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OTOLITH MORPHOLOGY OF FISHES FROM THE SOUTHERN COASTS OF THAILAND

Suwit Jitpukdee

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เก็บรวบรวมตัวอย่างปลาจากท่าเรือประมงและตลาด บริเวณชายฝั่งทะเลตอนใต้ของประเท ไทย ระหว่างเดือนมิถุนายน 2545 ถึงเดือน พฤษภาคม 2546 นำมาจัดจำแนกอนุกรมวิธาน รวบรว ผลึกแก้วหูซาจิตทอลจากหัวของปลาแต่ละชนิด วัดขนาดความยาวและความสูง นำผลึกแก้วหูปลาแ ละชนิดไปศึกษาสัณฐานวิทยาด้วยกล้องจุลทรรศน์อิเล็กตรอนแบบแสงส่องกราด กำหนดคำนิยามแ ละส่วนของผลึกแก้วหูซาจิตทอล

ผลึกแก้วหูซาจิตทอลของปลาจำนวน 211 ชนิด 2 ครอบครัวย่อย 60 ครอบครัว 14 อันดั พบลักษณะเด่นของผลึกแก้วหูซาจิตทอลมีความแตกต่างเฉพาะของปลาแต่ละชนิด ได้แก่ รูปร่า ซัลคัสอคุสติคุส ออสเทียม เคาดา รอสตรัม และแอนทิรอสตรัม ลักษณะสัณฐานวิทยาด้านอื่น เช่ รอยผลึกแก้วหูบนและล่าง คริสตาบนและล่าง แสดงลักษณะเฉพาะของปลาแต่ละชนิดเช่นกัน พ รูปร่างผลึกแก้วหู 17 ชนิด ซัลคัสอคุสติคุส 4 ชนิดและการเปิดของซัลคัสมี 4 ลักษณะ ขอบของผลึ แก้วหูมี 8 ลักษณะ อย่างไรก็ตามขนาดของผลึกแก้วหูเมื่อศึกษาความสัมพันธ์กับกลุ่มอนุกรมวิธา ของปลา พบมีความสัมพันธ์น้อย และเมื่อศึกษาความสัมพันธ์กับถิ่นอาศัยของปลาพบมีความสัมพัน กับถิ่นอาศัยของปลาที่เข้าไปอาศัยอยู่ ซึ่งมีอยู่ด้วยกัน 5 ถิ่นอาศัย คือ อาศัยผิวน้ำ อาศัยใต้ผิวน้ำ อาศ ใต้ทะเลลึก อาศัยพื้นด้านล่าง อาศัยติดพื้นดิน ความแตกต่างด้านสัณฐานวิทยาและขนาดผลึกแก้วหูซ จิตทอลของปลาแต่ละชนิด มีผลมาจากหลายปัจจัย ซึ่งปัจจัยหลักคือสภาพแวดล้อมและกลไก เกี่ยวกับชีววิทยาถิ่นอาศัยของปลาชนิดนั้น งานวิจัยนี้เป็นการศึกษาเบื้องต้นเพื่อสืบหาลักษณ สัณฐานวิทยาและขนาดของผลึกแก้วหูซาจิตทอลของปลาจากชายฝั่งทะเลตอนใต้ของไทย ผลจา การศึกษาครั้งนี้จะนำไปใช้ประโยชน์ สำหรับการศึกษาชีววิทยาของปลาในประเทศไทย

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OTOLITH MORPHOLOGY/ SAGITTAL/MARINE FISH/ SOUTHERN THAILAND

Fish specimens were collected from June 2002 to May 2003 from fishing piers and markets along the southern coasts of Thailand. Taxonomic classification was classified according to Bone, Marshall and Blaxter, (1995). The sagittal otoliths were removed from the skull of the fish. Length and height of each otolith was measured. The morphology of each otolith was studied and imaged by scanning electron microscope. Termonology for each part of an otolith was according to Smale, Wastson and Hecht, (1995).

The sagittal otoliths of 211 fish species, 2 sub-families 60 families, and 14 orders from the southern coasts of Thailand show distinctive morphology, which is species-specific, i.e. for shape, sulcus acusticus, ostium, cauda, rostrum and antirostrum. Other morphological features of sagittal otoliths, such as dorsal depression, ventral depression, crista superior, crista inferior are also species-specific. The shape displays 17 types, whereas the sulcus acusticus shows 4 types and the sulcus opening manifests 4 characters. The margin sculpturing of these otoliths have 8 characters. However, the otolith sizes are less correlated to taxonomic groups and more correlated to habitat, which shows 5 habitats: pelagic, bottom, demersal, bathypelagic, benthopelagic. The distinctive morphology and size of the sagittal otoliths of each species are due to many factors. The main factor is the environmental

and biological mechanisms that the fish live in. This research represents a pioneer study designed to investigate shapes and sizes of fish otoliths from coastal Thailand. The results of this research will be useful for future study of the fish biology of Thailand.

School of Biology

Academic Year 2005

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CHAPTER I

INTRODUCTION

1.1 Introduction

Thailand has several resources of marine organisms that are of high economic value, especially the marine fish, comprising many species capable of contributing in significantly to the annual income of the country. The population diversity of Thai marine fish total 1,950 species, 197 families, 40 orders, most of which are in the order Perciformes (Vithayanon, 2002). At present, however, the fundamental data on fish biology of these species is very limited and reflects a lack of serious research in this field.

Many overseas researchers, including biologists, physiologists, chemists, physicists, marine biologists, fisheries biologists, paleontologists, and archaeologists have conducted detailed studies in numerous branches of fish biology by using the otolith structure. As a result, they have a large and detailed reservoir of information on the biology of fish history, habitat, migration, feed and many environmental factors. Such information is urgently needed on the local species and their age, identification, population history and habitat if the fishing industry in Thailand is to develop and benefit from this potentially large economic resource.

The otoliths are small carbonaceous bodies found in the inner ear of fish and occur as paired structures. All Teleost or hard-boned fish species have three pairs of otoliths viz. the sagitta found within the sacculus, the asteriaus found within the

sagitta is considered the most important morphologically and shows more characteristic features than the astericus and lapilli forms as a means of studying fish biology (Maceina and Murphy, 1989; Lombarte and Castellon, 1991; Hunt, 1992; Lombarte and Morales-Nin, 1995; Khrustaleva and Pavlov, 1999; Miller, Herra, and Leggett, 1999; Torres, Lombarte, and Morales-Nin, 2000; Preliminary Work-*Cynoscion* Otolith Shape, www, 1999; Baldas, Macri, Volpedo, and Echeverria, 2002; Chen and Yan, 2002; Nicolaai and Jooste, 2002).

Little research has been conducted on the sagittal otolith morphology of Teleost species in Thailand and all the present data derive from research overseas. Hence, there is an urgent need for investigation of the otoliths of the Teleost species in Thailand if progress is to be made in the biological study of such fish species in Thailand waters.

In initiating this biological study of the Teleost species in the Thai marine environment, an examination of the sagittal otolith morphology of species was carried out in the southern coastal region of Thailand covering the Andaman Sea from Ranong province to Satun province and in the Gulf of Thailand from Prachuap KiriKhan to Pattani province. Sagittal otoliths were collected from fish caught in this southern region, including 15 orders and 50 families. However, it is considered that data obtained from this region can also apply to the whole of the coastal region of Thailand.

To date, the otolith morphology of fish species in Thailand waters has never been reported and hence this research is the first attempt to expand knowledge of fish biology by examining the sagittal otolith morphology of fish species from the Thai coastal waters.

1.2 Research Objectives

1.2.1. To investigate otolith morphology of fish species from the southern coasts of Thailand.

1.2.2. To investigate the relationships between otolith morphology and the taxonomic groups of fish.

1.2.3. To investigate the relationships between otolith morphology and fish habitats.

1.3 Scope and Limitations of the Study

The sagittal otoliths of fish were collected from fishing piers and markets in Prachuap KiriKhan, Surat Thani, Nakhon Sri Thammarat, Songkhla, Pattani, Ranong, Phuket, Satun and Trang from June 2002 to May 2003. Photomicrographs of otoliths of each fish species were taken by a scanning electron microscope and all photos were systematically arranged. The size (length and height) of sagittal otoliths and the standard length of fish were recorded. The correlations between sagittal otolith morphology, taxonomic groups and fish habitats were analysed.

1.4 Expected Results

1.4.1. Otolith morphology will be used as a tool for fish species identification in the future.

1.4.2. The results from this study will be useful for future researchers in the areas of fish biology, archaeology, palaeontology, etc.

CHAPTER II

LITERATURE REVIEW

2.1 The Coastal Area of Thailand

Thailand has a coastline that comprises the Andaman Sea coast and the Gulf of Thailand, covering a shoreline of about 26,000 kilometers. Using 100 meters depth as the edge of the shelf, the continental shelf is narrow in the north for about 90 kilometers bordering Myanmar, and expands to about 240 kilometers in the south bordering Malaysia. The Gulf of Thailand is a semi-enclosed sea, located in Southeast Asia, immediately to the west of the South China Sea. It is covering a shoreline of about 1,900 kilometers, while the Andaman Sea covers a shoreline of about 700 kilometers (Limpsaichol, www, 2002). The mean depth is 45 meters and the maximum depth 80 meters (The Gulf of Thailand, www, 2002).

The coastline of Thailand, both of the Gulf of Thailand and the Andaman Sea, is an important habitat for several aquatic animals and other organisms, especially the marine fish. There are large numbers of fish species found in this region.

2.2 The Marine Fish

Thai Marine Fish

Thai marine fish found in both the Gulf of Thailand and the Andaman Sea comprise a large number of species important to the fishing industry. The export of marine fish accounts for over $ 5 billion of the income of Southeast Asian countries

each year (Fisheries in the Gulf of Thailand, www, 2000). The Thai marine fish total 40 orders, 197 families and 1,950 species (Vidthayanon, 2002). Also, at least 135 fish species belonging to 43 families have been recorded in the mangrove estuary of Sikao Creek, Trang Province, in Thailand (Tongnunui et al., 2002).

2.3 The Fish Habitat

The habitats of fish vary greatly not only in physical features such as pH, salinity, temperature, oxygen content and light level, but also differ immensely in the space available. In the marine environment, living space is usually greater, although even here, some fish may be restricted to the reefs around single atolls, or like the bithytid vent fish, to the thermal vents of the Galapagos rift. In contrast, other marine fish, like the pelagic blue shark (*Prionotus*), range over all the oceans, whilst the minnow-sized bathypelagic stomiatoids, *Cyclothone microdon* and *C. acclinidens*, are found below 100 meters worldwide, and comprise many billions of individuals.

Bone, Marshall, and Blaxter (1995) have divided marine fish based on the habitat into 8 groups as following:

2.3.1 Epipelagic Fish

The open ocean beyond the continental shelf covers nearly two-thirds of the surface of the earth, and some 2,500 species are found there, about half being benthic, and half pelagic. Nearly 2,500 species are in the euphotic zone, where light drives (phytoplankton) photosynthesis year-round in the tropics and sub-tropics, and for the warmer part of the year in cold and temperate waters. This zone of primary production supports an epipelagic fish fauna of some 250 species, as well as many larvae of fish from deeper levels. Sharks, flying fish, scombroids, such as tunas, and billfish, halfbeaks, garfish, the large sunfish (*Mola*) and stromateoids are typical of

this zone, and are usually coloured dark blue above and lighter below. Floating objects attract both smaller epipelagic fish such as stromateoid drift fish (*Nomeus*) and medusa fish (*Schedophilus*), which hide under medusae for protection, as well as larger scombroids preying on the smaller fish. The perciform wreck fish (*Polyprion*) is named from its habit of living under floating wreckage, old tea cases seemingly being favorite lairs. The epipelagic fauna is the richest in warmer regions, but some species, like the warm isurid shark and blue-fin tuna (*Thunnus thynnus*), migrate to colder waters in the productive season.

2.3.2 Mesopelagic Fish

Nine hundred or so mesopelagic fish species live above the thermocline in the zones where daylight still penetrates while many fish migrate upwards at night towards the surface, sinking again before dawn, following the migrations of their zooplankton food. Not all vertical migrators travel upwards far enough to reach the surface and differences in the amplitude and timing of such migrations effectively partition different feeding areas and thus reduce composition. For example, in the Rockall trough, as judged by the species composition of the copepods, they feed on the hatchet fish (*Argyropelecus olfersi*), feeding at lower depth horizons than *A. hemigymnus*, while the third common sternoptychid (*Maurolicus muelleri*) feeds closest to the surface.

2.3.3 Bathypelagic Fish

Most of the one hundred and fifty or so species of bathypelagic fish are ceratoid anglerfish (about 100 species), but the dominant forms are black species of the stomiatoids (*Cyclothone*). Many bathypelagic fish must live a rather sedentary life, hanging in the water waiting opportunistically for the occasional meal to come

within range of their jaws. Although no daylight penetrates into the deep sea, many benthopelagic fish have normal-sized eyes, often with specializations to increase their sensitivity, and the fitful flashes and glows of bioluminescence must obviously be significant in their lives.

2.3.4 Benthopelagic Fish

The great majority of bottom-living fish from upper slope levels, at 200 meters to around 8,000 meters in the deep ocean, are neutrally buoyant and do not live on the bottom, but just off it, like the deep-sea squaloid sharks. Although shallow-water rays are squaloids with a long life and are also close to neutral buoyancy, presumably also being bathypelagic. Apart from those around thermal vents, the benthopelagic and benthic invertebrates ultimately depend on organic matter, like fecal material, raining down from surface waters, and it is understandable that the biomass of the plankton decreases rapidly with depth.

2.3.5 Benthic Fish

In contrast to the benthopelagic fish, benthic fish lack swim bladders and rest on the bottom; sometimes, like tripod fish (*Bathypterois* spp.) on stiff elongate fin-rays, they sit aligned into the currents that bring zooplankton to their mouths. Because of the lack of light and temperature change, it was once thought that there is no seasonality in the deep sea. This is not so and certainly in higher latitudes; there are annual growth cycles in sea fish species.

2.3.6 Coral Reef Fish

By far the greatest number (80%) of the ten thousand or more species of fish in shallow seas live in warm temperate or tropical waters, most associated with coral reefs and atolls in water where mean temperatures during the coldest part of the year

do not fall below 18° C. Coral reefs are widespread in the Indian and Western Pacific Oceans, between latitudes 30° C North and 30° C South, and there are also large reefs in the Caribbean and around the West Indies. There is a striking difference in the number of species of coral fish in different regions, from the richest central Indo-West Pacific reef of the Philippines, New Guinea, and the Australian Great Barrier Reef to the less rich reefs around Florida, where only 500-700 species live.

Nearly all coral fish are acanthopterygians, and many families like gobies (Gobiidae), wrasses (Labridae), damsel fish (Pomacentridae), butterfly fish (Chaetodontidae) and squirrel fish (Holocentridae) are represented globally at all coral reefs, though in each faunal area, the species are largely different. On the Great Barrier Reef, 43 percent of all fish are gobies, while wrasses and damsel fish each comprise 23 percent and butterfly fish 8 percent.

The coral fish make their living in many specialized ways. Some are herbivores, cropping algae, or like parrot fish (Scaridae) scraping and biting off coral to obtain the algal symbionts. Others, like puffer fish (Tetraodontidae), box fish (Ostraciontidae), gobies and some damsel fish eat invertebrates, and these include the file fish (Monacanthidae) and butterfly fish, which eat the coral polyps themselves, picking their food with their forceps-like mouths.

Most coral fish are dazzlingly bright coloured, and change colour during courtship as well as by day and night. During the night, large-eyed nocturnal feeders, like squirrel fish and the luminescent pempherids, emerge from their daytime hiding place, whilst day-feeding parrot fish retire to sleep in mucous cocoons. As well as the brightly-coloured and patterned coral fish, there are also cryptically camouflaged ambush predators like carpet sharks and frog fish.

2.3.7 Estuarine Fish

The fish found in estuarine and river mouths are mainly euryhaline forms which can live in unstable surroundings, where salinity is variable and the waters are often turbulent and muddy, edged in the tropics by mangroves. In temperate estuarine, typical fish are grey mullets (Mugilidae), flat fish like flounders (*Pleuronectes flesus*) and shads (*Alosa*), whilst in warm waters, many species of marine origin such as lutjanidae, pomadasyids, cat fish, sciaenidae and threadfins (Polynemidae), are found in estuarine. Many estuarine fish are migrants, entering estuaries seasonally, like herring and sprat, or on passage to and from the sea, like eels and salmonids. Fish of the muddy estuarine may look rather like deep-sea fish, with their long fin-rays and small eyes. The Bombay duck (*Harpadon*), of Indian estuaries, not only looks like a deep-sea fish, but is related to the deep-sea lizard fish.

2.3.8 Intertidal Fish

The intertidal zone is a demanding environmental, where fish are alternately buffeted by waves and isolated in pools or on mudflats. Some intertidal fish, such as the mudskippers (Periophthalmidae) and leaping blennies like *Alticus kirki* of the Red Sea, are truly amphibious, emerging from the water to graze on algal films on mud or rock in or above the splash zone. These fish have remarkable behavioural and physiological adaptation to avoid desiccation and to regulate nitrogen excretion. Most of intertidal fish, however, remain in the water to avoid being washed away, are generally dense, small fish (less than 20 cm), thin or flattened to hide in holes and crevices, or may have the pelvic fins modified into suckers. Interesting and obviously necessary behavioural features of many intertidal fish are their pronounced homing

ability, particularly striking in poll-dwelling blennies, which leap into the air to view the surrounding terrain.

2.4 The Ear of Fish

The fish do not have an outer or middle ear but have only an inner ear, which is close to the brain on either side of the head. The inner ear consists of a membranous labyrinth made up of sac and canals, filled with a liquid similar to the intestinal fluid known as endolymph. The labyrinth is divided into two parts as an upper part that comprising semicircular canals and a lower part comprising the utriculus, sacculus and lagena (Fig. 2.1). The semicircular canal has a spherical expansion, the ampulla, which is a sensory structure known as crista. The three parts of the lower labyrinth (utriculus, sacculus and lagena) have large areas of sensory epithelium know as maculae, which contain sensory hair cells. The function of the semicircular canal serves to detect turning movements of fish, while the three sacs (maculae) respond to sound, gravity and linear acceleration of the fish's bodies (Bone et al., 1995; Aguirre, 2001). The sacculus is the largest among the three sacs of most fish species except for clupeoids (Bone et al., 1995), minnows (Cypriniformes), and cat fish (Siluriformes) (Smale, Watson, and Hecht, 1995; Harvey, Loughlin, Perez, and Oxman, 2000).

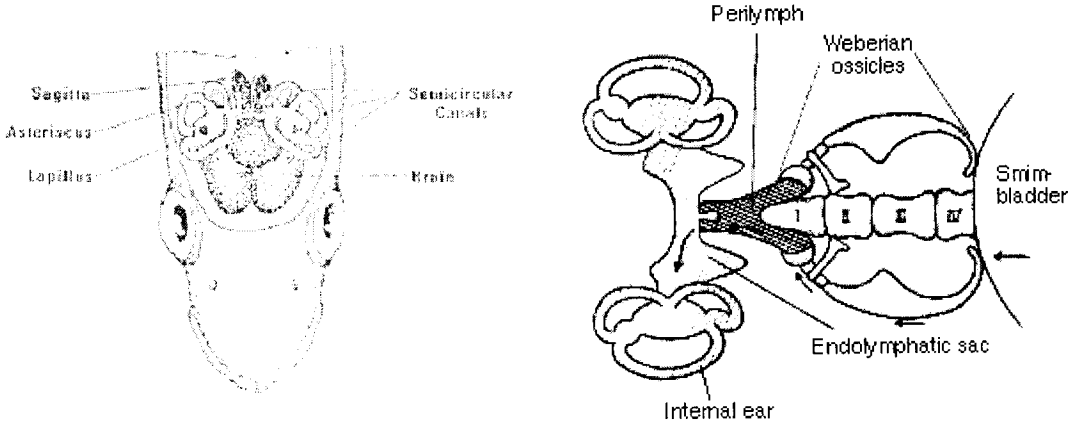


Figure 2.1 The inner ear of fish (Jamieson, 2001).

2.5 The Fish Otoliths

2.5.1 General Structure and Function of Otoliths

The otoliths are small carbonate bodies found in the inner ear of fish. They can be found in the fish skull located below the rear of the brain, attached to the skull, but rather float beneath the brain (Fig. 2.2). They are crystalline in nature and are built up around a primordium or core region, composed of calcium carbonate and protein, which are formed by the process of biomineralization. All Teleost fish have three pairs of otoliths: the sagittae, asteriscii and lapilli which are located in the three sacs in the inner ear: the sagittae within the sacculus, the asteriscii within the lagena and lapilli within the utriculus (Fig. 2.3), (Jamieson, 2001). The asteriscii and lapilli are usually millimeter-sized, but the sagittae can range from millimeter to centimeter in size and it is the largest in most fish except some fish species (Jamieson, www, 2001). The right and left structure of the sagittae otolith are similar in all species, except the group of bothidae where the left sagitta is larger than the right (Harkonen, 1986). Begg and Brown (2000) have reported that in haddock, overall otolith shape is not significantly different between the left and right in samples from the same region. Therefore, if the left sagittal otolith is not available, the photograph of the right sagittal otolith can be used.

The Teleost fish have sense organs to detect gravity, acceleration and hearing. Semicircular canal and ampulla detect angular acceleration, whereas the otolith organs appear to have a dual function, vestibular and auditory. The transducer of acoustic information, sensory hair cells in the fish ears, inserts apical ends of them into the lumen of the otolithic chamber (Fig. 2.4). When bent, producing a receptor

potential in the cells, it stimulates the innervating eighth nerve neurons (Popper and Carlson, 1998).

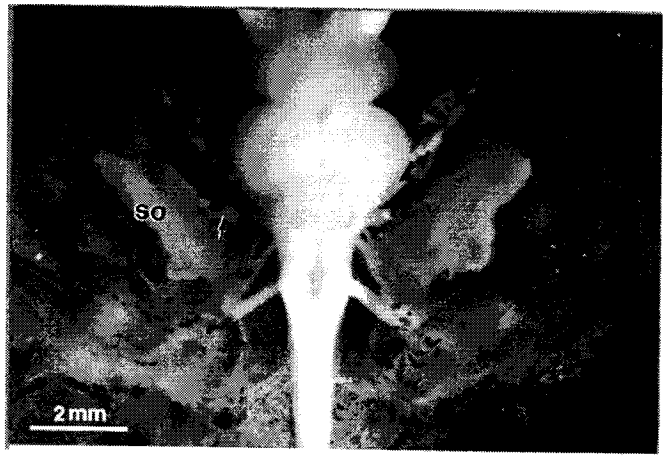


Figure 2.2 The goby's brain and ears (Lu and Popper, 2001).

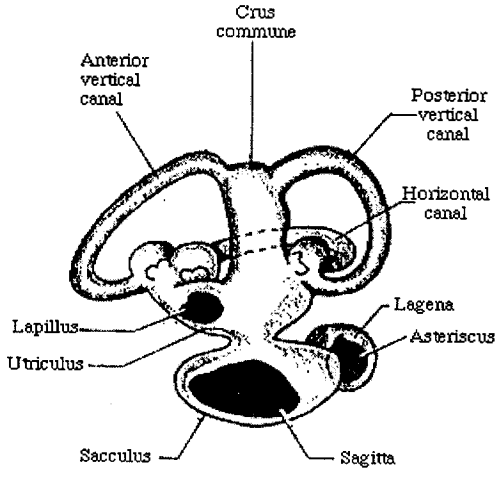


Figure 2.3 The three pairs of otolits (Jamieson, 2002)

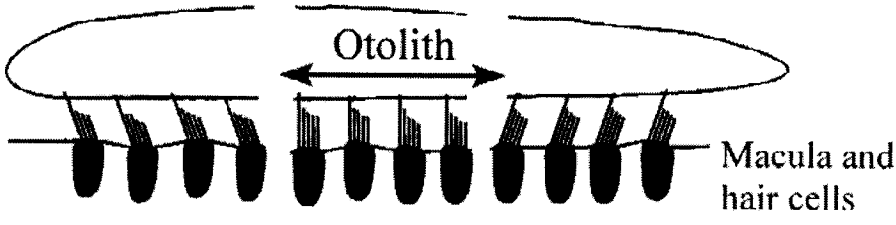


Figure 2.4 The otolith oscillating above the macular hair cells (Yoda, Rogers, and Baxter, 2002).

Fish hearing is the functional significance of interspecific differences that are found in the ear and peripheral structures among extant fish. The variation in the size and shape of the semicircular canal, otolithic end organs, saccule, and saccular otoliths influences the hearing ability of fish, and is associated with sound detection. The saccule, probably the main sound detector in most fish, is highly variant in structure, while the lagena is much less variant between different fish species, and utricle in most fish is very much like that found in all other vertebrate (Popper and Lu, 2000).

2.5.2 The Growth and Growth Regulation of Otoliths

Otolith accretions of crystalline calcium carbonate developed when juveniles hatch, over the anterior and posterior maculae in the ear, and are tethered in place by gelatinous otolithic membranes. After 18 to 24 hours from hatching, many small crystalline particles are present throughout the lumen of the ear. From 18.5 hours onwards, the particles coalesce to form the two otoliths, which appear as irregular clumps of material at anterior and posterior ends of the otic vesicle. After 24 hours, few free particles are observed and the otolith grows in size (Fig. 2.5), (Whitfield, Riley, Chiang, and Phillips, 2002).

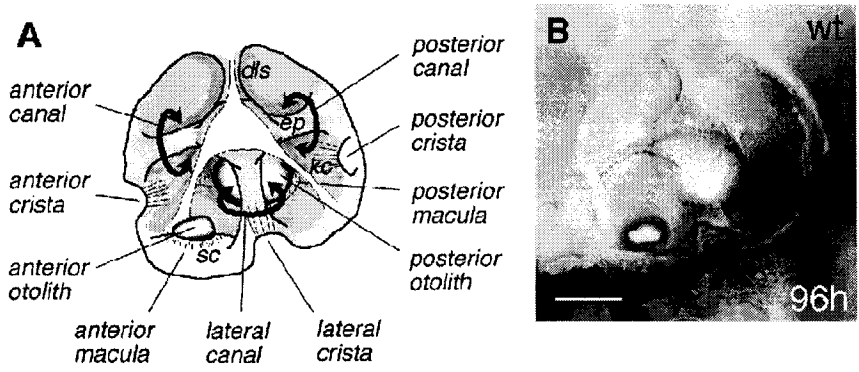


Figure 2.5 A: Diagram of otolith growth in the inner ear of fish and B**:** SEM photo of otolith (Whitfield, Riley, Chiang, and Phillips, 2002).

The sagittal otolith has alternating layers of a thick band known as the incremental zone and a thin band known as the discontinuous zone, which are deposited daily. During most of the day and night both the organic metric and inorganic minerals are deposited to form the incremental zone. The cycle of deposition of the incremental zone and discontinuous zone appears to be regulated by an endogenous rhythm within the fish, synchronized with the photoperiod and influenced by various other ecological factors such as water temperature, food availability and depth (Campana and Neilson, 1985; Gauldie, 1993).

Otolith growth is controlled by an endogeny or exogeny of fish (Marales-Nin, 2000) and ecological factors such as photoperiod, water temperature, food availability and depth (Wilson, 1985; Campana and Cassellman, 1993; Fey, 2001; Morales-Nin, 2000; Strelceck, Fitzhugh, Coleman, and Koenig, 2000). These factors have been shown to affect different growth rates, which cause variation in the shape and size of otolith, especially sagittal otoliths. In addition, the different growth rate of each otolith type may have been the result of differences in spawn-date (Karlou-Riga, 2000) and happenings at metamorphosis (Cieri and MeCleave, 2000). Besides, otolith shape might be controlled by several factors, such as the shape of the otic capsule and the cranium (Lombrate and Morales-Nin, 1995).

The otolith shape of juvenile fish is very different from adult fish. The rostrum, antirostrum and area of otolith of juveniles are weakly developed or lacking, but the differences of otolith shape between male and female are not apparent (Bird, Eppler, and Checkley, 1986; Harvey et al., 2000).

2.5.3 Sagittal Otolith Morphology

The morphology of sagittal otoliths is both more complete and shows more

characteristic features than the other two otoliths, utriculus and astericus. In addition, the shape and size of sagitta in different fish species is distinguished (Harkonen, 1986). Therefore, it can be used to distinguish species, genera, family or taxonomy (Harkonen, 1986; Smale et al., 1995) and can be used for many studies in fish biology.

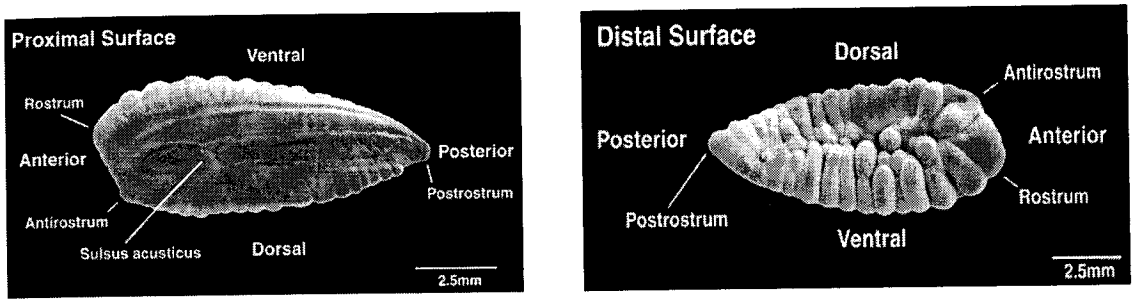


Figure 2.6 The inside (proximal surface) and outside (distal surface) of sagittal otolith of a haddock (Campana, 2001).

The sagittal otolith has two sides; the inside (proximal surface) and outside (distal surface), (Fig. 2.6). The outside is usually relatively even and often lacking in discrete structure, except for some fish species in the family Gadidae, where outside features of the sagitta provides other important other characters in identification of fish. Therefore, the outside is much less useful for identification of fish species or taxonomy, while the inside has more important characters that can be used to distinguish species, genera and family (Harkonen, 1986).

The sagittal otoliths are typically oval and laterally flattened in shape. Smale et al. (1995) has provided diagrams illustrating the terms for use in the description of otolith shape (Fig. 2.7). These otolith shapes have an inside surface which is divided into two parts e.g. the lateral face and medial face. The lateral face of the sagitta is

usually irregular, occasionally possessing large processes. The medial face is usually smooth and possesses well defined, regular features. The impression formed where the macula comes into contact with the medial face of the sagitta is known as the sulcus acusticus. It is typically the same shape as the macula and differs morphologically from one group to the next. The sulcus can be also divided into two regions, the anterior region is called the ostium and the posterior region, called the cauda (Aguirre, www, 2001).

The special terms for the various characters on the inside surface of the sagittal otolith, described by Smale et al. (1995), are listed and described here as follows:

2.5.3.1 The sulcus acusticus

The sulcus acusticus is partly or completely filled with aragonite of slightly different structure than otolith body. This aragonite is referred to as colliculum. Dorsal and often ventral of sulcus is mostly a flat or concave section of inside surface of the sagittal otolith. Sulcus acusticus is classified into 4 types i. e. archaesulcoid, pseudo-archaesulcoid, heterosulcoid, and homosulcoid (Fig. 2.8).

The shape and size of sulcus acusticus are very important characters for distinguishing fish species. It may be divided into ostium and cauda by a collum (Fig. 2.9). If the sulcus is undivided, the description reads "ostium and cauda undifferentiated". The ostium and cauda can reach the anterior and posterior margin respectively. If they reach the margin, they are called open and not closed. The sulcus acusticus generally opens on one or more margins (anterior or posterior of otolith). Therefore, the opening of sulcus acusticus is divided into 7 types i.e. mesial, ostial, pseudo-ostial, para-ostial, ostio-caudal, caudal, and pseudo-ostiocaudal (Fig. 2.10).

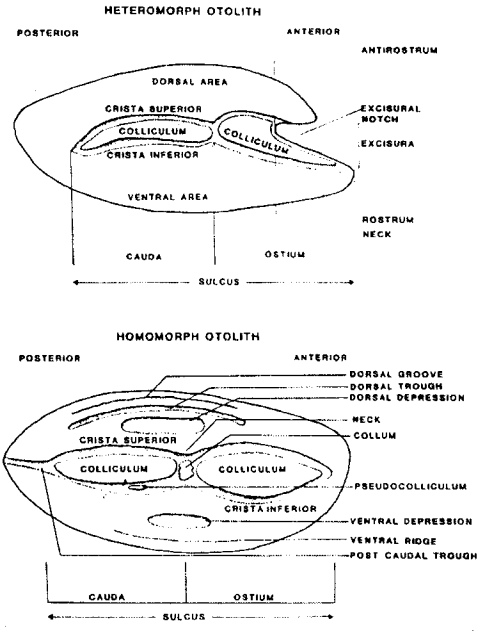


Figure 2.7 Diagrams of the inside (proximal surface) of sagitta otolith (Smale, Watson, and Hecht, 1995).

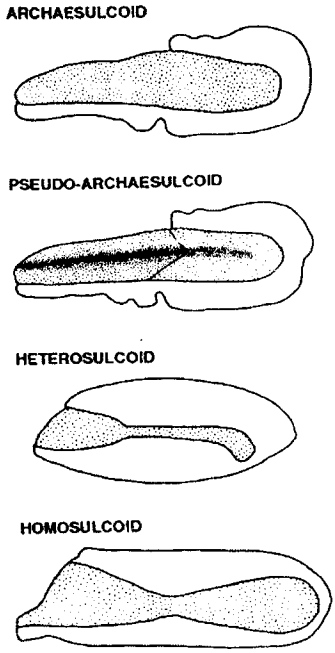


Figure 2.8 The sulcus acusticus types (Smale, Watson, and Hecht, 1995).

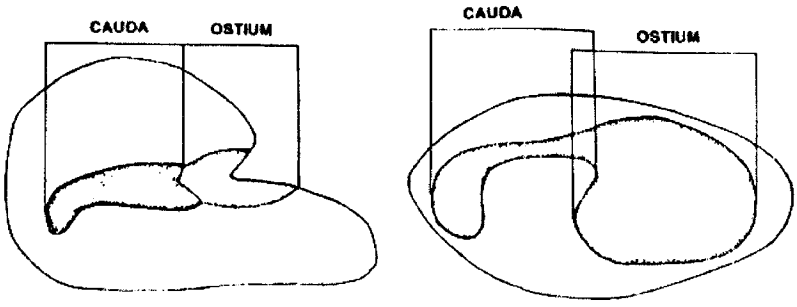


Figure 2.9 The ostium and cauda (Smale, Watson, and Hecht, 1995).

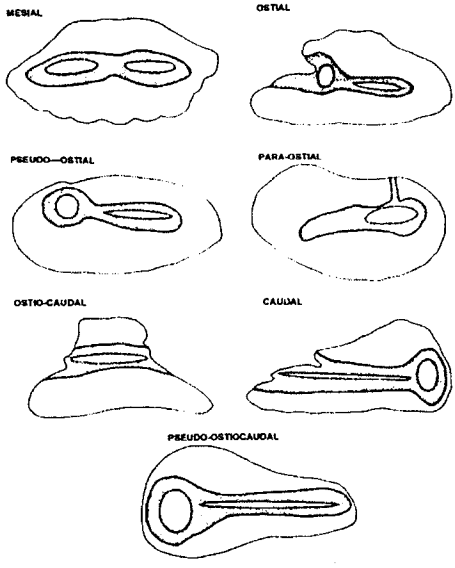


Figure 2.10 The opening of sulcus acusticus (Smale, Watson, and Hecht, 1995).

2.5.3.2 Rostrum, Antirostrum, Pseudorostrum and Pseudoantirostrum

The rostrum and antitrostrum are located at the anterior end of the sagittal otolith. Their shapes and sizes are very important for separation of fish species. The size of the rostrum is larger than the antirostrum in all species. In some species, the sulcus acusticus does not open on the anterior margin, and the rostrum and antirostrum are absent. The position and shape of rostrum, antirostrum, pseudorostrum and pseudoantirostrum are shown in Fig. 2.11.

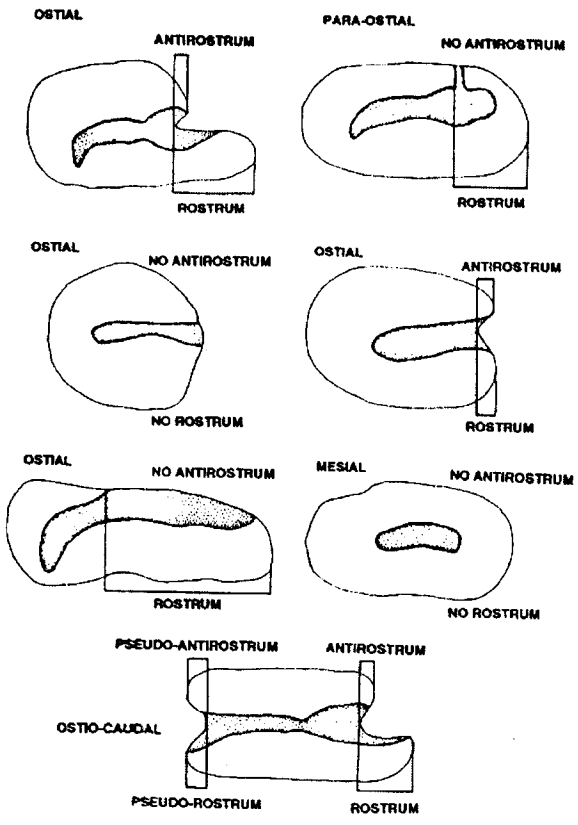


Figure 2.11 The position and shape of rostrum, antirostrum, pseudorostrum and pseudoantirostrum (Smale, Watson, and Hecht, 1995).

2.5.3.3 Margin shape and Sculpturing

The margin shape is the general characteristic of the margin, and the sculpturing is the finer surface feature of the margin, which may vary on each side within and among species. The sculpturing is divided into 7 types (Fig. 2.12).

2.5.3.4 Lateral surface feature

In some fish species, the lateral surface feature of sagitta may have characteristic features such as pits, notches or grooves and age ring that are useful for distinguishing the species or family.

2.5.3.5 Colliculum and Pseudocolliculum

The colliculum is part of the sulcus acusticus floor. It may be raised in

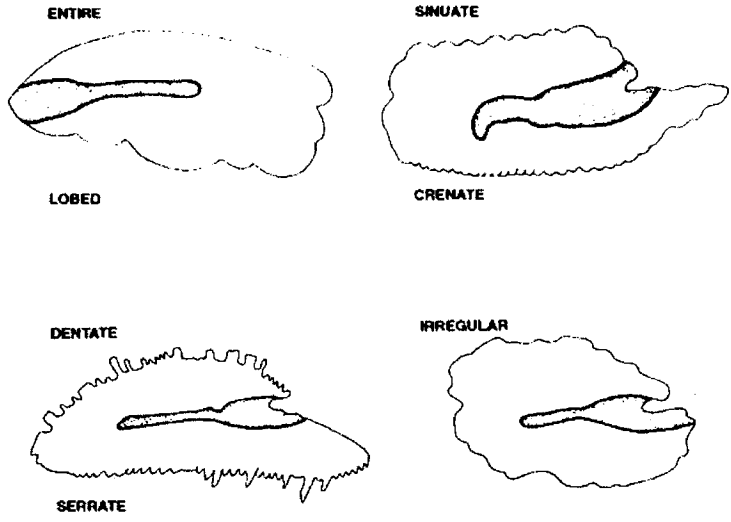


Figure 2.12 The type of margin shape (Smale, Watson, and Hecht, 1995).

the ostium, cauda or both, and can be divided into 7 types i.e. indistinct, homomorph, heteromorph, scombroid, incisive, ostial-incisive, and caudal-incisive. The pseudocolliculum are crests of the collicular that are located generally just above the crista inferior, and are found in some family such as Cadiformes and Myctophidae.

2.5.3.5 Collum or Neck

The collum is a raised tubercle or a wall-like structure that separates the ostium and cauda. In some fish species, e.g. *Stethojalis interrupta, Aulostomus Chinensis*, and *Atuterus monoceros*, the collum appears as depressed pits, while in many fish species, it is often absent. The collum is divided into 4 types i.e. collum absent, collum wall-like, collum raised tubercle, and collum solid bridge.

2.5.3.6 Dorsal depression and Ventral depression

The dorsal depression and ventral depression are depressions in the dorsal area and ventral area respectively. Both the dorsal depression and the ventral depression may have distinctive shapes and may be morphologically different from the rest of the area.

2.5.3.7 Excisura and Pseudoexcisura

The sulcus acusticus are usually openings on the anterior margin of the otolith and cause a separation between the rostrum and antirostrum. If the sulcus does not have an opening or does not reach the margin of otolith, there is no excisura. If the sulcus acusticus is open on the posterior margin of the otolith, there is pseudo-excisura.

2.5.4 General Structure of Otolith in Fish Biology Studies

The otoliths are widely utilized for the study of fish biology such as life history of fish, population, identification and taxonomy studies.

The compositions of otolith has also been used for the study of fish biology. Degens, Deuser, and Haedrich (1969) studied the chemical composition of fossil otolith in 25 different fish from various freshwater and marine habitat to determine environmental history, and to distinguish between the freshwater and marine fish in ancient deposits, and their migration of them. The variation of total organic matter and the isotope distribution in the aragonite of fossil otoliths from these fish were unique. They could be used as phylogenetic and environmental criteria to distinguish between freshwater and marine species, and to determine the migratory tendencies or measurements of the mean temperature at which they lived. Tzeng, Severin, Wickstrom, and Wang (1999) reported that changes in the Sr band in otolith of European eel (*Anguilla anguilla*) could be used to investigate their age and detect their migratory history. When the eel migrated from the brackish waters to the high saline waters, the higher concentrate of Sr in the otolith was deposited and synchronous with the hyaline zones that were formed once a year. Gillanders, Sanchez-Jerez, Bayle-Sempere, and Ramos–Espla (2001) used otolith chemistry of

two-band bream (*Diplodus vulgalis*) from along the Southwest Mediterranean to distinguishing groups of fish. They found that the otolith chemistry (Li, Mn, Sr, Cd, and Ba) of two-band bream was not significantly different between sites that were less than 100 meters from along the Southwest Mediterranean, while in location more than 10 kilometers apart differences were recorded but small.

The otolith weight has been used to determine age and size of fish. Pawson (1990) studied the otolith weight of sardine (*Sardinella aurita* Val.) from the population near Tripoli and Libya in the Southeast central Mediterranean to determine their fish age and the relationship between otolith weight and fish size. Results from on this study showed that it is possible to predict fish age for groups of fish in which growth rates are known, but this technique had a limited application in fish aging from the wild population. In a similar study, Araya, Cubillos, Guzman, Penailillo, and Sepulveda (2001) reported that the relationships between fish age and otolith weight of the Chilean jack mackerel (*Trachurus symmetricus murphyi*) from the central-southern area off Chile. The relationships between otolith weight and fish age were linear and significant and may be a useful tool for rapidly estimating the age of individuals and their possible age structure.

Using the ring of otolith in fish biology studies, Radtke, and Fey (1996) found that the otolith increment of Arctic charr (*Salvelinus alpinus*), when reared from hatching under low temperatures and starvation, depressed daily increment formation. However, this increment deposition was shown to be a daily deposit among the larvae reared at warm temperature and fed at least every third day. The differences of increment number and width of otolith in Arctic char appeared to be based on fish growth rate, which is influenced by temperature and feeding

conditions. Newman, Cappo, and Williams (2000) reported that the opaque and translucent increments of three species (*Lutjanus erythropterus*, *L. malabaricus*, and *L. sebae*) from the central Great Barrier Reef could be used to determine fish age, growth rate, and mortality rate of these fish species. The precision in determining the age of these species from the whole otolith declined significantly with increasing fish age. Suyama (1997) also reported the determination of fish age in eight species from the South Sulawesi, Indonesia by using this incremental technique and found that two of the eight species (*Atherinomorus lacunosus* and *Sphaeramia ordicularis*) had clear incremented deposition, which enabled the estimation of age in days, whereas other species had unclear increments, a deposit which proved too difficult to count.

2.5.5 The Sagittal Otolith Morphology in Fish Biology Studies

2.5.5.1 Sagittal otolith morphology for stock identification

Variation in otolith morphology among the population or stock of fish has been known to occur for some time and has the potential of becoming an important tool in fisheries biology (Jamieson, 2000). The shape and size of sagittal otolith often vary geographically even in the same species. However, in some cases they could not relate the appearance and shape to the stock difference. All of these cases have been reported in various studies.

Bird, Eppler, and Checklery (1986) reported the otolith shape in juvenile and adult herring from Alaska and the Northwest Atlantic by using Fouries Series Shape Analysis. Otolith shapes of these fish were different in fish age and fish trait, and in the juvenile fish were significantly different from adult fish. The differences of otolith shape from adult fish of different ages within the same stock (within the Alaska or within the Northwest Atlantic) were little different, but otolith

shape of these fish between the Alaska and the Northwest Atlantic were distinctly different. Smith (1992) reported the differences in otolith morphology of deep slope red snapper (*Etelis carbunculus*) in four populations from Hawaii, Vanuatu, Fiji, and French Polynesia. They found that the otolith shape and weight between populations were distinguishing. Otolith shape from Hawaii and French Polynesia showed the closeness of fish species, while the otolith shapes from Hawaii and Vanuatu were similar and distinct from the other regions. Friedland and Reddin (1994) studied the otolith morphology of Atlantic salmon (*Salmo salar*) from the continental origins, of North America and Europe, and the country origins, of United States, Canada, Ireland and United Kingdom. The otolith morphology from continental origins was different, with 88 percent having a continental model, while, the otolith morphology from the country origins was not different. Bolles and Begg (2000) used whole otolith morphometrics for distinguishing between silver hake (*Merluccius bilinearis*) stock in the United States waters of the Northwest Atlantic which was divided into two stocks, viz. a northern stock from the Gulf of Maine to Northern Georges Bank and a southern stock from Southern Georges Bank to the middle Atlantic. The otoliths of the northern stock were larger than southern stock. This method could be a useful tool in identifying silver hake stocks and other fish stock.

Recently, Tuset, Lozano, Gonzalez, Pertusa, and Garcia-Diaz (2003) studied the sagittal otolith morphology of comber fish (*Serranus cabrilla*) in determining the regional differences between the Atlantic and the Mediterranean regions by using shape indices, form-factor, roundness, circularity, rectangularity, ellipticity, and eccentricity. The characters of otolith morphology, the form-factor, circularity, and rectangularity were more related to origins, while ellipticity and

eccentricity were more related to species. This result had provided enough evidence to identify regional differences in the sagittal otolith morphology of comber fish.

Internal otolith morphology was used to identify haddock (*Melanogrammus aeglefinus*) stock on Georges Bank between eastern and western regions. Significant difference in internal sagittal otolith structure was found between eastern and western haddock. Otolith of eastern Georges Bank haddock tended to be smaller sized than Western Georges Bank haddock (Begg, Overholtz, and Munroe, 2001).

The shape and size variability of sagittal otolith was also used to separate three species of *Merluccius* from geographical intraspecific differences. The sagittal variation of *Merluccius garyi* was clear between the Chile and Peru site, also in *M. merluccius* between the Atlantic and Mediterranean. However, the sagittal variation of *M. bubbsi* was less effective at differentiating between the San Matias Gulf on the Patagonian Shelf and Argentinian (Torres, Lombarte, and Morales-Nin, 2000a). DeVries, Grimes, and Prager (2002) used otolith shape data to distinguish between population of king mackerel from Mexico and the Atlantic Ocean. They found that the otolith shape data of king mackerel from the Gulf of Mexico was different from the Atlantic Ocean and this data could be used to estimate stock composition in mixed-stock fisheries and to distinguish stock of king mackerel among regions.

By contrast, the redfish otoliths were compared between sampling areas and species by using Elliptical Fourier Analysis (EFA). The outline and shape (weight, height and length) of sagittal otolith in *Sebastes mentella* were analyzed between sampling area and the three species (*S. mentella, S. marinus and S. viviparus*)

were compared within one area, the Barents Sea. The sagittal otolith of *Sebastes mentella* from these different areas, viz. the East Greenland, the Irminger Sea and the Barents Sea, was not different, whereas the sagittal otolith of three species from within one area of the Barents Sea gave the clearest separation among the three species (Stransky, 2001).

2.5.5.2 Sagittal otolith morphology for species identification

Sagittal otolith morphology varies greatly among different groups and they are often distinct enough among species to be reliable in species identification. The variation of otolith shape relates to growth rate, which was influenced by the environmental factors and biological factors

L'Abee-Lund (1988) used otolith morphology (length and weight) to distinguish between juvenile Atlantic salmon and brown trout. The otolith shape of Atlantic salmon was more elongated than the otolith shape of brown trout, which was like a water drop. Analysis of the otolith measurements of the juvenile from of both species from a four rivers system was differed. Maceinna and Murphy (1989) studied the otolith shape among large mouth bass (*Microplerus salmoides foridanus*), northern largemouth bass (*M.s. salmoides*) and the first generatiom (F1) hybrids between these two subspecies. The otolith shape of large mouth bass was along the anterior axis, while in the two subspecies it was along the dorsal axis. The otolith shape of F1 hybrids was intermediate between those of the two subspecies.

Lombarte and Castellon (1991) determined the outline of sagittal otolith of six species of *Merluccius* (*M. productus* from the Northwest Pacific, *M. gayi* from the Southeast Pacific, *M. bilinearis* from the Northwest Atlantic, *M. merluccius* from the Northwestern Mediterranean, and *M. capensis* and *M. paradoxus*

both from the Southeast Atlantic) by using image analysis. The outline of the sagittal otolith in this study was divided into four size classes of fish: less than 20 centimeters total length: 21-40 centimeters: 41-60 centimeters: and greater than 60 centimeters. The sagittal otolith from individuals longer than 20 centimeters in total length could be classified into two geographic and phylogenetic groups: an Euro-African group (*M. merluccius*, *M. capensis*, and *M. paradoxus*), and an American group (*M. productus*, *M. bilinearis*, and *M. gayi*).

Hunt (1992) reported the relationships between sagittal otolith dimension and fish size in six demersal and two pelagic species by determining the relationships between otolith dimension, fish length and sex of red fish. The relationships between the otolith dimension (length, weight, width, and volume) and fish length in all species were marked, but the relationship between otolith dimension of red fish and sex was not significantly different.

Macrostructure and ultrastructure of sagitta otolith on sulcus acusticus can be used for identification of fish species. Lombarte and Morales-Nin (1995) reported that the crystal structure and macrostructure of sagittal otolith of the five species of *Caelorinchus* provided a good tool to use for separation of these species. Miller, Herra, and Leggett (1999) used otolith size to separate larval size (SL) of Atlantic cod. They reported that the correlation of otolith size of sagittal otolith and lapilli was low.

Shape (1999), working with Cynoscion otolith, reported that the sagittal otolith size (length and hight) of *Cynoscion* was variable among the different species. The differences were very clear in the sagittal otolith of *Cynoscion nothus*, *C. nebulosus*, *C. squamipinnis*, and *C. phoxocephalus*, but in some cases, the otolith of

C. squamipinnis was not significantly different from *C. regalis* and *C. arenarius*. From these results it was not known whether this similarity was due to phylogenetic closeness between these species or due to convergence. A similar study report of the length and height of sagittal otolith in nine species of *Cynoscion* reported that the growth rate of sagittal otolith length was faster than sagittal otolith height and that the greater length of sagital otolith was related to fish length (Mississippi Academy of Sciences Meeting, www, 2000).

Chen and Yan (2002) used three indices, the inter-utricular ratio (IUR); the inter-saccular ratio (ISR); and the inter-lagena ratio (ILR), for the separation of otolith in eight species of marine fish larvae. They found that by using the inter-utricular ratio (IUR) and the inter-saccular ratio (ISR), it was possible to separate species, but the inter-lagena ratio (ILR) was not useful in this regard because of the late development of the lagena.

Maldas, Marcri, Volpedo and Echeverria (2002) reported regression between otoliths morphometrics values and fish length, typical features of sagittal otolith morphology of carangidae, sciaenidae and mullidae from the Argentinean Bonaerense coast. The morphometrics and morphology of shape, rostrum, antirostrum, ostium, cauda and excisura of sagittal otolith from these fish were different among species. The distinctive character: rostrum, antirostrum, shape, margin, sulcus acusticus, between two species i.e. *Marcusenius macrolepidotus* and *Petrocephalus catostoma*, were also reported by Nicolaai and Jooste (2002).

2.5.5.3 Sagittal otolith morphology for feeding studies

Biologists have used the otolith morphology, recovered from stomach contents of predators, to determine the type of they have eaten. These important

predators are whales, seals, seabirds, squids and piscivorous fish. The first report on otolith from fish in cetacean stomach was reported by Scott (1903, Quoted in Harkonen, 1986). A large number of otoliths in different species belonging to the cod family have been found in stomach content of the common porpoise (*Phocaena phocaena*) and of sandeels (*Ammodytes* sp.). The fish otoliths from stomach contents of sea mammals was also reported, i.e. in whales: common dolphin (*Delphineus delphis*), white whales (*Delphinapterus leucas*) and three pygmy sperm whales (*Kogia sinus*) (Schmidt, 1923; Vladykor, 1946; Fitch and Brownell, 1968, Quoted in Harkonen, 1986). These otoliths have been primarily used for identification of species of fish preys, but some researchers have used the relationship between otolith length and fish length to estimate size of fish in predators (Finley and Gibb, 1982).

Harvey, Loughlin, Perez, and Oxman (2000) reported a relationship between fish size and otolith length for 63 species of fish from the Eastern North Pacific Ocean. This information was useful for predator-prey studies and archeological researches. In addition, otoliths from marine birds were utilized to study of the feeding of several marine birds: the Caspian term (*Hydropogone caspia*), the herring gull (*Larus argentatus*), and the western gull (*Larus occidentalis*) (Martini, 1964; Martini, 1966; Schafer, 1966, Quoted in Harkonen, 1986). The otolith morphology was also used to determine fish species in the stomach contents of those birds.

The ichthyologists Arnet, Neill, and Wheland (2002) reported the diet of grey seal (*Halichoerus grypus*) and their potential impact on local fisheries. Sixty percent of the otoliths in the stomach of seals were from commercial fish species: whiting, pollock, ling and cod. Phillips, Jackson, and Nichols (2001) reported that the

myctophid fish otoliths were found in stomach contents of the squid (*Moroteuthis ingeus*) around Macquarie and Heard Island. Waessle, Lasta, and Favero (2002) reported the relationship between otolith morphology and body size of seven species from juvenile sciaenidae, which were important prey of several top-predator species among large fish, seabirds and mammals. The sagittal morphology and morphometric relationships of these species could help researchers studying food habits of top predators to determine size and weight of usually juvenile fish-prey from the length and weight of recovered otoliths.

2.5.5.4 Sagittal otolith morphology for habitat studies

Several studies reported that the otolith morphology (size and shape of sagitta, sulcus acusticus and rostrum) was related to the habitats of fish. Otolith size changes of six species of *Merluccius* and five species of *Coelorhynchus* were studied by Lombarte and Lleonart (1993). They found that environmental condition and increased habitat depth influenced the otoliths. The increase in habitat depths seems to be an important factor regulating the growth of otolith in carbonate-saturated levels. Arelliano et al. (1995) found that the ratio of the sulcus acusticus area to the sagittal area (S: O ratios) of *Pomatoschistus minutus* and *P. lozanoi* was lower than that of demersal and pelagic fish. Aguirre and Lombarte (1999) found that the mean S: O ratio of two species, *Mullus barbatus* and *M. surmuletus*, was different. This may be associate with the difference in size and shape of sagitta, in somatic growth, in food and in spatial niches. The variability of the sulcus acusticus in the sagittal otolith of the genus *Merluccius* in 12 species was studied by means of image analysis. These results were related to function, environment and phylogenetic. The sulcus acusticus

of deep-water species, *M. polli* and *M. paradoxus*, was different from the surface water species (Torres, Lombarte and Morales-Nin, 2000b).

In addition, the individual variability of the otolith shape in five species, *Hoplostethus atlanticus*, *H. mediterraneus*, *Paratrichichthys trailli*, *Pagrus major* and *Trachyrus murphyi*, were compared with other species in terms of their depth of habitat. These five species showed a decreasing trend in scatter of otolith shape from the species at the deepest habitat (*H. atlantious*) to the most shallow (*T. murphyi*) (Gauldie and Crampton, 2000). Stransky (2002) also compared the otolith morphometry (length, breadth and weight) and otolith shape analysis of red fish between area/depth groups from the Irminger Sea by using Elliptical Fourier Analysis (EFA). The univariate measurements (otolith morphometrics) were significantly different between area/depth groups, only for the medium length groups (32.5-37.5), whereas shape otolith analysis gave poor discrimination, and was being slightly higher in the large length groups (38.5-43.5) than in the small (26.5-31.5) and medium (32.5-37.5) length groups.

Volpedo and Echeverria (2002) studied morphology and morphometry of sagittal otoliths from fish associated with different substrates. These fish were divided into three groups: soft substrate, hard substrate, and pelagic fish. They found that the morphology of sagittal otoliths in three groups was different. The sagittal otolith shapes of soft substrate were circular with a poorly developed rostrum, while groups of hard substrate had an elongated rostrum and pelagic groups had a v-shaped and prominent rostrum. Tuset, Lombarte, Gonzalez, Pertusa, and Lorentes (2003) compared the morphology of sagittal otoliths in *Serranus* spp. They found that the sagittal otolith morphology and sulcus area of shallower water species were smaller

than the deeper water species and the sulcus and ostium size were correlated with the habitat depth of the species.

Paxton (2000) used otolith size of 247 marine fish species in 147 families to compare taxonomic groups, habitats and presence or absence of luminescence. Luminous species had slightly larger otoliths than non-luminous species in the same family. Most fish of the epipelagic surface water had a very small otolith and no swim bladder. Moreover, other habitats had species with a range of otolith sizes. He suggested that the sizes of otoliths might be associated with hearing.

2.5.5.5 Sagittal otolith morphology for growth rate studies

Many researchers reported the relationship between otolith growth and somatic growth. They found that slow growing individuals had larger otoliths than fast growing individuals of the same size. Fey (2001) reported a relationship between otolith size (perimeter, length, width, area and weight) and fish size of larval and juvenile herring (*Clupea harengus*) from three cohorts. These relationships differed among the three cohorts. He found that temperature effected the otolith growth with individuals growing in warmer water having larger otoliths. Relationship between otolith size and fish size in juvenile gag (*Mycteroperca microlepsis*) of the eastern Gulf of Mexico was used to compare growth rate of juvenile gag of laboratory populations with field populations (Strelcheck, Fitzhugh, Coleman, and Koening, 2002). They found that food availability significantly effected growth rate. The slower growing gag had larger, heavier otoliths than the same sized and faster growing gag. The juvenile gag from the more northern latitudes appeared to grow faster than from southern latitudes.

CHAPTER III

MATERIALS AND METHODS

3.1 Fish Collection

3.1.1 Fish Collected

The fish were collected during June 2002 to May 2003 from fishing piers and markets in the southern coasts of Thailand (Prachuap Kiri Khan, Surat Thani, Nakhon Sri Thammarat, Songkhla, Pattani, Ranong, Phuket, Trang, and Satun) (Fig. 3.1 and Fig. 3.2). At least 15 orders, 60 families of fish were collected in this study. The size of fish in mature or adult stage was used as a standard size of each species. At least five fish of each species were collected.

3.1.2 Fish Measurements

The standard length (SL) of each fish, measuring from the tip of the snout to the base of the caudal fin, was measured to the nearest millimeter with a meter stick prior to removal of the otolith (Fig. 3.3). Data were recorded in Excel Spreadsheet. The other measurements of fish such as fork length, total length, head length, body depth, etc. were also measured to collect details of each fish. These extra data were not used in this research.

3.1.3 Fish Identification

Fish specimens were identified according to Bone, Marshall, and Blaxter (1995) and Nelson (1994).

Figure 3.1 The map of Thailand (Thailand Map, 2006).

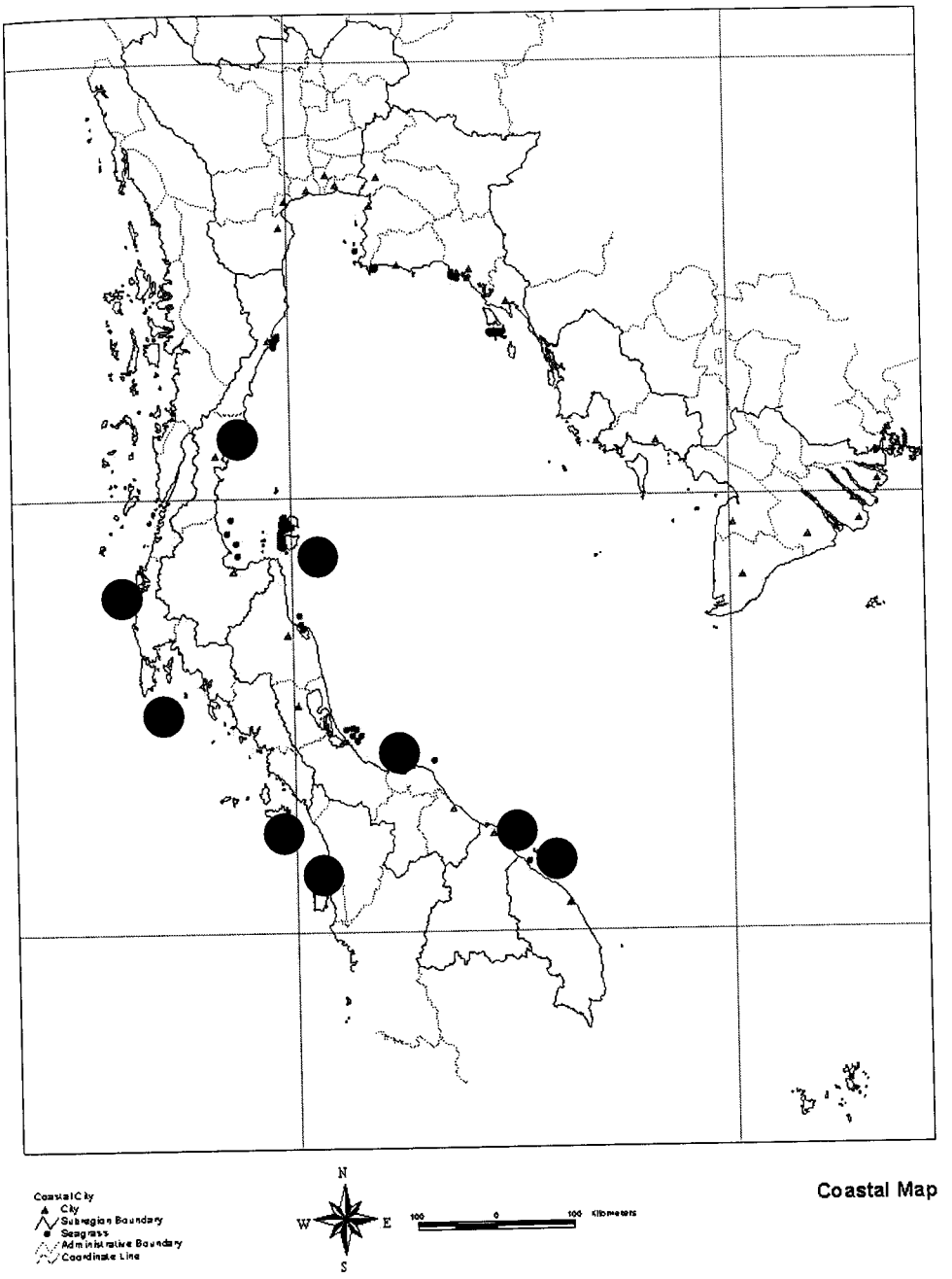


Figure 3.2 The coastal map of Thailand ● = Location of fish collection (GIS coastal map of the Gulf of Thailand, 1999).

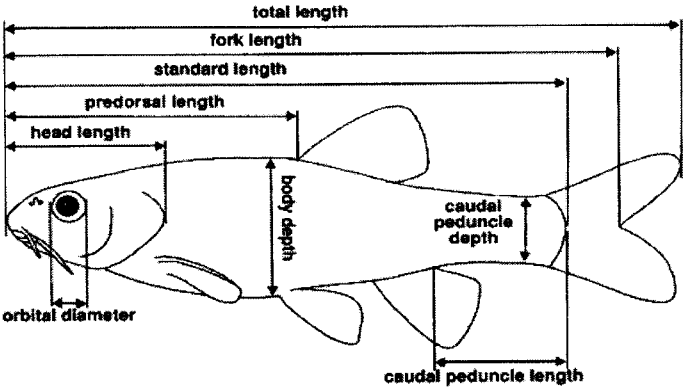


Figure 3.3 Measurement of standard length of fish (Jerry, 2002).

3.2 Otolith Preparation and Measurement

3.2.1 Otolith Removal

There are several ways to remove a pair of sagittal otoliths from the fish skull. The best method for otolith removal depends on the size of fish, morphology of otolith and auditory capsule. In this study, the following two methods were used.

3.2.1.1 Hidden cut method

This method was used for large and hardhead fish. There are 4 steps to remove otolith: 1) Cut the operculum by a sharp fish knife to fold forward and open it wide out of the way, then, cut away the gill arches at their insertion. 2) Gently removed the thin layer tissue from the otolith capsule. 3) Poped open the capsule with the chisel. When the capsule is open, a cavity appears with a visible white otolith. 4) Removed both otoliths with forceps or tweezers (Fig. 3.4).

3.2.1.2 Vertical cut method

This method was used for small and softhead fish. There are 5 steps to remove otoliths: 1) Griped the head of the fish by putting thumb and forefinger in its

eye sockets. 2) Put the knife blade on the top of the fish's head behind the eye near the edge of operculum. 3) Slanted the blade away from posterior to anterior of fish at about a 30^0 angle. 4) Sliced the blade back and down about one head length and cut through the top of the skull. The otic vesicle should appear as two small cavities with a visible white otolith. 5) Removed both otoliths with forceps or tweezers (Fig. 3.5).

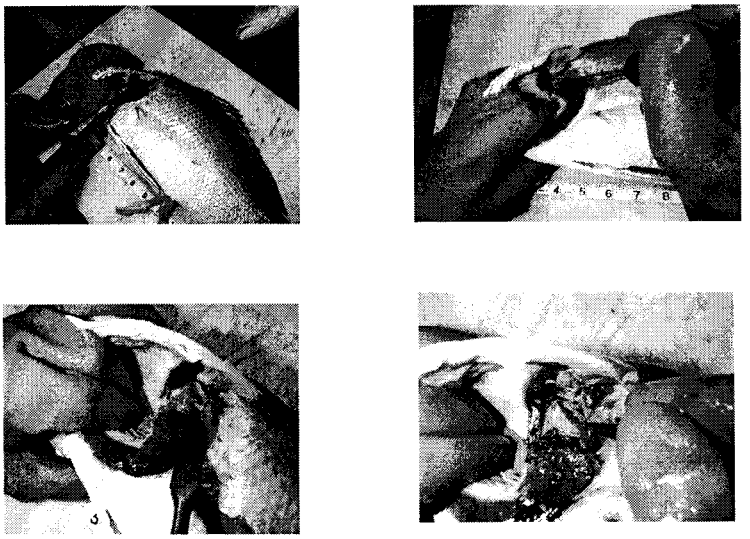


Figure 3.4 Hidden cut method (The Panama City Laboratory , 2002).

