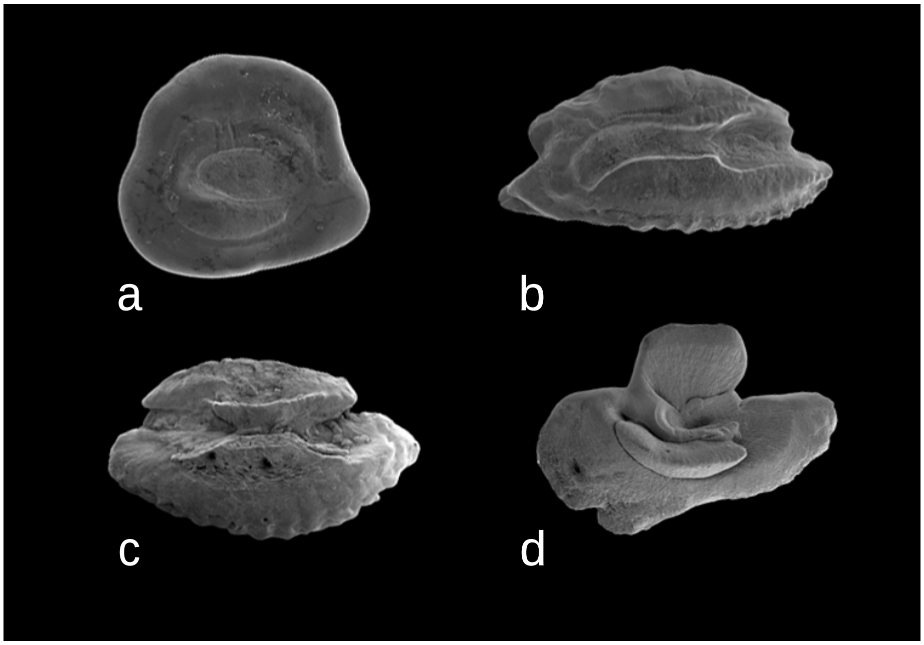

Figure 84. Sulcus types: *a*, archaesulcoid, on *Priolepis farcimen*; *b*, heterosulcoid, on *Cirrhitops fasciatus*; *c*, homosulcoid, on *Scarus psittacus*; *d*, pseudo-archaesulcoid, on *Canthigaster jactator*. See page 136 for definitions of terms.

Otoliths can, and frequently are, used as more than taxonomic indicators. For instance, the habitat preference of many species is known. This information can be used to infer the environment represented by geologic strata, the habitat where human fishing activity occurred, or the habitat in which a predator fed. However, a great deal of additional information is contained in the otolith: its chemical composition reflects environmental conditions during a fish's life (Devereux 1967), banding patterns within the otolith can be used to determine age at death, with daily resolution (Panella 1971), larger-scale banding patterns can be used to infer season of death (Wheeler and Jones 1989), and species-specific regressions can be used to relate otolith size to fish length or weight (Harvey et al. 2000).

4.1 About The Atlas

The following images are scanning electron micrographs of the sagittae of common Hawaiian reef fishes. Atlases featuring the otoliths of marine fishes from other regions include many fishes that are also found in Hawai‘i (Rivaton and Bourret 1999; Smale et al. 1995). However, because approximately 25 percent of Hawai‘i's reef fishes are endemic (Randall 1996), many Hawaiian fishes are not included in those atlases. This handbook complements the earlier publications and is based on a reference collection

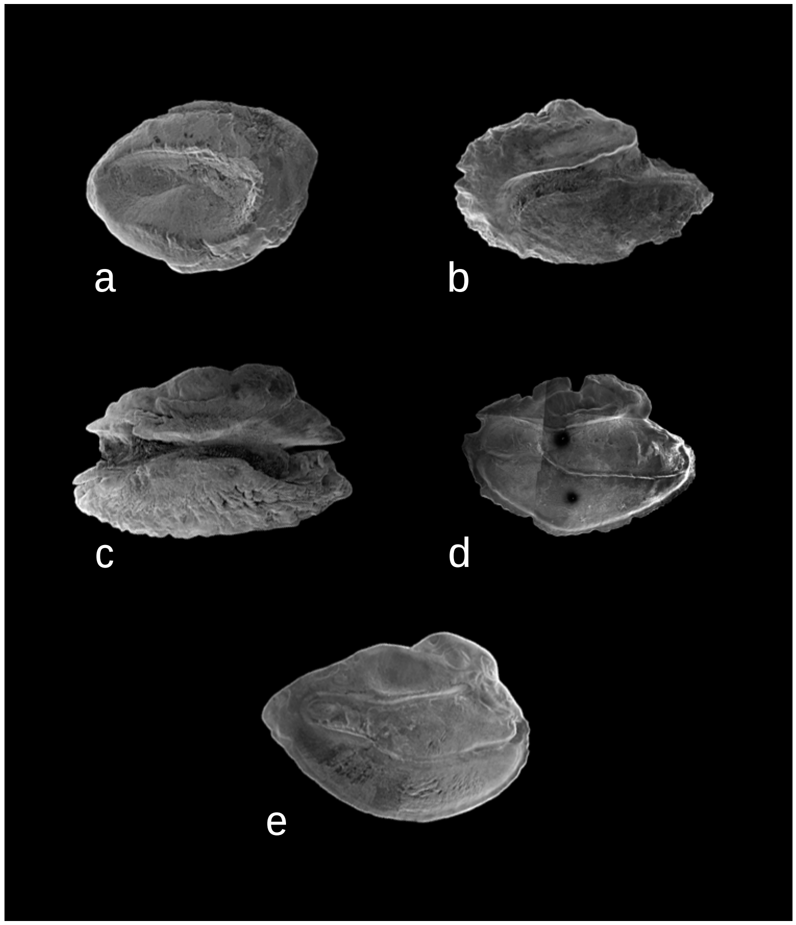

Figure 85. Sulcus opening types: *a*, mesial, on *Ichthyapus vulturis*; *b*, ostial, on *Chaetodon miliaris*; *c*, ostio-caudal, on *Thalassoma ballieui*; *d*, para-ostial, on *Apogon menesemus*; *e*, pseudo-ostial, on *Apogon erythrinus*. See page 136 for definitions of terms.

used to describe trophic relationships on the forereef of the Kāne‘ohe Bay barrier reef. As such, the collection is biased toward species found in high-energy marine habitats.

Fishes were collected from the forereef of Kāne‘ohe Bay, O‘ahu, Hawai‘i in depths from 5.5–30.5 m during 2001 and 2002 and frozen until analysis. All fishes were identified by Ken Longenecker (except Creediidae and Kraemeridae identified and donated by Ross Langston), measured (total length, fork length and standard length), and weighed. Otoliths were removed with forceps after making a mid-sagittal cut through the dorsal surface of the head using a single edged razor blade for small fishes or a boning knife for larger fishes. Larger otoliths were partially cleaned of blood and tissue by rubbing between thumb and forefinger. All sagittae were stored dry in 24-well tissue culture plates, with one species per plate and one individual per well.

Specimens were then selected for photography by scanning electron miscroscopy.

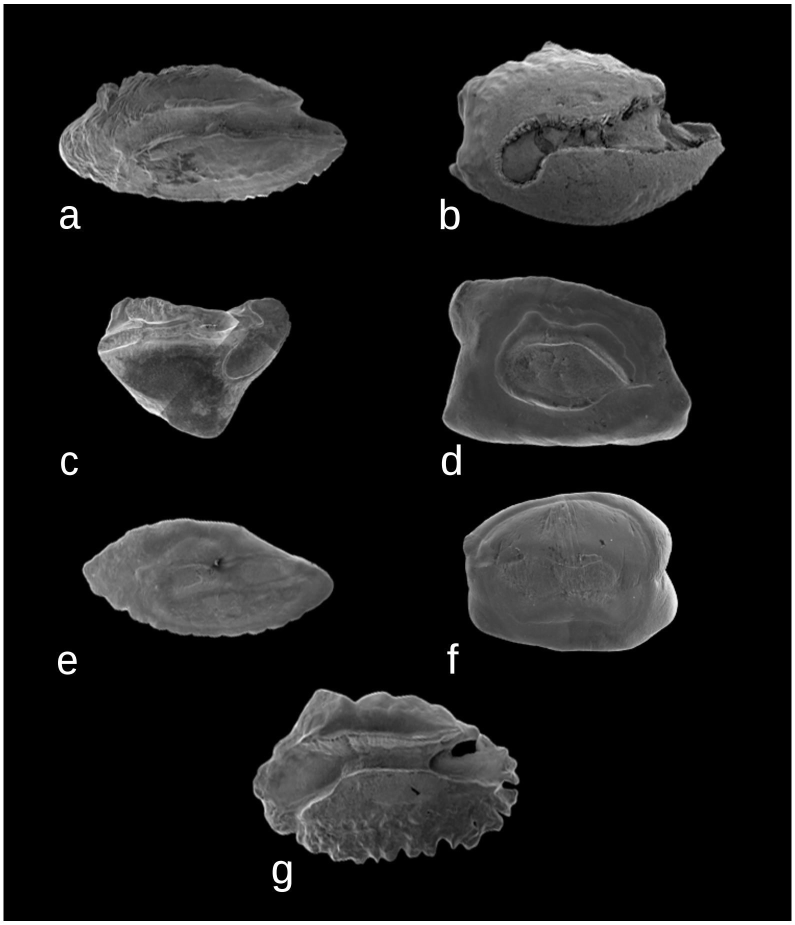

Figure 86. Colliculum types: *a*, absent, on *Sebastapistes coniorta*; *b*, heteromorph, 2 differing colliculi on *Acanthurus nigrofuscus*; *c*, heteromorph, single colliculum in ostium on *Myripristis kuntee*; *d*, heteromorph, fused colliculi differ in ostium and cauda on *Priolepis eugenius*; *e*, homomorph, two similar colliculi on *Scorpaenodes hirsutus*; *f*, homomorph, similar colliculi fused on an undescribed *Cabillus* species; *g*, indistinct, on *Mulloidichthys flavolineatus*. See page 136 for definitions of terms.

For some species, only one specimen was available for examination. When more than one specimen was available, the otoliths most representative of the species were chosen. When intraspecific variation was high, a series of otoliths was photographed. In all cases, both sagittae from a single individual were photographed. One sagitta was photographed on the medial side, the other sagitta was photographed on the lateral side. Many investigators consider the lateral surface void of diagnostic features; however some species do have lateral surface sculpturing that may be useful to the investigator. In any case an image of both sagittae shows individual shape variation.

Otoliths were prepared for scanning electron miscroscopy by dissolving any remaining tissue with bleach, rinsing with two changes of distilled water, drying with two changes of absolute ethanol, then evaporating the alcohol with heat from an incandescent bulb. Sagittae were mounted on an SEM stub with conductive tape, then stored in a dessicating chamber for at least 24 hours.

Mounted specimens were coated with a thin layer of gold-paladium in a Hummer II sputter coater. Images were obtained from a Hitachi S-800 scanning electron microscope at the highest possible magnification that allowed the whole otolith to be viewed in a single frame. Some otoliths were too large to be viewed in a single frame. A composite image of these large otoliths was created by merging frames in Photoshop software.

4.2 Recommendations for Examining Otoliths

The following images are intended to help investigators identify otoliths found in their own research. The reader is reminded that the following images are biased toward common fishes found between 5.5 and 30.5 m depth in areas with a strong surge. Other publications should be consulted when attempting to identify otoliths from Hawaiian fishes: Nolf (1985) includes a figure of an otolith from nearly every extant bony fish family; Nolf (1993) improves upon these images for the Percoidei (perch-like fishes); some species and many families of southern African marine fishes featured in Smale et al. (1995) are also found in Hawai‘i. Rivaton and Bourret (1999) feature 998 species of Indo-Pacific fishes and include most of the families and many species found in Hawai‘i. The latter publications are especially recommended for their coverage of carangid, deep-water, and pelagic species.

Researchers interested in using otoliths for taxonomic indicators must first develop a search image for the various otolith shapes. Weisler (1993) suggests that otoliths are often misidentified as mollusc opercula in archaeological studies.

In work requiring sieving, the effects of mesh size should be considered. Weisler (1993) warns that otoliths are not found in 6.4 mm sieve fractions. He advises that a 3.2 mm, or smaller, sieve (or a bulk sample) is necessary for otolith studies in archaeology. The reader is cautioned that using a mesh size of 3.2 mm can profoundly bias results. The following images are from a physical collection of the sagittae from 994 specimens. Of these only 458 had their longest axis larger than 3.2 mm. Thus, at least half of the total sagittae and all of some families (Gobiidae, Trypterygiidae, Blenniidae) and species (*Sufflamen bursa*, *Aulostomus chinensis*) would not be retained on a 3.2 mm sieve.

Stomach contents of predators should be examined in a fresh state. Exposing otoliths to formalin, particularly unbuffered formalin, causes erosion that makes identification unlikely (Hecht 1990). Longenecker has stored stomach contents in alcohol, although some authors advise against this practice over concern that the protein matrix may degrade.

Otoliths are most safely and conveniently stored dry. Some otolith researchers use coin envelopes for storage containers. This sysetm is best reserved for otoliths large enough to not be easily lost. These envelopes offer little protection from breakage. Storage options for medium-sized otoliths include small vials and tissue culture trays.

Gelatin capsules can be used for the smallest otoliths, however the capsules must be protected from moisture to avoid dissolution.

The otoliths are often reflective enough to make seeing surface features difficult. Two techniques can be used to address this problem:

1. Graphite coating is recommended by (Smale et al. 1995). Simply scribble on a sheet of paper with a pencil, rub a finger in the graphite, and rub the graphite-coated finger on the otolith (or paint it with an artist's brush dipped in the graphite).
2. Coating with ammonium chloride is a bit more difficult (Hecht 1977). Insert some ammonium chloride crystals into narrow glass tube, sublimate the chemical over a flame, and blow the vapors onto the otolith to provide a matte coating. Ammonium chloride is extremely hygroscopic and should be brushed from otolith prior to storage.

4.3 Otoliths of Hawaiian Fishes

Images of sagittal otoliths from Hawaiian fishes are arranged alphabetically by family. Within each family, arrangement is alphabetically by genus (except two carangids, for layout considerations) then species. Where several pairs of sagittae from a species are included, they are arranged by standard length of the fish specimen (smallest to largest). A description of sagittae, modified from descriptions given by Smale et al. (1995), is provided for each family.

4.3.1 Acanthuridae (figs. 87, 88, 89*a-c*)

Outline ovate, oblong or rounded-ovate. Outline discoid in juvenile *Zebrasoma* figured here, but see larger individual in Rivaton and Bourret (1999). Rostrum moderate. Heterosulcoid with ostial openings. Ostium flared and oval, elongate in the genus *Naso*. Cauda usually short and sharply flexed with rounded tip. Cristae well developed, a low ridge in *Naso*.

rostrum
ostial
heterosulcoid
ostium
cauda

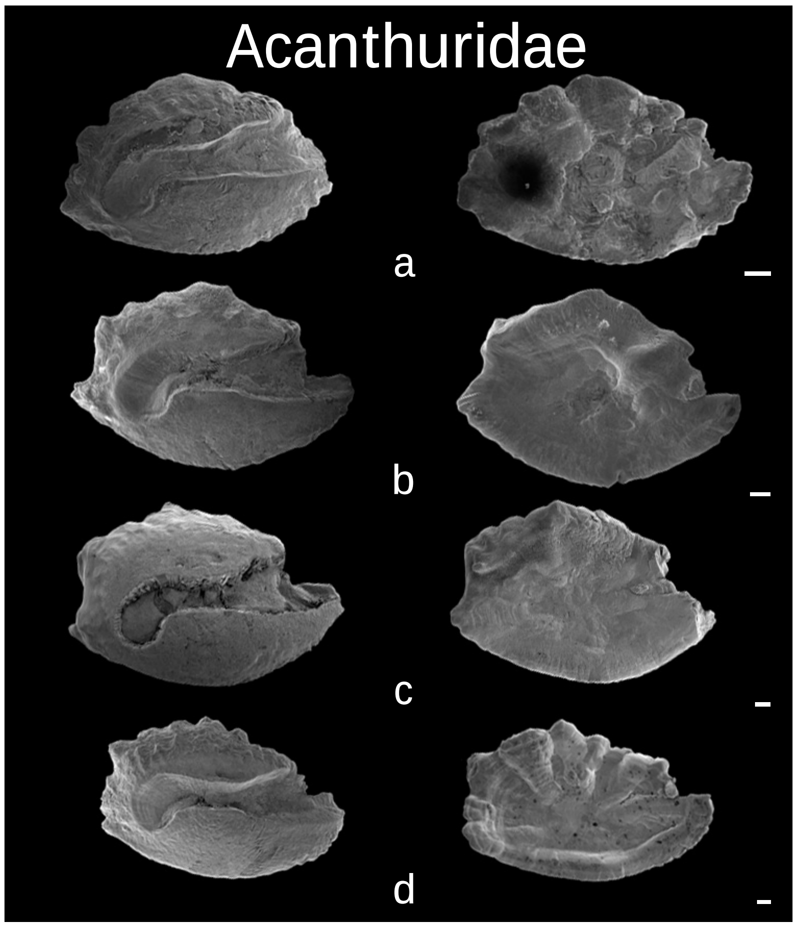

Figure 87. Acanthuridae: *a*, *Acanthurus leucopareius*, 56 mm SL; *b*, *Acanthurus leucopareius*, 88 mm SL; *c*, *Acanthurus nigrofuscus*, 123 mm SL; *d*, *Acanthurus olivaceus*, 156 mm SL. Scale bars = 300 μm.

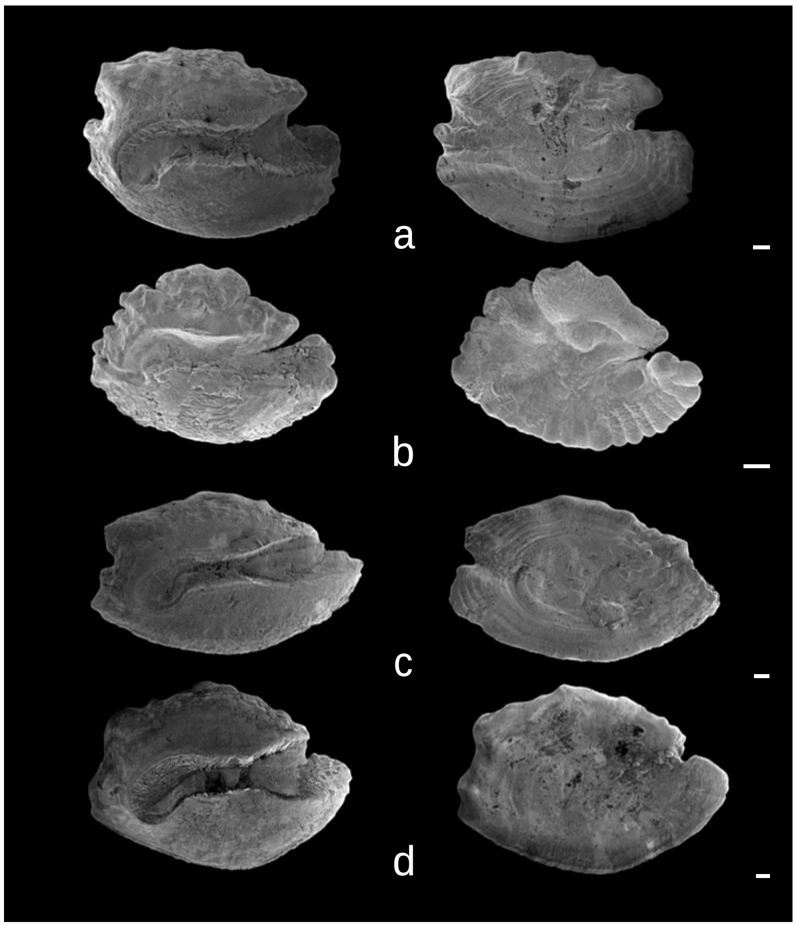

Figure 88. Acanthuridae: *a*, *Acanthurus triostegus*, 135 mm SL; *b*, *Acanthurus xanthopterus*, 51 mm SL; *c*, *Ctenochaetus strigosus*, 114 mm SL; *d*, *Ctenochaetus strigosus*, 127 mm SL; Scale bars = 300 μm.

4.3.2 Antennariidae (fig. 89*d*)

mesial archaesulcoid

Outline oval. Archaesulcoid with mesial opening. No raised colliculi. Raised hump under mid sulcus.

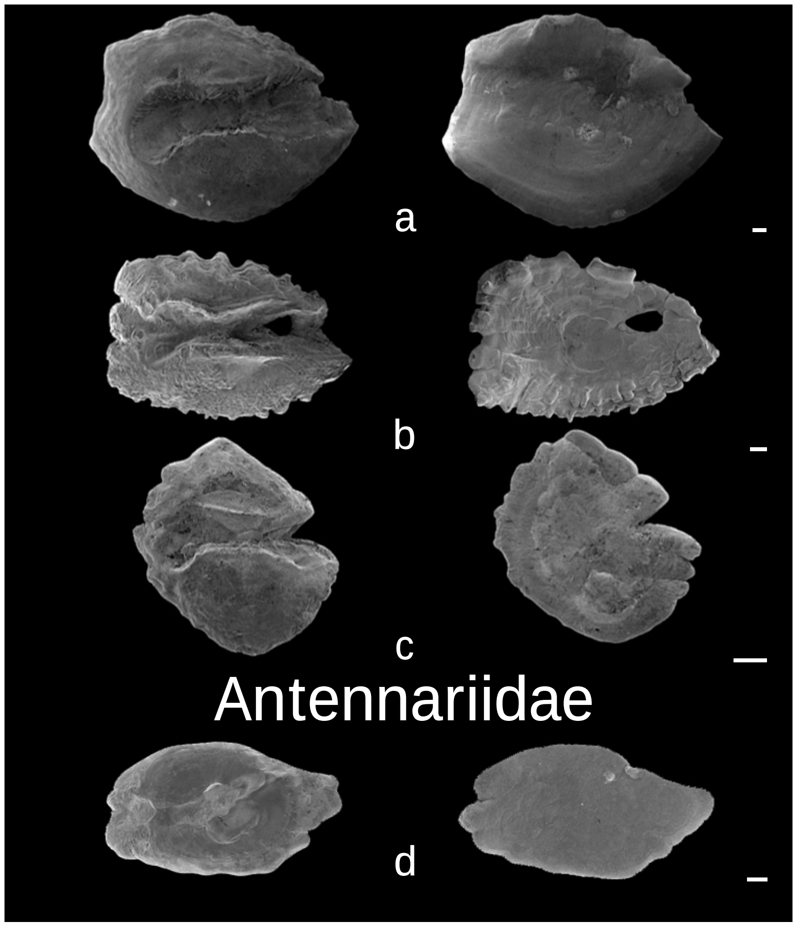

Figure 89. Acanthuridae and Antennariidae: *a*, *Ctenochaetus strigosus*, 129 mm SL; *b*, *Naso lituratus*, size unknown; *c*, *Zebrasoma flavescens*, 30 mm SL; *d*, *Antennarius drombus*, 44 mm SL; Scale bars = 300 μm.

