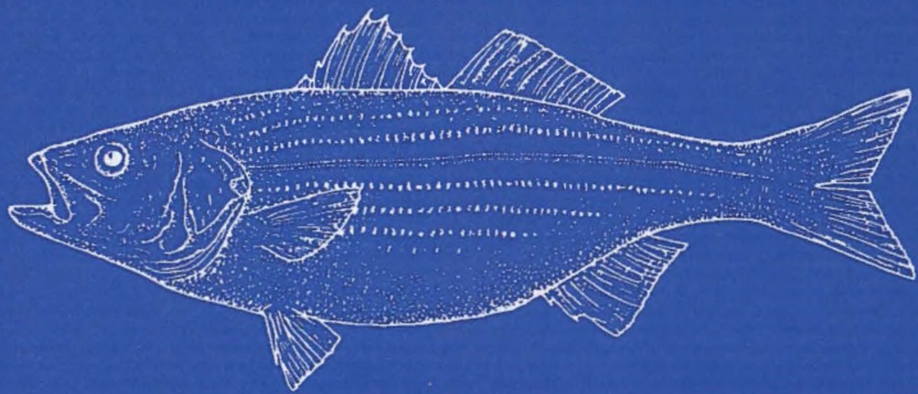
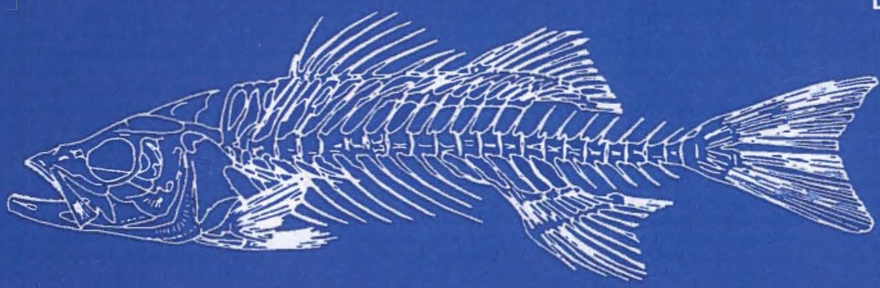
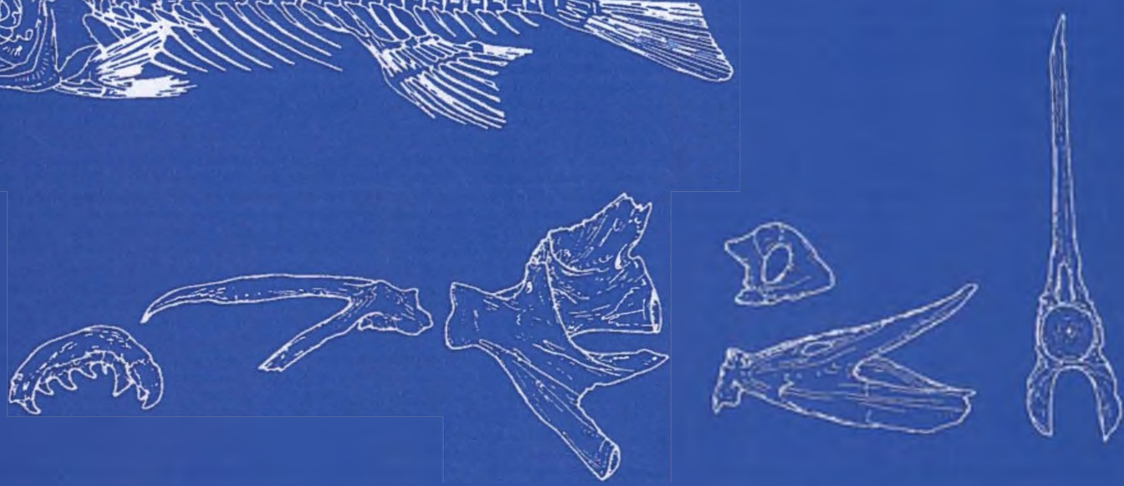
Marine Fish Osteology

A Manual for Archaeologists



Debbi Yee Cannon





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Debbi Yee Cannon

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Acknowledgements

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Introduction

The present work is a fully illustrated field and laboratory manual of practical interest to the experienced fish bone analyst and the student of fish osteology. It was especially designed with regard to the particular problems and requirements of archaeologists. In the field it is intended to be useful for preliminary identification when comparative material is not available. As a laboratory handbook, it will familiarize the user with all the bony elements to be found in archaeological and comparative material. Because the drawings are of disarticulated elements, and organized according to anatomical origin, this convenient illustrated guide will help make sense of the jumble of bones that results from the processing of specimens into a comparative skeletal collection. Above all, the prime objective of this manual is to show basic osteological differences between various fish taxa on the basis of complete osteologies.

Despite the limited number of species depicted, this manual can at the very least help to rough sort archaeological remains into a general category of fish as opposed to other vertebrates. Because it encompasses several of the most common marine forms found in the Northern Hemisphere, it will help to narrow identification in many cases down to the level of family, if not to genus or species. Finally, this manual can help reduce problems of quantification and interpretation by making the user familiar with all identifiable elements of the fish, and not just those most easily recognized. Although it is not practical to produce an exhaustive manual covering all fish species found in this area of the world, it is hoped that this handbook will precipitate further interest and offer practical aid in the generation of osteological collections of different fish species, and emphasize the importance of continued work in this previously neglected area of archaeological analysis.

Fish Identification

For the archaeologist interested in working with fish bones, the availability of published osteologies is very restricted. Those that have been produced are found widely scattered throughout the zoological literature, and are often difficult to obtain. Illustrated osteologies of fish are inevitably general, buried in general works of biological or zoological origin, and picturing mainly articulated skeletons. Most osteological studies were conducted in the early part of this century, and the early works such as Starks (1901),Allis (1909),Gregory (1933), and Tchernavin

(1938) are still the best illustrated. Later fish osteologies tend to focus on a single species, genus or family, and although some authors such as Norden (1961) have provided drawings of disarticulated elements, not every element is depicted individually. Other works such as those by Harrington (1955) and Mujib (1967) contain only very schematic diagrams. These fail to show sufficient detail for the identification purposes of the archaeologist. Most fish osteologies have naturally enough been prepared by zoologists for zoologists.

Until recently, fish remains in archaeological sites were largely ignored; partly due to the lack of adequate reference material, and partly due to the lack of familiarity with the bone elements. As more archaeologists have become concerned with the recovery and uses of fish remains, more attention has been paid to their analysis (eg. Olsen 1968; Casteel 1976; Jones 1976, 1982; Wheeler and Jones 1976; Morales and Rosenlund 1979; Marhn 1981; Huelsbeck 1981; Nichol 1982; Ham 1982; Le Gall 1984; Singer 1985; Leach 1986). To date, however, there has been little done towards producing illustrated material specifically for archaeological identification. Olsen (1968) has produced a general guide for the identification of fish, amphibians, and reptiles, but his intention in this work is to aid archaeologists in separating fish bones from those of other vertebrates. He does not attempt to provide an exhaustive guide to fish osteology.

Another basic reference in the archaeological analysis of fish remains is Casteel (1976), which functions primarily as an introduction to fish osteology, and as an invaluable source describing a variety of archaeological uses for identified fish remains. Other published references include Morales and Rosenlund (1979) and Le Gall (1984). The former is an attempt to standardize fish bone measurements, while the latter concentrates on fish vertebrae and a few other elements such as quadrates, dentaries, and angulars. None of these were ever intended as a comprehensive guide for the identification of fish remains in any part of the world.

Olsen (1968:4), Casteel (1976:7) and others agree that a detailed published study of many fish skeletons is badly needed. The present handbook is a collection of the osteologies of several different species, and its production was inspired by this recognized need. The fact that each osteology is a complete work in itself allows for additions to be made in the future. At present, however, it will perhaps suffice to produce a field and laboratory manual that will permit the archaeologist to begin a rough classification of his material, and make more effective use of comparative osteological collections as these become increasingly available.

Fish Remains in Archaeology

Fish remains have the same role to play in archaeological analysis as any other class of faunal remains; ie. as an aid in the reconstruction of palaeoeconomies and palaeoecology (see for example in Casteel (1976) and Jones (1982:79)). It is toward this end that the identification of fish remains should be undertaken. It is not the aim of this manual to solve the problems of identification to species; in fact its scope is far too limited for such a purpose. However, one of the purposes of this manual is to encourage the complete identification of all fish osteological elements. A basic understanding of the morphological characteristics of all elements is necessary if fish remains are to be treated to the same standards as other classes of faunal remains. Among archaeologists generally, basic knowledge of the forms of disarticulated fish bones is not as well developed as it is for mammal bones. As a result, there is from the beginning a potential for fish remains to be under represented to an unknown extent. Methods for the reconstruction and interpretation of palaeoeconomy and palaeoecology from faunal remains assume that the material has been identified as completely as possible. An unknown element of bias is introduced if quantification and interpretation are attempted on the basis of incomplete identification.

Much zooarchaeological literature is entirely devoted to methods of quantifying faunal assemblages (eg. Casteel 1976; Grayson 1979), with an aim toward overcoming the biases introduced by archaeological preservation and recovery techniques, and providing as 'true' a picture as possible of the relative importance of species in the economy or environment of a region. However, all methods assume that basic standards of element identification have been attained. The truth of this assumption of course depends upon the knowledge and skills of the individual investigator. In regard to fish remains, the necessary knowledge is not readily available.

In the area of mammal bone identification, fairly comprehensive manuals have been published (Olsen 1964; Gilbert 1973; Glass 1973). Arguably, it is the dissemination of knowledge by manuals such as these that has done so much to bring the analysis of mammalian remains into archaeological prominence. In the identification of fish remains, standards are likely to be much more variable between investigators, and it is perhaps for this reason that fish remains have not attained a greater significance in archaeology, despite the efforts of Casteel (1976) and others to promote their use. Therefore it is important for a fish osteology manual to depict all of the elements present in a fish skeleton if possible, regardless of whether such a range of elements has been previously identified in archaeological sites.

The fact that there are such a large number of fish elements, and the tendency for fish bone to break into tiny fragments has meant that identification and interpretation has come to focus mainly on the more substantial elements such as: vertebrae centra, otoliths, pre-maxillae, maxillae, dentaries, dermal structures, and head bones such as angulars and posttemporals (Rackham et al. 1984:40). The less familiar elements are sometimes mistaken for chips of mammal or bird bone and thus excluded from proper identification and quantification (Olsen 1968:ix). Without specialized knowledge, the best that can be done with such unfamiliar elements is to classify them as unidentified fish. As a result, a potentially incorrect or at least altered picture of palaeoeconomy or palaeoecology is likely to emerge.

There are a number of reasons for wanting to obtain as complete an identification of fish elements as possible; including cranial elements. Even though these may be less likely to survive archaeologically, they cannot be disregarded simply because they are not recognized, and they cannot be recognized unless their basic form is familiar to the investigator. The presence of cranial elements can help to answer questions concerning processing practices and help to establish a possible distinction between fishing/ processing sites and habitation sites. Cranial elements are also important because they are either median or paired and can therefore be used to aid in the calculation of the minimum number of individuals of different species. Because an individual fish has many different vertebrae. the number of these is often a less adequate representation of the number of individuals present.

One further reason for attaining as complete an identification of fish elements as possible concerns the importance of sampling in the analysis of faunal remains. Often, fish and other remains are present in such large numbers that it is only economically feasible to conduct their analysis on the basis of small samples of the originally recovered material. Such sampling severely restricts the number of elements of any one species available for potential identification. If the investigator's lack of knowledge further restricts identification to only a subset of available elements, then very serious distortion may arise, and even the presence of some species may be overlooked.

To whatever purpose the analysis of fish remains is applied, a basic knowledge of fish osteology is essential. As archaeologists are often forced to rely on their own efforts in the identification of fish or other remains which they recover, it is essential that they themselves develop the requisite level of knowledge and skill. It is for this reason that the drawing of each element of the species represented in this manual was undertaken.

Scope of Coverage

Four of the most common families of marine fish in the Northern Hemisphere are represented in this handbook; the Salmonidae, Gadidae, Scorpaenidae, and Pleuronectidae. They were chosen because they comprise species which are indigenous to both the North Atlantic and North Pacific Oceans, and were, according to a range of archaeological and ethnographic evidence, economically exploited in both regions in the past.

One species from each of the above families is illustrated.

Oncorhynchus keta (Pacific)

The first osteology constitutes a Pacific salmon (*O. keta*). Its Atlantic cousin, *Salmo salar*, belongs to a different genus, but both are of the sub-family Salmoninae, and the family Salmonidae. The external appearance of these species is distinct, but their skeletons, like those of all salmonids, are very characteristic. (see Tchernavin 1938 plates II,III, and V, for an illustrated comparison of the articulated skulls of *O. keta* and *S. salar*). In fact, it is difficult to identify bones of the Salmonidae to species, even with the aid of a comparative collection. There is also considerable variation introduced through breeding changes. As Tchernavin concludes in his study of the breeding changes in salmon:

> The skulls of adult migratory *Salmo* and *Oncorhynchus* are subject to striking changes throughout the whole life of the fish. These changes are so marked that the study of the salmon skull becomes in fact, a study of its changes. Many characteristics regarded as 'fortuitous variations' or 'taxonomic distinctions' are found to be features of particular phases of these regular changes. [Tchernavin 1938:165]

In this respect, the osteology of *Oncorhynchus keta* is typical of the salmons.

Of the four species of fish depicted in this manual, only the salmon (both Pacific and Atlantic) are anadromous; the remainder (cod, rockfish, and halibut) are exclusively marine. Anadromous fish breed in freshwater and migrate to marine feeding grounds where they spend the majority of their life cycle.

References: Parker 1873; Gregory 1933; Tchernavin 1938; Norden 1961; Vladykov 1962; Kazakov et al. 1982; Pichugin 1983; Jollie 1984.

Gadus morhua (Atlantic)

The Atlantic cod (*G. morhua*) is illustrated as a typical example of the family Gadidae. The same genus of cod exists in the Pacific (*G. macrocephalus*), and in terms of osteology, these two species show no discernible differences. In fact, in all respects the species are very similar. As early as 1887, investigators such as Bean (1887:198-199) questioned the validity of classifying Atlantic and Pacific cods as separate species. Schultz and Welander (1935:131-133) noted only visceral differences and differences in length of barbel and dorsal fin. Midgalski and Fichter (1977) noted no difference between the species, apart from the fact that the fins of the Pacific species are more pointed.

References: Bean 1887; De Beer 1928; Gregory 1933; Schultz and Welander 1935; Mujib 1967; Migdalski and Fichter 1977.

Sebastes marinus (Atlantic)

Rockfish are present in both the Atlantic and the Pacific, but are represented by a much greater number of Pacific species. The species illustrated here, the red rockfish, commonly called red snapper, is today highly valued commercially. Its common name is applied to different rockfish species from both the Pacific and the Atlantic, but each is a member of the genus *Sebastes*. The scientific name for the Atlantic species is *Sebastes marinus*, and it is this species that is used here to represent the family Scorpaenidae. Osteologically, all members of this family are very similar in appearance, and as a basic guide to fish elements, this family is a useful illustration of the osteology of the 'higher' bony fishes.

References: Starks 1898; Allis 1909; Gregory 1933; Echeverra 1986.

Hippoglossus stenolepis (Pacific)

The final osteology is of the Pacific halibut (*H. stenolepis*), of the family Pleuronectidae. When compared to the skeleton of the Atlantic species (*H.*

hippoglossus), there is little apparent difference in form. Personal examination of both species and consultation with experts left little doubt that the vertebrae and caudal bones of the two species are quite indistinguishable. Any variation in form was not easily detected in the individual elements of the head, and is therefore considered negligible for archaeological purposes.

References: Traquair 1865; Boulenger 1902; Regan 1910; Gregory 1933.

Comparative analysis of fish skeletons was conducted at the Museum of Zoology, University of Cambridge in England, where Atlantic specimens were available for examination. Pacific specimens were obtained from Vancouver, B.C., Canada.

Interoceanic comparative studies of fish osteologies are very rare. However, from an archaeological point of view, specimens from either ocean can be considered as representative of their respective families. This conclusion is based on an examination of the general form and particular distinguishing features and attributes of the individual bony elements. The aim of this comparative study was not to develop new criteria for species classification, but rather to confirm that the above specimens are representative of species from both oceans. Archaeologists working on the North Atlantic Coast can identify their material on the basis of illustrations of Pacific species, and the converse holds for North Pacific archaeologists.

Organization

The manual is divided into five sections. The first section is an introduction to the general fish skeleton; the cranium and lateral facial bones, the appendicular skeleton, and the axial skeleton. The subsequent sections are individually illustrated osteologies, presented in taxonomic order, of the salmon, cod, rockfish, and halibut. The bone elements are disarticulated and organized by anatomical region. The drawings are organized by species rather than element because the range and morphology of skeletal elements varies considerably between species. As an aid to preparing reference collections it is more useful to have the elements of each species kept together.