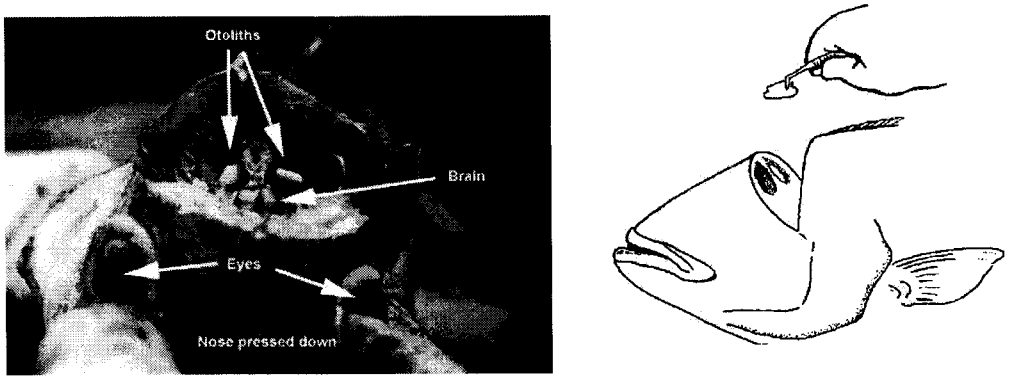


Figure 3.5 Vertical cut method (Campana, 2001).

3.2.2 Otolith Cleaning

After the sagittal otoliths were removed from the fish's head, they were washed to remove any residual tissue, gelatin membrane and blood. They were then washed with cloth, paper towel or rinsed with freshwater and allowed to air dry

3.2.3 Otolith Storage

After air drying, the sagittal otoliths of each fish were stored dry in each envelope with important data written on the outside of the envelope, such as sample number, name of fish, standard length, date caught, place of collection, etc (Fig. 3.6). The individual otolith envelope was then placed in a Ziplock bag and sealed.

3.2.4 Otolith Measurement

In this study, the lengths and height of the otoliths were measured by hand-held vernier calipers and the data recorded in Excel spreadsheet. Otolith length was measured from the anterior rostrum to the posterior edge. The height of the otolith was measured from dorsal margin to ventral margin to the nearest millimeter (Fig. 3.7).

Figure 3.6 Otolith storage (Munk and Smikrud, 2002).

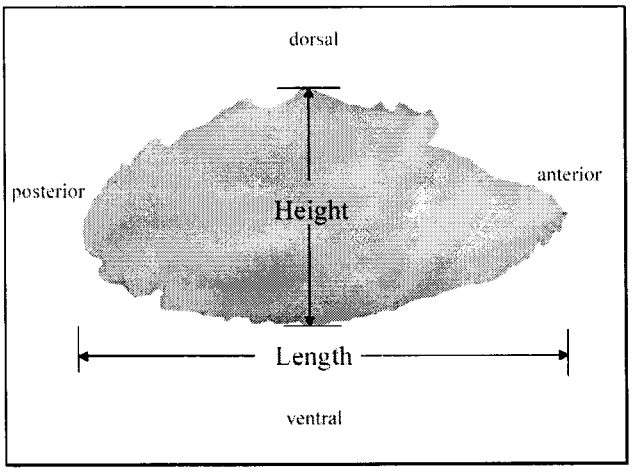


Figure 3.7 Measurement the otolith length and otolith height (Munk and Smikrud, 2002).

3.2.5 Otolith Preparation for the Scanning Electron Microscope (SEM)

The sagittal otoliths were mounted on a brass stub 50 millimeters in diameter and 4 millimeters thick with the sulcus acusticus up. The stub was divided into 8 segments. Individual otoliths were placed on each numbered segment, which was mapped and recorded. The otoliths were affixed to the stub with double-sided tape. Mounted otoliths were sputter-coated with a thin layer of gold using a standard coating time of two minutes.

Photomicrographs of otoliths were done at the Electron Microscopy Unit in the Center for Scientific and Technological Equipment, Suranaree University of Technology.

3.3 Equipment and Instrument

3.3.1 Scanning electron microscope (SEM) (JEOL, JSM – 6400)

3.3.2 Vernier calipers

3.3.3 Meter stick

3.3.4 Forceps or Tweezers

3.3.5 Fish knife

3.3.6 Vial or Envelope

3.3.7 Freezer box

3.3.8 Cloth or Paper towel

3.3.9 Ziplock bag

3.4 Data Collection

3.4.1 Photomicrographs of otoliths of each fish species were taken by a scanning electron microscope.

3.4.2 Lengths and heights of otoliths were converted to relative otolith size (% standard length,), separately.

3.4.3 Sizes (lengths and heights, % SL) of the otoliths and standard lengths (SL) of fish were recorded on the Excel Spreadsheet.

3.4.4 Average values of otolith size (% SL) of each fish species, families and orders were calculated.

3.4.5 Average values of standard length (SL) of each fish species, families and orders were calculated.

3.4.6 Habitats of the fish were determined according to Bone, Marshall, and Blaxter (1995) such as coral reef, shelf, inshore, epipelagic, mesopelagic and bathypelagic.

3.5 Data Analysis

3.5.1 Photos of sagittal otoliths of each fish species were studied. The sagitta morphology description and terminology were based on criteria written by Smale,

Watson, and Hecht, (1995). All sagittal otoliths were systematically arranged and a systematic key established according to fish taxonomic classification.

3.5.2 The relationships between the sagitta sizes, taxonomic groups and fish's habitat were plotted in terms of the otolith size (%standard length; SL) vs. the standard length (mm).

3.5.2.1 The relationships between the sagitta sizes and taxonomic groups were plotted in terms of the otolith size (% SL) vs. the standard length (mm) of order, family and species.

3.5.2.2 The relationships between the sagitta sizes and habitat of fish were plotted in terms of the otolith size (% SL) vs. the standard length (mm) for each habitat in fish order.

3.5.3 The relative otolith size ranges were categorized as the following: very small (0.01-0.99% SL), small (1.00-2.99% SL), moderate (3.00-4.99% SL), large (5.00-6.99% SL), and very large (7.00-12.00% SL) (Paxton, 2000).

3.6 Location of Research

3.6.1 Fishing piers and markets in Prachuap Kiri Khan, Surat Thani, Nakhon Sri Thammarat, Songkhla, Pattani, Satun, Trang, Phuket, and Ranong.

3.6.2 Instrument Building of the Center for Scientific and Technological Equipment, Suranaree University of Technology.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Results

From June 2002 to May 2003, fish from the southern coast of Thailand totalling 60 families, 2 subfamilies and 14 orders were collected and used in this study. Taxonomic classifications of fish were classified according to Nelson (1994), as shown in Table 4.1.

The sagittal otoliths were removed from the fish's head and investigated by scanning electron microscope. The results of investigation are separated into 2 main categories: general morphology of otoliths and characters of otoliths of each family and species. Analysis of correlation among sagitta sizes, taxonomic groups and habitats are shown as an Excel graph.

4.1.1 The general morphology of otoliths

The sagittal otolith morphology from fish in 211 species, 60 families, 2 subfamilies, 14 orders are species-specific. The shape, sulcus acusticus, ostium, cauda, rostrum and antirostrum are mainly prominent characters that show distinctive features of sagittal otoliths as well as other characters, i.e. margins sculpturing, margin, dorsal depression, ventral depression, crista superior, crista inferior, exisura, pseudo-excisura, collum, and collicullum. These characters differ in both infra groups and inter groups. The descriptions of typical sagittal otolith morphology have been based on the criteria given by Smale et al. (1995), as shown in Fig. 2.1.

Table 4.1 Taxonomic classification of collected fish

Order	Family	Sub Family
1 Elopiformes	Elopidae	
	Megalopidae	
2 Anguilliformes	Muraenesocidae	
3 Clupeiformes	Engraulidae	
	Pristigasteridae	
	Chirocentridae	
	Clupeidae	
4 Gonorhynchiformes	Chanidae	
5 Aulopiformes	Synodontidae	Harpadontinae
6 Ophidiiformes	Ophidiidae	
7 Mugiliformes	Mugilidae	
8 Atheriniformes	Atherinidae	
9 Beloniformes	Belonidae	
	Exocoetidae	
	Hemiramphidae	
10 Beryciformes	Holocentridae	Myripristinae
11 Scorpaeniformes	Scorpaenidae	
	Platycephalidae	
12 Perciformes	Priacanthidae	
	Centropomidae	
	Ambassidae	
	Serranidae	
	Apogonidae	
	Sillaginidae	
	Rachycentridae	
	Carangidae	
	Menidae	
	Gerreidae	
	Leiognathidae	
	Lutjanidae	
	Caesionidae	
	Haemulidae	
	Lethrinidae	
	Sparidae	
	Nemipteridae	
	Sciaenidae	
	Mullidae	
	Cepolidae	
	Pempheridae	
	Teraponidae	

Table 4.1 Taxonomic classification of collected fish (continued)

Order	Family	Sub Family
12 Perciformes	Ephippidae	
	Drepenidae	
	Labridae	
	Scaridae	
	Pomacentridae	
	Pomacantridae	
	Scatophagidae	
	Siganidae	
	Acanthuridae	
	Scombridae	
	Trichiuridae	
	Polynemidae	
	Sphyraenidae	
	Gobiidae	
13 Pleuronectiformes	Psettodidae	
	Paralichthyidae	
	Soleidae	
	Cynoglossidae	
14 Tetraodontiformes	Balistidae	
	Monacanthidae	

The terminology used for characteristic morphology of each sagittal otolith group in this study is as follows: shape, sulcus acusticus, ostium, cauda, rostrum, antirostrum, margin, margin sculpturing, dorsal depression, ventral depression, crista superior, crista inferior, collum, colliculum, excisura, and pseudo-excisura.

4.1.1.1 Shapes

Sagittal otoliths of fish from the southern coast of Thailand normally are small, moderate to very large, but in some groups they are very small, even tiny. The common shape of sagital otoliths are oval, oblong and ovate but other shapes, such as rectangular, obovate, discoid, trapezium, pyriform, circular, heart-shaped, bone-shaped, square, elliptic, tear-drop, rhomboidal, spindle-shaped, and hour-glass, are singular shapes also found in the small group. The sagittal otolith shape in all groups can be divided into 17 types (Table 4.2, Fig. 4.1).

4.1.1.2 Sulcus acusticus (Sulcus)

Sulcus acusticus on the sagittal otoliths can be classified in 4 types: archaesulcoid, pseudo-archaesulcoid, homosulcoid, and heterosulcoid (Fig. 4.2). Almost all types are heterosulcoid with ostial opening. An individual family usually has one type for the sulcus acusticus, but the group of Hemiramphidae, Carangidae, Labridae have two types and three types in Gobiidae. The characteristic sulcus acusticus of each sagittal otolith of the fish species commonly differs between groups. The types of sulcus acusticus found in groups of fish are shown in Table 4.3. The opening types of sulcus acusticus are mesial, ostial, ostio-cauda as well as pseudo-ostialcauda. (Fig. 4.3), and the most common opening type is the ostial opening.

Table 4.2 Types of sagittal otolith shape in-groups of fish

Types of shape	Order of fish	Family of fish
1 Tear-dop	Elopiformes	Elopidae
		Megalopidae
2 Oblong	Anguilliformes	Muraenesocidae
	Clupeiformes	Chirocentridae
		Engraulidae
		Clupeidae
	Beloniformes	Belonidae
	Scorpaeniformes	Scorpaenidae, Platycephalidae
	Aulopiformes	Subfamily: Harpadontinae
	Ophidiiformes	Ophidiidae
	Mugiliformes	Mugilidae
	Perciformes	Centropomidae
		Serranidae
		Sphyraenidae
		Carangidae
		Gerreidae
		Pomacentridae
		Polynemidae
		Sphyraenidae
3 Oval	Clupeiformes	Engraulidae
	Beloniformes	Belonidae
	Beloniformes	Exocoetidae
		Hemiramphidae
	Perciformes	Ambassidae
		Sillaginidae
		Apogonidae
		Gerreidae
		Lutjanidae
		Caesionidae
		Haemulidae
		Lethrinidae,
		Sparidae
		Nemipteridae
		Sciaenidae
		Mullidae
		Pempheridae
		Teraponidae
		Ephippidae
		Scaridae
		Pomacentridae

Table 4.2 Types of sagital otolith shape in-groups of fish (continued)

Types of shape	Order of fish	Family of fish
4 Pyriform	Gonorhynchiformes	Chanidae
5 Circular	Atheriniformes	Atherinidae
	Perciformes	Pempheridae
6 Obovate	Beloniformes	Exocoetidae
7 Elliptic	Aulopiformes	Synodontidae
	Perciformes	Gerreidae, Lutjanidae
	Beloniformes	Hemiramphidae
8 Tapezium	Beloniformes	Sub family Myripristinae
9 Ovate	Perciformes	Carangidae
		Acanthuridae
		Haemulidae
		Drepenidae
10 Rhomboidal	Perciformes	Cepolidae
	Pleuronectiformes	Paralichthyidae
11 Spindle-shape	Perciformes	Trichiuridae
		Ephippidae
12 Rectangular	Pleuronectiformes	Cynoglossidae
13 Hour-glass	Tetraodontiformes	Balistidae, Monacanthidae
14 Discoid	Pleuronectiformes	Paralichthyidae
15 Heart-shaped	Perciformes	Priacanthidae
16 Skull-shaped	Perciformes	Menidae
17 Square	Pleuronectiformes	Paralichthidae

Table 4.3 Types of sulcus acusticus on sagitlal otoliths in gtoups of fish

Types of sulcus acusticus	Order of fish	Families of fish
1 Archaesulcoid	Elopiformes	Elopidae, Megalopidae
	Anguilliformes	Muraenesocidae
2 Psuedo-archaesulcoid	Clupeiformes	Engraulidae, Chirocentridae, Clupeidae
3 Heterosulcoid	Gonorhynchiformes	Chanidae
	Aulopiformes	Synodontidae
	Ophidiiformes	Ophidiidae
	Mugiliformes	Mugilidae
	Atheriniformes	Atherinidae
	Beloniformes	Exocoetidae, Hemiramphidae
	Beryciformes	Holocentridae, Subfamily Myripristinae
	Scorpaeniformes	Scorpaenidae, Platycephalidae
	Perciformes	Priacanthidae,Centropomidae, Ambassidae
		Serranidae, Sillaginidae, Rachycentridae
		Gerreidae, Lutjanidae, Caesionidae
		Haemulidae, Lethrinidae, Sparidae
		Nemipteridae, Sciaenidae, Mullidae
		Cepolidae, Pempheridae, Teraponidae
		Ephippidae, Drepenidae, Labridae
		Pomacentridae, Scatophagidae, Siganidae
		Acanthuridae, Scombridae, Polynemidae
		Sphyraenidae, Gobiidae
	Pleuronectiformes	Psettodidae, Cynoglossidae
4 Homosulcoid	Perciformes	Carangidae, Menidae, labridae Scaridae, Gobiidae
	Pleuronectiformes	Paralichthyidae, Cynoglossidae
	Tetraodontiformes	Balistidae

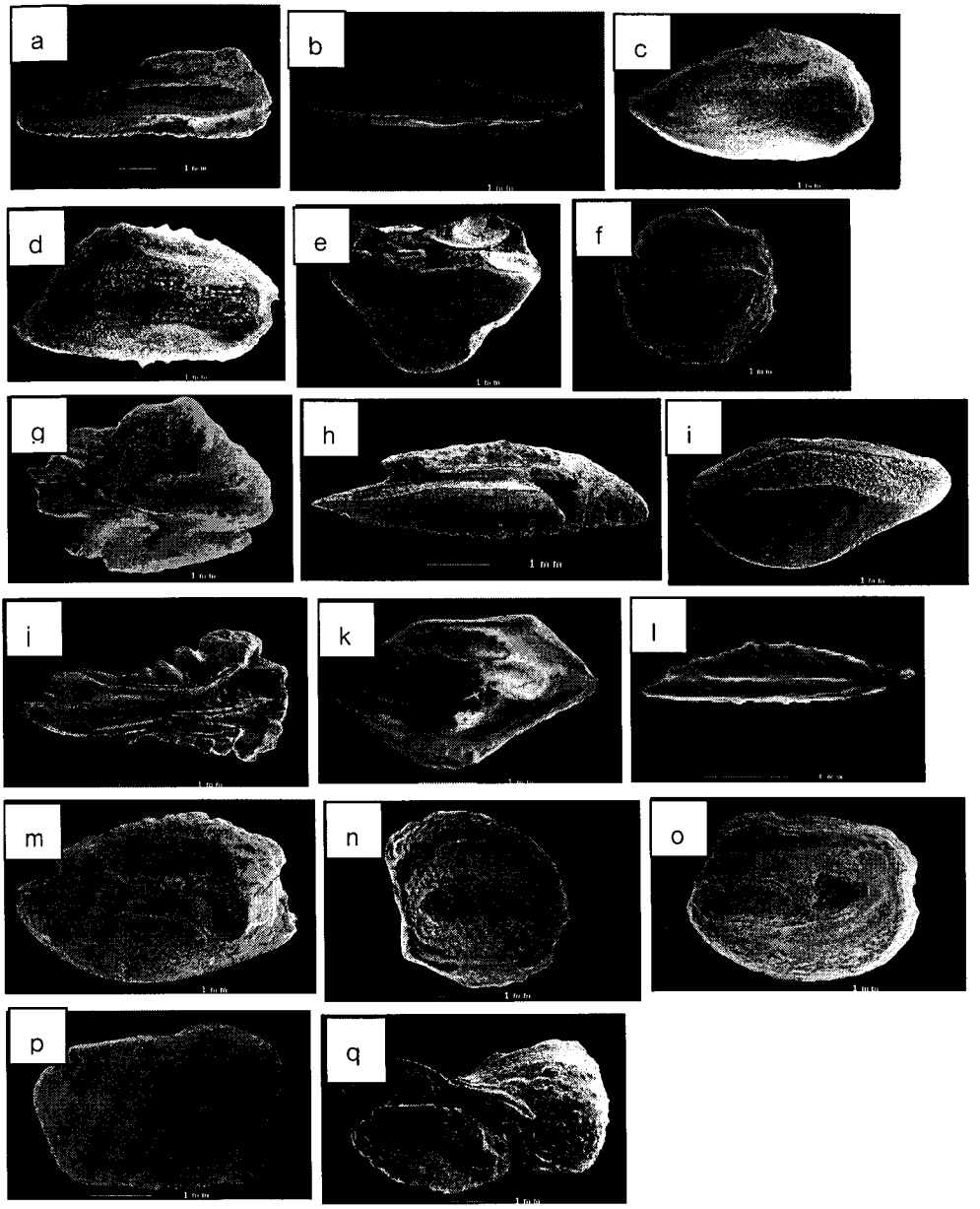


Figure 4.1 Types of shape, tear-drop (a), pyriform (b), ovate (c), obovate (d), trapezium (e), circular (f), heart-shaped (g), oblong (h), oval (i), bone-shaped (j), rhomboidal (k), spindle-shaped (l), elliptic (m), discoid (n), square (o), rectangular (p), hour-glass (q)

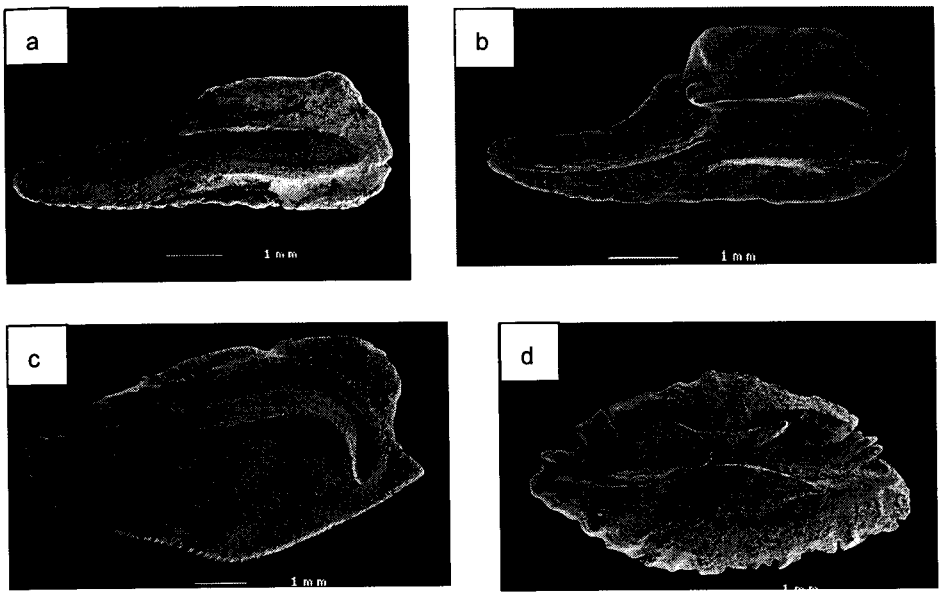


Figure 4.2 The sulcus acusticus types, achaesulcoid (a), pseudo-achaesulcoid (b), heterosulcoid (c), and homosulcoid (d)

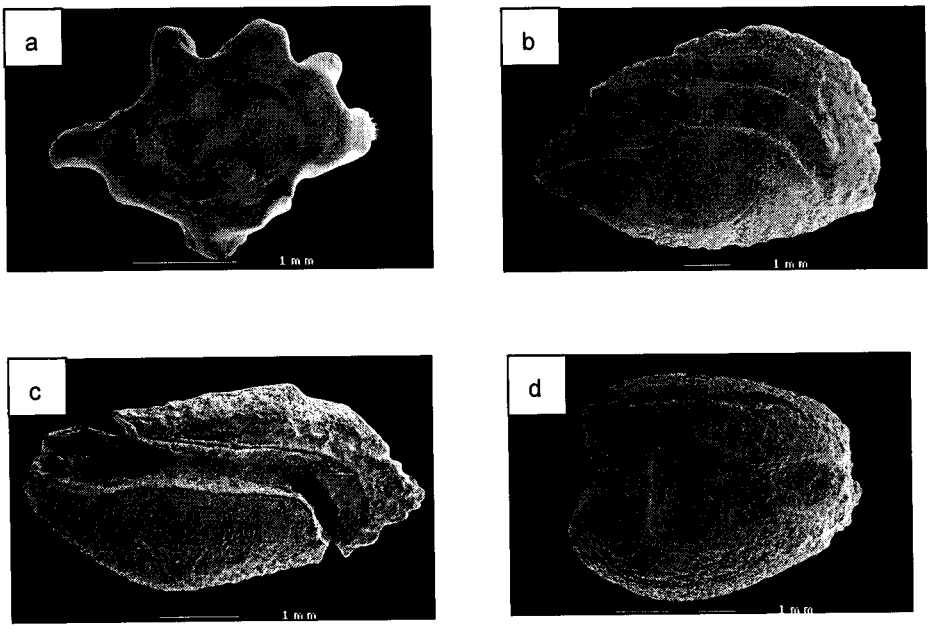


Figure 4.3 The opening types, mesial (a), ostial (b), ostio-caudal (c), and pseudo-ostiocaudal (d).

4.1.1.3 Ostium

The common ostium shape is oval, oblong, and elongate and the size is mainly moderate to very large. Other ostium shapes, circular (Atheriniformes, Atherinidae), hammer-head (Beryciformes, Sub Myripristinae) rectangular with grooved (Perciformes, Ambassidae), arrowhead (Perciformes, Apogonidae, Gobiidae), rectangular (Perciformes, Rachycentridae, Polynemidae), heart and mushroom (Perciformes, Sciaenidae), triangular with pit (Perciformes, Scombridae), and extremely straight (Perciformes, Trichiuridae) are singularly found (Fig. 4.4). The ostium length generally is shorter than the cauda in almost all groups, except in some groups, Perciformes: Scaridae and Pleuronectiformes: Cynoglossidae, ostium and cauda are equal. The ostium position on the sulcus acusticus is chiefly located on the mesial portion of the anterior sagitall otoliths, but in some groups of Perciformes, Lethrinidae and Chaetodontidae, the ostium is found ventrally. The ostium characteristic of each fish group is shown in Table 4.4 (1).

4.1.1.4 Cauda

The cauda normally is longer than the ostium in all groups; however, in Perciformes: Scaridae, the shape and size of cauda and ostium are very similar. Generally the cauda character is narrow and elongate, broad wide, straight and flexed at tip, gentle flexed, curved, recurved, broad grooved at the tip, ridge and funel shaped (Fig 4.5). Other characters of cauda in this study are shown in Table 4.4 (2).

4.1.1.5 Rostrum and Antirostrum

The rostrum appears in all groups except in Perciformes: Gobiidae, and Pleuronectiformes: Paralichthyidae, Soleidae and Cynoglossidae, where it is absent. The antirostrum is absent in many groups, such as Gonorhynchiformes:

Chanidae, Aulopiformes: Synodontidae and Subfamily Harpadontinae, Batrachoidiformes: Batrachoididae, Atheriniformes: Atherinidae, Beloniformes: Belonidae, Exocoetidae and Hemiramphidae, Beryciformes: Subfamily Myripristinae, Scorpaeniformes: Platycephalidae, Perciformes: Apogonidae, Sillaginidae, Sciaenidae and Gobiidae, Pleuronectiformes: Psettodidae, Paralichthyidae, Soleidae and Cynoglossidae, and Tetraodontiformes: Balistidae. The rostrum shapes generally are oval, oblong, and elongate and rarely are round (Perciformes: Ambassidae, and Chaetodontidae) and triangular (Sacombridae: *Rastelliger kanagurta*). The antirostrum shapes commonly are round and oblong and pointed in most groups, but in the group of Perciformes: Siganidae is extremely elongate and narrow. Moreover, some group is beak (Perciformes: Clupeidae, Tetraodontiformes: Balistidae). Sizes of rostrum generally are moderate to large (Fig. 4.6) [Table 4.4(a)].

4.1.1.6 Margin

Generally in almost all groups, the margin is irregular, smooth and rounds; the dome shape and indented characters rarely occur. The dome shape is found especially in Perciformes: Sparidae and Ephippidae, while indented characters are found in Beryciformes: Holocentridae, and Perciformes: Serranidae, Menidae, Mullidae and Scaridae. Moreover, the dorsal grooved is typically found only in Perciformes: Pempheridae [Table 4.4(b)].

4.1.1.7 Margin sculpturing

The margins sculpturing have established various characters and each species showed at least one character. In this study, eight types of margin sculpturing were found (Table 4.5, Fig. 4.7).

Table 4.4(a) Other characteristics morphology of sagitta otolith

Order	Family	rostrum	antirostrum	ostium
1 Elopiformes	Elopidae	very large and long	large height	elongate oval
	Megalopidae	very large long	small short	elongate flated
2 Anguilliformes	Muraenesocidae	wide large	minute	oval to circle
3 Clupeiformes	Engraulidae	large	small	oval, large
	Centropomidae	oval, large	triangle	oblong
	Chirocentridae	large oval	large height	large elongate
	Clupeidae	large elongate	very large	large elongate
4 Gonorhynchiformes	Chanidae	extremly elongate	absent	very narrow
5 Aulopiformes	Synodontidae	short	absent	naroow
	Subfamily: Harpadontinae	small	absent	small
6 Ophidiiformes	Ophidiidae	medium oval	large	elongate
7 Mugiliformes	Mugilidae	short oval	very small	oval
8 Atheriniformes	Atherinidae	very short height	absent	small circular
9 Beloniformes	Belonidae	verry small	absent	undifferent
	Exocoetidae	very small	absent	small
	Hemiramphidae	very small	absent	circular
10 Beryciformes	Holocentridae	large	small	large
	Sub: family Myripristinae	large	absent	hammerhed

Table 4.4 (a) Other characteristics morphology of sagitta otolith (continued)

Order	Family	rostrum	antirostrum	ostium
11 Scorpaeniformes	Scorpaenidae	very large wide	minute	oblong
	Platycephalidae	elongate	absent	elongate
12 Perciformes	Priacanthidae	round	round	elongate
	Centropomidae	veery large braod	oblong	large oblong
	Ambassidae	morderate triangular	round small	square grooved
	Serranidae	morderate oblong	small	oblong
	Apogonidae	absent	absent	arrow head
	Sillaginidae	small	absent	oval
	Rachycentridae	large	elongate	rectangular
	Carangidae	very large oval	large elongate	large
	Menidae	oval small	small	extremly Large
	Gerreidae	short	small	large, oval oblong
	Leiognathidae	large wide	large elongate	morderate elongate
	Lutjanidae	very large very wide	small to minute	large, oval elongate
	Caesionidae	large elongate	small to minute	large elongate
	Haemulidae	large oval	small to minute	large
	Lethrinidae	large	small to minute	large braod
	Sparidae	short wide	small	very large
	Nemipteridae	large wide	small to large	large oval
	Sciaenidae	absent short	absent	heart or mahroom
	Mullidae	moederate small	minute small, large	morderate
	Cepolidae	very small	minute	large

Table 4.4 (a) Other characteristics morphology of sagitta otolith (continued)

Order	Family	rostrum	antirostrum	ostium
12 Perciformes	Pempheridae	very small	minute	very large
	Teraponidae	very small and large	absent morderate	oval elongate
	Ephippidae	large, short wide	small	very large oval
	Drepenidae	short wide	small	large oblong
	Labridae	short moederate	absent large	elongate oval
	Scaridae	short	small minute	oval colliculi
	Pomacentridae	very large	small minute	oval
	Pomacantridae	moederate	minute absent	oval oblong
	Scatophagidae	very large	morderate round	small
	Siganidae	extremly elongate	extremly elongate	narrow elongate
	Acanthuridae	short very wide	minute	oval morderate
	Scombridae	short wide elongate	minute morderate large	triangular,pit oval elongate
	Trichiuridae	very small short	minute	very straight
	Polynemidae	large	small	large rectangular
	Sphyraenidae	moederate	absent minute	oval
	Gobiidae	absent	absent	arrowed shallow
13 Pleuronectiformes	Psettodidae	small	absent	elongate
	Paralichthyidae	absent	absent	oval
	Soleidae	absent	absent	oval elongate
	Cynoglossidae	absent	absent	very shallow

Table 4.4 (a) Other characteristics morphology of sagitta otolith (continued)

Order	Family	rostrum	antirostrum	ostium
14 Tetraodontiformes	Balistidae	morderate	absent	curved
	Monacanthidae	round	round	curved

*** 4.4(a):** Three characteristics morphology of sagitta otolith: rostrum, antirostrum and ostium.

Table 4.4 (b) Other characteristics morphology of sagitta otolith

Order	Family	cauda	margin	dorsal depression
1 Elopiformes	Elopidae	wide strengh	round posteriorly	elogate
	Megalopidae	gentle curved	irragular	minute
2 Anguilliformes	Muraenesocidae	very strenght	very smooth	oblong
3 Clupeiformes	Engraulidae	wide, short	smooth	oval
	Pristigasteridae	wide, short	irregular	shallow
	Chirocentridae	large pentagon	irregular	verry small
	Clupeidae	short wide	smooth	small
4 Gonorhynchiformes	Chanidae	slight narrow	flattened	deep at cauda
5 Aulopiformes	Synodontidae	naroow curved	smooth	groove at cauda
	Subfamily: Harpadontinae	strenght	smooth	lobe
6 Ophidiiformes	Ophidiidae	grooved at cauda	irregular	elongate
7 Mugiliformes	Mugilidae	naroow elongate	irregular	deep
8 Atheriniformes	Atherinidae	curved elongate		large oval
9 Beloniformes	Belonidae	undifferent straight	irregular	very shallow
	Exocoetidae	straight or slight	irregular	absent
	Hemiramphidae	elongate or slight	irregular	very shallow

Table 4.4 (b) Other characteristics morphology of sagitta otolith

Order	Family	cauda	margin	dorsal depression
1 Elopiformes	Elopidae	wide strengh	round posteriorly	elogate
	Megalopidae	gentle curved	irragular	minute
2 Anguilliformes	Muraenesocidae	very strenght	very smooth	oblong
3 Clupeiformes	Engraulidae	wide, short	smooth	oval
	Pristigasteridae	wide, short	irregular	shallow
	Chirocentridae	large pentagon	irregular	verry small
	Clupeidae	short wide	smooth	small
4 Gonorhynchiformes	Chanidae	slight narrow	flattened	deep at cauda
5 Aulopiformes	Synodontidae	naroow curved	smooth	groove at cauda
	Subfamily: Harpadontinae	strenght	smooth	lobe
6 Ophidiiformes	Ophidiidae	grooved at cauda	irregular	elongate
7 Mugiliformes	Mugilidae	naroow elongate	irregular	deep
8 Atheriniformes	Atherinidae	curved elongate		large oval
9 Beloniformes	Belonidae	undifferent straight	irregular	very shallow
	Exocoetidae	straight or slight	irregular	absent
	Hemiramphidae	elongate or slight	irregular	very shallow

Table 4.4 (b) Other characteristics morphology of sagitta otolith (continued)

Order	Family	cauda	margin	dorsal depression
9 Beloniformes	Holocentridae	straight, flexed tip	indent	deep elongate
10 Beryciformes	Sub: family Myripristinae	forked	smooth	oval deep
11 Scorpaeniformes	Scorpaenidae	short grooved	irregular	pool basin
	Platycephalidae	short narrow	indent posterior	shallow large
12 Perciformes	Priacanthidae	oval	irregular	shallow
	Centropomidae	curved deep	round	oval
	Ambassidae	deep flexed at tip	round	groove
	Serranidae	Straight flexed at tip	indented posterior	basin elongate
	Apogonidae	very straight shallow	smooth	basin
	Sillaginidae	sinuous	smooth	absent very small
	Rachycentridae	braod basin	irragular	groove elongate
	Carangidae	very deep braod at tip	irragular	groove basin
	Menidae	very deep braod	indent	large open at margin
	Gerreidae	not define cruved	irragular	narrow deep
	Leiognathidae	very deep straight	irragular	oval shallow
	Lutjanidae	gentle curve flexed at tip	irragular	shallow
	Caesionidae	gentle curve flexed at tip	round	shallow
	Haemulidae	gentle curve recurved	irragular	narrow elongate

Table 4.4 (b) Other characteristics morphology of sagitta otolith (continued)

Order	Family	cauda	margin	dorsal depression
12 Perciformes	Lethrinidae	gentle curve	round	shallow elongate
	Sparidae	gentle curve	domp	shallow
	Nemipteridae	wide, deep	irragular	elongate
	Nemipteridae	straigth		oval
	Sciaenidae	pit-like raisd recurved	smooth	elongate
	Mullidae	straight flex, pit	indent	elongate
	Cepolidae	short oval	very smooth	oblong shallow
	Pempheridae	gentle flexed	groove	oblong
	Teraponidae	narrow flexed, tip	irregular	absent groove
	Ephippidae	short, flexed broad	dome	shallow oval
	Drepenidae	narrow broad, tip	irregular	shallow oblong
	Labridae	broad, tip oval	irregular	narrow
	Scaridae	oval colliculi	indent posterior	basin or groove
	Pomacentridae	gentle curved	irregular	very shallow elongate
	Pomacantridae	gentle curved	smooth	very shallow
	Scatophagidae	wide	round	elongate
	Siganidae	broad groove	irregular	basin
	Acanthuridae	flexed broad	round	shallow oval
	Scombridae	broad posterior	round triangular	elongate shallow oblong
	Trichiuridae	very straight and shalow	flate	absent

Table 4.4 (b) Other characteristics morphology of sagitta otolith (continued)

Order	Family	cauda	margin	dorsal depression
12 Perciformes	Polynemidae	gentle curve broad, tip	irregular	shallow oblong
	Sphyraenidae	straight, flexed, tip	round	oblong
	Gobiidae	round	smooth	oval oblong very shallow
13 Pleuronectiformes	Psettodidae	narrow shallow elongate	irregular	oval shallow
	Paralichthyidae	oval	straight	oblong
	Soleidae	round elongate		oval elongate
	Cynoglossidae	very shallow	smooth	absent grooved shoe
14 Tetraodontiformes	Balistidae	curved	lobe	absent
	Monacanthidae	curved	oval, lobe	absent

* **4.4(b):** Three characteristics morphology of sagitta otolith: cuada, margin and dorsal depression.

Table 4.4 (c) Other characteristics morphology of sagitta otolith

Order	Family	ventral depression	excisura	collum
1 Elopiformes	Elopidae	elongate	absent	absent
	Megalopidae	absent	absent	absent
2 Anguilliformes	Muraenesocidae	absent	absent	absent
3 Clupeiformes	Engraulidae	elongate	wide	absent
	Pristigasteridae	narrow	shallow	absent
	Chirocentridae	absent	wide deep	tubercle
	Clupeidae	small elongate	wide very deep	solid bridge
4 Gonorhynchiformes	Chanidae	deep at cauda	wide	absent
5 Aulopiformes	Synodontidae	absent	absent	absent
	Subfamily: Harpadontinae	absent	absent	absent
6 Ophidiiformes	Ophidiidae	absent	wide	absent
7 Mugiliformes	Mugilidae	absent	narrow shallow	solid bridge
8 Atheriniformes	Atherinidae	absent	absent	absent
9 Beloniformes	Belonidae	very shallow	shallow narrow	absent
	Exocoetidae	absent	shallow narrow	absent
	Hemiramphidae	absent	shallow absent	absent
10 Beryciformes	Holocentridae	shallow at cauda	shallow wide	absent
	Sub: family Myripristinae	absent	absent	absent
11 Scorpaeniformes	Scorpaenidae	absent	shallow	solid bridge

Table 4.4 (c) Other characteristics morphology of sagitta otolith (continued)

Order	Family	ventral depression	excisura	collum
11 Scorpaeniformes	Platycephalidae	absent	absent	absent
12 Perciformes	Priacanthidae	absent	shallow wide	absent
	Centropomidae	absent	deep narrow	absent
	Ambassidae	absent	wide	solid bridge
	Serranidae	small	shallow narrow	absent
	Apogonidae	absent	absent	absent
	Sillaginidae	absent	absent	absent
	Rachycentridae	absent	extreamly deep	absent
	Carangidae	absent	very deep wide	absent solid
	Menidae	large open at margin	deep narrow	absent
	Gerreidae	absent elongate	very shallow narrow	absent
	Leiognathidae	absent	very deep wide	absent
	Lutjanidae	absent	very shallow	absent
	Caesionidae	absent	very shallow	absent
	Haemulidae	absent	very shallow narrow	absent
	Lethrinidae	absent	narrow absent	absent
	Sparidae	absent	very wide shallow	absent
	Nemipteridae	absent	wide shallow	absent
	Sciaenidae	absent	absent wide	absent
	Mullidae	abent	absent morderate	absent
	Cepolidae	silunar	very wide	solid, bridge

Table 4.4 (c) Other characteristics morphology of sagitta otolith (continued)

Order	Family	ventral depression	excisura	collum
12 Perciformes	Pempheridae	abent	very wide and shallow	absent
	Teraponidae	abent	absent narrow	absent
	Ephippidae	abent	very wide shallow	absent
	Drepenidae	absent	narrow deep	absent
	Labridae	absent	absent wide, deep	absent solid
	Scaridae	abent	wide shallow	solid
	Pomacentridae	abent	very wide and shallow	absent
	Pomacantridae	abent	absent	absent
	Scatophagidae	absent	very wide noth, deep	absent
	Siganidae	absent	very deep narrow	solid bridge
	Acanthuridae	absent	wide shallow	absent
	Scombridae	elongate absent	wide narrow, deep	absent solid
	Trichiuridae	absent	wide very shallow	absent
	Polynemidae	absent	absent	absent
	Sphyraenidae	absent	absent naroow	absent
	Gobiidae	oval oblong extremly shallow	absent	absent
13 Pleuronectiformes	Psettodidae	oval shallow	absent	absent
	Paralichthyidae	oval	absent	absent

Table 4.4 (c): Other characteristics morphology of sagitta otolith (continued)

Order	Family	ventral depression	excisura	collum
13 Pleuronectiformes	Soleidae	oval elongate	absent	absent
	Cynoglossidae	absent	absent	absent
14 Tetraodontiformes	Balistidae	absent	deep	shallow wide
	Monacanthidae	absent	very shallow and wide	very shallow and wide

*** 4.4 (c):** Three characteristics morphology of sagitta otolith: ventral depression, excisura and collum.

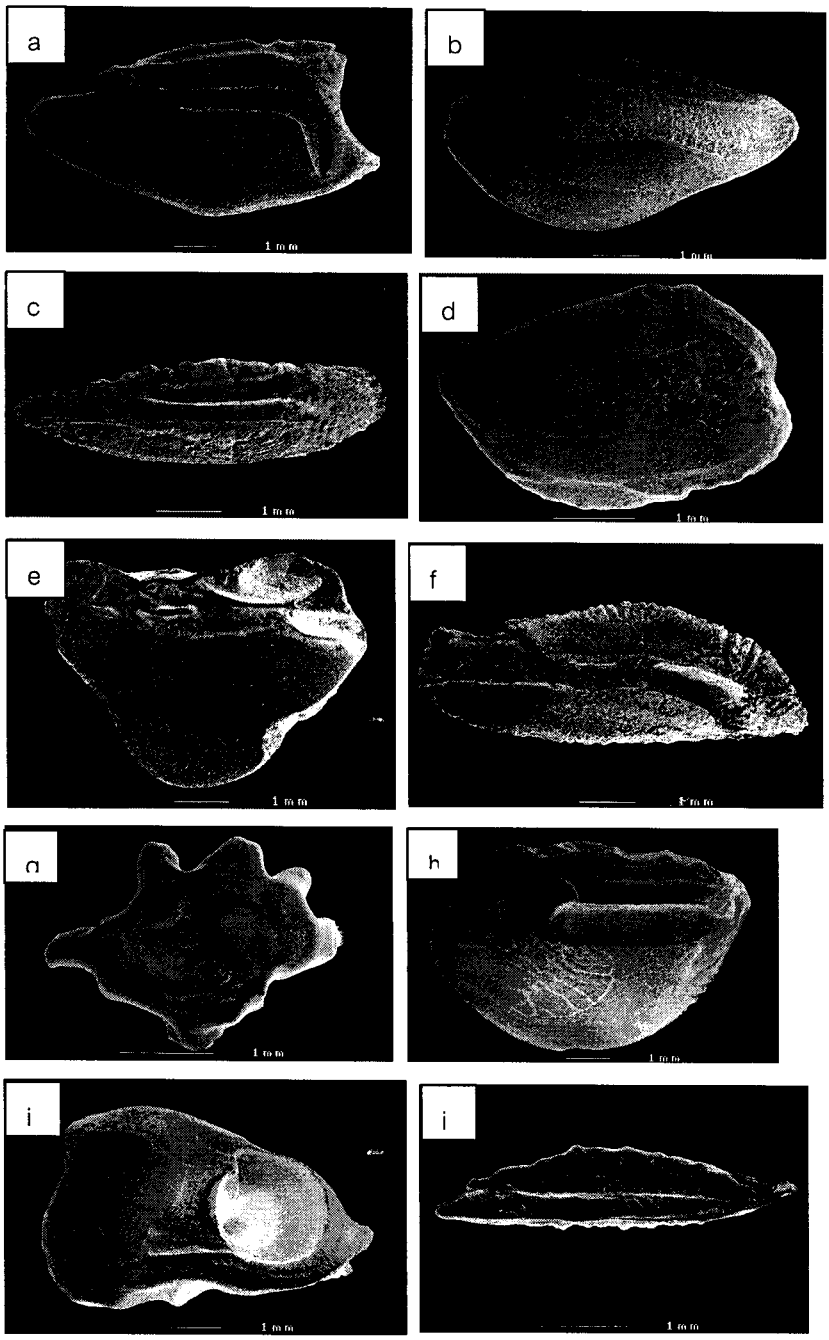


Figure 4.4 The characteristic of ostium; oval (a), oblong (b), elongate (c), circular (d), hammer-head (e), rectangular (f), arrow-head (g) mushroom-shaped (h), triangular (i), straight (j).

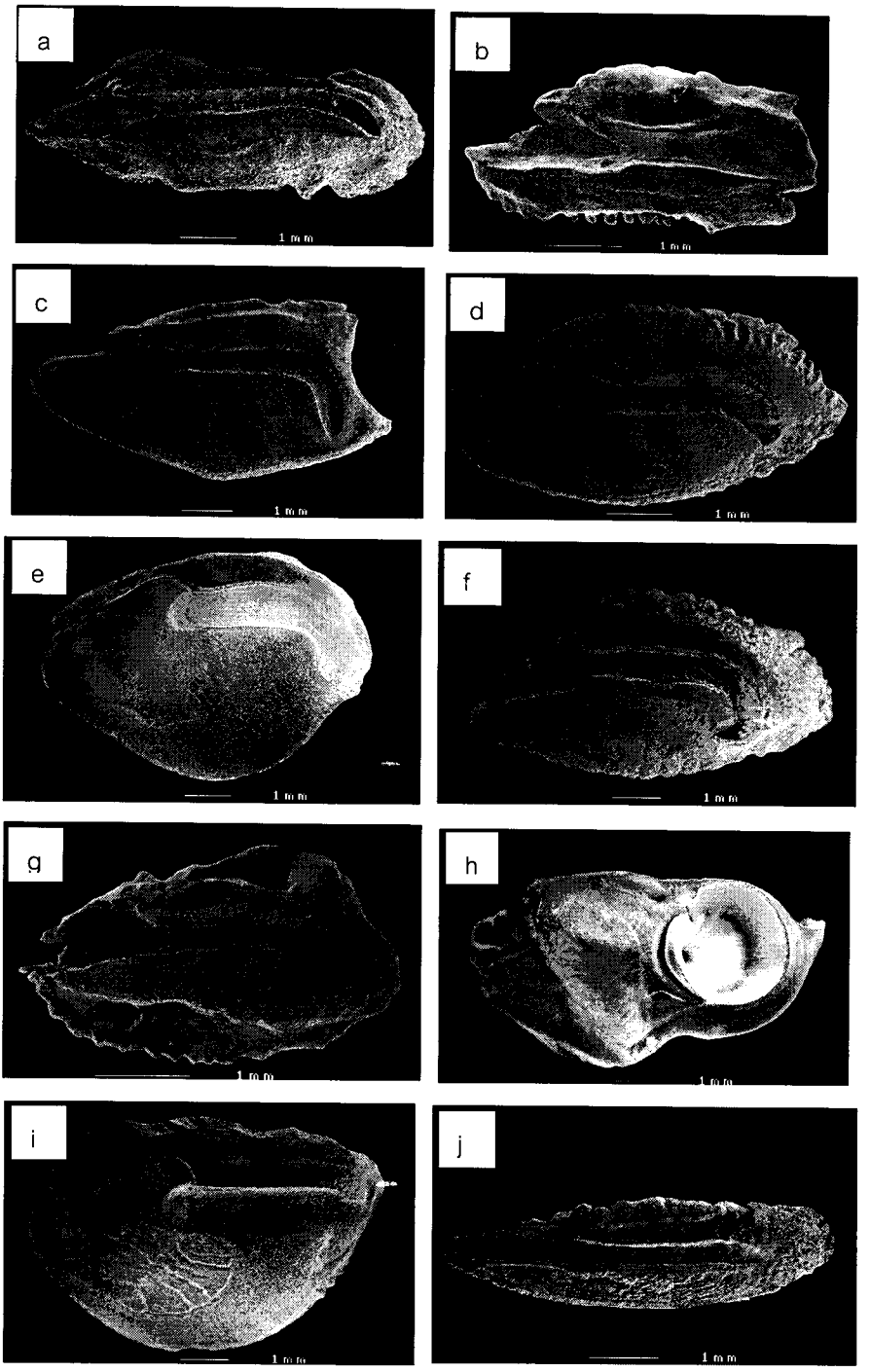


Figure 4.5 The characteristic of cauda; narrow and elongate (a), broad wide (b), straight and flexed (c), gently flexed (d), curved (e), recurred (f), broad grooved (g), funnel-shaped (h), and ridge (i), straight (j).

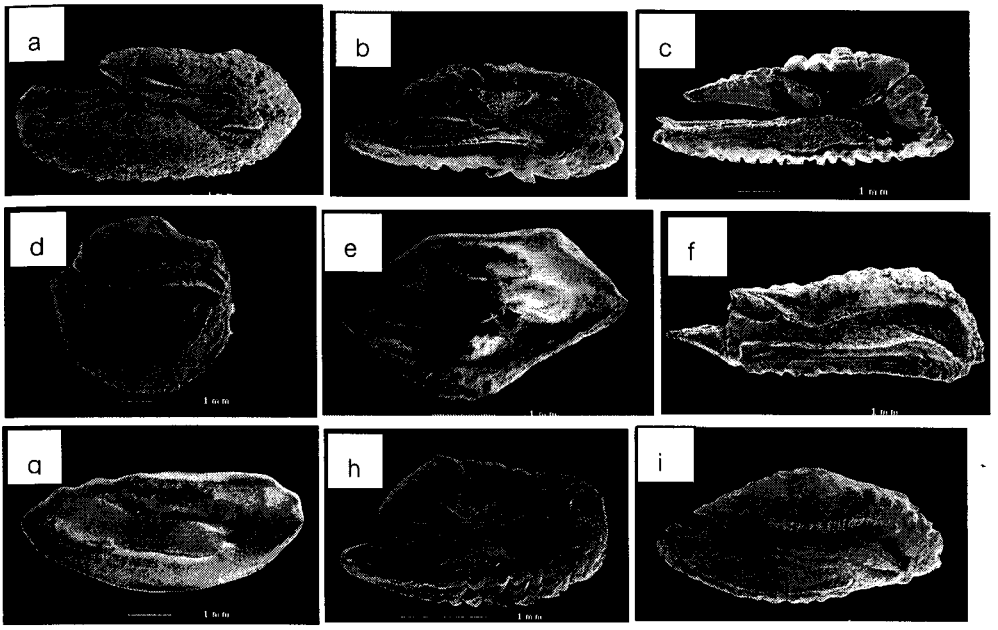


Figure 4.6 The characteristic of the rostrum; oval (a and g), oblong (b), elongate (c), round (d), and triangular (d and e): and the antirostrum; elongate (c), triangular (h), beak (b), and pointed (j).

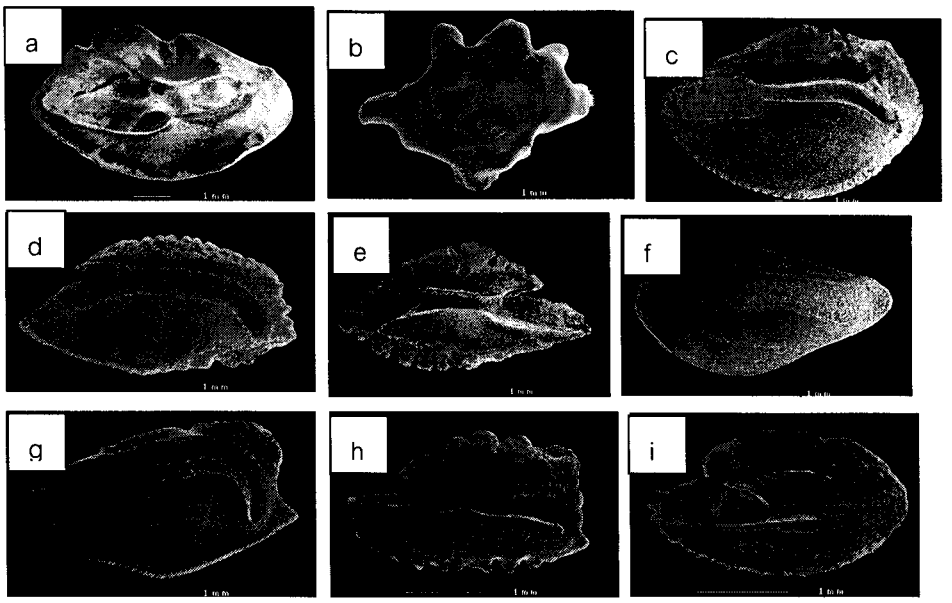


Figure 4.7 The margin sculpturing types; entire (a), lobe (b), sinuate (c), crenate (d), dentate (e), serrate (f and g), irregular (h), and needle (i).

4.1.1.8 Dorsal and Ventral depression

Dorsal depressions are developed in almost groups except in Beloniformes: Exocoetidae, Perciformes: Teraponidae, Trichiuridae, and Pleuronectiformes: Cynoglossidae, whereas ventral depressions are hardly developed. However, the ventral depressions of Clupeiformes: Engraulidae and Clupeidae, Gonorhynchiformed: Chanidae, Beryciformes: Holocentridae, Perciformes: Serranidae, Menidae, Gerreidae, Cepolidae, Scombridae and Gobiidae, Pleuronectiformes: Psettodidae, Paralichthyidae, Soleidae and Cynoglossidae are established. Dorsal and ventral depression are absent in Perciformes: Trichiuridae, and Pleuronectiformes: Cynoglossidae. The dorsal depressions vary in shape and size. The dorsal depression shape usually is oval, oblong, elongate and grooved, basin and the size is minute, small, large, shallow and deep, whereas the ventral depression commonly is elongate and extremely narrow along the ostium and cauda. Another typical feature of dorsal depression, horse-shoes, is singularly found in Pleuronectiformes: Cynoglossidae. The positions of dorsal and ventral depression are generally located above anterior, middle or posterior of cauda, it is rarely established above or under both the ostium and cauda area. However, it is possible to find the dorsal depression above both the ostium and cauda in Clupeiformes: Engraulidae, and the ventral depression under both the ostium and cauda in Perciformes: Sciaenidae. The dorsal and ventral depression opened at the dorsal and ventral margins is found only in Perciformes: Menidae [Table 4.4 (b), Table 4.4 (c) and Fig. 4.8].

4.1.1.9 Crista superior and Crista inferior

Mainly, crista superior is more developed than the crista inferior in almost all groups. In the small groups, Elopiformes: Megalopidae, Anguilliformes:

Muraenesocidae, Clupeiformes: Chirocentridae and Clupeidae, and Scorpaeniformes: Scorpaenidae, both crista superior and crista inferior are absent. The crista superior does not develop in one group of fish, Perciformes: Apogonidae, while the groups of Beryciformes: Subfamily Myripristinae, and Perciformes: Centropomidae, Rachycentridae, Teraponidae, Drepenidae, Scatophagidae, Siganidae, Acanthuridae, Trichiuridae, Polynemidae do not have the crista inferior (Table 4.6 and Table 4.7).

Poorly developed, developed, well-developed and ridge-like are descriptors for the development of crista. Occurrence of the crista both posterior and superior of sulcus acusticus area is generally found on the anterior part and middle part more than on the posterior part of cauda, and they are developed and differ in the same group. The crista development is divided into 4 degrees (Fig. 4.9).

1) Poorly developed

Poorly developed on both crista superior and crista inferior are found more than other crista developments. They are established on the Clupeiformes: Engraulidae, Ophidiiformes: Ophidiidae, Atheriniformes: Atherinidae, Beloniformes: Belonidae, Exocoetidae and Hemiramphidae, Perciformes: Ambassidae, Leiognathidae, Sciaenidae, Pomacentridae. Poorly developed only on the crista superior is found in the Elopiformes: Elopidae, Perciformes: Centropomidae, Menidae, Drepenidae, Scatophagidae, Trichiuridae and Polynemidae. For the crista inferior, poorly developed is found in the Gonorhynchiformes: Chanidae, Perciformes: Serranidae, Apogonidae, Lutjanidae, Caesionidae, Haemulidae, Lethrinidae, Nemipteridae, Mullidae, Pempheridae, Ephippidae, Scaridae, Sphyraenidae.

2) Developed

This crista development type in both crista

superior and crista inferior occurs in Beryciformes: Holocentridae, Scorpaeniformes: Platycephalidae, and Perciformes: Carangidae. That setup developed especially on crista superior is found only in the Perciformes: Caesionidae and Teraponidae and not on crista inferior that is developed in all groups.

3) Well-developed

The well-developed character occurring on the crista superior and crista inferior is found in the Mugiliformes: Mugilidae, Perciformes: Sillaginidae, Cepolidae, labridae, Scombridae, Gobiidae, and Pleuronectiformes: Psettodidae, Paralichthyidae, Soleidae, Cynoglossidae. But only the crista superior is well-developed, established in the group of Aulopiformes: Synodontidae and Subfamily Harpadontinae, and Perciformes: Rachycentridae, Gerreidae, Haemulidae, Lethrinidae, Sparidae, Pempheridae and Ephippidae, while the crista inferior, well-developed, occurred only in the Perciformes: Menidae.

4) Ridge-like

A lot of the ridge-like formations occurred only on the crista superior, which are found in the Gonorhynchiformes: Chanidae, Aulopiformes: Synodontidae and Subfamily Harpadontinae, Perciformes: Nemipteridae, Mullidaelabridae, Scaridae, Scombridae and Sphyraenidae. They are found in the Sciaenidae group both on the crista superior and crista inferior.

4.1.1.10 Collum or Neck

The collum or neck normally does not appear or is absent in almost all groups. However, in this study it can be seen in Clupeiformes: Chirocentridae, which was tubercle character. Another character, the solid bridge, occurs in Clupeiformes: Clupeidae, Mugiliformes: Mugilidae, Scorpaeniformes:

Scorpaenidae, Perciformes: Ambassidae, Carangidae, Cepolidae, labridae, Scaridae, Siganidae and Scombridae [Table 4.4 (c) and Fig. 4.10].

4.1.1.11 Colliculum

The colliculum has shown 3 types, absent, homomorph and heteromorph (Fig. 4.11) and the common coliculum type is heteromorph. The shape of colliculum commonly is oval or oblong and it has raised colliculi. Three types of colliculum found in-groups are shown in Table 4.8.

4.1.1.12 Pseudo-excisura

Usually, pseudo-excisura is absent in almost all groups but they are found in small groups when the sulcus acusticus is open on the posterior parts.

4.1.1.13 Excisura

The excisura is found with 5 characters: absent, narrow with deep notch, narrow with shallow notch, wide with deep notch, and wide with shallow notch (Fig. 4.12). The common character of excisura is narrow with a shallow notch, while the rare character is wide with a deep notch. These excisura types are characteristic for each fish group, which are shown in Table 4.4 (c).

Table 4.5 Types of margin sculturing of sagitlal otolith in groups of fish

Types of margin sculturing	Order of fish	Family of fish
1 Entrine	Elopiformes	Elopidae
	Aulopiformes	Harpadontinae
	Anguilliformes	Muraenesocidae
	Beryciformes	Holocentridae
	Perciformes	Apogonidae
		Sillaginidae
		Gerreidae
		Sciaenidae
2 Irregular	Elopiformes	Elopidae
	Gonorhynchiformes	Chanidae,
	Aulopiformes	Synodontidae
	Mugiliformes	Mugilidae
	Beloniformes	Belonidae,
		Exocoetidae,
		Hemiramphidae
	Beryciformes	Sub Myripristinae
	Scorpaeniformes	Scorpaenidae
	Perciformes	Centropomidae
		Ambassidae,
		Serranidae,
		Sillaginidae,
		Menidae,
		Gerreidae,
		Leiognathidae,
		Lutjanidae,
		Haemulidae,
		Lethrinidae,
		Sparidae,
		Nemipteridae,
		Sciaenidae
		Mullidae,
		Sphyraenidae,
		Centropomidae,
		Cepolidae,
		Pempheridae
		Teraponidae
		Ephippidae
		Drepenidae

Table 4.5 Types of margin sculturing of sagitlal otolith in groups of fish (continued)

Types of margin sculturing	Order of fish	Family of fish
2 Irregular	Perciformes	labridae
		Scaridae
		Pomacentridae
		Chaetodontidae
		Scatophagidae
		Siganidae
		Acanthuridae
		Scombridae
		Trichiuridae
		Polynemidae
		Pempheridae
		Gobiidae,
	Pleuronectiformes	Psettodidae
		Soleidae
		Cynoglossidae
3 Sinuate	Elopiformes	Megalopidae
	Clupeiformes	Chirocentridae
	Atheriniformes	Atherinidae
	Perciformes	Rachycentridae
		Carangidae
		Caesionidae
		Lethrinidae
		Nemipteridae
		Mullidae
		Ephippidae
		Polynemidae
4 Lobed	Aulopiformes	Harpadontinae
	Elopiformes	Megalopidae
	Anguilliformes	Muraenesocidae
	Ophidiiformes	Ophidiidae
	Mugiliformes	Mugilidae
	Beloniformes	Belonidae,
		Exocoetidae,
		Hemiramphidae
	Scorpaeniformes	Platycephalidae
	Pleuronectiformes	Paralichthyidae
		Soleidae

Table 4.5 Types of margin sculturing of sagitlal otolith in groups of fish (continued)

Types of margin sculturing	Order of fish	Family of fish
4 Lobed	Pleuronectiformes	Cynoglossidae
5 Needle	Clupeiformes	Engraulidae
6 Crenate	Clupeiformes	Clupeidae
	Beryciformes	Holocentridae
	Perciformes	Haemulidae
		Pomacentridae
7 Dentate	Clupeiformes	Clupeidae
	Perciformes	Lutjanidae,
		Siganidae
		Scombridae
8 Serrate	Scorpaeniformes	Scorpaenidae
	Perciformes	Lutjanidae
		Carangidae
		Lutjanidae
		Caesionidae

Table 4.6 Degree of crista superior in-groups of fish

Degree of crista superior	Order of fish	Family of fish
1 Poorly developed	Elopiformes	Elopidae
	Clupeiformes	Engraulidae
	Ophidiiformes	Ophidiidae
	Atheriniformes	Atherinidae
	Beloniformes	Belonidae, Exocoetidae, Hemiramphidae
	Beryciformes	Sub family: Myripristinae
	Perciformes	Centropomidae, Sciaenidae, Drepenidae, Polynemidae, Pomacentridae
2 Developed	Beryciformes	Holocentridae
	Scorpaeniformes	Platycephalidae
	Perciformes	Carangidae, Lutjanidae, Caesionidae Sciaenidae, Trichiuridae
3 Well-developed	Mugiliformes	Mugilidae
	Perciformes	Ambassidae, Sillaginidae, Labridae, Gerreidae, Haemulidae, Lethrinidae, Rachycentridae, Sparidae, Mullidae, Cepolidae, Pempheridae, Ephippidae, Scombridae, Gobiidae
	Pleuronectiformes	Psettodidae, Paralichthyidae, Soleidae, Cynoglossidae
4 Ridge-like	Gonorhynchiformes	Chanidae, Scatophagidae
	Aulopiformes	Synodontidae, Subfamily: Harpadontinae
	Perciformes	Mullidae, labridae, Scaridae, Scombridae, Sphyraenidae, Siganidae
5 Absent	Elopiformes	Elopidae, Megalopidae
	Anguilliformes	Muraenesocidae
	Clupeiformes	Chirocentridae, Clupeidae
	Scorpaeniformes	Scorpaenidae
	Perciformes	Serranidae, Apogonidae, Acanthuridae

Table 4.7 Degree of crista inferior in-groups of fish

Degree of crista inferior	Order of fish	Family of fish
1 Poorly developed	Gonorhynchiformes	Chanidae
	Atheriniformes	Atherinidae
	Beloniformes	Belonidae, Exocoetidae, Hemiramphidae
	Perciformes	Ambassidae, Serranidae, Apogonidae, Leiognathidae, Lutjanidae, Caesionidae, Haemulidae, Lethrinidae, Nemipteridae,Sciaenidae, Mullidae, Pempheridae Ephippidae, Scaridae, Pomacentridae
2 Developed	Beryciformes	Holocentridae
	Scorpaeniformes	Platycephalidae
	Perciformes	Carangidae, Gerreidae, Sparidae
3 Well developed	Aulopiformes	Synodontidae , Subfamily: Harpadontinae
	Mugiliformes	Mugilidae,
	Clupeiformes	Engraulidae
	Perciformes	Sillaginidae,Menidae, Cepolidae, labridae, Scombridae, Gobiidae
	Pleuronectiformes	Psettodidae, Paralichthyidae, Soleidae, Cynoglossidae
4 Absent	Elopiformes	Elopidae, Megalopidae
	Anguilliformes	Muraenesocidae
	Clupeiformes	Chirocentridae, Clupeidae
	Beryciformes	Sub Myripristinae
	Scorpaeniformes	Scorpaenidae
	Perciformes	Centropomidae, Rachycentridae Teraponidae, Scatophagidae, Siganidae, Acanthuridae, Scombridae, Trichiuridae Polynemidae

Table 4.8 Types of colliculum in-groups of fish

Types of colliculum	Order of fish	Family of fish
1 Hetero-morph	Elopiformes	Elopidae, Megalopidae
	Anguilliformes	Muraenesocidae
	Aulopiformes	Synodontidae
	Beryciformes	Holocentridae, Subfamily: Myripristinae
	Perciformes	Ambassidae,Serranidae, Apogonidae, Sillaginidae, Rachycentridae, Gerreidae, Lutjanidae,Caesionidae, Haemulidae, Lethrinidae, Sparidae, Nemipteridae, Sciaenidae, Mullidae, Pempheridae, Teraponidae, Ephippidae,Drepenidae labridae, Pomacentridae, Scatophagidae,Siganidae, Acanthuridae, Scombridae Polynemidae, Sphyraenidae
	Pleuronectiformes	Psettodidae, Cynoglossidae
2 Homo- morph	Clupeiformes	Engraulidae, Chirocentridae, Clupeidae
	Beloniformes	Belonidae, Exocoetidae, Hemiramphidae
	Scorpaeniformes	Scorpaenidae, Platycephalidae
	Perciformes	Centropomidae, Carangidae, Menidae Leiognathidae, labridae, Scaridae Chaetodontidae, Trichiuridae, Gobiidae
	Pleuronectiformes	Paralichthyidae, Soleidae

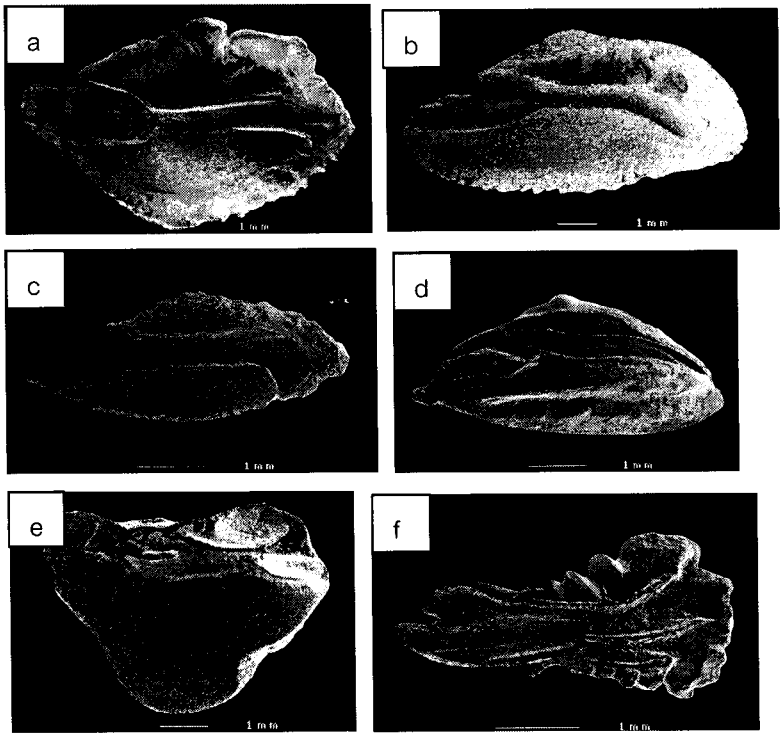


Figure 4.8 Characteristic of dorsal depression and ventral depression; oval (a), oblong (b), elongate (c), grooved (d), basin (e), and opened at dorsal and ventral margin (f).

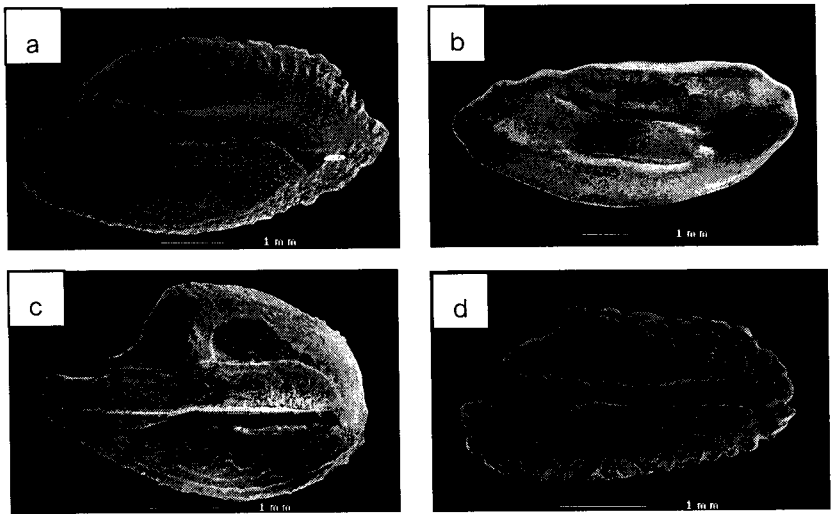


Figure 4.9 Degree of crista superior and crista inferior; poorly developed (a), develoved (b), well developed (c), and ridge-like (d).