4.3.3 Apogonidae (figs. 90, 91, 92*a, b*)

Outline oval to obovate. Deep, oval dorsal depression. Heterosulcoid, opening pseudo-ostial or para-ostial. Ostium oval. Cauda short and relatively straight. Heteromorph colliculi, anterior colliculum oval and large, posterior low and often with raised ventral margin.

dorsal depression
pseudo-ostial
para-ostial
anterior colliculum
heteromorph

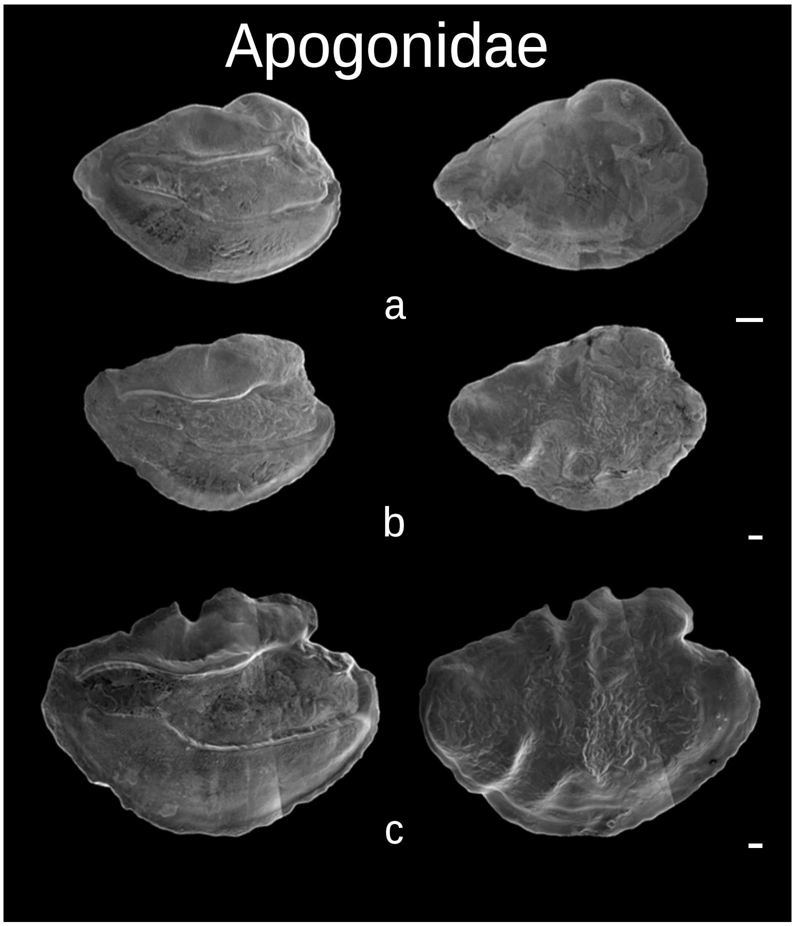

Figure 90. Apogonidae: *a*, *Apogon erythrinus*, 26 mm SL; *b*, *Apogon kallopterus*, 25 mm SL; *c*, *Apogon kallopterus*, 64 mm SL. Scale bars = 300 μm.

4.3.4 Aulostomidae (fig. 92*c*)

Outline rectangular. Homosulcoid with ostio-caudal openings. Colliculi absent.

ostio-caudal
homosulcoid
absent

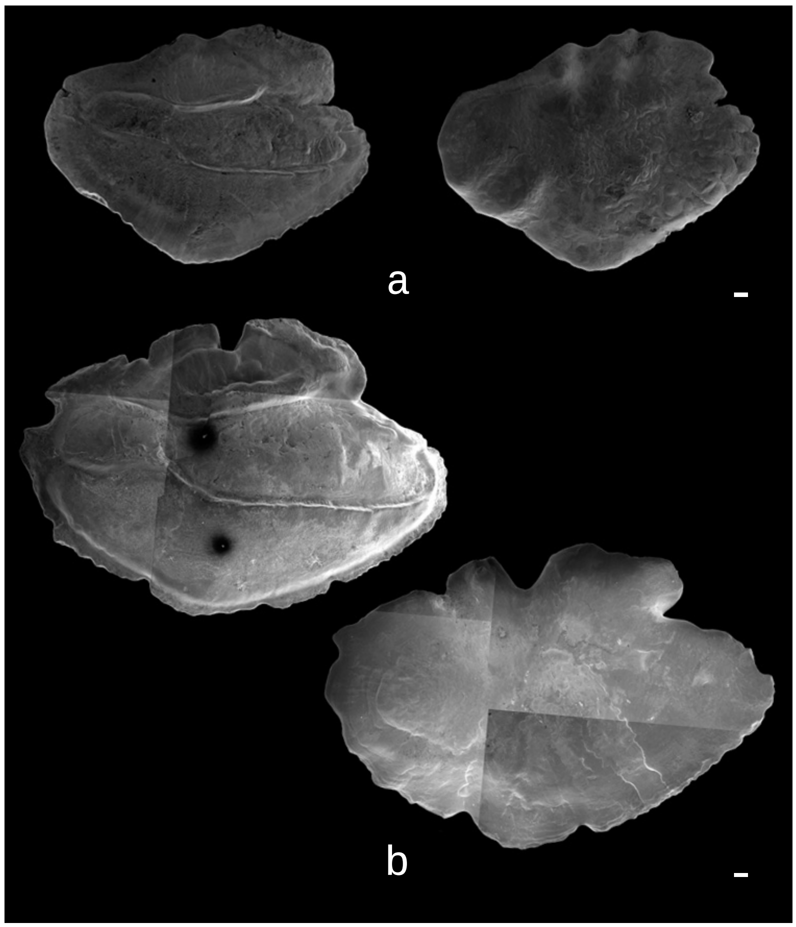

Figure 91. Apogonidae: *a*, *Apogon menesemus*, 97 mm SL; *b*, *Apogon menesemus*, 141 mm SL. Scale bars = 300 μm.

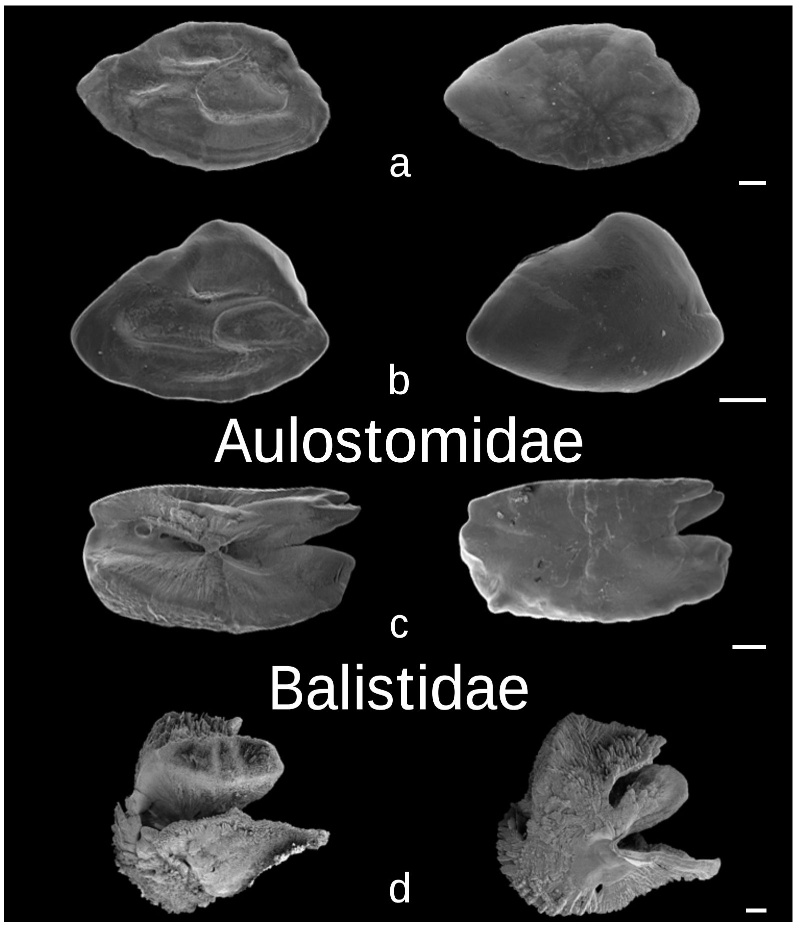

Figure 92. Apogonidae and Aulostomidae: *a*, *Apogonichthys perdix*, 38 mm SL; *b*, *Pseudaminops diaphanes*, 28 mm SL; *c*, *Aulostomus chinensis*, 464 mm SL. Balistidae: *d*, *Melichthys niger*, 269 mm SL. Scale bars = 300 μm.

4.3.5 Balistidae (figs. 92*d*, 93)

irregular

collum

Outline ovate with irregular dorsal margin (that of *Rhinecanthus* and *Sufflamen* delicate and lacy, likely to be broken, as in figure 93*a-c*). Heterosulcoid, with ostio-caudal openings. Sulcus very deep, usually with collum. Ostium and cauda flared. Colliculi not visible.

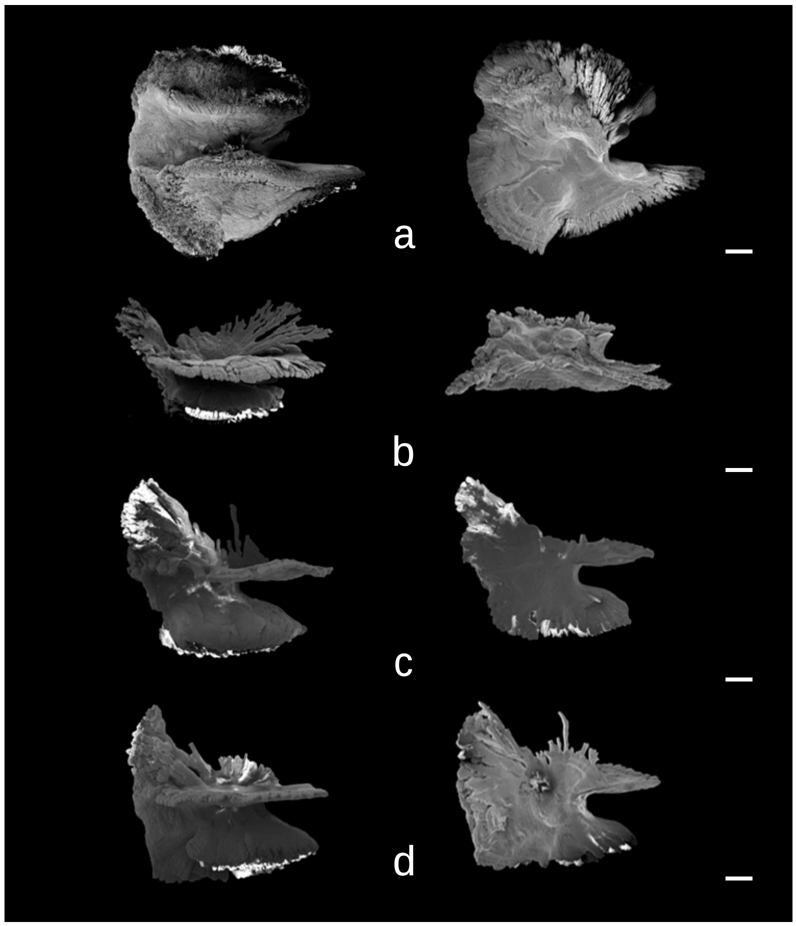

Figure 93. Balistidae: *a*, *Melichthys vidua*, 221 mm SL; *b*, *Rhinecanthus rectangulus*, 177 mm SL; *c*, *Sufflamen bursa*, 149 mm SL; *d*, *Sufflamen fraenatus*, 218 mm SL. Scale bars = 300 μm.

4.3.6 Blenniidae (figs. 94, 95*a, b*)

Outline oval or oval-ovate, square in *Plagiotremus*. Heterosulcoid, with ostial openings. Ostium flared anteriorly, pointed posteriorly. Cauda short, slightly flexed and flared. Heteromorph, colliculi low, reduced.

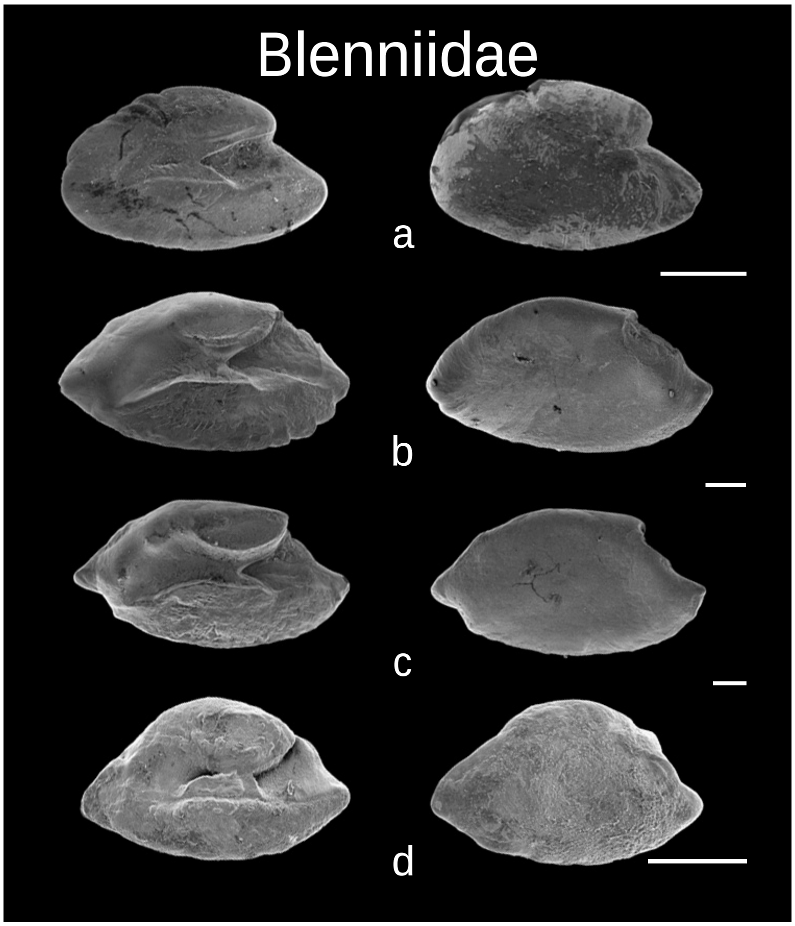

Figure 94. Blenniidae: *a*, *Cirripectes vanderbilti*, 24 mm SL; *b*, *Cirripectes vanderbilti*, 56 mm SL; *c*, *Cirripectes vanderbilti*, 57 mm SL; *d*, *Enchelyurus brunneolus*, 25 mm SL. Scale bars = 300 μm.

4.3.7 Bothidae (fig. 95*c*)

Outline oval. Homosulcoid. Ostial opening with ostium longer than cauda. Colliculi depressed, homomorph. homomorph

4.3.8 Callionymidae (figs. 95*d*, 96*a*, *b*)

indistinct

ventral depression

Outline rounded-triangular. Heterosulcoid with ostial opening. Ostium elongate and narrow, cauda short and oval. Heteromorph colliculi, anterior indistinct, posterior fills cauda. Dorsal depression constricted at anterior third of otolith. Ventral depression bowed.

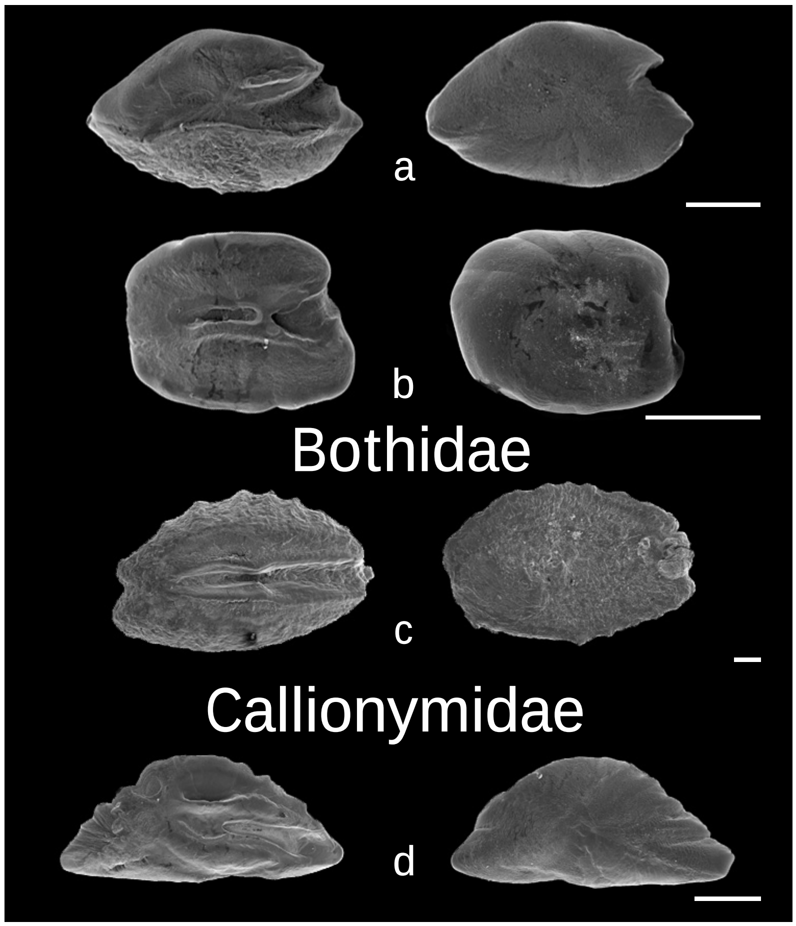

Figure 95. Blenniidae, Bothidae, and Callionymidae: *a*, *Entomacrodus strasburgi*, 28 mm SL; *b*, *Plagiotremus goslinei*, 35 mm SL; *c*, *Bothus pantherinus*, 128 mm SL; *d*, *Callionymus decoratus*, 31 mm SL. Scale bars = 300 μm.

4.3.9 Caracanthidae (fig. 96*c*)

Outline ovate. Rostrum moderate. Heterosulcoid with ostial opening. Ostium wide, blunt posteriorly. Cauda narrow, slightly flexed. Dorsal depression large, along most of sulcus. Ventral groove slight. ventral groove

4.3.10 Carangidae (figs. 96*d*, 97*a*)

Outline oblong or fusiform. Heterosulcoid, opening ostial. Heteromorph, colliculi very low and indistinct. Ostium elongate. Cauda fexed, deepening at tip. *Scomberoides lysan* shown here differs greatly from larger specimens illustrated by Smale et al. (1995) and Rivaton and Bourret (1999).

4.3.11 Chaetodontidae (figs. 97*b*, 98, 99, 100*a*)

Outline oval-ovate. Heterosulcoid with ostial opening. Cauda angled, slightly sinuous, tip ends near ventral margin. Ostium short, mainly on the margin of the rostrum. Heteromorph, colliculi very low.

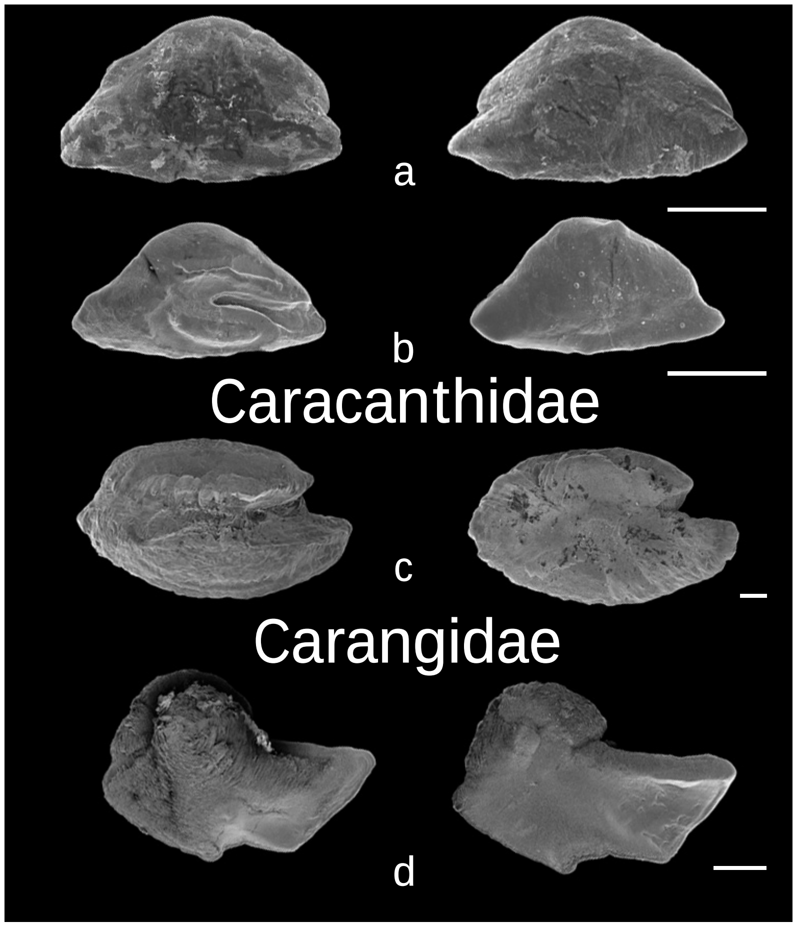

Figure 96. Callionymidae, Caracanthidae, and Carangidae: *a*, *Synchiropus corallinus*, 18 mm SL (both images from medial side); *b*, *Synchiropus rubrovinctus*, 15 mm SL; *c*, *Caracanthus typicus*, 35 mm SL; *d*, *Scomberoides lysan*, 281 mm SL. Scale bars = 300 μm.