Because the goals of archaeologists differ from those of biologists, the bones are not necessarily represented at the angle in which they naturally occur in the articulated skeleton. Most of the elements show at least two viewpoints from which the most identifiable and recognizable features are visible. Unless otherwise specified, the drawings are of the right side. Due to the asymmetric skull of the halibut, several elements from right and left sides show distinct differences. Where this applies, both sides are illustrated, unless the difference is merely one of size.

Each element is depicted actual size in order to emphasize as much detail as possible. Drawings at this scale and level of detail will enable the analyst to differentiate between various fish taxa through recognition of characteristic bone structures and features. At this scale, the relative size differences among various elements of different species also become apparent. For example, the coracoid of a 90cm long salmon is just slightly smaller than that of a rockfish just over half its size. However, it is important to remember that within families and within species, elements can exhibit a wide range of size and morphological variability. Within species element size is a direct function of fish size which continues to increase with the age of the fish.

Terminology

As far as terminology is concerned, five major sources have been drawn upon. These are Starks (1901), Gregory (1933), Norden (1961), Mujib (1967), and Bond (1979). Much controversy still exists among ichthyologists concerning the standardization of nomenclature. Therefore, most of the terminology used here is derived from Starks (1901) and Gregory (1933). Where there are bones specific to certain species, the terms have been taken from the relevant literature; ie. Mujib (1967) for the cod, and Norden (1961) for the salmon. Where new terms have come into common usage, these have been substituted for the older terms of Starks (1901) and Gregory (1933) (ie. from Gifford and Crader 1977; Bond 1979; Courtemanche and Legendre 1985).

An important factor to note in the naming of fish bones is the difference in the number of bones present among various fish taxa. While much of the skeleton of the lower bony fishes is cartilagenous, it also tends to have a greater variety of bones (Bond 1979). For example, the salmons have 7-8 circumorbitals, a mesocoracoid, orbitosphenoid, supramaxilla, suprapreopercle, and numerous caudal bones. The halibut (a higher teleost) lacks most of the above mentioned elements, and has only one nasal. The caudal fin has been reduced to two epurals and two hypurals, and the orbitals ave been reduced to several minute tubular ossicles.

Although the skeletal elements of the higher and lower bony fishes basically correspond, some of the names of the bones will be different due to specialization and particular adaptations. For example, there is no true mesethmoid in the salmon (Norden 1961:727). It has a supraethmoid bone which is not present in the cod, rockfish, or halibut. A further example is the basihyal of the salmon which is cartilaginous, overlaid with a well-ossified lingual plate (Norden 1961:734). It is the lingual plate which survives archaeologically. The basihyal of the rockfish and halibut is completely ossified. The cod has no basihyal.

Method of Specimen Preparation

For all intents and purposes, this manual is meant to supplement and complement a comparative fish bone collection. It is not intended to be a total replacement for a comparative collection, and the importance of access to such a collection for precise identification must be stressed. Adequate collections, however, are not always available, and the services of a specialist can be difficult to obtain and expensive. Making up a basic fish collection may be difficult and time consuming, but it is sometimes the only solution. What follows, is a short description of the method used for the preparation of specimens for the present manual.

The method of maceration used was a modification of the enzyme-base laundry presoaker and warm water technique described in Casteel (1976). The fish specimen was first gutted, being careful not to cut or remove any bones. To accelerate the maceration process, the fish was lightly steamed until superficial flesh flaked off easily. This excess flesh was carefully removed without damaging any bones. The remaining carcass was then left submerged in a strong presoaker solution for a few days, with checks on its progress made every day. Accurate graphic representation of the individual bony elements required a skeleton that was in the best condition possible. This meant that constant monitoring was necessary to ensure that the bones did not warp, dry-out, or begin to break down.

When the cartilage appeared to be sufficiently dissolved, the skeleton was removed in sections (ie. caudal, left and right pectoral, pelvic, and lateral facial sections, etc.). The neurocranium tended to take the longest to disarticulate. The bones were removed from the solution while they were still attached but soft enough to separate easily by hand. In this way left and right sides were not confused, and the articulated bones could be compared with the drawings in biological studies.

Once separated, the bones were hand cleaned under tepid water. Care was taken to work over a fine-meshed screen. Finally, the bones could be laid out to dry and later labelled.

The process used here was painstaking and time consuming. This was necessary in order to identify elements in comparison with the articulated drawings and descriptions of zoological osteologies. It is hoped that with the aid of the present manual, much quicker and more effective maceration techniques could be used (see Casteel 1976:7-16). During the maceration process, it should not be necessary to maintain articulations, or separate left from right, as these precise element identifications can be made later with reference to the drawings in this manual. However, it is important to stress again that for the recognition of morphological differences between various species, and their precise archaeological identification, a comparative osteological collection is essential. This manual is only intended as a useful adjunct to such a collection. It can be used in field situations in which the fragility of comparative fish collections makes their use impractical, and can also help prevent the deterioration of a collection by reducing the amount of handling required in laboratory analysis.

References: for the identification of whole specimens- Hart (1973) for Pacific species; Wheeler (1969) for Atlantic species.

Additional Notes

Although an attempt has been made to produce osteologies as complete as possible, some bones have been omitted. The otoliths of the salmon (*Oncorhynchus keta*) are so small as to make a to-scale drawing useless. Included is a detailed series of enlarged drawings of salmonid otoliths redrawn after Norden (1961). In addition, the following bones are absent: the extrascapulars of the salmon, suborbitals 4 and 5 of the rockfish, and the supratemporals, and orbitals of the halibut. Drawings of the extrascapulars and supratemporals were not attempted because they are merely a thin line of tubular bones enclosing a sensory canal. The orbitals of the halibut and supraorbitals 4 and 5 of the rockfish were omitted for the same reason. These bones are all extremely small or fragile, and therefore are not considered of essential importance. Their recovery is unlikely in archaeological sites.

The salmon bones are those of a spawning male, and therefore show the characteristic increase in the size of jaws and teeth, etc. (see Tchernavin 1938 for a description of breeding changes in the skull). It is interesting to note that in all species of sea-run *Oncorhynchus*, with the possible exception of *O. kisutch*, the teeth of half-grown and adult fish of both sexes are not fastened to the various teeth bearing bones. It is only close to the time of spawning that the teeth become fused to their respective bones (Vladykov 1962:50-52). In addition, unlike *Salmo*, the breeding teeth of *Oncorhynchus* are not set in sockets (Tchernavin 1938:164). Instead, they have large ossified bases which are easily recognized in archaeological specimens.

The cod otolith that was drawn came from a smaller specimen of the same species, while all of the other cod elements came from a single larger specimen. The branchial arches of the rockfish are from a Pacific species of rockfish (*Sebastes* sp.). The frontals, sphenotic and supraoccipital of the halibut were drawn from a larger specimen of the same species (*H. stenolepis*).

Table 1.
Specimen Data

Species	Total Length	Weight	Source	Date
Oncorhynchus keta (Chum salmon, Pacific)	90cm	unknown	Chehalis River, B.C. Canada	12/85
Gadus morhua (Atlantic cod)	109cm	12,115g	Dogger Bank England	02/85
Sebastes marinus (Red snapper, Atlantic)	57.5cm	2105g	Market Cambridge England	02/84
Sebastes sp. (Rockfish, Pacific)	45.5cm	1361g	Market Chinatown Vancouver Canada	11/86
Hippoglossus stenolepis(a) (Pacific halibut)	88.5cm	unknown	West Coast Vancouver Is. Canada	07/75
Hippoglossus stenolepis(b) (Pacific halibut)	unknown	unknown	Banks Island B.C. Canada	06/74

Table 2.
Anatomical Regions of the General Teleost Skeleton

OLFACTORY REGION

Ethmoid
(supraethmoid,
mesethmoid)
Prefrontal
Vomer

ORBITAL REGION

Alisphenoid
Parasphenoid
Orbitosphenoid

OCCIPITAL REGION

Supraoccipital
Exoccipital
Basioccipital

OTIC REGION

Sphenotic
Pterotic
Epiotic
Opisthotic
Prootic
Otolith

INVESTING BONES

Nasal
Frontal
Parietal
Supratemporal
(Extrascapular)

LATERAL SKULL BONES

Premaxilla
Maxilla
Supraorbital
Lachrymal
Suborbital
Dentary
Angular
Retroarticular
Suprapreopercle
Preopercle
Supramaxilla

OPERCULAR SERIES

Opercle
Subopercle
Interopercle
Branchiostegal Ray

MANDIBULAR ARCH

Palatine
Ectopterygoid
Quadrate
Mesopterygoid
Metapterygoid

HYOID ARCH

Hyomandibular
Symplectic
Interhyal
Epihyal
Ceratohyal
Hypohyal
Basihyal

BRANCHIAL ARCH

Pharyngeal Plate
Epibranchial
Ceratobranchial
Hypobranchial
Basibranchial
Basibranchial Plate
Urohyal
Pharyngobranchial

PECTORAL GIRDLE

Posttemporal
Supracleithrum
Scapula
Cleithrum
Postcleithrum
Coracoid
Mesocoracoid
Radials

PELVIC GIRDLE

Basipterygium
Interhaemal Spine

VERTEBRAL COLUMN

Atlas Vertebra
Thoracic Vertebra
Precaudal Vertebra

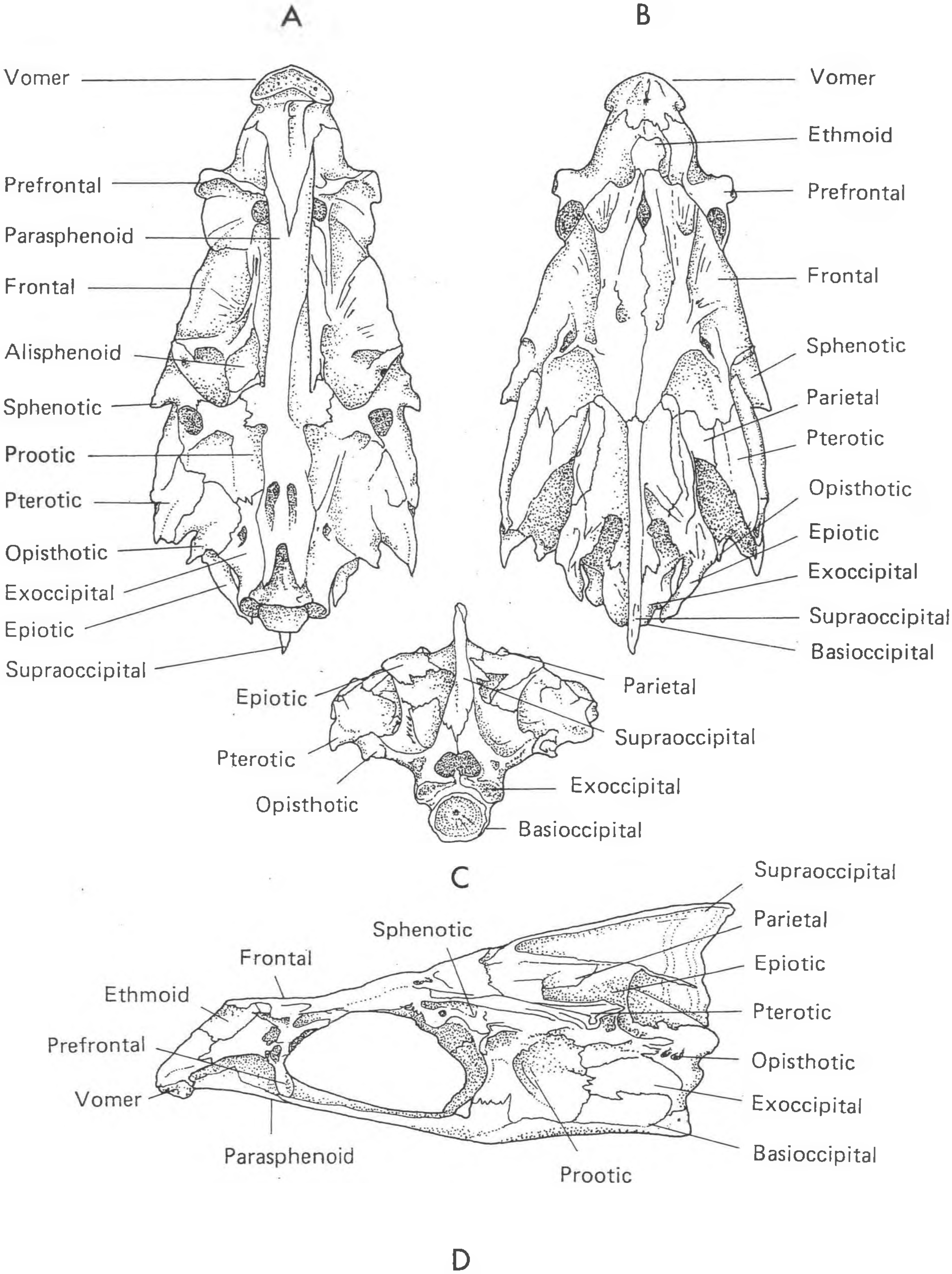
CAUDAL SKELETON

Caudal Vertebra
Penultimate Vertebra
Ultimate Vertebra
Hypural
Uroneural
Epural
Caudal Bony Plate
Expanded Neural Spine
Expanded Haemal Spine

INTRODUCTION TO THE GENERAL FISH SKELETON

THE CRANIUM - *Roccus saxatilis*

A. Ventral
B. Dorsal
C. Posterior
D. Left Lateral



Roccus saxatilis

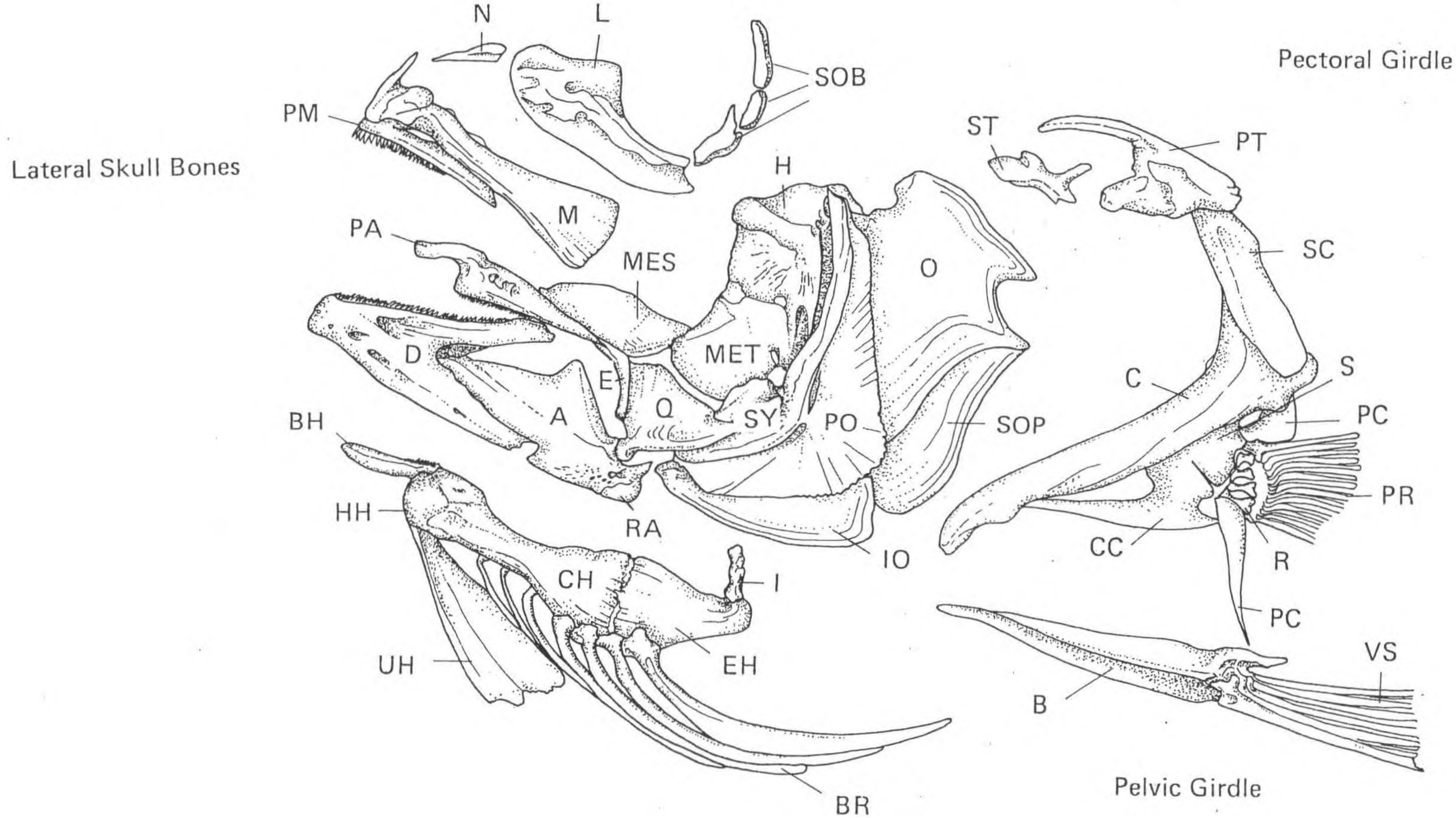
THE CRANIUM (after Starks 1901)