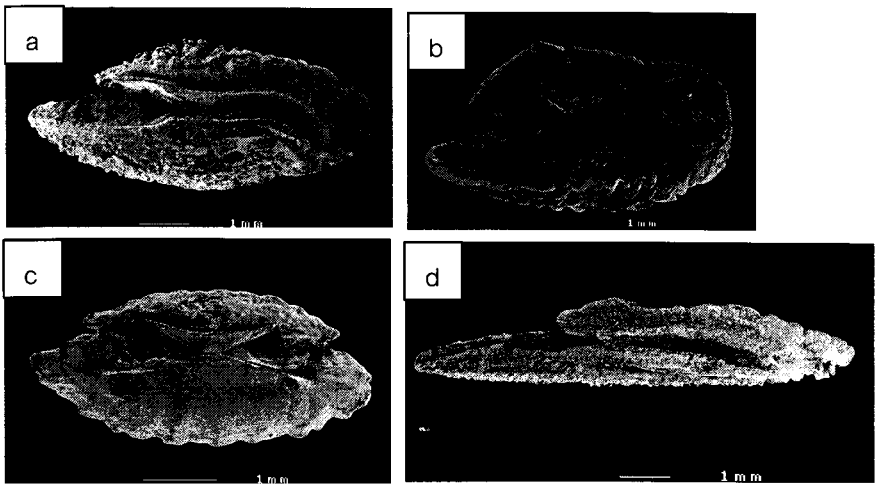


Figure 4.10 The characteristic of collum; absent (a), tubucle (b), and solid bridge (c and d).

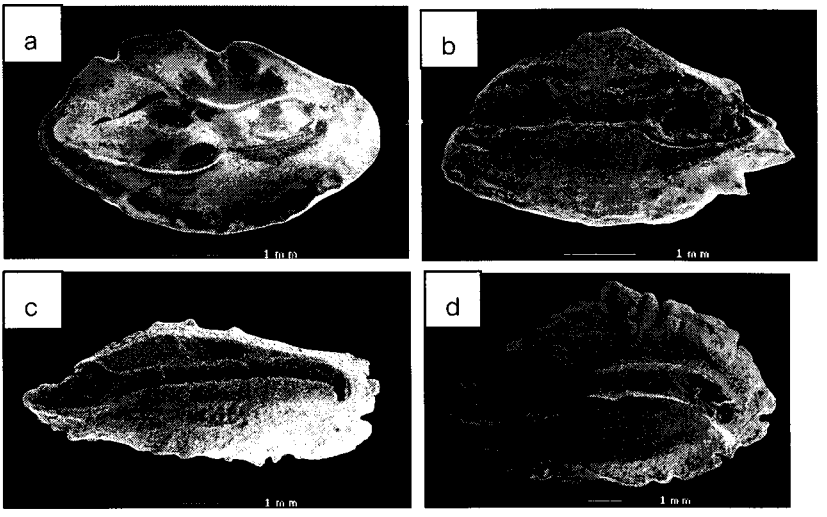


Figure 4.11 The types of colliculum; absent (a), homomorph (b), and heteromorph (c and d).

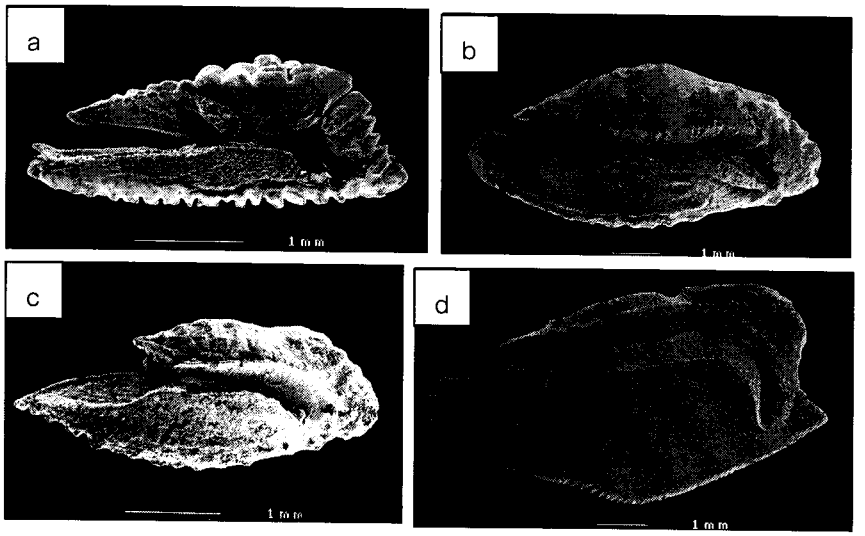


Figure 4.12 The characteristic of excisura; narrow and deep (a), narrow and shallow (b), wide and deep (c), and wide and shallow (d).

4.1.2 Characteristic sagittal otolith of each family and species

Order: Elopiformes

Family: Elopidae

The shape is tear-drop and is archaesulcoid type with ostial opening. The rostrum is very large and elongate, while the antirostrum is extremely wide and large.

Elops machnata (Fig. 4.13)

Ostium is elongate and deeper than cauda. Cauda is very wide, shallow and oblong in shape. Both dorsal and ventral depression is elongate around cauda. The crista superior is poorly developed and crista inferior is absent.

Family: Megalopidae

Sagittal otolith of this family is similar to Elopidae but Megalopidae is tear-drop in shape and the ostium is deeper than Elopidae. The sulcus acusticus is archaesulcoid with an ostial opening.

Megalop cyprinoids (Fig. 4.14)

The rostrum is elongate, but the antirostrum is very small. Ostium and cauda floor contain myriad crystals. Between the cauda area and dorsal area as well as ventral area there is grooving.

Order: Anguilliformes

Family: Muraenesocidae

The shape is pea-shaped. Sulcus acusticus is not filled with colliculi, is very smooth and of an archaesulcoid type with ostial opening. The ostium and cauda are not distinctly separated.

Muraenosox cinereus (Fig. 4.15)

The margin is very smooth, margin sculpturing is lobed and entire. Both crista superior and crista inferior are absent. The dorsal depression is oblong and shallow.

Order: Clupeiformes

Family: Engraulidae

The shape is oval to oblong and margin sculpturing is similar to a needle. Ventral depressions are elongate under both the cauda and ostium. The cauda is oval or oblong and broad into dorsal area. The crista inferior is ridge-like.

Coilia dussumieri (Fig. 4.16)

The shape is oval, rostrum and antirostrum is smaller than other species. The dorsal area is broader than ventral area. Ostium is noticeably oval and the cauda is oblong, the dorsal depression is circular and broad into the posterior cauda.

Stolephorus indicus (Fig. 4.17)

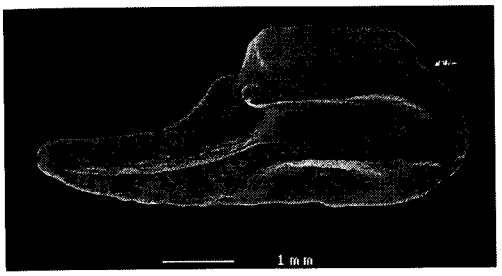
Margin sculpturing is clearly needled and oval in shape. The dorsal depression is very shallow.

Stolephorus sp. (Fig. 4.18)

The shape is oblong. The cauda is oval, broad into the dorsal area, whereas the ostium is oblong, broad into the ventral area. The posterior part is very rough with many grooves.

Family: Chirocentridae

This family has only one species. The shape is rectangular, heterosulcoid with an ositial opening. Rostrum and antirostrum are large and well-developed. The ostium and cauda are very wide and the collum is tubercle.



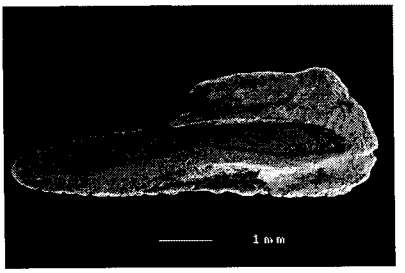
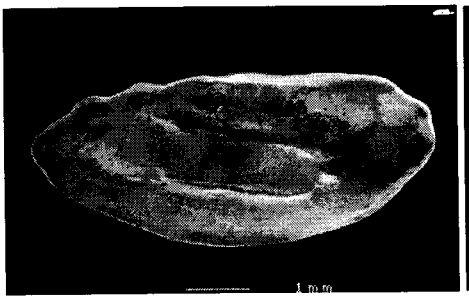


Figure 4.13 Order: Elopformes
Family: Elopidae
Species: *Elops machnata*

Figure 4.14 Order: Elopformes
Family: Megalopidae
Species: *Megalop cyprinoides*



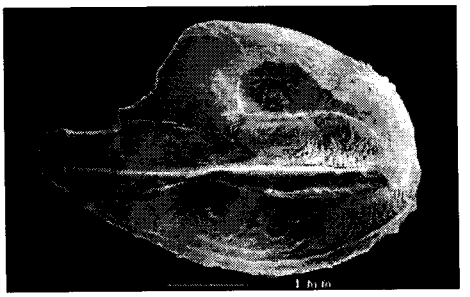
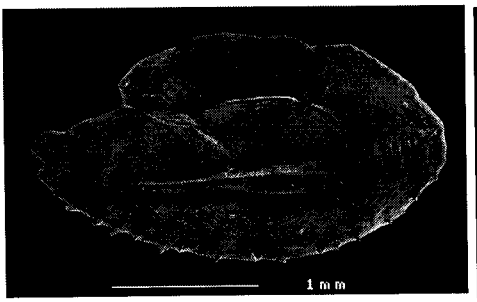


Figure 4.15 Order: Anguilliformes
Family: Muraenesocidae
Species: *Muraenesox cinereus*

Figure 4.16 Order: Clupeiformes
Family: Engraulidae
Species: *Coilia dussumieri*



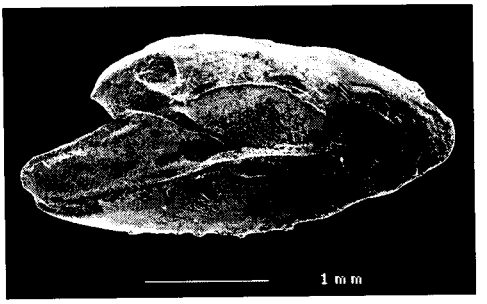


Figure 4.17 Order: Clupeiformes
Family: Engraulidae
Species: *Stolephorus indicus*

Figure 4.18 Order: Clupeiformes
Family: Engraulidae
Species: *Stolephorus* sp.

Chirocentrus dorab (Fig. 4.19)

The margin is irregular on the ventral part and posterior part, sinuate margin sculpturing. The rostrum is sharply round, and the antirostrum is large and pointed. The excisura is wide with a moderate to deep notch. Ostium and cauda are broad into the ventral and dorsal part. The cauda is pentagon-shaped. The crista superior and crista inferior are ridge-like both above and under the area of the anterior cauda, while they are well developed both above and below the area of the ostium and posterior cauda.

Family: Pristigasteridae

Opisthopterus tardoore (Fig. 4.20)

The antirostrum is small and pointed, whereas the rostrum is oblong. The posterior part at the dorsal area of the ostium has a circular pit. The dorsal depression is elongate and expands into the dorsal area on the posterior end of the cauda, where it is connected with the ventral depression that is elongate below both ostium and cauda. Margin sculpturing is sinuate and the collum is tubular.

Family: Clupeidae

Sagittal ololiths of this family are usually small and thin, pseudo-heterosulcoid or heterosulcoid. The crista superior is ridge-like but the crista inferior is well-developed and straight. The rostrum is usually elongate and narrow. Excisura is narrow with deeper notch. Dorsal depression is grooved and small but dorsal depression is elongate below both ostium and cauda.

Sardinella albella (Fig. 4.21)

Rostrum is very elongate but antirostrum is triangular and large. The ostium is narrow and elongate, the cauda is approximately circular,

shallow, and extends into the ventral and dorsal of the posterior part. The dorsal depression is oblong above the anterior cauda. The crista superior is ridge-like on the anterior cauda, whereas the crista inferior is well developed to ridge-like below and along ostium.

Sardinella fimbriata (Fig. 4.22)

Heterosulcoid is indistinctly separated. The cauda is raised on the central part of sulcus acusticus, the dorsal part is smooth, not defined, broad into the dorsal area. The dorsal depression is opened on the dorsal margin, but the ventral depression is elongate along both ostium and cauda. Ostium is oval.

Sardinella brachysoma (Fig. 4.23)

The excisura is very wide with the deepest notch. The rostrum is oval and the antirostrum is very large. The ostium is extremely oval and the cauda is not defined. The dorsal depression is small and shallow.

Order: Gonorhynchiformes

Family: Chanidae

Pyriform-shaped sagittal otolith with extremely long cauda. The sulcus acusticus is heterosulcoid with ostial opening. This family has only one species.

Chanos chanos (Fig. 4.24)

The antirostrum is absent and rostrum is elongate. The ostium is narrow and straight, while the cauda is slightly narrow. Margin sculpturing is irregular. The dorsal depression and ventral depression are deep at the cauda area. The ridge-like type is developed on the crista inferior

Order: Aulopiformes

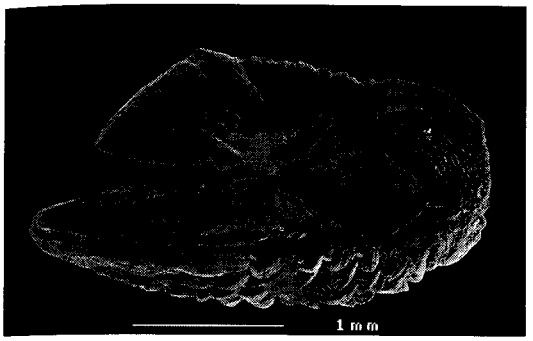


Figure 4.19 Order: Clupeiformes

Family: Chirocentridae

Species: *Chirocentrus dorab*

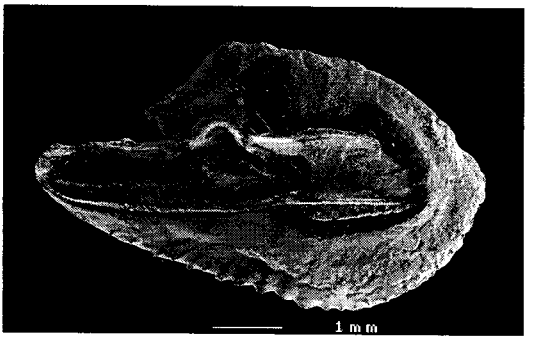


Figure 4.20 Order: Clupeiformes

Family: Pristigasteridae

Species: *Opisthopterus tardoore*

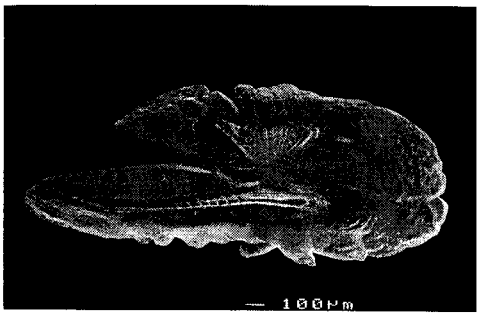


Figure 4.21 Order: Clupeiformes

Family: Clupeidae

Species: *Sardinella albella*

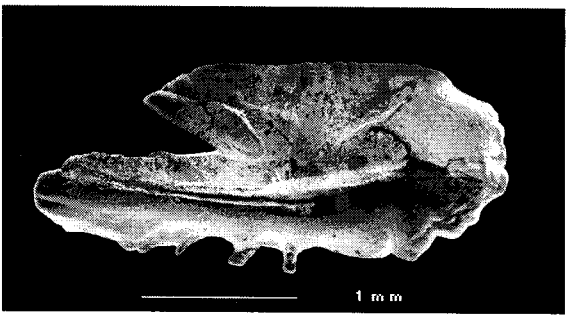


Figure 4.22 Order: Clupeiformes

Family: Clupeidae

Species: *Sardinella fimbriata.*

Figure 4.23 Order: Clupeiformes

Family: Clupeidae

Species: *Sardinella brachysoma*

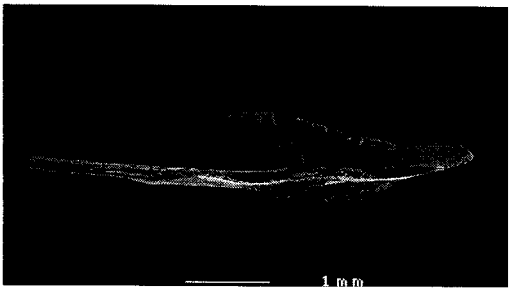


Figure 4.24 Order: Conorhynchiformes

Family: Chanidae

Species: *Chanos chanos*

Family: Synodontidae

This family varies in shape, is heterosulcoid with an ostail opening. The antirostrum is absent or minute. The ostium is deeper than cauda and heteromorph.

Trachinocephalus myops (Fig. 4.25)

The ostium is straight and cauda is curved and well-defined. The sulcus acusticus extends more into the dorsal. The crista superior is ridge-like on the anterior cauda and absent on posterior cauda, whereas crista inferior is well- developed along both the ostium and cauda.

Subfamily: Harpadontinae

Extremely oblong in shape, archaesulcoid. The cauda is very shallow, straight and narrow. Antirostrum and ventral depression do not appear. The cista superior is ridge-like and absent on crista inferior.

Saurida undosquamis (Fig. 4.26)

The ostium is oval and small. The ventral margin on both anterior and posterior sides curves gently into dorsal. The dorsal depression is shallow and broad into the dorsal margin. Margin sculpturing is sinuate on the dorsal margin. The cauda middle is narrower than the anterior and posterior part.

Saurida tumbil (Fig. 4.27)

The ostium is oblong and the cauda is very straight. The crista superior is very clearly ridge-like. Dorsal depression is oblong, deep above the cauda and defined.

Order: Ophidiiformes

Family: Ophidiidae

The shape is oblong and very small as well as thin. The sulcus acusticus is heterosulcoid with ostial opening. The cauda is expanded at the cauda tip.

Brotula (cf.) *multibarbata* (Fig. 4.28)

Antirostrum and rostrum are very large. The ostium is oblong and ventral. The crista superior is ridge-like but the crista inferior is well developed. The development of the dorsal depression is oblong and well defined. The cauda is oval or pitted at the posterior end.

Order: Mugiliformes

Family: Mugilidae

Oblong in shape, heterosulcoid with an ostial opening, the cauda is very long, narrow and gently flexed at the tip. The crista superior is well-developed to ridge-like, has both the dorsal depression and ventral depression.

Chelon tade (Fig. 4.29)

The ostium is oval and large, antirostrum minute and rostrum is wide and short. The dorsal depression is well-developed above middle to anterior cauda and the depression is well-developed along the cauda but very shallow. Irregulars in margin sculpturing.

Moolgarda buchanani (Fig. 4.30)

Rostrum and antirostrum small, the antirostrum is pointed. The excisura is narrow with a shallow notch. The dorsal depression extends along the dorsal margin and is very deep at the middle cauda area, while the ventral depression is very narrow along the cauda. Margin sculpturing is lobed.

Chelon subuiridis (Fig. 4.31)

No antirostrum and excisura, the cauda is very straight

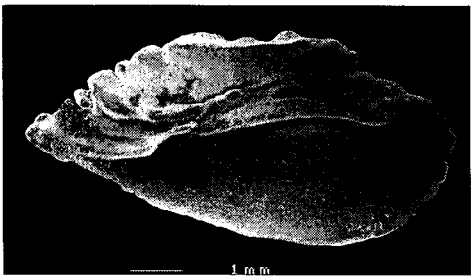


Figure 4.25 Order: Aulopiformes

Family: Synodontidae

Species: *Trachinocephalus myops*

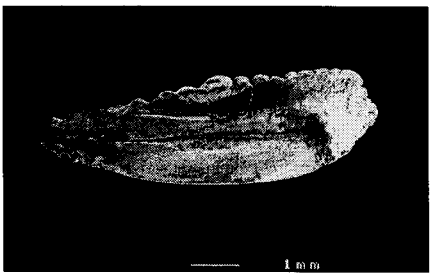


Figure 4.26 Order: Aulopiformes

Subfamily: Harpadontinae

Species: *Saurida undosquamis*

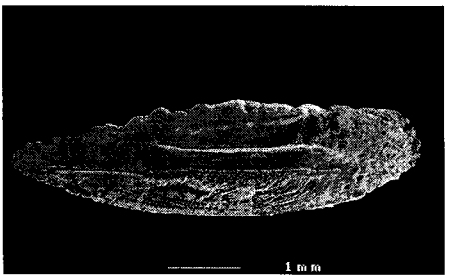


Figure 4.27 Order: Aulopiformes

Subfamily: Harpadontinae

Species: *Saurida tumbil*

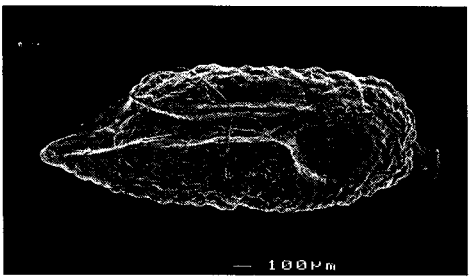


Figure 4.28 Order: Ophidiiformes

Family: Ophidiiidae

Species: *Brotula* (cf.) *multibarbata.*

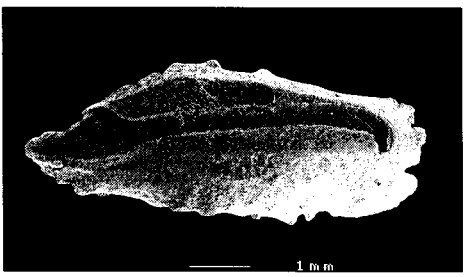


Figure 4.29 Order: Mugiliformes

Family: Mugilidae

Species: *Chelon tade*

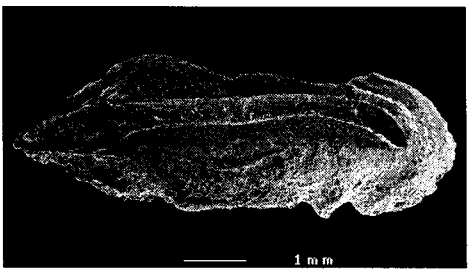


Figure 4.30 Order: Mugiliformes

Family: Mugilidae

Species: *Moolgarda buchanani*

and flexed at the tip. The dorsal depression is oval and expands into the dorsal area and the ventral depression is elongate and very shallow below the anterior cauda. Margin sculpturing is irregular.

Order: Atheriniformes

Family: Atherinidae

The shape is circular, heterosulcoid with an ostial opening. The rostrum is extremely short and wide, antirostrum absent. The dorsal area is smaller than ventral area.

Atherinomorus duodecimalis (Fig. 4.32)

The ostium is circular and small but the cauda is elongate and narrow, similar to a tail. The crista superior and crista inferior are developed along cauda. The dorsal depression is oval and broad into the middle cauda area. Margin sculpturing is sinuate.

Order: Beloniformes

Family: Belonidae

Oblong to oval in shape, rostrum and antirostrum are very small and absent or minute. The sulcus acusticus is archaesulcoid with an ostial opening and filled with much largely crystalline structure. The cauda and ostium are indistinctly separated. The crista is poorly developed, ridge-like or absent. The dorsal depression is very small and ventral depression is absent. The colliculum is raised both in ostium and cauda.

Tylosurus crocodilus (Fig. 4.33)

The dorsal depression and ventral depression are extremely shallow and developed especially in the posterior cauda area. Margin sculpturing is very irregular.

Platybelone argalus (Fig. 4.34)

The antirostrum is minute, ostium is oblong, narrow and smaller than the cauda. Ventral depression as well as crista superior and crista inferior are absent. The dorsal depression is extremely shallow, narrow and small above the posterior cauda.

Tylosurus acus melanotus (Fig. 4.35)

The ostium and cauda are depressed, the midline area of sulcus acusticus and the ostium is broader than the cauda. The dorsal depression is grooved on the middle area of the cauda. Margin sculpturing is lobed and minutely irregular. Crista superior is ridge-like.

Platybelone platyura (Fig. 4.36)

The ostium is somewhat circular and broader than the cauda. The exisura is very narrow with an extremely shallow notch. The rostrum is broad into dorsal and the antirostrum is minute. The dorsal depression is small, oblong on the middle cauda.

Strongylura strongylura (Fig. 4.37)

The cauda is curved and opened on the posterior part. The sulcus acusticus is heterosulcoid with an ostio-caudal opening. The pseudo-excisura is wide with a shallow notch. The dorsal depression is rectangular in shape and deep.

Family: Exocoetidae

The shape is ovate and oval, heterosulcoid with ostial opening. The sulcus acusticus contains crystalline structure. Both dorsal depression and ventral depression are absent.

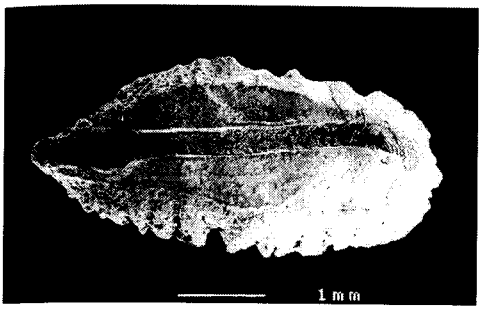


Figure 4.31 Order: Mugiliformes
Family: Mugilidae
Species: *Chelon subuiridis*

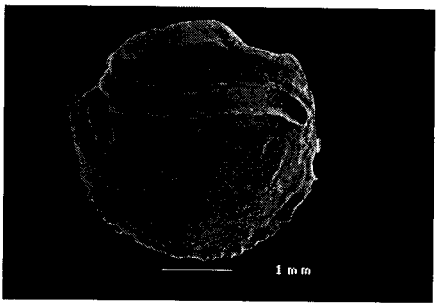


Figure 4.32 Order: Atheriniformes
Family: Atherinidae
Species: *Atherinomorus duodecimalis*

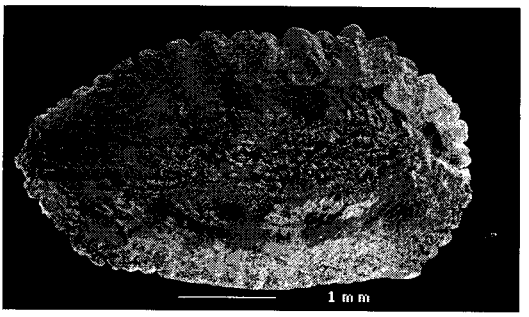


Figure 4.33 Order: Beloniformes
Family: Belonidae
Species: *Tylosurus crocodilus*

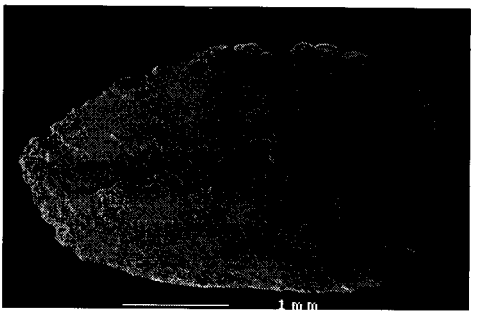


Figure 4.34 Order: Beloniformes
Family: Belonidae
Species: *Platybelone argalus*

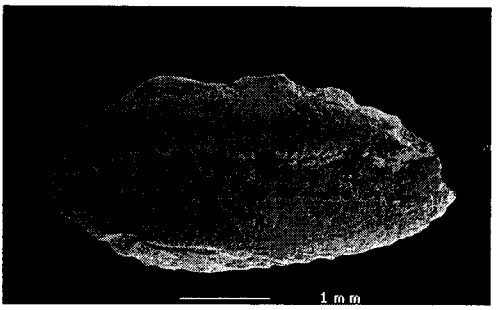


Figure 4.35 Order: Beloniformes
Family: Belonidae
Species: *Tylosurus acus melanotus*

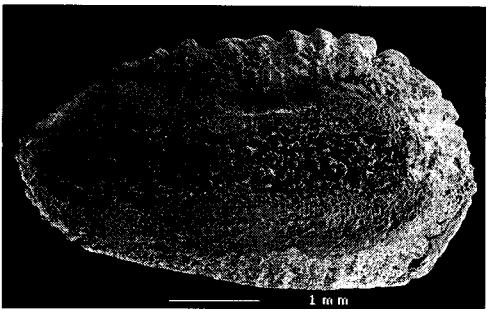


Figure 4.36 Order: Beloniformes
Family: Belonidae
Species: *Platybelone platyura*

Cypselurus maressi (Fig. 4.38)

Ovate in shape, the rostrum is ventral and antirostrum is absent. The ostium and cauda are wide and somewhat straight.

Cypselurus oligolipes (Fig. 4.39)

Oval in shape, the rostrum and antirostrum are small and pointed. The cauda is sinuous and opens on the posterior part.

Family: Hemiramphidae

The shape is elliptic and oval, heterosulcoid and archaesulcoid. The antirostrum is absent and rostrum is small. The dorsal depression is small, while ventral depression is absent.

Hyporhamphus limbatus (Fig. 4.40)

Elliptic in shape, heterosulcoid. The ostium is rather circular and the cauda is gentle dorsally, both are very large. The crista superior and crista inferior are ridge-like. Dorsal depression is oval above the middle cauda area.

Hemiramphus far (Fig. 4.41)

Elliptic in shape, heterosulcoid. Ostium is oval and cauda is straight. Crista superior and crista inferior are absent.

Hemiramphus archipelagicus (Fig. 4.42)

Oval in shape, archaesulcoid. The ostium and cauda are very narrow, elongate and indistinctly separated. Under the ostium there is a circular pit.

Order: Beryciformes

Family: Holocentridae

Approximate oval in shape, heterosulcoid. The dorsal area has a

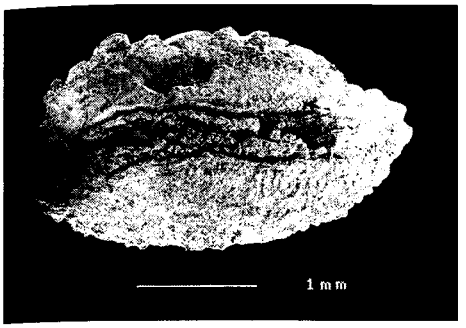


Figure 4.37 Order: Beloniformes

Family: Belonidae

Species: *Strongylura strongylura*

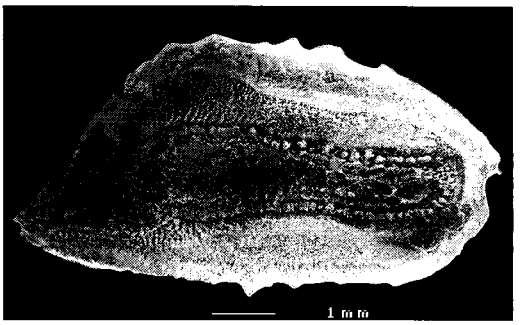


Figure 4.38 Order: Beloniformes

Family: Exocoetidae

Species: *Cypselurus maressi*

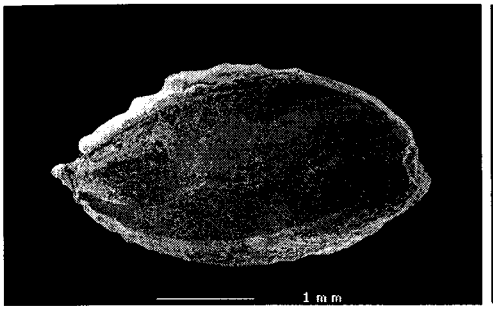


Figure 4.39 Order: Beloniformes

Family: Exocoetidae

Species: *Cypselurus oligolipes*

Figure 4.40 Order: Beloniformes

Family: Hemiramphidae

Species: *Hyporhamphus limbatus*

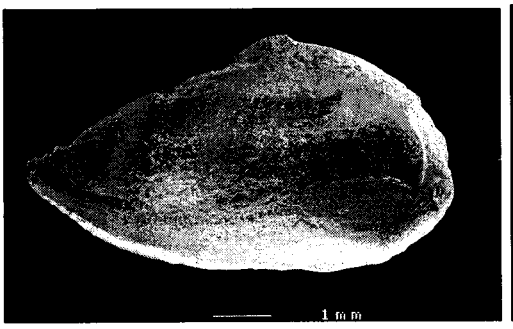


Figure 4.41 Order: Beloniformes

Family: Hemiramphidae

Species: *Hemiramphus far*

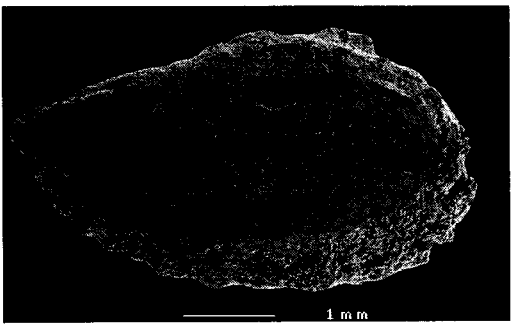


Figure 4.42 Order: Beloniformes

Family:Hemiramphidae

Species: *Hemiramphus archipelagicus*

deeper groove along the dorsal margin. The posterior portion is indented. Culliculum is heteromorph, raised on ostium floor with oval shape.

Holocentrus rubrum (Fig. 4.43)

Ovate in shape, the posterior part at dorsal area is rather sharp. Margin sculpturing is entire or minutely irregular. Cauda is straight at the anteriorportion and gently flexed at the posterior part.

Ostichthys kaianus (Fig. 4.44)

The posterior part at the dorsal area is rounded. Cauda is straight at posterior end but gently flexed from middle to posterior area. Margin sculpturing is crenate.

Subfamily: Myripristinae

The shape is somewhat like tapezium, and is the only one found in this study. Sulcus acusticus is heterosulcoid with ostio-caudal opening.

Myripristis murdjan (Fig. 4.45)

The ostium is hammer-shaped, broad into ventral area and the cauda is forked. Dorsal depression is oval and deep above the posterior cauda.

Order: Scorpaeniformes

Family: Scorpaenidae

The shape is oblong, heterosulcoid with ostio-caudal opening. The dorsal area and ventral area are small. The ostium is elongate into the cauda area. The posterior part is indented. The dorsal depression is basined while the ventral depression is elongate both under ostium and cauda and connected to the cauda area and ostium.

Pterois milles (Fig. 4.46)

The dorsal area and ventral area are small, which is caused by the dorsal depression, ventral depression and sulcus are broad into those areas. The size and shape of ostium and cauda are very similar and elongate. The cristae superior and cristae inferior are poorly developed. The ventral depression is well-developed, broad and elongate, connected to the ostium and cauda.

Pterois russelli (Fig. 4.47)

The ostium is oval and elongate, while cauda is narrow and short and the posterior end of them show the oval broad. The dorsal depression is narrow and elongate, while the dorsal depression shape is basined and the floor is very smooth.

Coccotopus sp. (Fig. 4.48)

The ventral depression clearly shows the connection with the ostium and cauda. The dorsal depression is shallow and broad into the dorsal rim. The dorsal sculpturing is indented and lobed but ventral is irregular.

Scopaenopsis neglecta (Fig. 4.49)

There is only one species in this study, oblong in shape and with serrate margin sculpturing. The posterior margin is very rough. Dorsal and ventral depression are absent, as is the caista superior, whereas the crista inferior is poorly developed. The cauda is gently curved into the ventral part of the posterior end. The ostium is oblong and deeper than the cauda. The antirostrum is absent, and the rostrum is small and short.

Family Platycephalidae

The shape is similar to a boat. The posterior portion is indented and posterior end extended, while the anterior end is pointed. The sulcus is shallow in

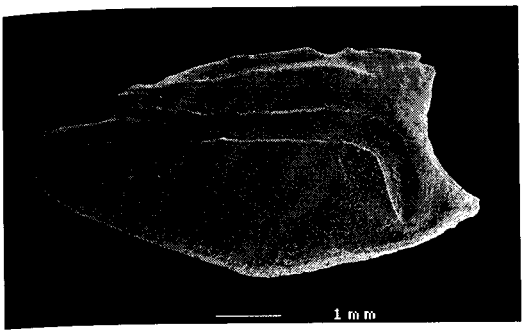


Figure 4.43 Order: Beryciformes

Family: Holocentridae

Species: *Holocentrus rubrum*

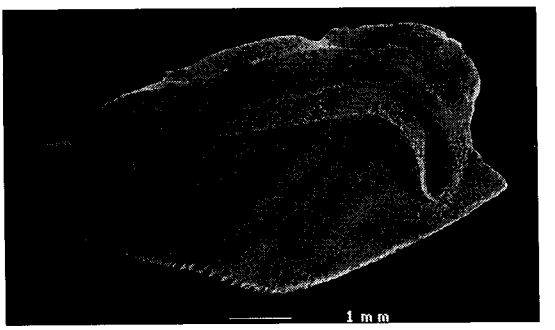


Figure 4.44 Order: Beryciformes

Family: Holocentridae

Species: *Ostichthys kaianus*

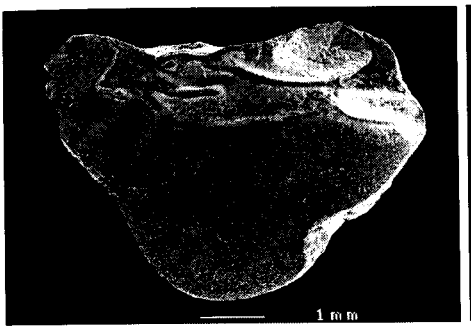


Figure 4.45 Order: Beryciformes

Family: Subfamilies Myripristinae

Species: *Myripristis murdjan*

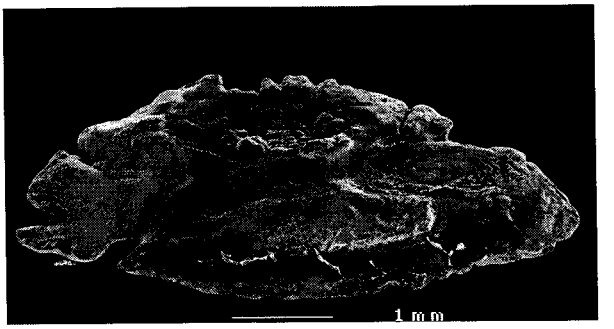


Figure 4.46 Order: Scorpaeniformes

Family: Scorpaenidae

Species: *Pterois milles*

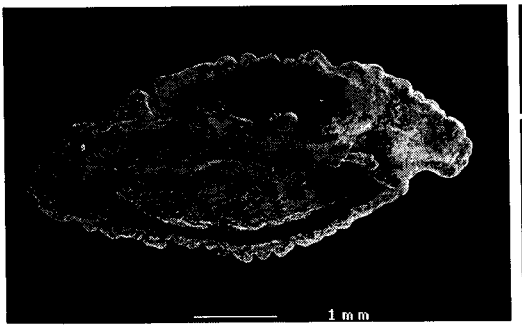


Figure 4.47 Order: Scorpaeniformes

Family: Scorpaenidae

Species: *Pterois russelli*

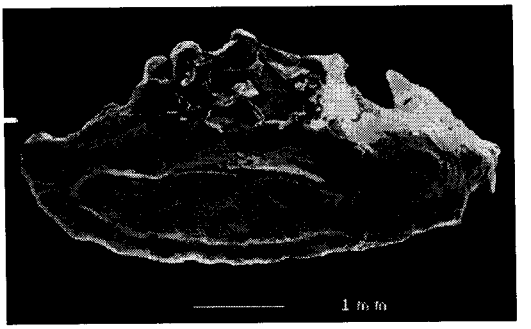


Figure 4.48 Order: Scorpaeniformes

Family: Scorpaenidae

Species: *Coccotopus* sp.

ostium and deep, very short in cauda.

Grammoplites asper (Fig. 4.50)

One species is found in this study. The sculpturing is smooth. The crista superior is developed, whereas crista inferior is poorly developed. The dorsal depression is broad but the ventral inferior is absent.

Order Perciformes

Family Priacanthidae

The shape is similar to a heart. The posterior portion is indented and it has a long spine, whereas the anterior portion is small. The excisura is very wide with a shallow notch. Lotus-leaf shaped heterosulcoid. Posterior part has one rectangular and one oval hole, whereas the anterior part is small. Exisura is very wide with shallow notch.

Priacanthus tayenus (Fig. 4.51)

This is the only species in the study, margin sculpturing is lobed and margin is slightly smooth.

Family Centropomidae

The shape is oblong with the large rostrum and heterosulcoid type, ostial opening. The margin sculpturing is irregular. The posterior portion is round and gentle curved ventrally. The ventral depression is absent, while the dorsal depression is oblong above the anterior cauda. Rostrum is oval and extremely large, while antirostrum is triangular-shaped.

Lates calcarifer (Fig. 4.52)

The ostium is very oblong and gently broad ventrally, whereas the cauda is initially straight and gentle curved at the posterior portion. The

excisura is deep and narrow. Dorsal depression is oval and shallow above the cauda, while the ventral depression is absent. The crista superior is ridge-like but absent at crista inferior. The dorsal margin at anterior part has the shape of a small dome.

Family Gerreidae

The shape is approximately circular but the anterior portion is narrower than the posterior portion. Sulcus is heterosulcoid with ostial opening. The cauda is wide and deep while the ostium is somewhat triangular with elongate groove, connected with a small oval pit at the rostrum end. The posterior and medial portion of it is straight and flexed at tip. Rostrum and antirostrum are rather triangular.

Pentaprion longimanus (Fig. 4.53)

This species has a special character with a long deep groove under the ostium. The crista superior is very well-developed and the crista inferior is developed as well. The ostium is approximately square but the cauda is very straight and curved at the tip. The rostrum is wide, while the antirostrum is medium with a wide and shallow excisura.

Family Serranidae

Normally the otolith shape is oblong with heterosulcoid type of sulcus acusticus. The rostrum and antirostrum generally are oblong and moderate. The ostium is oblong but the cauda initially is straight and gently flexed at tip. The posterior portion commonly is indented at the dorsal posterior.

Epinephelus sexfasciatus (Fig. 4.54)

Shape is oblong with ostio-caudal opening. Anterior portion at the ventral area is gently curved dorsally and excisura is very wide and shallow. Ostium is oval and very large. Dorsal area is very rough while ventral area is

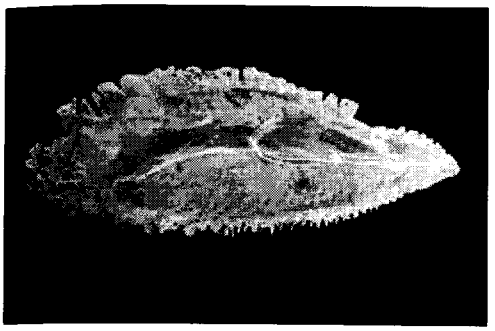


Figure 4.49 Order: Scorpaeniformes

Family: Scorpaenidae

Species: *Scopaenopsis neglecta*

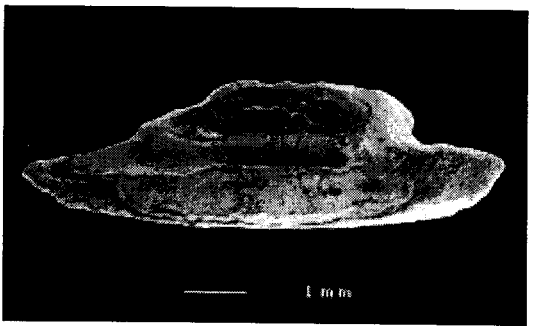


Figure 4.50 Order: Scorpaeniformes

Family: Platycephalidae

Species: *Grammoplites asper*

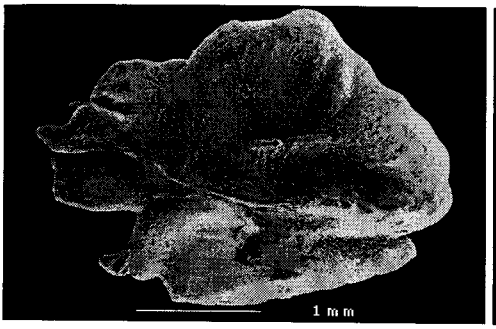


Figure 4.51 Order: Perciformes

Family: Priacanthidae

Species: *Priacanthus tayenus*

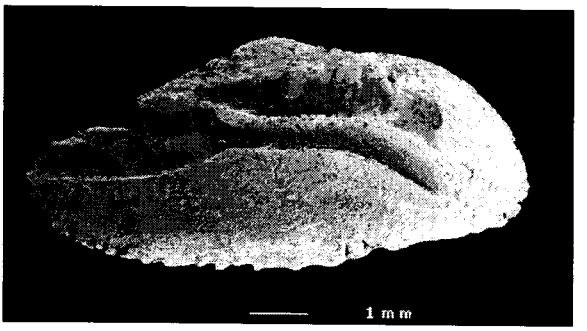


Figure 4.52 Order: Perciformes

Family: Centropomidae

Species: *Lates calcarifer*

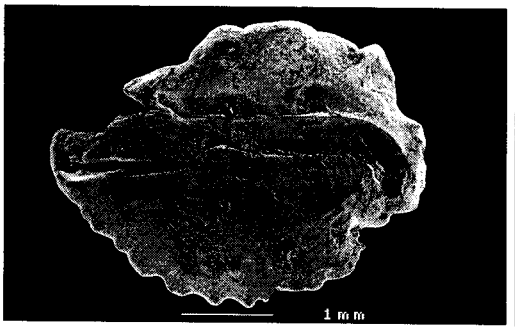


Figure 4.53 Order: Perciformes

Family: Gerreidae

Species: *Pentaprion longimanus*

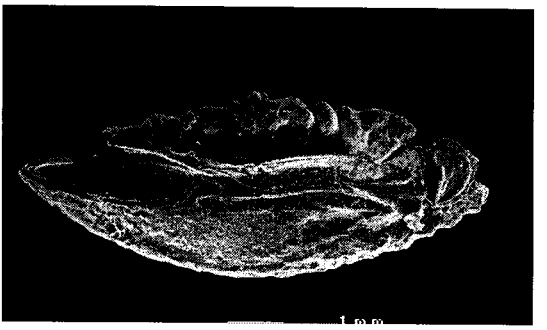


Figure 4.54 Order: Perciformes

Family: Serranidae

Species: *Epinephelus sexfasciatus*

smooth.

Epinephelus areolatus (Fig. 4.55)

Shape is oblong with ostial opening. Ostium is oblong and very large, while the posterior cauda is gently curved dorsally. Dorsal depression appears at the posterior end of cauda. Dorsal depression is found along the ostium and cauda area. Rostrum is very large and oval.

Shape is oval with ostio-caudal opening. Both dorsal area and ventral area are rough. Dorsal depression is oval on the anterior cauda while ventral depression is absent. Ostium is oval, as is the rostrum.

Cephalopholis formosa (Fig. 4.56)

Shape is oval but the anterior portion is narrower than the posterior portion. The crista superior is absent but crista inferior is developed. Dorsal deression is shallow and small, set up on the medial of cauda. The ostium is oblong and not defined.

Cephalophlois miniatus (Fig. 4.57)

The shape is elongate with rather straight both dorsal and ventral rim. Ostium is very large and expanded into both postventral and predorsal. The cauda is shallow and gently curving ventral rim. One special character is a pit, found at the postventral. Excisura is narrow and deep.

Cephalophlois argus (Fig. 4.58)

The shape is strong oblong with large crystal on the sulcus. Dorsal depression is very shallow and found upper the cauda. Rostrum and antirostrum are large and extend into the anterior. Postdorsally and predorsally there is a pit.

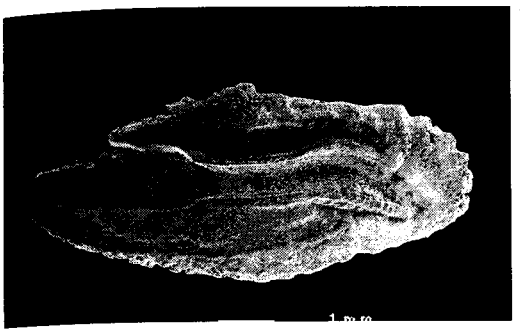


Figure 4.55 Order: Perciformes

Family: Serranidae

Species: *Epinephelus areolatus*

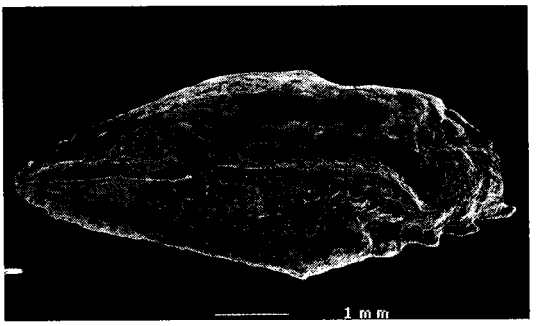


Figure 4.56 Order: Perciformes

Family: Serranidae

Species: *Cephalopholis formosa*

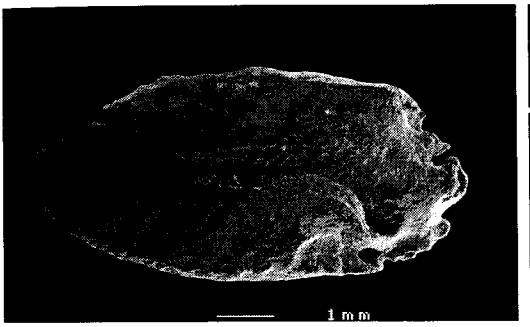


Figure 4.57 Order: Perciformes

Family: Serranidae

Species: *Cephalophlois miniatus*

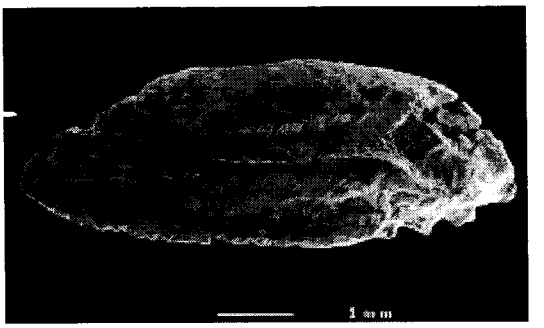


Figure 4.58 Order: Perciformes

Family: Serranidae

Species: *Cephalophlois argus*

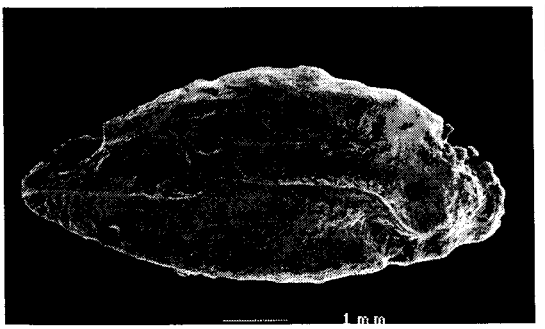


Figure 4.59 Order : Perciformes

Family: Serranidae

Species: *Cephalopholis oligostitus*

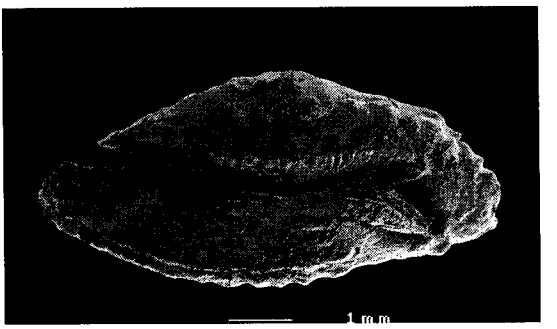


Figure 4.60 Order: Perciformes

Family: Serranidae

Species: *Epinephelus quoyanus*

Cephalopholis oligostitus (Fig. 4.59)

Shape is extremely oval and gently narrowing anterior portion. Ostium is circular and expanded into predorsal, while the cauda is expanded at the tip into ventral. The dorsal depression is extremely shallow but expanded around the upper part of the cauda.

Epinephelus quoyanus (Fig. 4.60)

The shape is oval with ostial-caudal opening. The dorsal area is expanded. Ostium is extremely oval and projected preanteriorly. Cauda is deep, gently curving dorsally and flexed ventrally. Ventral depression is narrow, small and found at tip and connected to cauda. Excisura is wide, deep rectangular shape.

Cephalopholis formosa (Fig. 4.61)

The shape is oval, postventrally is narrow and gently sloping upward. Anterior portion is oval with large ostium, expanded into the dorsal area. Ventral depression is shallow and expanded under the post cauda. Excisura is very narrow and shallow.

Epinephelus leucogrammicus (Fig. 4.62)

The shape is oblong, anterior portion smaller than the posterior portion. Rostrum is small while cauda is very shallow and expanded dorsally. The posterior rim is only lobed dorsally. The dorsal depression is extremely shallow and oval.

Epinephelus argus (Fig. 4.63)

The shape is oval with ostial-caudal opening. Dorsal depression is small and oval set up around the anterior cauda. The postdorsal is rough and smaller than the anterior portion.

Epinephelus faveatus (Fig. 4.64)

The shape is oval, dorsal rim and posterior rims are very rough. Ostium is oblong and very large, extending into cauda. Cauda is deep, gently flexed and open at postventral rim. Dorsal depression is narrow but deep. Cristae superior is well-developed along the cauda.

Cephalopholis baenak (Fig. 4.65)

The shape is oval with ostial-caudal opening. The dorsal depression is very large, wide and extremely shallow, but ventral depression is oblong, small, narrow and set up along the medial and the end of cauda. The posterior portion and anterior portion are gently curving both dorsally and ventrally. Ostium is large and expanded ventrally.

Cephalopholis sp. (Fig. 4.66)

The shape is oval with heterosulcoid. The posterior portion is projected and anterior portion gently curving upward. Ostium is large, oval and expanded dorsally and ventrally. Rostrum is oval and antirostrum is notched.

Cephalopholis heniochus (Fig. 4.67)

The shape is oblong with ostio-caudal opening. The posterior portion is small and gentle curved ventrally, while the anterior portion is approximately oval. The ostium is oval and very large, extended into the anterior cauda. The cauda initially is straight and gently flexed at posterior

Family Apogonidae

Apocal elioti (Fig. 4.68)

The dorsal area and ventral areas are smooth. Leaf-like shape with para-ostial opening, heterosulcoid. The dorsal rim is lobed but ventral rim

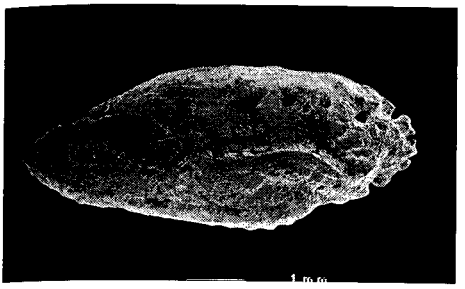


Figure 4.61 Order: Perciformes
Family: Serranidae
Species: *Cephalopholis formosa*

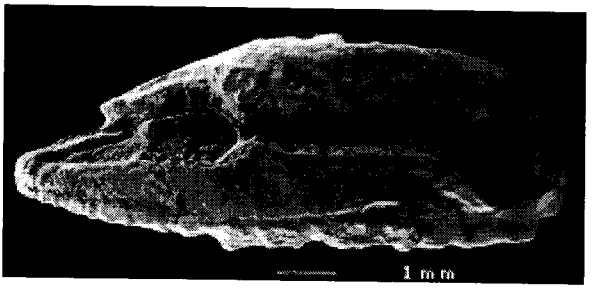


Figure 4.62 Order: Perciformes
Family: Serranidae
Species: *Epinephelus leucogrammicus*

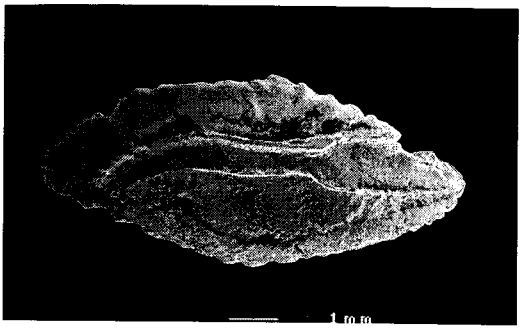


Figure 4.63 Order: Perciformes
Family: Serranidae
Species: *Epinephelus argus*

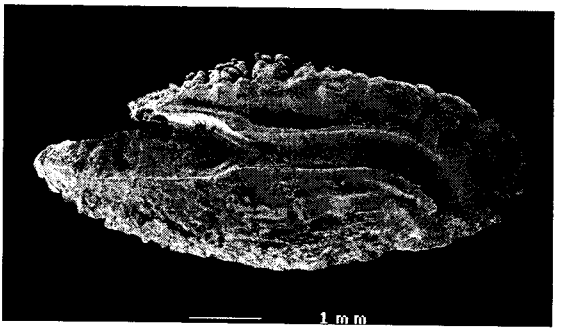


Figure 4.64 Order: Perciformes
Family: Serranidae
Species: *Epinephelus faveatus*

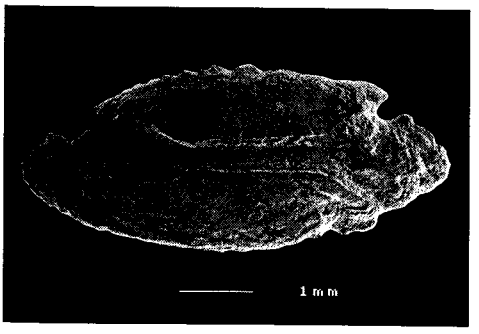


Figure 4.65 Order: Perciformes
Family: Serranidae
Species: *Cephalopholis baenak*

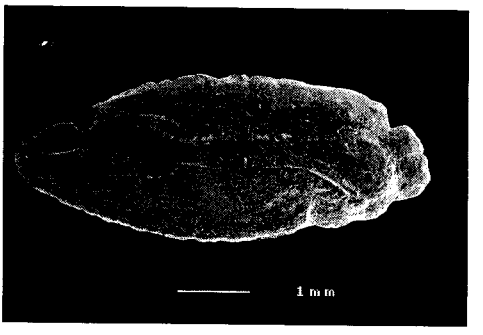


Figure 4.66 Order: Perciformes
Family: Serranidae
Species: *Cephalopholis* sp.

smooth. Sulcus acusticus character is arrow-shaped. Ostium is oval, while the cauda is straight, shallow and gently curving into dorsal area. Dorsal depression is basined and ventral depression is absent.

Family Sillaginidae

The shape is oval with ostial opening, heterosulcoid and pseudo-archaesulcoid. Ventral area is large, deep and gently curving dorsally, while the dorsal area is small, oblong and nearly straight. Ostium is very short but cauda is elongate. Rostrum and antirostrum are absent.

Sillago aeolus (Fig. 4.69)

Shape is oval with heterosulcoid. Ventral area is very smooth. Dorsal depression is not clearly defined along the cauda. Ostium is circular and indented at anterior end. Cauda is sinusoid, wide and shallow.

Sillago sihama (Fig. 4.70)

Shape is oval with heterosulcoid. Ostium is oval and expanded ventrally. Cauda is gently curving into dorsal area and flexed and expanded ventrally. Dorsal and ventral depression are absent. Crista superior is ridge-like along both the ostium and cauda

Sillago ingenuua (Fig. 4.71)

Shape is long oval with pseudo-archaesulcoid. Ostium is rectangular. Cauda is gently curving dorsally, wide and shallow. The dorsal depression is very small, oval and shallow, set up under the cauda medial.

Sillago asiatica (Fig. 4.72)

Shape is oval with pseudo-archaesulcoid. The sulcus area contains large crystal structure. Medial ventral area is deep and gently curving

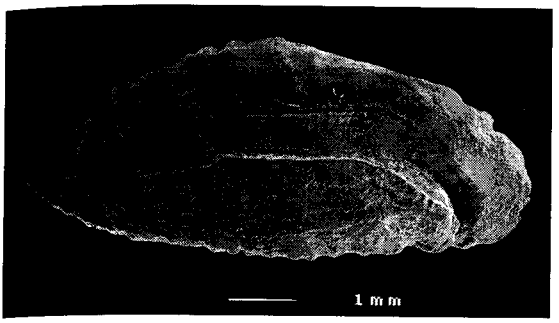


Figure 4.67 Order: Perciformes

Family: Serranidae

Species: *Cephalopholis heniochus*

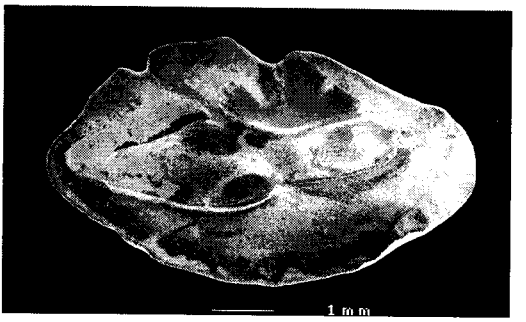


Figure 4.68 Order: Perciformes

Family: Apogonidae

Species: *Apocal elioti*

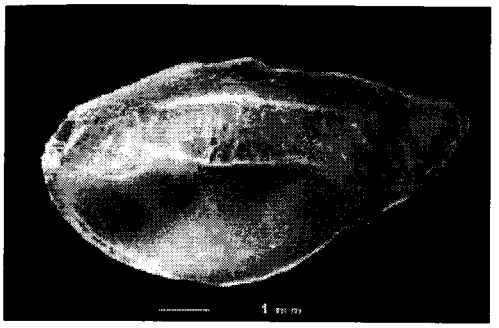


Figure 4.69 Order: Perciformes

Family: Sillaginidae

Species: *Sillago aeolus*

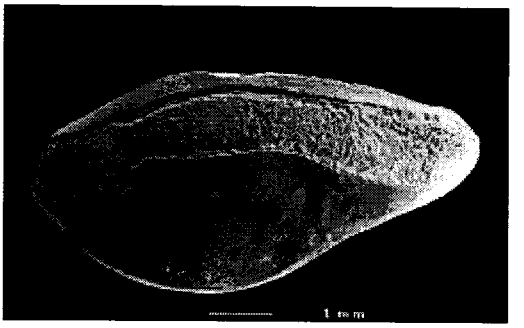


Figure 4.70 Order: Perciformes

Family: Sillaginidae

Species: *Sillago sihama*

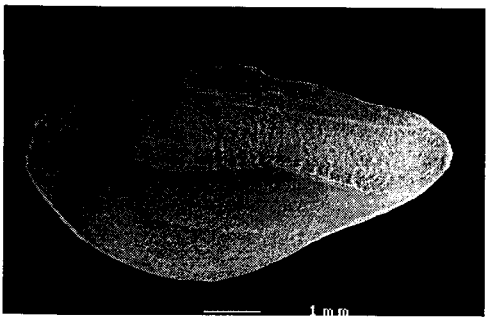


Figure 4.71 Order: Perciformes

Family: Sillaginidae

Species: *Sillago ingenuua*

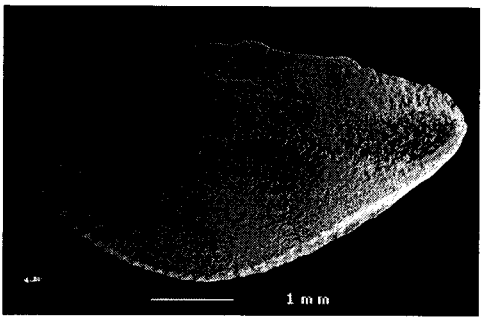


Figure 4.72 Order: Perciformes

Family: Sillaginidae

Species: *Sillago asiatica*

dorsally, but dorsal area is nearly straight. Ostium is oblong and curved. Cauda initially is straight and the cauda end is gently curving ventrally.

Sillago chondropus (Fig. 4.73)

Shape is oval with pseudo-archaesulcoid and gently narrowing postdorsally and postventrally. Sulcus contains many large crystals. Ostium is oval and gently curving dorsally, while the cauda is elongate and narrow at the tip.

Family: Rachycentridae

Rachycentron canadus (Fig. 4.74)

This family has one species in this study. The shape is oblong with heterosulcoid. Sulcus is very deep, cauda short and wide at the posterior end. The dorsal margin gently curving pre-and postdorsally. Rostrum is triangular and antirostrum is oblong, rod-like. Dorsal depression is oblong in the upper medial cauda but ventral depression is absent.

Family: Carangidae

The otolith of this family is oval and oblong in shape, heterosulcoid. The opening type of sulcus acusticus is mainly ostial and in some species is ostio-caudal. The rostrum is rather large, antirostrum is small to minute. Ostium is rather oval and broad into ventral. Cauda is wide, shallow, initial straight and gently flexed at tip. Dorsal depression elongate, narrow, while ventral depression is absent. Crista superior is well- developed, while crista inferior is developed.

Carangoides malabaricus (Fig. 4.75)

Oval shape, ostial opening, heterosulcoid. Rostrum large, triangular-shaped. Antirostrum rather large and notched. Dorsal depression very shallow, located under the anterior cauda. The medial portion of otolith is wide

and gently curves into posterior and anterior end.

Alepes djeddaba (Fig. 4.76)

Oblong shape, ostial opening and heterosulcoid. The postdorsal portion gently curves into ventral, whereas the postventral is quite straight. Antirostrum very elongate, rod-shaped. Rostrum large, triangular-shaped. Cauda narrow, initially straight and steeply flexed ventrally. Dorsal depression small, shallow. located under the anterior cauda, while ventral depression is absent.

Decapterus dayi (Fig. 4.77)

Oblong shape, heterosulcoid and ostio-caudal opening. Rostrum short but large, triangular-shaped. Antirostrum is rather short and wide. The ostium is steeply inclined ventrally, with oval shape and short. Cauda very long, wide, shallow, initially very straight and gentle flexes at the caudal tip. Dorsal depression is broad and elongated above the posterior cauda.

Decapterus kurroides (Fig. 4.78)

Oval shape, heterosulcoid and ostio-caudal opening. The anterior portion is small and triangular-shaped, while the posterior portion is large and oval. Rostrum shorts and sloped into ventral, antirostrum minute. Crista superior is ridge-like along the posterior ostium and anterior cauda. Ostium, rectangular shaped, steeply inclined into ventral. The cauda is rather wide and steeply flexed at cauda tip before opening at postventral margin. Dorsal depression shallow, narrow along the top. The anterior cauda and the posterior ostium opened at the anterior end near the antirostrum.