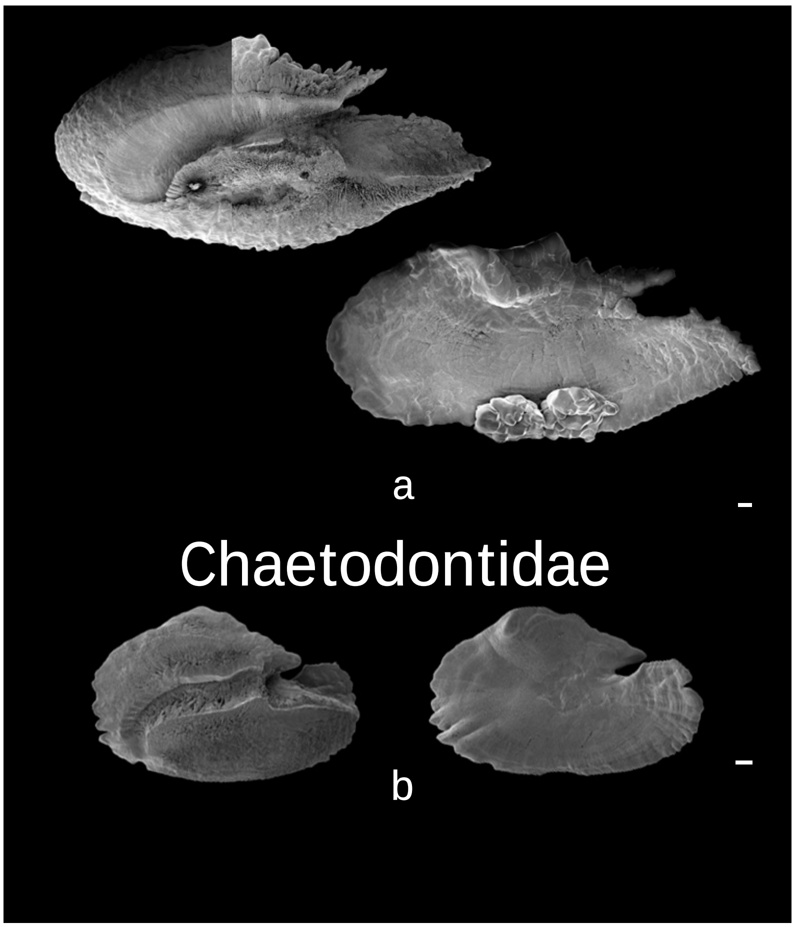

Figure 97. Carangidae and Chaetodontidae: *a*, *Carangoides orthogrammus*, 465 mm SL; *b*, *Chaetodon fremblii*, 108 mm SL. Scale bars = 300 μm.

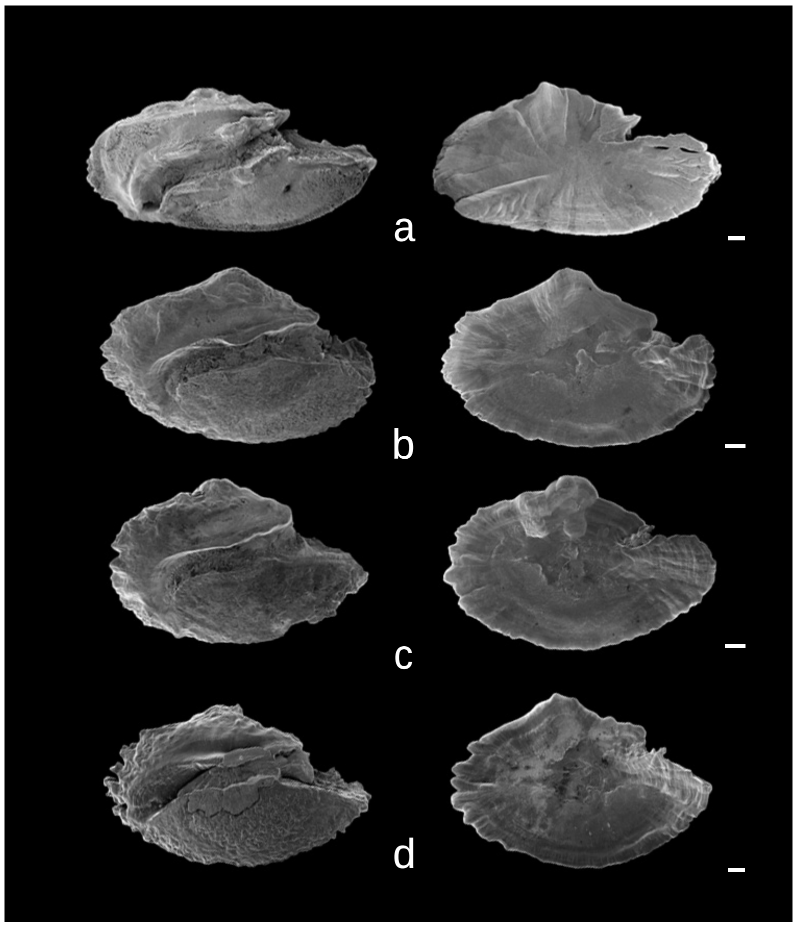

Figure 98. Chaetodontidae: *a*, *Chaetodon lunulatus*, 119 mm SL; *b*, *Chaetodon miliaris*, 76 mm SL; *c*, *Chaetodon miliaris*, 76 mm SL; *d*, *Chaetodon miliaris*, 93 mm SL. Scale bars = 300 μm.

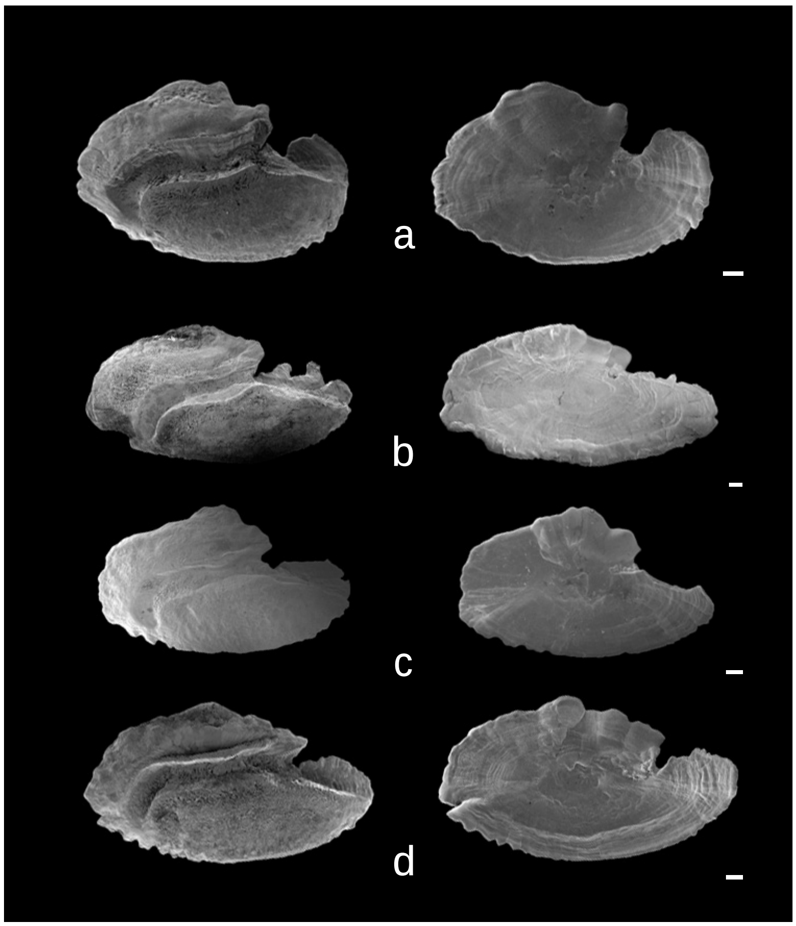

Figure 99. Chaetodontidae: *a*, *Chaetodon multicinctus*, 90 mm SL; *b*, *Chaetodon ornatissimus*, 140 mm SL; *c*, *Chaetodon quadrimaculatus*, 112 mm SL; *d*, *Chaetodon unimaculatus*, 114 mm SL. Scale bars = 300 μm.

4.3.12 Cirrhitidae (figs. 100*b–d*, 101, 102*a, b*)

Outline oblong to oblong-ovate. Heterosulcoid with ostial opening. Cauda long, straight anteriorly, flexed at tip. Heteromorph, with low colliculi.

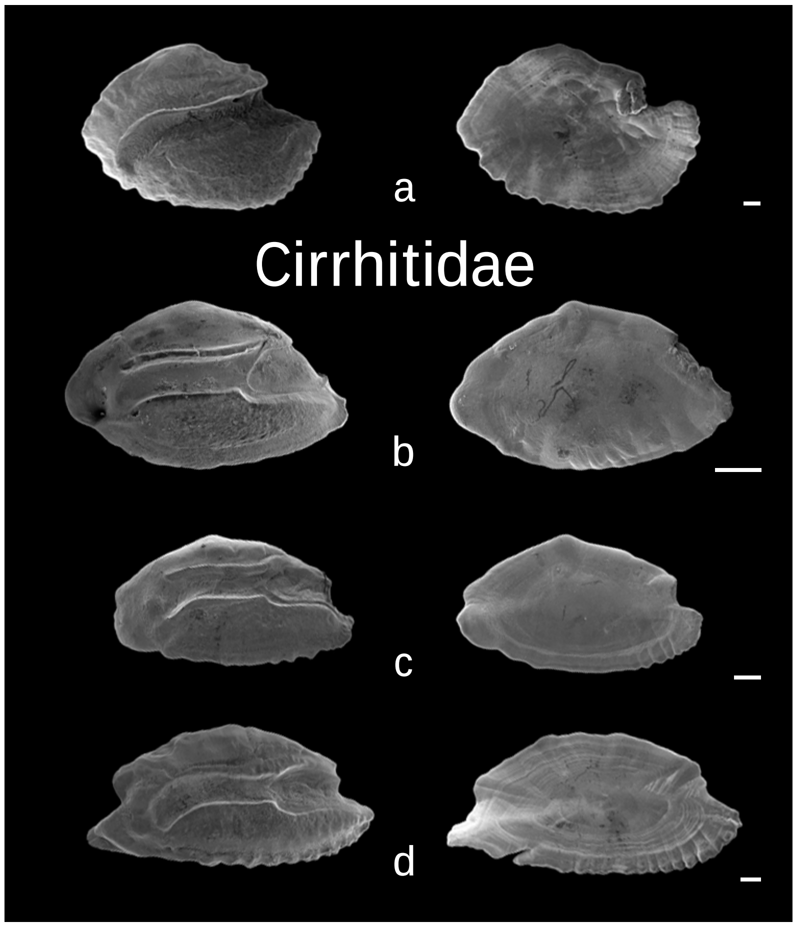

Figure 100. Chaetodontidae and Cirrhitidae: *a*, *Forcipiger flavissimus*, 125 mm SL; *b*, *Amblycirrhitus bimacula*, 28 mm SL; *c*, *Amblycirrhitus bimacula*, 49 mm SL; *d*, *Cirrhitops fasciatus*, 78 mm SL. Scale bars = 300 μm.

4.3.13 Creediidae (fig. 102*c, d*)

Outline rectangular-obovate. Archaesulcoid with ostial opening. Homomorph, colliculi indistinct.

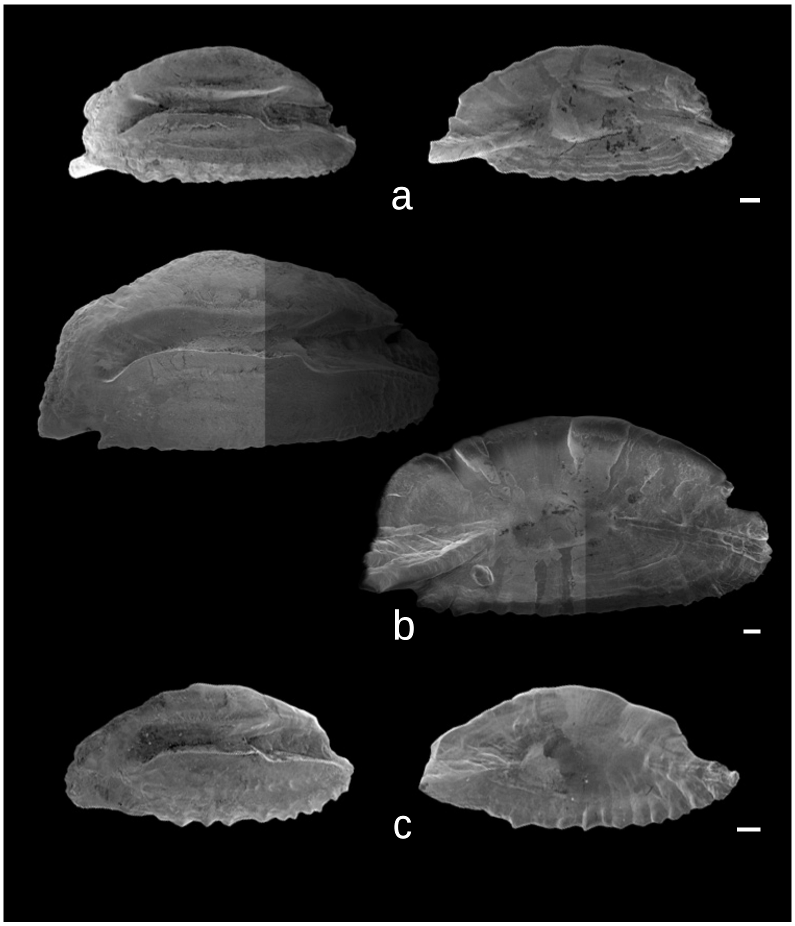

Figure 101. Cirrhitidae: *a*, *Cirrhitus pinnulatus*, size unknown; *b*, *Cirrhitus pinnulatus*, size unknown; *c*, *Paracirrhites arcatus*, 73 mm SL. Scale bars = 300 μm.

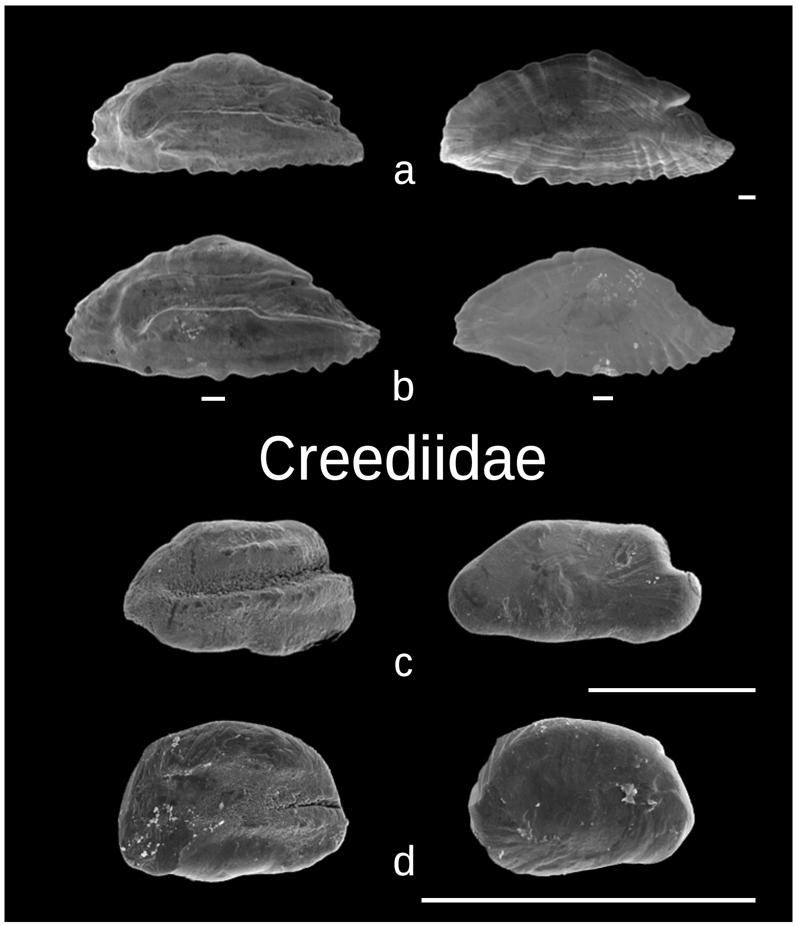

Figure 102. Cirrhitidae and Creediidae: *a*, *Paracirrhites forsteri*, 133 mm SL; *b*, *Paracirrhites forsteri*, 134 mm SL (note change in scale); *c*, *Crystallodytes cookei*, size unknown; *d*, *Limnichthys donaldsoni*, size unknown. Scale bars = 300 μm.

4.3.14 Gobiidae (figs. 103–105)

Outline square. Heterosulcoid with mesial opening. Ostium arrowhead shaped. Cauda oblong with rounded tip. Homomorph, colliculum undifferentiated. Cristae well developed. Dorsal depression shallow and large.

Greenfield and Randall have submitted a description of the *Cabillus* species, below.

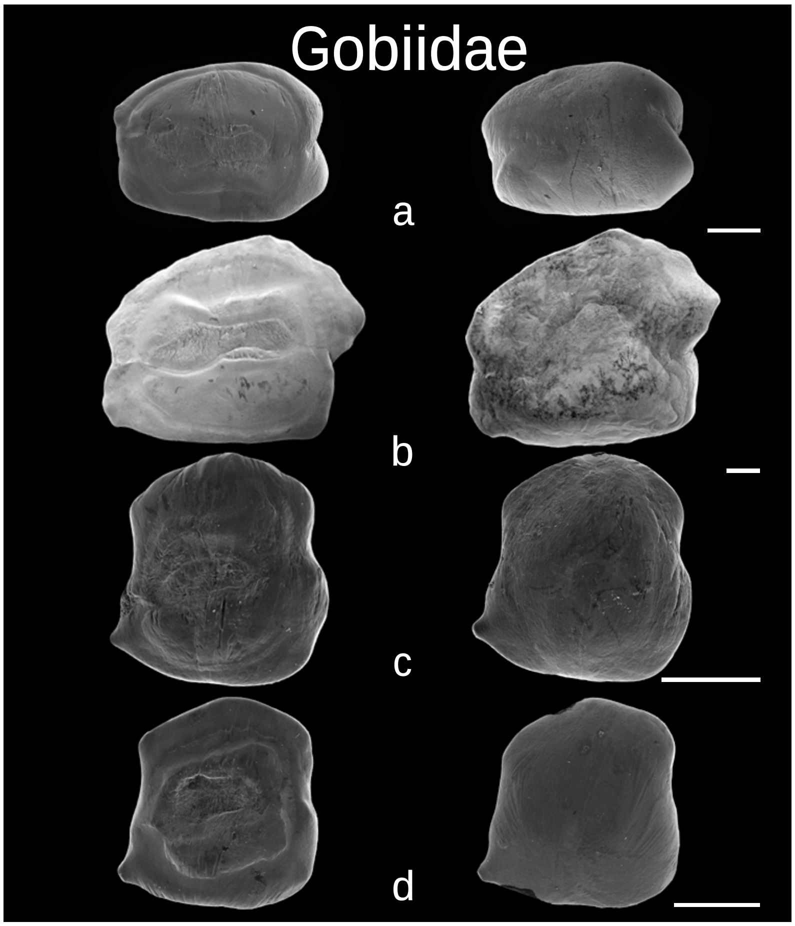

Figure 103. Gobiidae: *a*, *Cabillus*, undescribed species, 18 mm SL; *b*, *Coryphopterus duospilos*, 35 mm SL; *c*, *Eviota epiphanes*, 13 mm SL; *d*, *Eviota rubra*, 13 mm SL. Scale bars = 300 μm.

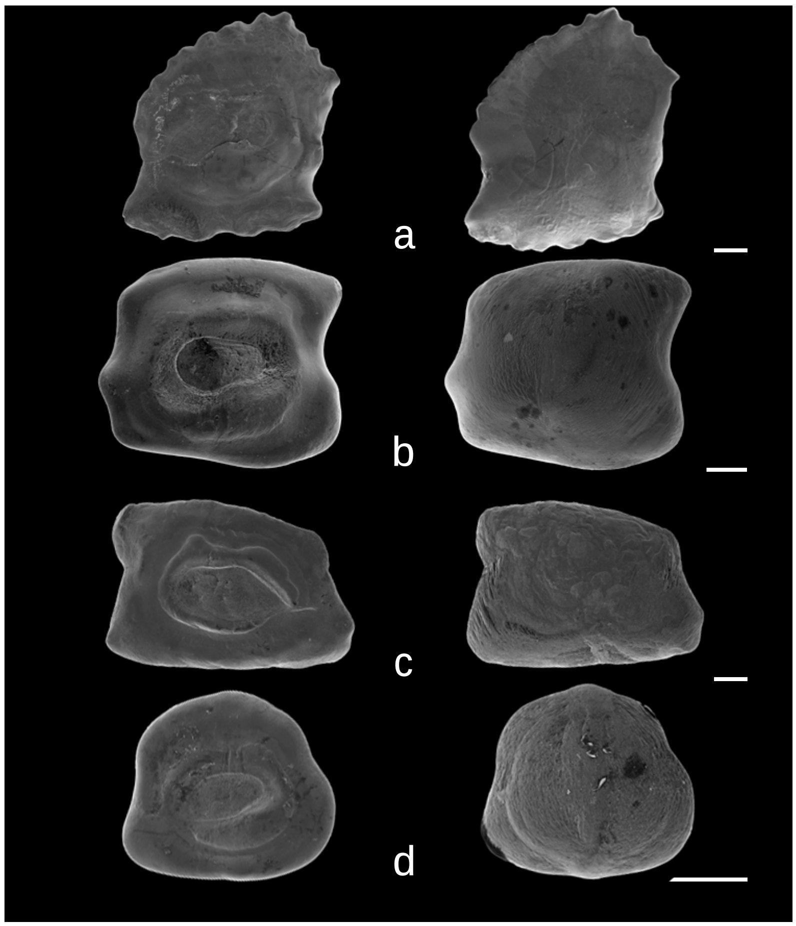

Figure 104. Gobiidae: *a*, *Gnatholepis cuarensis*, 35 mm SL; *b*, *Priolepis aureoviridis*, 26 mm SL; *c*, *Priolepis eugenius*, 31 mm SL; *d*, *Priolepis farcimen*, 12 mm SL. Scale bars = 300 μm.