THE LATERAL FACIAL BONES AND APPENDICULAR SKELETON

Roccus saxatilis

KEY

A	Angular
B	Basipterigium
BH	Basihyal
BR	Branchiostegal Ray
C	Cleithrum
CC	Coracoid
CH	Ceratohyal
D	Dentary
E	Ectopterygoid
EH	Epihyal
H	Hyomandibular
HH	Hypohyal
I	Interhyal
IO	Interopercle
L	Lachrymal
M	Maxilla
MES	Mesopterygoid
MET	Metapterygoid
N	Nasal
O	Opercle
PA	Palatine
PC	Postcleithrum
PM	Premaxilla
PO	Preopercle
PR	Pectoral Ray
PT	Posttemporal
Q	Quadrate
R	Radial
RA	Retroarticular
S	Scapula
SC	Supracleithrum
SOB	Suborbital
SOP	Subopercle
ST	Supratemporal
SY	Symplectic
UH	Urohyal
VS	Ventral Spine

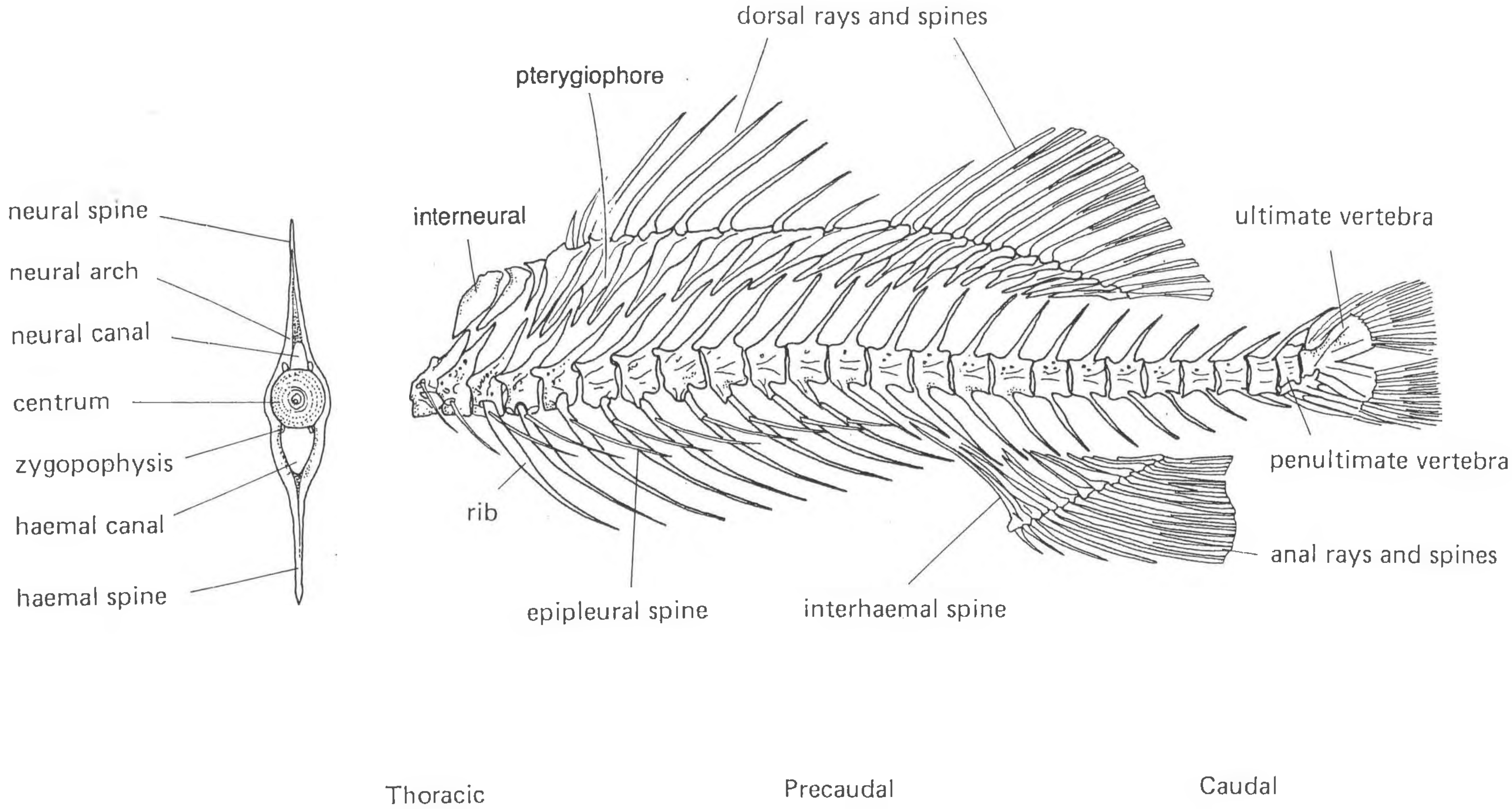


Roccus saxatilis

THE LATERAL FACIAL BONES AND APPENDICULAR SKELETON (after Starks 1901)

THE AXIAL SKELETON - *Roccus saxatilis*

THE AXIAL SKELETON

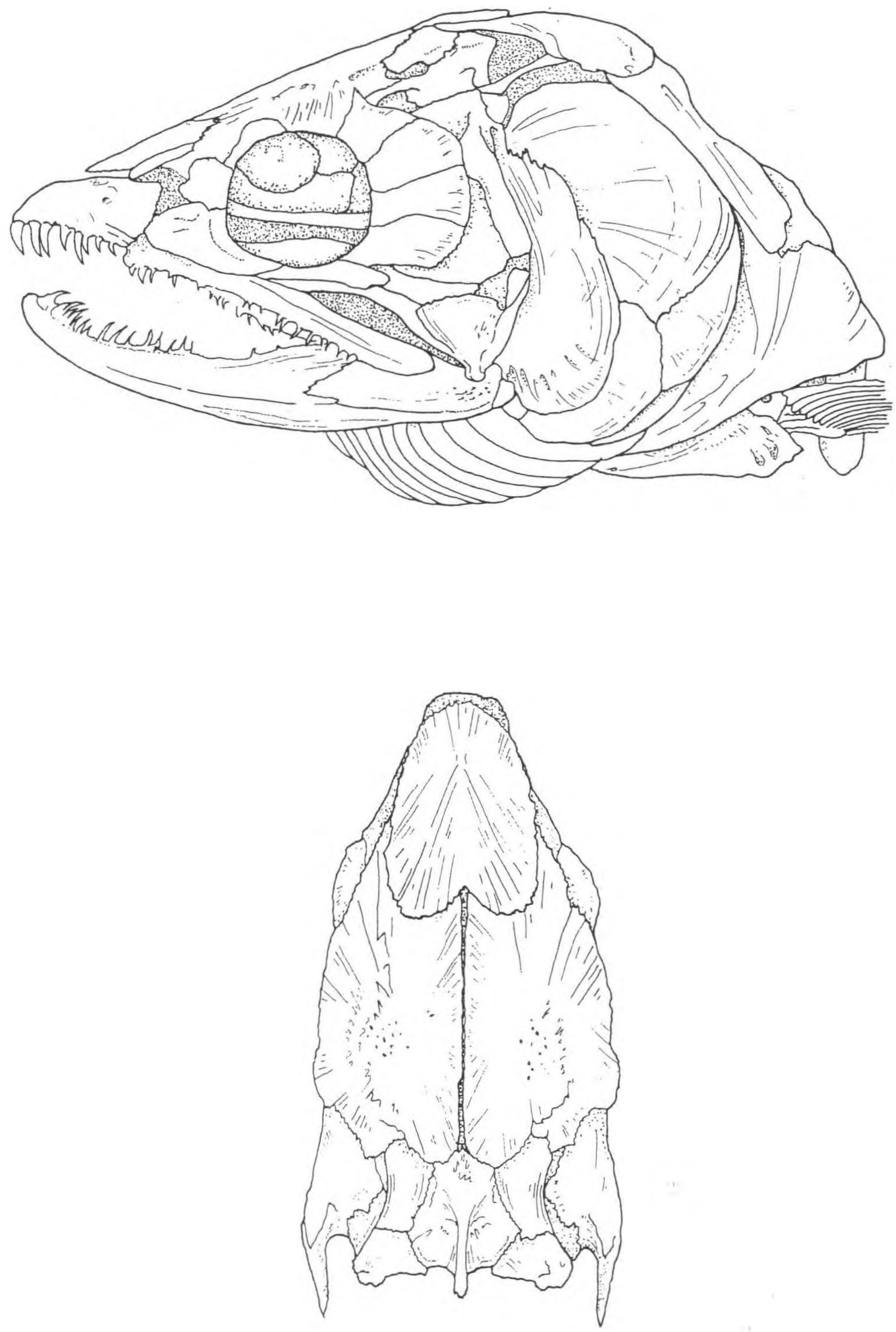


Roccus saxatilis (after Starks 1901)

KEY TO ELEMENT VIEW

L Lateral
M Mesial
A Anterior
P Posterior
D Dorsal
V Ventral

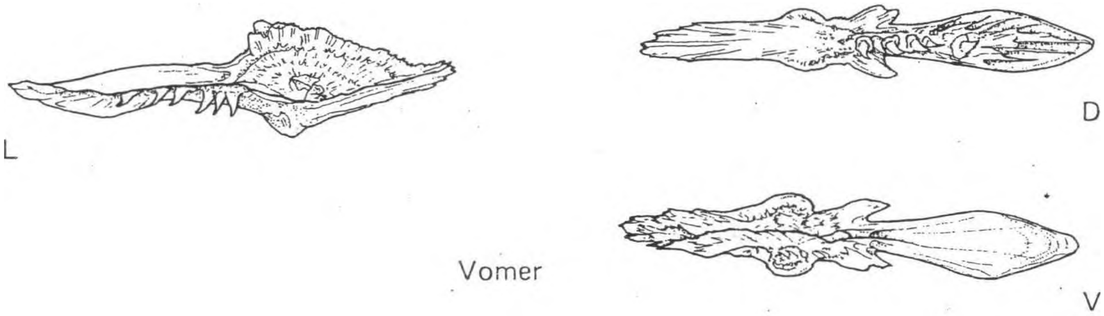
FAMILY SALMONIDAE



(after Gregory 1933)