Seriolina nigrofasciata (Fig. 4.79)

Oval shape, heterosulcoid and ostial opening. The

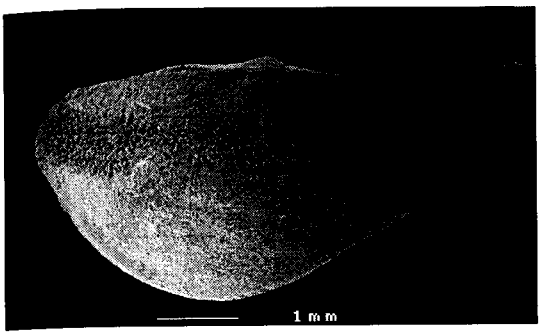


Figure 4.73 Order: Perciformes
Family: Sillaginidae
Species: *Sillago chondropus*

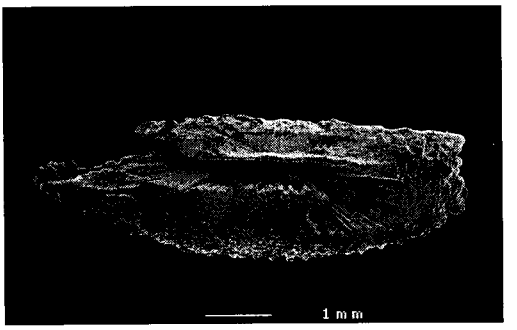


Figure 4.74 Order: Perciformes
Family: Rachycentridae
Species: *Rachycentron canadus*

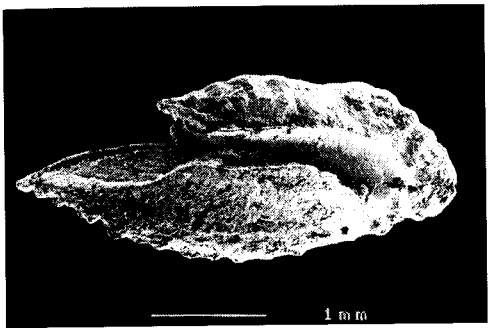


Figure 4.75 Order: Perciformes
Family: Carangidae
Species: *Carangoides malabaricus*

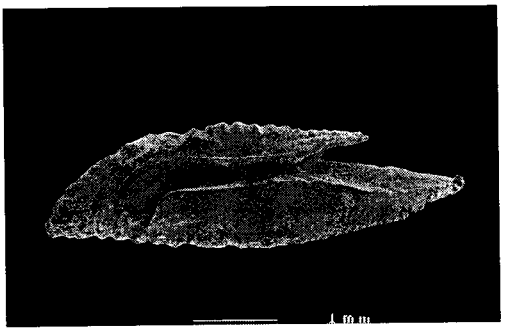


Figure 4.76 Order: Perciformes
Family: Carangidae
Species: *Alepes djeddaba*

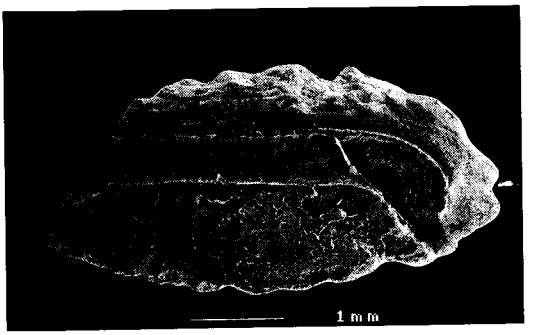


Figure 4.77 Order: Perciformes
Family: Carangidae
Species: *Decapterus dayi*

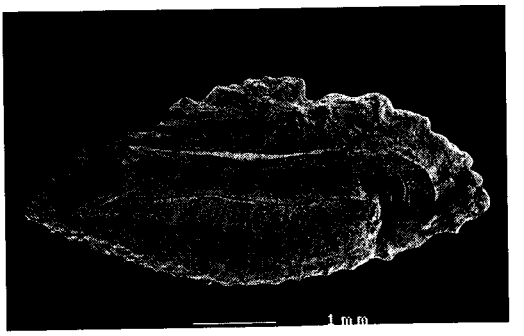


Figure 4.78 Order: Perciformes
Family: Carangidae
Species: *Decapterus kurroides*

portion is very round, while the anterior portion is rather sharp. Rostrum is long, extends anterior. Antirostrum is small and round. Ostium oblong gently inclined ventrally. Cauda is very wide, short and broad into postdorsal area. Dorsal depression I is very small and located above the ostium.

Atule mate (Fig. 4.80)

Strongly oblong, heterosulcoid and ostio-caudal opening. The posterior and anterior portion is elongate. Rostrum strongly triangular and the posterior end very sharp. Antirostrum is small and projected at the anterior. Ostium elongated and gently narrower at anterior but the posterior is broad extending upwards into predorsal area. Cauda narrow, shallow, initial very straight and gently curving into ventral and open at postventral. Dorsal depression is very shallow and narrow, located above the anterior of cauda.

Elagatis bipinnulata (Fig. 4.81)

Oval shape, heterosulcoid and ostio-caudal opening. Dorsal area reduced, caused by the extending of the cauda. Rostrum is triangular-shaped and gently curves upwards. Antirostrum is notched and small. Ostium oval-shaped, broad downward.

Ulua aurochs (Fig. 4.82)

Ovate shape, heterosulcoid and ostio-caudal opening. The posterior portion is very large and broad at postdorsal, while the ventral margin is rather straight and at the preventral it is gently curved upwards. Rostrum is extremely large and round.Antirostrum rather small and round. Ostium is oblong and broad downward. Cauda tip gently narrower before opening at posterior end of otolith. Dorsal depression is very shallow and not defined, located only above the anterior of

cauda.

Alepes melanoptera (Fig. 4.83)

Oblong shape, heterosulcoid and ostial opening. Rostrum large, oblong toward anterior. Antirostrum medial, similar spine and project at the anterior. Ostium elongate, narrow. Cauda initially straight and slight curved at cauda tip. Dorsal depression is very shallow, located above the anterior cauda.

Decapterus sp. (Fig. 4.84)

The characteristic of otolith of this species differs from other species. Oblong shape, homosulcoid and ostio-caudal opening. Dorsal area and ventral area are reduced, due to expanding of ostium and cauda. Rostrum is extremely large, while antirostrum is minute. Ostium very large, broad downwards. The anterior of cauda is triangular-shaped and broad at the posterior before opening at postventral margin. The collum is a solid bridge. Dorsal depression extremely narrow, short, located above the collum.

Alepes kleinii (Fig. 4.85)

Oblong, heterosulcoid and ostial opening. Rostrum is rather sharp and projects at the anterior. Antirostrum is rather small. Ostium is oblong, broad upward, near the rostrum. Cauda very narrow and shallow at anterior part but posterior part gently curves into ventral area. Dorsal depression is elongate and very shallow.

Scomberoides tol (Fig. 4.86)

Oblong, homosulcoid and ostial opening. The ventral area reduced, while the dorsal area expanded into predorsal. Rostrum very oblong, projected at anterior. Antirostrum rather large inclined upwards. Ostium very

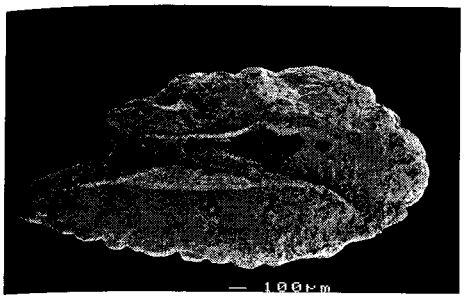


Figure 4.79 Order: Perciformes

Family: Carangidae

Species: *Seriolina nigrofasciata*

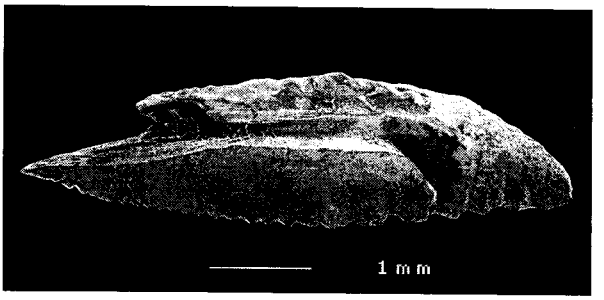


Figure 4.80 Order: Perciformes

Family: Carangidae

Species: *Selar boops*

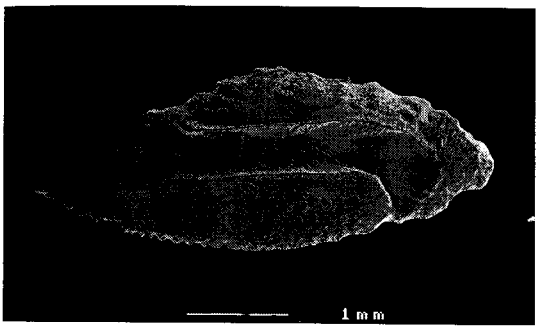


Figure 4.81 Order: Perciformes

Famil: Carangidae

Species: *Elagatis bipinnulata*

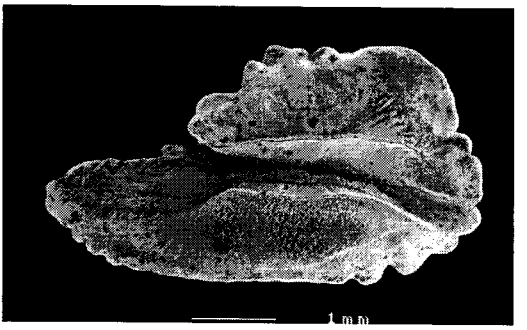


Figure 4.82 Order: Perciformes

Family: Carangidae

Species: *Ulua aurochs*

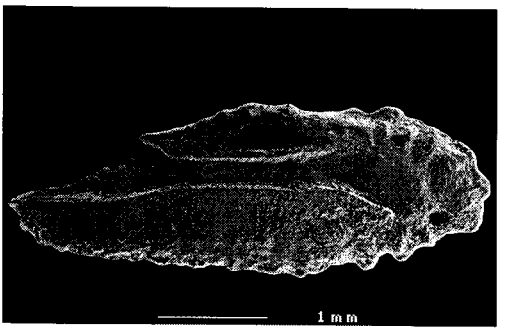


Figure 4.83 Order: Perciformes

Family: Carangidae

Species: *Alepes melanoptera*

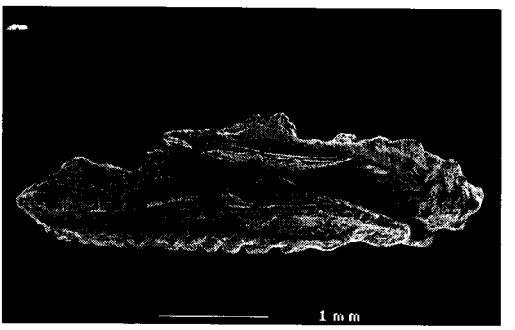


Figure 4.84 Order: Perciformes

Family: Carangidae

Species: *Decapterus* sp.

grooved, short, extremely narrow and upper part of cauda expanded into dorsal. Collum is a solid bridge. Dorsal depression is basined at predorsal of otolith.

Scomberoides commersonnianus (Fig. 4.87)

Extremely oblong, homosulcoid and ostial opening. Dorsal area and ventral area are reduced but anterior part and posterior part are elongated. Rostrum extremely elongate, similar to a rod. Antirostrum large and round. Ostium small and oval. Cauda very narrow, has groove, and short. Dorsal depression extremely shallow and not defined. Collum is a solid bridge.

Carangoides plagiotaenia (Fig. 4.88)

Oblong, heterosulcoid and ostial opening the dorsal area gently curving into posterior end of otolith, whereas ventral area very straight. Rostrum rather large, slight curved downwards. Antirostrum round and small. Ostium elongated, narrow at anterior end. Cauda rather deep, narrow and slightly curved at cauda tip. Dorsal depression very shallow located above the anterior of cauda.

Megalaspis cordyla (Fig. 4.89)

Oblong, heterosulcoid and ostial opening Rostrum large, triangular-shaped, while antirostrum is notched, pointing upward. Ostium oblong and extended into the anterior of cauda. The beginning of cauda is very shallow and rather deep and broad at cauda tip. Dorsal depression expanded into anterior and opening at the antirostrum.

Decapterus macarellus (Fig. 4.90)

Oval shape, heterosulcoid and ostial opening. Ventral area at medioventral rather deep and gently inclined into postventral and preventral.

Rostrum is strongly triangular, rather large, while antirostrum large. Ostium very oval shaped, extending into the anterior of cauda. Cauda initially straight and strongly flexed at the cauda tip. Dorsal depression is very shallow, not defined.

Selaroides leptolepis (Fig. 4.91)

Oval, heterosulcoid and ostio-caudal opening. Ventral area reduced, due to broadening of the rostrum. Rostrum extremely large, very high, anterior end round. Antirostrum extremely large. Ostium narrow, elongate. Cauda initial straight, broad at cauda tip before opening at postventral margin. Dorsal depression broad at anterior cauda and gently expands above the posterior cauda to cauda tip.

Alepes malam (Fig. 4.92)

Oblong, heterosulcoid and ostial opening. Rostrum triangular-shaped, rather large, while antirostrum minute. Ostium very narrow and long. Cauda very narrow, shallow and broad at cauda tip. Excisura extremely wide and shallow. Dorsal depression oblong, shallow and narrow located above the anterior of cauda.

Caranx ignobillis (Fig. 4.93)

Oval, homosulcoid and ostial opening Rostrum extremely large, oval shape and upper line has two large spines. Antirostrum is notched, projected upwards. Ostium oblong, smooth and slight downwards. Cauda broad and gently curving into postventral area. Collum is a solid bridge.

Carangoides gymnostethoides (Fig. 4.94)

Oval, homosulcoid and ostial-caudal opening. Rostrum extremely large and connected with the antirostrum. Antirostrum small, triangular-

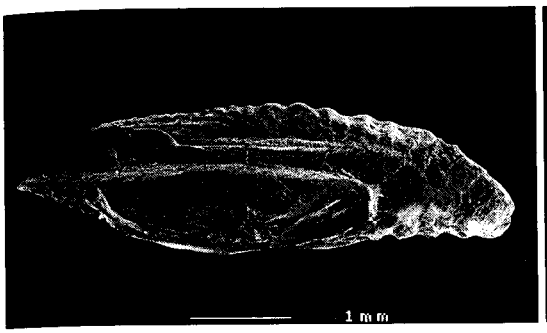


Figure 4.85 Order: Perciformes

Family: Carangidae

Species: *Alepes kleinii*

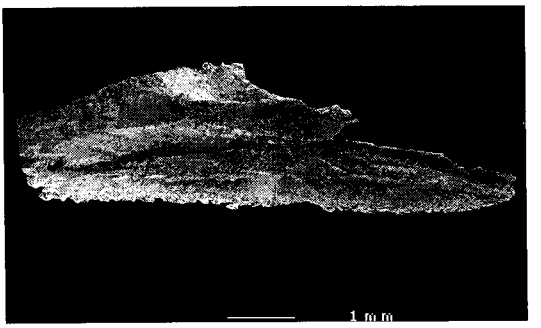


Figure 4.86 Order: Perciformes

Family: Carangidae

Species: *Scomberoides tol*

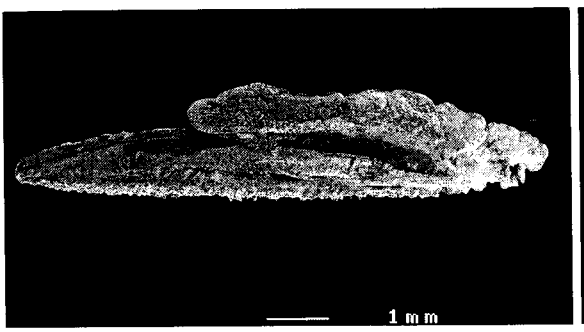


Figure 4.87 Order: Perciformes

Family: Carangidae

Species: *Scomberoides commersonnianus*

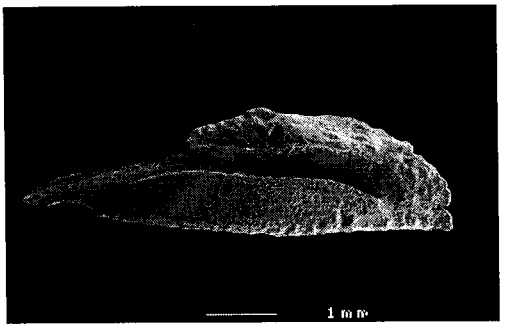


Figure 4.88 Order: Perciformes

Family: Carangidae

Species: *Carangoides plagiotaenia*

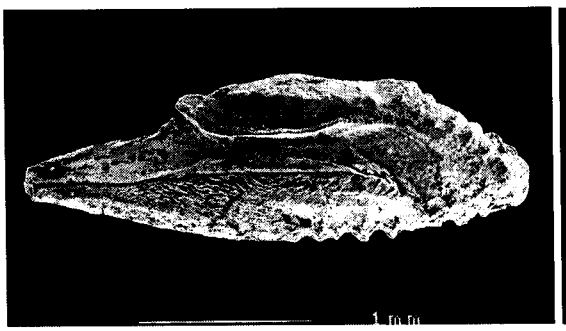


Figure 4.89 Order: Perciformes

Family: Carangidae

Species: *Megalaspis cordyla*

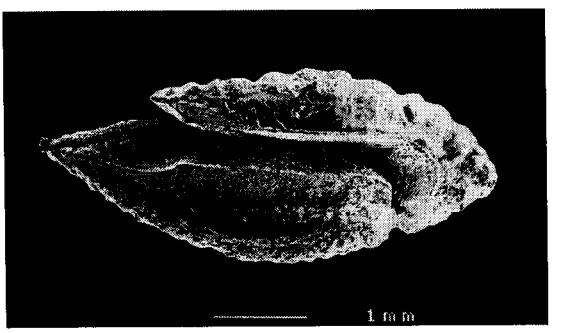


Figure 4.90 Order: Perciformes

Family: Carangidae

Species: *Decapterus macarellus*

shaped. Ostium oblong broad extending upwards and downwards. Cauda short, broad and gently curved and open at postventral margin. Dorsal depression small, shallow, oval, located above the collum. Collum is a solid bridge.

Decapterus macrosoma (Fig. 4.95)

Oblong, heterosulcoid and ostio-caudal opening. Rostrum rather large, triangular, whereas antirostrum medium and round. Ostium oblong, gently broad downwards and inclined upwards. Cauda rather long, wide, shallow at initial but deep at the cauda tip.

Selar boops (Fig. 4.96 and Fig. 4.97)

Oval, heterosulcoid and ostio-caudal opening. Rostrum very large, rectangular, high but short and upwards. Medioventral deep and gently inclined upward into both the anterior and the posterior. Antirostrum rather large to small, similar spine. Ostium oval and large broad extending downward, approximately rectangular. Cauda wide, shallow at anterior and broad, gently curving and open at postventral margin. Pseudo-excisura narrow and shallow. Dorsal depression extremely narrow and shallow, located along the cauda.

Family: Menidae

The shape is bone shaped with homosulcoid and ostio-caudal opening. Crista superior is ridge-like and crista inferior well-developed. Dorsal depression is narrow and curved, located in the upper part of the anterior cauda. Ostium is smaller than cauda and cauda broad dorsally and ventrally before open at posterior margin.

Mene maculata (Fig. 4.98)

Shape is similar to a bone with homosulcoid and ostio-

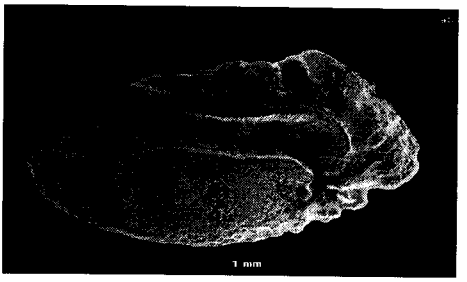


Figure 4.91 Order: Perciformes
Family: Carangidae
Species: *Selaroides leptolepis*

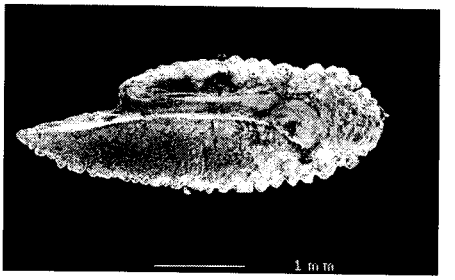


Figure 4.92 Order: Perciformes
Family: Carangidae
Species: *Alepes malam*

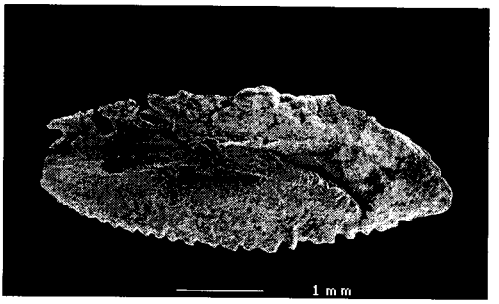


Figure 4.93 Order: Perciformes
Family: Carangidae
Species: *Caranx ignobillis*

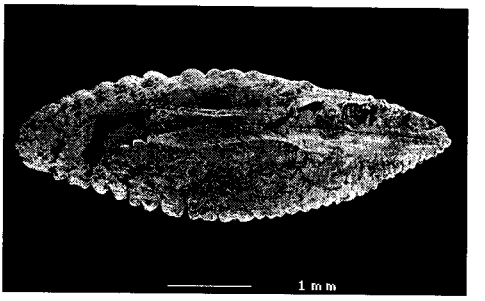


Figure 4.94 Order: Perciformes
Family: Carangidae
Species: *Carangoides gymnostethoides*

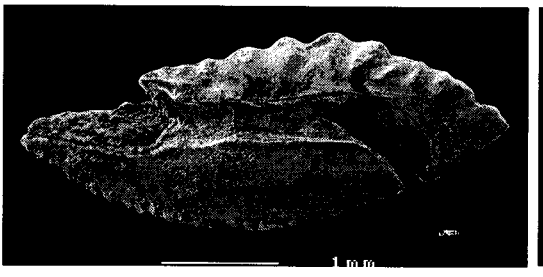


Figure 4.95 Order: Perciformes
Family: Carangidae
Species: *Decapterus macrosoma*

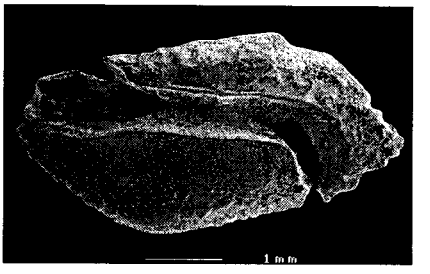


Figure 4.96 Order: Perciformes
Family: Carangidae
Species: *Selar boops*

caudal opening. The shape and character of this species are extremely singular. The posterior portion is expanded whereas the anterior portion is small and elongate. Ostium is narrow where it connects with the cauda and gently expanded dorsally and ventrally. Cauda is short, gently curving dorsally and open at posterior margin. Dorsal depression is basined, set up between upper ostium and cauda. Ventral depression is small and the ventral margin is opened under posterior cauda. Rostrum is small and antirostrum is notched.

Family: Gerreidae

The shape is oval with heterosulcoid and ostial opening. Crista superior is ridge-like and crista inferior well-developed. Dorsal depression is very deep and narrow.

Gerres oyena (Fig. 4.99)

The shape is oval and the dorsal area gently curving preventrally and postventrally. Dorsal depression is very deep, narrow and expanded along the ostium and anterior of cauda. Ostium is oval, expanded ventrally.

Gerres sp. (Fig. 4.100)

The shape is oval and the anterior portion is sharp, while the posterior portion is gently curving ventrally. Ostium is oblong and cauda initially is straight and curves at posterior area.

Gerres filamentosus (Fig. 4.101)

The shape is extremely oval. The anterior portion and posterior portion are similar. Dorsal margin is indented at medial area. Margin sculpturing ventrally is dentate, larger. Rostrum is large and wide, while antirostrum

is absent. Dorsal depression is located on the upper part of anterior cauda, narrow and oblong. The cauda is long, flexed at the posterior.

Gerres argyreus (Fig. 4.102)

The shape is approximately circular, anterior portion is narrower than posterior portion. Margin sculpturing is irregular. Ostium is oval, cauda is wide, shallow along the ostium and anterior to medial of cauda.

Gerres decacanthus (Fig. 4.103)

The shape is oval with ostial-caudal opening, the anterior portion is small and extended, while the posterior pertion is deeply grooved and narrow. Ostium is oblong, expanded ventrally. Cauda expanded dorsally. Tip of cauda flexed and narrow.

Family: Leiognahidae

The shape is oval, with heterosulcoid and ostial-caudal opening. Rostrum and antirortrum are very large, oblong or oral. Margin sculpturing is regular or dentate. Ostium extended into the anterior cauda and cauda broad dorsally at cauda tip. Dorsal depression is basined, located in the upper part of the anterior cauda and expanded predorsally.

Leiognathus equulus (Fig. 4.104)

Shape is oblong with ostial-cauda opening. Ventral and dorsal sculpturing are dentate. Dorsal depression is basined, expanded into the anterior portion upper ostium. Ostium extended into cauda area, triangular.

Leiognathus splendens (Fig. 4.105)

Shape is oval, posterior portion is round. Both ventral and dorsal sculpturing are regular or lobed for anterior of dorsal margin. Ostium is

Figure 4.97 Order: Perciformes
Family: Carangidae
Species: *Selar boops*

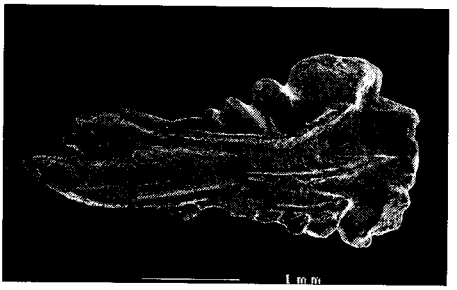


Figure 4.98 Order: Perciformes
Family: Menidae
Species: *Mene maculata*

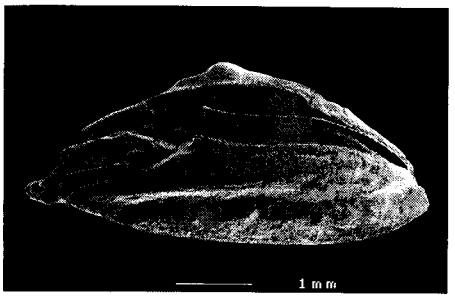


Figure 4.99 Order: Perciformes
Family: Gerreidae
Species: *Gerres oyena*

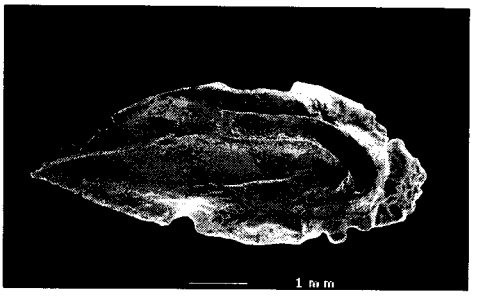


Figure 4.100 Order: Perciformes
Family: Gerreidae
Species: *Gerres* sp.

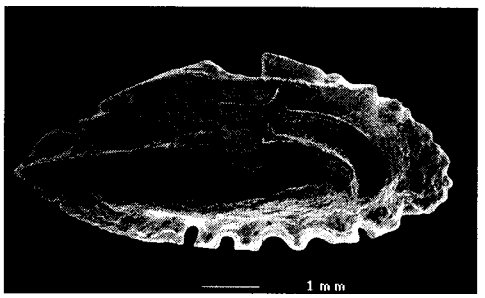


Figure 4.101 Order: Perciformes
Family: Gerreidae
Species: *Gerres filamentosus*

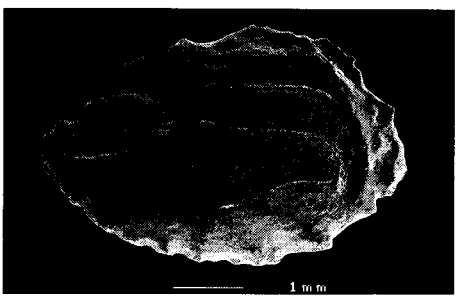


Figure 4.102 Order: Perciformes
Family: Gerreidae
Species: *Gerres argyreus*

oblong and expanded at medial portion, extending into the anterior cauda. The cauda is defined, narrow, shallow and broad at end tip.

Leiognathus sp.1 (Fig. 4.106)

The shape is oval, dorsal margin is regular but ventral margin is dentate. Dorsal depression is large, basined, expanded dorsally and broad at posterior end. Rostrum and antirostrum are large with deeper and wide excisura.

Leiognathus sp.2 (Fig. 4.107)

Shape is approximately rectangular. The posterior portion is straight. Dorsal margin is lobed but ventral margin is dentate. Ostium is oblong and expanded at posterior. Dorsal depression is shallow and not clearly defined. Cauda is short and opened ventrally.

Leiognathus stercorarius (Fig. 4.108)

Shape is approximately ovate. Predorsally sloped from medial dorsal area. Posterior both dorsally and ventrally gently curving to posterior end. Ventral sculpturing is sinuate along ventral margin. Crisura is extremely wide and moderately deep. Rostrum is short, square-shaped and gently curving dorsally. Ostium is triangular, expanded broad at anterior portion. Posterior portion of cauda broad and gently curving and recurving anteriorly and opened ventrally.

Leiognathus sp.3 (Fig. 4.109)

Shape is approximately rectangular with large rostrum and antirostrum. Dorsal depression is basined, set up on the anterior cauda. Ventral sculpturing is serrate, while dorsal sculpturing is irregular.

Leiognathus sp.4 (Fig. 4.110)

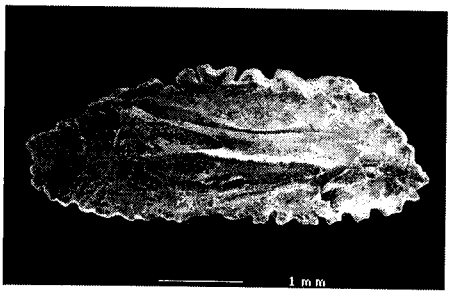


Figure 4.103 Order: Perciformes
Family: Gerreidae
Species: *Gerres decacanthus*

Figure 4.104 Order: Perciformes
Family: Leiognathidae
Species: *Leiognathus equulus*

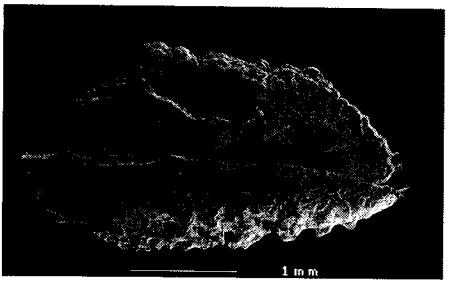
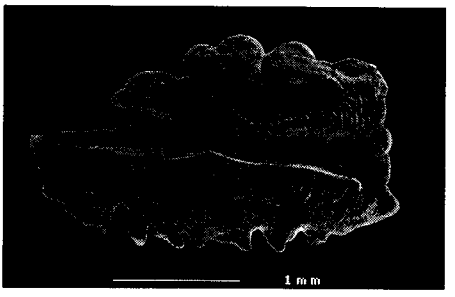


Figure 4.105 Order: Perciformes
Family: Leiognathidae
Species: *Leiognathus splendens*

Figure 4.106 Order: Perciformes
Family: Leiognathidae
Species: *Leiognathus* sp.1



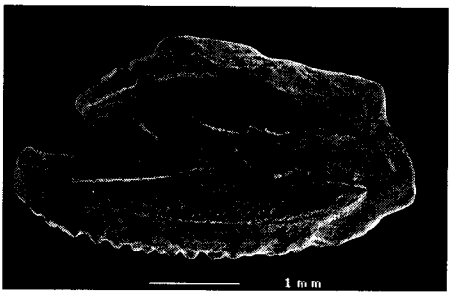


Figure 4.107 Order: Perciformes
Family: Leiognathidae
Species: *Leiognathus* sp.2

Figure 4.108 Order: Perciformes
Family: Leiognathidae
Species: *Leiognathus stercorarius*

Shape is approximately ovate. Postdorsally there is a spine and lower part of this spine is gently curving ventrally and indented at postventral area. Ventral margin is gently curving into dorsal section at medial area and it is dentate. Cauda is very shallow, straight and broad at cauda tip, while ostium is oblong. Antirostrum is large and round, rostrum is very large, wide.

Family: Lutjanidae

Shape generally is oblong and oval with heterosulcoid and ostial opening. Margin sculpturing commonly is irregular and in some species is dentate. Sulcus acusticus, ostium is mainly rectangular but in some species is oval or oblong. Cauda initially is straight and gently curving ventrally. Dorsal depression is shallow and oblong along the cauda. Rostrum is short and wide, while antirostrum is minute. Ventral depression absents.

Lutjanus vitta (Fig. 4.111)

Shape is oblong, the postdorsal margin is small, indented. Predorsally there is a long groove. Ostium is reetangular, gently curving ventrally. Cauda is defined deep and gently flexed ventrally to margin.

Lujanus quinquelineatus (Fig. 4.112)

Shape is oval, ventral margin is gently curving into the postdorsal area. Dorsal depression is not defined and very shallow. Ostium is rectangular and large. Excisura is absent, narrow and shallow.

Pristipomiodes multiden (Fig. 4.113)

Shape is oval with the domed shape at the dorsal margin. Preventrally sloped into anterior ostium. Ostium is large oval with one pit in central area.

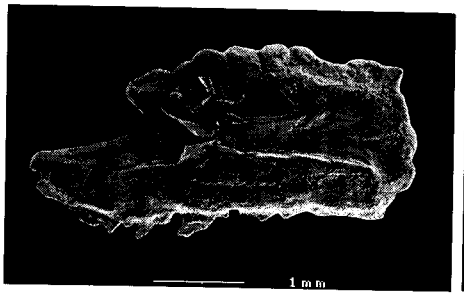


Figure 4.109 Order: Perciformes
Family: Leiognathidae
Species: *Leiognathus* sp.3

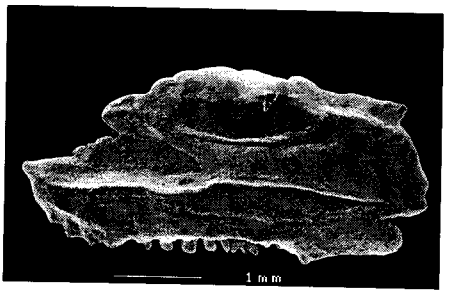


Figure 4.110 Order: Perciformes
Family: Leiognathidae
Species: *Leiognathus* sp.4

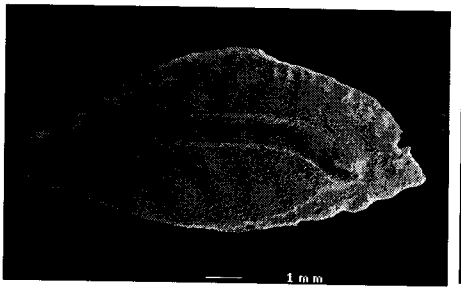


Figure 4.111 Order: Perciformes
Family: Lutjanidae
Species: *Lutjanus vitta*

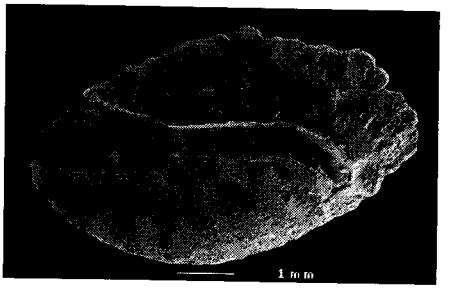


Figure 4.112 Order: Perciformes
Family: Lutjanidae
Species: *Lujanus quinquelineatus*

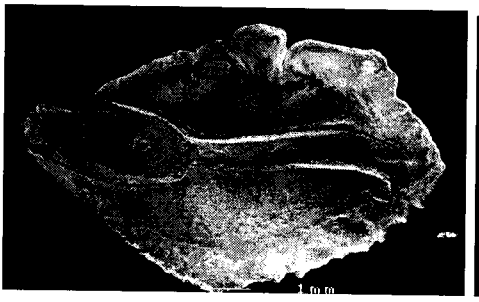


Figure 4.113 Order: Perciformes
Family: Lutjanidae
Species: *Pristipomiodes multiden*

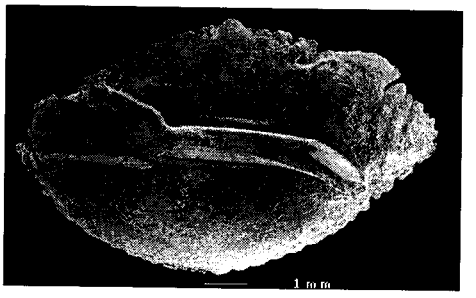


Figure 4.114 Order: Perciformes
Family: Lutjanidae
Species: *Lutjanus malabaricus*

Lutjanus malabaricus (Fig. 4.114)

Shape is oval. Ostium is very large and rectangular shape, ventrally the line of ostium is very straight, but dorsally sloped into antirostrum. Cauda is shallow, narrow and slightly flexed at cauda tip. Dorsal depression is not defined and very shallow.

Lutjanus madras (Fig. 4.115)

Shape is oblong, Margin sculpturing both predorsally and preventrally is entire. Ostium is smooth and round at anterior end. Rostrum is very large and short. Antirostrum is minute. Excisura is very wide and shallow.

Pterocaesio sp. (Fig. 4.116)

Shape is like a mango both dorsally and ventrally, gently curving posterior and anterior margin. The sulcus acusticus character of both ostium and cauda is curved. Cauda is similar to a tail, while ostium is oblong.

Lutjanus vitta (Fig. 4.117)

Shape is oblong. The dorsal and ventral area are rough. Both dorsal sculpturing and ventral sculpturing irregular. Cauda initial and gently curving postventrally.

Lutjanus lutjanus (Fig. 4.118)

Shape is oval, margin sculpturing is irregular. Ostium is large oval and gently sloping ventrally. Rostrum projection, similar to a tooth. Antirostrum is triangular. Dorsal depression shallow and set up along the anterior to medial area of caudal.

Lutjanus sp. (Fig. 4.119)

Shape is oval, ostium is rectangular and gently sloping into dorsal area. Cauda is small, shallow and slightly flexed at caudal tip. Margin

sculpturing is approximately entire. Dorsal depression is shallow and expanded along the ostium and cauda.

Lutjanus russelli (Fig. 4.120)

Shape is oblong, postdorsally sloped and gently curving portion. Ostium is long, rectangular, part that connects with cauda is gently sloping and connected to anterior cauda. Cauda is gently curving from medial to caudal tip. Dorsal depression is oblong, shallow in the upper part of the anterior and medial of cauda.

Lutjanus malabaricus (Fig. 4.121)

Shape is oval, the dorsal and ventral area are rough. Margin sculpturing is serrate. Antirostrum is ansent. Dorsal depression is rectangular in the upper anterior caudal. Ostium is rectangular and posterior portion is expanded and gently sloping, connected to cauda.

Lutjanus johnii (Fig. 4.122)

Shape is oblong, the area of predorsal, medial dorsal and postdorsal is not compact. Margin sculpturing is irregular. Ostium is larger, rectangular and it has longer groove above along ostium. Cauda is initially extremely straight and rectangular shape, gently flexed and narrow at tip. Dorsal depression set up along the ostium and anterior cauda.

Lutjanus lemniscatus (Fig. 4.123)

Shape is like a mango. Postdorsally gently curving in posterior portion. Ostium is similar to a rod, or dorsal margin gently curving pre- and post ventrally. Lower part of anterior ostium has longer groove and opened on anterior end. Rostrum very large and wide, but antirostrum minute.

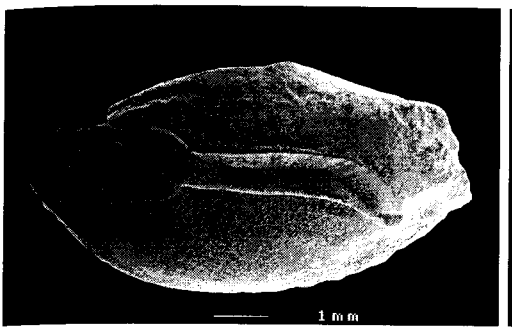


Figure 4.115 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus madras*

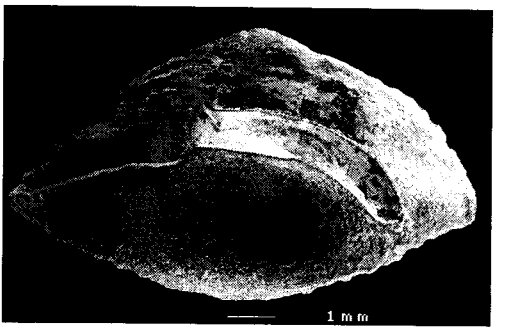


Figure 4.116 Order: Perciformes

Family: Lutjanidae

Species: *Pterocaesio* sp.

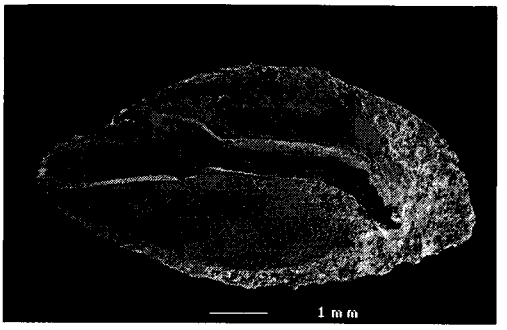


Figure 4.117 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus vitta*

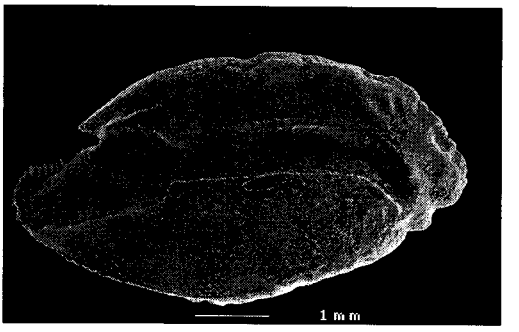


Figure 4.118 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus lutjanus*

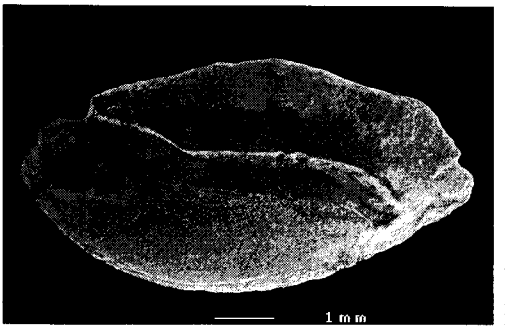


Figure 4.119 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus* sp.

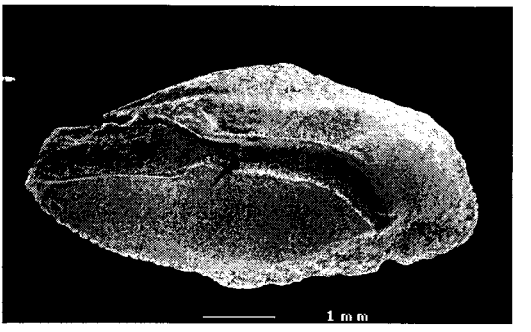


Figure 4.120 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus russelli*

Lutjanus decussatus (Fig. 4.124)

Shape is oblong, similar to Sap2. Ostium is rod-like. Cauda is wide and strongly flexed at posterior part. Dorsal depression is small, set up above the anterior cauda Antirostrum is triangular.

Lutjanus bohar (Fig. 4.125)

Shape is oval. Ostium is oblong and not defined, sloping ventrally. Cauda is deep and more strongly flexed, upper area is smooth. Dorsal depression is oblong. in the upper cauda Antirostrum minute and excisura is very small or absent.

Lutjanus lutjanus (Fig. 4.126)

Shape is oblong, the posterior part is lobed and gently sloping at posterior end. Ostium is round-oval and very large. Cauda is large, wide and gently flexed at tip. Dorsal depression is shallow and approximately rectangular in shape.

Lutjanus sebae (Fig. 4.127)

Shape is oval and large, dorsal and ventral area are smooth. Postdorsally there is one small hole. Dorsal depression is extremely shallow along the cauda. Ostium is oblong, rectangular in shape. Cauda is gently curving from anterior to posterior end, narrow and small.

Aphareus sp. (Fig. 4.128)

Shape is oval, margin sculpturing is dentate except at the ventral margin. Ostium is oblong, sloped into ventral area. Cauda initially is narrow and gently broadening at the tip.

Pristipomoides sp. (Fig. 4.129)

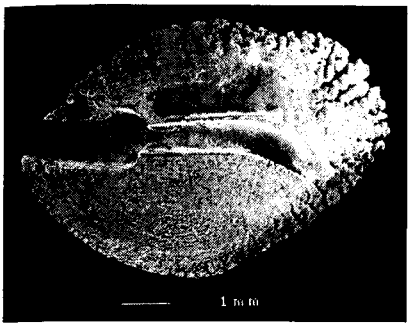


Figure 4.121 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus malabaricus*

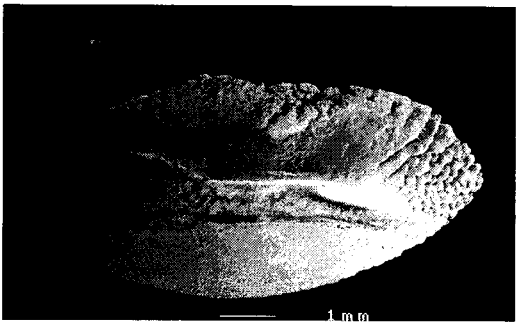


Figure 4.122 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus johnii*

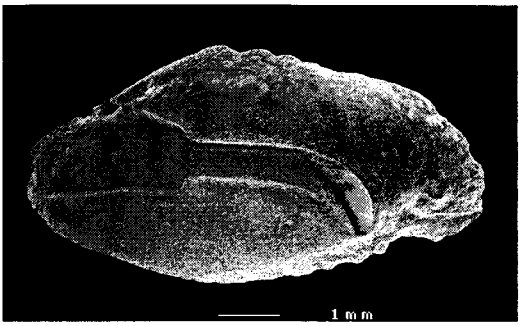


Figure 4.123 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus lemniscatus*

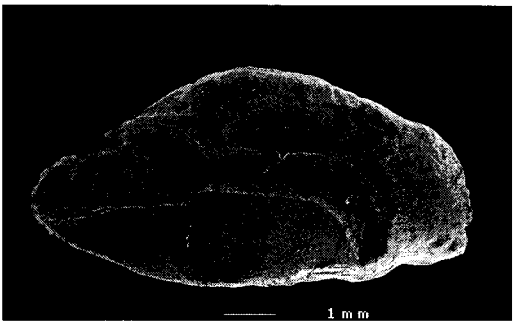


Figure 4.124 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus decussatus*

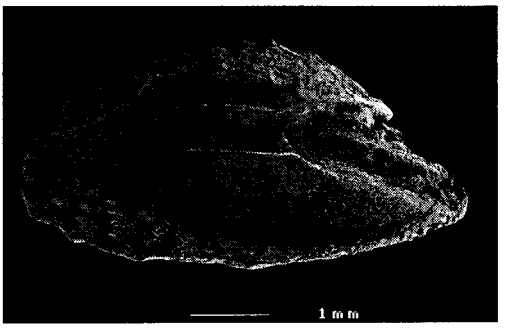


Figure 4.125 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus bohar*

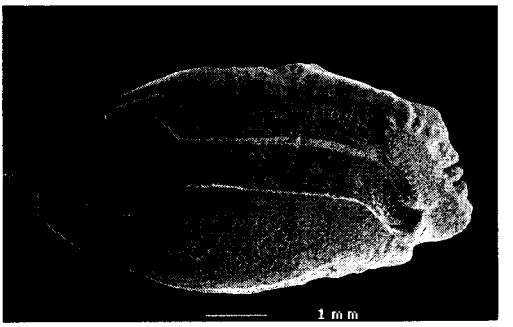


Figure 4.126 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus lutjanus*

Shape is approximately elliptic, margin sculpturing is irregular and dentate postdorsally. Ostium is oblong, gently curving and narrow at tip. Dorsal depression is defined, set up along ostium anterior cauda.

Family: Caesionidae

Character of sagittal otolith in this family is similar to family Lutjandae. Shape is oval in all species. Ostium mainly is oblong and gently curving into ventral area. Cauda initially is straight and flexed at the tip. Ventral depression is absent, while dorsal depression mainly set up above the anterior cauda. Antirostrum is minute but rostrum is large and broad.

Pterocaesio tile (Fig. 4.130)

Shape is oval with hetersulcoid and ostial opening. Ostium is triangular and it has floor at posterior end, indented. Gently sloping ventrally. The posterior part is triangular with irregular margin sculpturing. Dorsal depression is oblong and extended along both ostium and cauda.

Caesio caerulaurea (Fig. 4.131)

Shape is oval with large rostrum and antirostrum. Ostium is very large and oval, and cauda is short, broad at the flexed cauda. Dorsal depression is oblong in the upper part of the cauda and ostium. Posterior portion is small and projected. Margin sculpturing of postdorsal area is sinulate and area is irregular.

Caesio teres (Fig. 4.132)

Shape is oval with one to three holes postdorsally, while postventrally there is a single large lobe at the cauda tip. Ostium is not defined and gently sloping into ventral area. Rostrum and antirostrum are triangular. Cauda is

long and gently curving posteriorly. Dorsal depression is shallow and expanded dorsally, located in the upper anterior cauda.

Caesio cuning (Fig. 4.133)

Shape is oblong-oval. The anterior part is larger than posterior. Ostium and cauda are equal. Ostium oblong, very large, gently curving dorsally at the anterior end or it is round. Cauda is narrow and flexed at tip. Rostrum very large, while antirostrum is minute. Dorsal depression is shallow and rather wide.

Caesio xanthonota (Fig. 4.134)

Shape is similar to a mango. No antirostrum but large rostrum, and round at posterior end. Ostium is oblong and well-defined, while cauda is initially straight and strongly flexed at tip. Dorsal depression is wide and shallow in the upper anterior to medial portion.

Family: Haemulidae

Shape is oval, the posterior portion and anterior portion are gently curving. Important character of this family is the flexed, recurved cauda. Other characters: the dorsal and ventral area are very rough with irregular margin sculpturing. Dorsal depression is defined and deep. Cristae superior is ridge-like at anterior cauda and poorly developed at cauda tip.

Pomadasys kakaan (Fig. 4.135)

Sulcus: ostium rather rectangular, shallow; cauda elongate, narrow, moderately deep and gently curving at caudal tip. Posterior tips broadly rounded, anterior tips rather narrow and small. Dorsal rim rough, ventral rim deeply curved. Ventral depression absent, dorsal depression elongate, shallow and expanded above posterior ostium. Margin sculpturing.

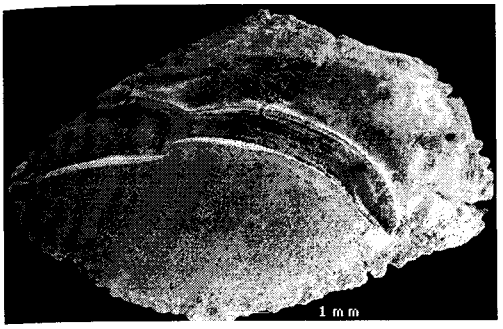


Figure 4.127 Order: Perciformes
Family: Lutjanidae
Species: *Lutjanus sebae*

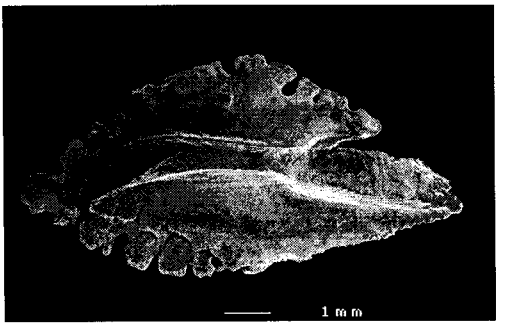


Figure 4.128 Order: Perciformes
Family: Lutjanidae
Species: *Aphareus* sp.

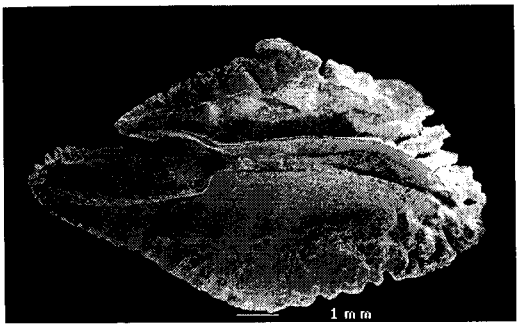


Figure 4.129 Order: Perciformes
Family: Lutjanidae
Species: *Pristipomoides* sp.

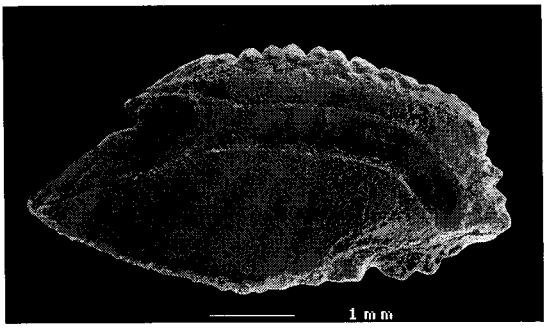


Figure 4.130 Order: Perciformes
Family: Caesionidae
Species: *Pterocaesio tile*

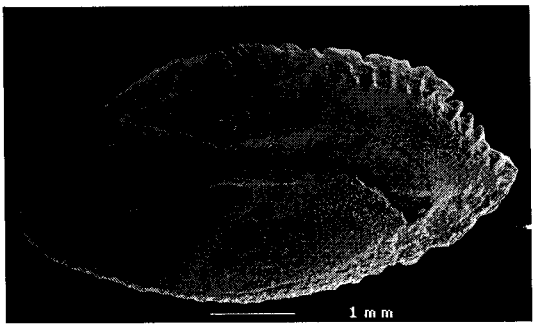


Figure 4.131 Order: Perciformes
Family: Caesionidae
Species: *Caesio caerulaurea*

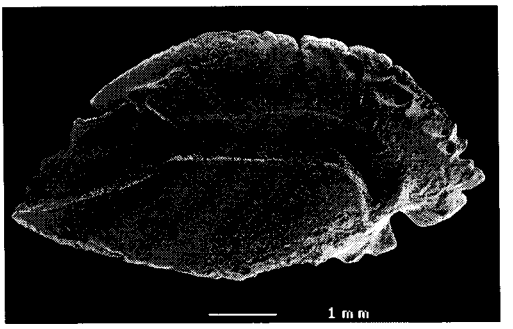


Figure 4.132 Order: Perciformes
Family: Caesionidae
Species: *Caesio teres*

Pomadasys argyreus (Fig. 4.136)

Sulcus: similar to animal sperm, ostium opened at anterior end, consisting of three circles, shallow and strongly similar to a tail. Dorsal rim and ventral rim very smooth but compressed mediodorsally. Dorsal depression not clearly defined and very shallow while ventral depression absent.

Plectorhinchus flavomaculatus (Fig. 4.137)

Oval shape, all rims rather sharp or rough. Sulcus: ostium very elongate ventrally, cauda moderately deep, narrow, steeply curving and recurved. Dorsal depression rather oval, distinct and deep above the medial of cauda. Rostrum very small and notched, antirostrum rather round. Slightly curved, sloping to both posterior and anterior end.

Diagramma pictum (Fig. 4.138)

Sulcus: ostium rather round and large, cauda initially strong, gently curved at posterior part and recurved. Dorsal depression elongate, extended above the cauda and opened at anterior and posterior end of cauda. Posterior end strongly absent but anterior end stronly rounded.

Family: Lethrinidae

Ovate in shape, the posterior smaller than anterior portion. Dorsal depression strongly elongate above the cauda and posterior part of ostium. Sulcus: heterosulcoid, ostial opening, ostium very large, wide and extended ventrally, cauda rather short, gently curving and narrow at caudal tip.

Lethrinus microdon (Fig. 4.139)

Sulcus strongly curving, ostium moderately deep, elongate, cauda rather wide, short but rather deep. Rostrum rather large, sharp.

Dorsal depression narrow, defined and oblong. Cristae superior ridge-like but cristae superior developed.

Letthrinus sp. (Fig. 4.140)

Ostium very large, strongly curving ventrally, and broad at the posterior part. Cauda gently curving, narrow at caudal tip. Rostrum very small but antirostrum very wide and large.

Lethrinus lentjan (Fig. 4.141)

Oval, heterosulcoid and ostial opening. The dorsal area near the margin is rather rough but ventral area is rather smooth. Rostrum is very short and high. Antirostrum is rather small and notched. Ostium is rough, rather deep, wide and rectangular in shape. The cauda initially is straight and gently curves narrow at posterior. Dorsal depression is shallow, broad above the anterior cauda and extends into the back of cauda tip.

Lethrinu ornatus (Fig. 4.142)

Oval, heterosulcoid and ostial opening. Rostrum short, triangular shape, but antirostrum minute. Ostium is large, slightly inclined downwards and the anterior part is narrow. Cauda is slightly curve into postventral, wide and rather deep. Dorsal depression is shallow, narrow and broad above the anterior cauda. It is slightly narrow above the posterior ostium and posterior cauda.

Family: Sparidae

Shape relatively oval. Sulcus: heterosulcoid ostial opening. Dorsal rim very rough with mediodorsal dome. Cristae superior and cristae inferior are curving. Ostium very large with very narrow groove at center of it, and anterior end expanded.

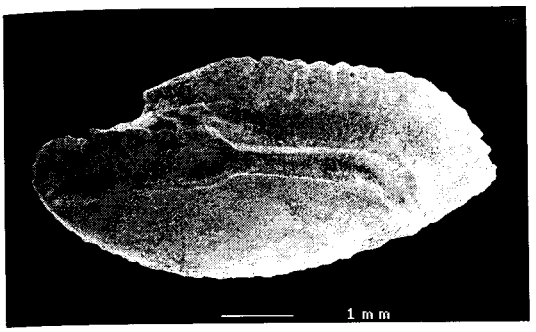


Figure 4.133 Order: Perciformes

Family: Caesionidae

Species: *Caesio cuning*

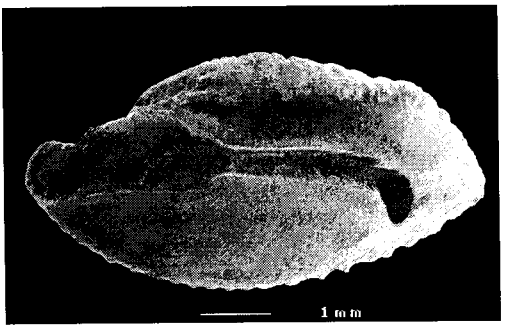


Figure 4.134 Order: Perciformes

Family: Caesionidae

Species: *Caesio xanthonota*

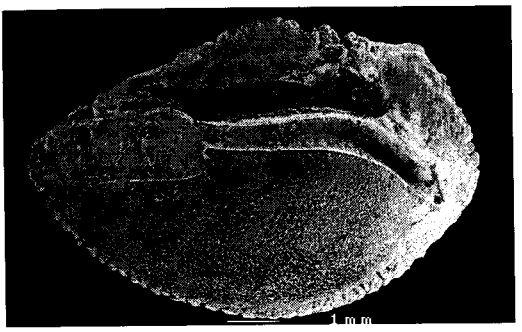


Figure 4.135 Order: Perciformes

Family: Haemulidae

Species: *Pomadasys kakaan*

Figure 4.136 Order: Perciformes

Family: Haemulidae

Species: *Pomadasys argyreus*

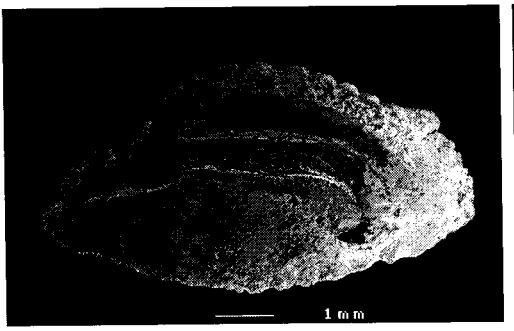


Figure 4.137 Order: Perciformes

Family: Haemulidae

Species: *Plectorhinchus flavomaculatus*

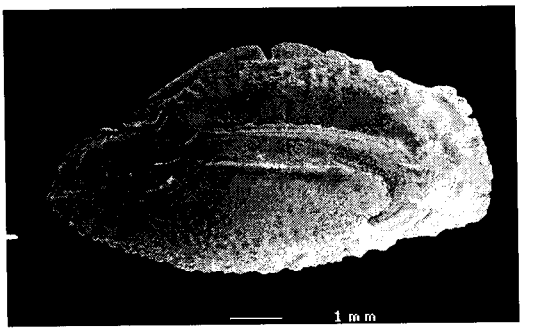


Figure 4.138 Order: Perciformes

Family: Haemulidae

Species: *Diagramma pictum*

Argyrops spinifer (Fig. 4.143)

Ostium very large, wide, expanded both on the dorsal side and ventral side, posterior end of ostium is moderately grooved.

Family: Nemipteridae

Rectangular and ovately shaped, relatively large otolith. Sulcus: heterosulcoid type and ostia opening, relatively large ostium cauda. Crista superior ridge-like along cauda.

PScolopsis monogramma (Fig. 4.144)

Rectangular, ventral area deeply and gently curving, dorsal rim straight with large notch above postdorsal margin. Ostium very large and broad ventrally. Cauda very wide, deep and steeply curving and terminating gently close to the postventral rim ot the otolith. Dorsal depression narrow and moderately deep. Crista superior strongly ridge-like along cauda and postostium. Rostrum very large.

Scolopsis taenioptera (Fig. 4.145)

Rectangular, dorsal rim very straight with grooved and spined postdorsal angle. Cauda rather long, deep with slight u-turning. Ostium rough, wide, broad dorsally. Deep dorsal depression above anterior portion of cauda. Crista superior is ridge-like at anterior portion, grooved ventral area. Antirostrum rather small and rostrum rather large.

Nemipterus tambuloide (Fig. 4.146)

Strongly ovally shaped, dorsal rim and ventrally gently curved. In particular, the dorsal rim has a small mediodorsal lobe. The posteror portion is strongly reduced, and rounded. Ostium very oval, strong inclined upwards

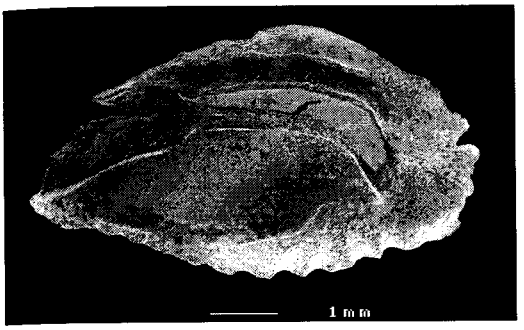


Figure 4.139 Order: Perciformes

Family: Lethrinidae

Species: *Lethrinus micodon*

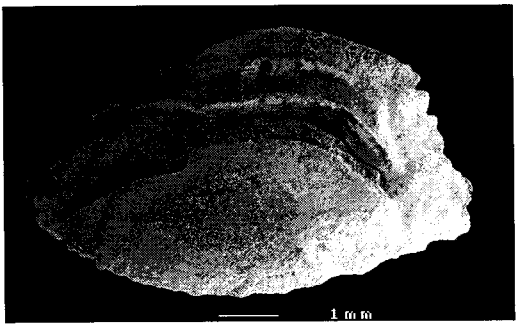


Figure 4.140 Order: Perciformes

Family: Lethrinidae

Species: *Lethrinus* sp.

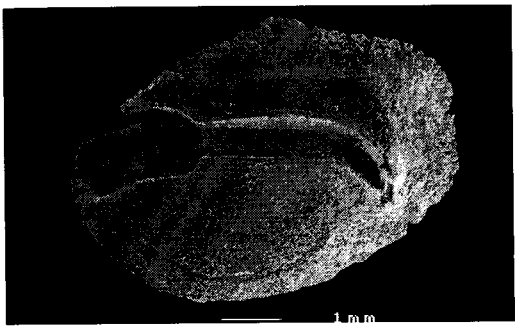


Figure 4.141 Order: Perciformes

Family: Lethrinidae

Species: *Lethrinus lentjan*

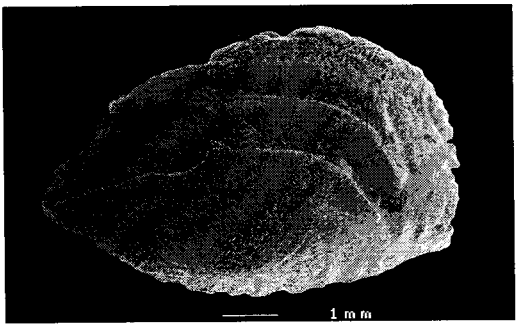


Figure 4.142 Order: Perciformes

Family: Lethrinidae

Species: *Lethrinu ornatus*

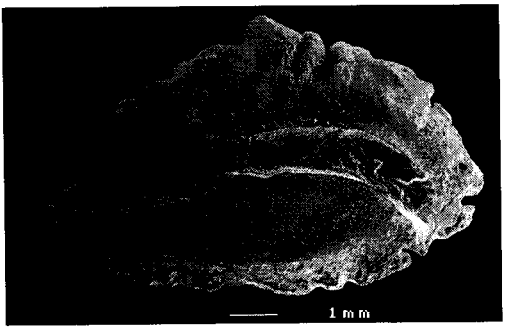


Figure 4.143 Order: Perciformes

Family: Sparidae

Species: *Argyrops spinifer*

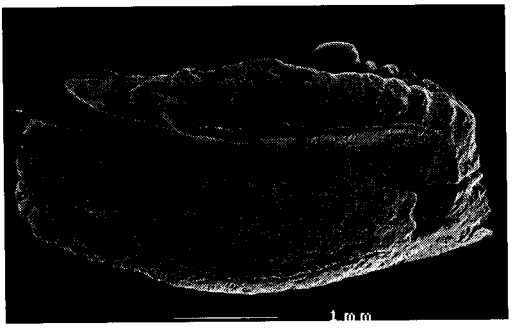


Figure 4.144 Order: Perciformes

Family: Nemipteridae

Species: *Scolopsis monogramma*

and slightly inclined downward. Cauda shallow, gently curving, terminating with somewhat shallow tip. Dorsal depression very shallow above anterior cauda of the otolith.

Scolopsis sp. (Fig. 4.147)

Strongly rectangular with notch rounded at postdorsal area. Posterior portion very straight with small lobe. Rostrum very wide but short, anterior tip regularly rounded, antirostrum moderately large. Postostial lobe very strong so that caudal joint is moved above the ostium. Ostium very large and broadly rounded dorsally and ventrally. Cauda wide, deep, steeply curving.

Family: Sciaenidae

Otoliths of the family Sciaenidae are very singular, extended, widened and thick. The cauda shows several different caudal shapes. Ostium is wide, short, much higher than long. Dorsal depression is extremely shallow and narrow, while ventral depression absent. Dorsal rim and ventral rim smooth, in particular ventral rim steeply curving. Cristae are poorly developed to developed. Rostrum and antirostrum very small, not defined.

Johnius macropterus (Fig. 4.148)

Thickset otolith, highest anteriorly. Ventral rim deeply curved anteriorly. Dorsal rim more straight with notch postdorsal angle and steeply curving in postventral portion. Ostium short, much higher than long, steeply inclined to near vertical position. Anterior portion of cauda very short, narrow, shallow and almost closing before opening into the cauda, extremely deep, funnel-shaped. Dorsal depression short and narrow, indented at mediodorsal. Anterior end steeply inclined ventrally.

Otolithes ruber (Fig. 4.149)

Compact otoliths, dorsal rim only slightly curving, without distinct pre- and postdorsal angles. Dorsal rim deep and rather regularly curving. Anterior portion broadly rounded, posterior portion rounded, but more narrow and shifted, considerably rounded under the anterior cauda. Cauda moderately narrow, shallow and terminating in buffer-shaped tip. Rostrum is extremely small. Dorsal depression very long from anterior ostium to posterior cauda.

Johnius macrorhynus (Fig. 4.150)

Ostium very short but high, dorsal portion wide and gently declined into ventral area. Anterior portion of cauda very shallow, narrow and opening into cauda funnel. Dorsal depression extremely shallow short and small. Rostrum broadly rounded anterior end. Posterior tip developed into a massive spine.

Pennahia pawak (Fig. 4.151)

Oval dorsal rim and ventral rim gently curving into anterior and posterior end. Ostium very smooth, large, broadly rounded into ventral area. Cauda gently curving ventrally before cauda.

Otolithoides pama (Fig. 4.152)

Oval, heterosulcoid and pseudo-ostiocaudal opening. The otolith of this species is much deeper at medioventral and gently inclines upward into the posterior end and anterior end of otolith. Ostium is very large, extremely shallow, smooth, heart shaped and broad downwards under the cauda. The cauda is a ridge, initially very straight and more flexed at the middle part of cauda. Dorsal depression is very narrow, shallow and rather straight, located at medial of dorsal area.