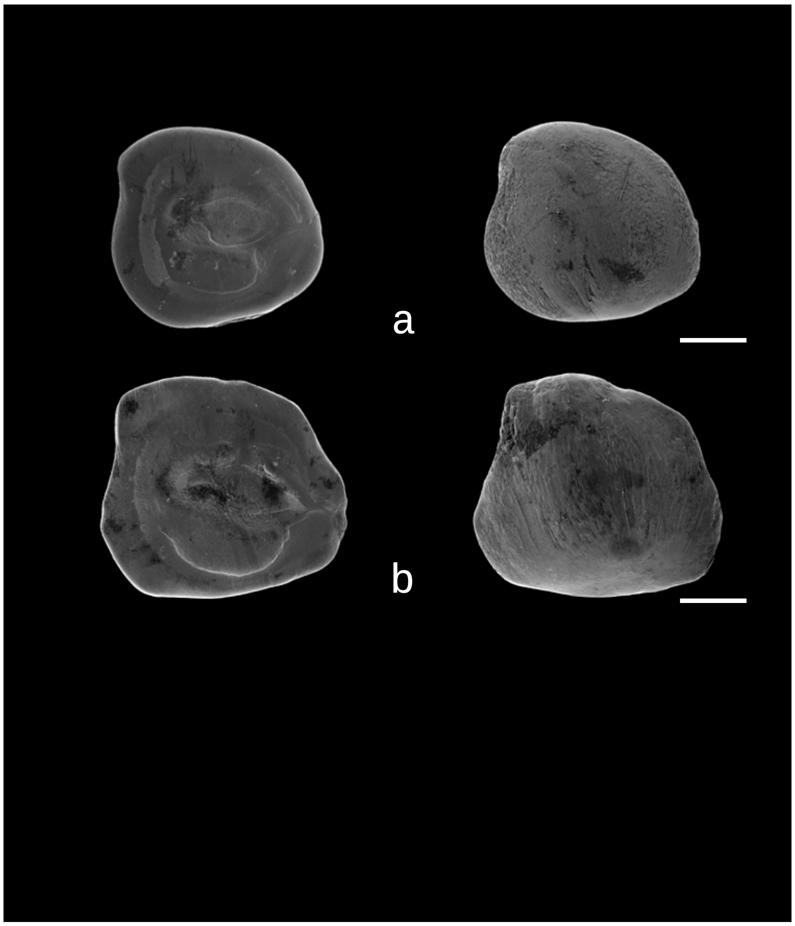

Figure 105. Gobiidae: *a*, *Trimma unisquamis*, 16 mm SL; *b*, *Trimma unisquamis*, 17 mm SL. Scale bars = 300 μm.

4.3.15 Holocentridae

This family is composed of two subfamilies (the Myripristinae, or soldierfishes, and the Holocentrinae, or squirrelfishes) with strikingly different otoliths. The subfamilies are treated separately below.

Myripristinae (figs. 106, 107) Outline rounded-triangular. Heterosulcoid, opening ostial, onto dorsal margin. Ostium large, reniform. Cauda complex, forked. Heteromorph colliculi. Ventral area large. Dorsal area reduced, with distinct depression.

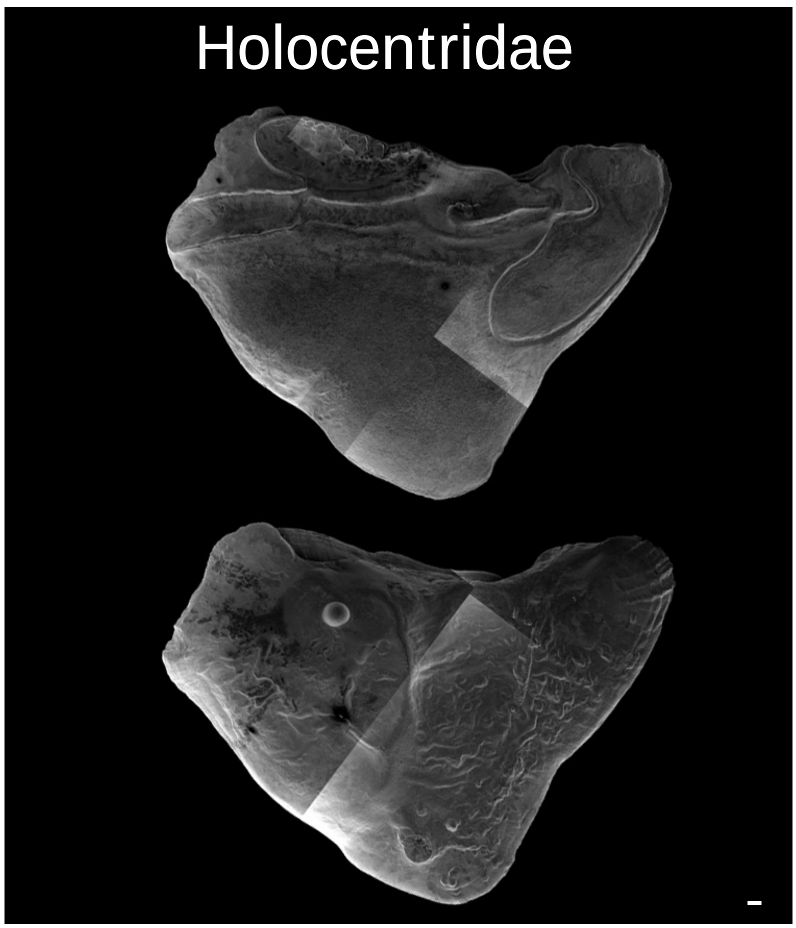

Figure 106. Holocentridae: *Myripristis berndti*, 150 mm SL. Scale bar = 300 μm.

Holocentrinae (fig. 108) Outline oval-ovate. Heterosulcoid, opening ostial. Ostium is bulbous ventrally with straight dorsal wall. Cauda long, flexed. Heteromorph with single anterior colliculum.

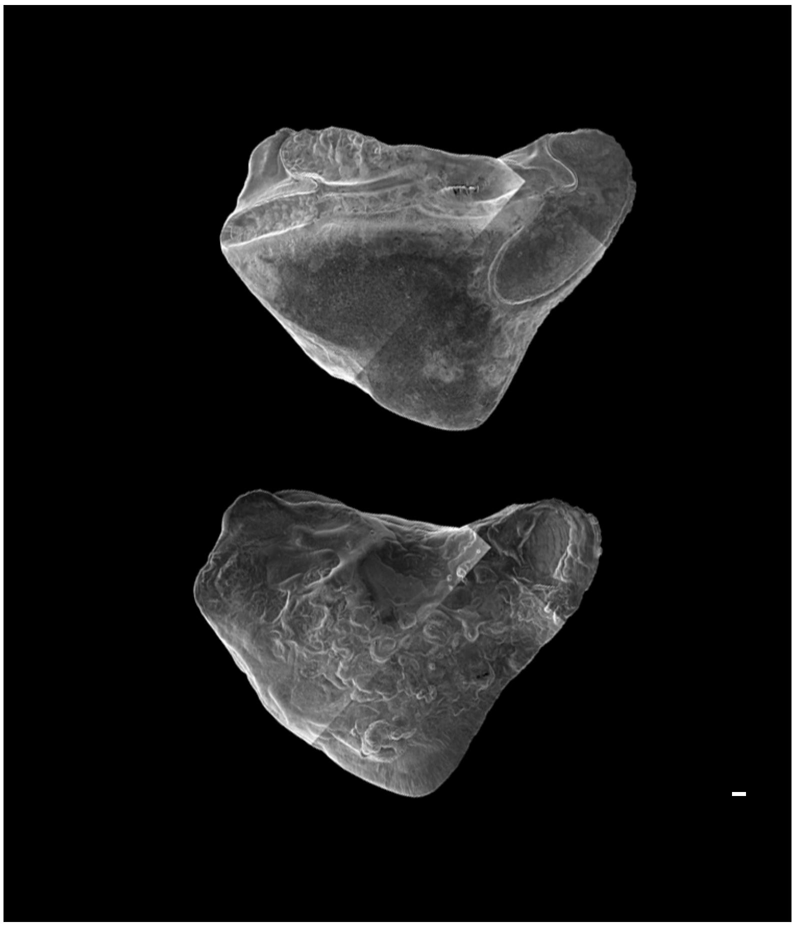

Figure 107. Holocentridae: *Myripristis kuntee*, 135 mm SL. Scale bar = 300 μm.

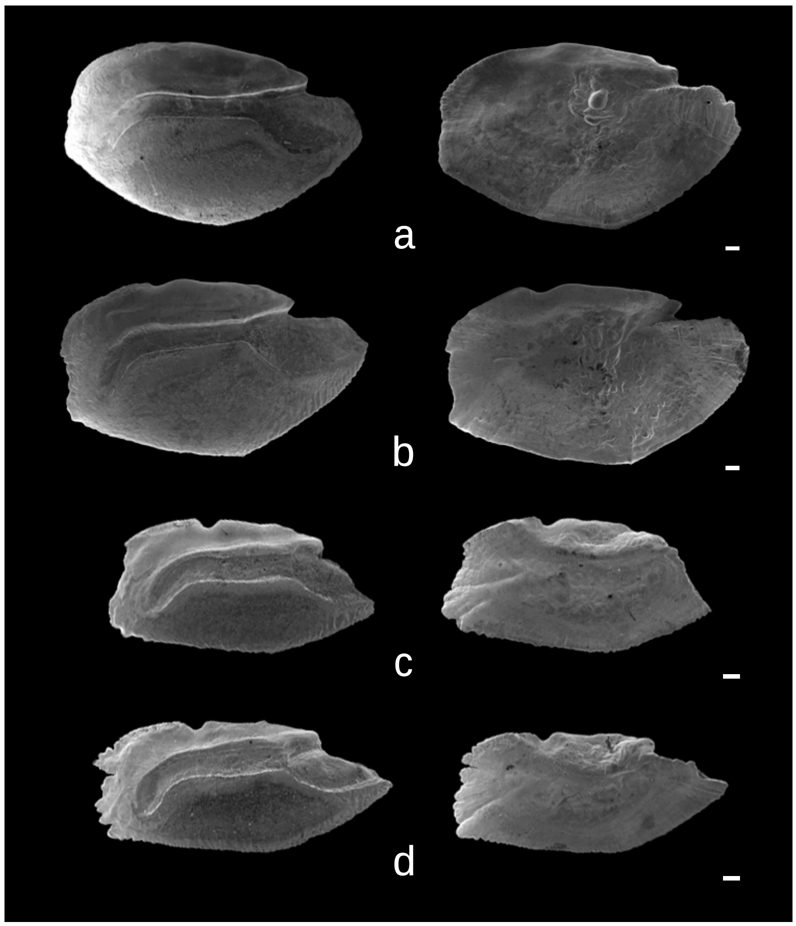

Figure 108. Holocentridae: *a*, *Sargocentron diadema*, 122 mm SL; *b*, *Sargocentron diadema*, 131 mm SL; *c*, *Sargocentron punctatissimum*, 103 mm SL; *d*, *Sargocentron punctatissimum*, 105 mm SL. Scale bars = 300 μm.

4.3.16 Kraemeridae (fig. 109*a*)

Outline tall. Archaesulcoid, opening mesial.

4.3.17 Kuhliidae (fig. 109*b*)

Outline oblong-ovate. Heterosulcoid, ostial opening. Heteromorph, indistinct colliculi. Cauda long and narrow, flexed at tip.

4.3.18 Kyphosidae (fig. 109*c*)

Outline oblong. Heterosulcoid with ostial opening, slightly flared, not confined to rostrum. Cauda straight with flexed tip near ventral margin. Crista superior ridge-like from neck to flexion, crista inferior well developed. Heteromorph with indistinct colliculi.

neck
crista inferior

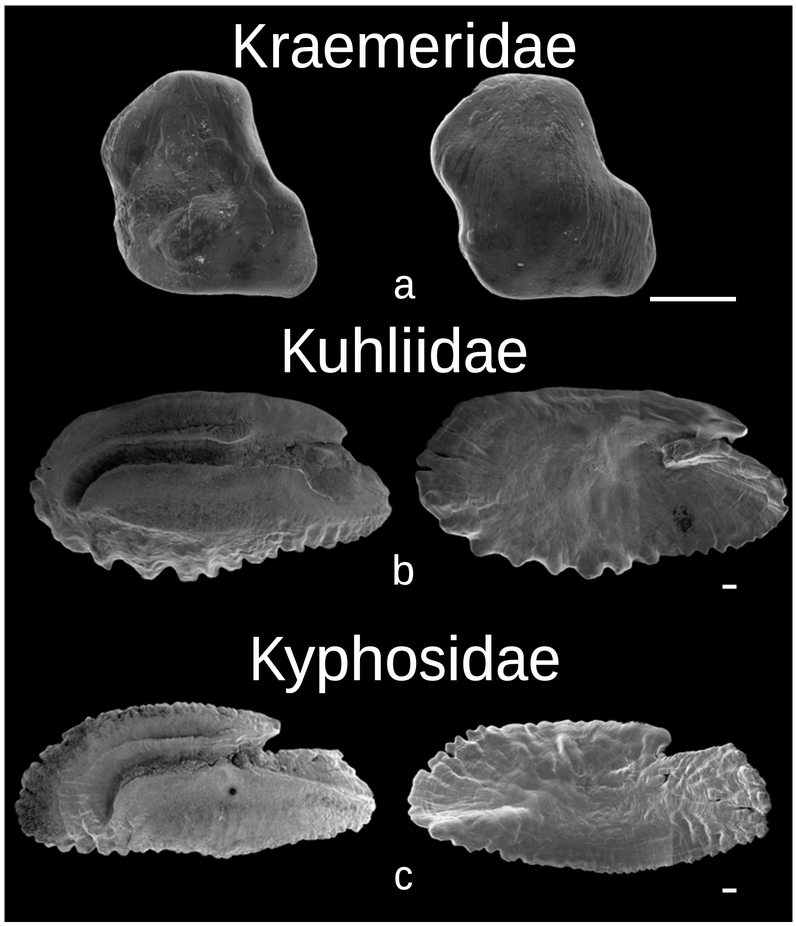

Figure 109. Kraemeridae, Kuhliidae and Kyphosidae: *a*, *Kraemeria bryani*, size unknown; *b*, *Kuhlia* species, 181 mm SL; *c*, *Kyphosus bigibbus*, 366 mm SL. Scale bars = 300 μm.

4.3.19 Labridae (figs. 110–114)

Outline varied: oblong, fusiform, obovate, or anvil-shaped. Heterosulcoid. Openings varied: ostial, ostio-pseudocaudal, or ostio-caudal. Cauda usually flared. Often with a wall-like collum. Heteromorph, colliculi usually low or indented with raised margins but may be indistinct and difficult to see. Cristae usually well developed along the sulcus and ridge-like over neck.

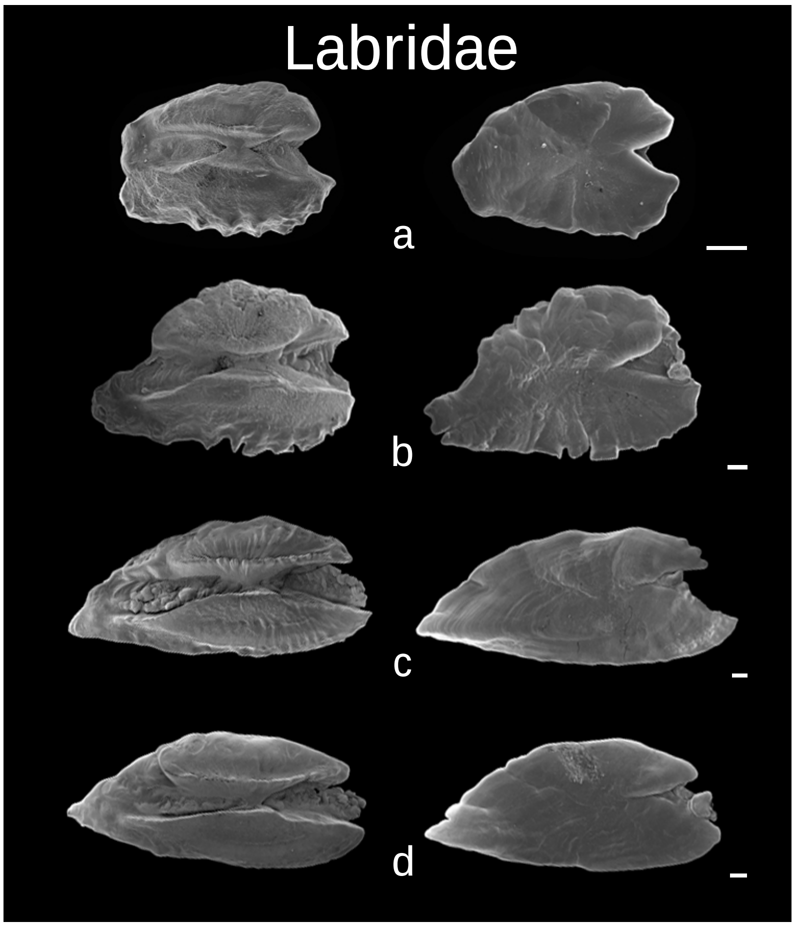

Figure 110. Labridae: *a*, *Anampses chrysocephalus*, 60 mm SL; *b*, *Anampses cuvier*, 182 mm SL; *c*, *Bodianus bilunulatus*, 178 mm SL; *d*, *Bodianus bilunulatus*, 255 mm SL. Scale bars = 300 μm.

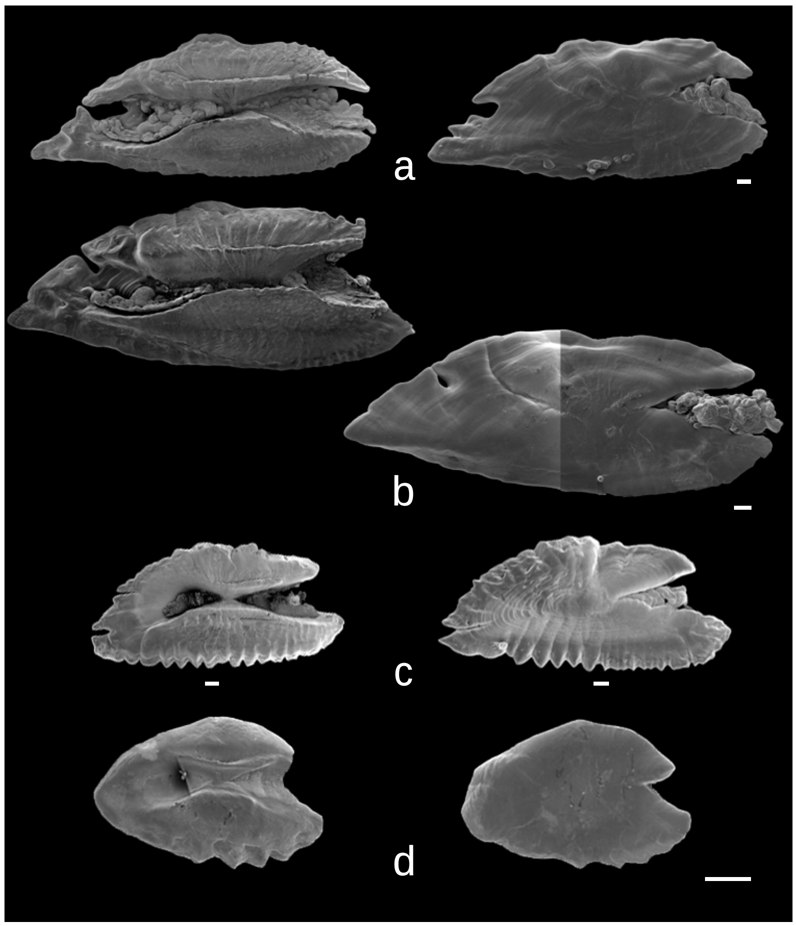

Figure 111. Labridae: *a*, *Bodianus bilunulatus*, 265 mm SL; *b*, *Bodianus bilunulatus*, 360 mm SL; *c*, *Cheilio inermis*, 315 mm SL (note change in scale); *d*, *Coris gaimard*, 46 mm SL. Scale bars = 300 μm.