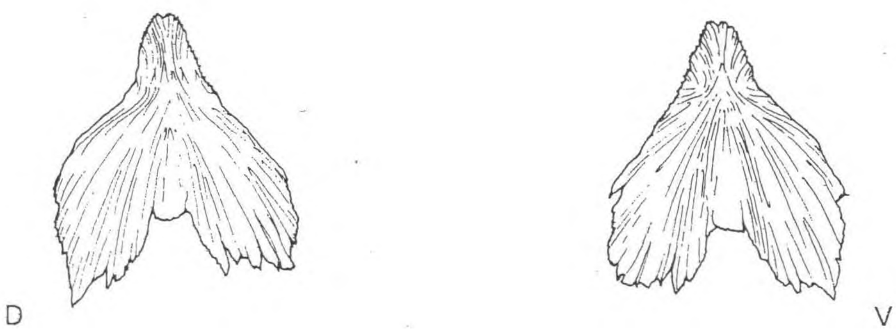
SALMONIDAE *Oncorhynchus keta*

OLFACTORY REGION



Vomer

Prefrontal

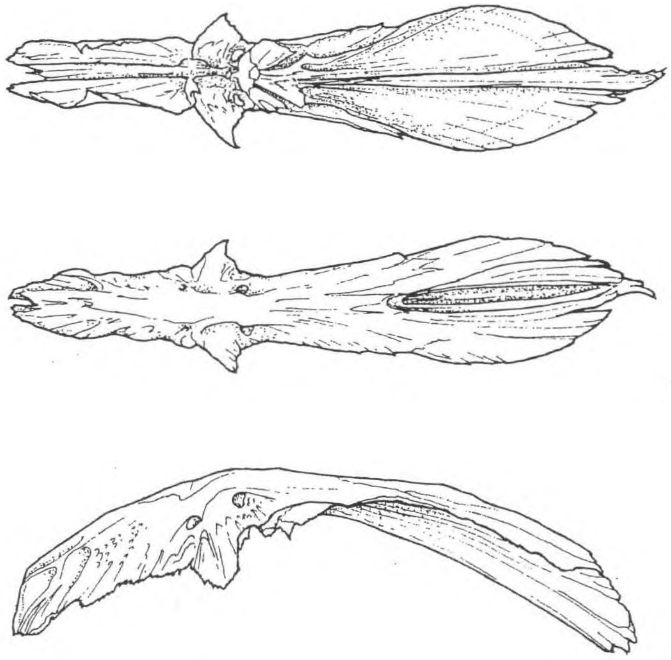


Supraethmoid

SALMONIDAE *Oncorhynchus keta*

ORBITAL REGION

Parasphenoid



D

V

L

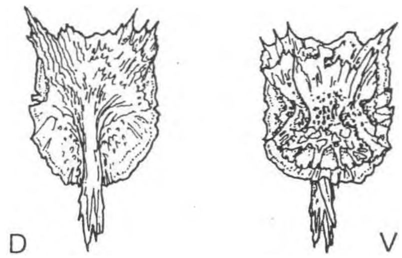
Alisphenoid

Orbitosphenoid

SALMONIDAE *Oncorhynchus keta*

OCCIPITAL REGION

Exoccipital

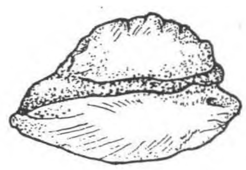


Supraoccipital

Basioccipital

OTIC REGION

Otoliths of some Marine Species of Salmonidae

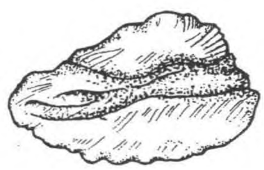


Oncorhynchus mykiss

2.3x

Salmo trutta

1.0x

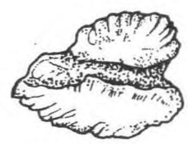


Oncorhynchus gorbuscha

2.9x

Oncorhynchus keta

1.6x



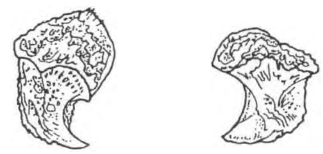
Oncorhynchus nerka

1.6x

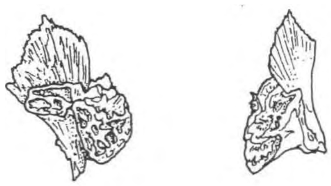
SALMONIDAE *Oncorhynchus keta*

OTIC REGION

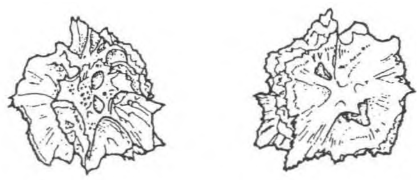
Opisthotic



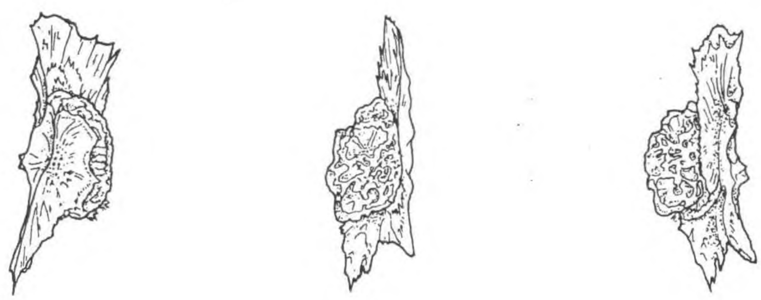
Sphenotic



Epiotic



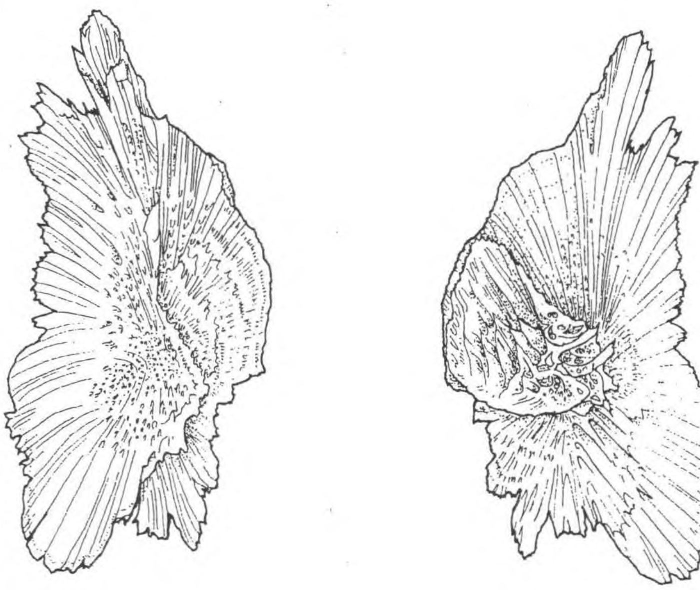
Prootic



Pterotic

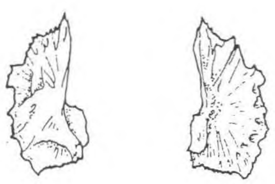
SALMONIDAE *Oncorhynchus keta*

INVESTING BONES



D V

Frontal

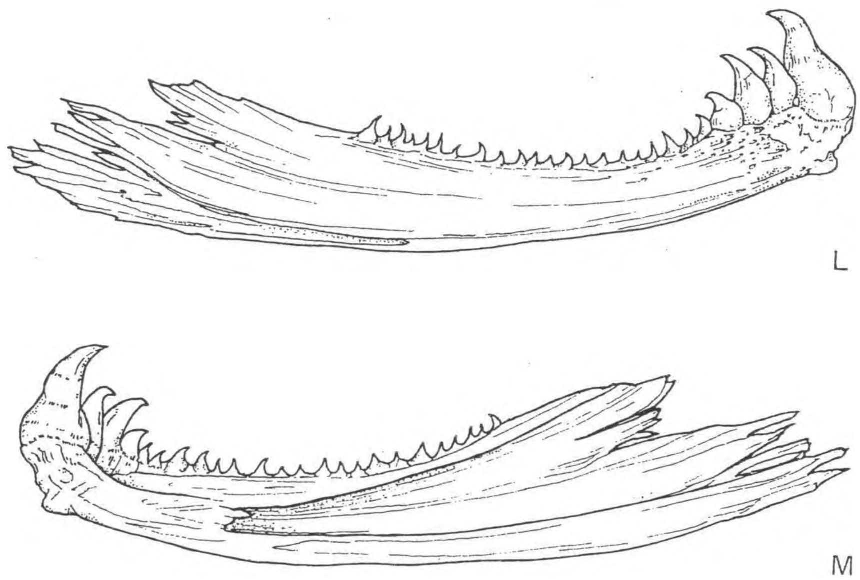


Parietal

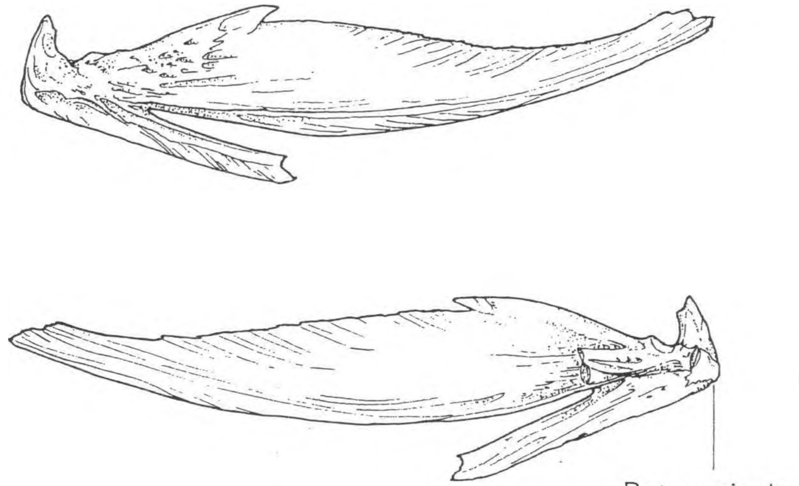
Nasal

SALMONIDAE *Oncorhynchus keta*

LATERAL SKULL BONES



Dentary



Angular

SALMONIDAE *Oncorhynchus keta*

LATERAL SKULL BONES

L M

Premaxilla

Supramaxilla

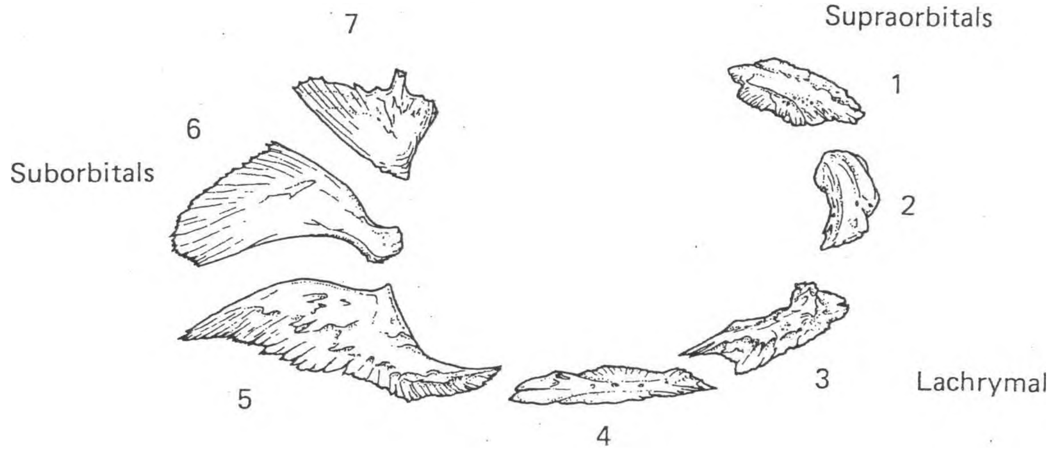
L M

L M

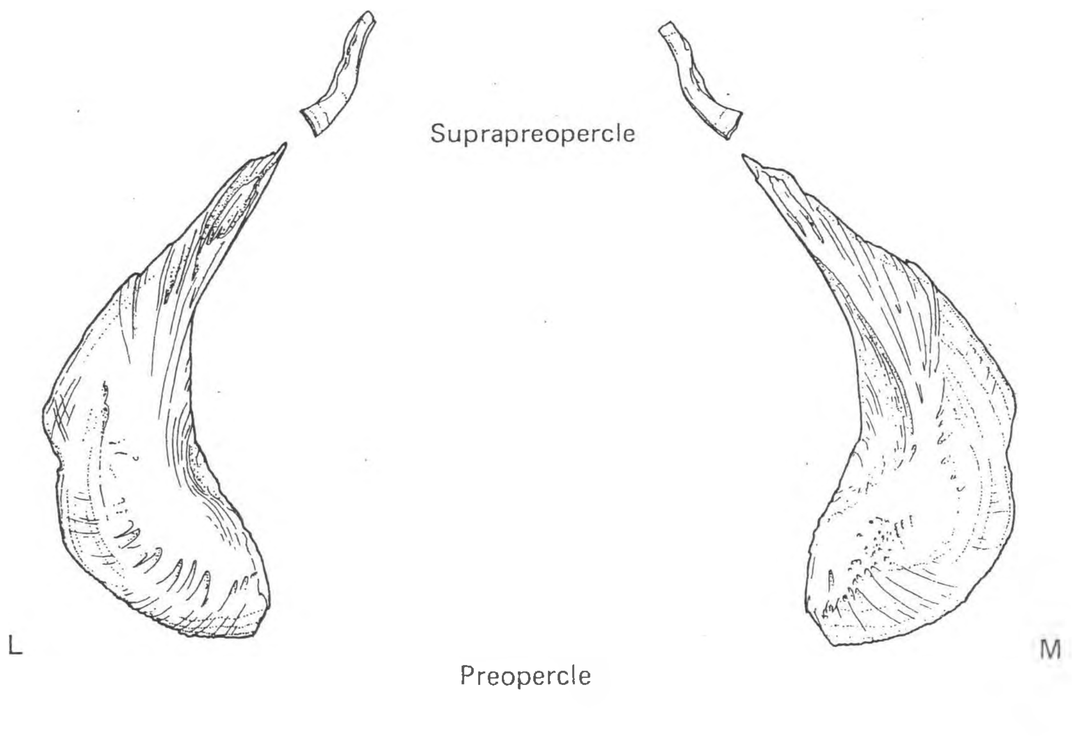
Maxilla

SALMONIDAE *Oncorhynchus keta*

LATERAL SKULL BONES



Circumorbital Series



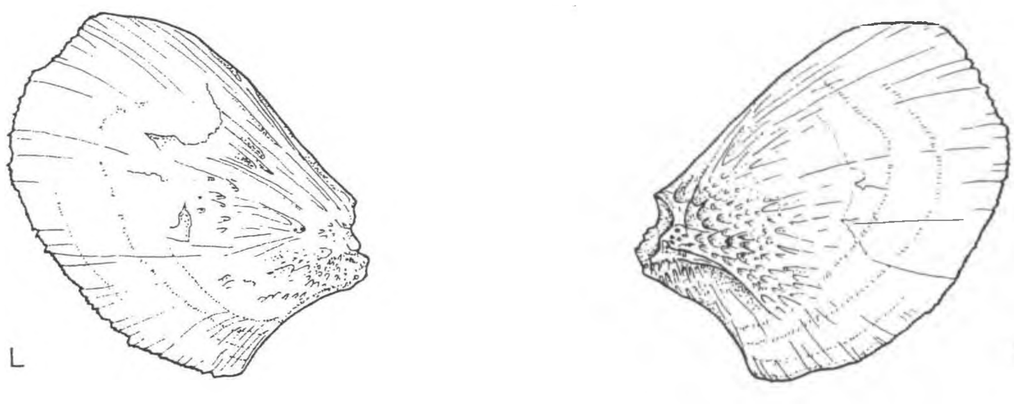
Preopercle

SALMONIDAE *Oncorhynchus keta*

OPERCULAR SERIES

L  M

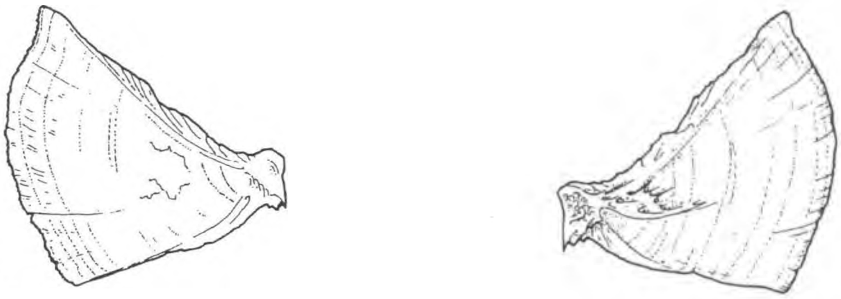
Branchiostegal Ray

L  M

Opercle

SALMONIDAE *Oncorhynchus keta*

OPERCULAR SERIES



L M

Subopercle

L M

Interopercle