Figure 4.145 Order: Perciformes
Family: Nemipteridae
Species: *Scolopsis taenioptera*

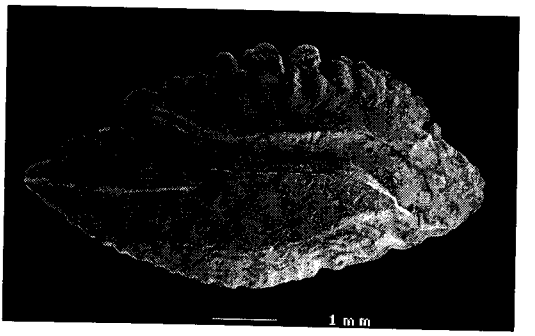


Figure 4.146 Order: Perciformes
Family: Nemipteridae
Species: *Nemipterus tambuloides*

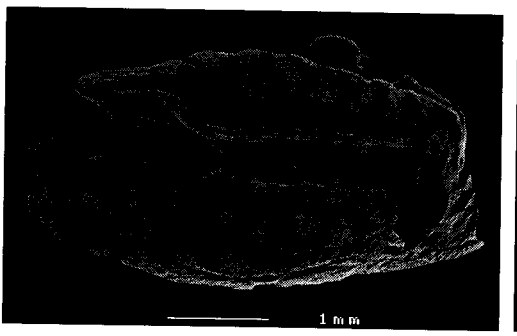


Figure 4.147 Order: Perciformes
Family: Nemipteridae
Species: *Scolopsis* sp.

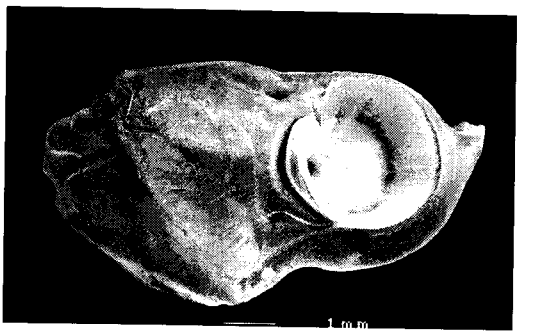


Figure 4.148 Order: Perciformes
Family: Sciaenidae
Species: *Johnius macropterus*

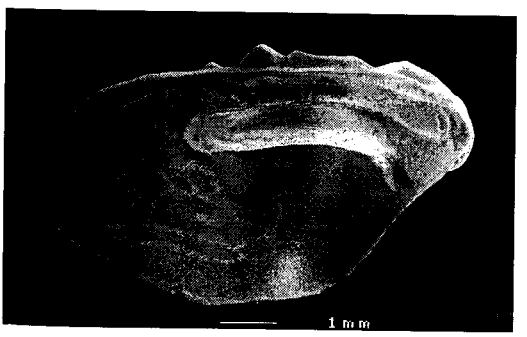


Figure 4.149 Order: Perciformes
Family: Sciaenidae
Species: Species: *Otolithes ruber*

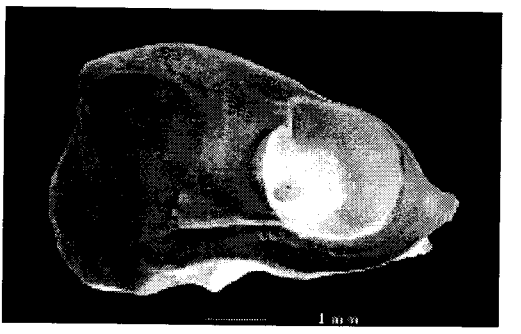


Figure 4.150 Order: Perciformes
Family: Sciaenidae
Species: *Johnius macrorhynus*

Johnius osseus (Fig. 4.153)

Ostium oval, rough at dorsal portion but smooth at ventral portion. Cauda extremely shallow, short and triangular at anterior portion before opening into cauda funnel. Rostrum very short, high and gently curving ventrally so that the anterior part of it is higher than posterior part.

Dendrophysa russelli (Fig. 4.154)

Oval, heterosulcoid and pseudo-ostiocaudal opening. The posterior part of otolith is a rather solid angle, while the anterior part is very large, deep and round. Ostium very large smooth, broad at postventral and gently narrower at the anterior part and its shape is similar to a heart. Cauda is more long and wide. The initial part of cauda is slightly curved and strongly flexed, broad from the middle of cauda to postventral of otolith. The sulcus is extremely large so the dorsal area and ventral area are more reduced. Dorsal depression is not clear, whereas ventral area is absent.

Family: Mullidae

Oval, heterosulcoid with ostial opening. Cristae superior and cristae inferior are ridge-like along the cauda. Anterior portion smaller than the posterior portion. Dorsal area and ventral area are rough with large spine. Cauda very wide, deep and broadly circular. Connecting point between ostium and cauda is not defined. Dorsal depression is grooved, defined and long. Rostrum and antirostrum rather small and triangular.

Upeneus vittatus (Fig. 4.155)

Anterior part is very small and broadly expanded onto mediodorsal and ventral and gently curving posterior end. Rostrum rather small,

round. Ostium rather small, long and shallow. Cauda wide, shallow at anterior part and opening oval at posterior end. Dorsal depression shallow, not defined.

Upeneus sulphureus (Fig. 4.156)

Rostrum small, triangular. Antirostrum absent. Ostium oval, small. Cauda slightly deep, wide and broadly oval shaped at posterior end. Dordal depression narrow and clear.

Upeneus moluceensis (Fig. 4.157)

Dorsal area is rather strongly reduced with large indentation at mediodorsal and postdorsal. The posterior end rather round, closed with posterior part of cauda. Cauda long, wide at anterior part and extremely expanded at posterior end. Ostium very small, rather deep and considerably narrowed towards anterior. Dorsal depression long, narrow above anterior part of cauda but ventral depression is absent.

Upeneus tragular (Fig. 4.158)

Rostrum very large, rather round and antirostrum triangular. Excisura extremely wide, deep. Ostium very small, narrow, inclined downwards. Cauda wide, rough, rather deep before opening, oval. Dorsal rim shows the spine. Posterior portion round.

Mulloidichthys vanicolensis (Fig. 4.159)

Ventral rim is dentate while dorsal rim is irregular. Posterior ostium very small and steeply broad sloping upwards, relatively circular. Cauda very wide, moderately deep at anterior part and broadly oval, very deep. Dorsal depression very defined above anterior cauda, narrow.

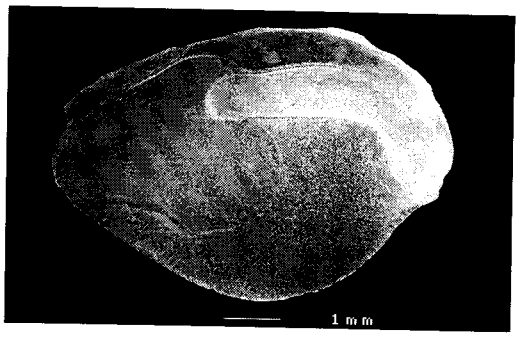


Figure 4.151 Order: Perciformes

Family: Sciaenidae

Species: *Pennahia pawak*

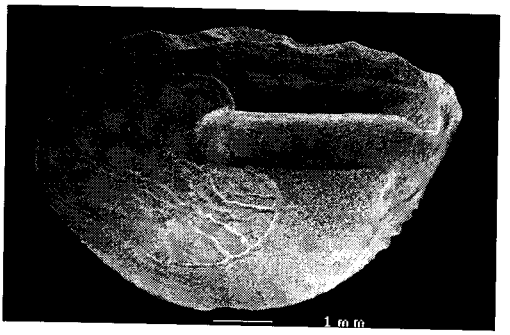


Figure 4.152 Order: Perciformes

Family: Sciaenidae

Species: *Otolithoides pama*

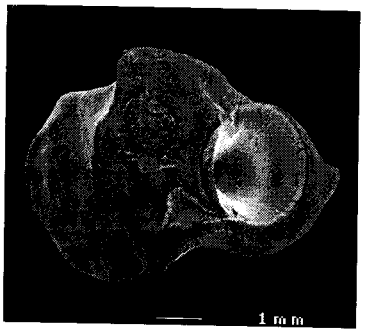


Figure 4.153 Order: Perciformes

Family: Sciaenidae

Species: *Johnius osseus*

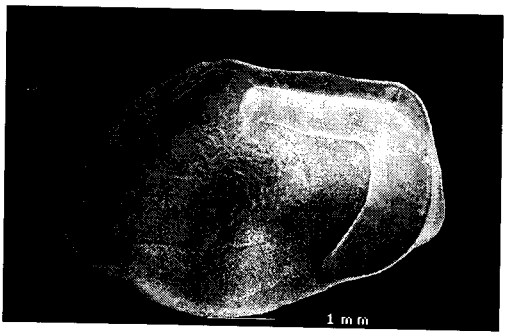


Figure 4.154 Order: Perciformes

Family: Sciaenidae

Species: *Dendrophysa russelli*

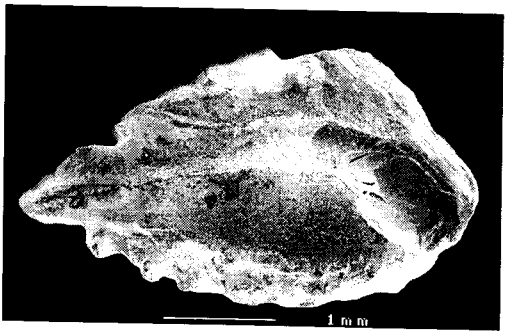


Figure 4.155 Order: Perciformes

Family: Mullidae

Species: *Upeneus vittatus*

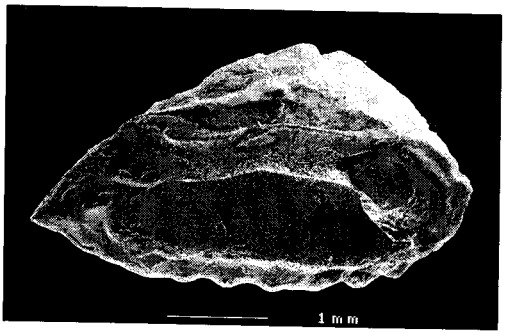


Figure 4.156 Order: Perciformes

Family: Mullidae

Species: *Upeneus sulphureus*

Parupeneus cyclostomus (Fig. 4.160)

Oval with large spine at mid-dorsal and large hole in ventral area. Ostium rather triangular, inclined downward and upward. Cauda deep, rather long and more broadly circular at posterior part, its tip extremely deep. Antirostrum relatively notched or spine-like, while rostrum projected forward and extremely small

Family: Cepolidae

Acanthocepola abbreviata (Fig. 4.161)

Rhomboidal, singular species in this family from this study, extremely smooth otolith. Posterior portion is rectangular, postventrally steeply inclined, postventral steeply inclined toward medioventral. Sulcus, homosulcoid types, ostium is larger than cauda, wide, shallow, smooth, inclined downward. Cauda small, shallow , smooth, oval. Dorsal depression very shallow above anterior cauda and posterior ostium. Rostrum triangular, small, while antirostrum minute.

Family: Pempheidae

Otolith circular, heterasulcoid ostial opening, Ventral rim steeply convex, while dorsal rim reduced and rough. Sulcus slightly deep, rather wide and rough. Ostium funnel-shaped, while cauda is similar to a tail. Dorsal depression narrow, shallow above ostium and cauda. Rostrum and antirostrum absent.

Pempheris oualensis (Fig. 4.162)

Circular, heterosulcoid types, dorsal area and ventral area rather rough. Pre- and post ventral extremely inclined to medioventral, so that its ventral is very deep and dorsal area is considerably reduced. Rostrum is round and

small, high,while antirostrum is minute. Ostium is rather rectangular, very large, inclined upwards and vertically downwards before anterior. Anterior cauda narrow, rather shallow and broadly widened at medial part before steeply curving at posterior part, terminating narrow and closed.

Pempheris vanicolensis (Fig. 4.163)

Otolith rather round, Ventral area not compact, while dorsal area rough and reduced. Dorsal depression shallow, narrow, narrow above ostium and along the cauda and closed at caudal tip. Ostium rather rough, relatively rectangular. Cauda rather smooth, steeply curving and narrow at posterior end.

Pempheris adusta (Fig. 4.164)

Circular mediodorsal rim concave and rough, steeply inclined at posterior end. Ostium broader downward and gently curving, so the anterior part of ostium wider than posterior. Wide at posterior and steeply curving at posterior end. Dorsal depression extremely shallow, narrow above posterior ostium and anterior

Family: Terapontidae

Oval, heterosulcoid type, ostial opening in ventral and dorsal area very rough, in particular above and below the cauda. Dorsal and ventral depression absent. Ostium rather long, deep and narrow with collicullum, cauda rather narrow, moderately deep and gently curving at the cauda posterior. Antirostrum very small while antirostrum absent. The postdorsal gently curving and inclined toward the posterior end.

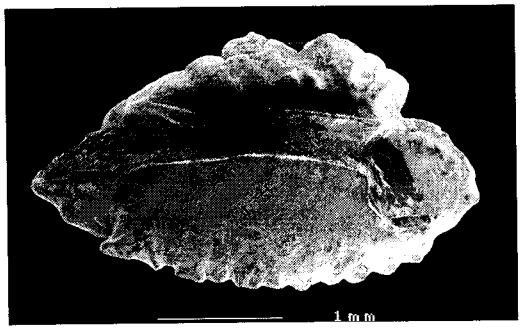


Figure 4.157 Order: Perciformes
Family: Mullidae
Species: *Upeneus moluccensis*

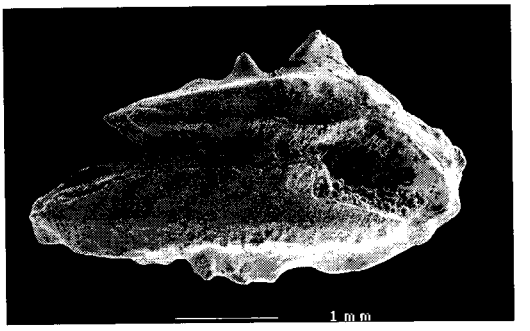


Figure 4.158 Order: Perciformes
Family: Mullidae
Species: *Upeneus tragular*

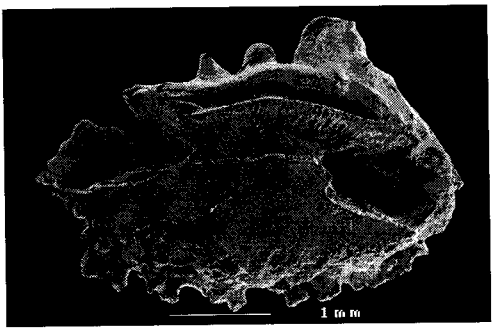


Figure 4.159 Order: Perciformes
Family: Mullidae
Species: *Mulloidichthys vanicolensis*

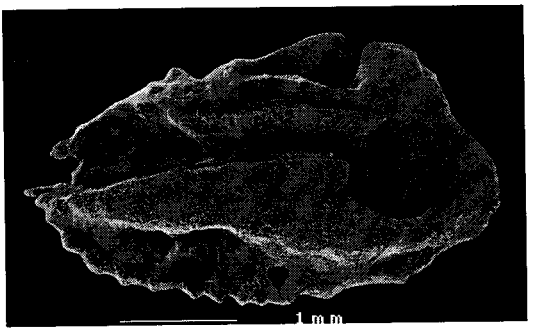


Figure 4.160 Order: Perciformes
Family: Mullidae
Species: *Parupeneus cyclostomus*

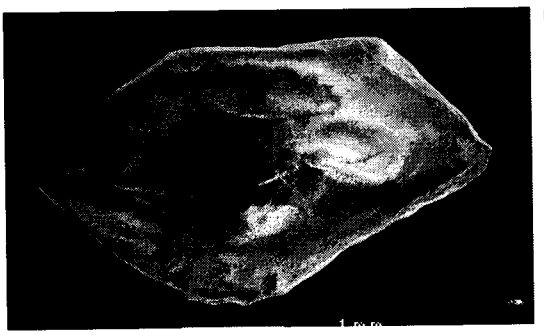


Figure 4.161 Order: Perciformes
Family: Cepolidae
Species: *Acanthocepola abbreviata*

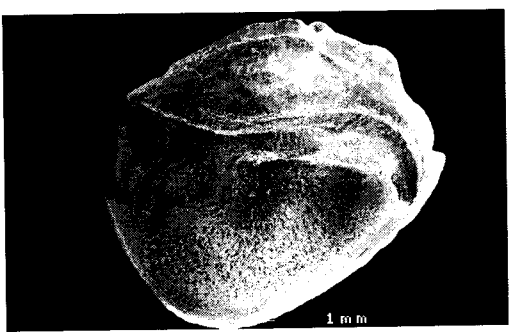


Figure 4.162 Order: Perciformes
Family: Pempheidae
Species: *Pempheris oualensis*

Terapon jarbua (Fig. 4.165)

Oval, very rough above anterior cauda. The postdorsal gently inclined and deep, narrow, relatively rectangular. Cauda narrow, moderately deep, initially straight and broadly curved, terminating in closed u-turning postventral. No antirostrum, rostrum very small and rounded.

Terapon theraps (Fig. 4.166)

Oblong, extremely rough at dorsal area and post area. Dorsal depression very small, shallow, located between ostium and cauda. Cristae superior is ridge-like at ostium and cauda anterior. Ostium extremely long with many colliculi, cauda very shallow, narrow and gently curving. Rostrum extremely long and antirostrum rather sharp.

Terapon sp.1 (Fig. 4.167)

Oval, dorsal margin and ventral margin extremely irregular. Ostium rather shallow, postostium broadly expanded upward and downward and gently inclined towards anterior end. Cauda narrow rather shallow slightly curving at anterior part and gently curving at posterior part.

Terapon sp.2 (Fig. 4.168)

Relatively oval, the postdorsal steeply inclined and gently curved at posterior end, spine shaped. Ostium rather large with many colliculi, oval, central portion of ostium shallow at anterior and gently curving and deep at posterior.

Family: Ephippidae

Oblong, homosulcoid, ostia-caudal opening. Dorsal area short, reduced. Dorsal margin rather straight and inclined posterior end. Dorsal depression

very small, shallow at anterior of cauda. Ostium and cauda are similar. Rostrum extremely large.

Ephippus orbis (Fig. 4.169)

Oval heterosulcoid type, ostial opening. Otolith area smooth, anterior portion higher than posterior portion. Ostium extremely large, smooth at posterior part and rather rough and deep at anterior. Cauda short, shallow, narrow at anterior and wide, deep at posterior. Dorsal depression extremely shallow, oval, not defined above posterior ostium and anterior cauda. Rostrum extremely high and wide, relatively rectangular, antirostrum rather small. Cristae superior and cristae inferior well developed.

Platax orbiclalis (Fig. 4.170)

Oblong, rostrum extremely large, one half of otolith is part of the rostrum, round and projected. Ostium extremely shallow, broad downward and open to anterior end and upper line of rostrum. Cauda initially small, narrow, short and steeply broadened postventrally, oval. Dorsal depression rather small, shallow above anterior cauda.

Platax teira (Fig. 4.171)

Oblong, rather rough, homosulcoid, ostio-cauda opening. The dorsal margin and ventral margin are straight and gently curving toward posterior end. Rostrum very large, rough and the anterior part shows irregular notch. Cauda narrow and shallow at anterior and steeply broadened, oval at posterior part before open postventral end. Dorsal depression very shallow, broadened towards posterior ostium.

Family: Drepenidae

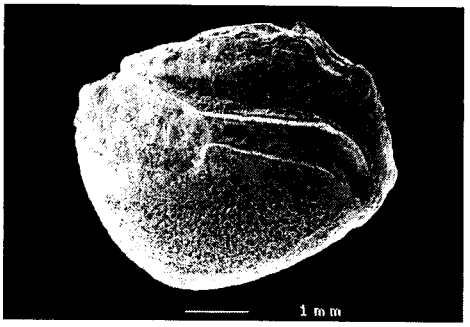


Figure 4.163 Order: Perciformes
Family: Pempheridae
Species: *Pempheris vanicolensis*

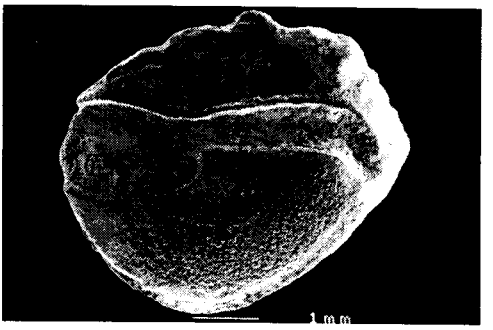


Figure 4.164 Order: Perciformes
Family: Pempheridae
Species: *Pempheris adusta*

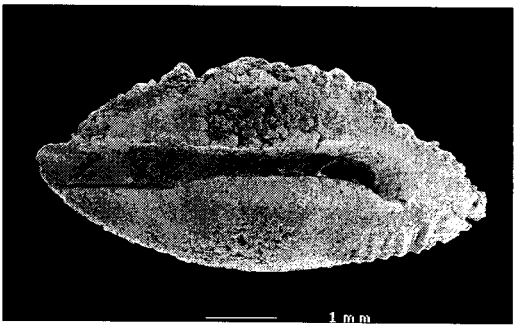


Figure 4.165 Order: Perciformes
Family: Terapontidae
Species: *Terapon jarbua*

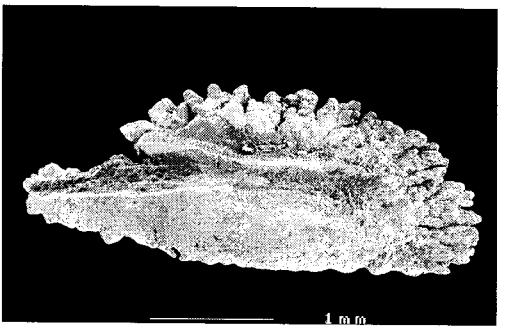


Figure 4.166 Order: Perciformes
Family: Terapontidae
Species: *Terapon theraps*

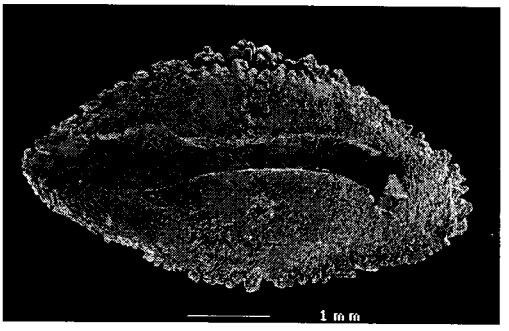


Figure 4.167 Order: Perciformes
Family: Terapontidae
Species: *Terapon* sp.1

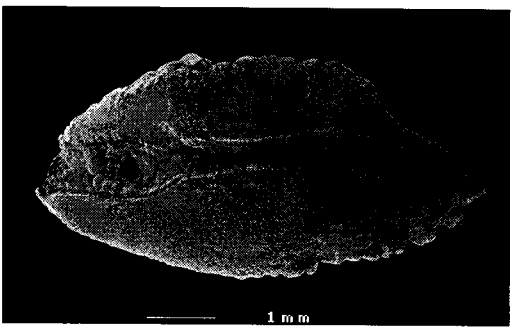


Figure 4.168 Order: Perciformes
Family: Terapontidae
Species: *Terapon* sp.2

Drepane punctata (Fig. 4.172)

Oblong, relatively smooth area, heterosulcoid, ostial opening. Margin sculpturing is irregular at ventral margin and dentate at dorsal margin. Ostium relatively rectangular, upper line of it open at excisura notch. Cauda very narrow, shallow at anterior and broadened, deep, oval at posterior. Dorsal depression extremely shallow, wide above ostium and cauda. Rostrum very large, rounded and antirostrum small.

Family: Labridae

Oval, homosulcoid, ostial opening, The anterior portion is higher than posterior portion. Dorsal margin slightly inclined to posterior portion, while ventral margin steeply curving upwards at posterior end. Collum is of solid bridge type. Cristae inferior and cristae superior are strongly ridge-like. Dorsal depression extremely narrow. Ostium and cauda are similarly shaped.

Halichoeres bicolor (Fig. 4.173)

Oval, ostial opening at medioanterior. Ostium relatively rounds, rather deep, small, similar to the cauda. Dorsal margin relatively dome-shaped and gently inclined toward anterior part and posterior part. Ventral margin rather straight. Dorsal depression extremely narrow, shallow above calliculeum, while ventral depression extended along ostium and cauda. Rostrum and antirostrum similar in size and shape.

Cymolutes praetextatus (Fig. 4.174)

Extremely oval, posterior part strongly round. The posterior portion at the ventral margin and dorsal margin is gently inclined into posterior end. Antirostrum rather small, while rostrum rather large. Ostium small,

posterior part rod-shaped. Cauda similar to ostium but upper part widened. Dorsal depression is developed mainly above ostium.

Cheilinus sp.1 (Fig. 4.175)

Oval, homosulcoid. Ostium and cauda extremely similar, triangular and rather deep. Rostrum similar to a notch, while antirostrum similar to the beak of a bird. Dorsal depression small, narrow, shallow above anterior cauda and posterior ostium. Cristae superior strongly ridge-like.

Cheilinus sp.2 (Fig. 4.176)

Orally shaped, homosulcoid, ostio-caudal opening. The posterior portion strongly rounded, while the anterior portion slightly broader than the posterior portion. Ostium and cauda very similar in shape and size, deep triangular and rough. Dorsal depression extremely straight, narrow and shallow. Antirostrum beak-shaped, while rostrum projected toward anterior end.

Hemigymnus melapterus (Fig. 4.177)

Relatively rectangular, the ventral margin very straight. The anterior part of dorsal margin is very straight and gently curving postdorsally. Ostium very rectangular, deep, steeply inclined downward in anterior area. Cauda broadly wide sloping upwards and open at postdorsal area. Cristae superior more strongly ridge-like above, along ostium and anterior cauda. Rostrum triangular, antirostrum rectangular.

Family: Scaridae

Oval, Homosulcoid type, ostio-cauda homomorph, two colliculi almost equal in size and shape. Cristae superior is more strongly ridge-like, similar buffalo-horn shaped. Dorsal depression shallow, narrow above anterior cauda

and posterior ostium. Ostium and caudal similar in shape and size and very rough.

Scarus sp.1 (Fig. 4.178)

Relatively oblong, homosulcoid type, ostio-caudal opening. Dorsal margin and vertral margin gently inclined into anterior portion and posterior positions. Ostium and cauda are similar in shape and size. Cristae superior strongly ridge-like above anterior cauda and posterior ostium. Postdorsal shows one spine. Rostrum rather large, smooth and gently sloping downwards, antirostrum relatively round, extremely smooth.

Scarus sp.2 (Fig. 4.179)

Oval, homosulcoid, ostio-caudal opening. Ostium rather large with rough colliculum and toward anterior broad. Cauda narrow at anterior part and steeply broad at posterior part and open towards posterior end. Crista superior extremely curved, similar to buffalo horn. Dorsal depression shallow, wide and broad up and down the dorsal area.

Scarus tricolor (Fig. 4.180)

Oval, homosulcoid, ostio-caudal opening. Ostium and cauda very large and broad, wide pre-and post dorsal, deep. The postdorsal has spine, rod-shaped, while predorsal is rectangular. Dorsal depression rather short, narrow shallow and open at both anterior part and posterior part. Cristae superior slightly curved and short, ridge-like. Rostrum rather small and short.

Scarus rivulatus (Fig. 4.181)

Oval, heterosulcoid and ostio-caudal opening. The posterior portion and anterior portion are similar in shape. Ostium oblong, has small groove under the anterior. Cauda oblong, rough and opens at the posterior end of

otolith. Crista superior is ridge-like, established above the posterior ostium and the anterior cauda, but it is not connected to the dorsal area. Dorsal depression is rather deep, located above the crista superior.

Scarus quoyi (Fig. 4.182)

Shape is singular in this family. The anterior portion shows large spine. Homosulcoid, ostio-caudal opening. Ostium oval, extremely rough with longer groove at upper line. Cauda relatively oblong and slightly inclined at postventral margin with large groove at upper line. Postdorsal shows notch while predorsal is round.

Scarus frenatus (Fig. 4.183)

Oval, homosulcoid, ostio-caudal opening. Rostrum very small while antirostrum absent. The postventral shows two triangular ends. The mediodorsal is relatively dome-shaped and gently inclined in the anterior portion and posterior portion. Ostium very rough, orally shaped, slightly inclined downward with large groove at anterior part. Cauda extremely rough strongly oval shaped with narrowly curving groove before opening at posterior end. Dorsal depression very shallow and not defined.

Scarus ghobban (Fig. 4.184)

Oval, homosulcoid and ostio-caudal opening. Ostium and cauda are rather rough, oval, deep and the posterior ostium and anterior cauda are narrower and triangular in shape. Crista superior is ridge-like above the posterior ostium and anterior cauda. Dorsal depression is basined, rather deep and clear at the edge.

Family: Pomacentridae

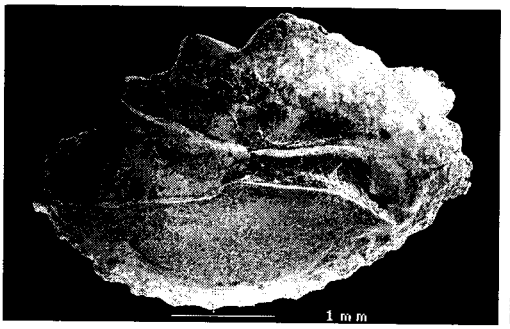


Figure 4.169 Order: Perciformes

Family: Ephippidae

Species: *Ephippus orbis*

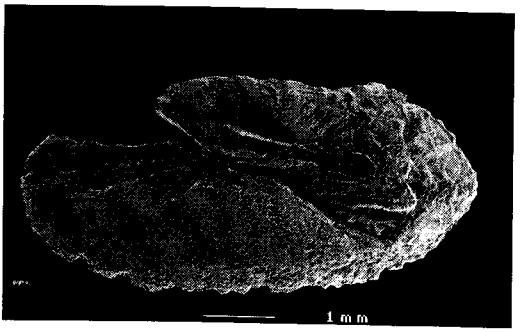


Figure 4.170 Order: Perciformes

Family: Ephippidae

Species: *Platax orbiclalis*

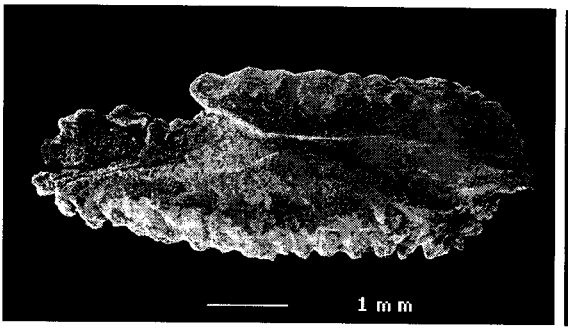


Figure 4.171 Order: Perciformes

Family: Ephippidae

Species: *Platax teira*

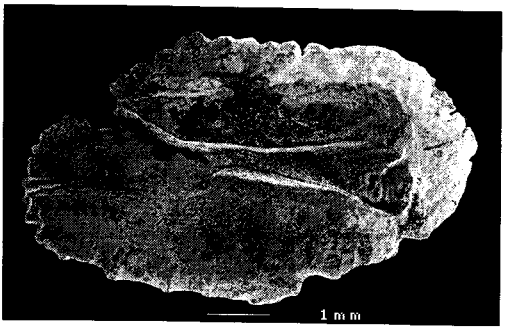


Figure 4.172 Order: Perciformes

Family: Drepenidae

Species: *Drepane punctata*

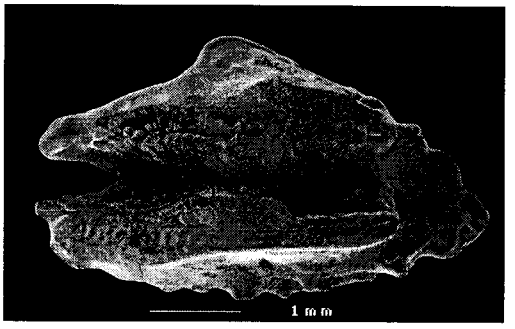


Figure 4.173 Order: Perciformes

Family: labridae

Species: *Halichoeres bicolor*

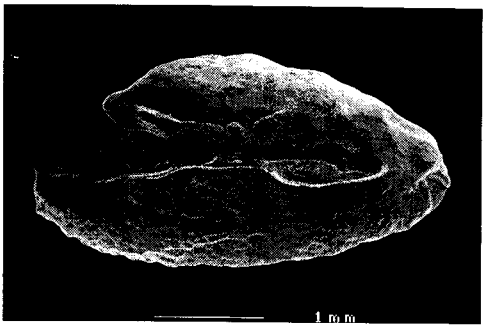


Figure 4.174 Order: Perciformes

Family: labridae

Species: *Cymolutes praetextatus*

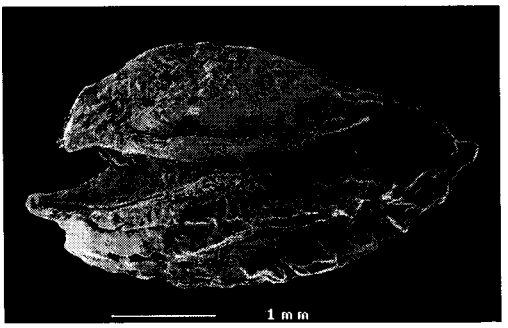


Figure 4.175 Order: Perciformes

Family: labridae

Species: *Cheilinus* sp.1

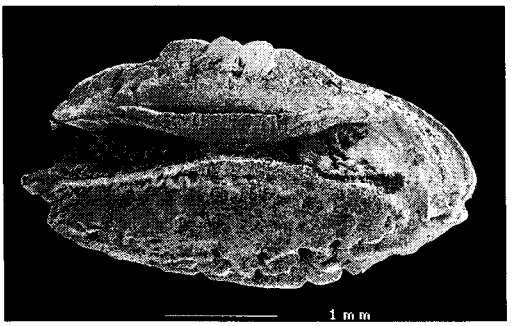


Figure 4.176 Order: Perciformes

Family: labridae

Species: *Cheilinus* sp.2

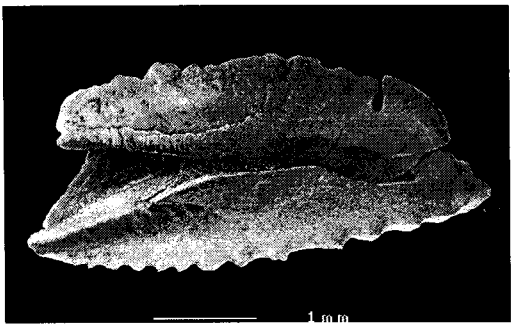


Figure 4.177 Order: Perciformes

Family: Labridae

Species: *Hemigymnus melapterus*

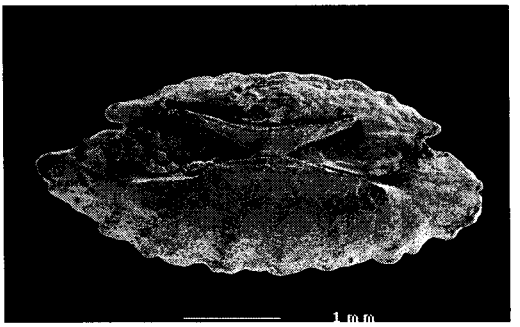


Figure 4.178 Order: Perciformes

Family: Scaridae

Species: *Scarus* sp.1

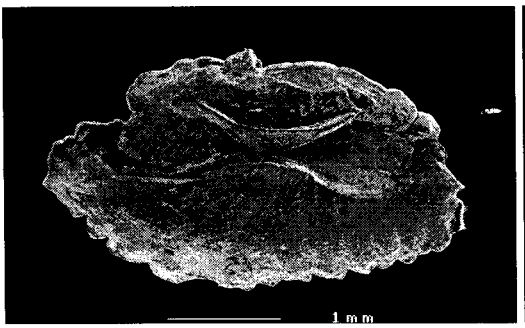


Figure 4.179 Order: Perciformes

Family: Scaridae

Species: *Scarus* sp.2

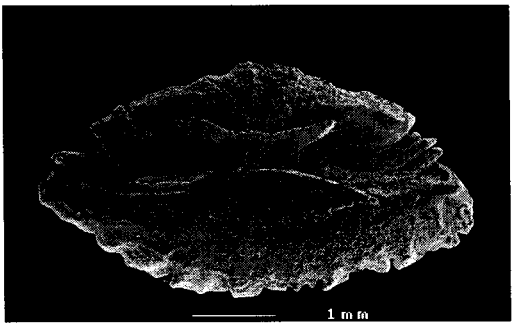


Figure 4.180 Order: Perciformes

Family: Scaridae

Species: *Scarus tricolor*

Oblong and oval in shape, heterosulcoid, ostial opening. Ostium, shorter than cauda, cauda rather shallow, gently curved posterior. Dorsal depression extremely shallow, not defined and only located above the anterior cauda. Ventral depression above cristae superior is developed and ridge-like.

Abudefduf sp.(Fig. 4.185)

Oblong, heterosulcoid, ostial opening, the anterior portion higher than the posterior end, relatively rounded. Antirostrum medial, with notch. Dorsal depression extremely shallow, narrow above anterior cauda. Ostiun slightly inclined downward, moderately large, cauda long, slightly curving at anterior part before gently curving at posterior part.

Amphirion ocellaris (Fig. 4.186)

Oval, heterosulcoid, ostial opening. The posterior smaller than the anterior. Ostium short small, moderately shallow, triangular. Cauda rather shallow, longer than ostium, initially straight and gently curving at posterior part. Rostrum rather large while antirostrum absent.

Family:Pomacantridae

Pomacanthus annularis (Fig. 4.187 and Fig. 4.188)

Oblong, heterosulcoid, ostial opening. Dorsal depression more extremely shallow, narrow and not define and expecally setup anterior part of cauda. Rostum and antirostrum absent. The anterior postion rather small, while posterior portion rather round. Ostiun oblong, extremely shallow, broad upwards and gently inclined downswards. Cauda similarly grooved, inclined postrentral.

Family: Scatophagidae

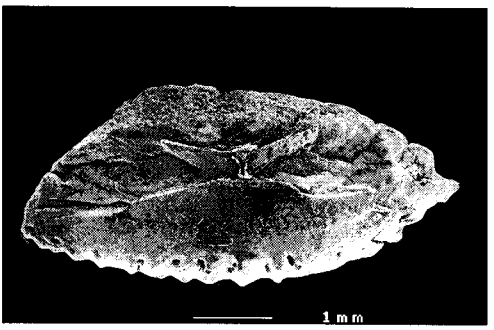


Figure 4.181 Order: Perciformes

Family: Scaridae

Species: *Scarus rivulatus*

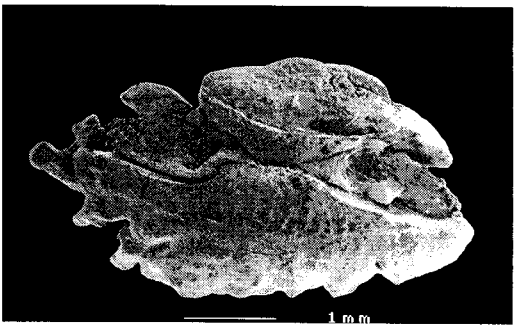


Figure 4.182 Order: Perciformes

Family: Scaridae

Species: *Scarus quoyi*

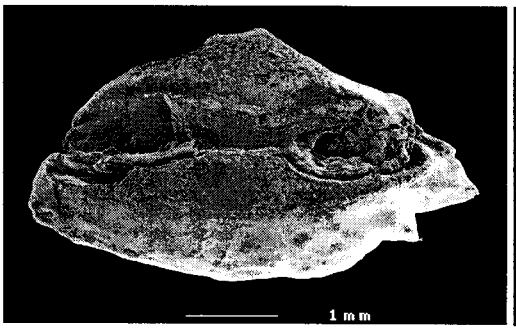


Figure 4.183 Order: Perciformes

Family: Scaridae

Species: *Scarus frenatus*

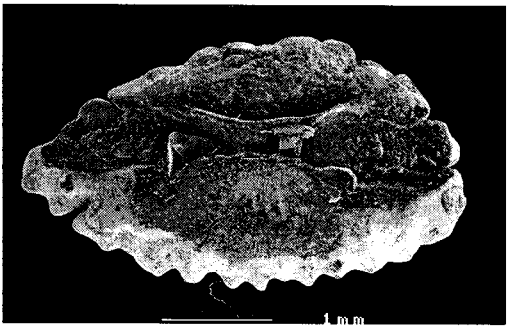


Figure 4.184 Order: Perciformes

Family: Scaridae

Species: *Scarus ghobban*

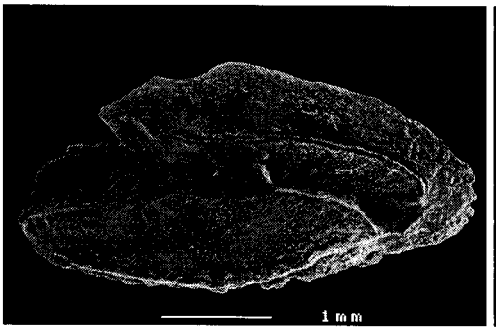


Figure 4.185 Order: Perciformes

Family: Pomacentridae

Species: *Abudefduf* sp.

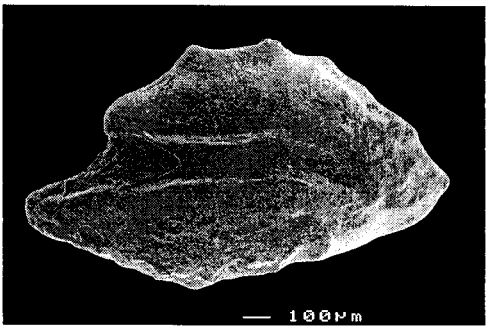


Figure 4.186 Order: Perciformes

Family: Pomacentridae

Species: *Amphirion ocellaris*

Scatophagus argus (Fig. 4.189)

Oval, heterosulcoid, ostial opening, sulcus steeply curved downward preventrally and postventrally. Excisura extremely wide. Rostrum very large and antirostrum rather small. Posterior portion is strongly rounded. Ostium steeply inclined downward, long shape. Cauda rather wide, very shallow, gently curved from anterior to posterior end and closed at postventral, recurving.

Family: Siganidae

Relatively rectangular, heterosulcoid astial opening. Rostrum and antirostrum extremely long, projected and slightly curved. Dorsal area long and narrow. Excisura very deep. Posterior part steeply inclined to vertical. Dorsal depression rather small and narrow.

Siganus guttatus (Fig. 4.190)

Relatively rectangular, heterosulcoid ostial opening, postdorsal steeply inclined into postventral. Dorsal margin and ventral margin very straight. Rostrum extremely oblong and gently narrow at the anterior end. Antirostrum very large, projected towards one-half of the rostrum. Cristae superior strongly ridge-like above post-ostium and along cauda. Ostium extremely narrow and very long. Cauda initially straight, wide and broad at posterior part.

Siganus javus (Fig. 4.191)

Rectangular, heterosulcoid, ostial opening. Rostrum long, large, gently curving upwards. Antirostrum very large, relatively triangular. Posterior end of otolith strongly vertical. Ostium gently inclined dewnwards, very long, very narrow. Cauda rather short, wide and shallow. Dorsal depression small, and shallow.

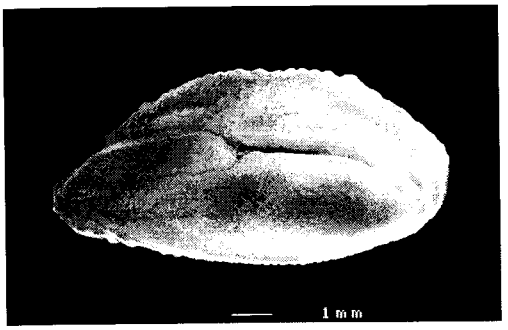


Figure 4.187 Order: Perciformes
Family: Pomacantridae
Species: *Pomacanthus annularis*

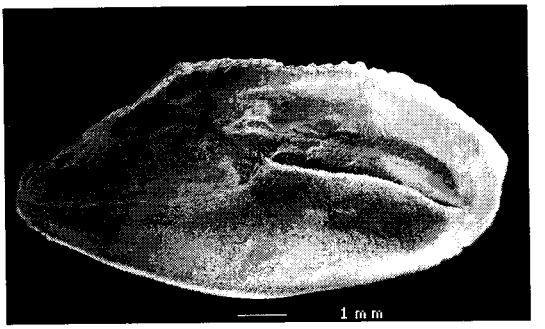


Figure 4.188 Order: Perciformes
Family: Pomacantridae
Species: *Pomacanthus annularis*

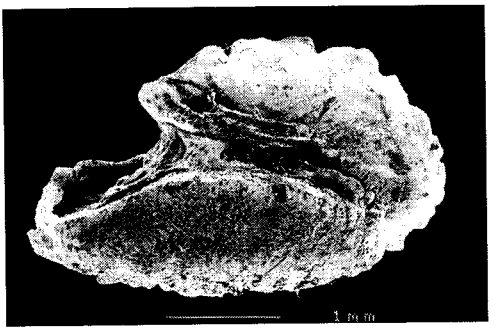


Figure 4.189 Order: Perciformes
Family: Scatophagidae
Species: *Scatophagus argus*

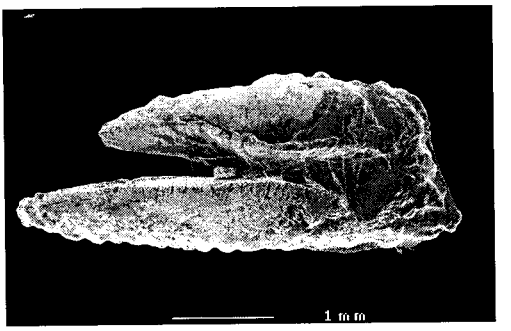


Figure 4.190 Order: Perciformes
Family: Siganidae
Species: *Siganus guttatus*

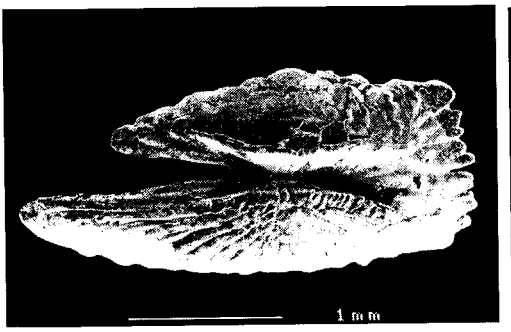


Figure 4.191 Order: Perciformes
Family: Siganidae
Species: *Siganus javus*

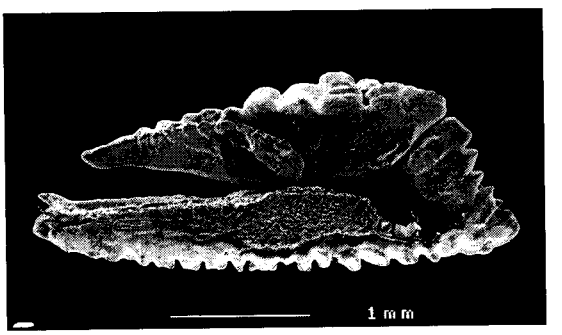


Figure 4.192 Order: Perciformes
Family: Siganidae
Species: *Siganu* sp.

Siganu sp. (Fig. 4.192)

Heterosulcoid, ostial opening. Postdorsal gently inclined into postventral end and projected. Rostrum very long, shows spine at posterior end. Antirostrum very long and projected near rostrum, triangular. Dorsal area small, reduced because of broad cauda. Cristae superior strongly ridge-like, located only at posterior ostium, vertical line. Dorsal depression very small and opening into cauda. Ostium inclined slightly downwards, extremely narrow, long. Cauda broadened postventrally, not shaped.

Family: Acanthuridae

Ovate, heterosulcoid, ostial opening. Collum absent. Posterior portion indented and gently inclined postventrally. Dorsal depression poorly developed, very shallow, not defined, while ventral depression absent. Cristae superor developed to well-developed. Ostium very shallow, wide. Cauda initially straight, short and steeply curved at postventral margin. Rostrum very short but high, while antirostrum minute.

Acanthurus nigricauda (Fig. 4.193)

Ovate, ostium rather wide with colliculi, rough and sloping broadly upwards to antirostrum. Cauda initially straight, wide, shallow and steep strongly curved at posterior end. Dorsal depression poorly developed, extremely shallow. Rostrum curved upwards, short. Antirostrum minute and rounded.

Acanthurus nigrofuscus (Fig. 4.194)

Oval, ostium oval, smooth and gently narrow at posterior, while anterior gently broadened upward and downward. Cauda very short, shallow and broadened, oval at posterior end. Dorsal depression small, very shallow

at anterior cauda. Rostrum relatively rounded, preventral margin gently curved upwards. Antirostrum minute.

Acanthurus xanthopterus (Fig. 4.195)

Ovate, relatively higher more than longer. The ventral area reduced, while dorsal area broadly widened. Rostrum relatively rectangular and rounded at posterior end. Antirostrum strongly rounded and gently curved into predorsal area. Ostium gently inclined downward and upwards anterior, shallow. Cauda narrow, shallow and gently curved at postventral margin. Dorsal depression extremely shallow.

Acanthurus sp. (Fig. 4.196)

Ovate, medioventral margin slightly inclined upward postventrally. Ostium oval, rough, shows spine at predorsal. Cauda narrow, shallow and curved at posterior end. The postdorsal rounded and gently inclined postventrally. Dorsal depression very shallow, not defined.

Family: Sacombridae

Vary in shape, ovate, oblong, and relatively fusiform. Heterosulcoid, ostio-caudal opening. Cristae inferor and cristae superior are ridge-like, rostrum long, narrow and antirostrum rather moderate. Sulcus, ostium varies in shape and size, the cauda also varies. Dorsal depression very narrow, shallow, while ventral depression appears in some species.

Rastelliger Kanagurta (Fig. 4.197)

Singular in shape in this family. The anterior portion shows strongly triangular shape of the rostrum, only projected at anterior part. Ostium rather short, narrow, shallow and above it has one depression, opened at the

predorsal. Cauda gently inclined upwards and steeply curved at posterior before opening at postventral margin. Antirostrum minute.

Thunnus albacares (Fig. 4.198)

Ovate, heterosulcoid ostio-caudal opening. Ostium strongly oval and broad downwards. Cauda rather wide, straight and open at posterior end. Cristae superior and cristae inferior ridge-like along the cauda. Dorsal depression extremely shallow. Rostrum very large but antirostrum small.

Scomber japonicus (Fig. 4.199)

Oblong shape, ostio-caudal opening, sulcus: pseudo-archaesulcoid. Ostium rather long, gently narrow at anterior end. Cauda rather wide, gently curving postventrally. Cristae superior and cristae superior more strongly ridge-like. Dorsal depression small, narrow and shallow above anterior cauda. Postdorsal and postventral gently inclined at posterior end.

Scomberomorus commersoni (Fig. 4.200)

Relatively fusiform, posterior portion relatively triangular. Ostium steeply inclined downward ventrally, small and narrow at posterior part. Cauda steeply inclined downward, basined. Rostrum long, rough antirostrum smooth, round. Dorsal depression very narrow, shallow.

Sacomberomorus guttatus (Fig. 4.201)

Oblong, pseudo-archaesulcoid. Posterior portion stoongly round. Rostrum long and gently narrow at anterior part. Antirostrum rather large. Ostium broad ventrally along the rostrum. Cauda short and wide at posterior end. Dorsal depression shallow, narrow and curved along the posterior ostium and anterior cauda.

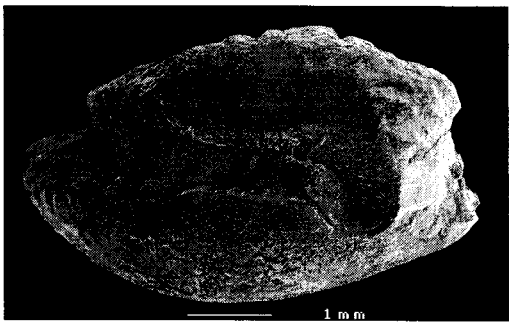


Figure 4.193 Order: Perciformes
Family: Acanthuridae
Species: *Acanthurus nigricauda*

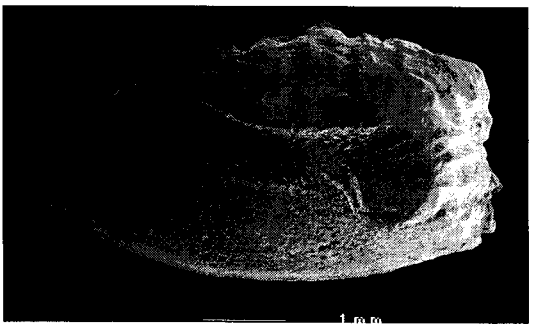


Figure 4.194 Order: Perciformes
Family: Acanthuridae
Species: *Acanthurus nigrofuscus*

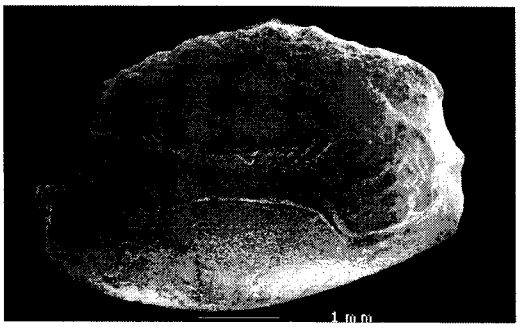


Figure 4.195 Order: Perciformes
Family: Acanthuridae
Species: *Acanthurus xanthopterus*

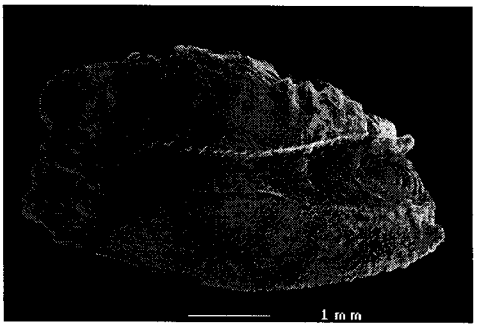


Figure 4.196 Order: Perciformes
Family: Acanthuridae
Species: *Acanthurus* sp.

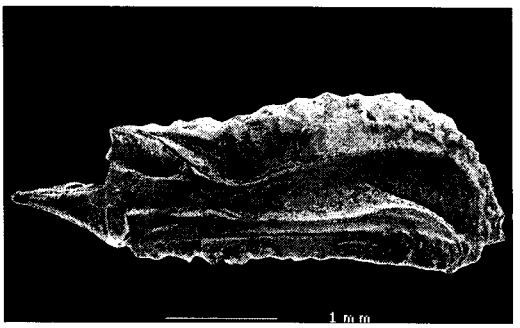


Figure 4.197 Order: Perciformes
Family: Sacombridae
Species: *Rastelliger kanagurta*

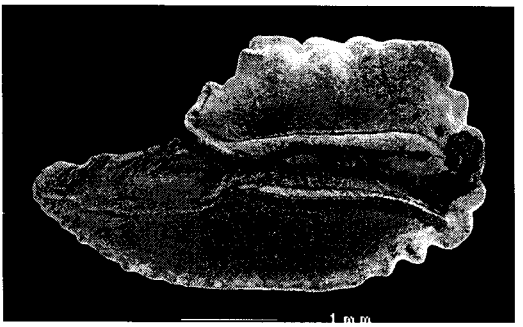


Figure 4.198 Order: Perciformes
Family: Sacombridae
Species: *Thunnus albacares*

Family: Trichiuridae

Trichiurus sp. (Fig. 4.202)

Singularly shaped, spindle-shaped. Otolith very small, pseudo-archaesulcoid, ostio-caudal. Dorsal area extremely reduced. No antirostrum, while rostrum rather short and small. Dorsal depression extremely shallow and small, not defined. Ostium very straight, short, shallow, narrow. Cauda very straight, shallow, narrow and gently narrowing at posterior part before opening at the posterior end.

Family: Polynemidae

Oblong, heterosulcoid, ostial opening. Posterior portion relatively triangular. Ototith rather rough, not compact. Sulcus narrow, rough and long. Dorsal depression extremely shallow, opening at dorsal margin. Rostrum wide, and short.

Eleutheronema tetradactylum(Fig. 4.203 and Fig 4.204)

Oblong, postdorsal steeply inclined at posterior end, while ventral margin is rather straight. Ostium oblong, relatively rectangular, projected. Cauda narrow, gently curving at posterior part and returning to postventral margin. Dorsal depression extremely shallow, not defined. Upper anterior cauda. Rostrum rectangular, large and wide, while antirostrum small.

Family: Sphyraenidae

Oblong, heterosulcoid, ostial opening. The anterior portion smaller than the posterior portion. Sulcus narrow and shallow. Dorsal depression very narrow.

Sphyraena forsteri (Fig. 4.205)

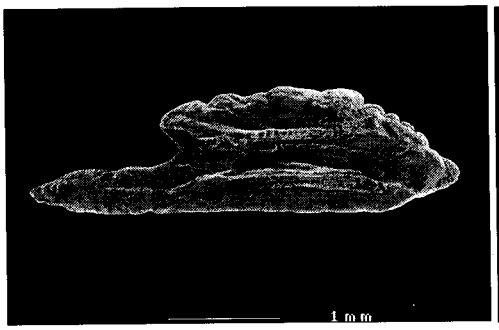


Figure 4.199 Order: Perciformes

Famil: Sacombridae

Species: *Scomber japonicus*

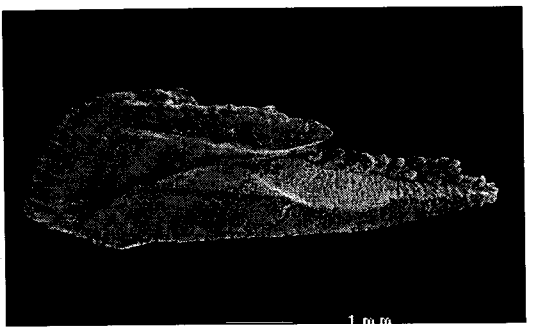


Figure 4.200 Order: Perciformes

Family: Sacombridae

Species: *Sacomberomorus commersoni*

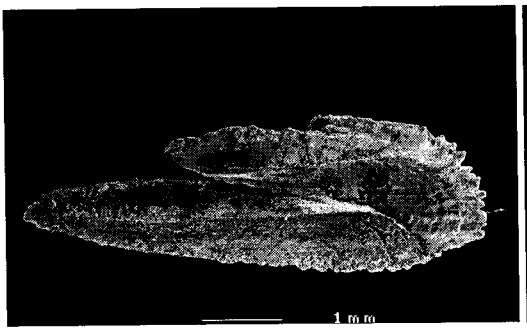


Figure 4.201 Order: Perciformes

Family: Sacombridae

Species: *Sacomberomorus guttatus*

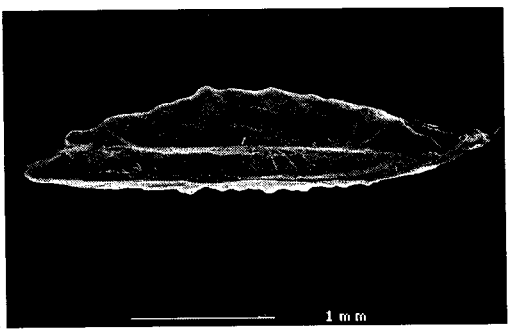


Figure 4.202 Order: Perciformes

Family: Trichiuridae

Species: *Trichiurus* sp.

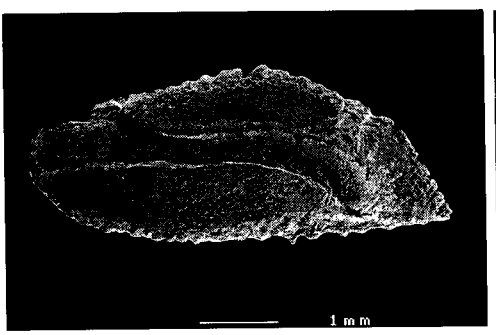


Figure 4. 203 Order: Perciformes

Family: Polynemidae

Species: *Eleutheronema tetradactylum*

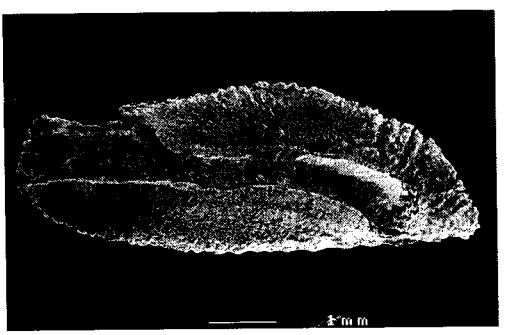


Figure 4.204 Order: Perciformes

Family: Polynemidae

Species: *Eleutheronema tetradactylum*

Otolith smooth, anterior portion small, gently inclined at anterior end. Ostium rather large, smooth, strongly oval, widened both upwards and downwards. Cauda rather wide and deep, rough, initially straight and short curve at posterior end. Dorsal depression very narrow along the cauda.

Phyraena obtusata (Fig. 4.206)

Strongly oblong, dorsal margin and ventral margin very straight and steeply inclined at postdorsal and postventral. Ostium smooth oval, narrowing at posterior part. Cauda very straight at anterior cauda, narrow, shallow and steeply curved at posterior end. Dorsal depression shallow, narrow and oblong. Rostrum and antirostrum are small.

Phyraena jello (Fig. 4.207)

Strongly oblong, smooth anterior portion and posterior portion narrow but medio-dorsally and ventrally wide. Ostium more oblong, broadened upwards, and gently narrow at posterior part. Cauda rather short, narrow, shallow and very straight along cauda, not curving. Dorsal depression more shallow, short above anterior cauda. Rostrum small and antirostrum absent.

Family: Gobidae

Vary in shape, star-, square- and relatively discoid-shaped, homosulcoid, mesial opening. Antirostrum and antirostrum absent. Margin sculpturing shows large irregular indentation/hump or spine. Dorsal depression and ventral depression absent or extremely shallow, and small. Sulcus shallow, relatively narrow, short, anteriorly and posteriorly closed. Ostium slightly shorter and wider than cauda. Otolith somewhat smooth.

Periophthalmus walailaku (Fig. 4.208)

Star-shaped, otolith very smooth with large irregular indentations in margin sculpturing. Ostium slightly widened ventrally near junction with cauda. Cauda slightly narrower than ostium and slightly curved. Dorsal and ventral depression well developed, shallow, narrow and completely fused around sulcus. Margin sculpturing shows large spine or large irregular indentrations, similar to a star fish.

Glossogobius aurcus (Fig. 4.209)

Rectangular, otolith smooth, post dorsal tip sharply pointed. The anterior portion smaller than posterior portion. Sulcus moderately long, narrow and shallow, ostium wider than cauda but shorter. Dorsal and ventral depression shallow, not completely fused around the caudal tip. Homosulcoid type.

Pseudopocryptes borneensis (Fig. 4.210)

Discoid, posterior portion wider than anterior, postdorsal round, very wide, postventrally very straight in vertical direction. Sulcus more strongly shallow, short and narrow. Ostium larger than cauda and broadened ventrally, while cauda somewhat short and narrow. Dorsal and ventral depression shallow, completely fused around the cauda and ostium tip.

Parapocryptes serperaster (Fig. 4.211)

Relatively square in shape. The anterior portion is much smaller than posterior portion, postdorsal moderately sharp and steeply inclined before vertical direction at posterior end to ventral. Sulcus very shallow, not well marked and short. Ostium wider than cauda, posterior end more sharp. Cauda short, narrow. Dorsal and ventral depression well marked, wide, shallow and completely fused around the caudal tip and ostium

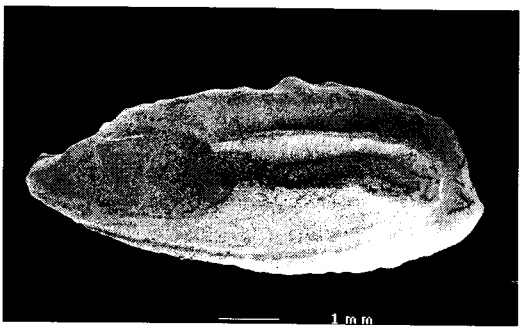


Figure 4.205 Order: Perciformes
Family: Sphyraenidae
Species: *Sphyraena forsteri*

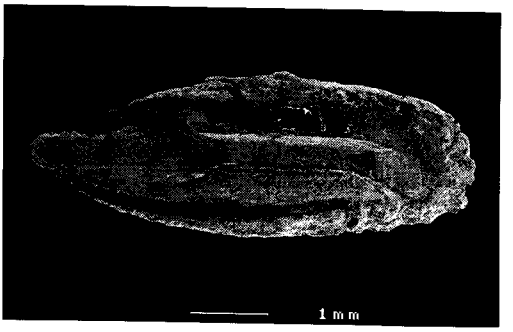


Figure 4.206 Order: Perciformes
Family: Sphyraenidae
Species: *Phyraena obtusata*

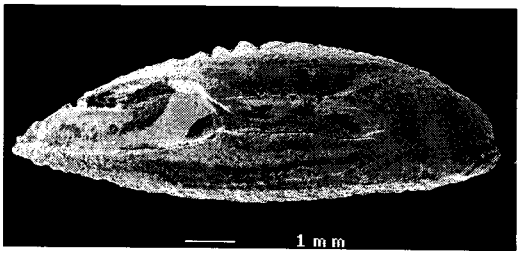


Figure 4.207 Order: Perciformes
Family: Sphyraenidae
Species: *Sphyraena jello*

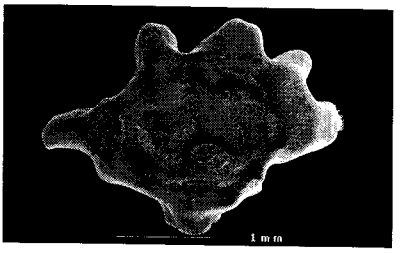


Figure 4.208 Order: Perciformes
Family: Gobiidae
Species: *Periophthalmus walailaku*

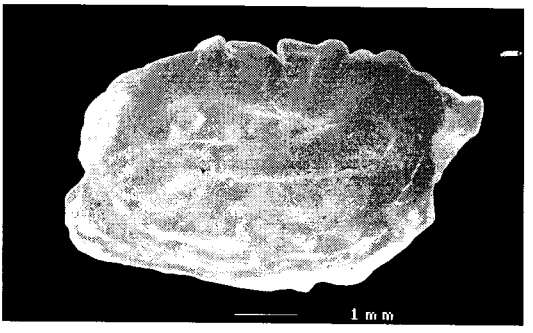


Figure 4.209 Order: Perciformes
Family: Gobiidae
Species: *Glossogobius aureus*

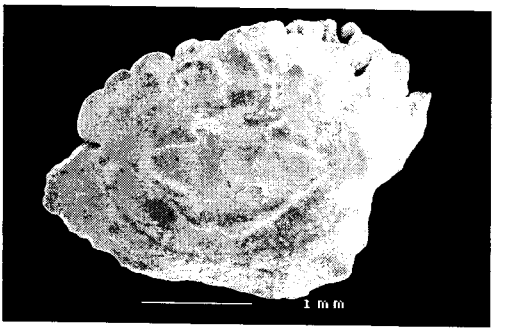


Figure 4.210 Order: Perciformes
Family: Gobiidae
Species: *Pseudapocryptes borneensis*

Trypauchen vagina (Fig. 4.212)

Relatively discoid, postdorsal long sharp and rough. Ototlith higher than long. The posterior end in a more strongly vertical direction. Anterior end gently curved to postventral. Sulcus narrow in shape. Ostium short, narrow, similar to arrow, while cauda very narrow, straight and longer than ostium. Dorsal and ventral depression shallow, wide fused around the cauda tip, but not completely fused around ostium tip.

cauda.

Order: Pleuronectiformes

Family: Psettodidae

Oval shape, heterosulcoid and ostial opening. Ventral area gently inclines upwards into the anterior and the posterior, whereas dorsal area straight at medial and steeply inclined at posterior end. Sulcus extremely shallow, narrow and smooth. Rostrum medium and no antirostrum. This family has both dorsal depression and ventral depression.

Psettodes erumei (Fig. 4.213 and Fig. 4.214)

Otolith rather smooth, oval, heterosulcoid and ostial opening. The postdorsal steeply inclined and reduced. No antirostrum. Ostium very smooth, gently broad at anterior end, while cauda narrow, shallow and gently curved at the posterior. Dorsal and ventral depression are extremely shallow, elongate above and under the anterior cauda.