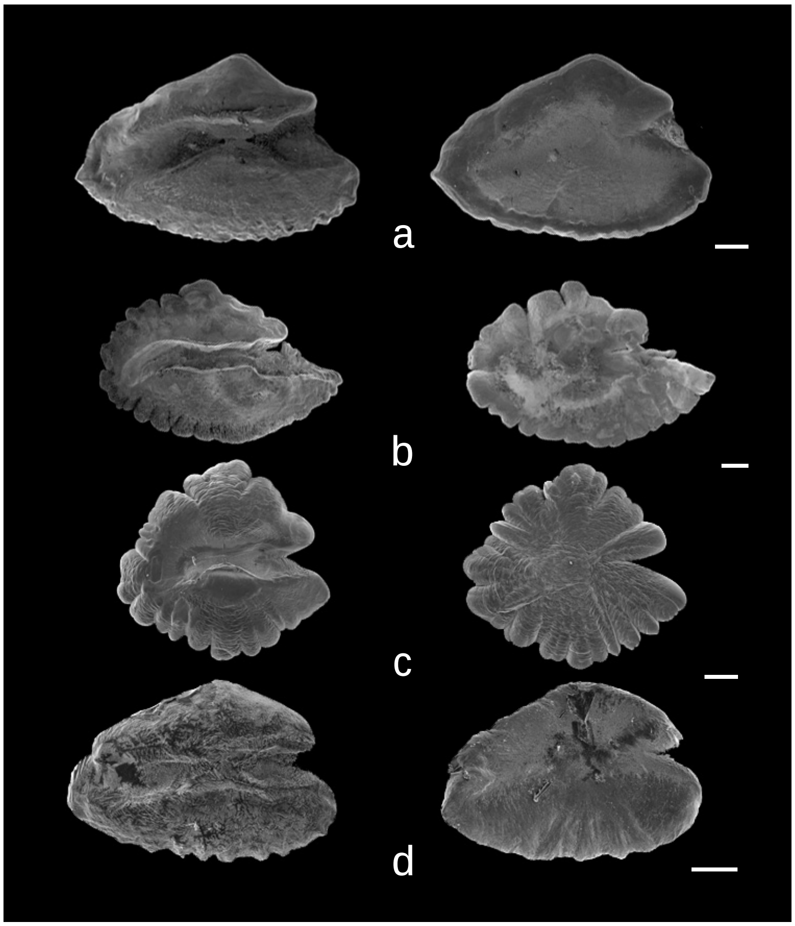

Figure 112. Labridae: *a*, *Coris venusta*, 82 mm SL; *b*, *Halichoeres ornatissimus*, 42 mm SL; *c*, *Iniistius pavo*, 66 mm SL; *d*, *Labroides phthirophagus*, 55 mm SL. Scale bars = 300 μm.

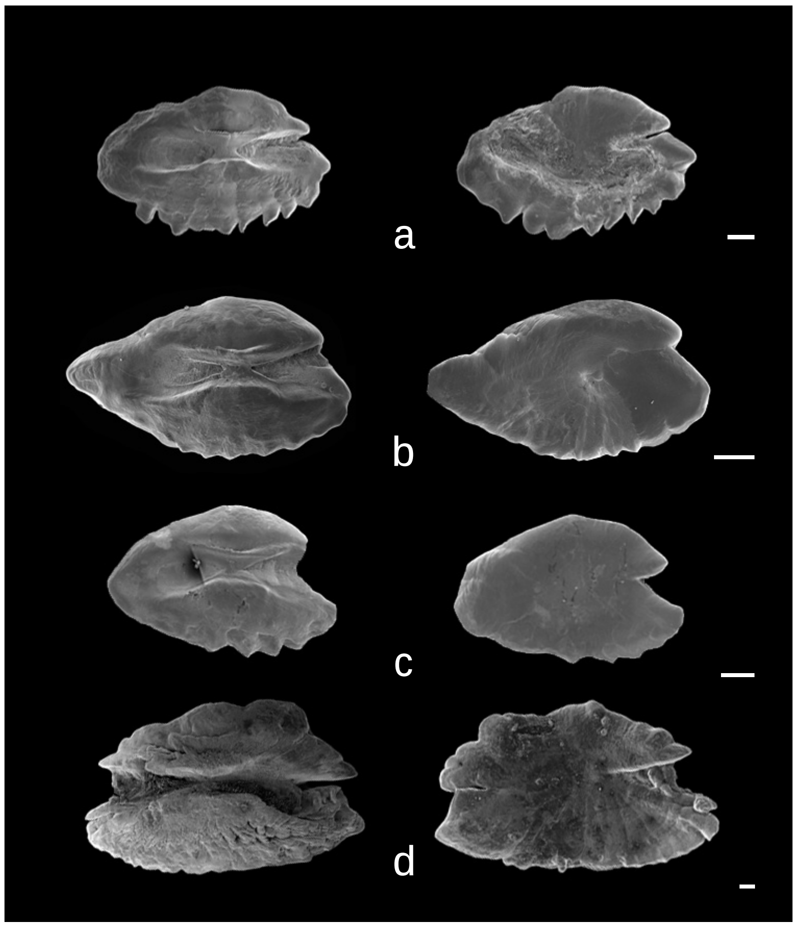

Figure 113. Labridae: *a*, *Oxycheilinus bimaculatus*, 60 mm SL; *b*, *Pseudocheilinus octotaenia*, 45 mm SL; *c*, *Pseudojuloides cerasinus*, 65 mm SL; *d*, *Thalassoma ballieui*, 219 mm SL. Scale bars = 300 μm.

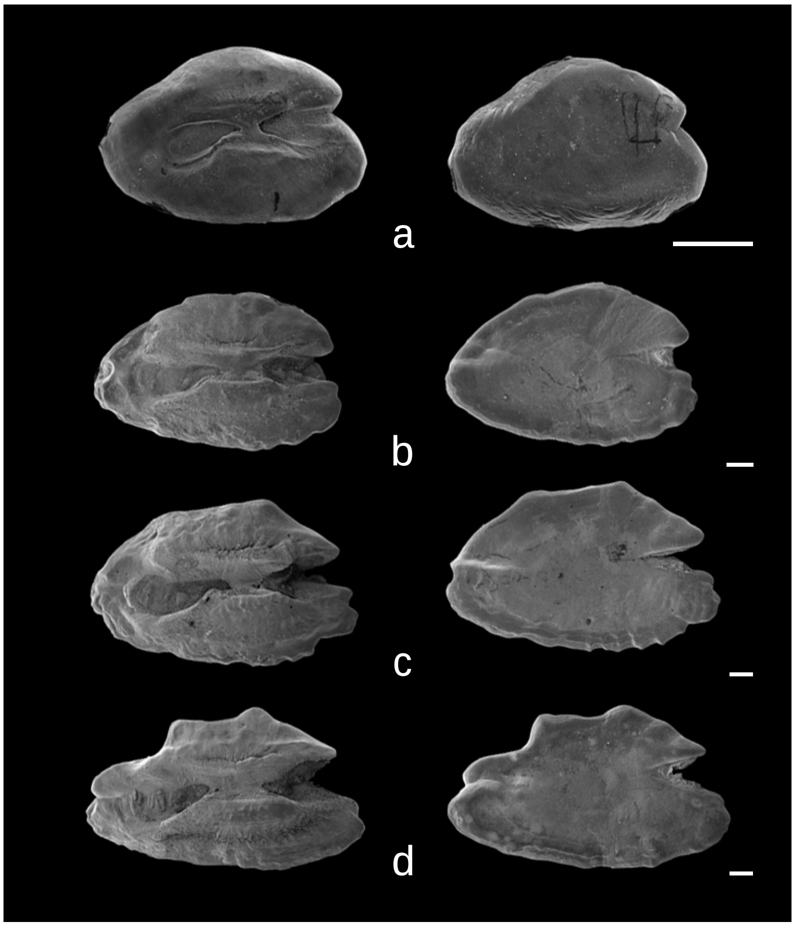

Figure 114. Labridae: *a*, *Thalassoma duperrey*, 25 mm SL; *b*, *Thalassoma duperrey*, 87 mm SL; *c*, *Thalassoma duperrey*, 110 mm SL; *d*, *Thalassoma duperrey*, 117 mm SL. Scale bars = 300 μm.

4.3.20 Lethrinidae (fig. 115)

Outline ovate with pronounced postero-ventral corner. Heterosulcoid with ostial openings. Ostium broad. Cauda narrower, flexed. Heteromorph with low colliculi.

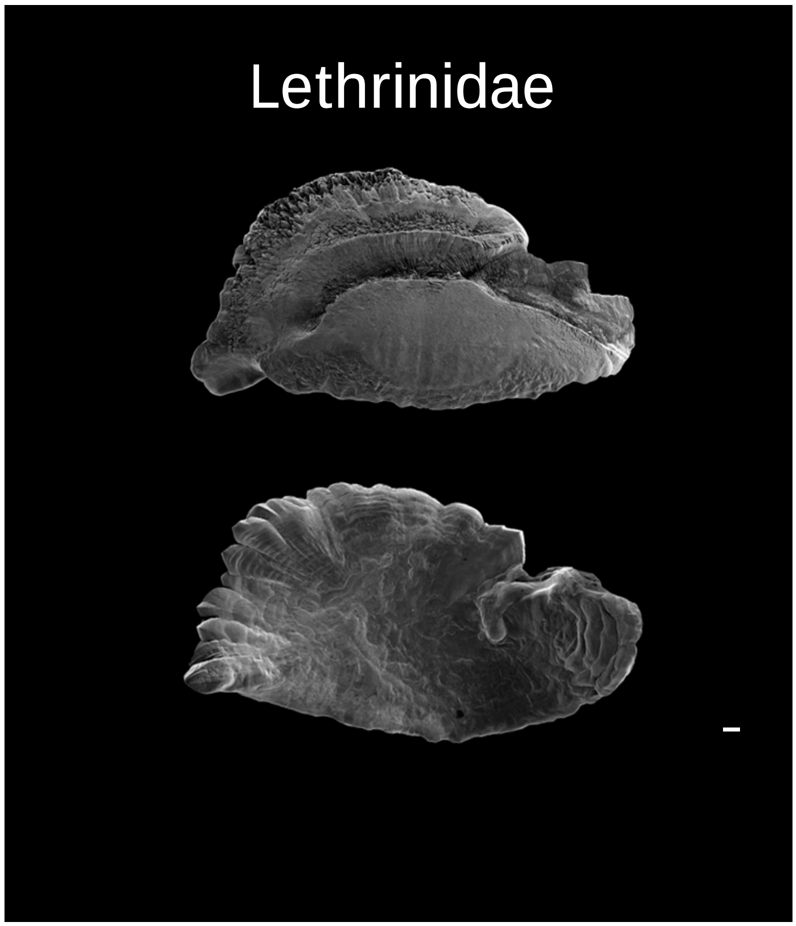

Figure 115. Lethrinidae: *Monotaxis grandoculis*, 207 mm SL. Scale bar = 300 μm.

4.3.21 Lutjanidae (figs. 116, 117)

Outline oval. Heterosulcoid with ostial openings although and may open into ventral depression. Ostium short. Cauda long, narrow and flexed near tip. Cauda not distinctly closed in some specimens. Heteromorph with low but distinct anterior colliculum; posterior colliculum indented and indistinct but margins visible. posterior colliculum

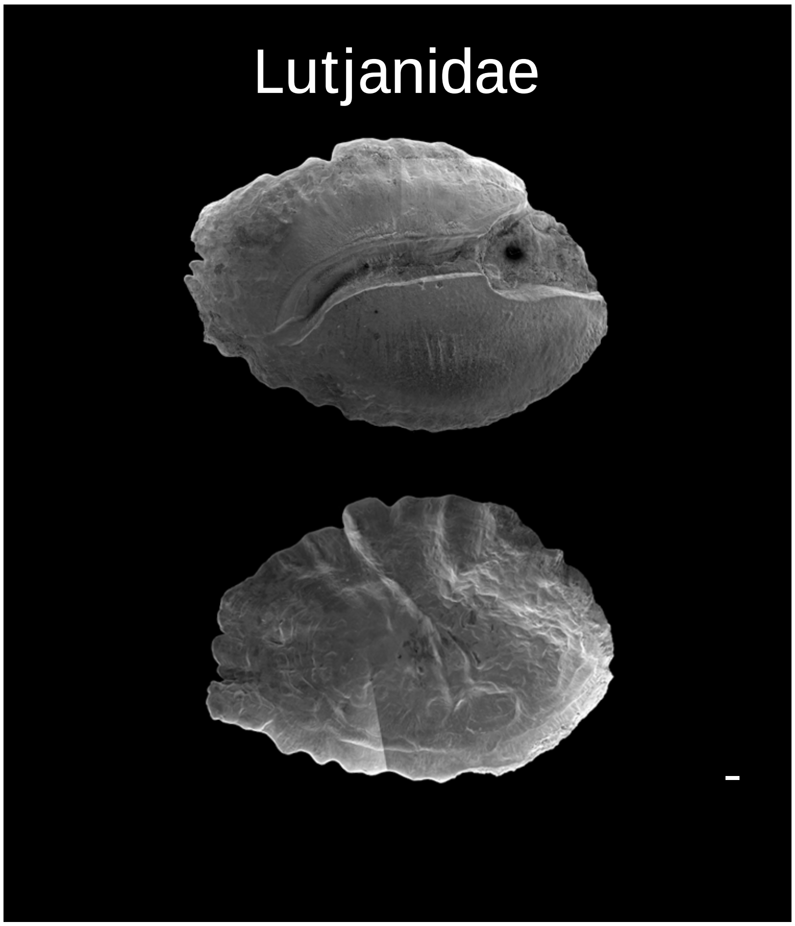

Figure 116. Lutjanidae: *Lutjanus kasmira*, 178 mm SL. Scale bar = 300 μm.

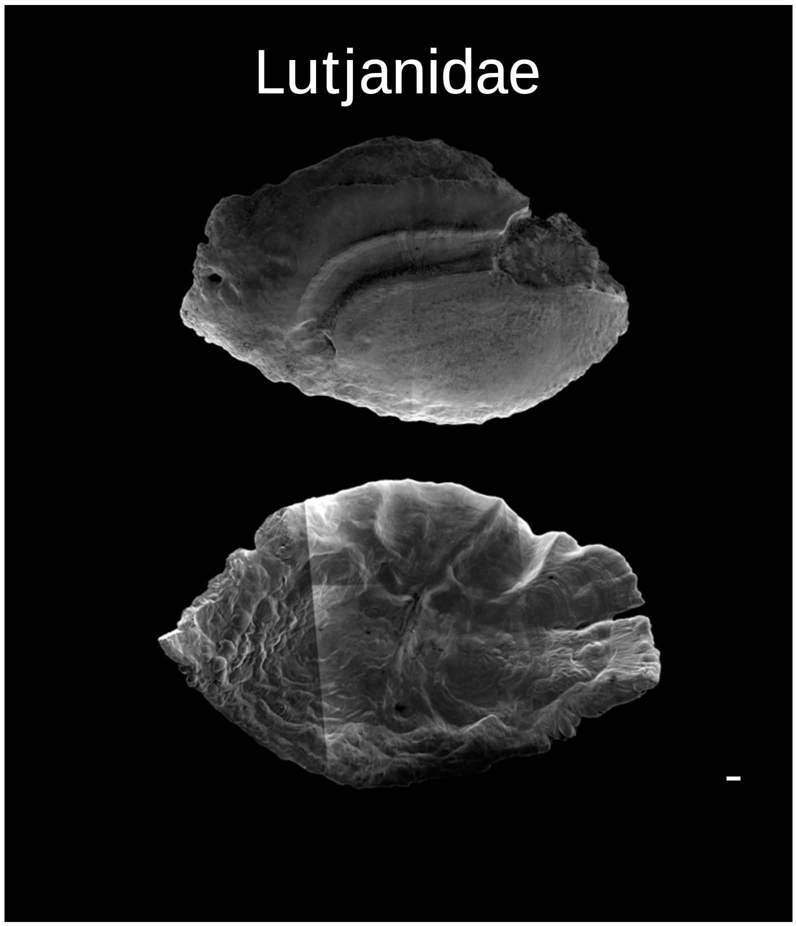

Figure 117. Lutjanidae: *Lutjanus kasmira*, 183 mm SL. Scale bar = 300 μm.

4.3.22 Monacanthidae (figs. 118, 119*a*)

Outline hourglass-shaped. Homosulcoid with ostio-caudal opening. Ostium and cauda flared. With wall-like collum and indistinct colliculi.

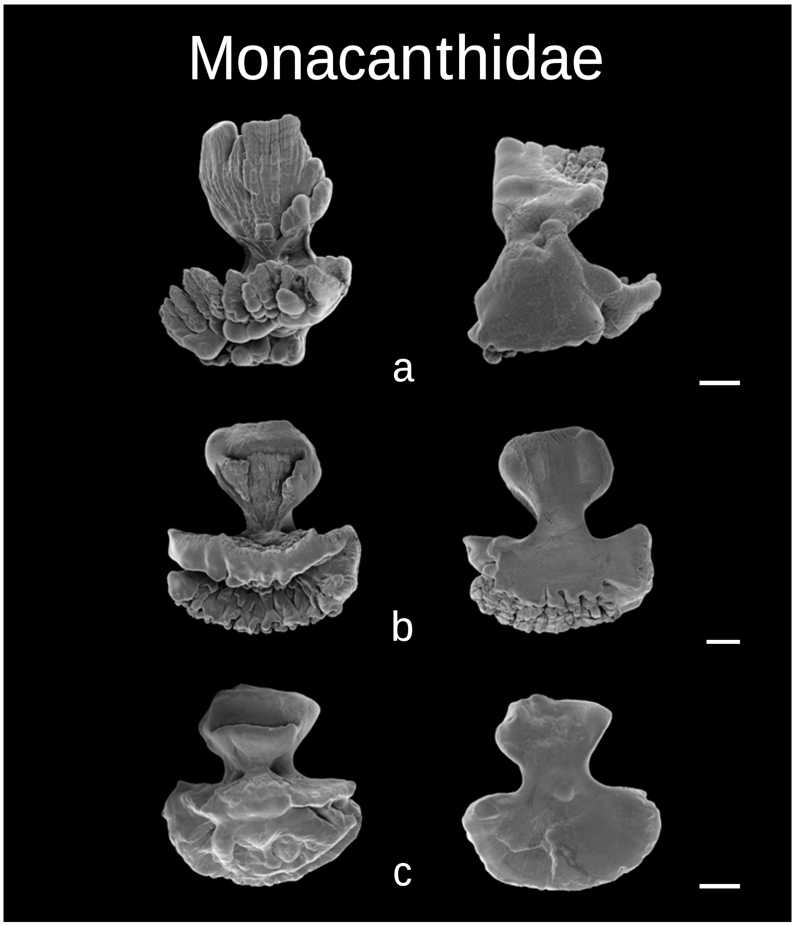

Figure 118. Monacanthidae: *a*, *Cantherhines dumerilii*, 308 mm SL; *b*, *Cantherhines sandwichiensis*, 140 mm SL; *c*, *Pervagor aspricaudus*, 79 mm SL. Scale bars = 300 μm.

4.3.23 Mullidae (figs. 119*b-d*, 120)

Outline oval to elliptic. Ventral margin irregular-dentate. Heterosulcoid with ostial opening. Ostium small, may have a pit or perforation. Cauda straight and narrow anteriorly, with ventrally flexed, wide and rounded posteriorly. Crista superior ridge-like along anterior cauda. Heteromorph with very indistinct colliculi.

dentate

crista superior

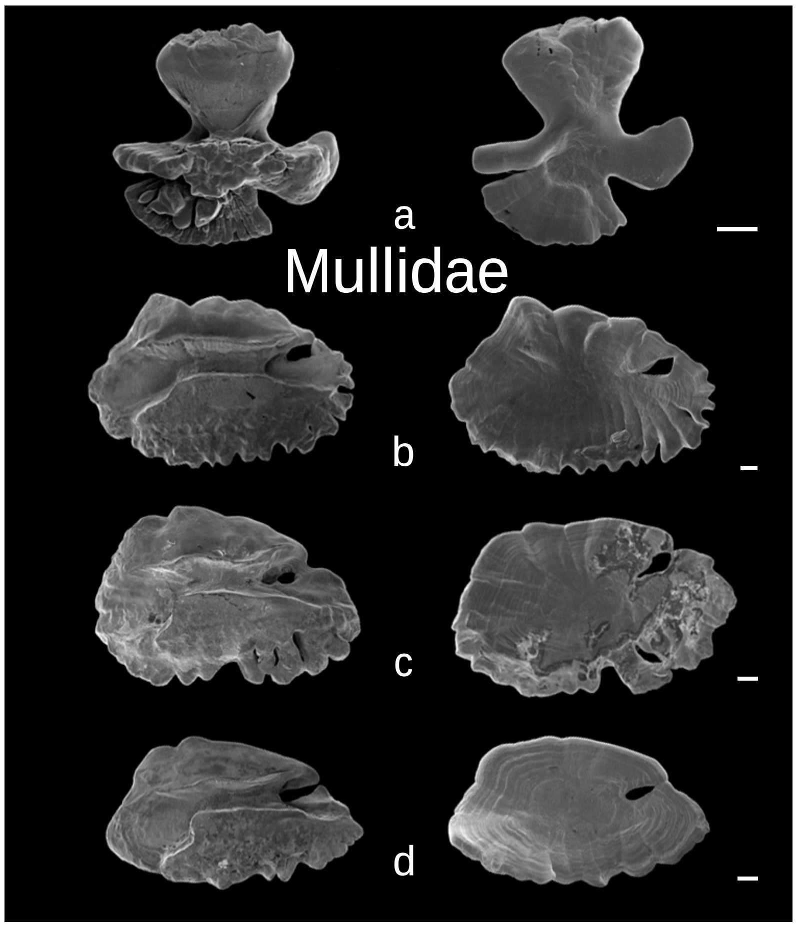

Figure 119. Monacanthidae and Mullidae: *a*, *Pervagor spilosoma*, 182 mm SL; *b*, *Mulloidichthys flavolineatus*, 182 mm SL; *c*, *Parupeneus bifasciatus*, 169 mm SL; *d*, *Parupeneus cyclostomus*, 139 mm SL. Scale bars = 300 μm.