SALMONIDAE *Oncorhynchus keta*

MANDIBULAR ARCH

L  M

Palatine

L Ectopterygoid M

L M

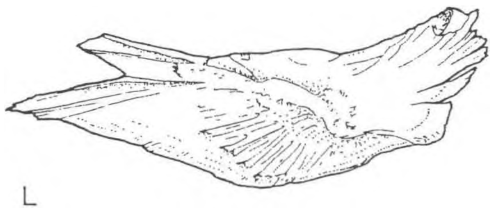
Quadrate

L  M

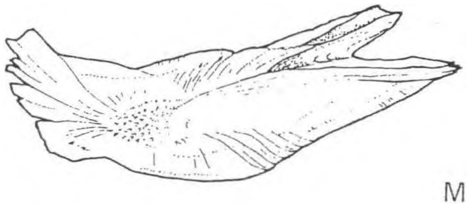
Metapterygoid

SALMONIDAE *Oncorhynchus keta*

MANDIBULAR ARCH



L

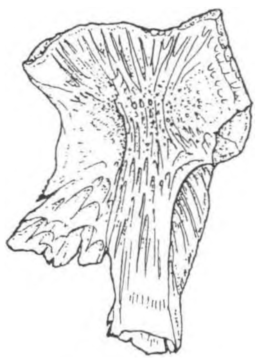


M

Mesopterygoid

HYOID ARCH

L



M

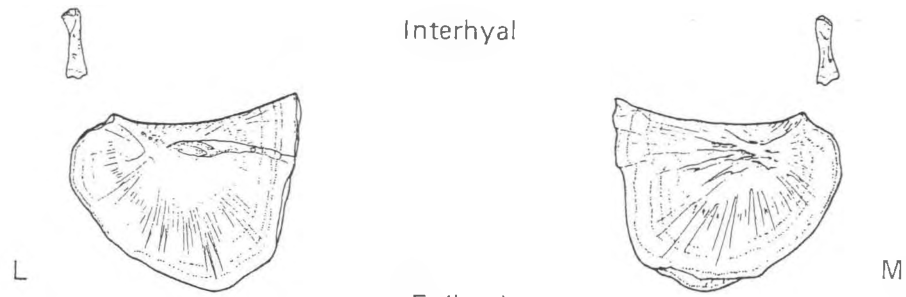
Hyomandibular

SALMONIDAE *Oncorhynchus keta*

HYOID ARCH

Ceratohyal

Interhyal



Epihyal

Symplectic

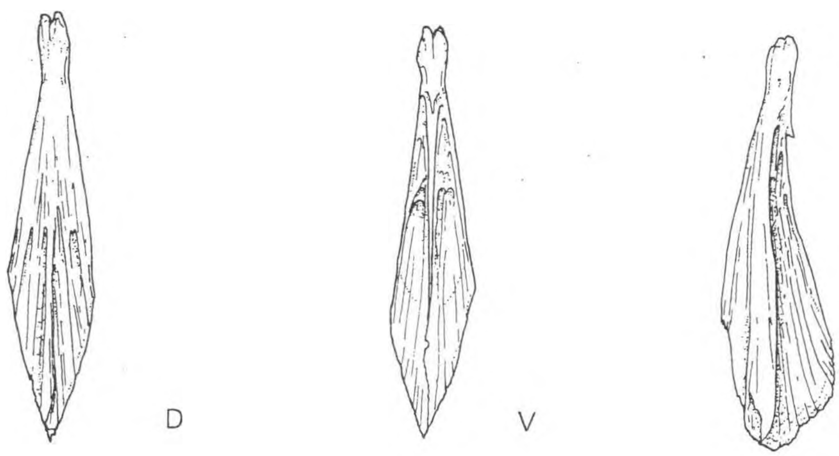
SALMONIDAE *Oncorhynchus keta*

HYOID ARCH

D L

Lingual Plate

BRANCHIAL ARCH

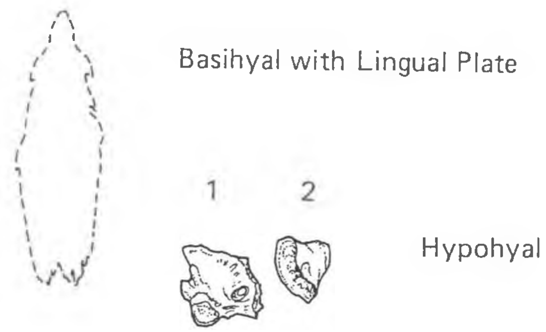


D V L

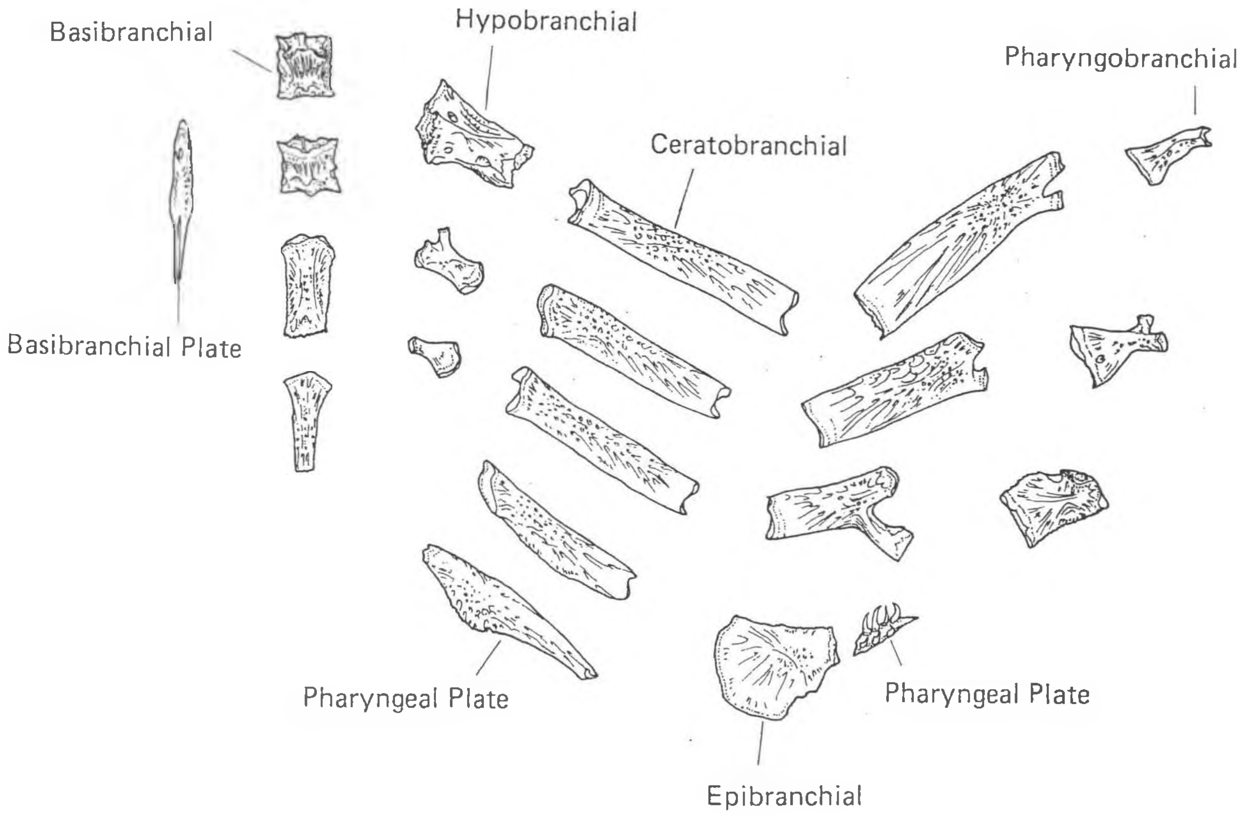
Urohyal

SALMONIDAE *Oncorhynchus keta*

HYOID ARCH



BRANCHIAL ARCH



SALMONIDAE *Oncorhynchus keta*

PECTORAL GIRDLE

L

M

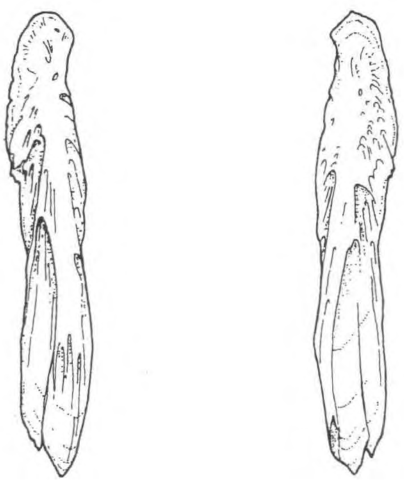
Cleithrum

1 upper

2 middle

3 lower

Postcleithrum



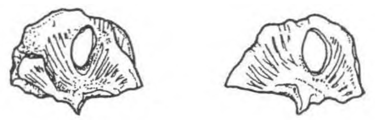
L

M

Supracleithrum

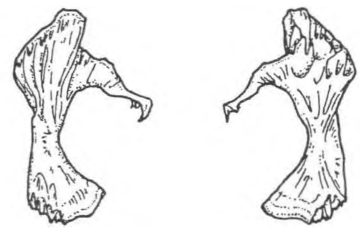
SALMONIDAE *Oncorhynchus keta*

PECTORAL GIRDLE



L M

Scapula

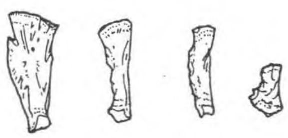


L M

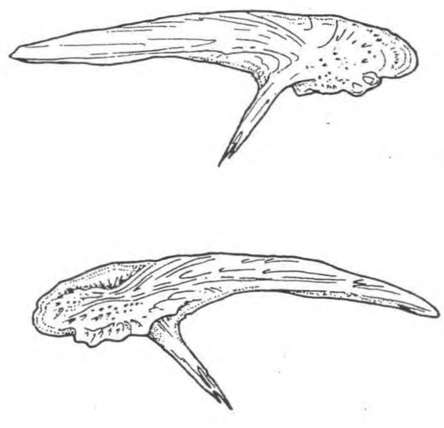
Mesocoracoid

L M

Coracoid



Radials



L

M

Posttemporal

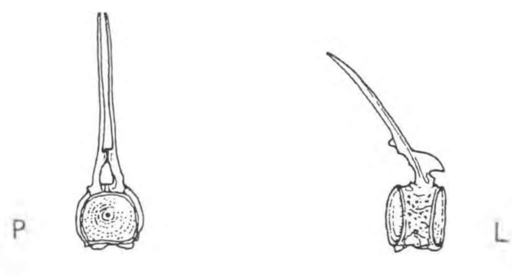
SALMONIDAE *Oncorhynchus keta*

PELVIC GIRDLE

Basipterygium

VERTEBRAL COLUMN

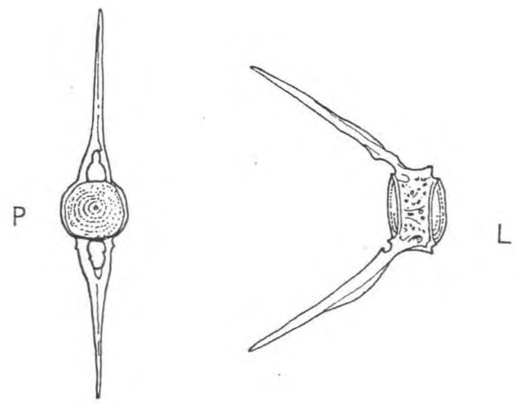
Thoracic Vertebra



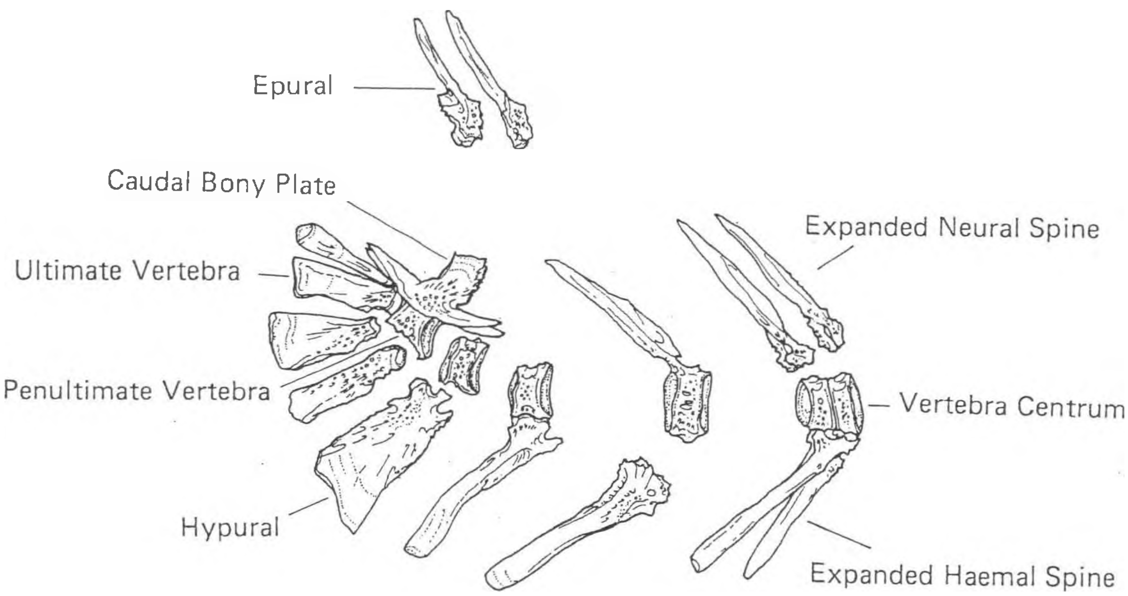
Precaudal Vertebra

SALMONIDAE *Oncorhynchus keta*

CAUDAL SKELETON



Caudal Vertebra

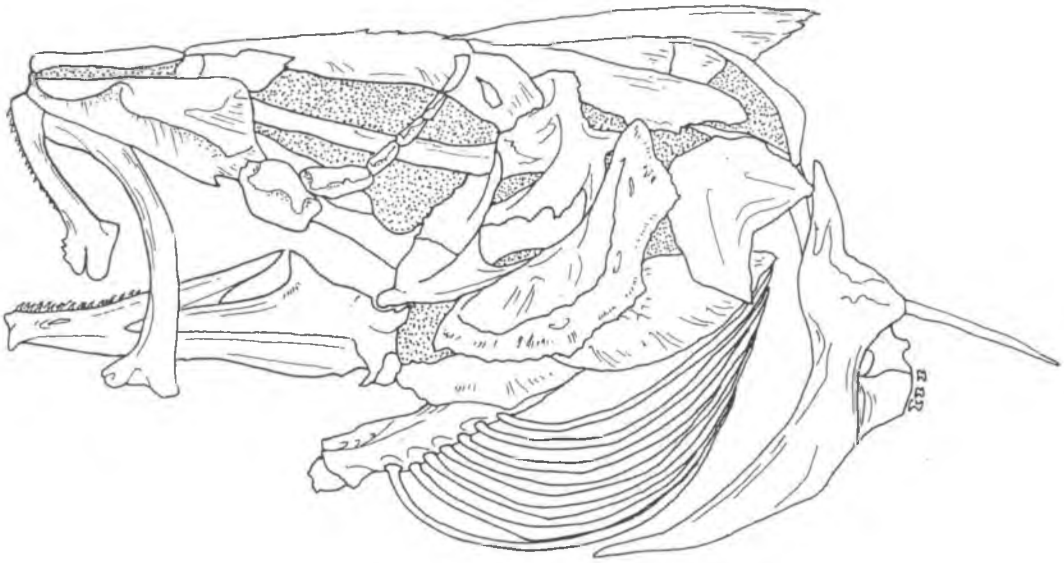


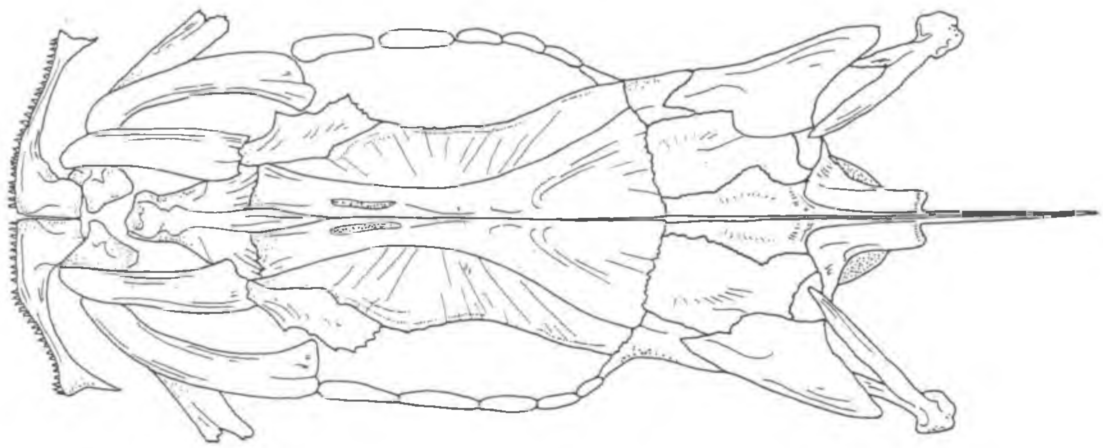
Lateral View

KEY TO ELEMENT VIEW

L Lateral
M Mesial
A Anterior
P Posterior
D Dorsal
V Ventral

FAMILY GADIDAE

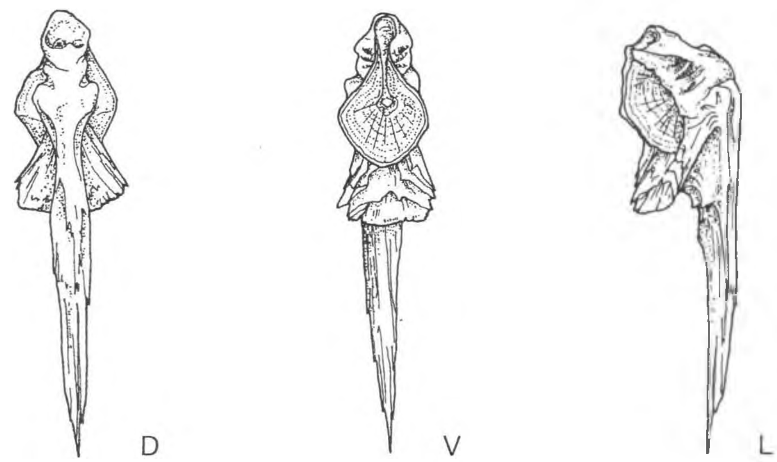




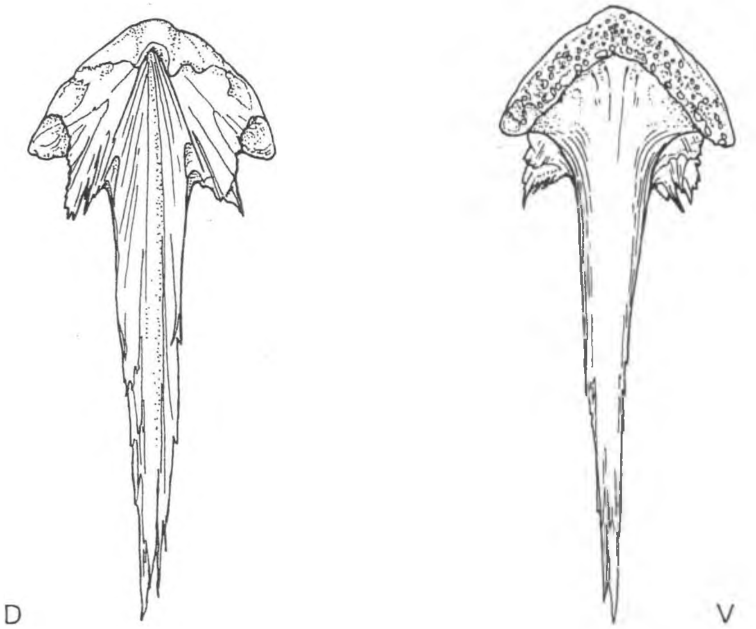
(after De Beer 1928)