Family: Paralichthidae

Square shape, homosulcoid and mesial opening. Rostrum and antirostrum are absent. Sulcus extremely shallow, located in central portion of otolith.

Figure 4.211 Order: Perciformes
Family: Gobiidae
Species: *Parapocryptes serperaster*

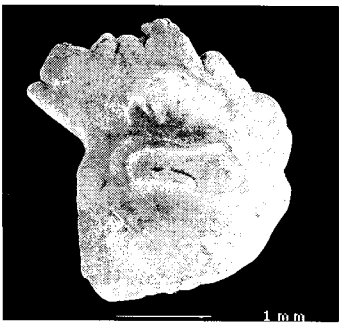


Figure 4.212 Order: Perciformes
Family: Gobiidae
Species: *Trypauchen vagina*

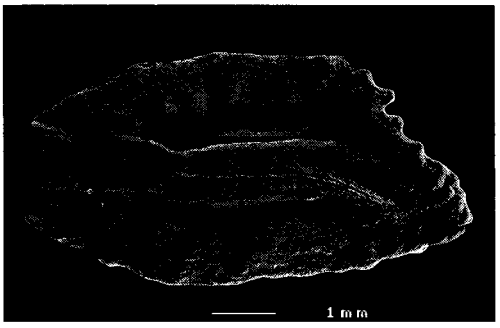


Figure 4.213 Order: Pleuronectiformes
Family: Psettodidae
Species: *Psettodes erumei*

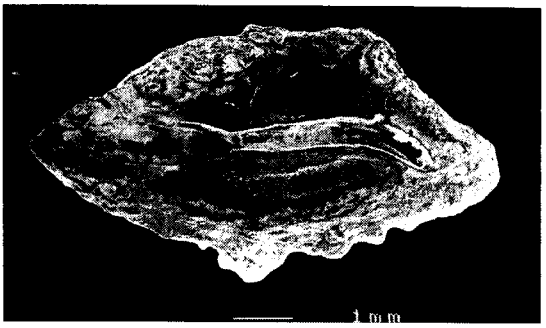


Figure 4.214 Order: Pleuronectiformes
Family: Psettodidae
Species: *Psettodes erumei*

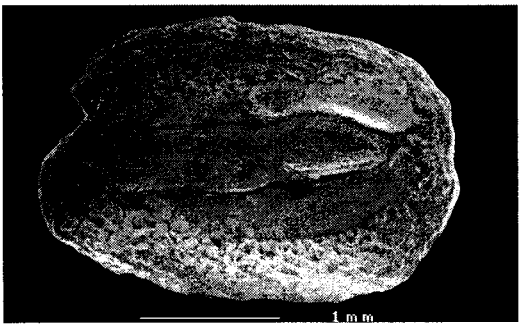


Figure 4.215 Order: Pleuronectiformes
Family: Paralichthidae
Species: *Pseudorhombus elevatus*

Figure 4.216 Order: Pleuronectiformes
Family: Paralichthidae
Species: *Pseudorhombus elevatus*

Pseudorhombus elevatus (Fig. 4.215 and Fig.4.216)

Square, homosulcoid and mesial opening. Ostium extremely shallow, wide, not defined and longer than cauda. Cauda oval shape, shallow but deeper than ostium. Dorsal depression located along the cauda, narrow but rather defined, whereas ventral depression not clear.

Family: Soleidae

Discoid and oval in shape Heterosulcoid and mesial opening. Rostrum and antirostrum are absent. Sulcus rather shallow and varies in shape. This family has both the dorsal depression and the ventral depression.

Zebrias zebra (Fig. 4.217 and Fig.2.218)

Oval, heterosulcoid and mesial opening. The posterior end of ototith indented, whereas anterior end is round. Ostium similar to an arrow head, while cauda is similar to an arrow tail. Dorsal depression extremely shallow, broad above the cauda but ventral depression narrow and extremely shallow, located posterior of cauda.

Zebrias ovata (Fig. 4.219)

Oval, homosulcoid with mesial opening. The sulcus of this species is located near the ventral margin, curved, extremely shallow and not defined. The connection between ostium and cauda is difficult to separate. The dorsal depression and the ventral depression are shallow, very long and they are connected together around the sulcus.

Pardachirus pavominus (Fig. 4.220)

Discoid, homosulcoid and pseudo-ostiocaudal opening. The posterior of otolith is strongly vertical and gently curves into dorsal and steeply

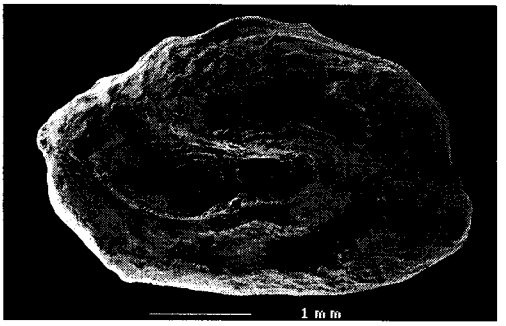


Figure 4.217 Order: Pleuronectiformes

Family: Soleidae

Species: *Zebrias zebra*

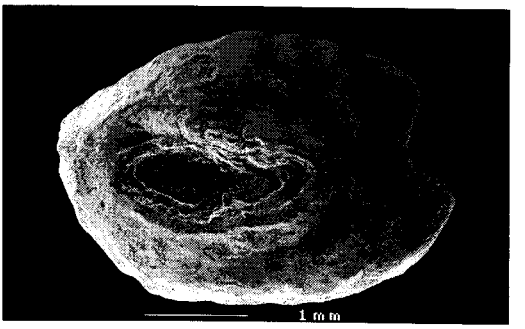


Figure 4.218 Order: Pleuronectiformes

Family: Soleidae

Species: *Zebrias zebra*

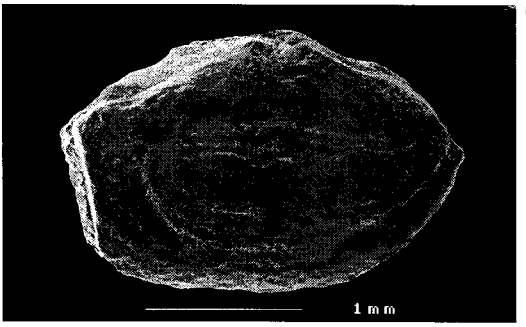


Figure 4.219 Order: Pleuronectiformes

Family: Soleidae

Species: *Zebrias ovata*

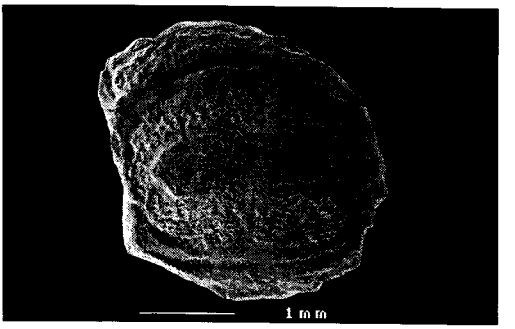


Figure 4.220 Order: Pleuronectiformes

Family: Soleidae

Species: *Pardachirus pavoninus*

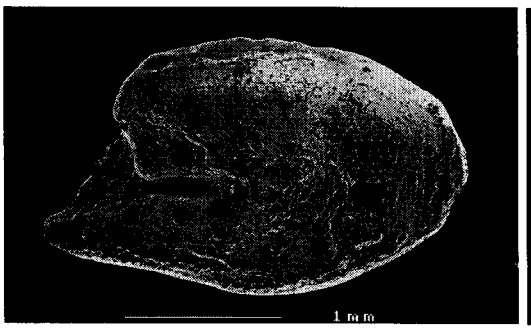


Figure 4.221 Order: Pleuronectiformes

Family: Cynoglossidae

Species: *Paraplagusia bilineata*

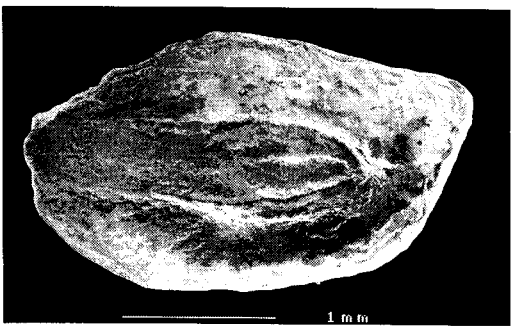


Figure 4.222 Order: Pleuronectiformes

Family: Cynoglossidae

Species: *Cynoglossus bilineatus*

inclines into the ventral. The difference between the ostium and ostium is difficult to separate but cauda is narrower than ostium. They are extremely shallow and not defined. Dorsal depression and ventral depression is small grooved, located at center of the dorsal area and the ventral area.

Family: Cynoglossidae

This family varies in shape and sulcus opening. The shape is oval, rectangular and square. The sulcus opening type is ostial, mesial and pseudo-ostiocaudal and sulcus type is heterosulcoid and homosulcoid. Ostium and cauda extremely shallow, not clear and vary in shape. Some species do not have ventral depression, while dorsal depression of these is not clear.

Paraplagusia bilineata (Fig. 4.221)

Oval, heterosulcoid and ostial opening. The dorsal depression and ventral depression are absent. Rostrum is rather large but antirostrum minute. Ostium is triangular, shallow and small. Cauda extremely short, narrow, straight, but deep. The posterior portion of otolith is extremely round and smooth.

Cynoglossus bilineatus (Fig. 4.222)

Square, homosulcoid and mesial opening. Ostium and cauda very shallow, moderately wide. Cauda moderate size, oblong shape, whereas ostium oval and small. Dorsal depression and ventral depression area are not clear and located around the sulcus.

Cynoglossus cynoglossus (Fig. 4.223)

Oval, heterosulcoid and pseudo-ostiocaudal opening. The anterior of otolith is narrow, more inclined at the posterior end. Ostium and cauda extremely shallow, not dense and they contain crystalline structure. The shape of the

ostium is similar to a rod, rather oblong but cauda is of rectangular shape, located in the vertical plane. Dorsal depression is small grooved, located along medial of dorsal area and extends into posterior area before gently curving into ventral of otolith.

Cynoglossus arel (Fig. 4.224)

Rectangular, heterosulcoid and pseudo-ostiocaudal opening. Otolith is rather smooth and is not dense at the central area. The anterior part is narrow, whereas the posterior is wide and is largely lobed. Crista superior and crista inferior are absent.

Cynoglossus sp.1 (Fig. 4.225 and Fig. 4.226)

Rectangular, heterosulcoid and pseudo-ostiocaudal opening. Ostium is rather long, very narrow and shallow, but the point of connection between the ostium and anterior cauda is not clear. The cauda is very short, broad into the posterior area and rectangular in shape. The plane of the sulcus is located in 30 degree angle by ostium part upwards the predorsal area. The ventral depression is more developed than dorsal depression, which is shallow, broad under the posterior of cauda and steeply inclined into the back of cauda in vertical plane.

Order: Tetraodontiformes

Family: Balistidae

Abalistes stellatus (Fig. 4.227)

In this study, this family has one species. Characteristic of otolith in this family is singular. Hour-glass in shape, heterosulcoid and ostio-cauda opening. Crista superior is ridge-like, located at the anterior of cauda. The ventral area of otolith is oval, whereas the dorsal area is round. Ostium and cauda are extremely deep. The plane of sulcus clearly separated the dorsal area and ventral area. Rostrum

larger, thick and oval, whereas antirostrum is similar to the beak of a horn-hill bird.

Family: Monocanthidae

Aluterus monoceros (Fig. 4.228)

Otolith of this family has one species from this study. It is extremely small when compared with the standard length of fish. Heterosulcoid and ostio-caudal opening. The ventral area is oval, while dorsal area is rectangular in shape. The sulcus curves downwards and opens at the anterior and posterior end.

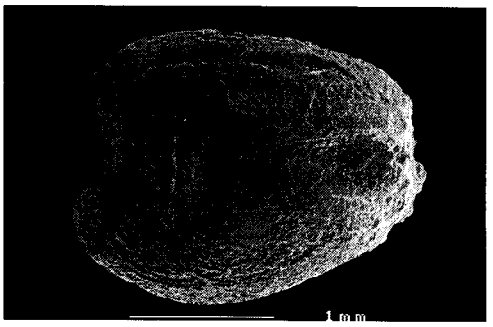


Figure 4.223 Order: Pleuronectiformes
Family: Cynoglossidae
Species: *Cynoglossus cynoglossus*

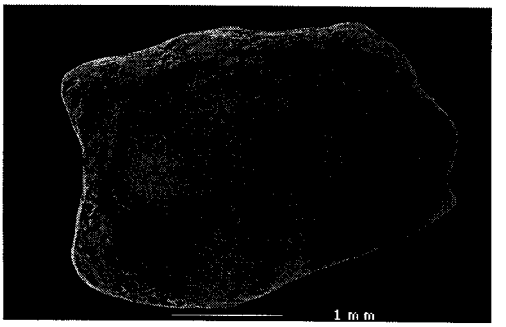


Figure 4.224 Order: Pleuronectiformes
Family: Cynoglossidae
Species: *Cynoglossus arel*

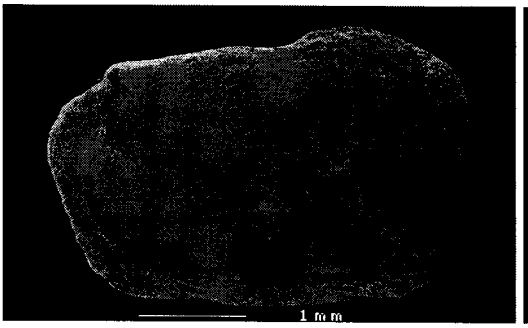


Figure 4.225 Order: Pleuronectiformes
Family: Cynoglossidae
Species: *Cynoglossus* sp.1

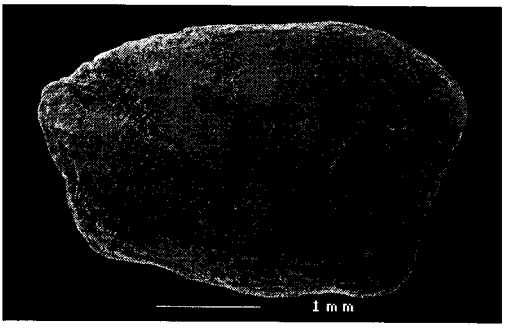


Figure 4.226 Order: Pleuronectiformes
Family: Cynoglossidae
Species: *Cynoglossus* sp.1

Figure 4.227 Order: Tetraodontiformes
Family: Balistidae
Species: *Abalistes stellatus*

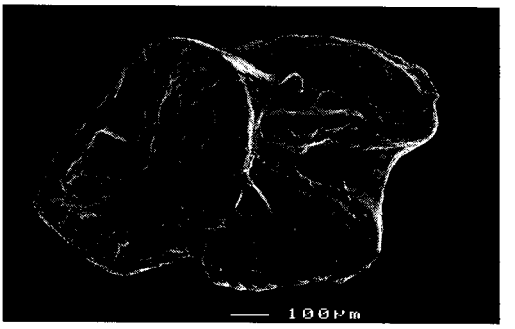


Figure 4.228 Order: Tetraodontiformes
Family: Monacanthidae
Species: *Aluterus monoceros*

4.1.3 The Relationships between Otolith Size and Taxonomic Groups

Otolith size (otolith length, OL; and otolith height, OH) range as a percentage of standard length (OL% SL and OH% SL) versus standard length (SL) were studied in fish family and fish order. These results of fish order are shown in the Fig. 4.229 and Fig. 4.230, whereas the fish family is shown in Fig. 4.231 – Fig. 4.240. The results of the relationships between otolith size and taxonomic groups that focused on the family and order are described as follows.

4.1.3.1 Otolith length as a percentage of standard length versus standard length in fish order (Fig. 4.229). In this study, it was found that the otolith size range can be divided in three categories as follows:

Very small (0.01% SL – 5.00% SL). The otolith size range of this category is found in two orders, i.e. Elopiformes, Clupeiformes and Tetraodontiformes. However, the order Tetraodontiformes has the largest of these three.

Small (5.01% SL – 10.0% SL). The otolith size range of this category is found in the orders Ophidiiformes, Aulopiformes, Mugiliformes, Perciformes and Pleuronectiformes.

Moderate (10.01% SL – 15.0% SL). The otolith size range moderate appears in seven orders, i.e. Anguilliformes, Beloniformes, Beryciformes and Scorpaeniformes.

4.1.3.2 Otolith height as a percentage of standard length (OH% SL) versus standard length (SL) in fish order.

The relationships between otolith height and standard length in fish order are present in three categories as shown in Fig. 4.230. The results are as

Large (15.01% SL – 20.0% SL). Synodontidae and Holocentridae.

Very large (20.01% SL – 25.0% SL). Sparidae and Scaridae.

4.1.3.4 Otolith height as a percentage of standard length (OH%SL) versus standard length (SL) in fish family.

The relationships between otolith height and standard length in fish family in five categories are shown in Fig. 4.236 - Fig. 4.240.

Very small (0.01% SL – 5.00% SL). Sub family: Harpadontinae, family Chirocentridae, Ophidiidae, Belonidae, Priacanthidae, Menidae, Carangidae, Leiognathidae, Scombridae, Trichiuridae, Gobiidae, Balistidae, Scatophagidae, Labridae, Scaridae, Acanthuridae, Sphyraenidae, Cynoglossidae, Psettodidae and Paralichthyidae.

Small (5.01% SL – 10.0% SL). Engraulidae, Mugilidae, Exocoetidae, Scorpaenidae, Platycephalidae, Ambassidae, Serranidae, Lutjanidae, Nemipteridae, Ephippidae, Muraenesocidae, Mugilidae, Holocentridae, Hemiramphidae, Gerreidae, Caesionidae, Rachycentridae, Teraponidae, Drepenidae, Pempheridae, Pomacentridae, Soleidae.

Moderate (10.01% SL – 15.0% SL). Sub family: Myripristinae, family Megalopidae, Synodontidae, Sillaginidae, Lethrinidae, Sciaenidae, Haemulidae and Sparidae.

Large (15.01% SL – 20.0% SL). Family Centropomidae.

Very large (20.01% SL – 25.0% SL). Family Clupeidae, Polynemidae and Monacanthidae.

4.1.4 The Relationships between Otolith Size and Fish Habitat

4.1.4.1 Otolith length as a percentage of standard length versus standard length in fish habitat.

The otolith length is compared by fish habitat, which are divided in five groups: pelagic, demersal, bottom, benthopelagic and benthypelagic. The results are shown in Fig. 4.241. The otolith size range that related to fish habitat is divided in five categories, very small (0.01% SL – 5.00% SL), small (5.01% SL – 10.0% SL), moderate (10.01% SL – 15.0% SL), large (15.01% SL – 20.0% SL) and very large (20.01% SL – 25.0% SL). The fish habitat in pelagic has otolith size range 0.01 – 11.00% SL; demersal, 0.01 – 22.00% SL; bottom, 0.01 – 24.00% SL; benthypelagic, 10.00 - 16.00% SL; and benthopelagic, 0.01 – 11.50% SL. Only the fish habitats at pelagic shows a significant trend toward a very small otolith. These are found in the orders Perciformes; Carangidae, Gerreidae Nemipteridae and Mullidae.

4.1.4.2 Otolith height as a percentage of standard length versus standard length in fish habitat.

The otolith height in five fish habitats is shown in Fig. 4.242. The pelagic fish has otolith size ranging from 0.01% SL to 8.50% SL; demersal from 0.25% SL to 19.00% SL; bottom from 0.01% SL to 23.00% SL; benthypelagic from 6.00% SL to 7.00% SL; and benthopelagic, from 4.00% SL to 14.00% SL. Only the fish habitats in pelagic displays a significant trend of a very small to small size, which was found in the orders Elopiformes (Elopidae), Clupeiformes (Engraulidae), Mugiliformes (Mugilidae), Beloniformes (Belonidae). In contrast, the demersal and bottom habitat have a significant trend toward very large.

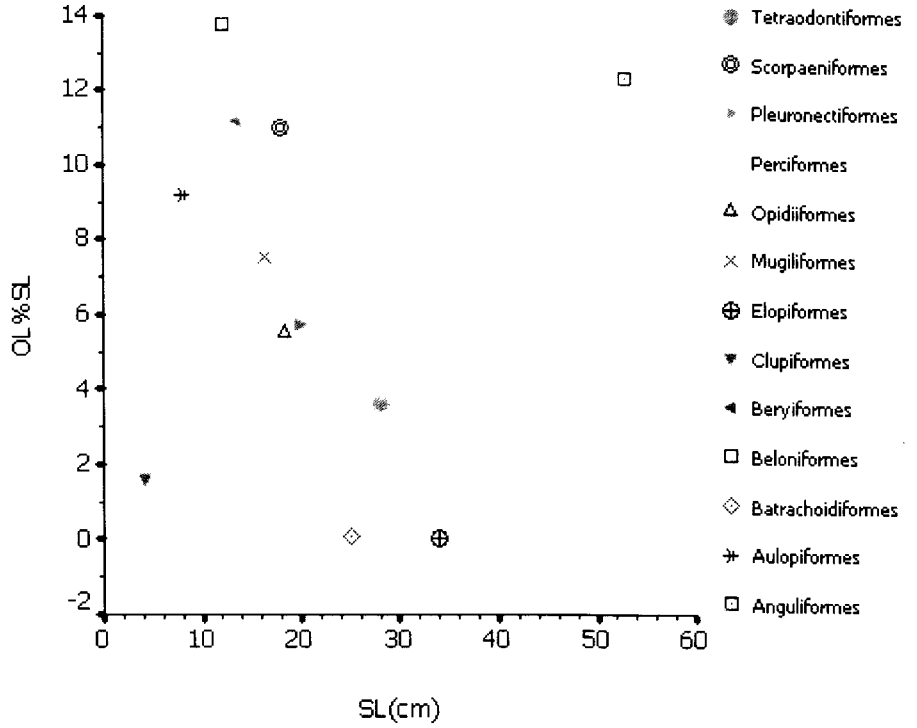


Figure 4.229 Otolith length presented as percentage standard length (OL% SL) versus standard length (SL) in thirteen fish orders

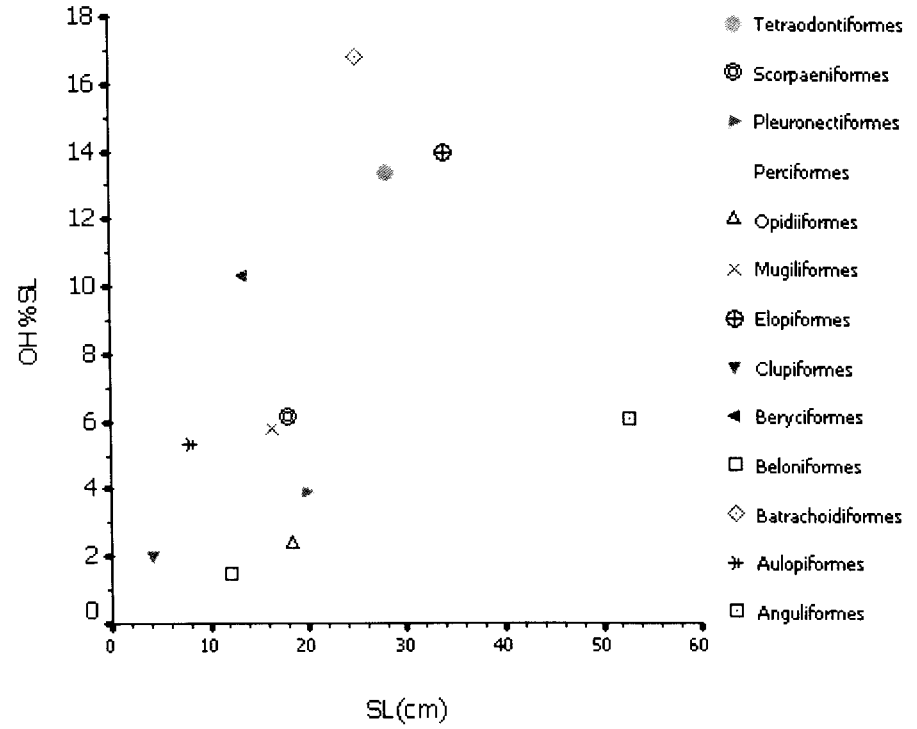


Figure 4.230 Otolith height presented as percentage standard length (OH% SL) versus standard length (SL) in thirteen fish orders

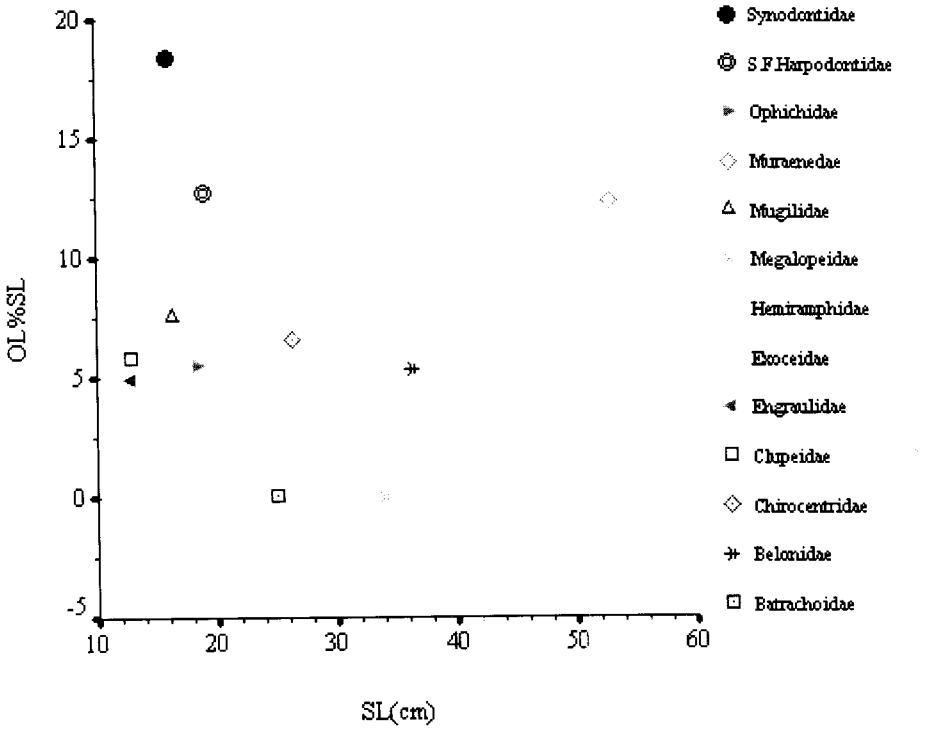


Figure 4.231 Otolith length presented as percentage standard length (OL% SL) versus standard length (SL) in thirteen fish families

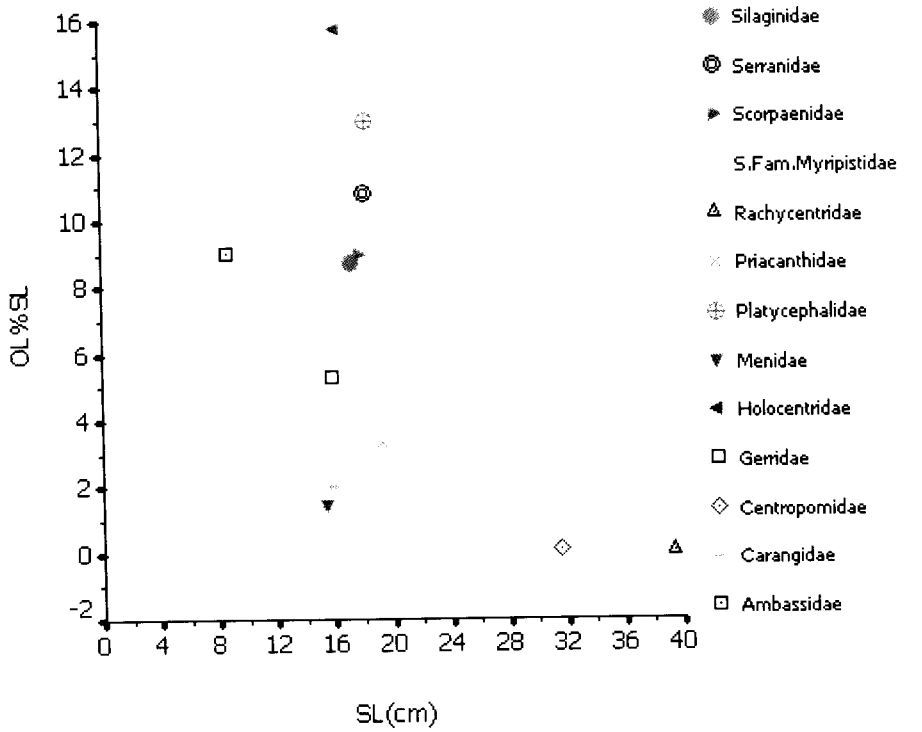


Figure 4.232 Otolith length presented as percentage standard length (OL% SL) versus standard length (SL) in thirteen fish families

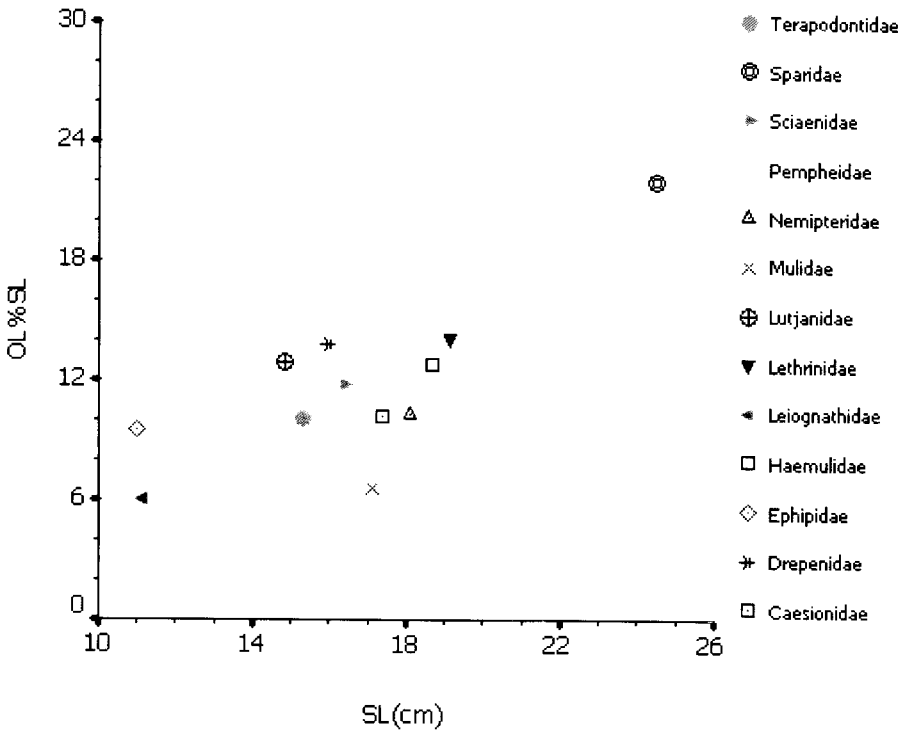


Figure 4.233 Otolith length presented as percentage standard length (OL% SL) versus standard length (SL) in thirteen fish families

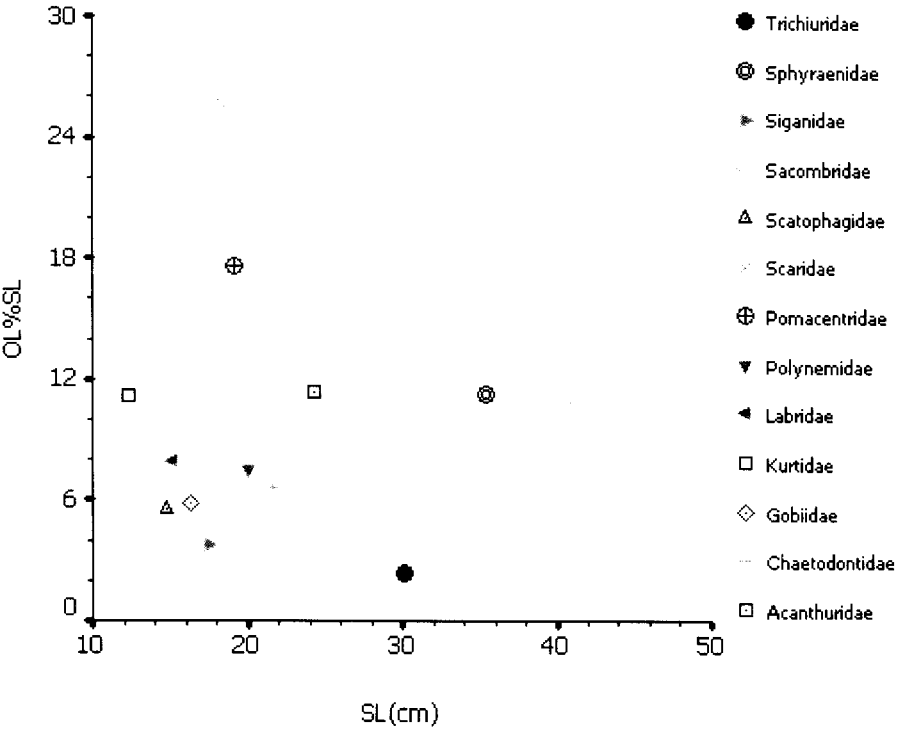


Figure 4.234 Otolith length presented as percentage standard length (OL% SL) versus standard length (SL) in eleven fish families

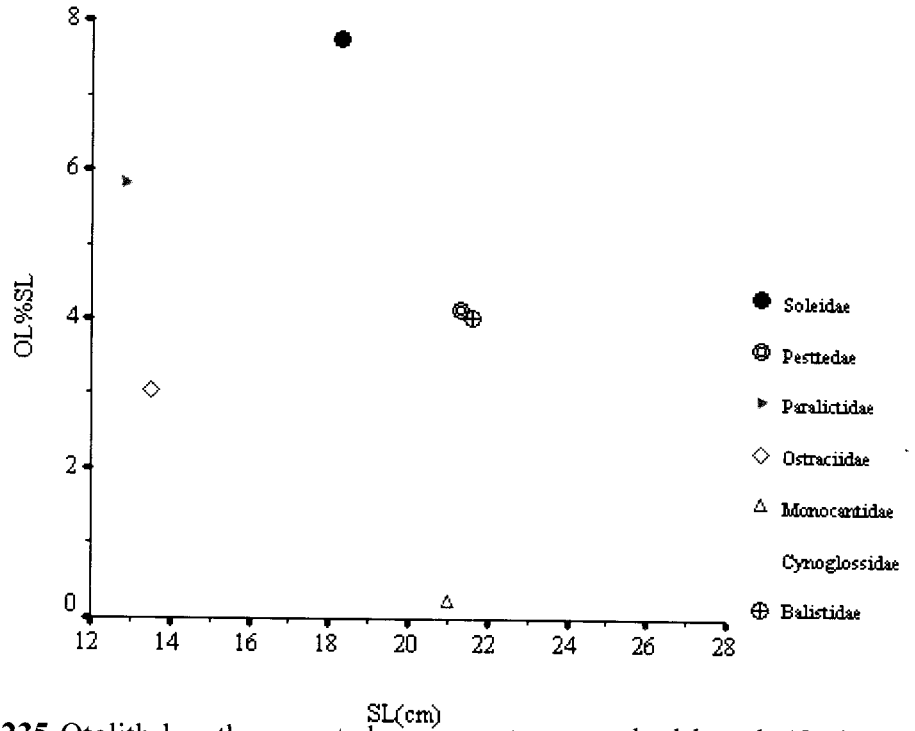


Figure 4.235 Otolith length presented as percentage standard length (OL% SL) versus standard length (SL) in seven fish families

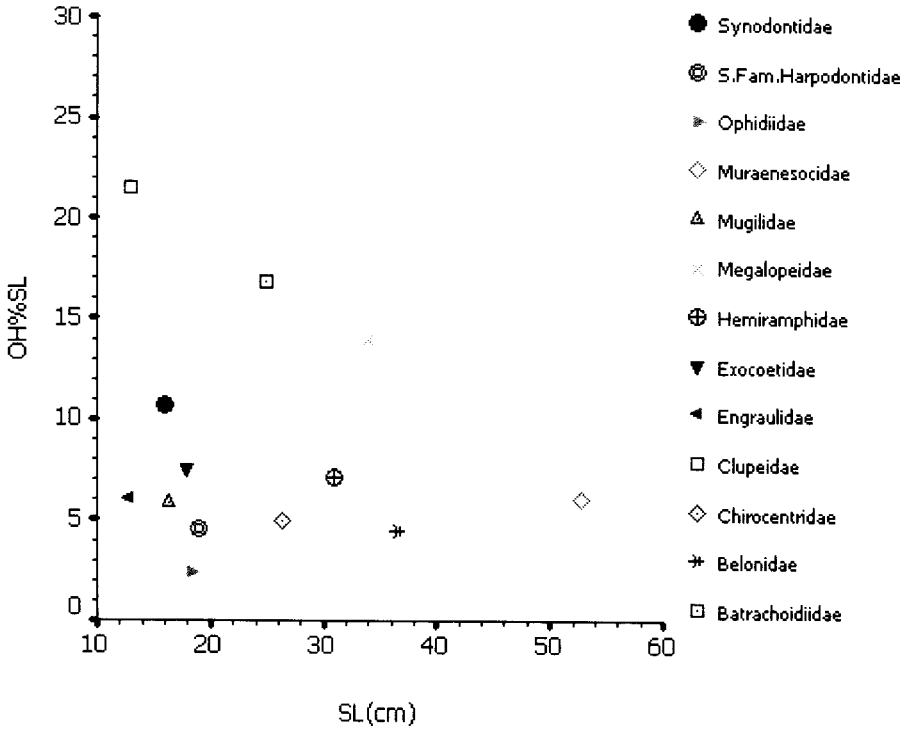


Figure 4.236 Otolith height presented as percentage standard length (OH% SL) versus standard length (SL) in thirteen fish families

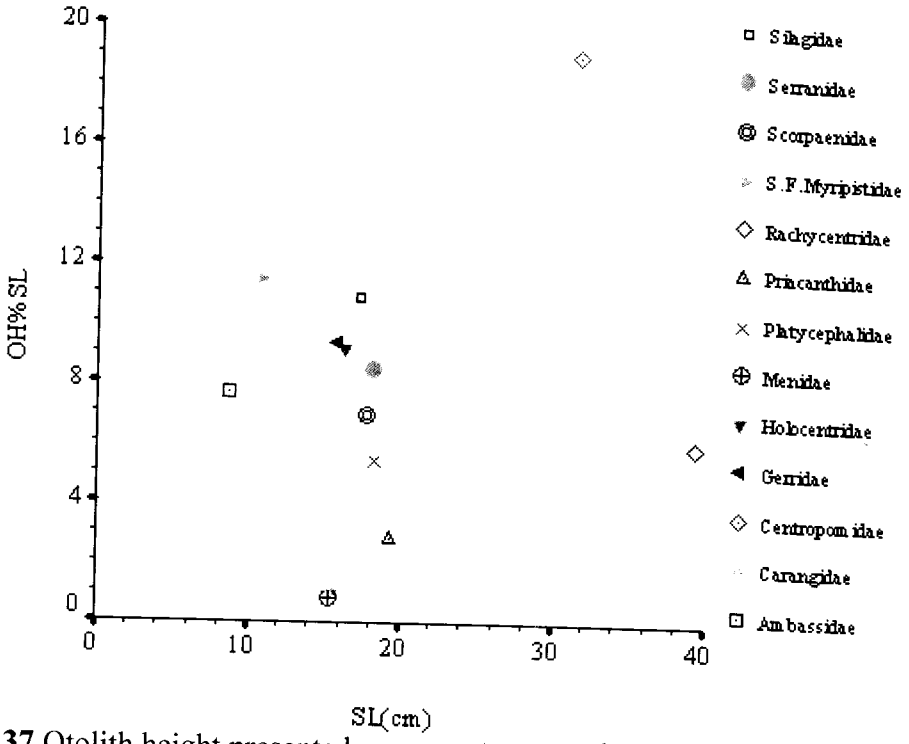


Figure 4.237 Otolith height presented as percentage standard length (OH% SL) versus standard length (SL) in thirteen fish families

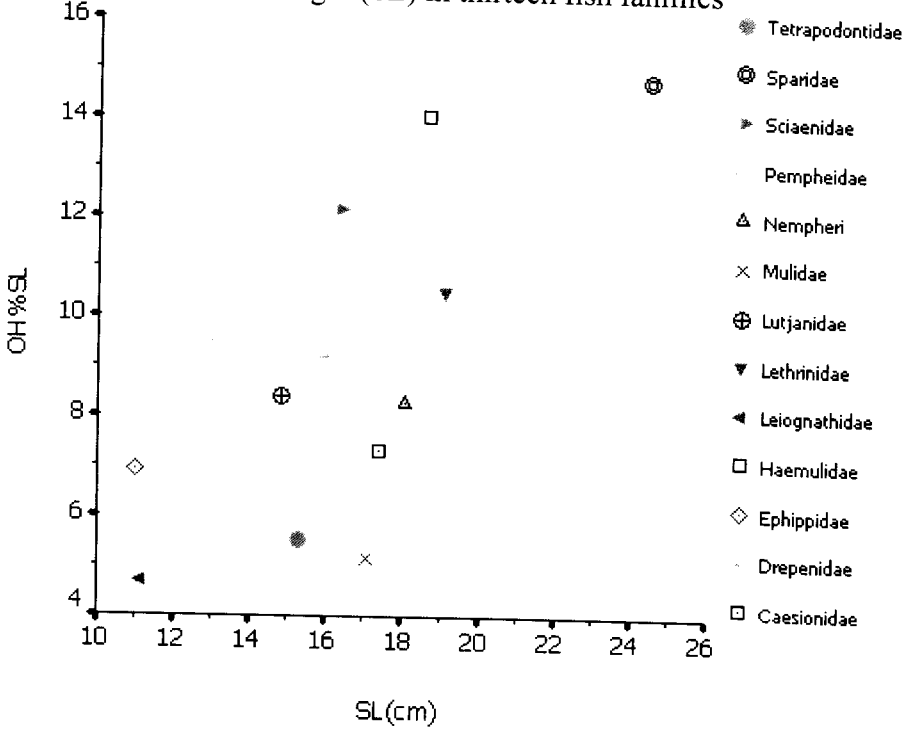


Figure 4.238 Otolith height presented as percentage standard length (OH% SL) versus standard length (SL) in thirteen fish families

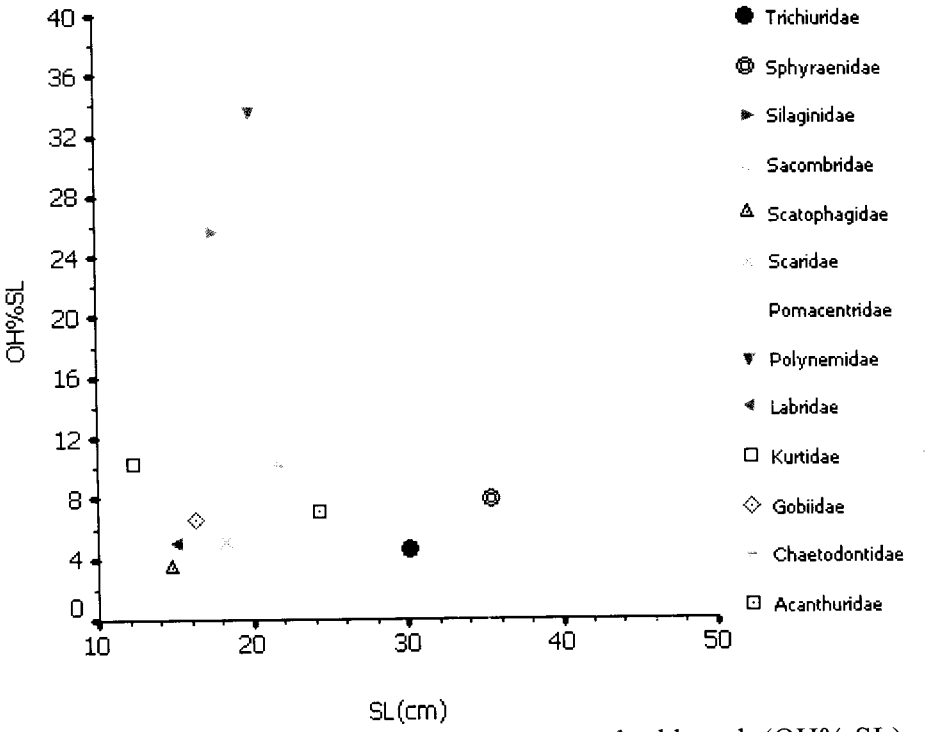


Figure 4.239 Otolith height presented as percentage standard length (OH% SL) versus standard length (SL) in eleven fish families

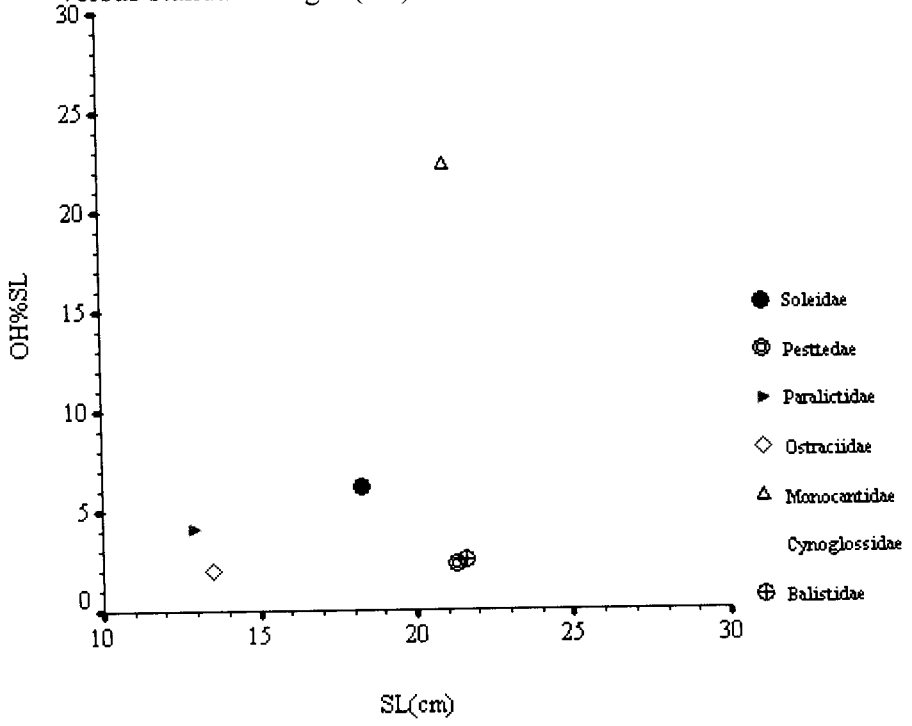


Figure 4.240 Otolith height presented as percentage standard length (OH% SL) versus standard length (SL) in seven fish families

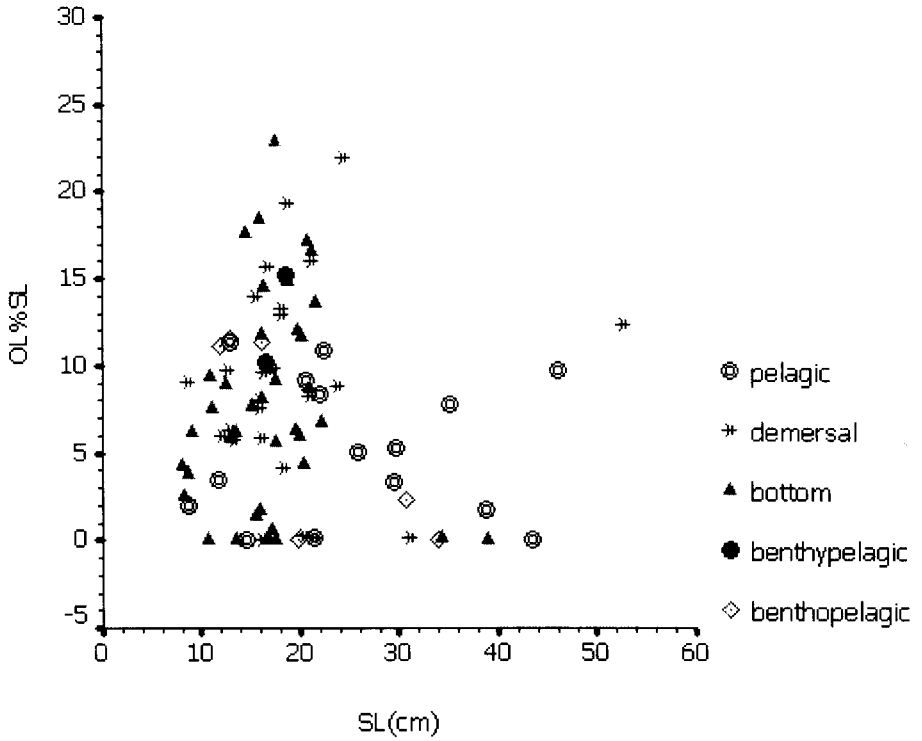


Figure 4.241 Otolith length presented as percentage standard length (OL% SL) versus standard length (SL) in five fish habitats

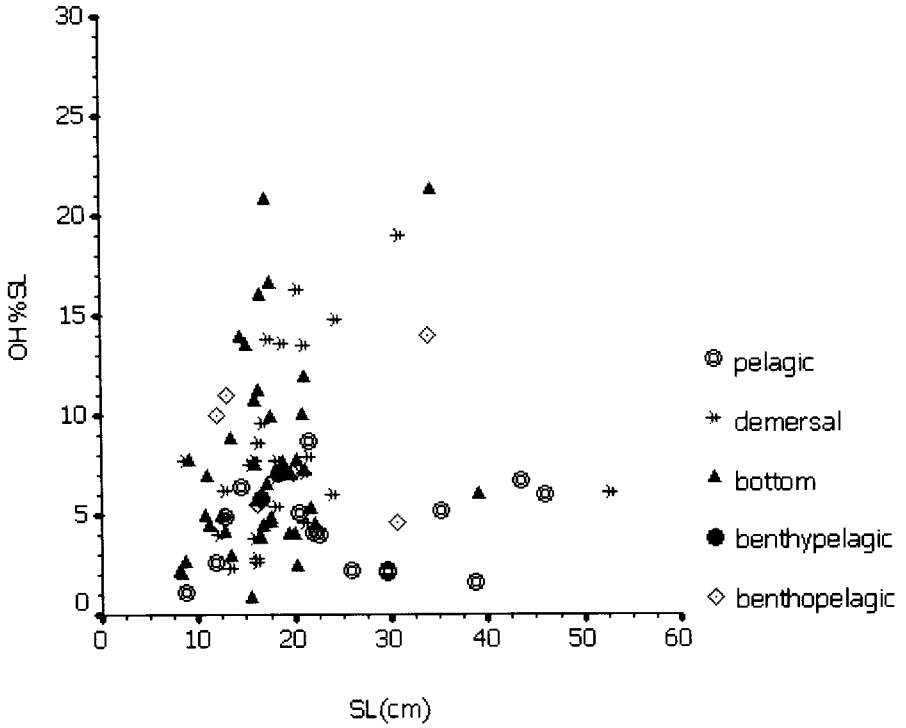


Figure 4.242 Otolith height presented as percentage standard length (OH% SL) versus standard length (SL) in five fish habitats

4.2 Discussion

4.2.1 Morphological Characters of the Sagittae

The present description of sagittal otolith morphology of Thai marine fish is the first study in Thailand. Two hundred and sixteen species in fifteen orders, sixty families and two sub-families showed differences in typical morphology groups of the fish. Generally, the shape, sulcus acusticus ostium, cauda, rostrum and antirostrum are important characters. Other characters, such as margin sculpturing, margins, dorsal depression, ventral depression, crista superior, crista inferior, exisura, pseudo-excisura, collum and colliculum also showed distinctive features of sagittal otoliths in the groups of fish.

The data reported in this study is consistent with the previous study it that the sagittal otoliths are normally the largest otolith pairs and are very robust and large when compared with the corresponding two pairs in asteriscii and lapilli. But in the order Siluriformes, the asteriscii are the largest pairs and also very robust when compared with sagittae (Bone, Marshall, and Blaxter, 1995).

The shape of sagittae varies it is frequently oval, however, lesser number can display a broaded range of shapes, such as spindle, hour–glass, skull-shape, tear drop, trapezium and square. Some shapes differ from the fish in Southern African Marine Fishes reported by Smale, Watson, and Hecht (1995). In this study, the primitive taxonomic group, order Elopiformes, family Eloppidae and family Megalopidae are tear-drop in shape, whereas the advanced taxonomic group, order Pleuronectiformes, is discoid, square or rectangular. In addition, in the medial groups of fish, order Perciformes, the shape also varies and can be oval, oblong or ovate. Such stages can only be found in the families e.g. Carangidae, Gerreidae, but not in

other families are not found. The shape is related to the taxonomic groups, whose infra-groups are similar, whereas the inter-groups are different; except in some groups between the family Lutjanidae and Caesionidae, they are most similar. The reason for this is the close connection between these two families and possible genetic linkage (Lombarte and Castellon, 1991).

The sulcus acusticus is mainly heterosulcoid, with an ostial opening that is found in the medial taxonomic groups. For example, in some groups of the family Menidae, it is wide and deep, while in others it is narrow such as in the family Mugilidae and shallow such as in the family Muraenesocidae and Sillaginidae. Nevertheless, the shape of sulcus is different in each group, however, they are mainly similar for intra-groups. The differences of these sulcus are inter-specific characteristics related to the habitat of the species (Tuset, Lombarte, Gonzalez, Pertuas, and Lorentes, 2003; Tuset, Lozano, Gonzalez, Pertusa, and Garcia-Diaz, 2003) Therefore, the sulcus acusticus is shown to have a species-specific character. The inter-specific differences are due to the differential development of the two areas of the sulcus acusticus: the ostial colliculum and the caudal colliculum. These areas correspond with the main variability in the caudal part of the sensorial macula for each group of fish or species. The principal difference between the groups of fish was found in the development of the ostium and cauda, which are relatively shorter and wider in each group. In the groups of fish in the order Elopiformes (Elopidae; *Elops machnata*), the ostium is elongate and narrow, whereas the cauda is rather shallow and shorter. In contrast, in some groups of the order Aulopiformes (Synodontidae), the ostium is very short but the cauda is very long. Rostrum and antirostrum appear in all groups that show a feature of the ostial opening type of sulcus acusticus. In some

groups of fish, the rostrum is very long, large and robust, such as in the groups of order Elopiformes and order Clupeiformes, whereas others are very small and minute, such as in the groups of the order Aulopiformes. Moreover, in some groups the rostrum and antirostrum are absent, such as in the order Perciformes, Gobiidae and Pleuronectiformes. The difference in the rostrum and antirostrum in some groups may be related to the otic of the fish. The orders Elopiformes and order Clupeiformes have a large rostrum and are robust and live in geographical regions that differs from that of typical for the order Aulopiformes. Volpedo and Echeverria (2002) argued that the sagittae of fish associated with the bottom differed in their morphology. The common feature of the morphology was rounded. The rostrum of the sagittae was absent or insinuated in fish related to a soft bottom, whereas the rostrum of fish related to hard substrates was short and not prominent. High length of rostrum values was also associated with fish that live in the pelagic habitat, whereas low length of rostrum values was related tofish that live in the soft substrate. The order Beloniformes (Belonidae), *Tylosurus crocodilus* that live in the pelagic habitat has a very small rostrum, while the order Beryciformes (Holocentridae) *Holocentrus rubrum* living in coral reefs is short.

Among other characteristics of the sagittal otolith, Smale, Watson, and Hecht (1995) and Harkonen (1986) have described those characters, which are species-specific, such as dorsal depression, ventral depression and crista superior. In this study, other characteristics are also species-specific. However, the margin sculpturing type, needle, is a new finding never seen before.

All of the reasons why the otolith morphology is species-specific can be associated with many factors. However, the main set of factors that account for the

difference in the sagittal otolith morphology can be divided into two factors, as follows.

(1) Ecological niches of the fish

The otic capsule and stato-acoustic system must have a shape and organization that represent a compromise between different needs and functions, swimming, hearing and equilibration. (Parmentier, Vandewalle, and Lagardere, 2001). Gualdie (1988) postulated that the ratio of macula area to otolith area and hence the ratio of sulcus area to otolith area of pelagic fish is higher than for demesal fish. The differences in such morphology may be better explained by environmental and physiological factors (Paxton, 2000). It is known that the morphology of sagittal otolith is not only related to common ancestry, but also to the habitat where a particular species of fish lives and to the anatomical specialization connected with macular and perception (Assis, 2003). The distribution of otolith morphotypes reflects adaptations to optimize fish survival in the context of different sounds in the environments. (Gauldie and Crampton, 2000). Some species are an eye-dependent predators with a simple otolith, and others night-time predators in surface water, with greater dependence on hearing and with a more complex shape in the otolith. There was also a clear shift in the complexity of the otolith from the deeper species to the shallow water species. At a depth range of 310 - 640 meters, the fish must rely heavily on sound both for predation and predator avoidance.

The differences in morphology between species is caused by the variation in the otolith movement pattern and the difference in oriented pattern of hair cells that codify these movements (Fay, 1984). However, behavioral flexibility of organisms frequently causes problems in corrective ecomorphlogy. For example, the

groups of fish that live in the pelagic habitat differ in their food, spatial niches and depth from the species *Sillago aeolus*, living in a demersal habitat. Such difference in species ecology was also discussed in the papers by Lombarte (1992) and Arellnaro et al. (1995).

Relatively flat proximal face, an almost absent excisura, a rostrum and a sulcus are very inconspicuous. There is compromise between several functions, but they must also be determined by various lifestyle–linked environmental factors. These multiple influences could be translated as differences in ecomorphlogical types characterized by certain proportions, shapes, and sizes.

Like all functional structures in an organism, the otic capsule and stato-acoustic system must have a shape and organization that represent a compromise between different needs and functions (swimming, hearing, equilibration, etc.). Many authors have reported the influence of environmental factors on the construction of an organism. Many fish species display otic capsules and sagittae whose shapes and sizes can be related to the ecological niches of the fish. For example, the otic cavities are proportionately larger in demersal species *(Sillago aeolus, S. ingenuuaand* and *Gerres macracanthus)* than that of pelagic species *(Tylosurus crocodilus* and *Platybelone platyura*). These differences coincided with the thickness data for the sagittae studied. *Tylosurus crocodilus* and *Platybelone platyura* live in open water, and have the thinnest otoliths in the shortest otic cavities, whereas the demersal species, *Sillago aeolus, S. ingenuua* and *Gerres macracanthus*, with its lesser mobility, possess one of the largest otic cavities and thicker otolith. Parmentier, Vandewalle and Lagardere

(2001) likewise reported that the sagittae of demersal are thicker than that of pelagic fish.

(2) Biological mechanism of fish

Changes in plasma calcium concentrations and subsequent changes of the endolymph have long been the prevailing hypothesis explaining the mechanism of variation in otolith accretion rate. It has been shown that different species have quite different hearing capacities at different frequencies. The morphology of the sulcus area as well as the total shape of all three pairs of otolith vary with phylogeny as well as ontogeny. The sound perception may to some degree be linked to the otolith shape as a whole or to certain aspects of the shape. The sound-receptive properties of the otolith lie in their ability to oscillate with frequencies different from the surrounding aquatic medium. In addition, the temperature in both shallow and deep-water and, the changes in daily migration behavior between different depths and water temperature by some species were reflected in the otolith. However, the existence of a similar structure in non-migratory populations of the same species indicates that the phenomena may be explained by an endogenous mechanism (Mosegagrd and Morsales-Nin, 2000).

Sagittae vary significantly in shape and size in different groups of fish. Several different factors have been reported to influence sagittal morphology. Among key factors are the reflective pressure acting on sagittae so their morphology meets specific auditory needs, and the effect of differences in growth rate caused by environmental factors, such as water temperature, depth, and mineral and food availability (Lombarte, 1992; Lombarte and Lleonart, 1993; Arellano et al., 1995; Aguirre and Lombarte, 1999).

Sagittae are the major receptors of sound in fish. They may be subjected to strong selective pressures related to the specific auditory needs of different taxa. Fish hear when sound waves cause the sensory epithelium and the sagittae to vibrate. Because of their different densities, these structures vibrate at different rates, producing a hearing action, which bonds. The sensory cell is translated into a sound signal by auditory nerves. Morphological differences in sagittal shape and sculpturing may effect the patterns (Gualdie, 1988).

Otolith growth rate increases with temperature even at super-optimal temperatures, where growth sometimes declines (Morales-Nin, 2000). The growth rate is attributed in many cases to inter-specific and intra-specific differences in sagitta morphology. The larger sagittae in each group of fish and associated lower somatic growth rates have been attributed to a process known as uncoupling, in which sagittae grow independently of somatic growth rate. Lychakov and Rebane (2000) reported that the sacular mass over utricular and lagenar masses results from the faster growth of the saccular otoliths compared to the other two otoliths. As a result of this, lager fish have the larger otoliths. The mass of the otoliths gradually increases with fish growth. The continuous otolith growth seems to be the characteristic feature of the aquatic invertebrate, oldest vertebrates and amphibians. In addition, the postembryonic addition of receptor cells occurs in the otolith organs and in other sensory systems of these animals.

The greatest variation in ear structure is associated with sound detection (Popper, 1983). The scale is the major sound detector in most fish, and is highly variant in structure, whereas the lagena is much less variant between different fish species, and the utricle in most fish is very much like that found in all other

vertebrates (Popper and Lu, 2000). In some species, the skull and the endolymphatic sac restrict the ventral sagitta growth (Aguirre and Lombarte, 1999)

The shape of the otolith itself is highly species-specific, with a strong similarity between otolith of individual fish, even when there are differences between individuals. This implies some genetically programmed control over otolith shape (Gauldie, 1988).

Regional difference in growth rate may be a primary factor in the development of differences in otolith shape. Faster growing fish have more elongated and thinner otoliths, while slower growing species have a thicker and wider otolith (Gauldie and Crampton, 2000). The shape differences may be attributed to regional and depth-related differences in temperature and/or fish growth rates. Other factors, such as differences in feeding and food availability between locations, may also influence regional variation in size (Smith, 1992). The stocks are different when the growth rate varies among them (Tuset et al., 2003). Lombarte and Castellon (1991) argued that the inter-specific differences in the shape of otoliths in the genus group are a reflection of the genetic distance between species.

Accordingly, the specific changes in relative size and shape of the otolith and the macula imply differences in the sensory thresholds for different frequencies of sound and environments. It has been observed that the ratio of sulcus area to otolith area (S:O ratio) increases in species with a high mobility pattern (Gualdie, 1988; Lombarte, 1992; Aguirre and Lombarte, 1999). Inter-specific differences in the S:O ratio are larger in species inhabiting deeper waters. The relationship between different morphology and different migratory behavior would confirm the hypothesis that the

development of sulcus acusticus could be related to the eco-morphological adaptation of the auditory system (Torres, Lombarte, and Morales-Nin, 2000a).

4.2.2 The Relationship of Otolith Size to Taxonomic Group and Habitat

The otolith length and height as a percentage of standard length versus standard length (SL) related to (a) habitat and (b) taxonomic group present in five categories of otolith size range: very small (0.01% SL - 5% SL), small (5.01% SL - 10.00% SL), moderate (10.01% SL - 15% SL), large (15.01% SL - 20% SL) and very large (20.01% SL - 25% SL). Most fish species apparently have some allometric growth of the otolith. The largest species in otolith length, *Pomadasys kakaan*, has, a relative otolith size with standard length at, 26% of 250.05 mm SL, while in the one smallest species, *Scomberoides tala*, has, a relative otolith size with standard length at 0.006% of 270 mm SL. The *Pomadasys kakaan* species live in the muddy bottom habitat, whereas *Scomberoides tala* live in the inshore habitat. In addition, the cranial morphology and body of these fish are different between two species. Thus, the different relationships in otolith size by taxonomic group and habitat in each otolith size range (very small, small, moderate, large and very large) are caused by several factors. Such as the life history of fish, environment, biology and genetics of fish, which can be described as follows.

The decrease in relative otolith size is related to the decreasing body growth rate with increasing age, but it is unlikely that growth rate is the only variable which can influence relative otolith size. The decrease in temperature with increasing habitat depth seems to be an important factor regulating the growth of otoliths (Wilson, 1985). Species which live in cold water have a smaller, thinner and less sculptured shell than warmer water species (Lombarte and Lleonart, 1993). Otolith

growth has a different response to environmental factors compared with somatic growth. The deposition of material in the otolith is an extra-cellular process, which is associated with a different physiology from somatic cellular growth (Lombarte and Lleonart, 1993). In this study, the size of otolith in each group of fish showed a similar relationship between size and temperature. The study found that the largest relative size, *Pomadasys kakaan* (Perciformes: Haemulidae), may live in the warmest waters, while the group of fish that has the smallest otolith may live in cooler water. Lombarte and Lleonart (1993) found that otolith development occurs under dual regulation: with the genetic conditions regulating the form of the otolith, while environmental conditions, mainly temperature in carbonate-saturated waters, regulate the quantity of material deposited during the formation of the otolith.

The relation between the rostrum size, the otolith length and the cauda size are specific characteristics that may be related to the habit of the species. The relationships of otolith length, height and standard length were species-specific, and even within closely related species considerable differences occurred. Results indicated that otolith linear dimensions were related to fish length. Increasing linear dimensions (OL and OH.) appeared not to keep pace with increases in fish length and the otolith may reach a limiting size before maximum fish length was achieved (Hunt, 1992). We can see this in the family Belonidae and Exocoetidae. However, for the other species examined in this study, a more linear relation with fish length was evident.

The large size of the par interior seems due, principally, to hyper-development of the sagittae. The structure of sagittae and asteriscus are the otolith showing the greatest variability in the teleost ear. Both structures are involved in

hearing (Parmentier, Vandewalle, and Lagardere, 2001). The movements of the otolith produced a shearing action in the cilliary bundle of the macula sensory hair cells, thus causing mechanical stimulation of the ear.

On the other hand, in some instances the larger fish have the smaller otoliths. The reason for this discrepancy is that the otolith mass and size depend not only on the absolute value of the fish length, but also on the fish growth rate. It has been shown that slower growing fish have larger otoliths relative to fish length. Within each growing group, otolith and fish size are highly correlated.

The functional transformation should be more noticeable in the bottom and littoral fish than in the pelagic fish. This shift can be associated with the fact that the larger fish produce lower frequency sound. These are sounds produced by moving, grinding of teeth against one another and involving the swim bladder, etc. In other words, a little fish "speaks" in high voice, but the large fish "speaks" in a deep voice.

Moreover, the bottom and littoral fish display a strong difference in the otolith masses of the sacculus and lagena due to the great difference in the otolith growth rates. The pelagic fish exhibit smaller differences in the otolith masses of the sacculus and lagena. Nevertheless, there is some evidence that the bottom and littoral fish can produce and process more types of acoustic signals than that of the pelagic school fish.

The largest otoliths are found in bottom and littoral fish, because the largest saccular otoliths provide the high sensitivity of the labyrinth to vestibular stimuli. Furthermore, since only the saccular otoliths are in a vertical plane in the labyrinth, the sacculi provide the maximal sensitivity in the vertical plane, which is the most significant one in the case of the finely tuned movements executed near the

bottom. Thus, the otolithic organs are tuned to cope with different acceleration and possess different functional properties. For pelagic fish, which move through an unobstructed environment, the demands for the exclusively sensitive otolithic organs seem to be less than for the bottom and littoral fish. However, for these fish, it is more important to develop and sustain high speed of movement and acceleration . Therefore, their need for otolithic organs tuned to high accelerations is the same or greater compared to the bottom fishes.