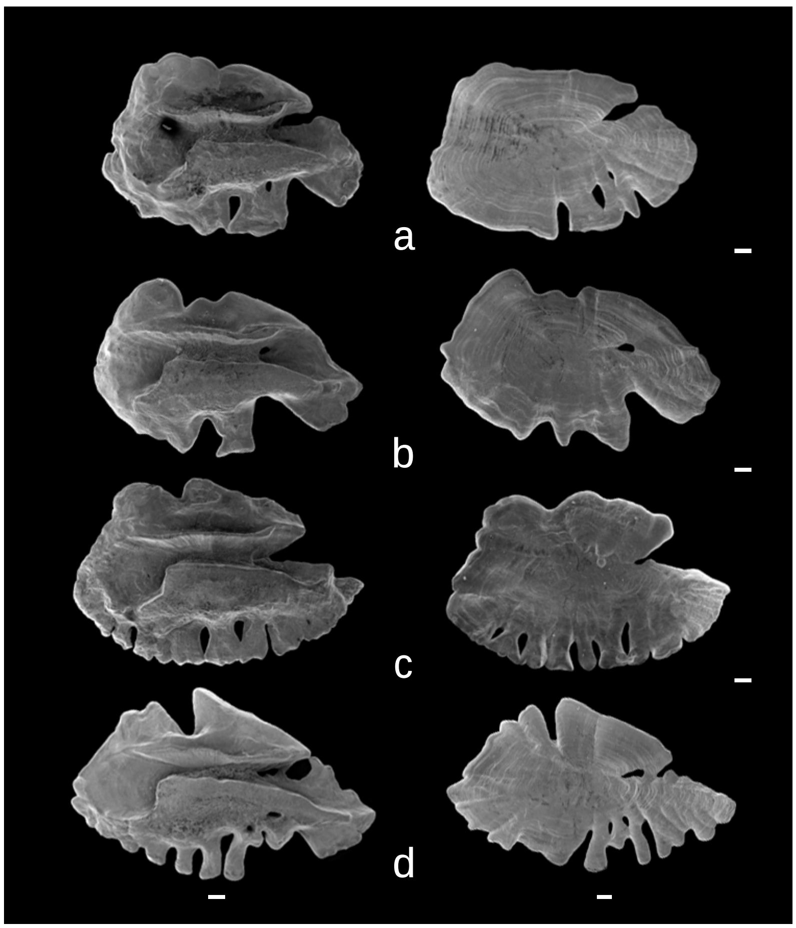

Figure 120. Mullidae: *a*, *Parupeneus multifasciatus*, 107 mm SL; *b*, *Parupeneus multifasciatus*, size unknown; *c*, *Parupeneus pleurostigma*, 238 mm SL; *d*, *Parupeneus porphyreus*, 227 mm SL (note change in scale). Scale bars = 300 μm.

4.3.24 Muraenidae (figs. 121, 122*a*)

Outline elliptic with notched anterior margin. Heterosulcoid with ostial opening. Ostium flared with parallel walls. Cauda straight, with groove extending from tip. Homomorph colliculum.

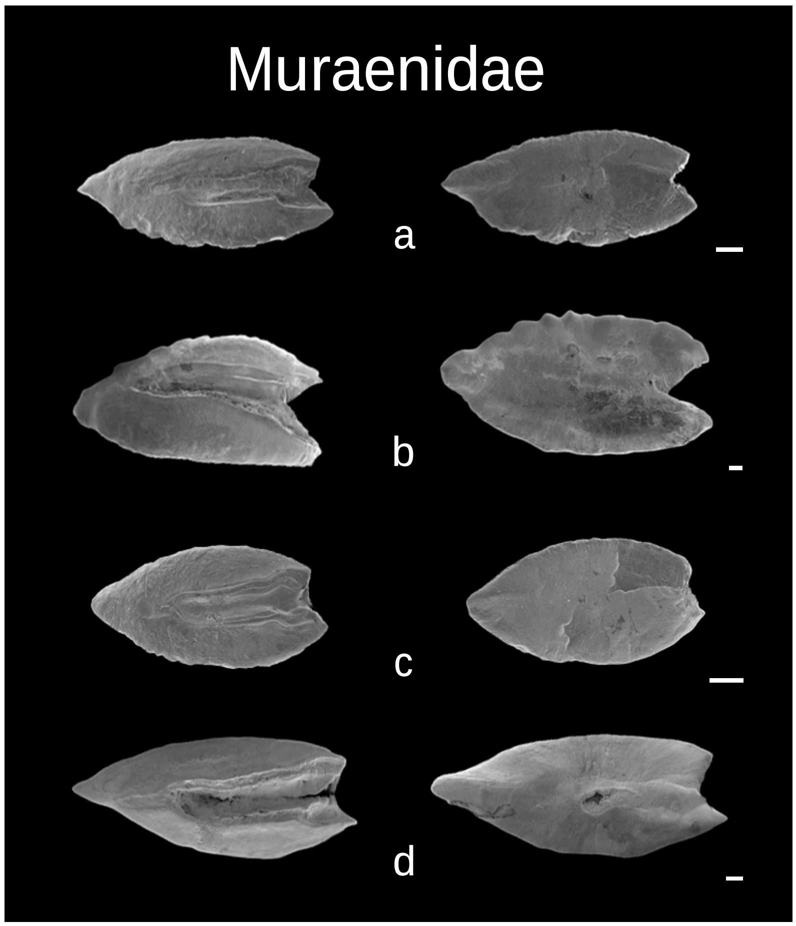

Figure 121. Muraenidae: *a*, *Gymnothorax eurostus*, 242 mm TL; *b*, *Gymnothorax flavimarginatus*, 873 mm TL; *c*, *Gymnothorax melatremus*, 243 mm TL; *d*, *Gymnothorax meleagris*, 600 mm TL. Scale bars = 300 μm.

4.3.25 Ophichthidae (fig. 122*b, c*)

Outline oval or oblong. Small. Archaesulcoid with ostial opening or heterosulcoid with para-ostial opening.

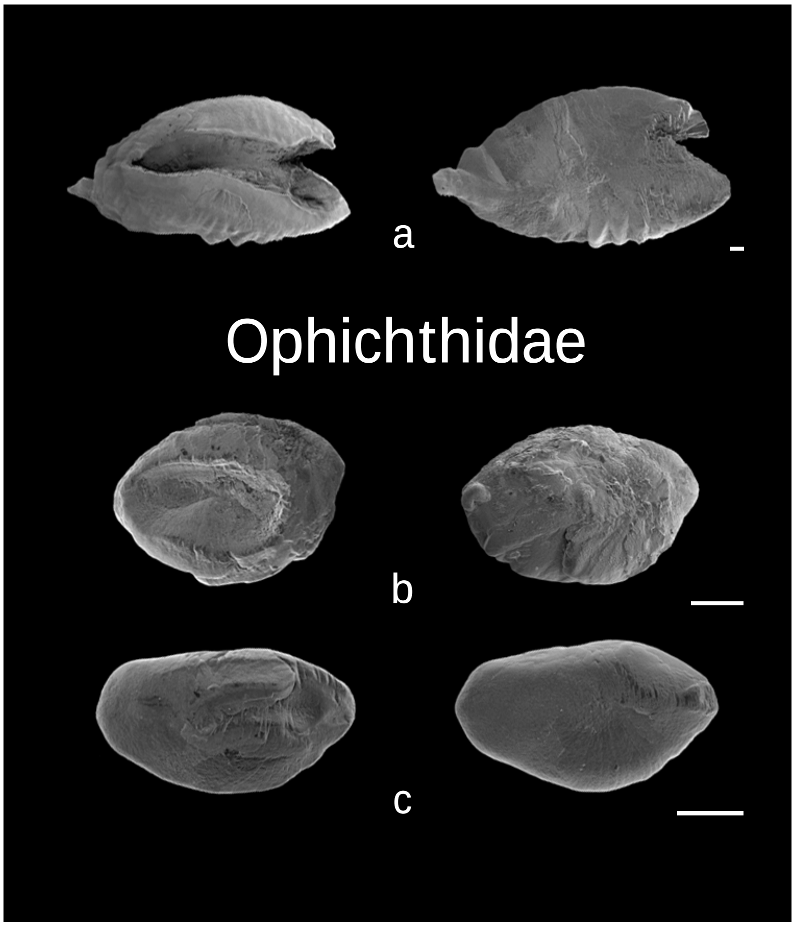

Figure 122. Muraenidae and Ophichtidae: *a*, *Gymnothorax undulatus*, 972 mm TL; *b*, *Ichthyapus vulturis*, 270 mm TL; *c*, *Moringua macrochir*, 242 mm SL. Scale bars = 300 μm.

4.3.26 Ophidiidae (fig. 123*a*)

Outline spindle-shaped. Archaesulcoid, with homomorph colliculum.

4.3.27 Ostraciidae (fig. 123*b*)

Outline tall. Heterosulcoid with ostio-caudal openings. Sulcus slightly flared anteriorly, narrows posteriorly with deep pit in center. Heteromorph, colliculi indistinct.

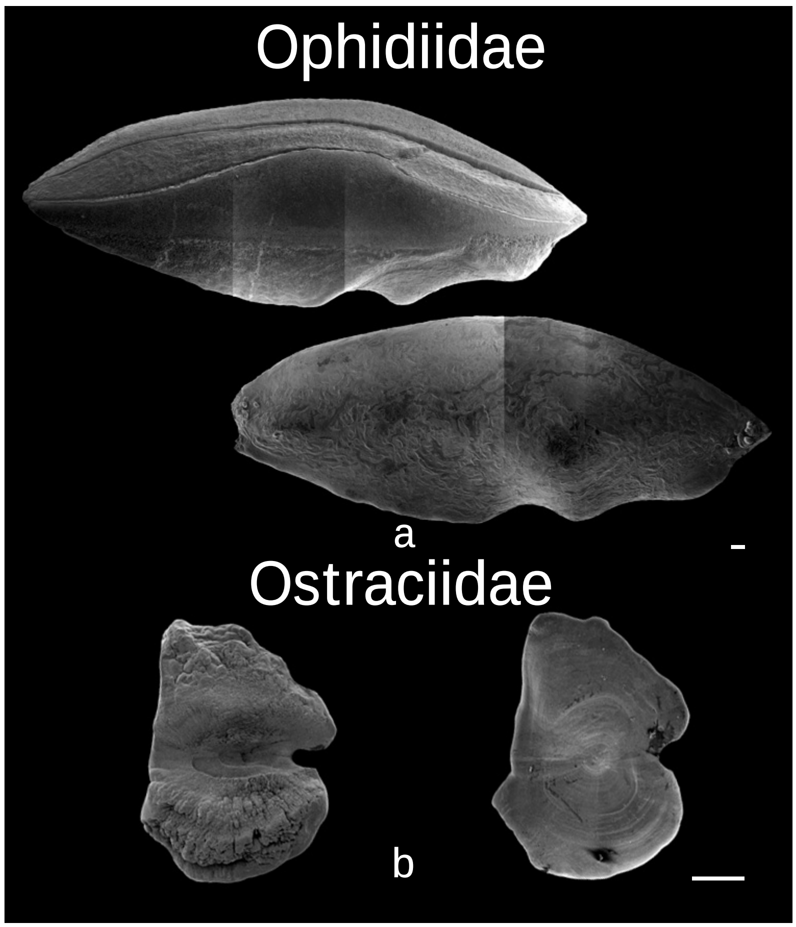

Figure 123. Ophidiidae and Osctraciidae: *a*, *Brotula multibarbata*, 198 mm SL; *b*, *Ostracion meleagris*, 60 mm SL. Scale bars = 300 μm.

4.3.28 Pinguipedidae (fig. 124*a*)

Outline fusiform. Heterosulcoid with ostial openings. Ostium slightly flared, cauda approximately straight, flared, slightly flexed and deeper at tip. Heteromorph, colliculi indented and indistinct.

4.3.29 Pomacanthidae (fig. 124*b, c*)

Outline oval. Heterosulcoid with ostial opening. Ostium elongate and approximately oval. Cauda narrow, angled ventrally and slightly flexed near tip. Sharp projection from ventral edge of sulcus forms neck. Heteromorph, anterior colliculum oval, raised, almost filling ostium; posterior colliculum very indistinct and depressed, margins visible. Cristae well developed.

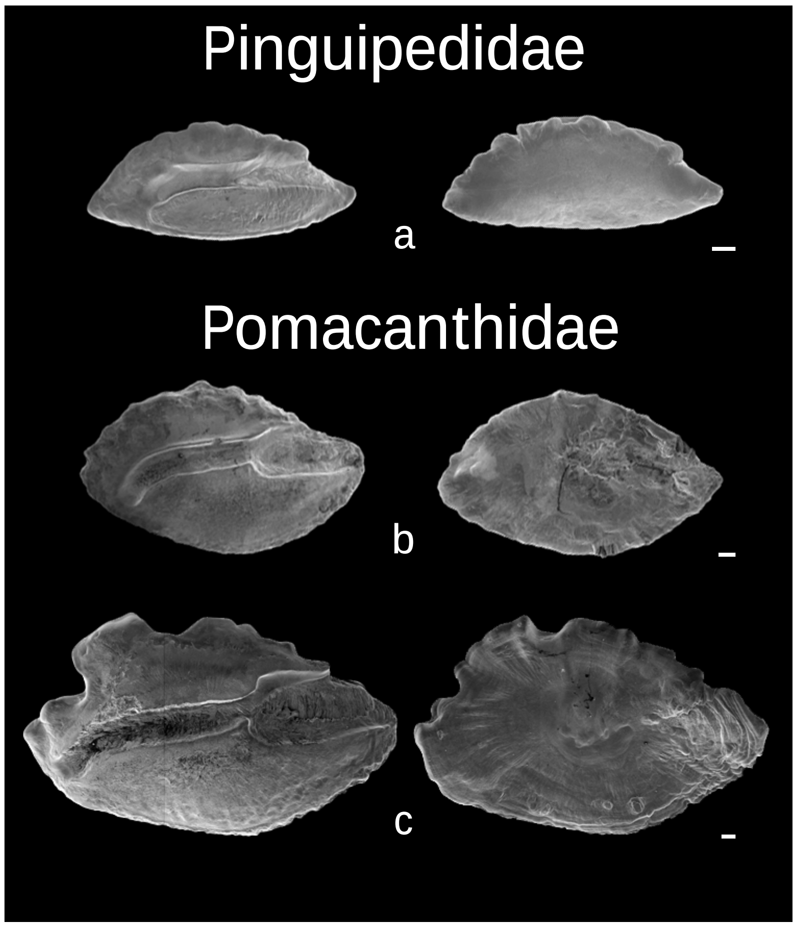

Figure 124. Pinguipedidae and Pomacanthidae: *a*, *Parapercis schauinslandii*, 68 mm SL; *b*, *Centropyge potteri*, 65 mm SL; *c*, *Desmoholacanthus arcuatus*, 123 mm SL. Scale bars = 300 μm.

4.3.30 Pomacentridae (figs. 125–127)

Outline oval-ovate or rhomboidal. Heterosulcoid with ostial opening. Ostium wider than flexed cauda. Crista superior usually ridge-like. Heteromorph, with indistinct colliculi.

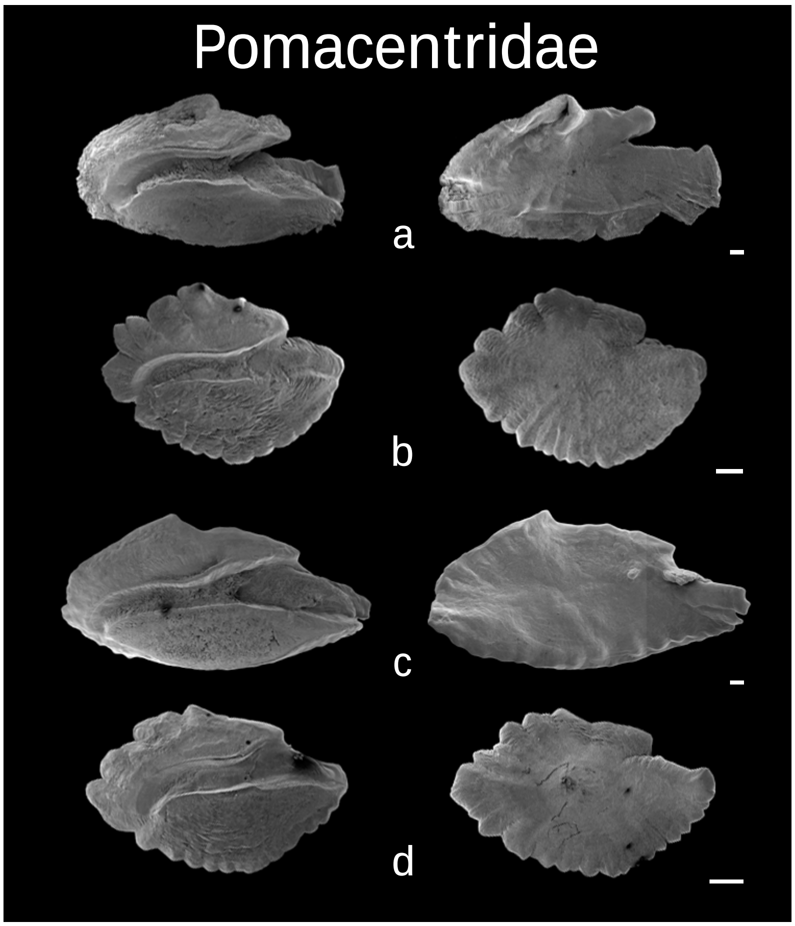

Figure 125. Pomacentridae: *a*, *Abudefduf abdominalis*, 129 mm SL; *b*, *Chromis hanui*, size unknown; *c*, *Chromis ovalis*, 122 mm SL; *d*, *Chromis vanderbilti*, 33 mm SL. Scale bars = 300 μm.

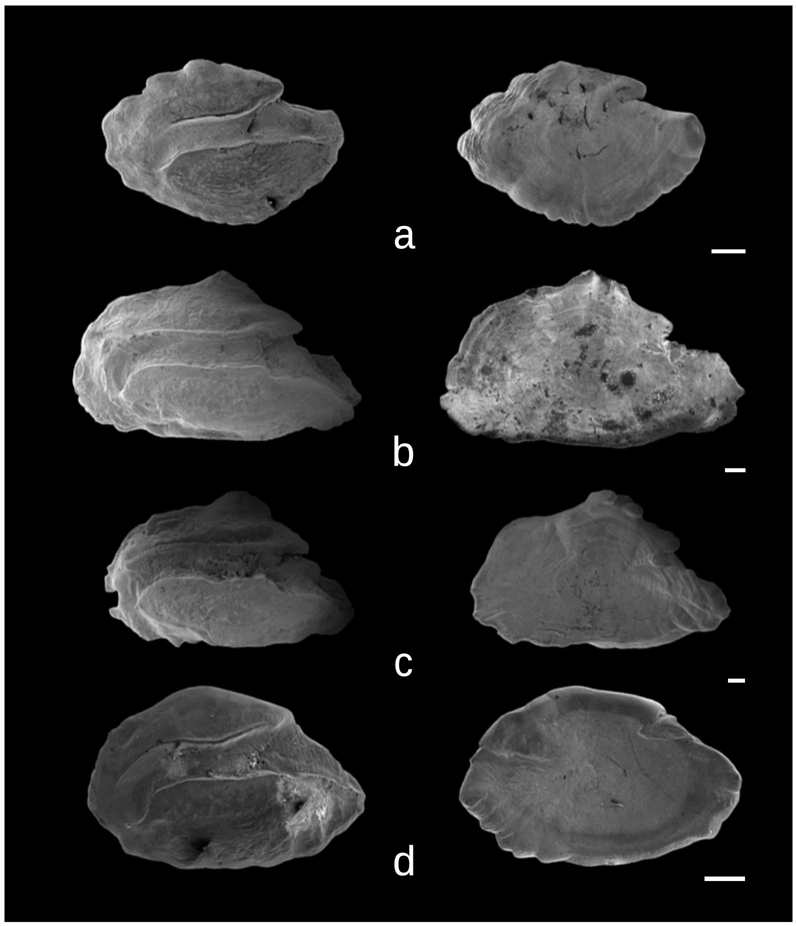

Figure 126. Pomacentridae: *a*, *Chromis vanderbilti*, 37 mm SL; *b*, *Dascyllus albisella*, 73 mm SL; *c*, *Dascyllus albisella*, 82 mm SL; *d*, *Plectroglyphidodon imparipennis*, 33 mm SL. Scale bars = 300 μm.

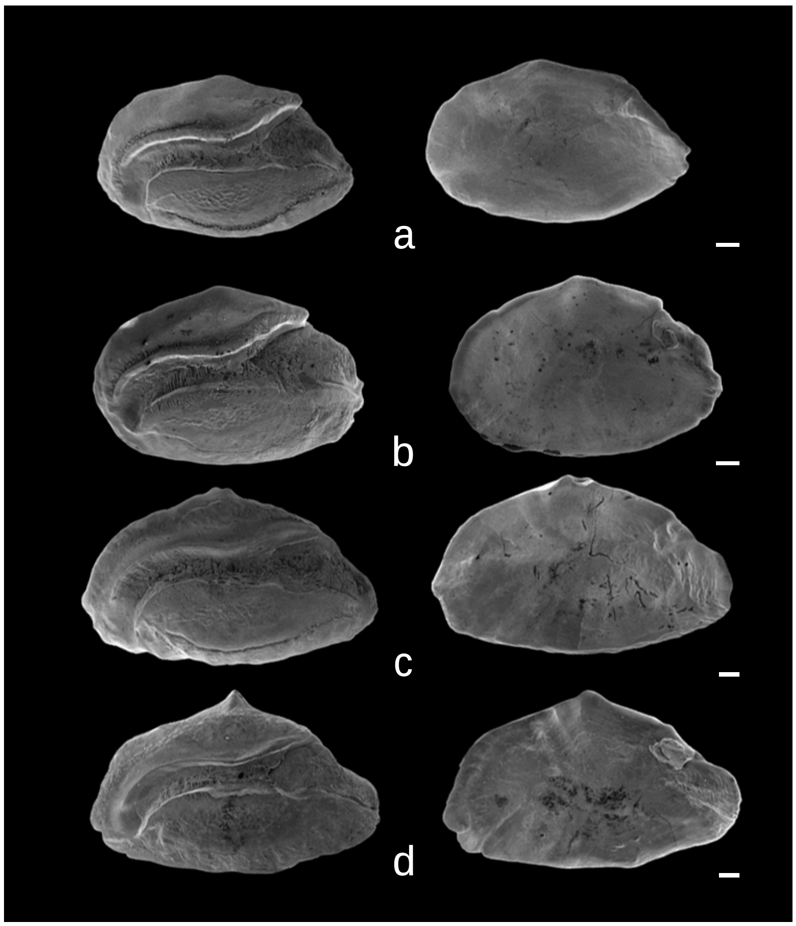

Figure 127. Pomacentridae: *a*, *Plectroglyphidodon johnstonianus*, 49 mm SL; *b*, *Plectroglyphidodon johnstonianus*, 55 mm SL; *c*, *Stegastes fasciolatus*, 68 mm SL; *d*, *Stegastes fasciolatus*, 71 mm SL. Scale bars = 300 μm.