GADIDAE *Gadus morhua*

OLFACTORY REGION



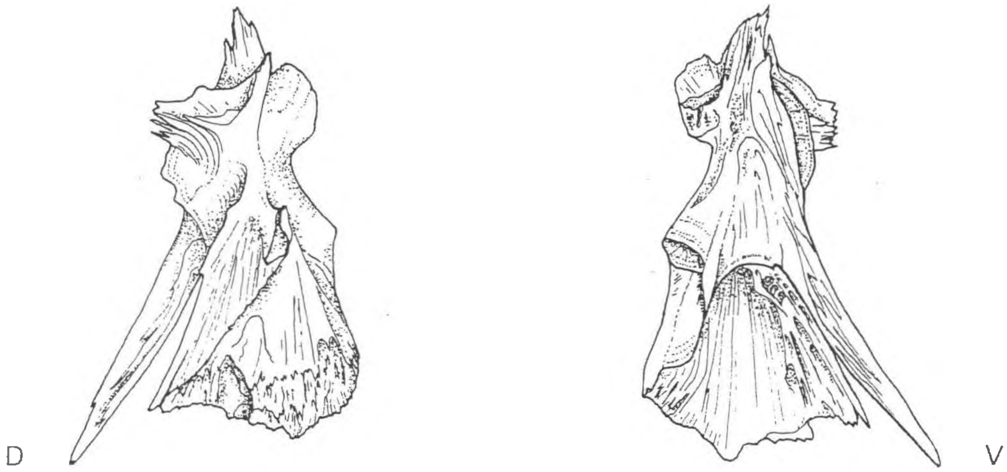
Mesethmoid



Vomer

GADIDAE *Gadus morhua*

OLFACTORY REGION



Prefrontal

ORBITAL REGION

Alisphenoid

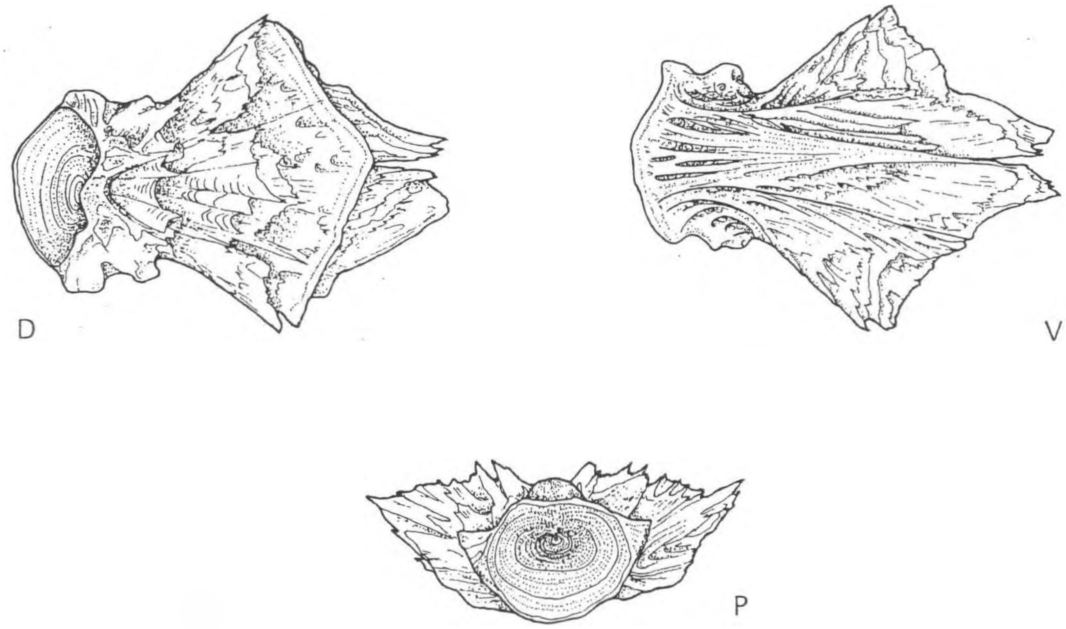
GADIDAE *Gadus morhua*

ORBITAL REGION

Parasphenoid

GADIDAE *Gadus morhua*

OCCIPITAL REGION

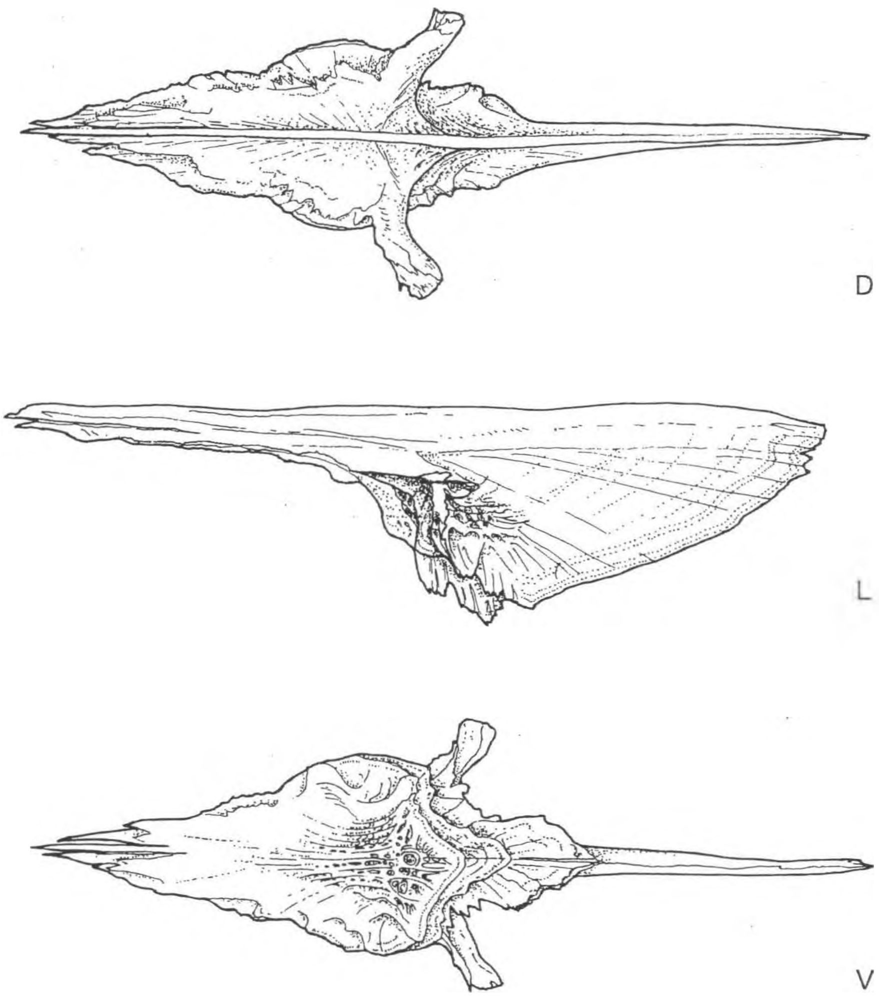


Basioccipital

Exoccipital

GADIDAE *Gadus morhua*

OCCIPITAL REGION

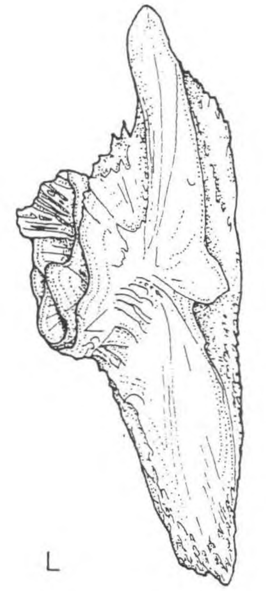


Supraoccipital

GADIDAE *Gadus morhua*

OTIC REGION

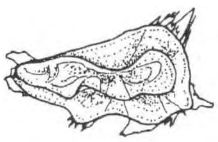
Pterotic



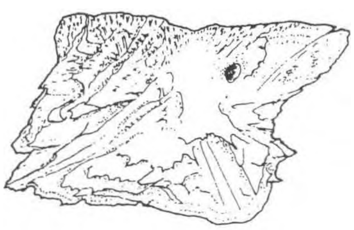
L

M

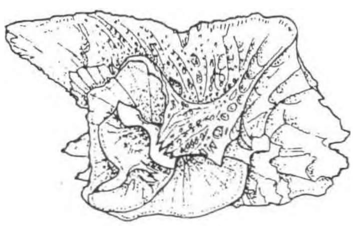
Epiotic



Sphenotic



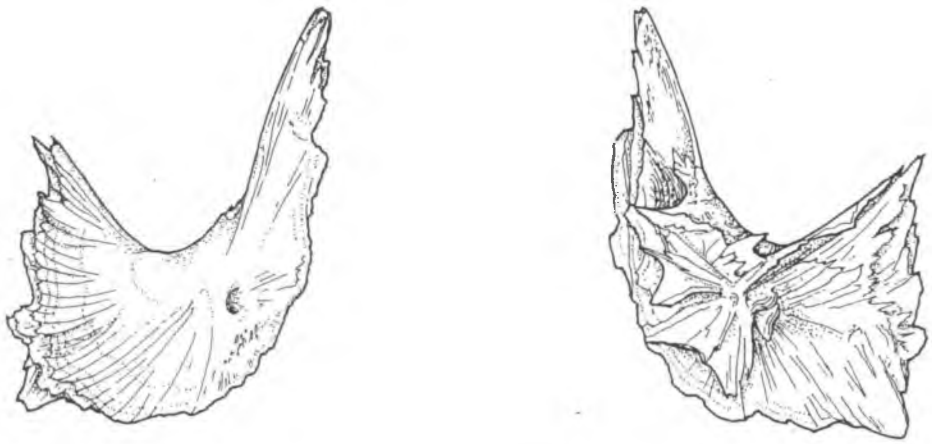
L



M

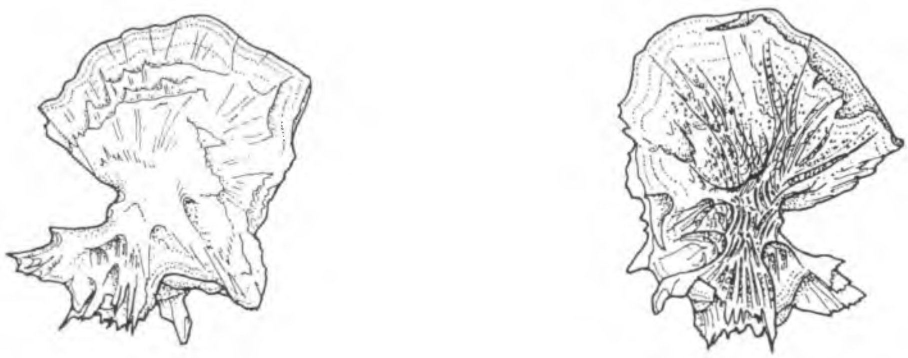
GADIDAE *Gadus Morhua*

OTIC REGION



L M

Opisthotic



L M

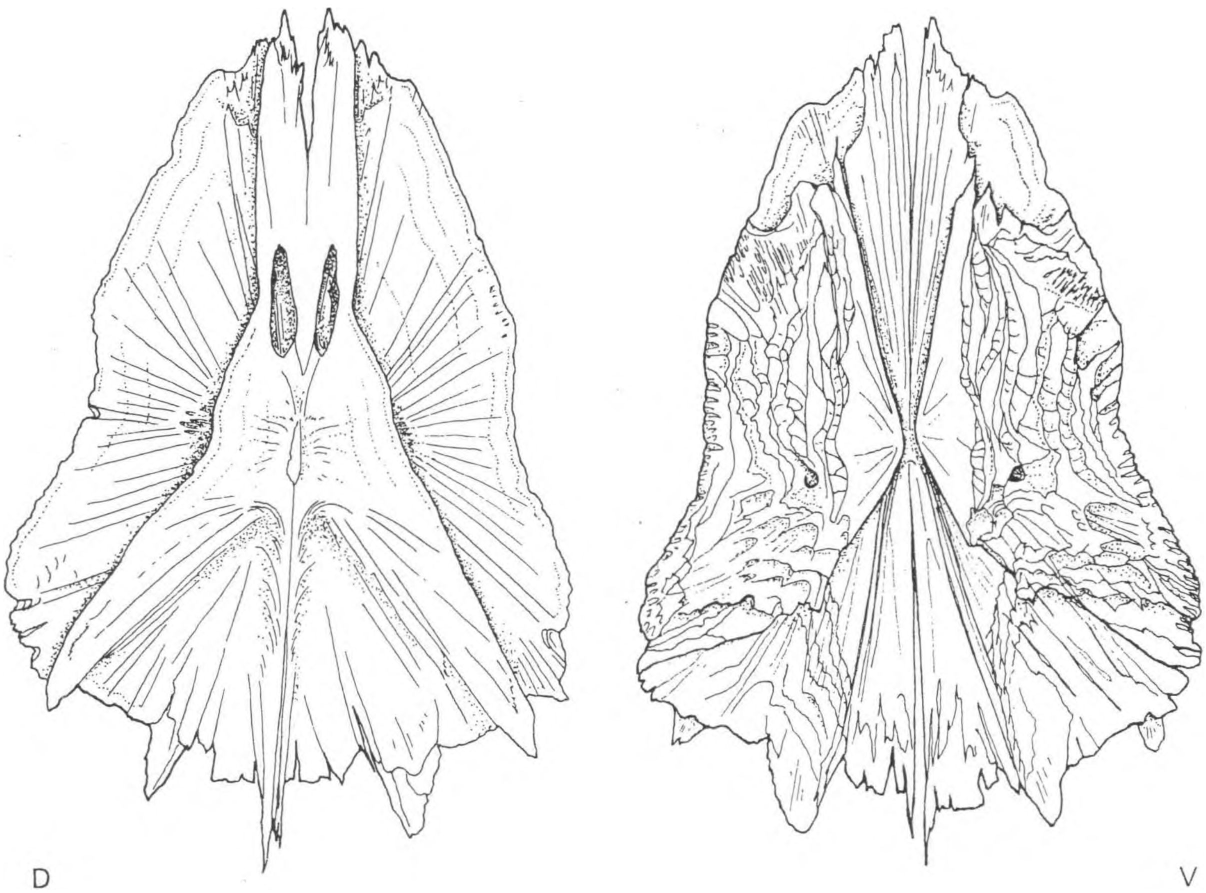
Prootic

Otolith

GADIDAE *Gadus morhua*

INVESTING BONES

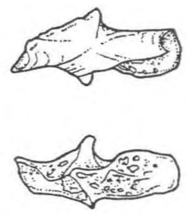
Nasal



Frontal

GADIDAE *Gadus morhua*

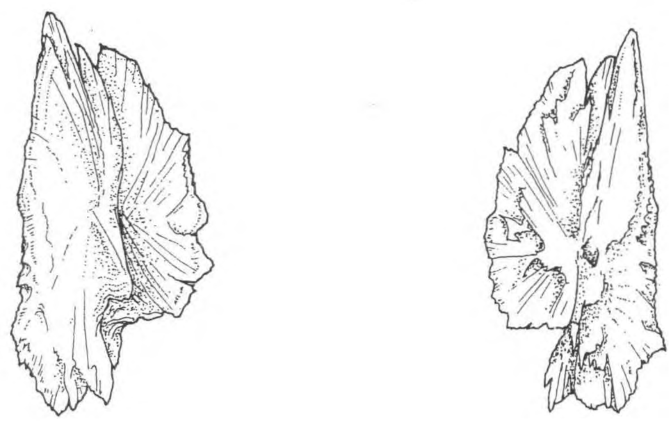
INVESTING BONES



L

M

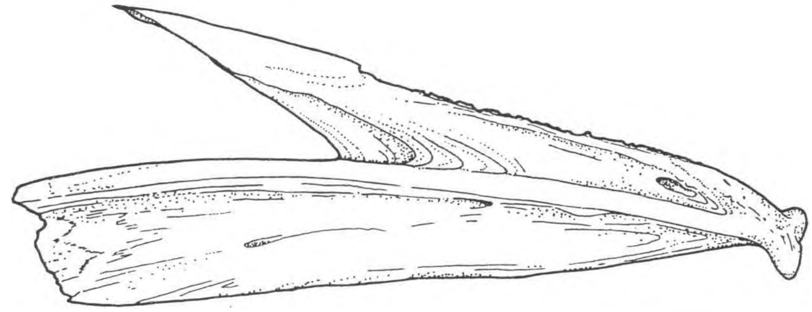
Supratemporals



Parietal

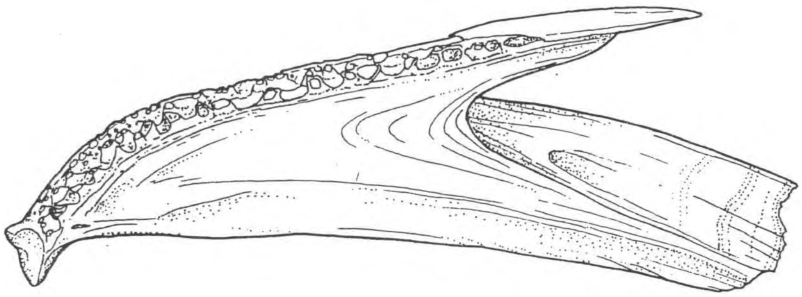
GADIDAE *Gadus morhua*

LATERAL SKULL BONES



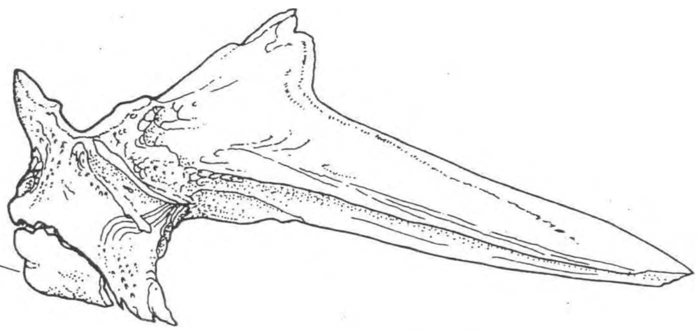
L

Dentary



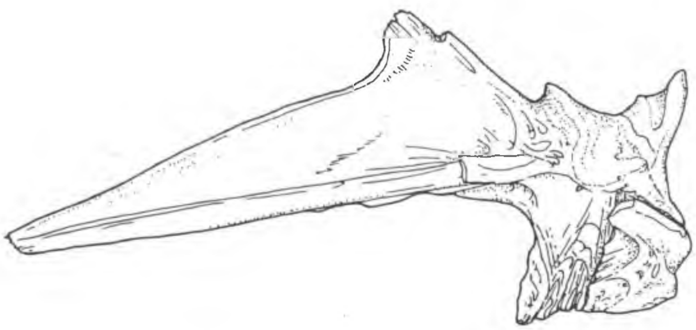
M

Retroarticular



L

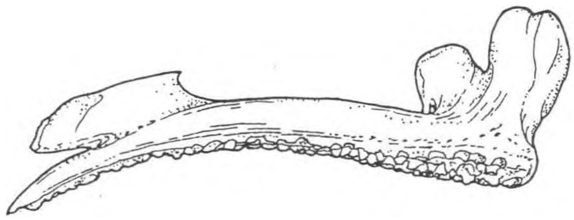
Angular



M

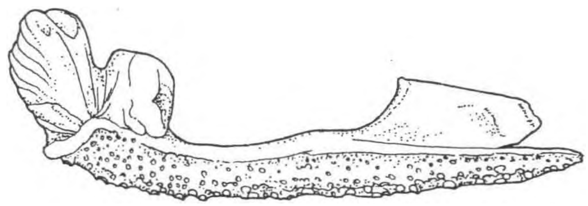
GADIDAE *Gadus morhua*

LATERAL SKULL BONES

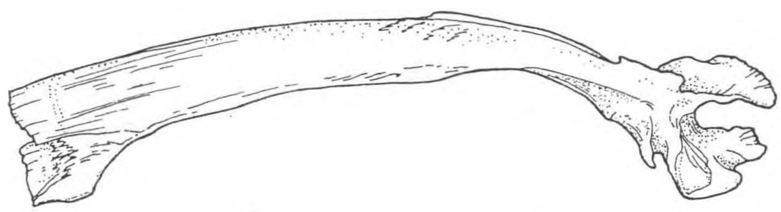


L

Premaxilla

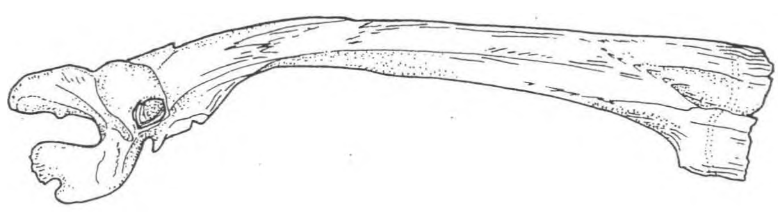