The inter-specific growth difference of the sagittae is related to differences in size of the skull and the endolymphatic sac. Sagittae growth at the ventral side is known to be restricted by the groove in the base of the otric cleft (Gauldie and Nelson, 1990). Although the relative sizes of the endolymphatic sac and the skull were not measured, it is deduced that some species have larger sagittae than other species due to the difference in the skull and the endolymphatic sac. This observation is not common in other congeneric teleost fish.

The only difference related to the length of adult fish is in high order harmonics which measure surface roughness. This is surprising because several authors have observed that there is a linear relationship between otolith length and fish length. Slight changes in otolith length–to–height ratio produce marked changes in amplitudes of both low–order and high–order harmonics. It is possible that increases of otolith size in adults are relatively uniform, and that changes in otolith shape are very slight after maturity is reached (Bird, Eppler, and Checkley, 1986).

According to Gauldie (1988), the auditory capacity of fish could be determined in part by a lever system between the sagitta and its macula. The efficacy of this lever would depend on the ratio of the size of the macula to that of the otolith. More than size, the differences in density between the otolith and the neurocranium must be a determining factor in the movements of the otolith with respect to the rest of the body, and thus also in hearing. A massive otolith could be considered immobile during acoustic stimulation, while the body moves around it. Otoliths were not weighed in this study. However, a thicker otolith gives intuitively a greater inertia and more pronounced shearing action on the macula hair cells. If gravity is ignored, the inertia is proportional to the product of the mass and the radius. First, the mass should be higher in a thicker otolith. Second, the radius between the otolith centre of gravity and the macula is inevitably longer in a thick otolith than in a thin one.

For the species that live in demersal and bottom habitats, the swimming constraint is obviously weaker. Therefore, it does not act as a restricting factor on sagitta development. This is reinforced by thick otoliths found in the well-known benthic Congridae. The demersal species have thinner cranial bones and thicker otoliths than the pelagic species. The inertia of their sagittae should be greater with respect to the movements of the cranium. This difference in inertia might lead to more efficient perception for the demersal and bottom species than for the pelagic and benthopelagic species (Parmentier, Vandewalle, and Lagardere, 2001).

In this study, only the right otolith was used to investigate the morphology. This is because several reseachers reported that the symmetry between

left and right otolith of each individual is high (Gauldie and Crampton, 2000). Similarity, Hunt (1992) found that lack of a significant difference between the left and right otolith for all but Plaice is consistent with the observation that the otolith pairs are a mirror image of each other. The influence of body rotation during the developmental stage may be a factor resulting in the differences in the pairs. Other researchers likewise wrote that the differences between left and right of otolith in the sagitta were not significant (Aguirre and Lombarte, 1999), as others have found in teleost fish with axial symmetry (Lombarte, 1992; Arellano et al., 1995).

In very rare cases (three observations in Pomatoschistus *minutus* and one observation in *P. lozanoi*), the shapes of the right and left sagitta were different due to aberrant calcium deposition on one side. In these cases, the sagitta function for balancing and equilibrium was not met. The detection of homogeneous variances in the data and the overall geometrical similarties between the right and left sagittae indicate that no gender–related intra-specific growth variation occurs (Arellano et al., 1995).

CHAPTER V

CONCLUSIONS

5.1 The General Morphology of Otoliths

The sagittal otolith morphology of fish, including 14 orders, 60 families, 2 sub-families and 211 species from the southern coasts of Thailand, was studied by scanning electron microscope. The distinctive morphology of the otoliths, which was species-specific, involved features such as shape, sulcus acusticus (ostium and cauda), rostrum, antirostrum. Other characters, i.e. margin sculpturing, dorsal depression, ventral depression, crista superior, crista inferior, exisura, pseudo-excisura, collum, and collicullum were also species-specific. In this study, it was found that the principal characters of sagittal otolith are shape, sulcus acusticus (ostium and cauda), rostrum, antorostrum and dorsal depression. These are very important for distinguishing the otolith morphology in each species. Other characters are also important, but they are not necessary for classification of those otoliths if the main characters are clearly distinctive.

The shape of sagittal otoliths from the southern coasts of Thailand in this study displays seventeen types. The singular type of shape appears in small groups, whereas the most common type is the oval and oblong, manifested in several groups. Sulcus is mainly of the heterosulcoid type and has four types of ostial opening The ostium and cauda are clearly characteristic for classifying sagittal otoliths. Rostrum and antirostrum are robust, small to large in size and is absent in some groups. Other

characters, such as dorsal depression, are generally elongate, oval and very shallow, while the ventral depression is largely absent. Crista inferior and crista superior are in four degrees: poorly developed, developed, well-developed and ridge-like. The margin sculpturing has eight types, with the only new type found in this study being the needle-shaped. The colliculum shows 3 types: absent, homomorph and heteromorph. Usually, pseudo-excisura is absent in almost all groups, but the excisura is found classifiable with five characters: absent, narrow with deep notch, narrow with shallow notch, wide with deep notch, and wide with shallow notch. The collum or neck is normally absent in almost all groups.

5.2 The Relationship between the Otolith size and Taxonomic Groups

Otolith size range of sagittal otoliths can be divided into five categories: very small; (0.01% SL – 5.00% SL), small (5.01% SL – 10.0% SL), moderate (10.01% SL – 15.0% SL), large (15.01% SL – 20.0% SL) and very large (20.01% SL – 25.0% SL). The relationship of otolith size and standard length by taxonomic groups shows a few groups that are correlated to otolith size. The largest otolith size appears in the medial taxonomic groups, order Perciformes, while the smallest otolith size appears in the primitive taxonomic groups, order Beloniformes and family Belonidae. Nevertheless, the most common otolith size range is the moderate size, which is found in the medial taxonomic groups. Moreover, the otolith size in the advanced taxonomic groups tends to be small to very small. On the other hand, the otolith size in the primitive taxonomic groups tends to be moderate, small and very small.

5.3 The Relationship between the Otolith Size and Fish Habitat

The relationship of the otolith size and standard length correlated with fish habitat was found in five habitats: pelagic, demersal, bottom, benthopelagic, and benthypelagic. The otolith in pelagic tends to be small to very small, whereas the bottom and demersal habitat tends to be moderate to large in the otolith size range.

The results from this study will be useful for researchers in several ways. The difference in sagittal otolith shape and size shows that the sagittal otolith can be used as a tool for identifying fish species and may provide valuable additional data for other studies, such as in fish phylogenics and systematics, as reported by other authors. Consequently, they can be used for the study of fish in several ways, such as in investigating growth, paleontology, identification in fish species, and food habit of marine animals. The sulcus acusticus and shape are characters that can be used to identify fish more than other characters. However, differences in crystalline structure on sulcus acusticus of sagittae of each species increase the information to confirm the identification of fish.

The size of otoliths can also be used to examine food habits of piscivorous fish and to determine their size. In this research, it was found that otolith size in fish is correlated with fish habitats and taxonomic groups, and otolith size might be associated with hearing. The relationships between OL and OH and standard length of fish can be used to identify prey size from stomach content samples, paleontology, and habitat of fish. Moreover, they have implications for back-calculation of fish age.

These morphological differences are linked to the environment, history of fish, and biological mechanism of fish rather than to any genetic differences. For example, sagitta morphology is influenced by the difference in the growth rate and is

caused by environmental factors such as water temperature, depth, mineral and food availability.

The objective of this study was to compile information regarding the morphology of sagittae for marine fish of Thailand. Specific characters of each sagitta will be used to establish a systematic key to help in the identification of fish species from recovered otoliths in feces and stomach contents of predators or in archaeological deposits. The data will be useful for study of food habits of predators and ancient fish. Otoliths of fishes in Thailand are not well known and it is difficult to find relevant data on them. This research represents a pioneer study to investigate shapes and sizes of the otoliths of fish from coastal Thailand. The results of this research will be useful for studying fish biology of Thailand. It is planned that many more species of fish will be sampled to cover all Thai marine fish and a reference collection of otoliths will be established in the future.

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APPENDIX

Taxonomic classifications of collected fish refer to the sagittal otoliths

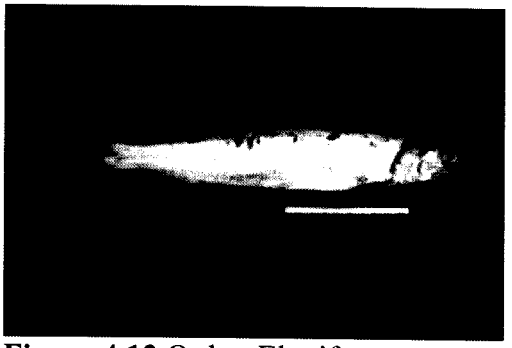

Figure 4.13 Order: Elopiformes

Family: Elopidae

Species: *Elops machnata*

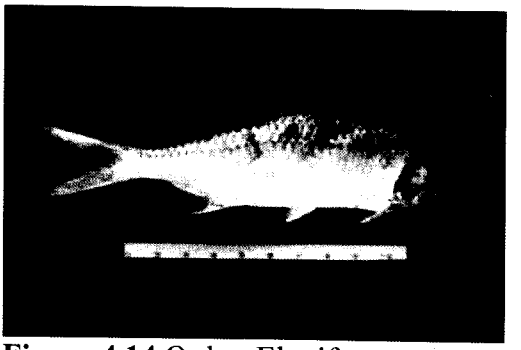

Figure 4.14 Order: Elopiformes

Family: Megalopidae

Species: *Megalop cyprinoides*

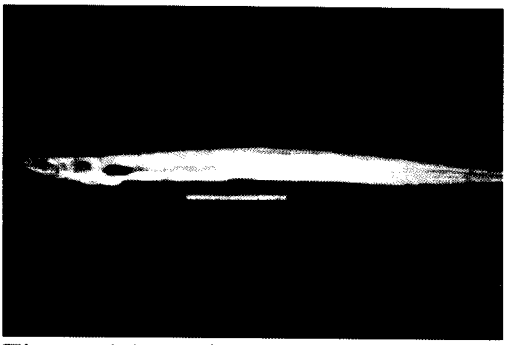

Figure 4.15 Order: Anguilliformes

Family: Muraenesocidae

Species: *Muraenesox cinereus*

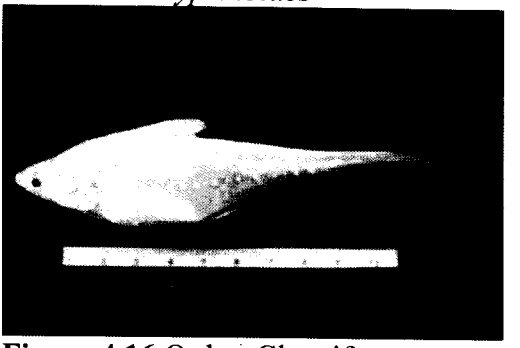

Figure 4.16 Order: Clupeiformes

Family: Engraulidae

Species: *Coilia dussumieri*

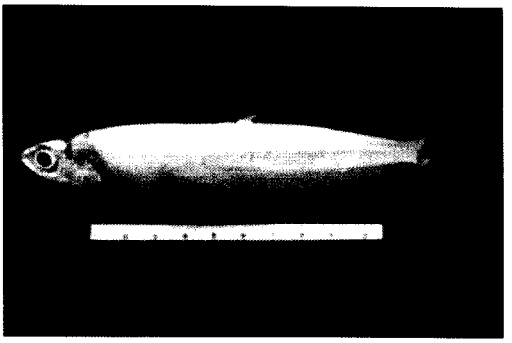

Figure 4.17 Order: Clupeiformes

Family: Engraulidae

Species: *Stole indicus*

Figure 4.18 Order: Clupeiformes

Family: Engraulidae

Species: *Stole* sp.

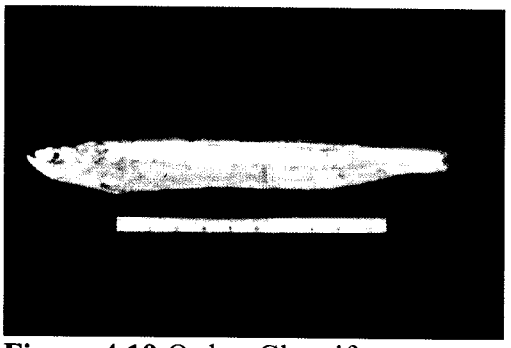

Figure 4.19 Order: Clupeiformes

Family: Chirocentridae

Species: *Chirocentrus dorab*

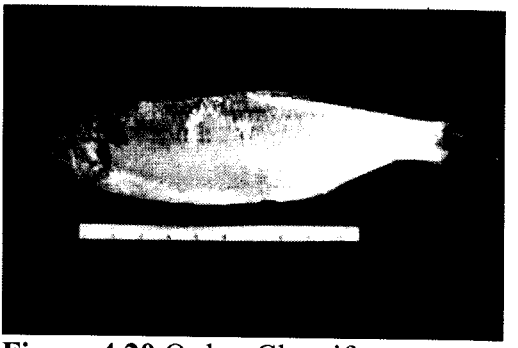

Figure 4.20 Order: Clupeiformes

Family: Pristigasteridae

Species: *Opisthopterus tardoore*

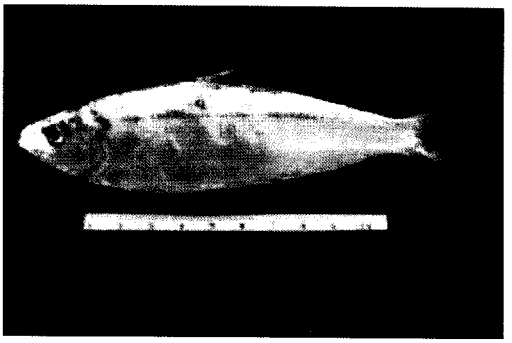

Figure 4.21 Order: Clupeiformes

Family: Clupidae

Species: *Sardinella albella*

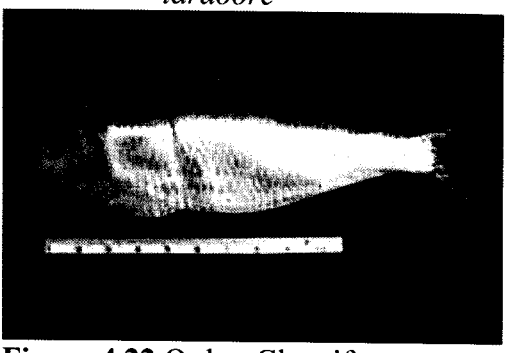

Figure 4.22 Order: Clupeiformes

Family: Clupidae

Species: *Sardinella fimbriata.*

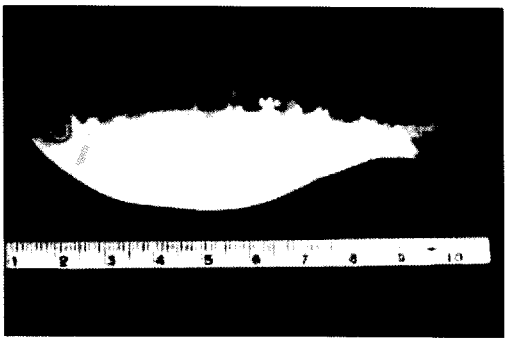

Figure 4.23 Order: Clupeiformes

Family: Clupidae

Species: *Sardinella brachysoma*

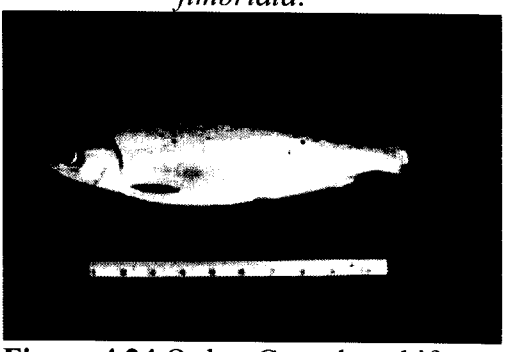

Figure 4.24 Order: Gonorhynchiformes

Family: Chanidae

Species: *Chanos chanos*

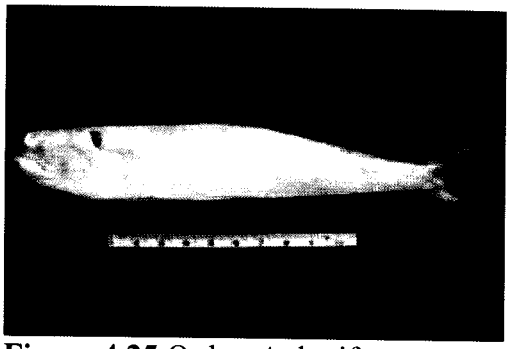

Figure 4.25 Order: Aulopiformes

Family: Synodontidae

Species: *Trachinocephalus myops*

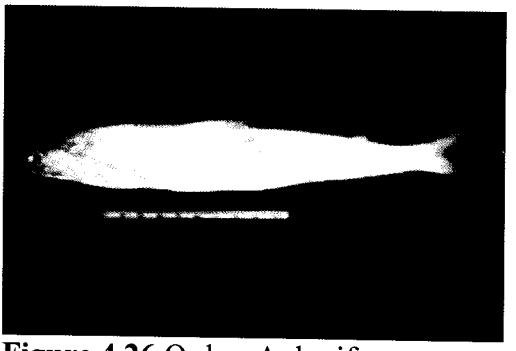

Figure 4.26 Order: Aulopiformes

Sub family: Harpadontinae

Species: *Saurida undosquamis*

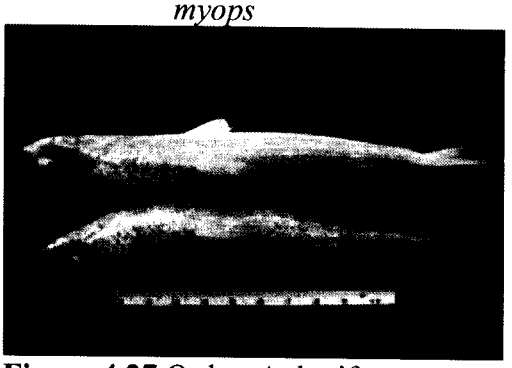

Figure 4.27 Order: Aulopiformes

Subfamily:Harpadontinae

Species: *Saurida tumbil*

Figure 4.28 Order: Ophidiiformes

Family: Ophidiidae

Species: *Brotula* (cf.) *multibarbata*

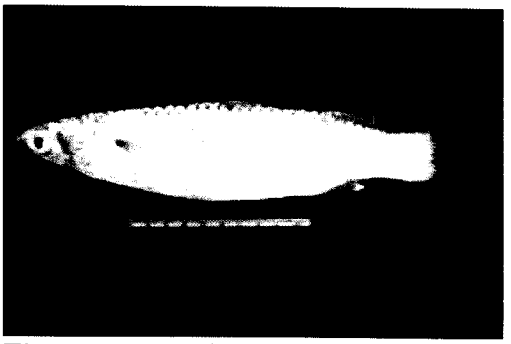

Figure 4.29 Order: Mugiliformes

Family: Mugilidae

Species: *Chelon tade*

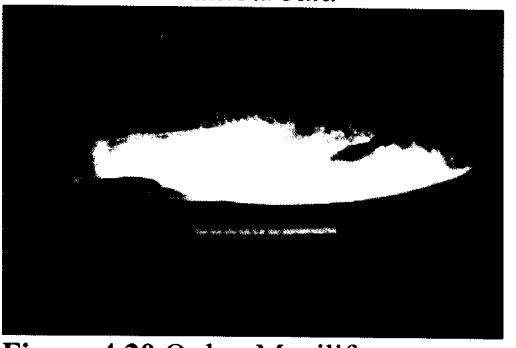

Figure 4.30 Order: Mugiliformes

Family: Mugilidae

Species: *Moolgarda buchanani*

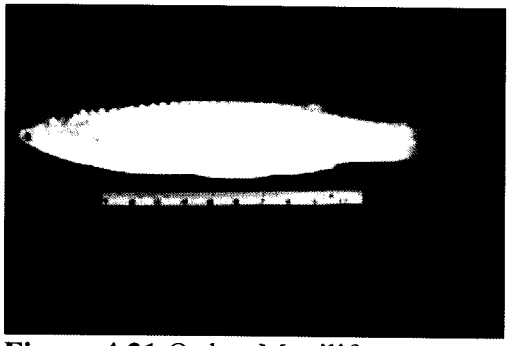

Figure 4.31 Order: Mugiliformes

Family: Mugilidae

Species: *Chelon subuiridis*

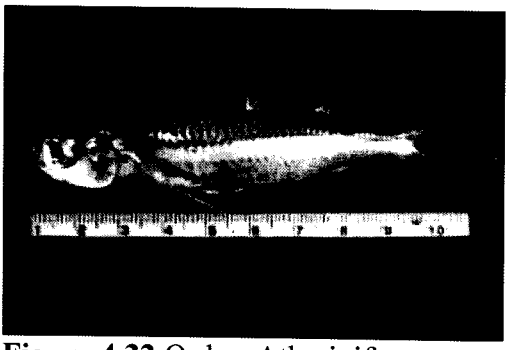

Figure 4.32 Order: Atheriniformes

Family: Atherinidae

Species: *Atherinomorus duodecimmalis*

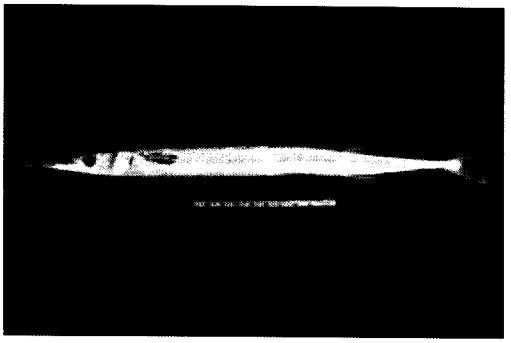

Figure 4.33 Order: Beloniformes

Family: Belonidae

Species: *Tylosurus crocodilus*

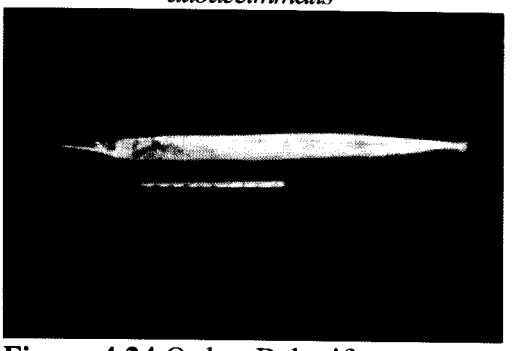

Figure 4.34 Order: Beloniformes

Family: Belonidae

Species: *Platybelone argalus*

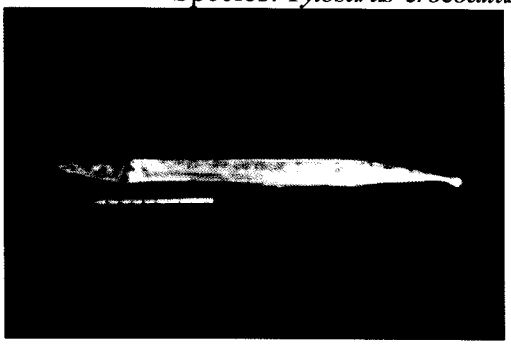

Figure 4.35 Order: Beloniformes

Family: Belonidae

Species: *Tylosurus acus melanotus*

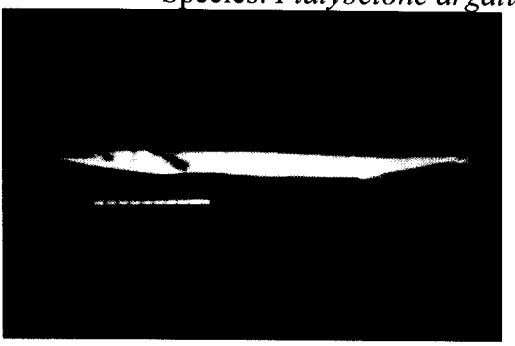

Figure 4.36 Order: Beloniformes

Family: Belonidae

Species: *Platybelone platyura*

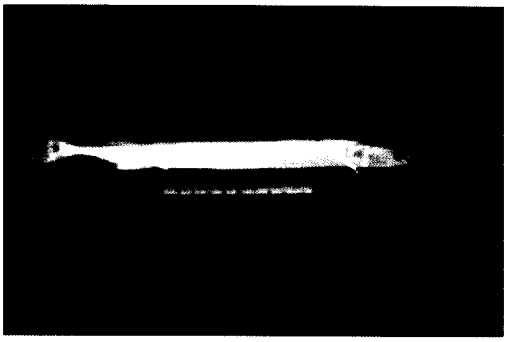

Figure 4.37 Order: Beloniformes

Family: Belonidae

Species: *Strongylura strongylura*

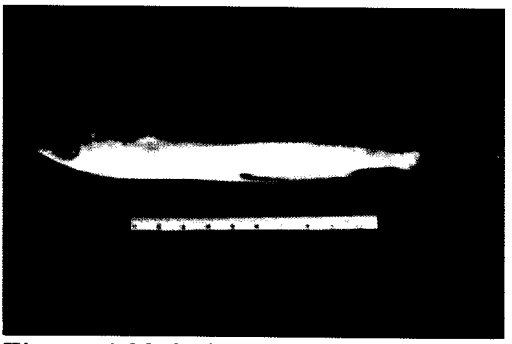

Figure 4.38 Order: Beloniformes

Family: Exocoetidae

Species: *Cypselurus maressi*

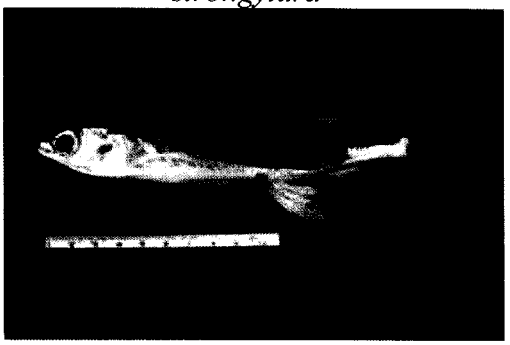

Figure 4.39 Order: Beloniformes

Family: Exocoetidae

Species: *Cypselurus oligolipes*

Figure 4.40 Order: Beloniformes

Family: Hemiramphidae

Species: *Hyporhamphus limbatus*

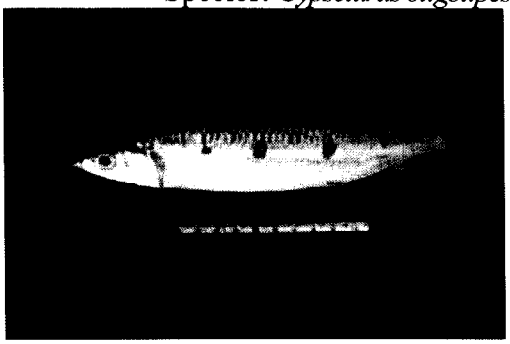

Figure 4.41 Order: Beloniformes

Family: Hemiramphidae

Species: *Hemiramphus far*

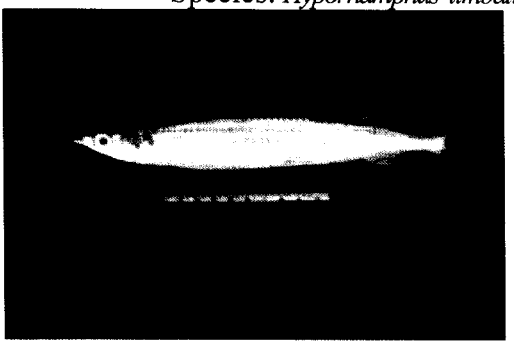

Figure 4.42 Order: Beloniformes

Family: Hemiramphidae

Species: *Hemiramphus archipelagicus*

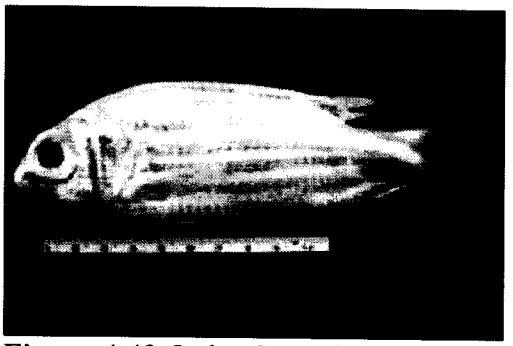

Figure 4.43 Order: Beryciformes

Family: Holocentridae

Species: *Holocentrus rubrum*

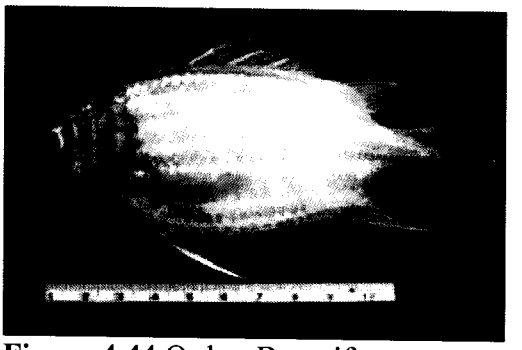

Figure 4.44 Order: Beryciformes

Family: Holocentridae

Species: *Ostichthys kaianus*

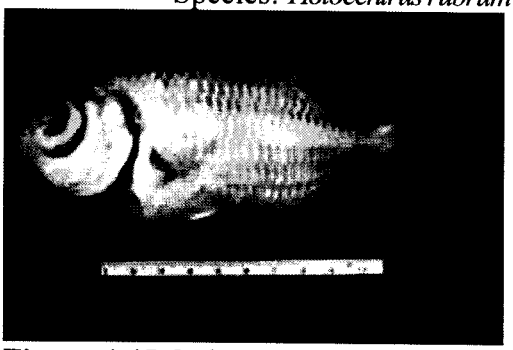

Figure 4.45 Order: Beryciformes

Subfamilies: Myripristinae

Species: *Myripristis murdjan*

Figure 4.46 Order: Scorpaeniformes

Family: Scorpaenidae

Species: *Pterois milles*

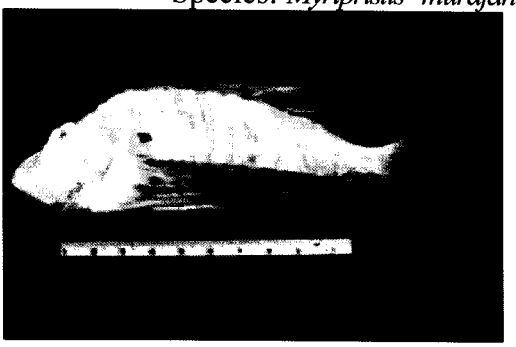

Figure 4.47 Order: Scorpaeniformes

Family: Scorpaenidae

Species: *Pterois russelli*

Figure 4.48 Order: Scorpaeniformes

Family: Scorpaenidae

Species: *Coccotopus* sp.

Figure 4.49 Order: Scorpaeniformes

Family: Scorpaenidae

Species: *Scorpaenopsis neglecta*

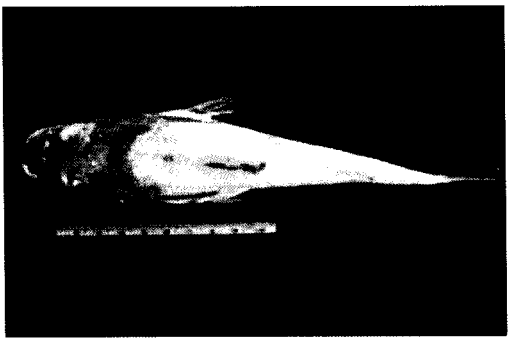

Figure 4.50 Order: Scorpaeniformes

Family: Platycephalidae

Species: *Grammoplites asper*

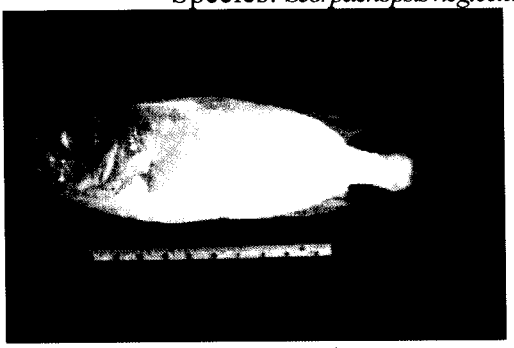

Figure 4.51 Order: Perciformes

Family: Priacanthidae

Species: *Priacanthus tayenus*

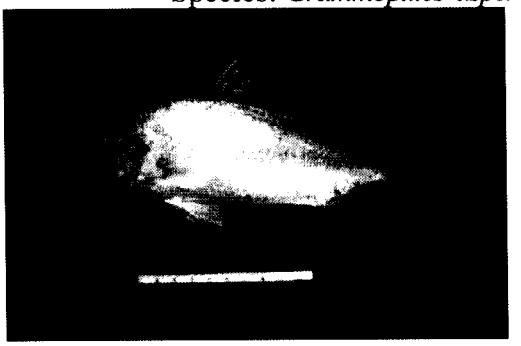

Figure 4.52 Order: Perciformes

Family: Centropomidae

Species: *Lates calcarifer*

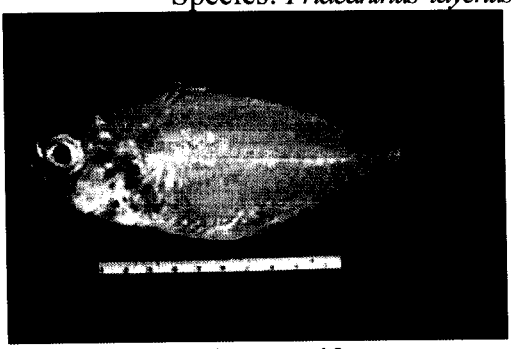

Figure 4.53 Order: Perciformes

Family: Gerreidae

Species: *Pentaprion longimanus*

Figure 4.54 Order: Perciformes

Family: Serranidae

Species: *Epinephelus sexfasciatus*

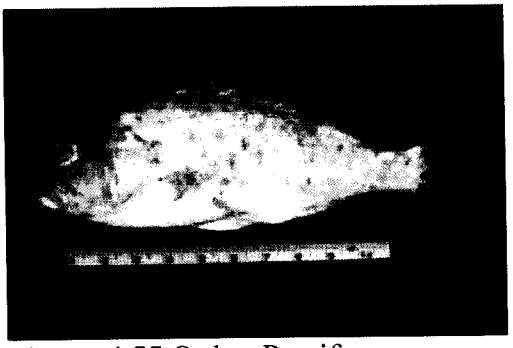

Figure 4.55 Order: Perciformes

Family: Serranidae

Species: *Epinephelus bilobatus*

Figure 4.56 Order: Perciformes

Family: Serranidae

Species: *Cephalopholis formosa*

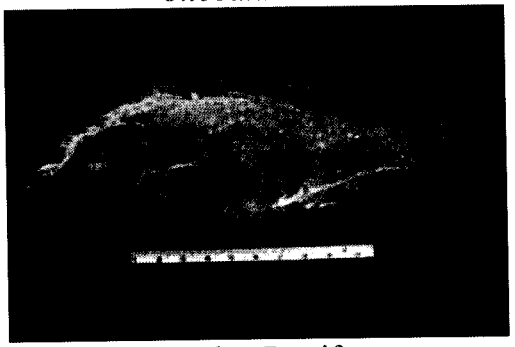

Figure 4.57 Order: Perciformes

Family: Serranidae

Species: *Cephalophlois miniatus*

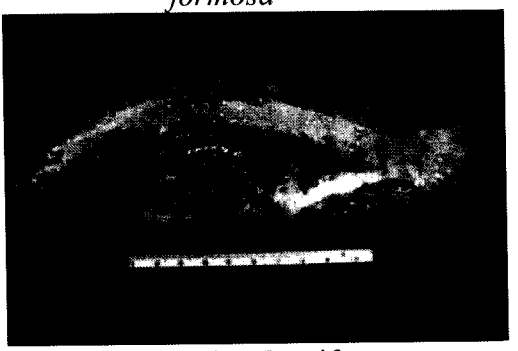

Figure 4.58 Order: Perciformes

Family: Serranidae

Species: *Cephalophlois argus*

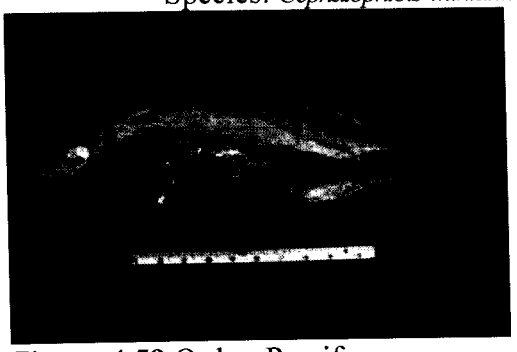

Figure 4.59 Order: Perciformes

Family: Serranidae

Species: *Cephalopholis oligostitus*

Figure 4.60 Order: Perciformes

Family: Serranidae

Species: *Epinephelus quoyanus*

Figure 4.67 Order: Perciformes

Family: Serranidae

Species: *Cephalopholis heniochus*

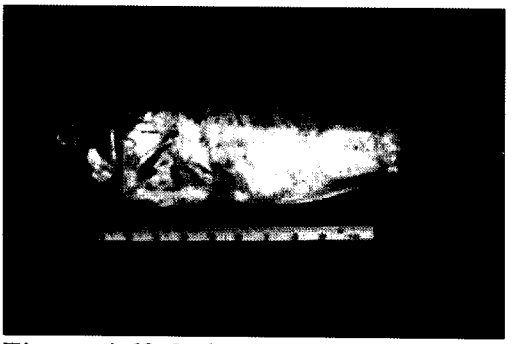

Figure 4.68 Order: Perciformes

Family: Apogonidae

Species: *Apocal elioti*

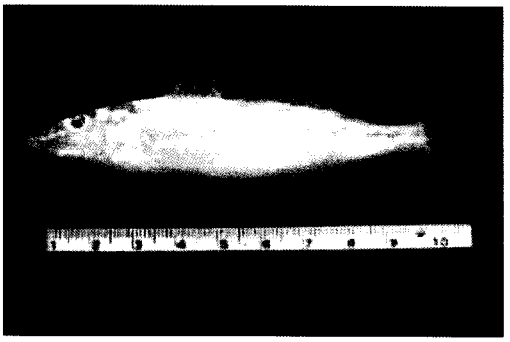

Figure 4.69 Order: Perciformes

Family: Sillaginidae

Species: *Sillago aeolus*

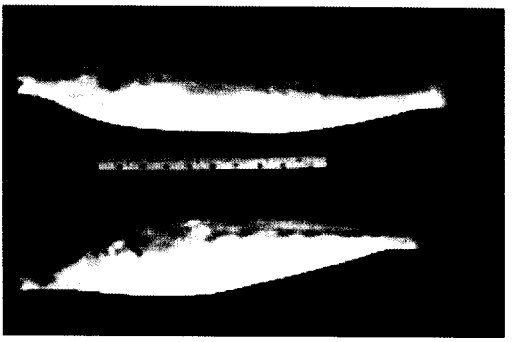

Figure 4.70 Order: Perciformes

Family: Sillaginidae

Species: *Sillago sihama*

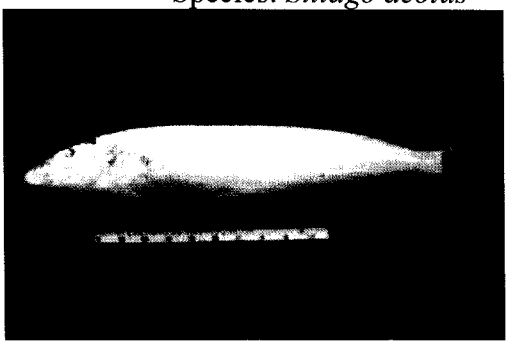

Figure 4.71 Order: Perciformes

Family: Sillaginidae

Species: *Silago ingenuua*

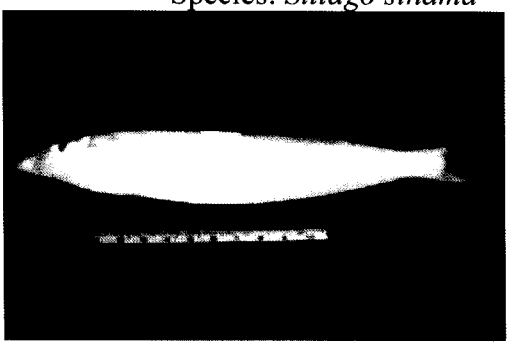

Figure 4.72 Order: Perciformes

Family: Sillaginidae

Species: *Sillago asiatica*

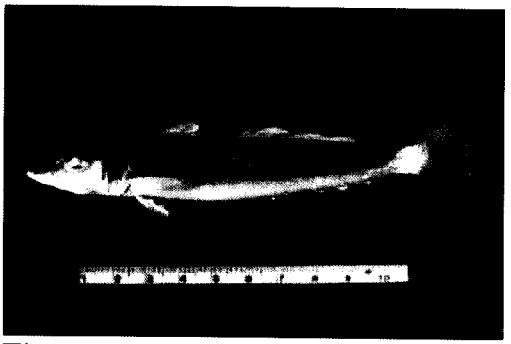

Figure 4.73 Order: Perciformes

Family: Sillaginidae

Species: *Sillago chondropus*

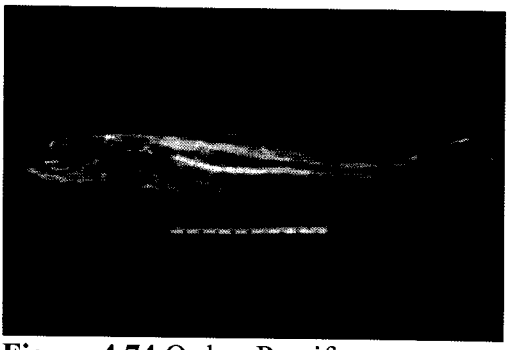

Figure 4.74 Order: Perciformes

Family: Rachycentridae

Species: *Rachycentron canadus*

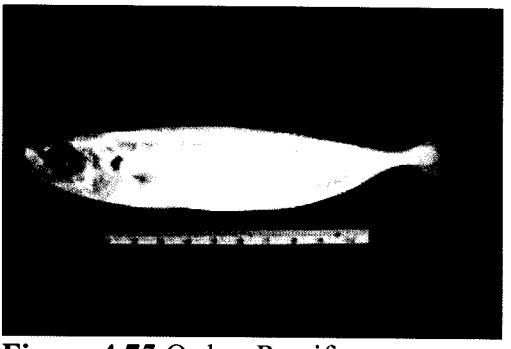

Figure 4.75 Order: Perciformes

Family: Carangidae

Species: *Carangoides malabaricus*

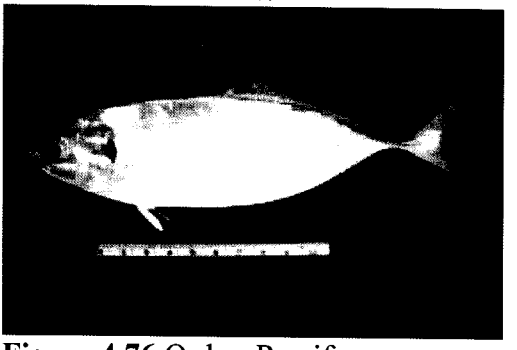

Figure 4.76 Order: Perciformes

Family: Carangidae

Species: *Alepes djeddaba*

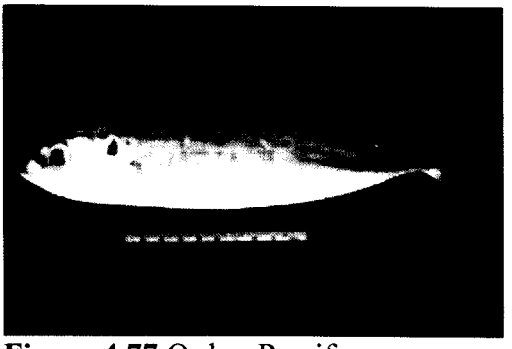

Figure 4.77 Order: Perciformes

Family: Carangidae

Species: *Decapterus dayi*

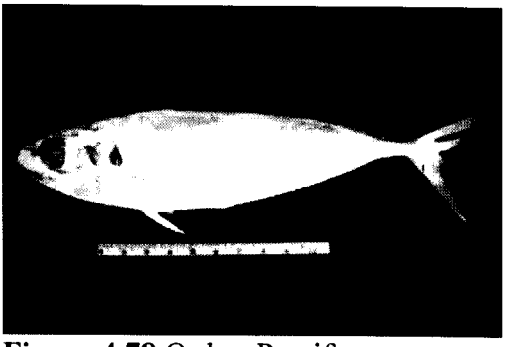

Figure 4.78 Order: Perciformes

Family: Carangidae

Species: *Decapterus kurroides*

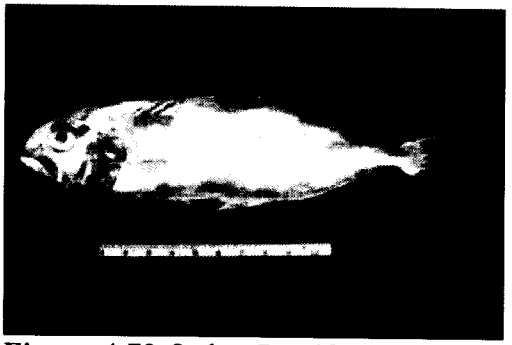

Figure 4.79 Order: Perciformes

Family: Carangidae

Species: *Seriolina nigrofasciata*

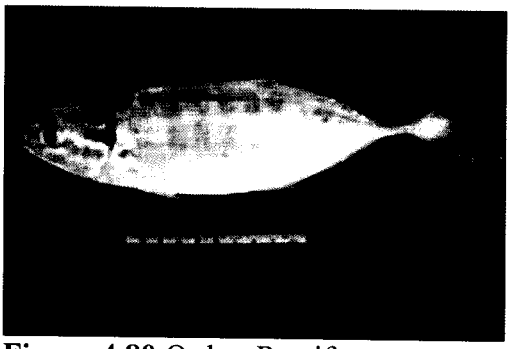

Figure 4.80 Order: Perciformes

Family: Carangidae

Species: *Atule mate*

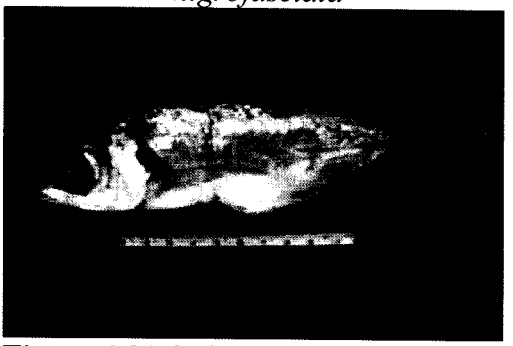

Figure 4.81 Order: Perciformes

Family: Carangidae

Species: *Elagatis bipinnulata*

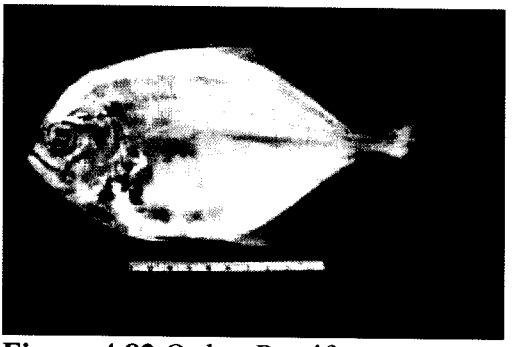

Figure 4.82 Order: Perciformes

Family: Carangidae

Species: *Ulua aurochs*

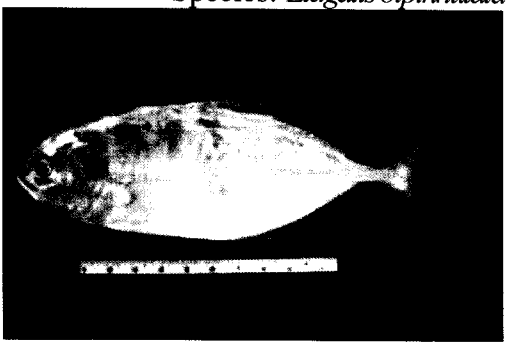

Figure 4.83 Order: Perciformes

Family: Carangidae

Species: *Alepes melanoptera*

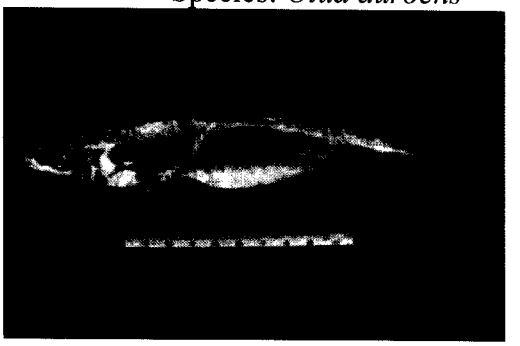

Figure 4.84 Order: Perciformes

Family: Carangidae

Species: *Decapterus* sp.

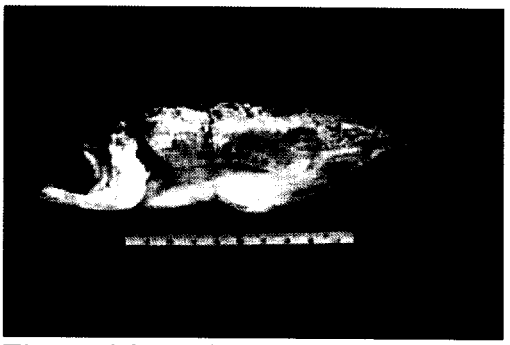

Figure 4.85 Order: Perciformes

Family: Carangidae

Species: *Alepes kleinii*

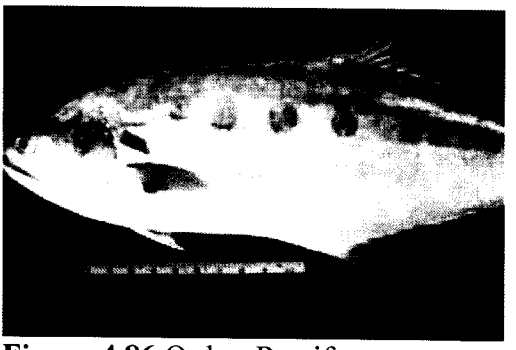

Figure 4.86 Order: Perciformes

Family: Carangidae

Species: *Scomberoides tol*

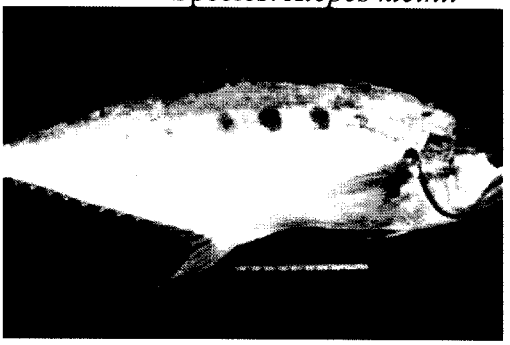

Figure 4.87 Order: Perciformes

Family: Carangidae

Species: *Scomberoides commersonnianus*

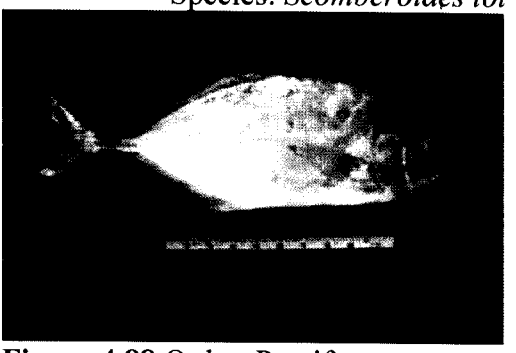

Figure 4.88 Order: Perciformes

Family: Carangidae

Species: *Carangoides plagiotaenia*

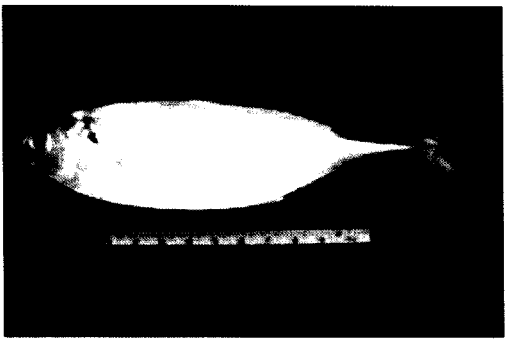

Figure 4.89 Order: Perciformes

Family: Carangidae

Species: *Megalaspis cordyla*

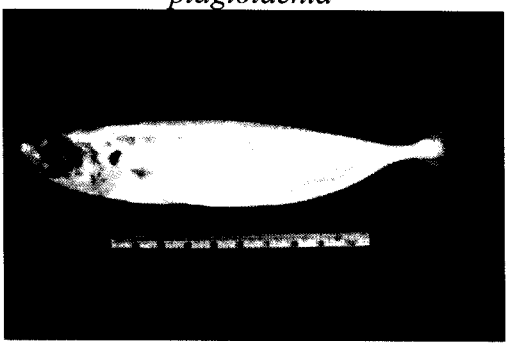

Figure 4.90 Order: Perciformes

Family: Carangidae

Species: *Decapterus macarellus*

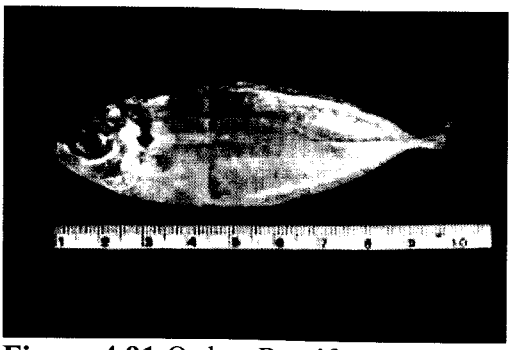

Figure 4.91 Order: Perciformes

Family: Carangidae

Species: *Selaroides leptolepis*

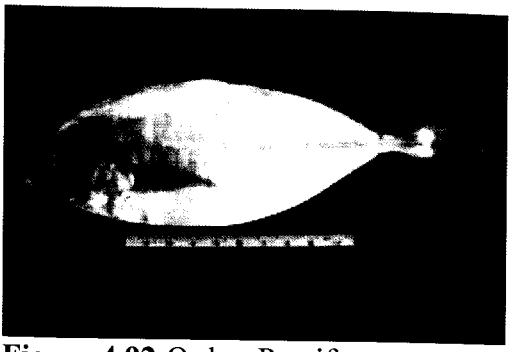

Figure 4.92 Order: Perciformes

Family: Carangidae

Species: *Alepes malam*

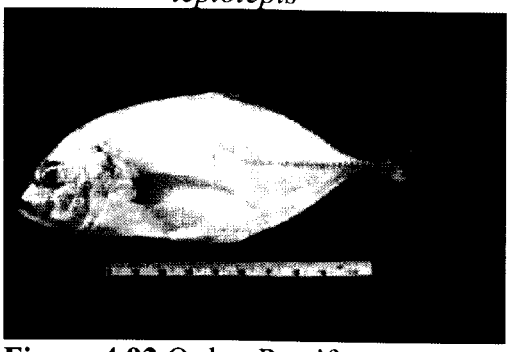

Figure 4.93 Order: Perciformes

Family: Carangidae

Species: *Caranx ignobillis*

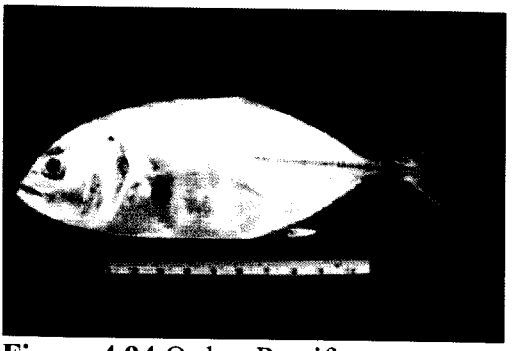

Figure 4.94 Order: Perciformes

Family: Carangidae

Species: *Carangoides gymnostethoides*

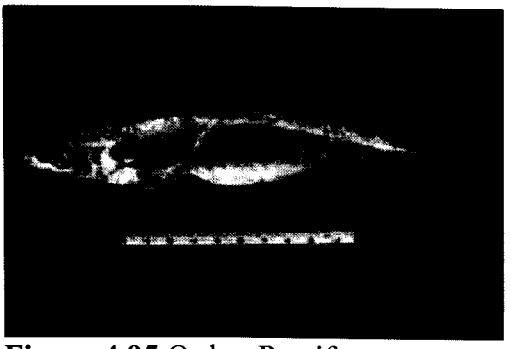

Figure 4.95 Order: Perciformes

Family: Carangidae

Species: *Decapterus macrosoma*

Figure 4.96 Order: Perciformes

Family: Carangidae

Species: *Selar boops*

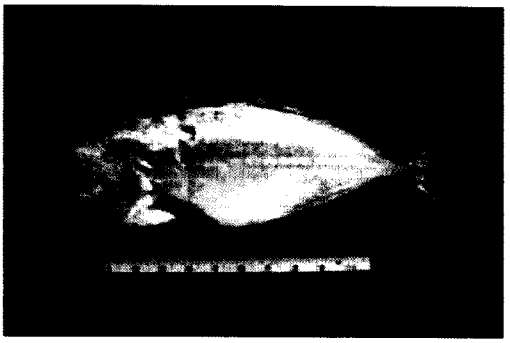

Figure 4.97 Order: Perciformes

Family: Carangidae

Species: *Selar boops*

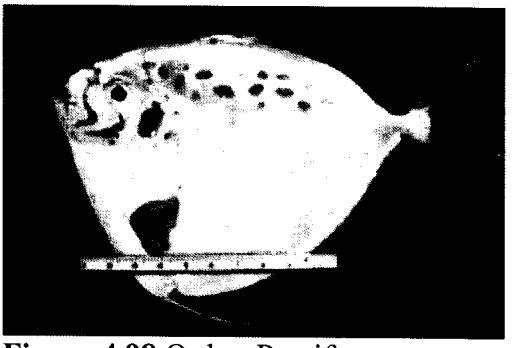

Figure 4.98 Order: Perciformes

Family: Menidae

Species: *Mene maculata*

Figure 4.99 Order: Perciformes

Family: Gerreidae

Species: *Gerres oyena*

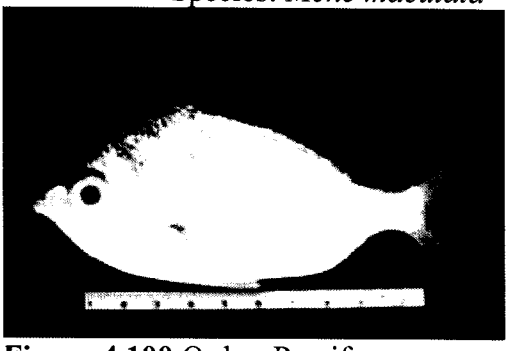

Figure 4.100 Order: Perciformes

Family: Gerreidae

Species: *Gerres* sp.

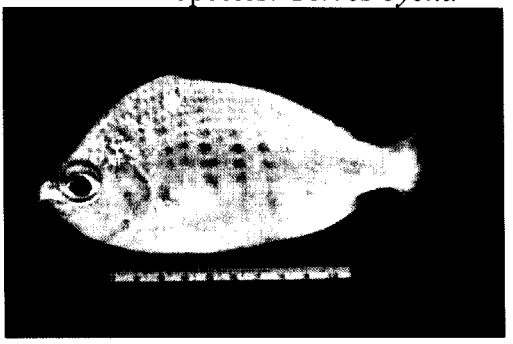

Figure 4.101 Order: Perciformes

Family: Gerreidae

Species: *Gerres filamentosus*

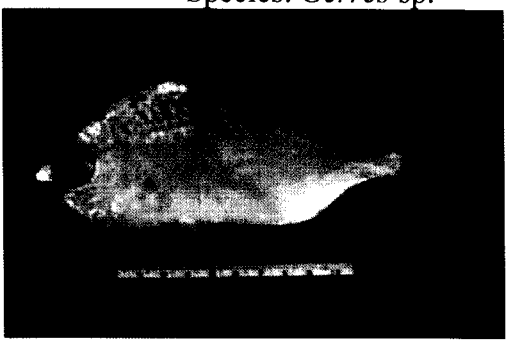

Figure 4.102 Order: Perciformes

Family: Gerreidae

Species: *Gerres argyreus*

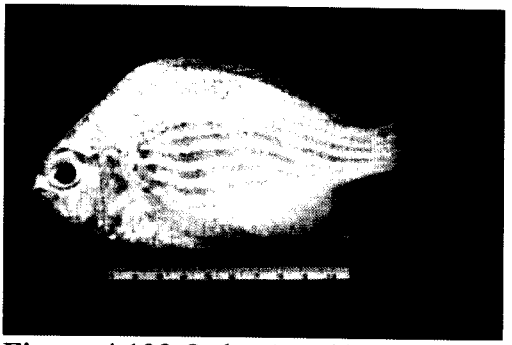

Figure 4.103 Order: Perciformes

Family: Gerreidae

Species: *Gerres decacanthus*

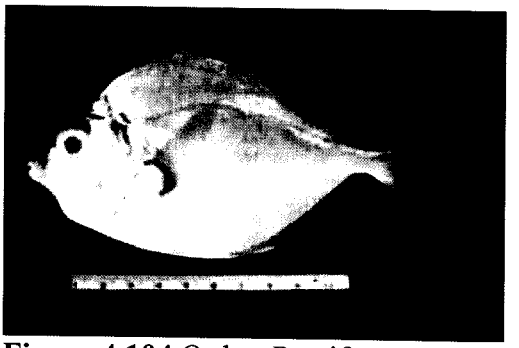

Figure 4.104 Order: Perciformes

Family: Leiognathidae

Species: *Leiognathus equulus*

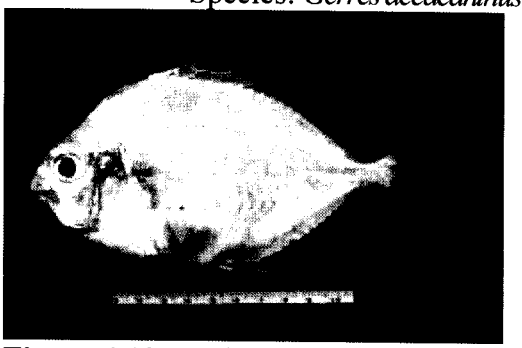

Figure 4.105 Order: Perciformes

Family: Leiognathidae

Species: *Leiognathus splendens*

Figure 4.106 Order: Perciformes

Family: Leiognathidae

Species: *Leiognathus* sp.

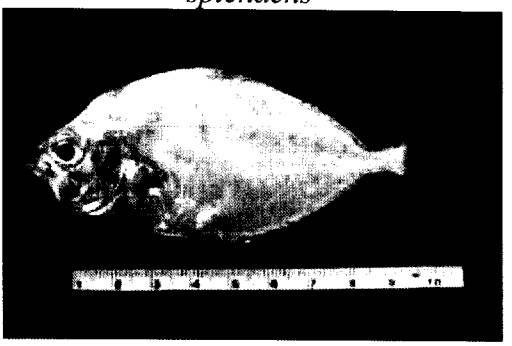

Figure 4.107 Order: Perciformes

Family: Leiognathidae

Species: *Leiognathus* sp.

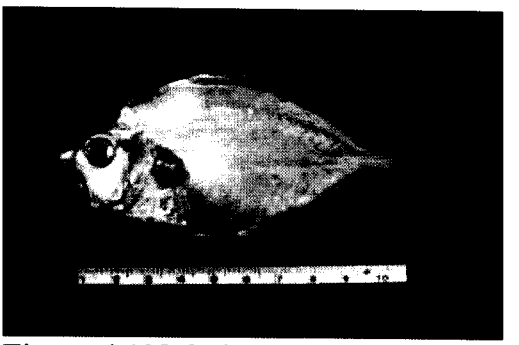

Figure 4.108 Order: Perciformes

Family: Leiognathidae

Species: *Leiognathus stercorarius*

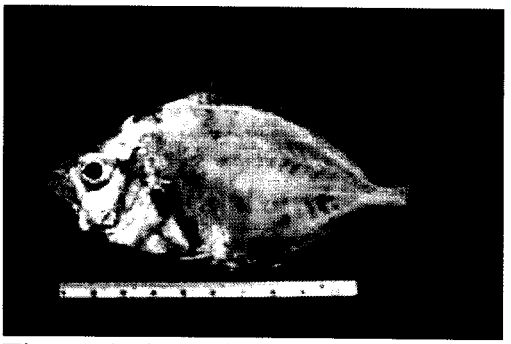

Figure 4.109 Order: Perciformes

Family: Leiognathidae

Species: *Leiognathus* sp.1

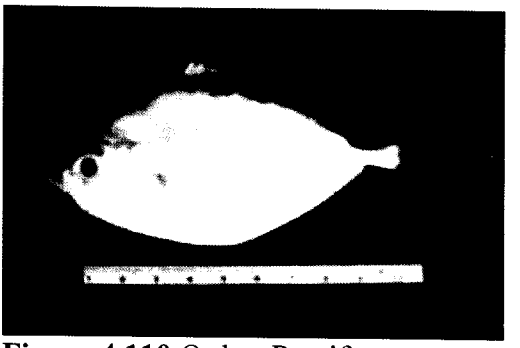

Figure 4.110 Order: Perciformes

Family: Leiognathidae

Species: *Leiognathus* sp.2

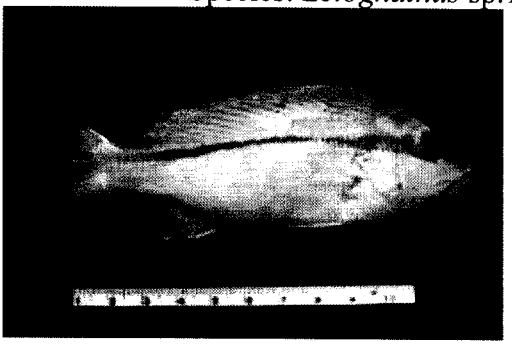

Figure 4.111 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus vitta*

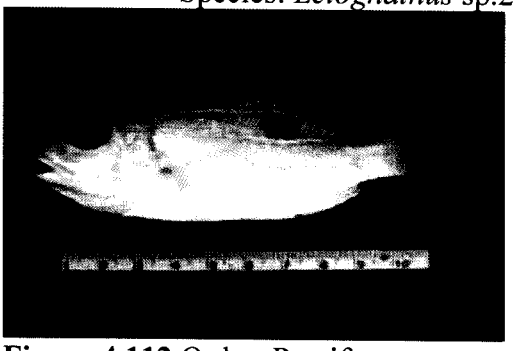

Figure 4.112 Order: Perciformes

Family: Lutjanidae

Species: *Lujanus quinquelineatus*

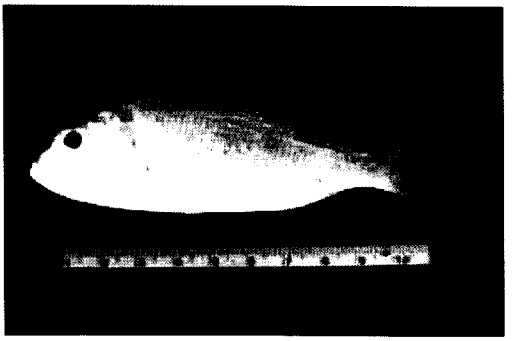

Figure 4.113 Order: Perciformes

Family: Lutjanidae

Species: *Pristipomiodes multiden*

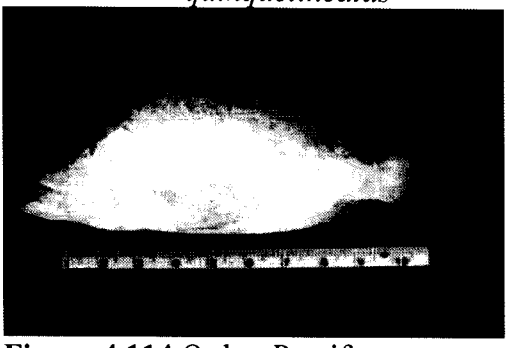

Figure 4.114 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus malabaricus*

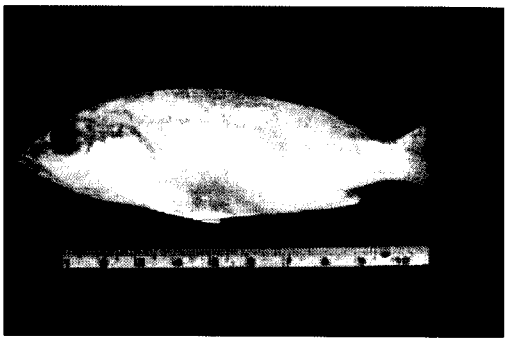

Figure 4.115 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus madras*

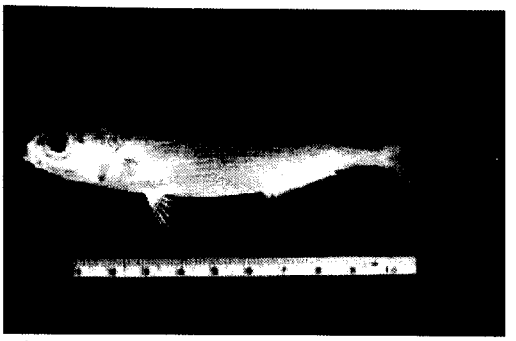

Figure 4.116 Order: Perciformes

Family: Lutjanidae

Species: *Pterocaesio* sp.