4.3.31 Sammaridae (fig. 128*a*)

Outline sub-oval. Rostrum distinct, moderate. Homosulcoid with ostial opening. Ostium with parallel walls. Cauda straight. Heteromorph with indistinct anterior colliculum and raised posterior colliculum. Cristae well developed

4.3.32 Scaridae (figs. 128*b*, 129, 130*a*)

Outline oval. Homosulcoid with ostio-caudal openings. Ostium slightly broader than cauda, separated by a low collum. Homomorph with low colliculi that may be sculpted. Crista superior ridge-like over neck, poorly developed at extremes.

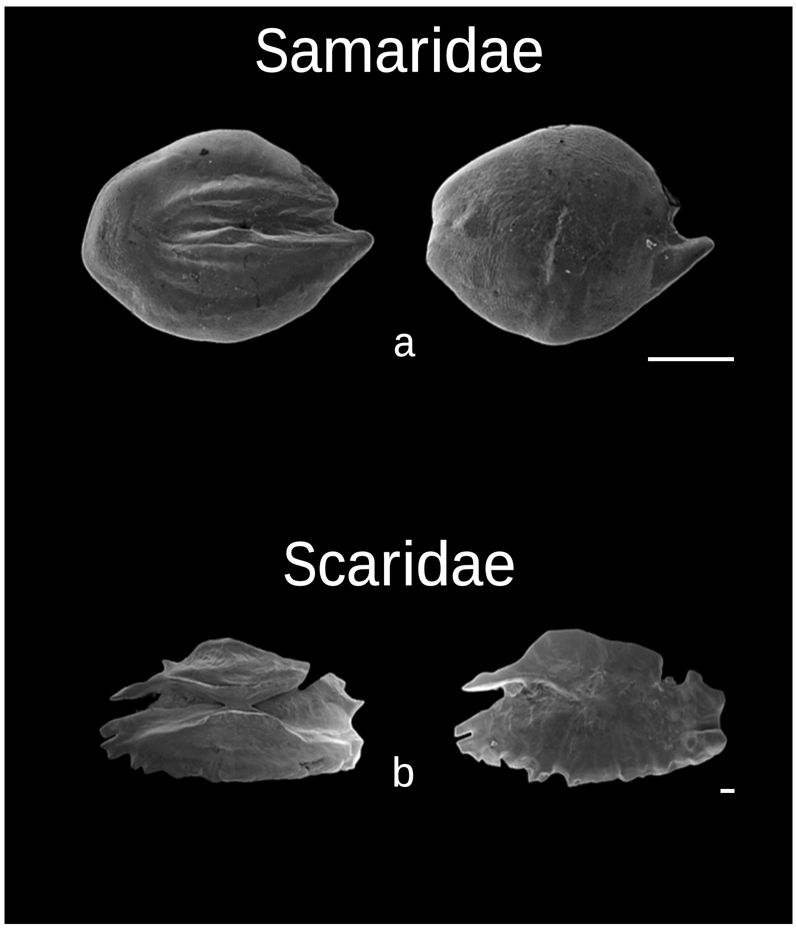

Figure 128. Samaridae and Scaridae: *a*, *Samariscus triocellatus*, 33 mm SL; *b*, *Calotomus carolinus*, 302 mm SL. Scale bars = 300 μm.

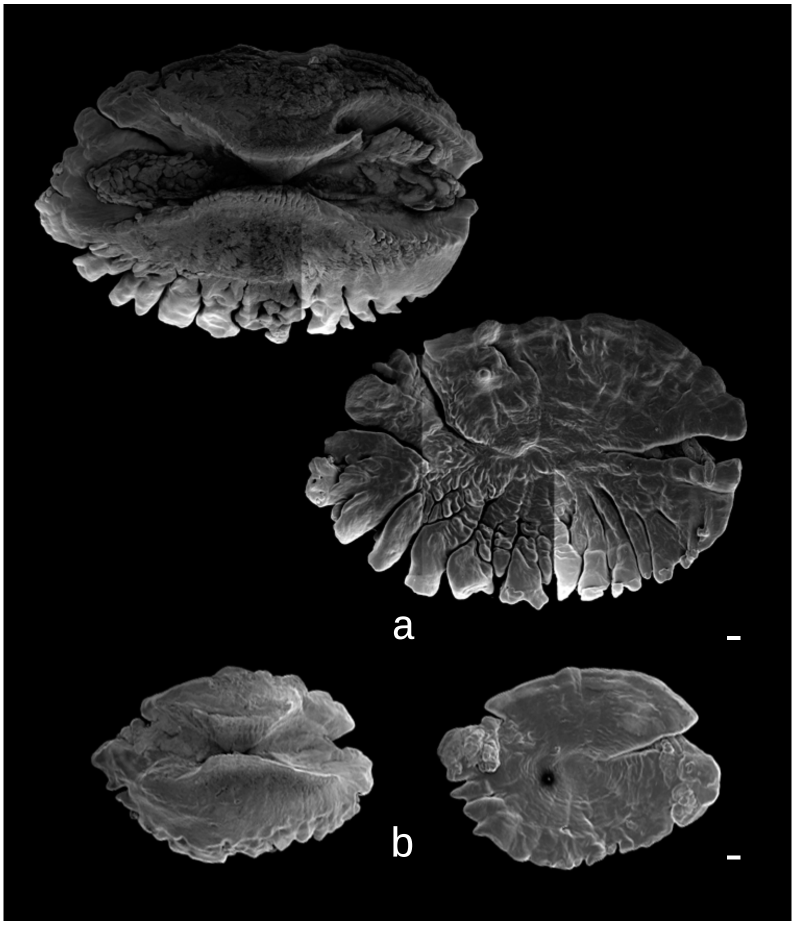

Figure 129. Scaridae: *a*, *Chlorurus perspicillatus*, 470 mm SL; *b*, *Chlorurus sordidus*, 194 mm SL. Scale bars = 300 μm.

4.3.33 Scorpaenidae (figs. 130*b-d*, 131, 132, 133*a*)

Outline fusiform or ovate. Heterosulcoid with ostial opening. Heteromorph, with low colliculi.

4.3.34 Serranidae (figs. 133*b* and *c*, 134)

Outline oblong to ovate or fusiform. Heterosulcoid with ostial opening but the subfamily Epinephelinae (*Cephalopholis*) may have an incompletely closed and appear ostio-caudal. Ostium oval to elongate with cauda flexed. Heteromorph, with anterior colliculum low and some with posterior colliculum barely visible. Non-epinepheline genera tending toward fusiform outline and all possess a distinct dorsal depression and ventral groove.

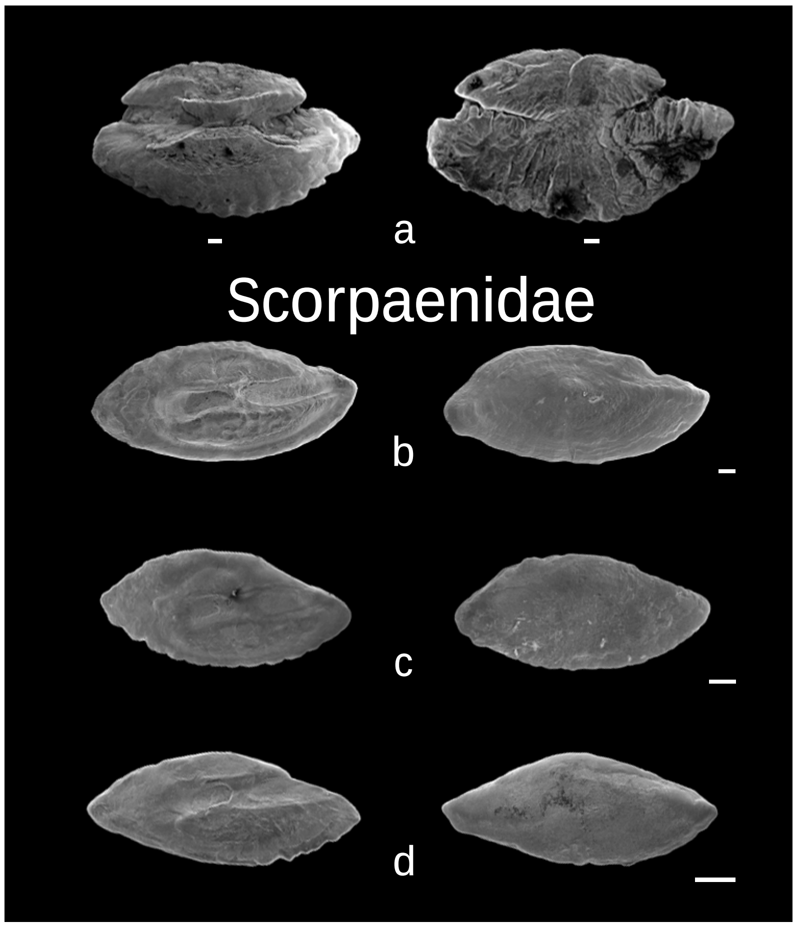

Figure 130. Scaridae and Scorpaenidae: *a*, *Scarus psittacus*, 165 mm SL (note change in scale); *b*, *Scorpaenodes corallinus*, 60 mm SL; *c*, *Scorpaenodes hirsutus*, 33 mm SL; *d*, *Scorpaenodes kelloggi*, 22 mm SL. Scale bars = 300 μm.

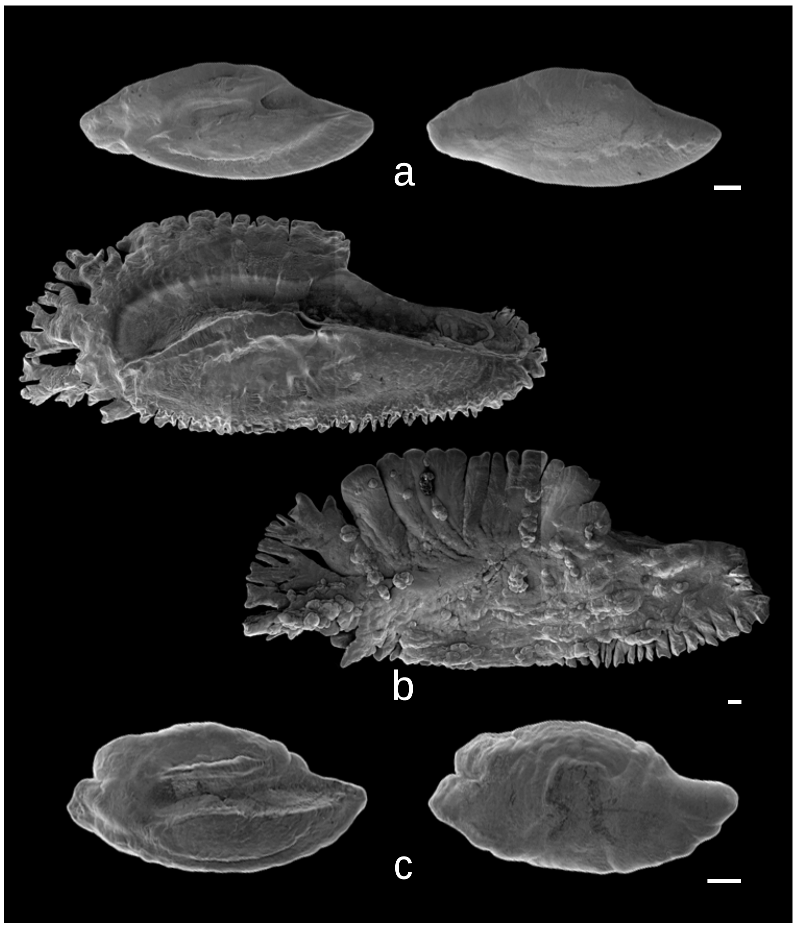

Figure 131. Scorpaenidae: *a*, *Scorpaenodes kelloggi*, 36 mm SL; *b*, *Scorpaenopsis cacopsis*, 344 mm SL; *c*, *Scorpaenopsis fowleri*, 32 mm SL. Scale bars = 300 μm.

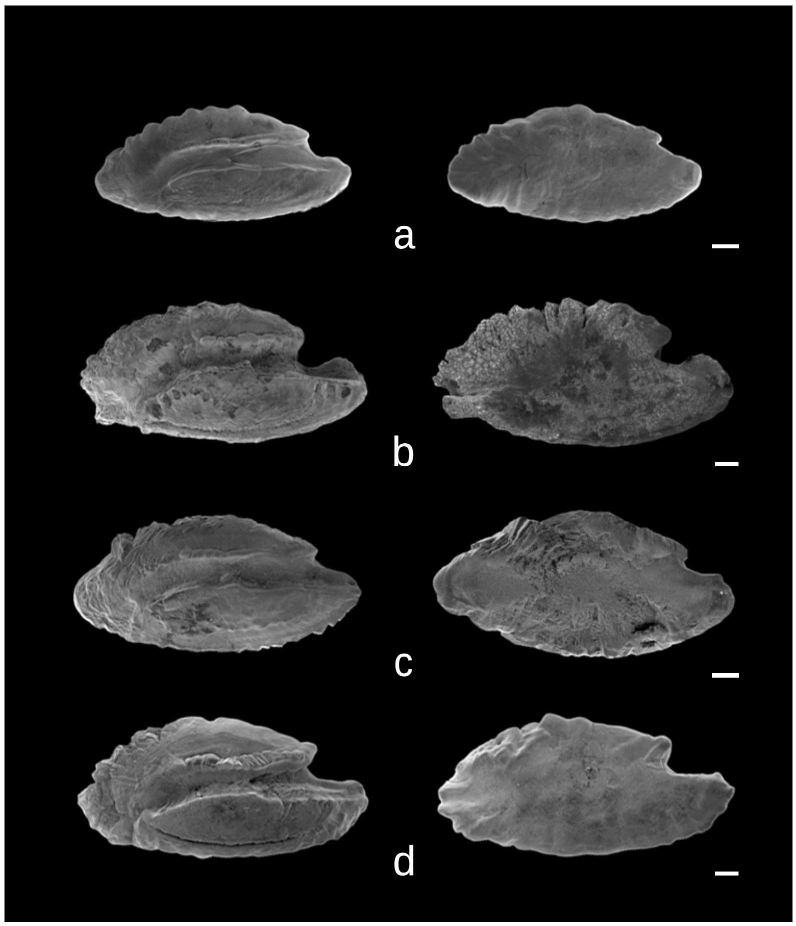

Figure 132. Scorpaenidae: *a*, *Sebastapistes ballieui*, 39 mm SL; *b*, *Sebastapistes coniorta*, 41 mm SL; *c*, *Sebastapistes coniorta*, 44 mm SL; *d*, *Sebastapistes galactacma*, 52 mm SL. Scale bars = 300 μm.

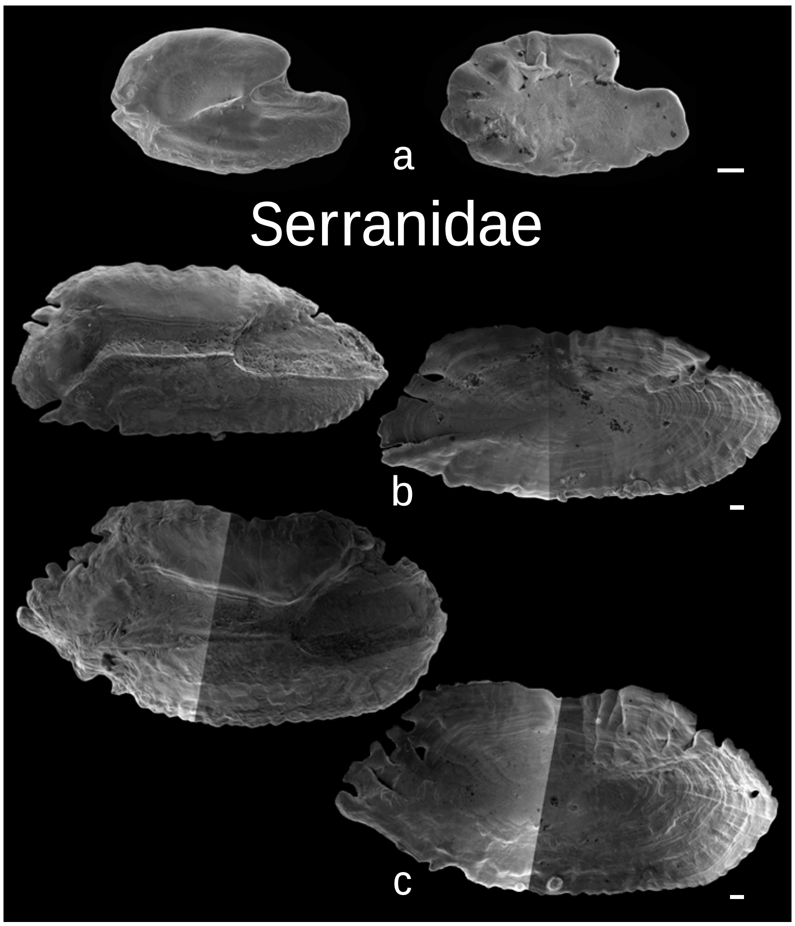

Figure 133. Scorpaenidae and Serranidae: *a*, *Taenianotus triacanthus*, 49 mm SL; *b*, *Cephalopholis argus*, 240 mm SL; *c*, *Cephalopholis argus*, 360 mm SL. Scale bars = 300 μm.

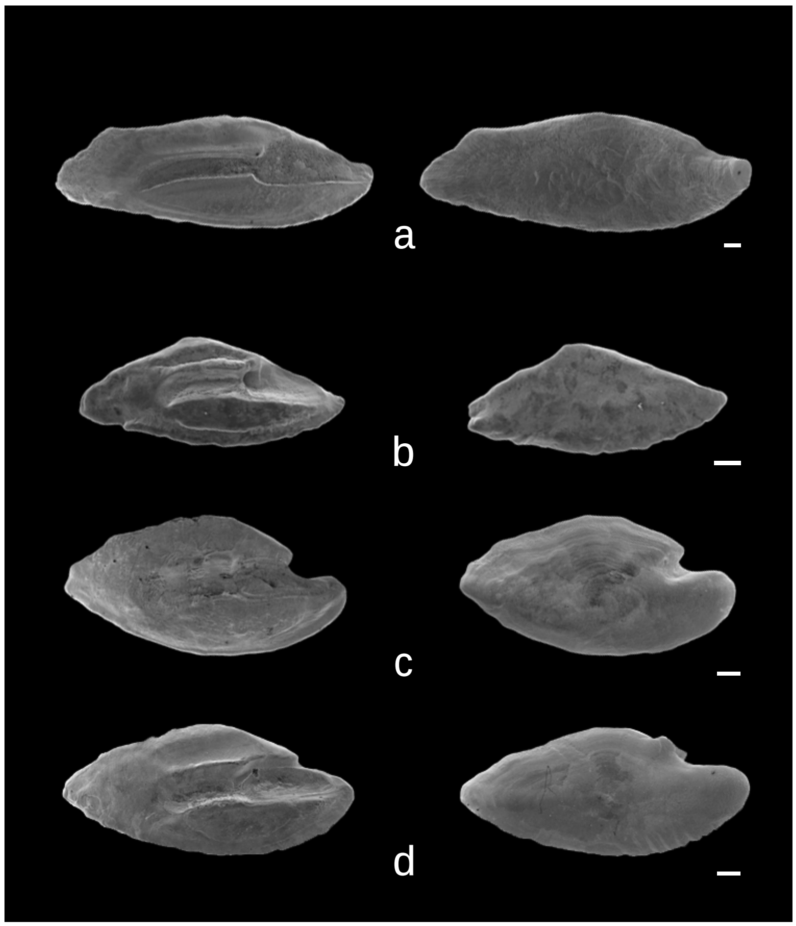

Figure 134. Serranidae: *a*, *Liopropoma collettei*, 63 mm SL; *b*, *Plectranthias nanus*, 34 mm SL; *c*, *Pseudogramma polyacanthum*, 57 mm SL; *d*, *Pseudogramma polyacanthum*, 59 mm SL. Scale bars = 300 μm.

4.3.35 Synodontidae (fig. 135*a*-*c*)

Outline rectangular-ovate. Rostrum large. Heterosulcoid with ostial opening. Cauda with slight ventral flexure. Crista superior ridge-like over neck. Crista inferior well-developed along sulcus nearly end of rostrum. Heromorph with very low colliculi.