M



L

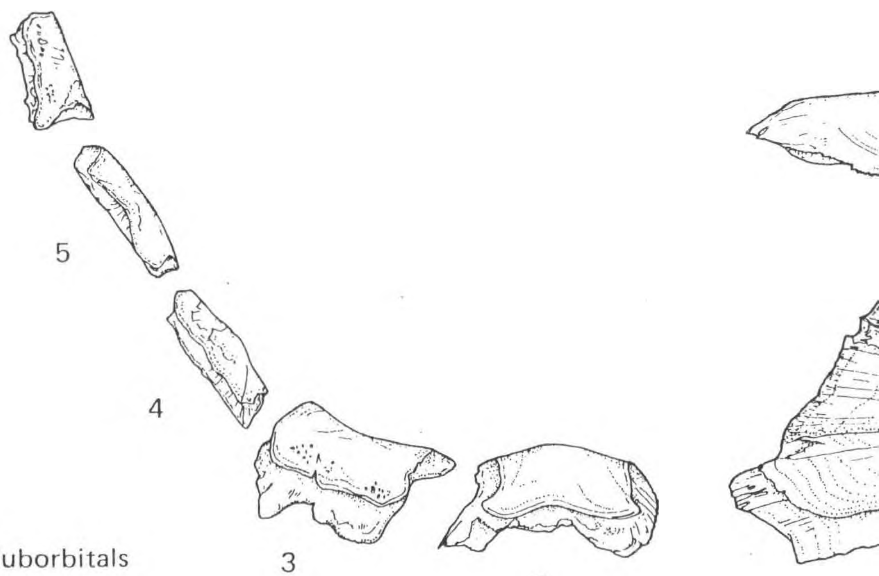
Maxilla



M

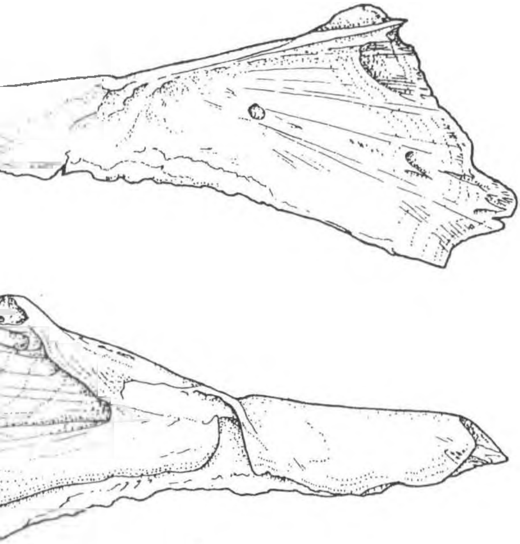
GADIDAE *Gadus morhua*

LATERAL SKULL BONES



Suborbitals

Circumorbital Series



M

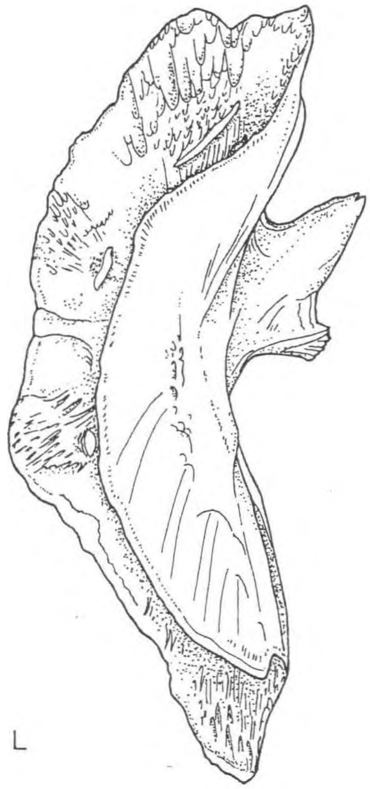
L

1

Lachrymal

GADIDAE *Gadus Morhua*

LATERAL SKULL BONES



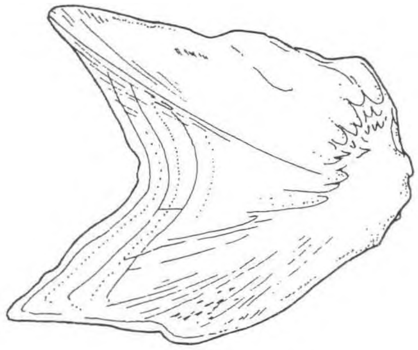
L

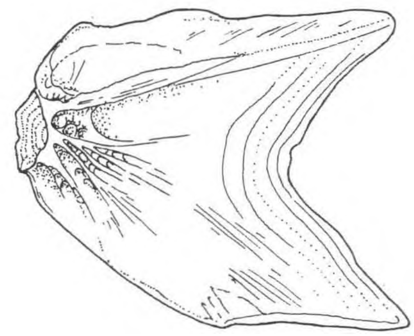
M

Preopercle

OPERCULAR SERIES

L



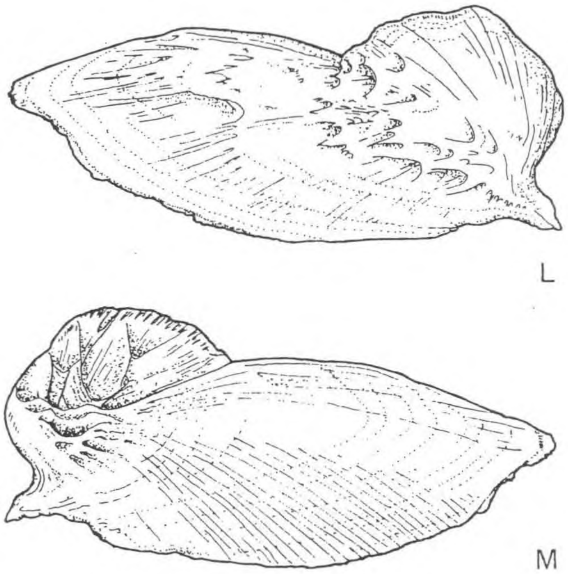


M

Opercle

GADIDAE *Gadus morhua*

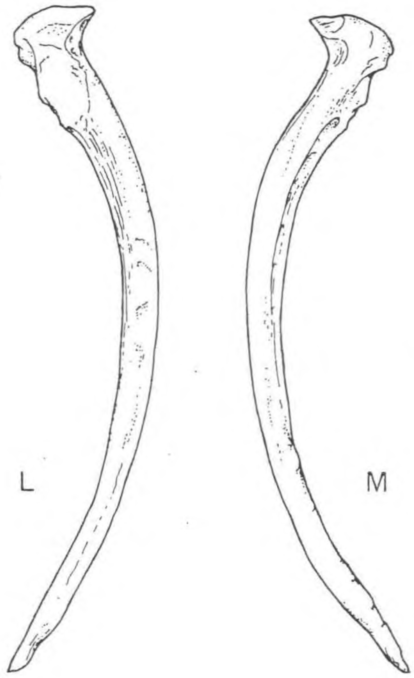
OPERCULAR SERIES



Subopercle

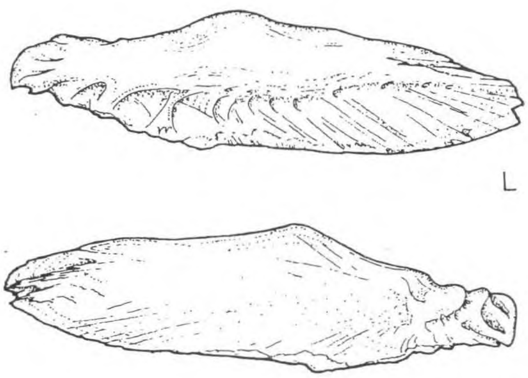
L

M



L M

Branchiostegal Ray



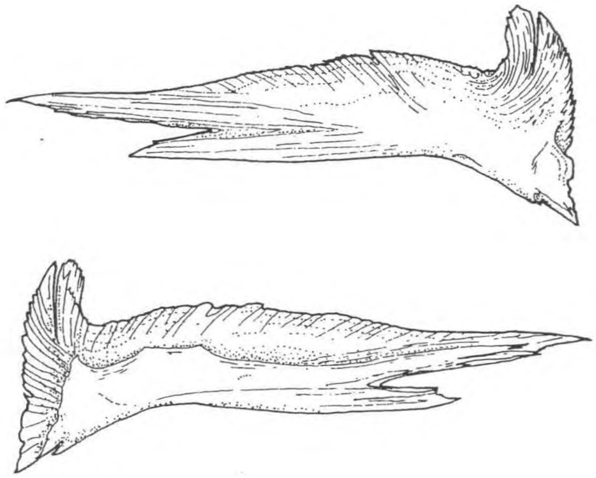
L

Interopercle

M

GADIDAE *Gadus morhua*

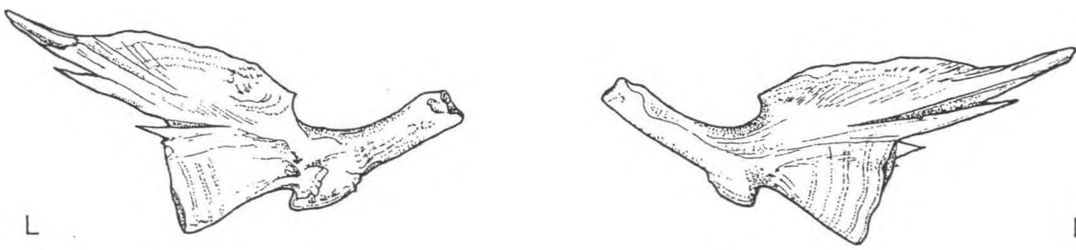
MANDIBULAR ARCH



L

M

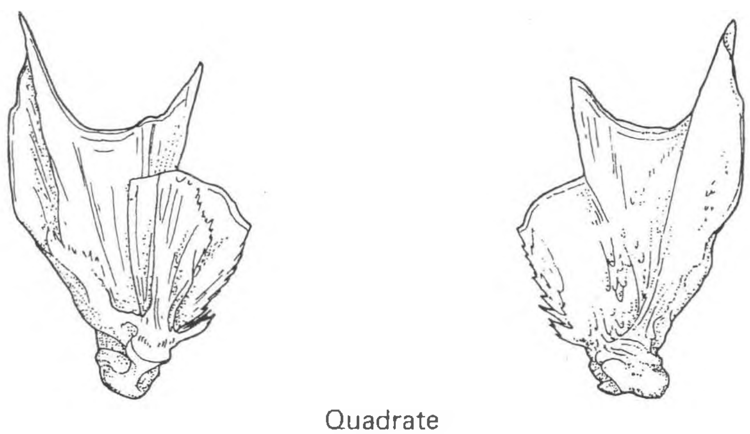
Ectopterygoid



L

M

Palatine



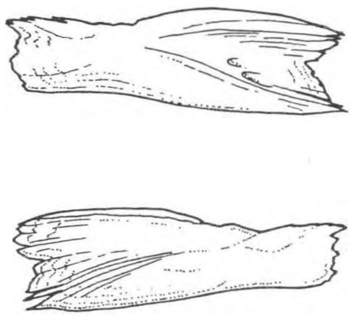
L

M

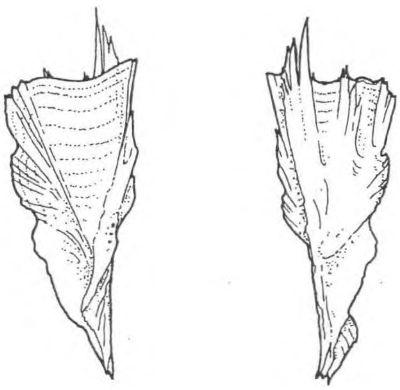
Quadrate

GADIDAE *Gadus morhua*

MANDIBULAR ARCH

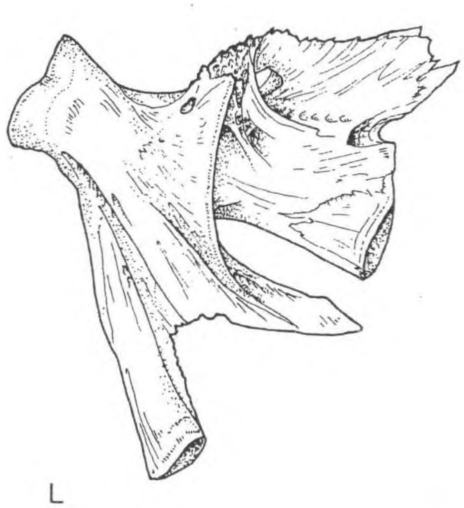


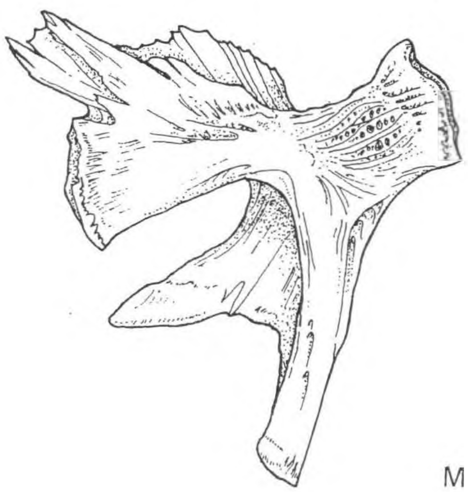
Mesopterygoid



Metapterygoid

HYOID ARCH



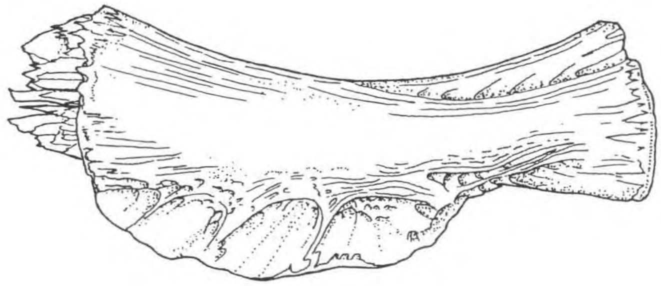


Hyomandibular

GADIDAE *Gadus morhua*

HYOID ARCH

Ceratohyal



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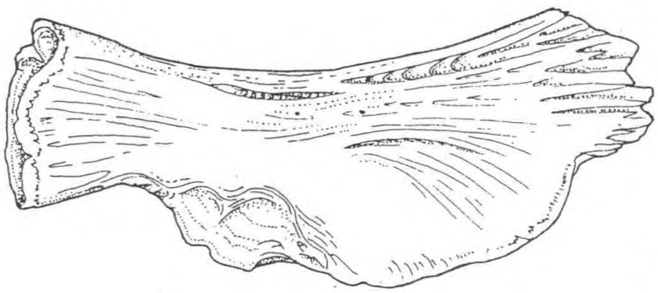

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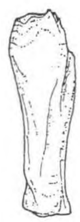
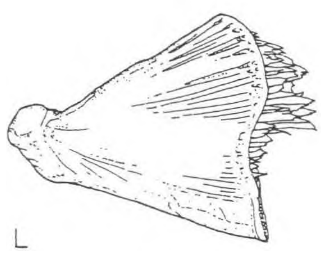


Interhyal



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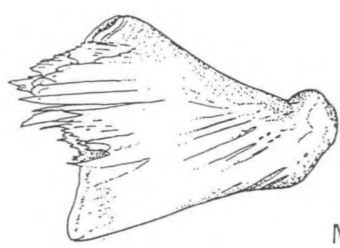