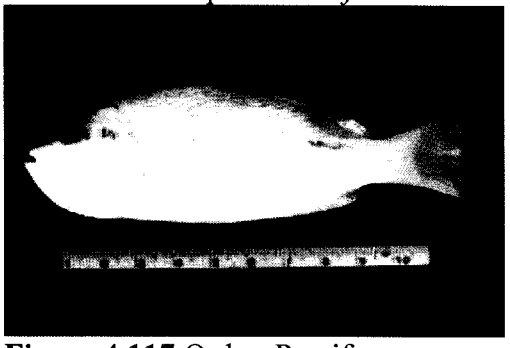

Figure 4.117 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus vitta*

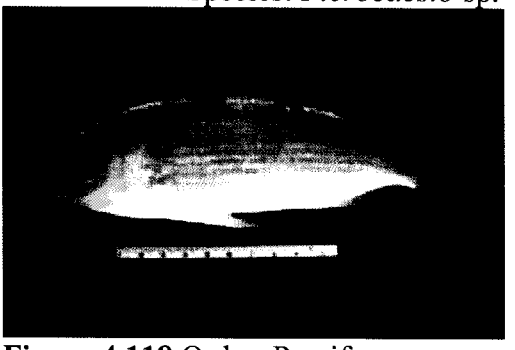

Figure 4.118 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus lutjanus*

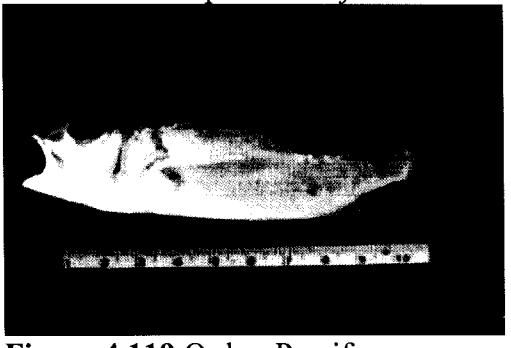

Figure 4.119 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus* sp.

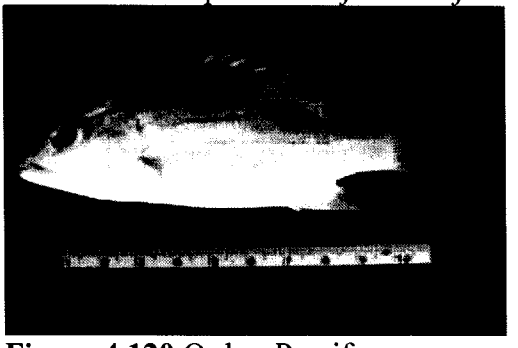

Figure 4.120 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus russelli*

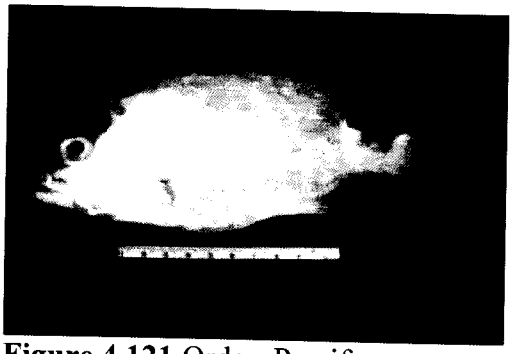

Figure 4.121 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus malabaricus*

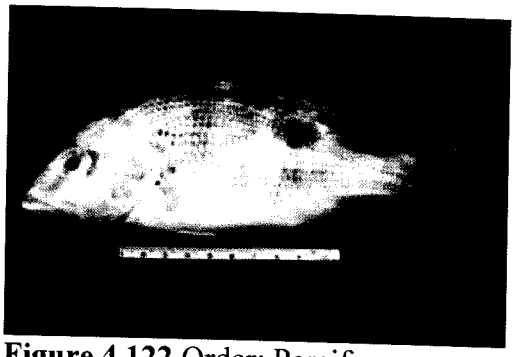

Figure 4.122 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus johnii*

Figure 4.123 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus lemniscatus*

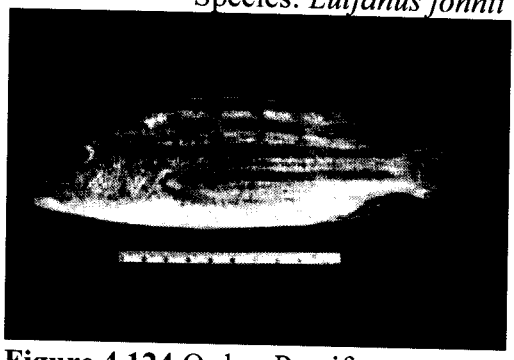

Figure 4.124 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus decussatus*

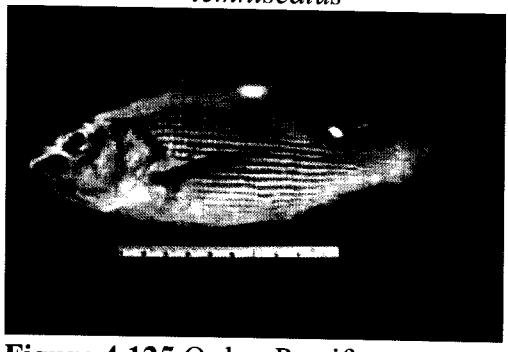

Figure 4.125 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus bohar*

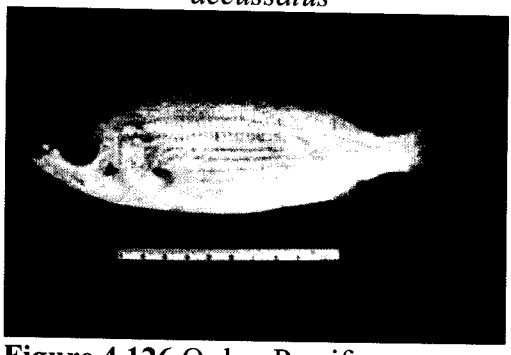

Figure 4.126 Order: Perciformes

Family: Lutjanidae

Species: *Lutjanus lutjanus*

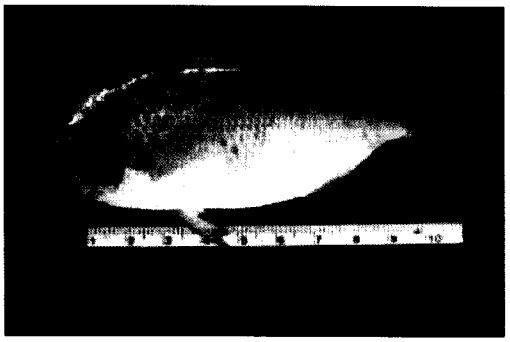

Figure 4.133 Order: Perciformes

Family: Caesionidae

Species: *Caesio cuning*

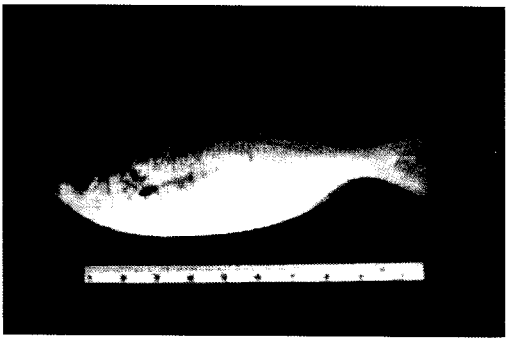

Figure 4.134 Order: Perciformes

Family: Caesionidae

Species: *Caesio xanthonota*

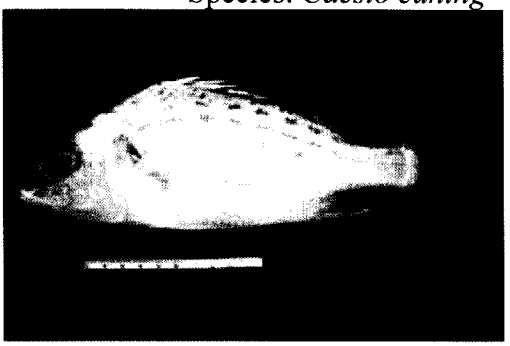

Figure 4.135 Order: Perciformes

Family: Haemulidae

Species: *Pomadasys kakaan*

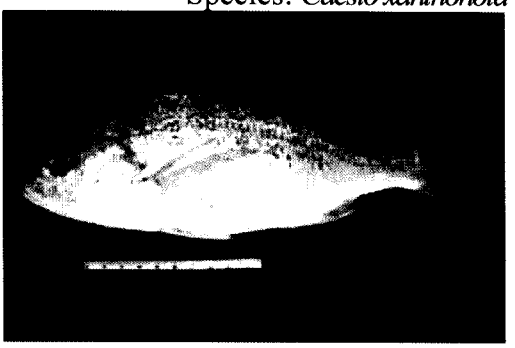

Figure 4.136 Order: Perciformes

Family: Haemulidae

Species: *Pomadasys argyreus*

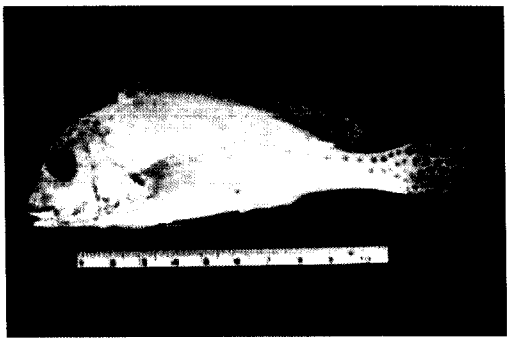

Figure 4.137 Order: Perciformes

Family: Haemulidae

Species: *Plectorhinchus flavomaculatus*

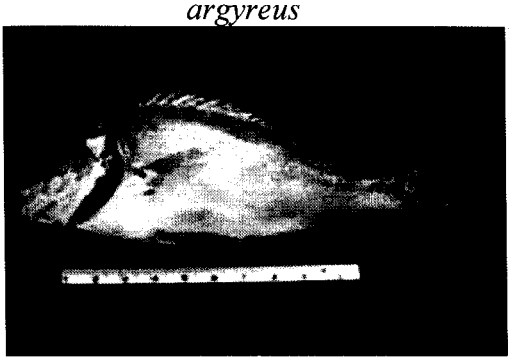

Figure 4.138 Order: Perciformes

Family: Haemulidae

Species: *Diagramma pictum*

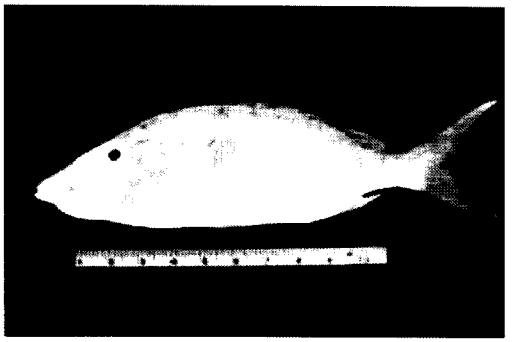

Figure 4.139 Order: Perciformes

Family: Lethrinidae

Species: *Lethrinus microdon*

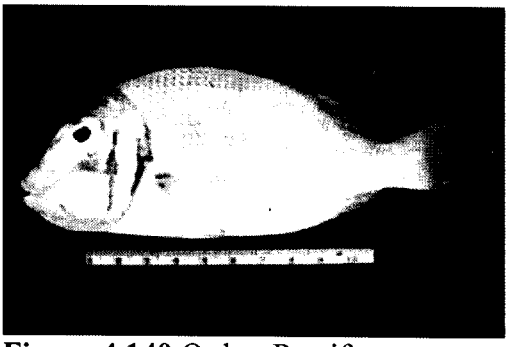

Figure 4.140 Order: Perciformes

Family: Lethrinidae

Species: *Lethrinus* sp.

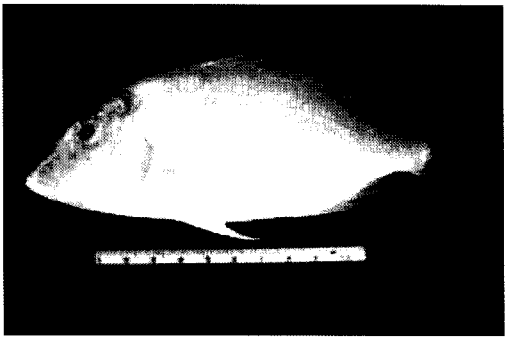

Figure 4.141 Order: Perciformes

Family: Lethrinidae

Species: *Lethrinus lentjan*

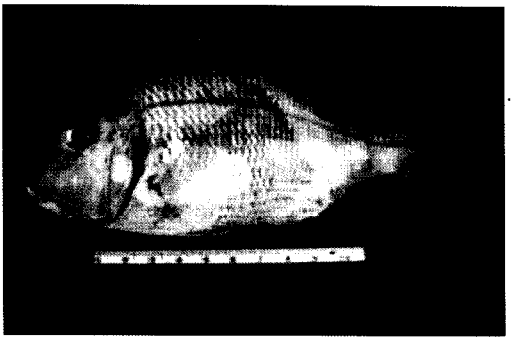

Figure 4.142 Order: Perciformes

Family: Lethrinidae

Species: *Lethrinus ornatus*

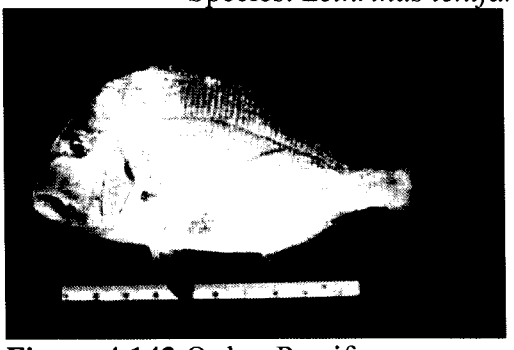

Figure 4.143 Order: Perciformes

Family: Sparidae

Species: *Argyrops spinifer*

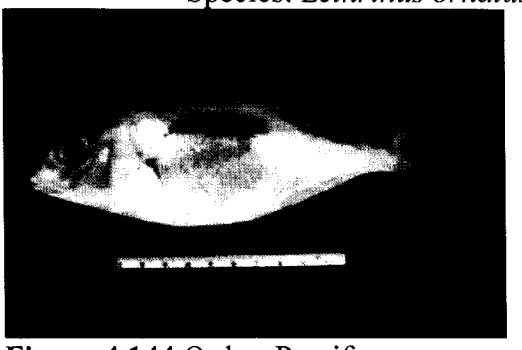

Figure 4.144 Order: Perciformes

Family: Nemipteridae

Species: *Scolopsis monogramma*

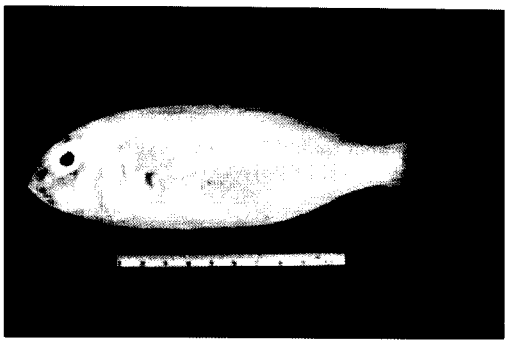

Figure 4.145 Order: Perciformes

Family: Nemipteridae

Species: *Scolopsis taenioptera*

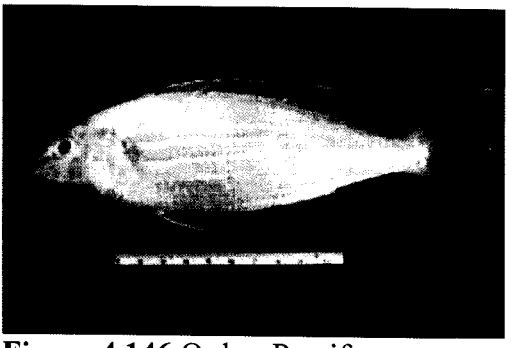

Figure 4.146 Order: Perciformes

Family: Nemipteridae

Species: *Nemipterus tambuloides*

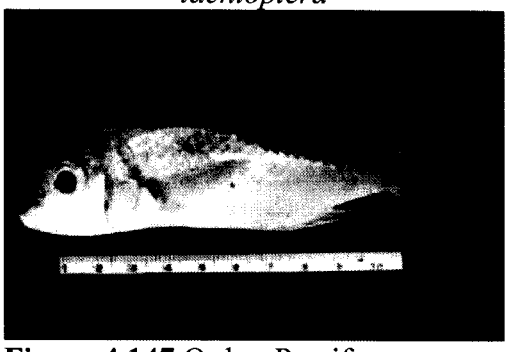

Figure 4.147 Order: Perciformes

Family: Nemipteridae

Species: *Scolopsis* sp.

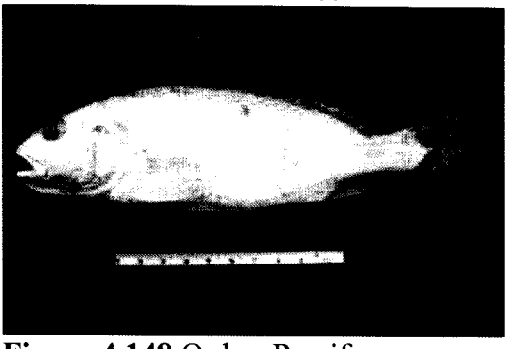

Figure 4.148 Order: Perciformes

Family: Sciaenidae

Species: *Johnius macropterus*

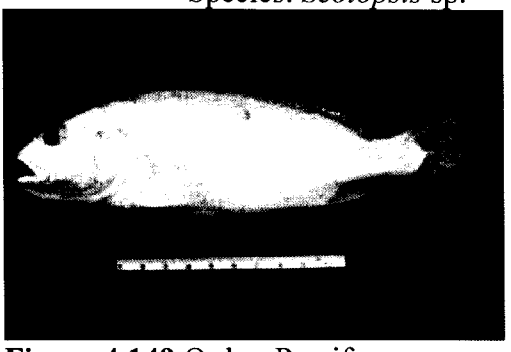

Figure 4.149 Order: Perciformes

Family: Sciaenidae

Species: *Otolithes ruber*

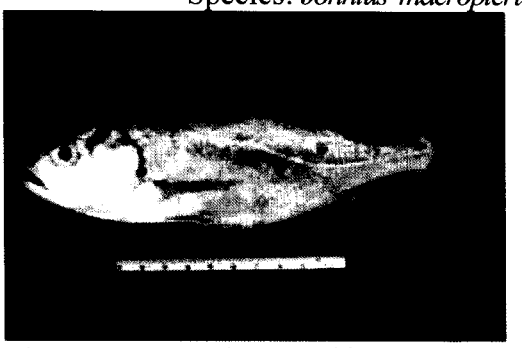

Figure 4.150 Order: Perciformes

Family: Sciaenidae

Species: *Johnius macrorhynus*

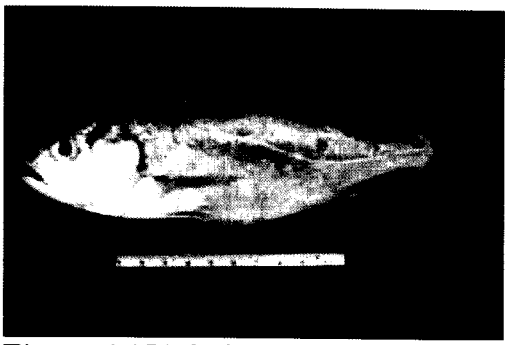

Figure 4.151 Order: Perciformes

Family: Sciaenidae

Species: *Pennahia pawak*

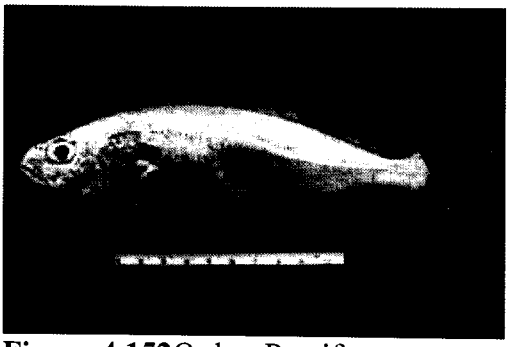

Figure 4.152 Order: Perciformes

Family: Sciaenidae

Species: *Otolithoides pama*

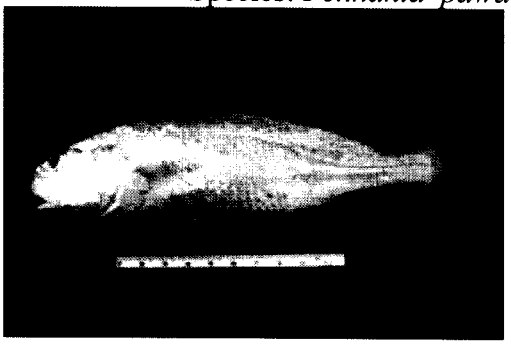

Figure 4.153 Order: Perciformes

Family: Sciaenidae

Species: *Johnius osseus*

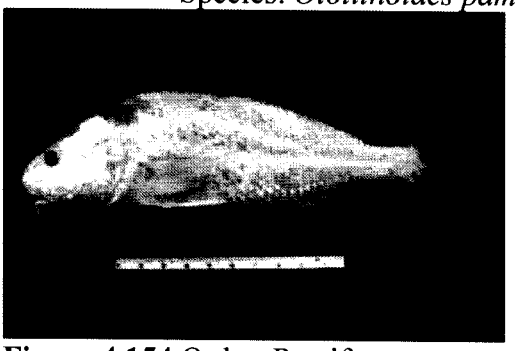

Figure 4.154 Order: Perciformes

Family: Sciaenidae

Species: *Dendrophysa russelli*

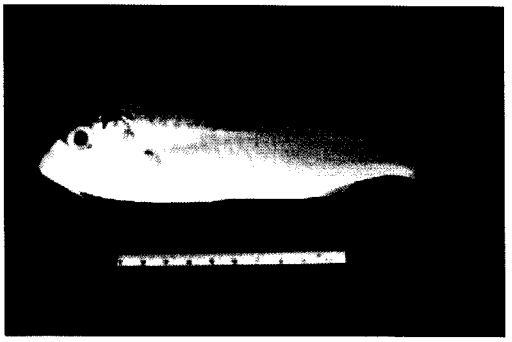

Figure 4.155 Order: Perciformes

Family: Mullidae

Species: *Upeneus vittatus*

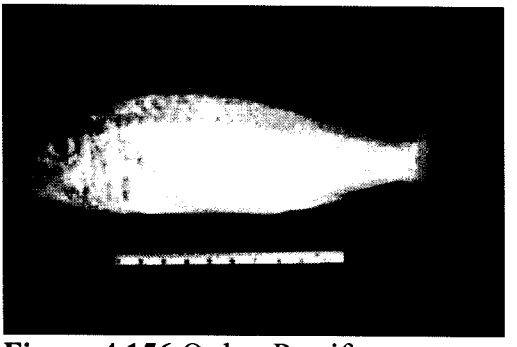

Figure 4.156 Order: Perciformes

Family: Mullidae

Species: *Upeneus sulphureus*

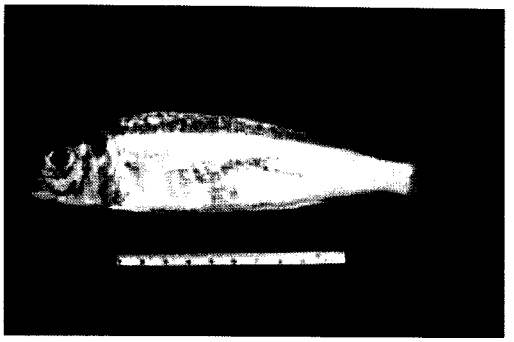

Figure 4.157 Order: Perciformes

Family: Mullidae

Species: *Upeneus moluccensis*

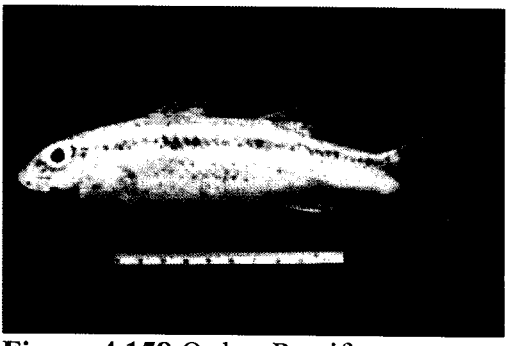

Figure 4.158 Order: Perciformes

Family: Mullidae

Species: *Upeneus tragular*

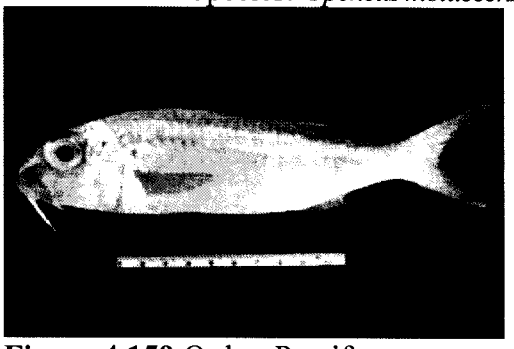

Figure 4.159 Order: Perciformes

Family: Mullidae

Species: *Mulloidichthys vanicolensis*

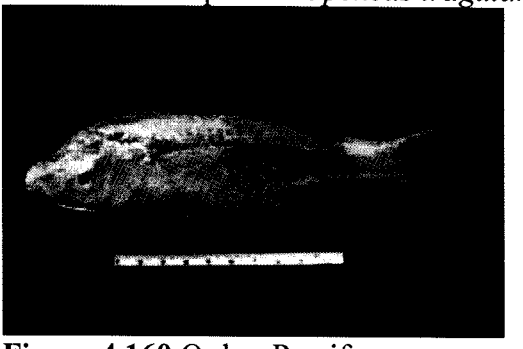

Figure 4.160 Order: Perciformes

Family: Mullidae

Species: *Parupeneus cyclostomus*

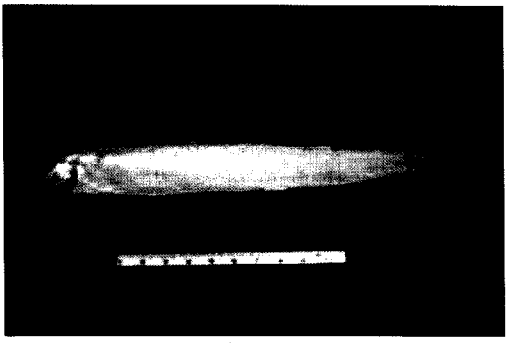

Figure 4.161 Order: Perciformes

Family: Cepolidae

Species: *Acanthocepola abbreviata*

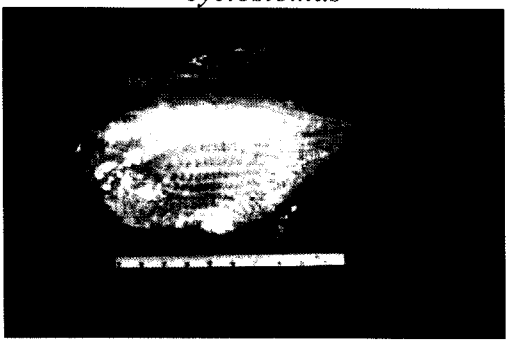

Figure 4.162 Order: Perciformes

Family: Pempheridae

Species: *Pempheris oualensis*

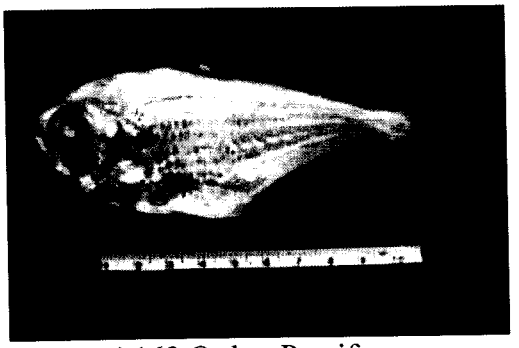

Figure 4.163 Order: Perciformes

Family: Pempheridae

Species: *Pempheris vanicolensis*

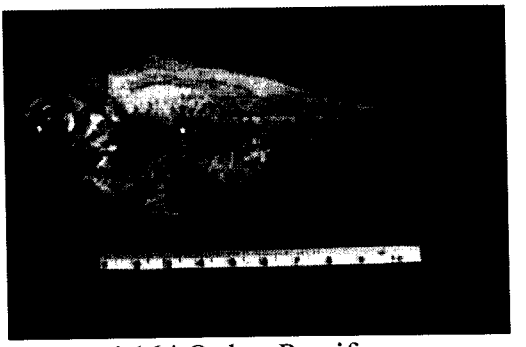

Figure 4.164 Order: Perciformes

Family: Pempheridae

Species: *Pempheris adusta*

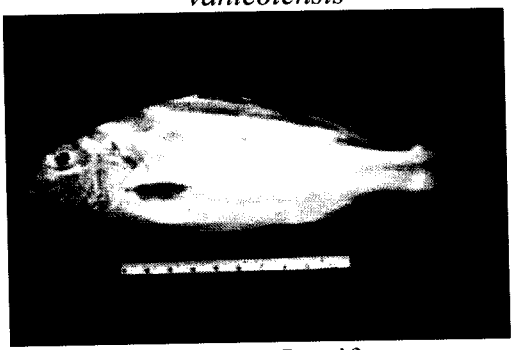

Figure 4.165 Order: Perciformes

Family: Teraponidae

Species: *Terapon jarbua*

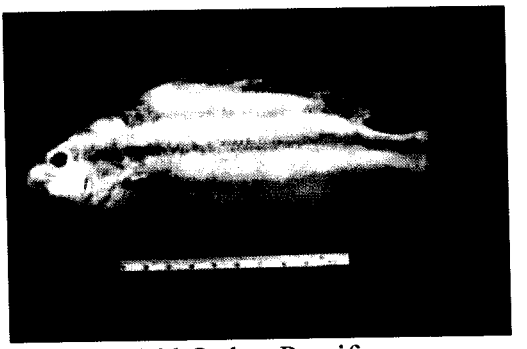

Figure 4.166 Order: Perciformes

Family: Teraponidae

Species: *Terapon theraps*

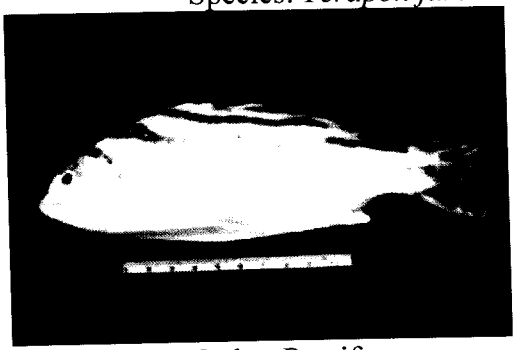

Figure 4.167 Order: Perciformes

Family: Teraponidae

Species: *Terapon* sp.1

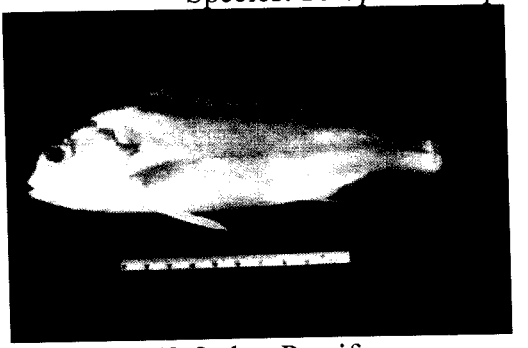

Figure 4.168 Order: Perciformes

Family: Teraponidae

Species: *Terapon* sp.2

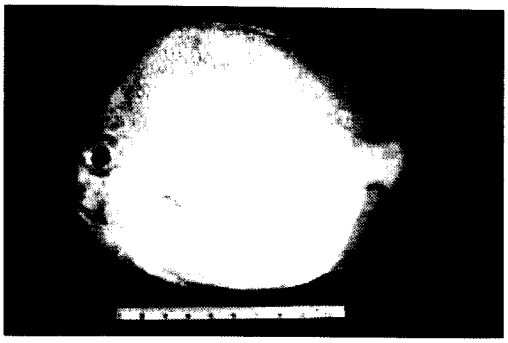

Figure 4.169 Order: Perciformes

Family: Ephippidae

Species: *Ephippus orbis*

Figure 4.170 Order: Perciformes

Family: Ephippidae

Species: *Platax orbiculalis*

Figure 4.171 Order: Perciformes Ra2sp1

Family: Ephippidae

Species: *Platax teria*

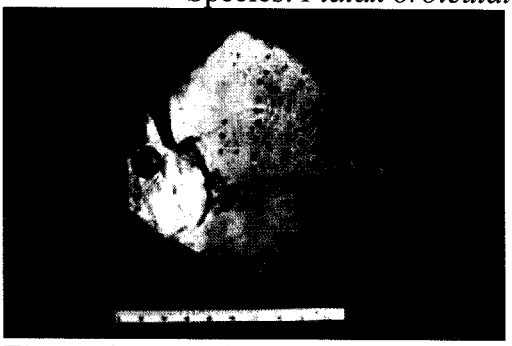

Figure 4.172 Order: Perciformes

Family: Drepenidae

Species: *Drepane punctata*

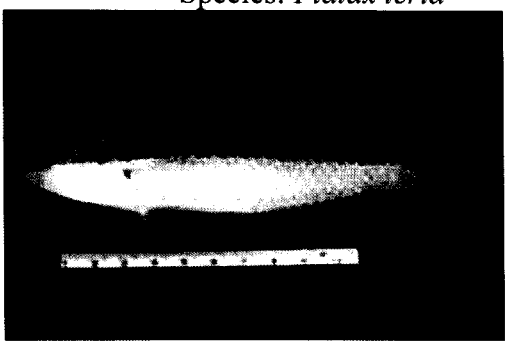

Figure 4.173 Order: Perciformes

Family: labridae

Species: *Halichoeres bicolor*

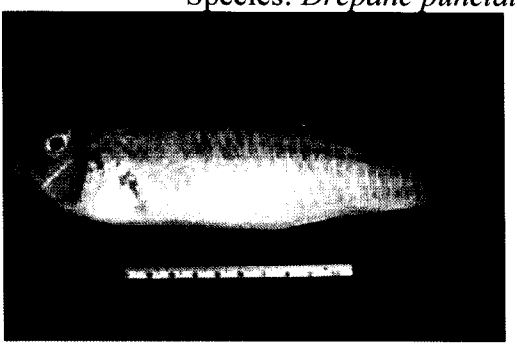

Figure 4.174 Order: Perciformes

Family: labridae

Species: *Cymolutes praetextatus*

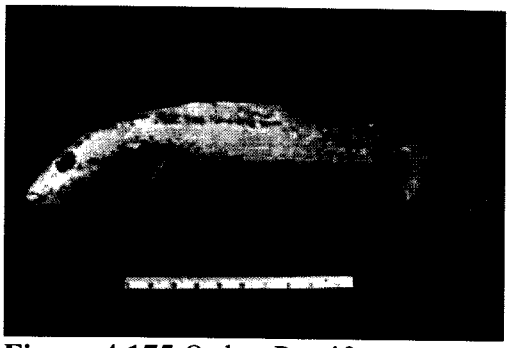

Figure 4.175 Order: Perciformes

Family: labridae

Species: *Cheilinus* sp.1

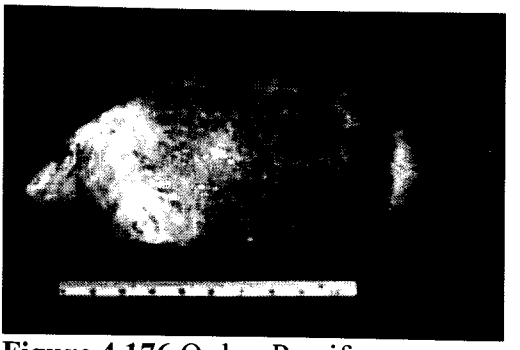

Figure 4.176 Order: Perciformes

Family: labridae

Species: *Cheilinus* sp.2

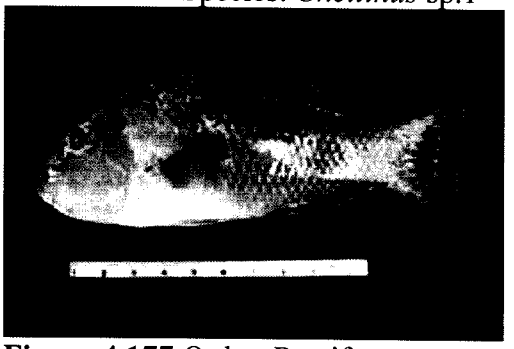

Figure 4.177 Order: Perciformes

Family: labridae

Species: *Hemigymnus melapterus*

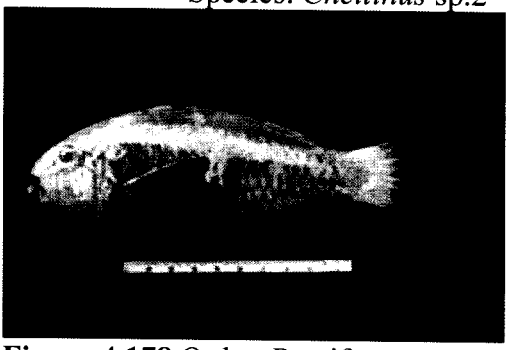

Figure 4.178 Order: Perciformes

Family: Scaridae

Species: *Scarus* sp.1

Figure 4.179 Order: Perciformes

Family: Scaridae

Species: *Scarus* sp.2

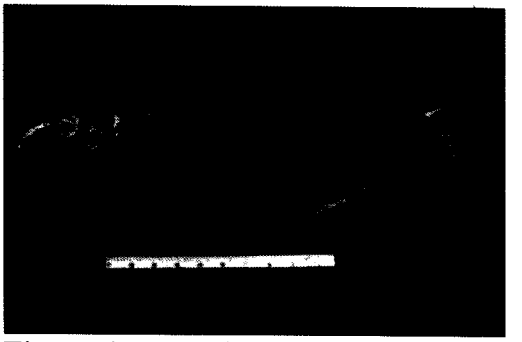

Figure 4.180 Order: Perciformes

Family: Scaridae

Species: *Scarus tricolor*

Figure 4.181 Order: Perciformes

Family: Scaridae

Species: *Scarus rivulatus*

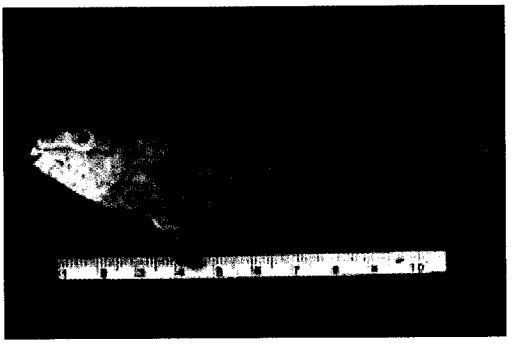

Figure 4.182 Order: Perciformes PuSp51.1

Family: Scaridae

Species: *Scarus quoyi*

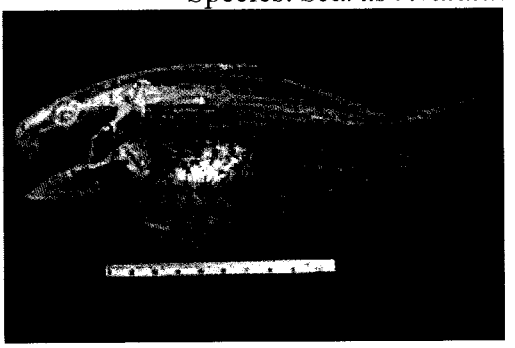

Figure 4.183 Order: Perciformes

Family: Scaridae

Species: *Scarus frenatus*

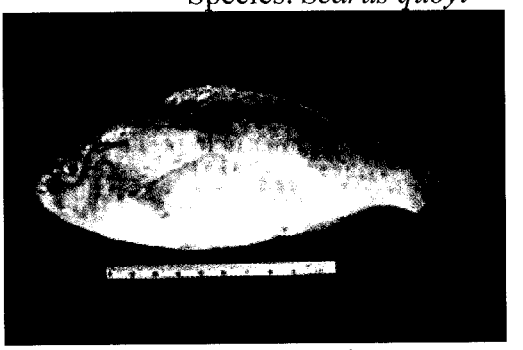

Figure 4.184 Order: Perciformes

Family: Scaridae

Species: *Scarus ghobban*

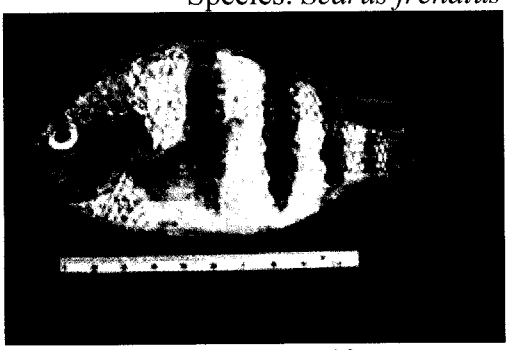

Figure 4.185 Order: Perciformes

Family: Pomacentridae

Species: *Abudefduf* sp.

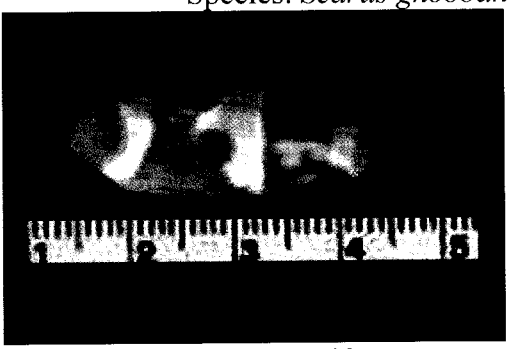

Figure 4.186 Order: Perciformes

Family: Pomacentridae

Species: *Amphiprion ocellaris*

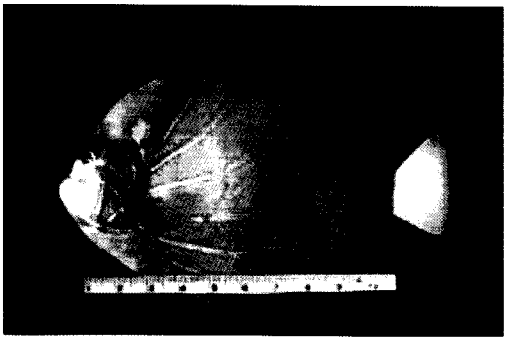

Figure 4.187 Order: Perciformes

Family: Pomacantridae

Species: *Pomacanthus annularis*

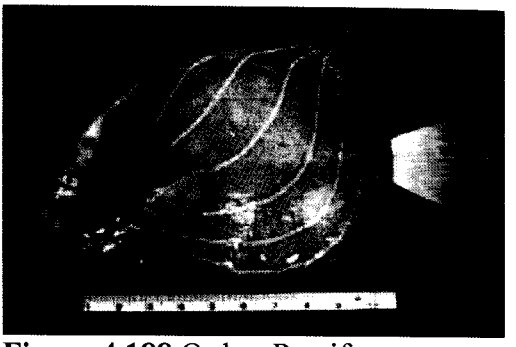

Figure 4.188 Order: Perciformes

Family: Pomacantridae

Species: *Pomacanthus annularis*

Figure 4.189 Order: Perciformes

Family: Scatophagidae

Species: *Scatophagus argus*

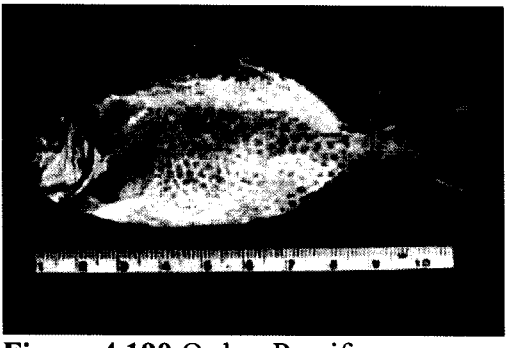

Figure 4.190 Order: Perciformes

Family: Siganidae

Species: *Siganus guttatus*

Figure 4.191 Order: Perciformes

Family: Siganidae

Species: *Siganus javus*

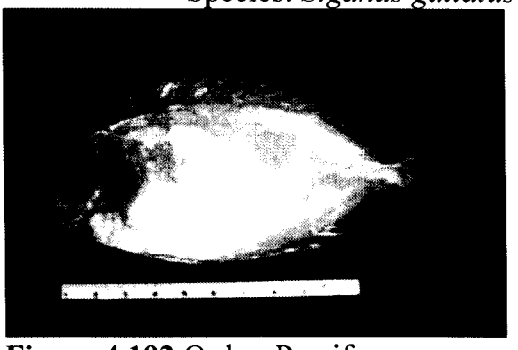

Figure 4.192 Order: Perciformes

Family: Siganidae

Species: *Siganus* sp.

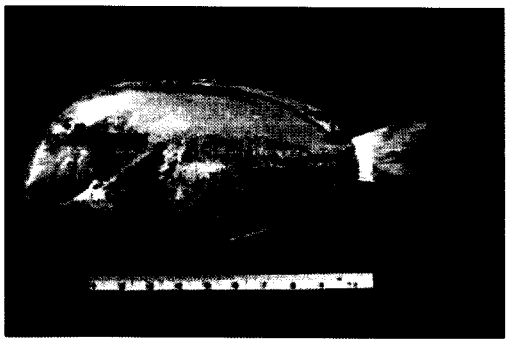

Figure 4.193 Order: Perciformes

Family: Acanthuridae

Species: *Acanthurus nigricauda*

Figure 4.194 Order: Perciformes

Family: Acanthuridae

Species: *Acanthurus nigrofuscus*

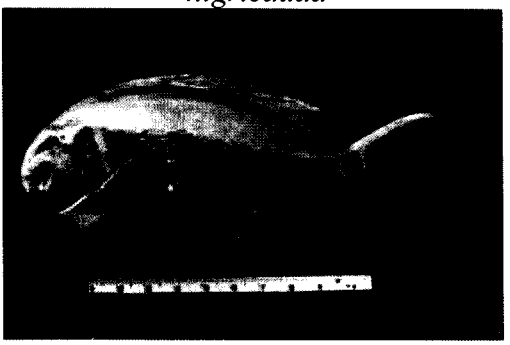

Figure 4.195 Order: Perciformes

Family: Acanthuridae

Species: *Acanthurus xanthopterus*

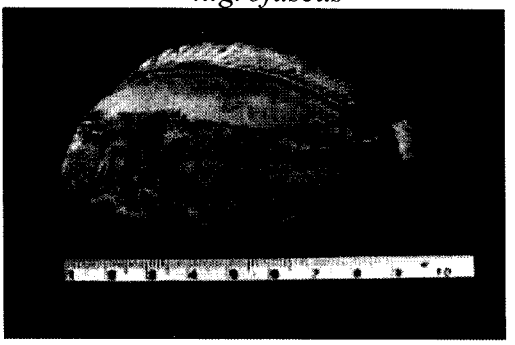

Figure 4.196 Order: Perciformes

Family: Acanthuridae

Species: *Acanthurus* sp.

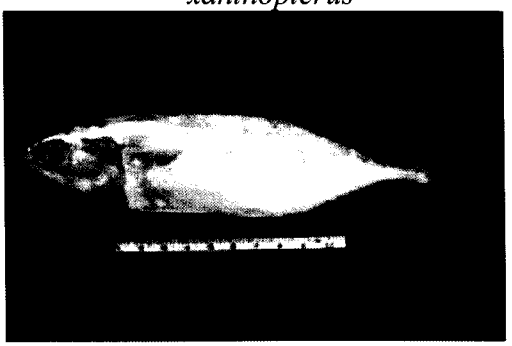

Figure 4.197 Order: Perciformes

Family: Scombridae

Species: *Rastelliger kanagurta*

Figure 4.198 Order: Perciformes

Family: Scombridae

Species: *Thunnus albacares*

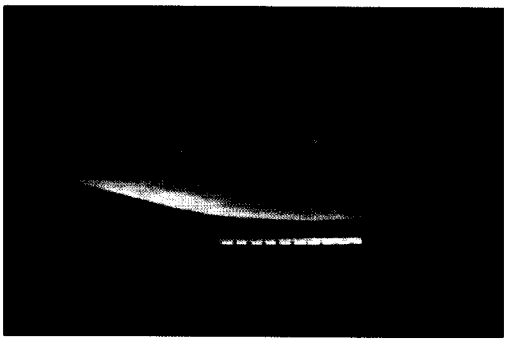

Figure 4.199 Order: Perciformes

Family: Scombridae

Species: *Scomber japonicus*

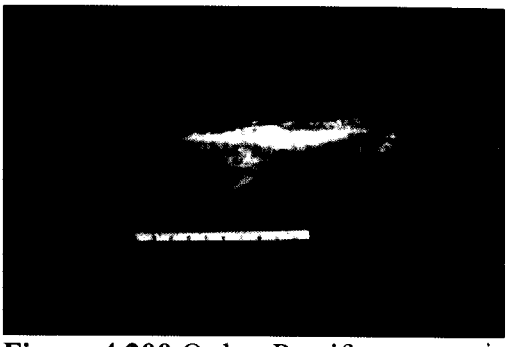

Figure 4.200 Order: Perciformes

Family: Scombridae

Species: *Sacomberomorus commersoni*

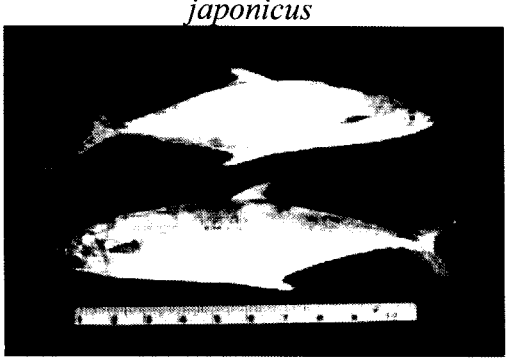

Figure 4.201 Order: Perciformes

Family: Scombridae

Species: *Sacomberomorus guttatus*

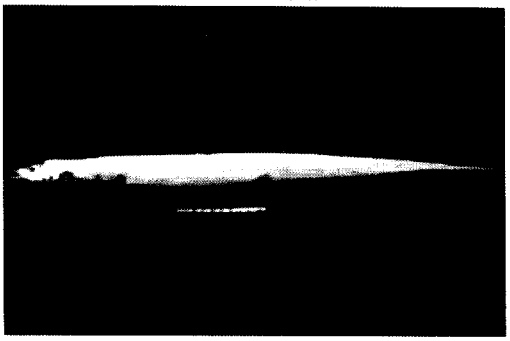

Figure 4.202 Order: Perciformes

Family: Trichiuridae

Species: *Trichiurus* sp.

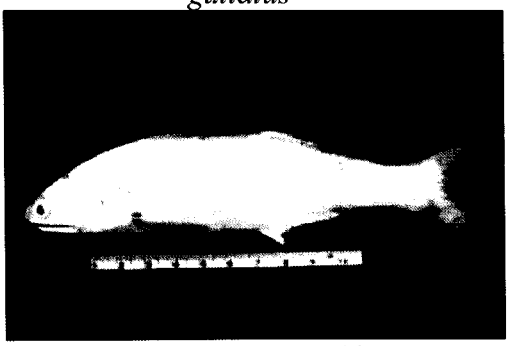

Figure 4. 203 Order: Perciformes

Family: Polynemidae

Species: *Eleutheronema tetradactylum*

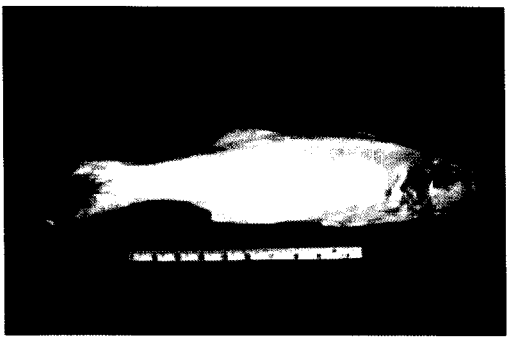

Figure 4. 204 Order: Perciformes

Family: Polynemidae

Species: *Eleutheronema tetradactylum*

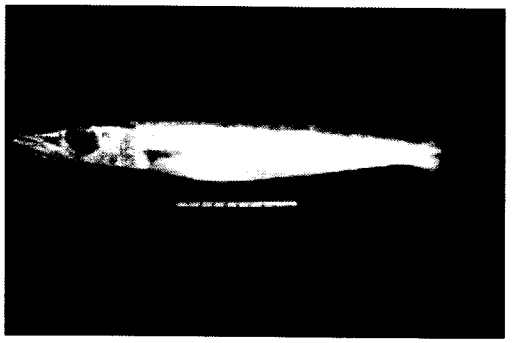

Figure 4.205 Order: Perciformes

Family: Sphyraenidae

Species: *Sphyraena forsteri*

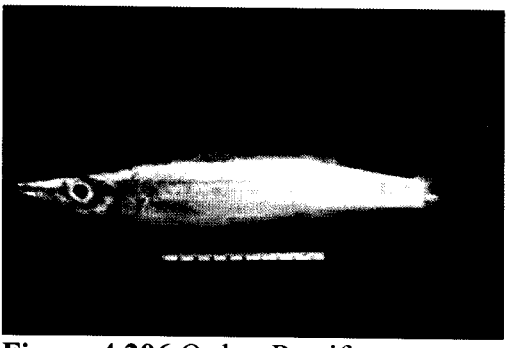

Figure 4.206 Order: Perciformes

Family: Sphyraenidae

Species: *Sphyraena obtusata*

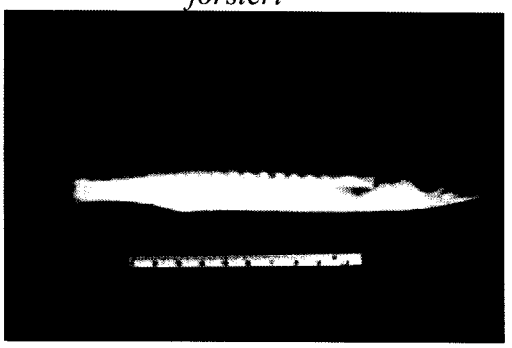

Figure 4.207 Order: Perciformes

Family: Sphyraenidae

Species: *Sphyraena jello*

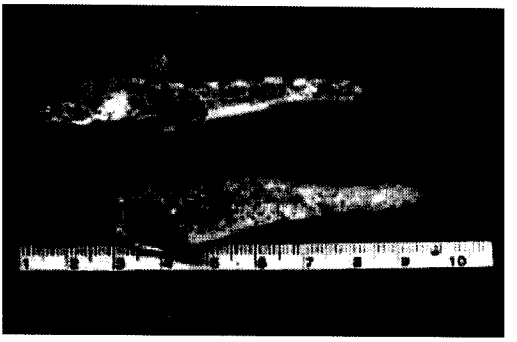

Figure 4.208 Order: Perciformes

Family: Gobiidae

Species: *Periophthalmus walailaku*

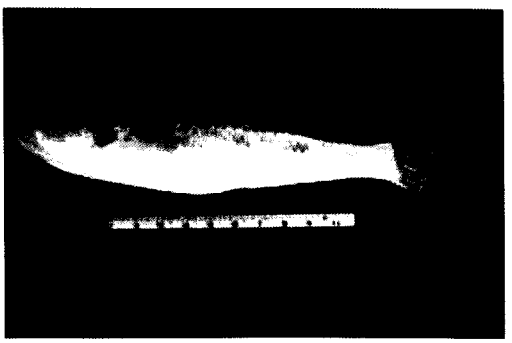

Figure 4.209 Order: Perciformes

Family: Gobiidae

Species: *Glossogobius aureus*

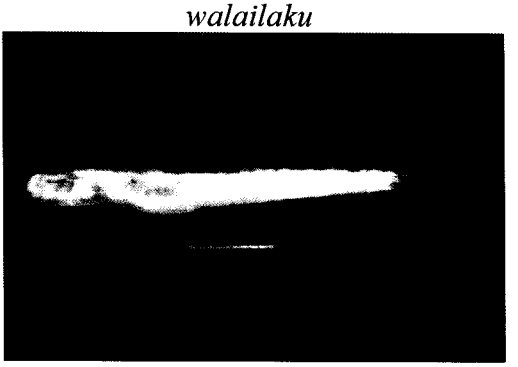

Figure 4.210 Order: Perciformes

Family: Gobiidae

Species: *Pseudapocryptes borneensis*

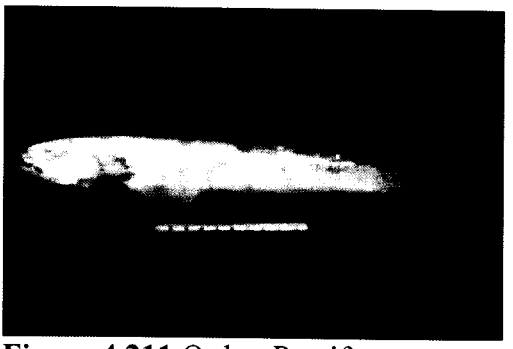

Figure 4.211 Order: Perciformes

Family: Gobiidae

Species: *Parapocryptes serperaster*

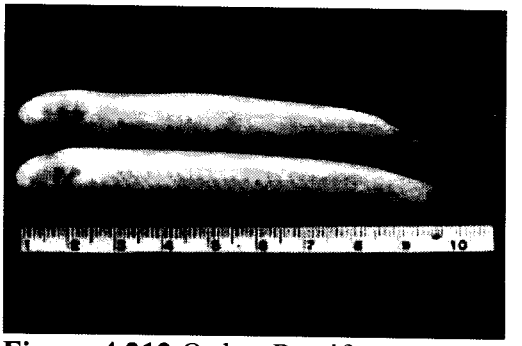

Figure 4.212 Order: Perciformes

Family: Gobiidae

Species: *Trypauchen vagina*

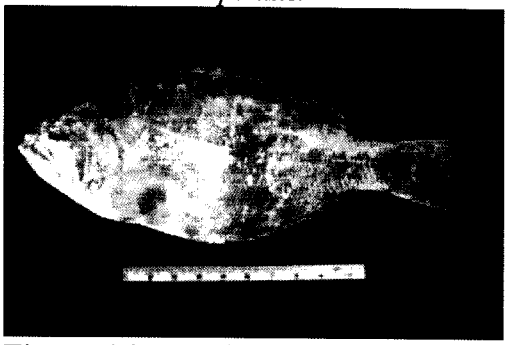

Figure 4.213 Order: Pleuronectiformes

Family: Psettodidae

Species: *Psettodes erumei*

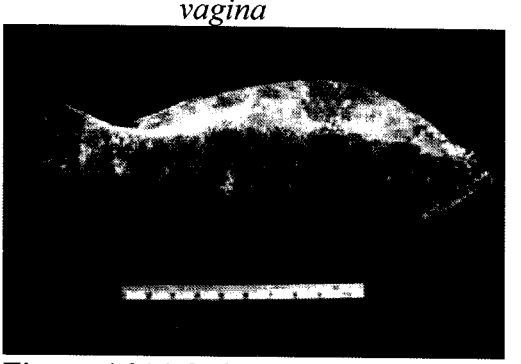

Figure 4.214 Order: Pleuronectiformes

Family: Psettodidae

Species: *Psettodes erumei*

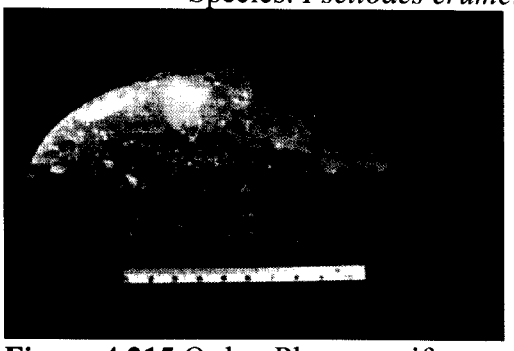

Figure 4.215 Order: Pleuronectiformes

Family: Paralichthyidae

Species: *Pseudorhombus elevatus*

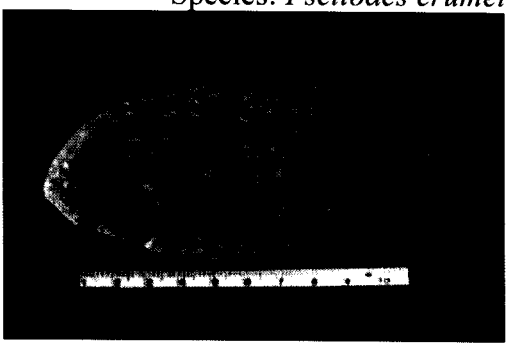

Figure 4.216 Order: Pleuronectiformes

Family: Paralichthidae

Species: *Pseudorhombus elevatus*

Figure 4.217 Order: Pleuronectiformes

Family: Soleidae

Species: *Zebrias zebra*

Figure 4.218 Order: Pleuronectiformes

Family: Soleidae

Species: *Zebrias zebra*

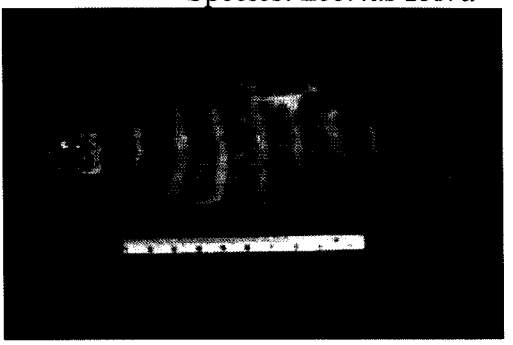

Figure 4.219 Order: Pleuronectiformes

Family: Soleidae

Species: *Zebrias ovata*

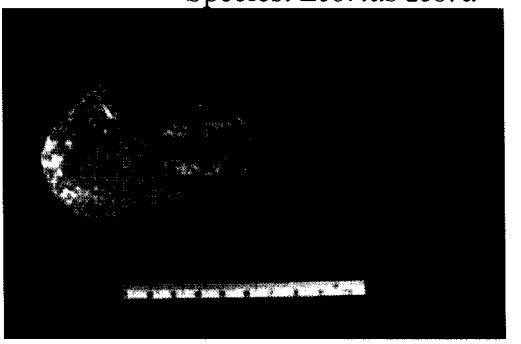

Figure 4.220 Order: Pleuronectiformes

Family: Soleidae

Species: *Pardachirus pavoninus*

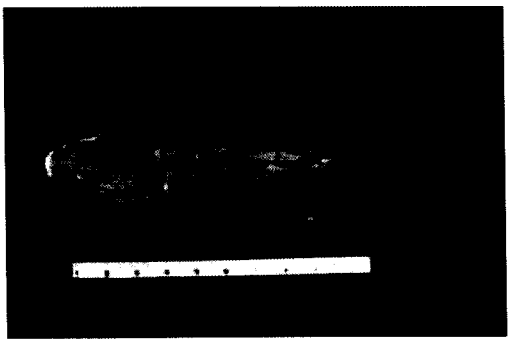

Figure 4.221 Order: Pleuronectiformes

Family: Cynoglossidae

Species: *Paraplagusia bilineata*

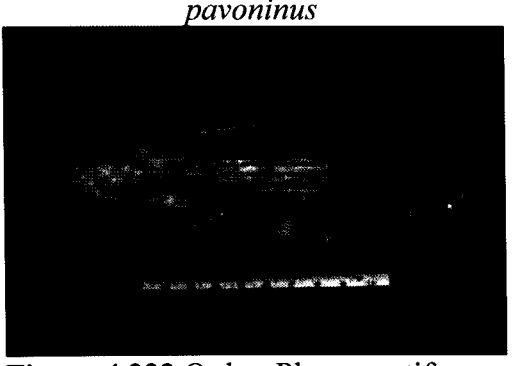

Figure 4.222 Order: Pleuronectiformes

Family: Cynoglossidae

Species: *Cynoglossus bilineatus*

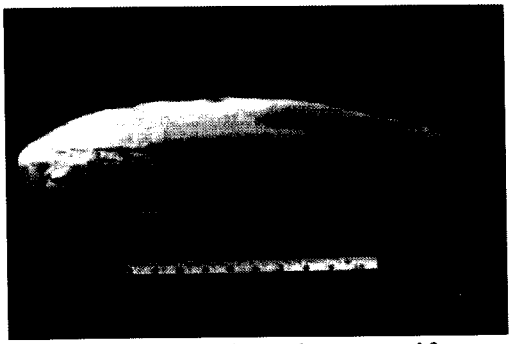

Figure 4.223 Order: Pleuronectiformes

Family: Cynoglossidae

Species: *Cynoglossus cynoglossus*

Figure 4.224 Order: Pleuronectiformes

Family: Cynoglossidae

Species: *Cynoglossus arel*

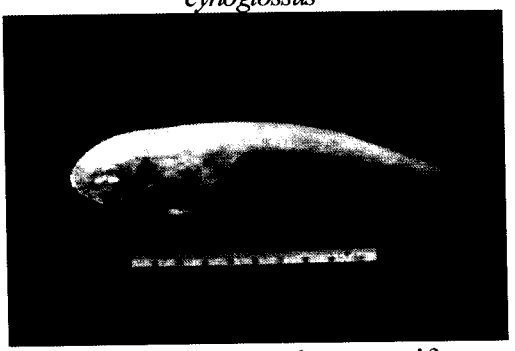

Figure 4.225 Order: Pleuronectiformes

Family: Cynoglossidae

Species: *Cynoglossus* sp.1

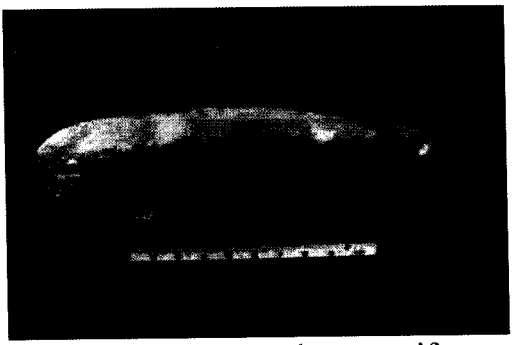

Figure 4.226 Order: Pleuronectiformes

Family: Cynoglossidae

Species: *Cynoglossus* sp.1

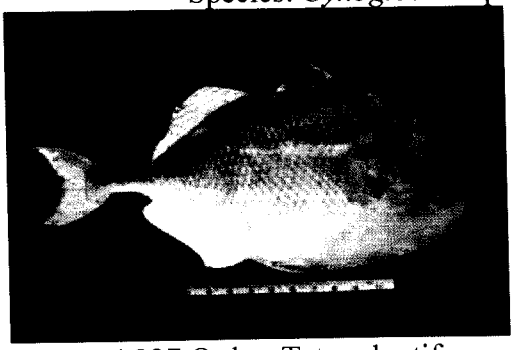

Figure 4.227 Order: Tetraodontiformes

Family: Balistidae

Species: *Abalistes stellatus*

Figure 4.228 Order: Tetraodontiformes

Family: Monacanthidae

Species: *Aluterus monoceros*

CURRICULUM VITAE

Mr. Suwit Jitpukdee was born on November 28, 1963 in Phattalung province. He received his B. Ed. in Biological Sciences from Thaksin University in 1994 and his M. Sc. in Zoology from Kasetsart University in 1999. He then worked as a lecturer in Biology Department at Rajamangala Institute of Technology, Trang. He began his Ph.D. studies in 2001. He is now Asst. Professor of Biology at Rajamangala University of Technology Srivijaya, Trang province. His research interests are in fish and marine biology.