4.3.36 Tetraodontidae (figs. 135 *d* and 136 *a*, *b*)

Outline hourglass-shaped. Pseudo-archaesulcoid with ostio-caudal openings. Colliculum fused, with pit. Crista superior absent, crista inferior very high, ridge-like and broad. pseudo-archaesulcoid

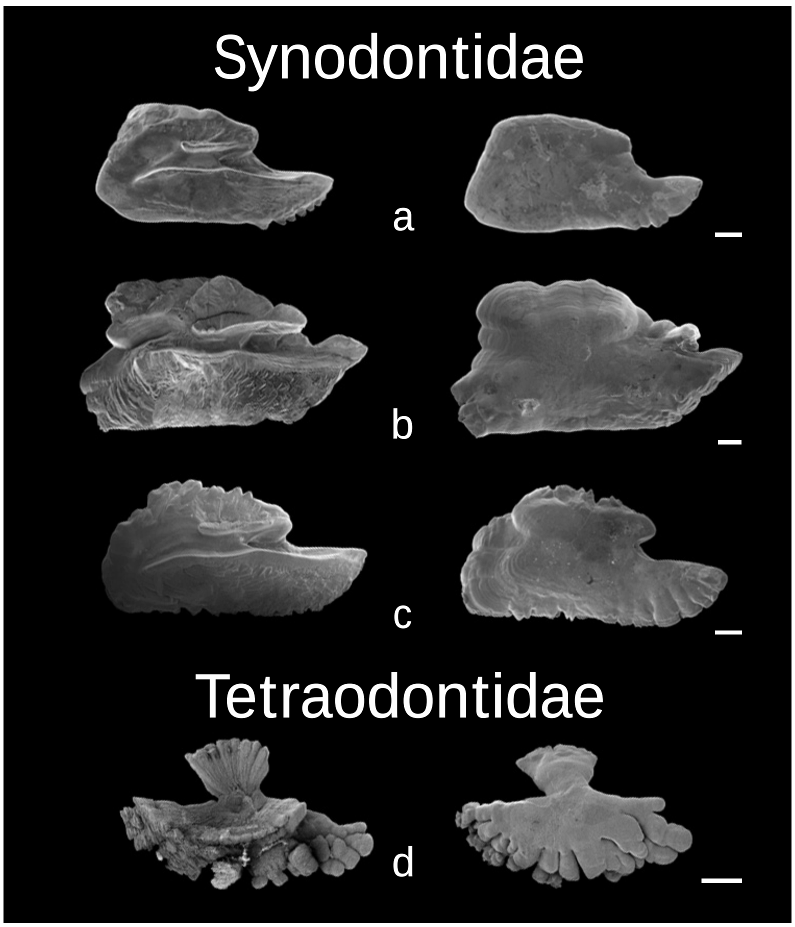

Figure 135. Synodontidae and Tetraodontidae: *a*, *Synodus dermatogenys*, 141 mm SL; *b*, *Synodus ulae*, 248 mm SL; *c*, *Synodus variegatus*, 188 mm SL; *d*, *Canthigaster amboinensis*, 94 mm SL. Scale bars = 300 μm.

4.3.37 Tripterygiidae (fig. 136*c*)

Outline fusiform. Heterosulcoid with ostial openings. Sulcus shallow with slightly flared ostium. Cauda approximately straight, slightly flexed at tip. Heteromorph, colliculi very indistinct.

4.3.38 Zanclidae (fig. 136*d*)

excisura

Outline approximately discoid. Heterosulcoid with ostial opening. Excisura deep. Ostium and cauda of similar width and not obviously differentiated. Sulcus approximately horizontal, slightly curved, ends close to posterior margin. Heteromorph, colliculi very low. Crista superior ridge-like along its length.

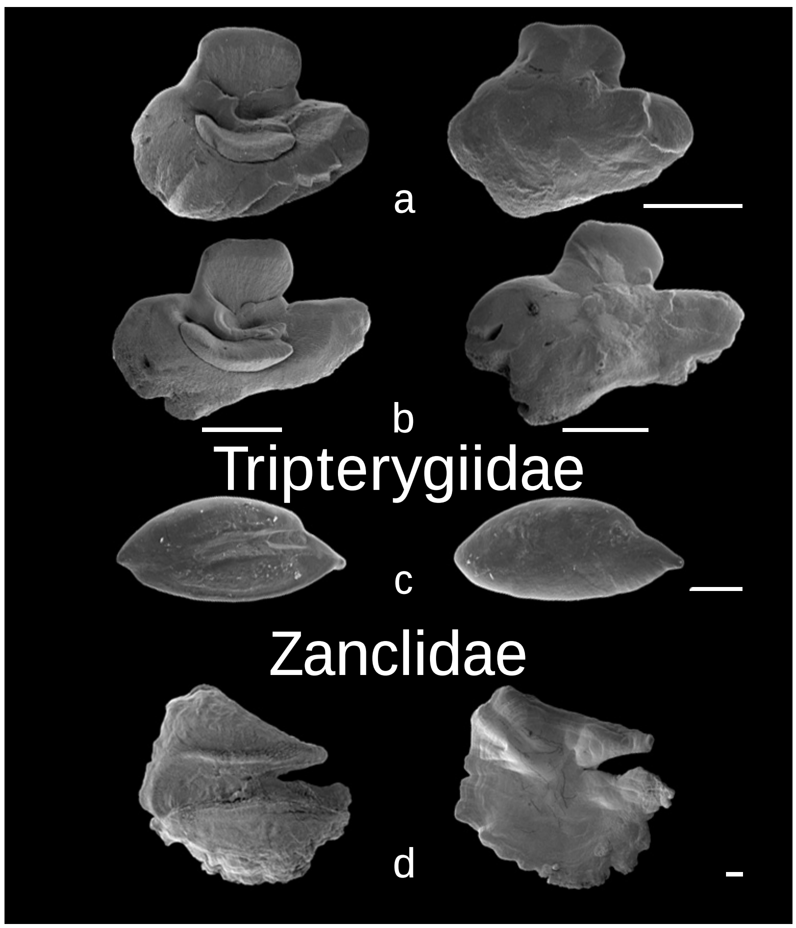

Figure 136. Tetraodontidae, Tripterygiidae and Zanclidae: *a*, *Canthigaster jactator*, 24 mm SL; *b*, *Canthigaster jactator*, 33 mm SL; *c*, *Enneapterygius atriceps*, 18 mm SL; *d*, *Zanclus cornutus*, 123 mm SL. Scale bars = 300 μm.

A Alan Ziegler's Fish Bone Identification Categories

This appendix presents examples of the taxonomic levels used by Alan Ziegler when identifying archaeological fish bones. It gives a general indication of the level to which fish bone identifications can be carried using the reference collection illustrated in this manual. Taxonomic revisions since Ziegler prepared the list have rendered some of the taxa and/or their descriptions obsolete and no attempt has been made to bring them up-to-date.

Taxon	**Vernacular**	**Comments**
Acanthurid	Surgeonfishes	Member(s) of the family Acanthuridae, of which there are over 20 species in Hawaiʻi, most of them inshore forms, with the genus *Naso* (Unicornfish or [mostly] *Kala*) comprising the five generally largest of these, reaching 40–75 cm in length.
Albulid	Bonefishes	Member(s) of the family Albulidae, of which there is a single species reported for Hawaiʻi; usually found near shore in open sand-bottomed areas, and reaching about 90 cm in length.
Apogonid	Cardinalfishes	Member(s) of the family Apogonidae, of which there are 11 species in Hawaiʻi; all relatively common inshore forms but active mostly only at night, with the largest species reaching no more than about 18 cm in length.
Balistid	Triggerfishes	Member(s) of the family Balistidae, of which there are about 10 species in Hawaiʻi; mostly inshore forms, with the largest reaching about 35 cm in length.
Belonid	Needlefishes	Member(s) of the family Belonidae, of which there are three species in Hawaiʻi; usually found somewhat offshore near the ocean surface, and reaching 100 cm in length.
Carangid	Jacks	Member(s) of the family Carangidae, of which there are over 20 species in Hawaiʻi; most of them deeper-water and fairly large forms; the species *Caranx ignobilis* (*Ulua*—or *Pāpio* for the smaller young) sometimes ranging in close to shore, and reaching 100 cm or more in length.
Chaetodontid	Butterflyfishes	Member(s) of the family Chaetodontidae, of which there are between 25 and 30 species in Hawaiʻi (including eight species separated as the family Pomacantidae [Angelfishes] by some authors), most often inshore reef forms, reaching no more than about 30 cm in length.

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Taxon	**Vernacular**	**Comments**
Cirrhitid	Hawkfishes	Member(s) of the family Cirrhitidae, of which there are five or six species in Hawaiʻi, all inshore forms, only one of which reaches as much as 30 cm in length.
Congrid	Conger Eels	Member(s) of the family Congridae, of which there are at least seven species in Hawaiʻi; some reaching a length of 150 cm.
Coryphaenid	Mahimahis	Member(s) of the family Coryphaenidae, of which there are two species in Hawaiʻi; both normally being found offshore, and reaching respective lengths of about 75 cm and perhaps 150 cm.
Diodontid	Spiny Puffers	Member(s) of the family Diodontidae, of which two species of the genus *Diodon*, ranging from 35 to 70 cm in maximum length, are by far the most abundant in Hawaiian inshore waters, the single remaining species reported for Hawaiʻi (genus *Chilomycterus*, 50 cm in length) apparently being quite rare here; all of these species are suspected of possessing an intrinsic poison although the flesh is apparently eaten without ill effects.
Exocoetid	Flyingfishes	Member(s) of the family Exocoetidae, of which there are about 10 species in Hawaiʻi; usually found somewhat offshore, and reaching 40 cm in length.
Fish		Material of indeterminate class and family, although essentially always a bony fish rather than shark or ray.
Fistulariid	Cornetfishes	Member(s) of the family Fistulariidae, of which there is one relatively common and one apparently very rare species in Hawaiʻi; at least the former of these usually found in nearshore reef areas, and reaching a length of about 1.2 m.
Holocentrid	Squirrelfishes	Member(s) of the family Holocentridae, of which there are about 15 species in Hawaiʻi; many of them found in deeper reef areas, with most of them fairly small and only one or two approaching 45 cm in length.
Kuhliid	Aholeholes	Member(s) of the family Kuhliidae, of which the sole reported representative in Hawaiʻi seems to be *Kuhlia sandvicensis* (*Āholehole*), extending inshore into brackish and even fresh water, and reaching a length of about 30 cm or so.

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Taxon	Vernacular	Comments
Kyphosid	Rudderfishes	Member(s) of the family Kyphosidae, the most often encountered of the four species reported from Hawai‘i being two members of the inshore genus *Kyphosus* (*Nenue*), which may reach 60 cm in length.
Labrid	Wrasses	Member(s) of the family Labridae, which is the largest family of fishes in Hawai‘i with over 40 species; predominately inshore forms, most of them fairly small but with a few larger forms reaching about 50 cm in length.
Lethrinid	Emperors	Member(s) of the family Lethrinidae, which does not occur in Hawai‘i but of which a number of species are found in the West and Southwest Pacific; being apparently relatively common fish of lagoons and nearshore waters of many islands, and reaching at least 65 cm in length.
Lutjanid	Snappers	Member(s) of the family Lutjanidae, of which there are 10 or 11 native species in Hawai‘i; most of them offshore deep-water—although not pelagic—forms, reaching maximum lengths of 30 cm to almost 100 cm.
Marine Eel	Eels	Member(s) of one (or more) of the 10 eel families recorded for Hawaiian waters, of which the Muraenidae (Moray Eels), Congridae (Conger Eels), and Ophichthidae (Snake Eels) are by far the most speciose and frequently encountered groups.
Monacanthid	Filefishes	Member(s) of the family Monacanthidae, of which the small *Pervagor spilosoma* (Fantail Filefish), reaching only about 15 cm in length and sometimes washing up on beaches dead in great numbers, is by far the most aboundant of the eight species to be expected in near-shore Hawaiian waters.
Mugilid	Gray Mullets	Member(s) of the family Mugilidae, of which there are only two species in Hawai‘i; both relatively common inshore forms, reaching a maximum length of about 45 cm.
Mullid	Goatfishes	Member(s) of the family Mullidae, of which there are 10 species in Hawai‘i; many of them living on the reef or frequently visiting it, usually about 20–25 cm long but a few reaching 40–60 cm.

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Taxon	Vernacular	Comments
Muraenid	Moray eels	Member(s) of the family Muraenidae, of which there are over 35 species in Hawai‘i; some reaching a length of 150 cm.
Ostraciontid	Boxfishes	Member(s) of the family Ostraciontidae, of which there are about six species in Hawai‘i, most of them less than 15 cm long.
Polynemid	Threadfins	Member(s) of the family Polynemidae, of which *Polydactylus sexfilis* (*Moi*) of inshore sand-bottomed areas is apparently the only species thus far reported for Hawai‘i, reaching perhaps 45 or 50 cm in length.
Pomacentrid	Damselfishes	Member(s) of the family Pomacentridae, of which there are about 14 species in Hawai‘i, all except two characteristic of inshore waters (most in abundance), and reaching maximum lengths of near 25 cm.
Priacanthid	Aweoweos or Bigeyes	Member(s) of the family Priancanthidae, of which four species are usually encountered in Hawai‘i; either near-shore or deeper-water forms, with maximum lengths of about 35 cm.
Scarid	Parrotfishes	Member(s) of the family Scaridae, of which the genera *Calotomus* (2? species) and *Scarus* (4–5 species) are essentially the only two expected to occur in Hawai‘i, both being typically inshore groups, and including one or two species that may reach 70 cm in length.
Scombrid	Tunas and Mackerels	Member(s) of the family Scombridae, of which there are perhaps a dozen species in Hawaiian waters; almost all open-ocean (pelagic) forms, many reaching a meter or more in length.
Serranid	Groupers	Member(s) of the family Serranidae, of which there are about 15 species in Hawai‘i; most of them being deeper-water, and fairly small (2–20 cm), forms, although one species reaches 40–45 cm and two others are occasionally between 1 m and almost 3 m long.
Sphyraenid	Barracudas	Member(s) of the family Sphyraenidae, of which there are two species in Hawai‘i; most often pelagic but sometimes found either singly or in small schools near shore, usually about 50–80 cm in length although an occasional individual may reach almost 200 cm.

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Taxon	**Vernacular**	**Comments**
Tetraodontid	Smooth Puffers	Member(s) of the family Tetraodontidae, of which there are about five species, ranging up to 50 cm in length, in Hawai‘i (—or perhaps close to a dozen if the several, generally small, species of the genus *Canthigaster* [considered to constitute the family Canthigasteridae Sharp-backed Puffers by some authors] are included—); a few of both types of these puffers may be found in shallower inshore areas, and all of the species may possess an intrinsic poison although the flesh is apparently sometimes eaten without ill effects.

Glossary

absent Sulcus lacking colliculi (fig. 86*a*).

acrodont A term applied to teeth fixed to the biting surfaces of bone by connective tissue. Most fish teeth are acrodont.

angular A paired bone forming the posterior section of the lower jaw and the articulation with the quadrate. In teleosts, it is typically triangular with the anterior angle fitting into the posterior bifurcation of the dentary. Synonym: articular.

ankylose To join or consolidate; fuse.

ankylosis The consolidation of fusion of bones to form a single unit.

anterior colliculum Raised area within the ostium.

antirostrum Anterior-most projection of the otolith dorsal to the sulcus.

apophysis A narrow extension from the body of a bone.

archaesulcoid No clear differentiation between ostium and cauda (fig. 84*a*).

articular *See* angular.

articular process An extension from the dorsal edge of the premaxilla, posterior to the ascending process. This process is found in most derived actinopterygians and acts as a fulcrum for the maxillary when the mouth opens.

articulation The area of contact between two bones.

ascending process A vertical extension from the anterior part of the premaxillary. This process is found in most teleosts.

caniniform A term applied to teeth that are conical or elongated and have a sharp end. They may be straight or curved. These teeth are typical of predaceous fishes.

cardiform A term applied to teeth that are numerous, short, fine and pointed. The term refers to the fine-toothed card used to prepare wool. These teeth are found in many members of the Serranidae.

cauda Posterior portion of the sulcus, sometimes separated from the ostium by a collum (fig. 81*i*).

caudal process A posterior extension from the premaxilla.

chevron *V*-shaped. The term also applies to the ventral *V*-shaped scales of some members of the Clupeidae.

collum A raised area between the ostium and cauda.

condyle A rounded protuberance at the end of a long bone. A condyle typically forms part of an articulation.

coronoid process The dorsal, posterior branch of the dentary; also, a dorsal extension from the angular.

crenate Margin with small, compressed humps (fig. 83*a*).

crest A long, narrow protrusion from the surface of a bone.

crista inferior Ventral rim of the sulcus (fig. 81*k*).

crista superior Dorsal rim of the sulcus (fig. 81*c*).

cuneiform A term applied to teeth shaped like a wedge or arrowhead.

deciduous A structure likely to be lost (as in weakly attached teeth or scales).

dentary A paired bone forming the anterior section of the lower jaw. Anteriorly, both dentaries meet at the mandibular symphysis. Typically there are two posterior processes, the dorsal, coronoid process and a ventral process.

dentate Margin with truncate projections (fig. 83*b*).

dentigerous Bearing teeth.

diastema A space between teeth in the jaw.

dorsal depression Depression in the area dorsal to the sulcus (fig. 81*a*).

edentulous Without teeth.

entire Margin smooth (fig. 83*c*).

ethmoid A median bone formed in the nasal septum between the two nasal capsules. In the Anguilliformes, the premaxilla is ankylosed to the ethmoid, lateral ethmoid, and vomer.

excisura Anterior notch between rostrum and antirostrum (fig. 81*e*).

face A term applied to the surface of any bone.

facet A flat to slightly curved surface on a bone. A facet is typically part of an articulation.

fissure Any naturally-occurring furrow or groove on the surface of a bone.

foramen Any hole in a bone through which nerves or blood vessels pass.

fossa A cavity, forming the articulating surface of a bone, receiving the process of another bone.

head A round process on a bone.

heterodont A term applied to teeth that vary in shape and size within the same individual.

heteromorph Single colliculum in either ostium or cauda (fig. 86*c*), or with two colliculi (one each in ostium and cauda) differing in shape (fig. 86*b*), these may be fused (fig. 86*d*).

heterosulcoid Ostium and cauda distinguishable and differ in shape (fig. 84*b*).

homodont A term applied to teeth that are all the same shape and size within an individual.

homomorph Single colliculum spanning ostium and cauda and undifferentiated between two areas (fig. 86*f*), or with two colliculi (one each in ostium and cauda) very similar in shape and size (fig. 86*e*).

homosulcoid Ostium and cauda distinguishable but similar in shape (fig. 84*c*).

incisiform A term applied to teeth used for cutting and similar in appearance to mammalian incisors

incisure Any naturally-occurring notch or cleft in a bone.

indistinct Colliculi not clearly defined, floor of sulcus may be uneven (fig. 86*g*; this term will usually be used in combination with homomorph or heteromorph.

irregular Margin with no recurring pattern (fig. 83*d*).

lateral ethmoid A paired bone present in teleosts. In the Anguilliformes, the premaxilla is ankylosed to the lateral ethmoid, ethmoid, and vomer.

lobed Margin with large rounded humps (fig. 83*e*).

mandibular symphysis The articulation between the dentaries.

maxilla A paired bone of the upper jaw located posterior to the premaxilla. Synonym: maxillary.

maxillar symphysis The articulation between the premaxillae.

maxillary *See* maxilla.

mesial Sulcus does not open onto any margin (fig. 85*a*). Alternatively, medial.

MNI *minimum number of individuals* Minimum number of individuals. The smallest number of individuals necessary to account for all of the skeletal elements of a taxon in a faunal collection.

molariform A term applied to teeth with flat surfaces used for crushing or grinding. These teeth are similar in appearance to mammalian molars.

mosaic *See* pavement.

neck A constriction of the sulcus between the ostium and cauda (fig. 81*b*).

NISP *number of identified specimens* Number of identified specimens. The total number of identified fragments of any part of the anatomy of a taxon in a faunal collection.

ostial Sulcus opens only to anterior (or dorsal) margin (fig. 85*b*).

ostio-caudal Sulcus opens widely to both anterior and posterior margins (fig. 85*c*). Alternatively, biostial.

ostium Anterior portion of the sulcus (fig. 81*g*).

para-ostial Sulcus opening on anterior (or dorsal) margin reduced to a narrow channel (fig. 85*d*).

pavement A term applied rows of teeth packed into large figures. Synonym: mosaic.

pleurodont A term applied to teeth implanted in the lateral surface of a bone. These teeth are found in some members of the Balistidae and Scaridae.

posterior colliculum Raised area within the cauda.

postmaxillary process An extension from the posterior half of the dorsal surface of the premaxilla. The postmaxillary process prevents the lateral dislocation of the premaxilla when the mouth opens.

premaxilla A paired bone forming the anterior part of the upper jaw. Synonym: premaxillary.

premaxillary *See* premaxilla.

prevomer *See* vomer.

process Any extension from the body of a bone. Processes are named according to size and shape (e.g., apophysis, condyle, head, tuberosity).

pseudo-archaesulcoid Ostium and cauda differentiated only by features on floor of sulcus, not by constriction of cristae (fig. 84*d*).

pseudo-ostial Sulcus with ostium close to anterior (or dorsal) margin but otherwise not opening onto any margin (fig. 84*e*).

quadrate A paired bone which, in most teleosts, has a triangular shape. The anteroventral angle of the quadrate articulates with the angular, acting as a pivot for the lower jaw.

retroarticular A bone attached to the posterioventral portion of the angular. It does not form part of the mandibular articulation.

rostrum Anterior-most projection of the otolith ventral to the sulcus (fig. 81*f*).

serrate Margin with pointed projections (fig. 83*f*).

sinuate Margin with sine-shaped waves (fig. 83*g*).

sulcus A distinct groove on the medial face (fig. 81*h*). Alternatively, sulcus acusticus.

suture A joint composed of thin connective tissue, such that there is no movement between the two bones.

symphysis A joint in which the two bony surfaces are firmly united by cartilaginous tissue.

ventral depression Depression in the area ventral to the sulcus.

ventral groove A distinct groove ventral to the sulcus (fig. 81*j*).

villiform A term applied to long, thin teeth.

vomer A paired bone, frequently dentigerous, forming the anterior roof of the palate. In derived actinopterygians, the pair is ankylosed to form a single bone. In the Angulliformes, the premaxilla is ankylosed with the vomer, ethmoid, and lateral ethmoid. Synonym: prevomer.

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