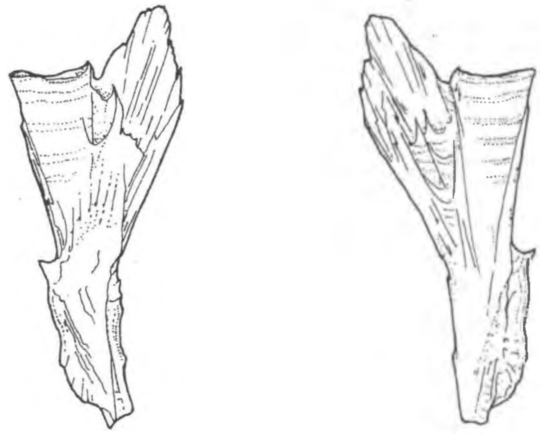
M

Epihyal

GADIDAE *Gadus morhua*

HYOID ARCH

Symplectic

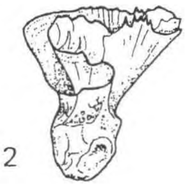


1

upper

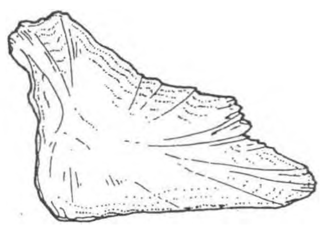
Hypohyal

2



lower

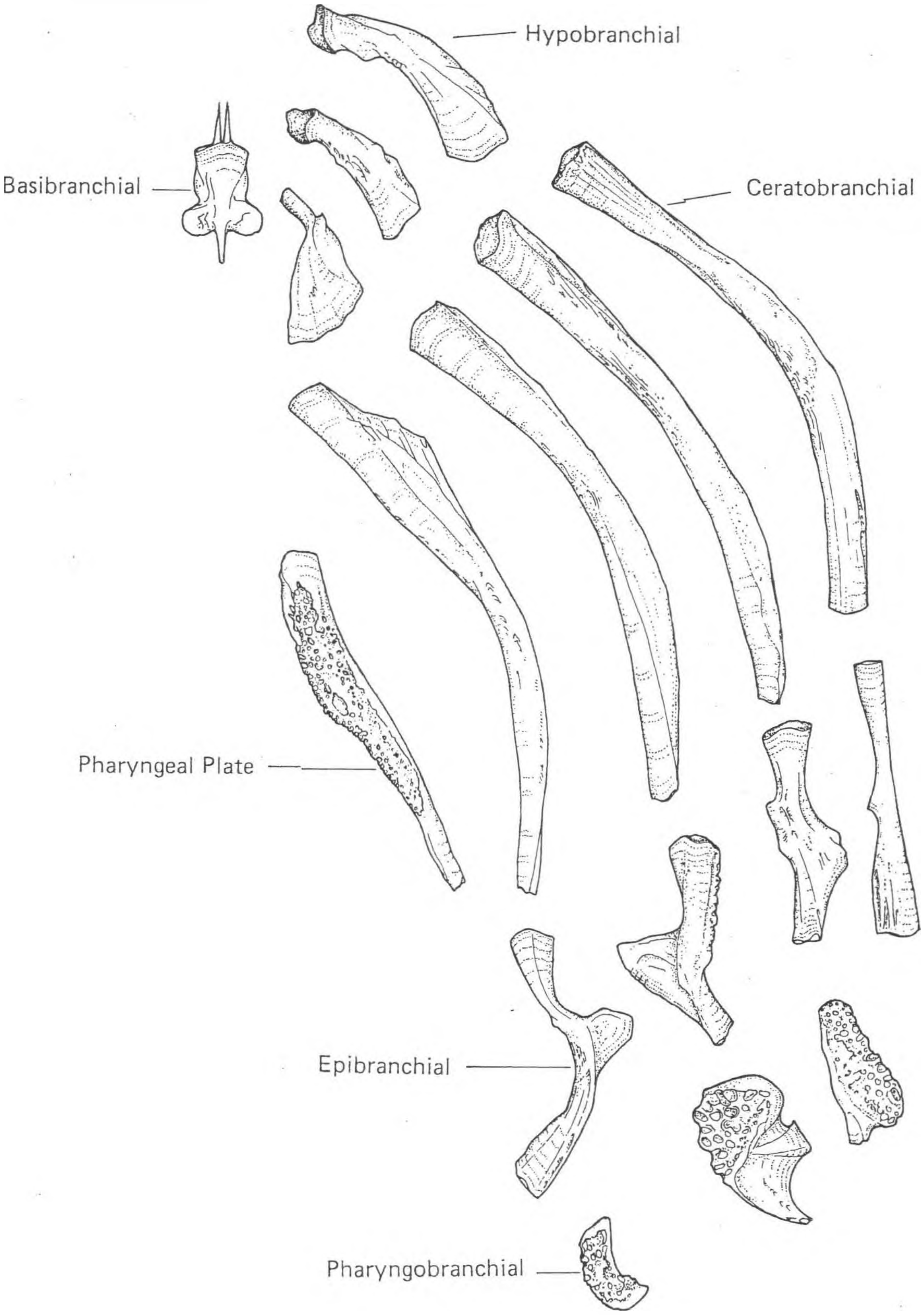
BRANCHIAL ARCH



Urohyal

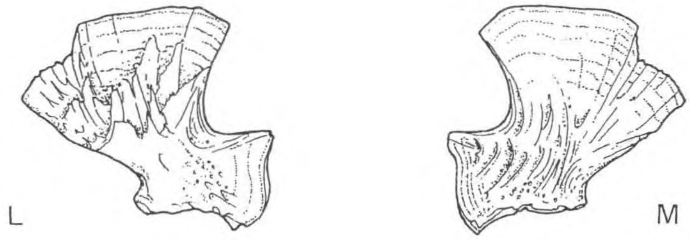
GADIDAE *Gadus morhua*

BRANCHIAL ARCH

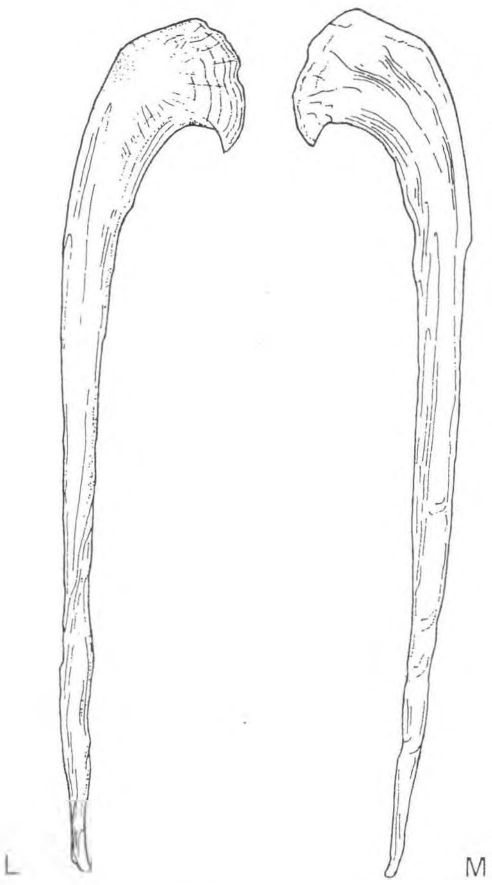


GADIDAE *Gadus Morhua*

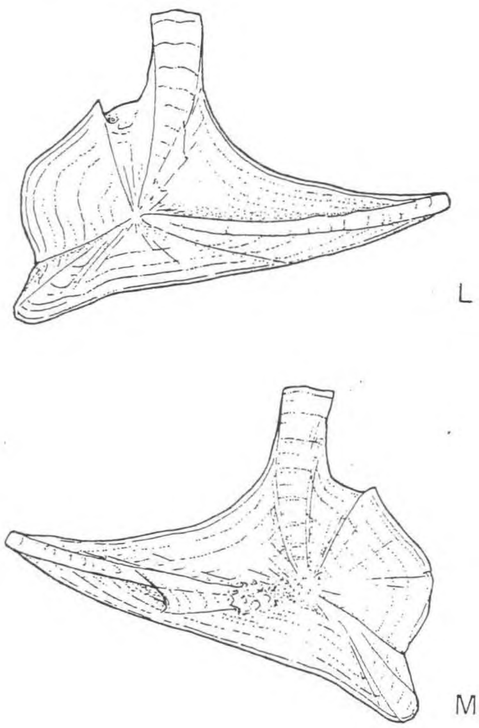
PECTORAL GIRDLE



Scapula



Postcleithrum

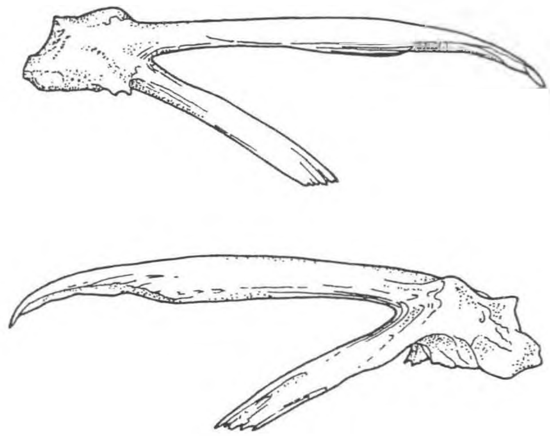


Coracoid

GADIDAE *Gadus morhua*

PECTORAL GIRDLE

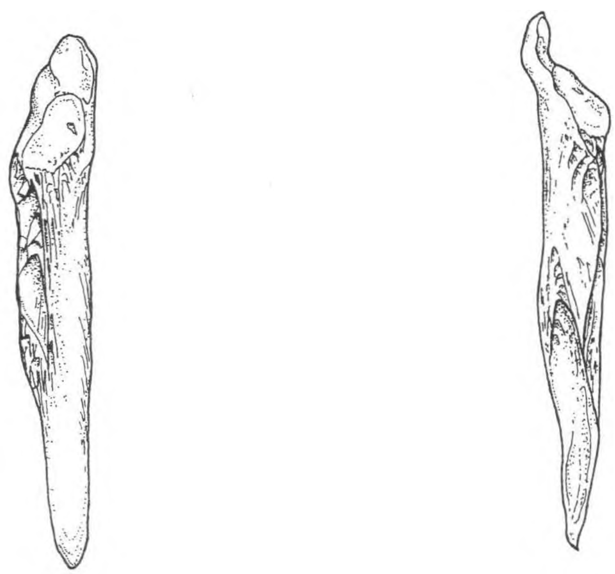
Radials



L

M

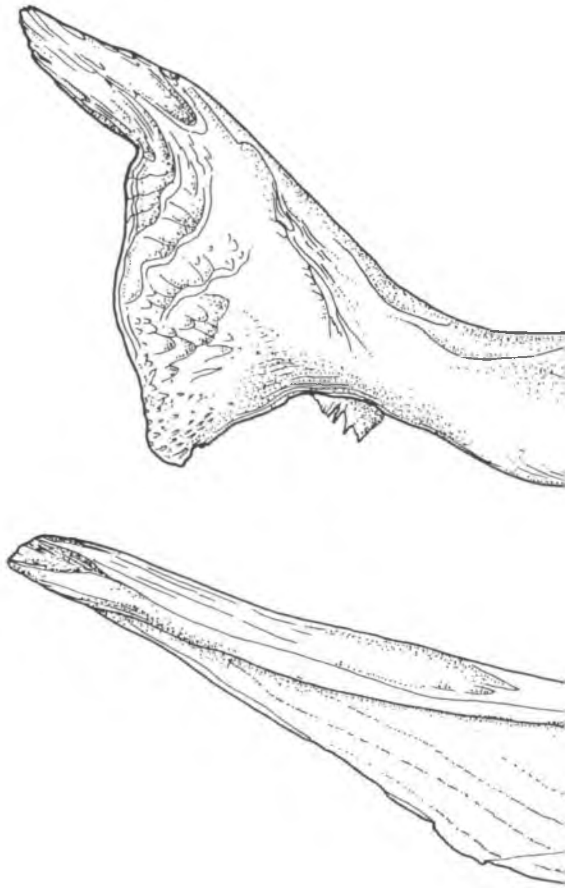
Posttemporal



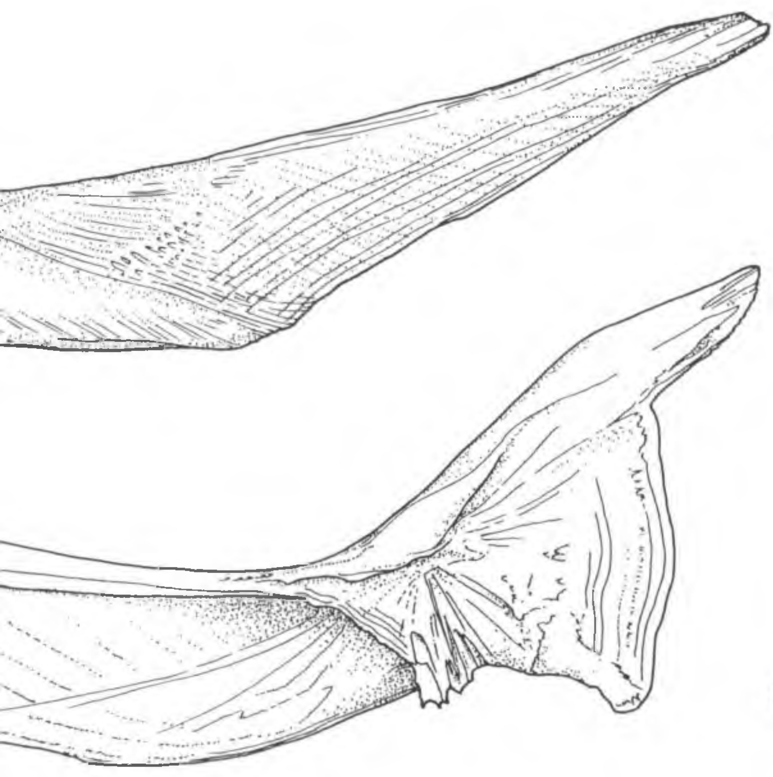
Supracleithrum

GADIDAE *Gadus morhua*

PECTORAL GIRDLE



Cleithrum

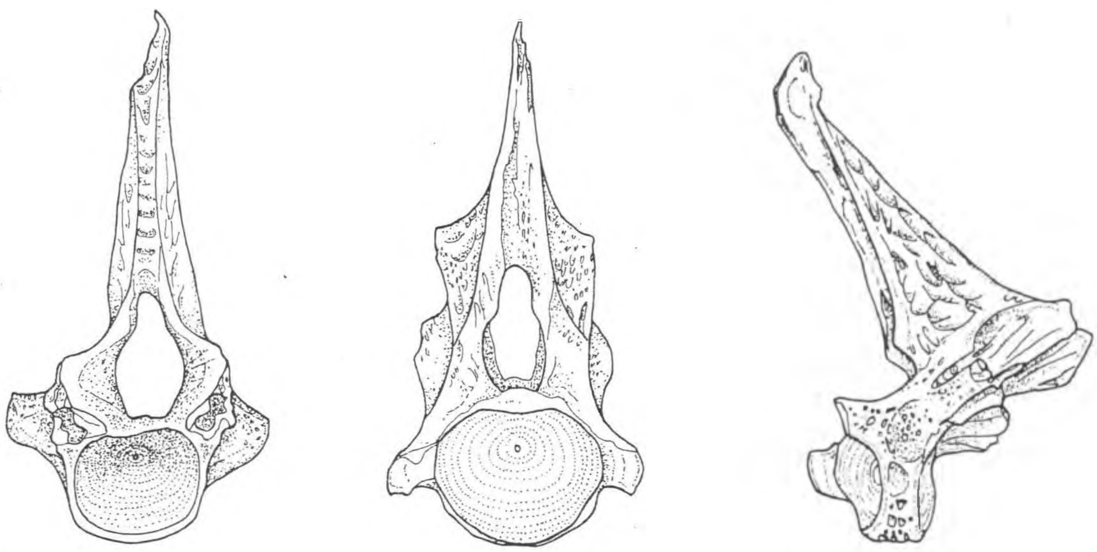


GADIDAE *Gadus morhua*

PELVIC GIRDLE

Basipterygium

VERTEBRAL COLUMN

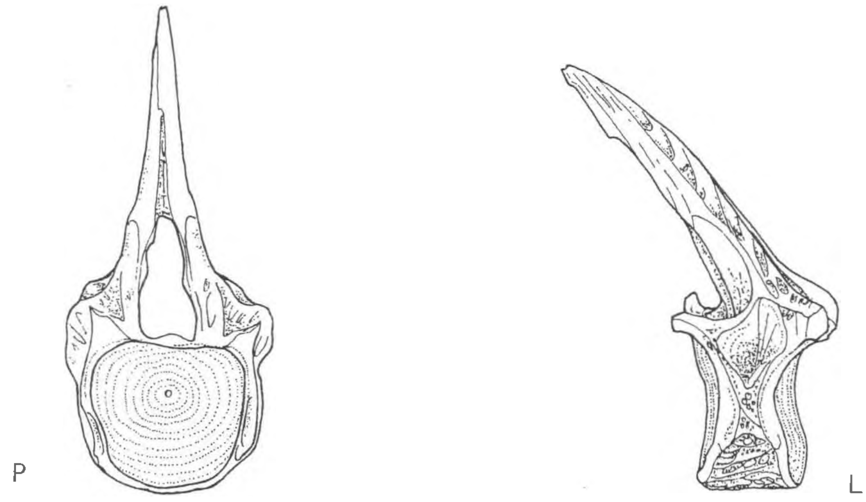


A P L

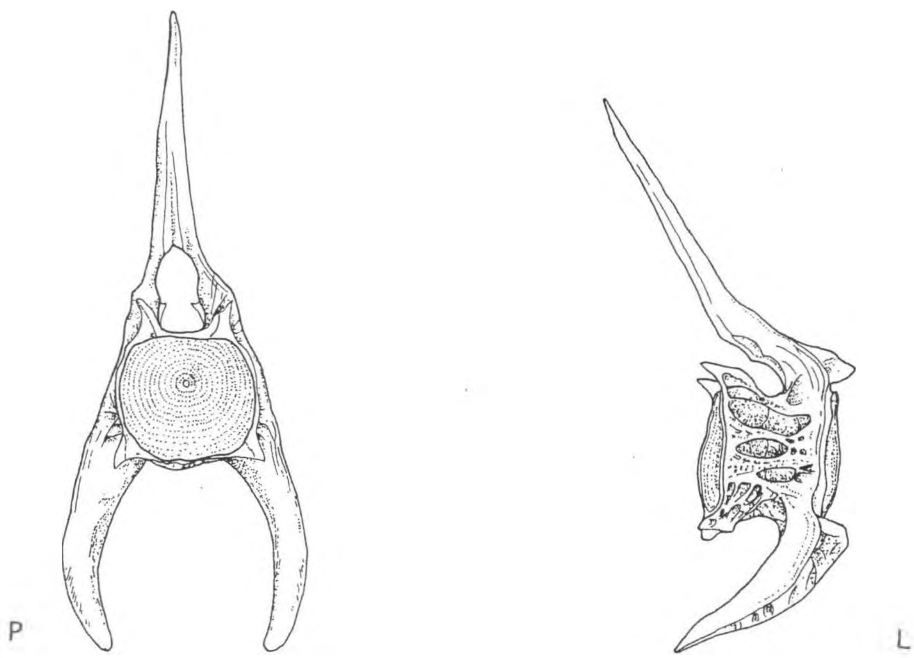
Atlas Vertebra

GADIDAE *Gadus morhua*

VERTEBRAL COLUMN



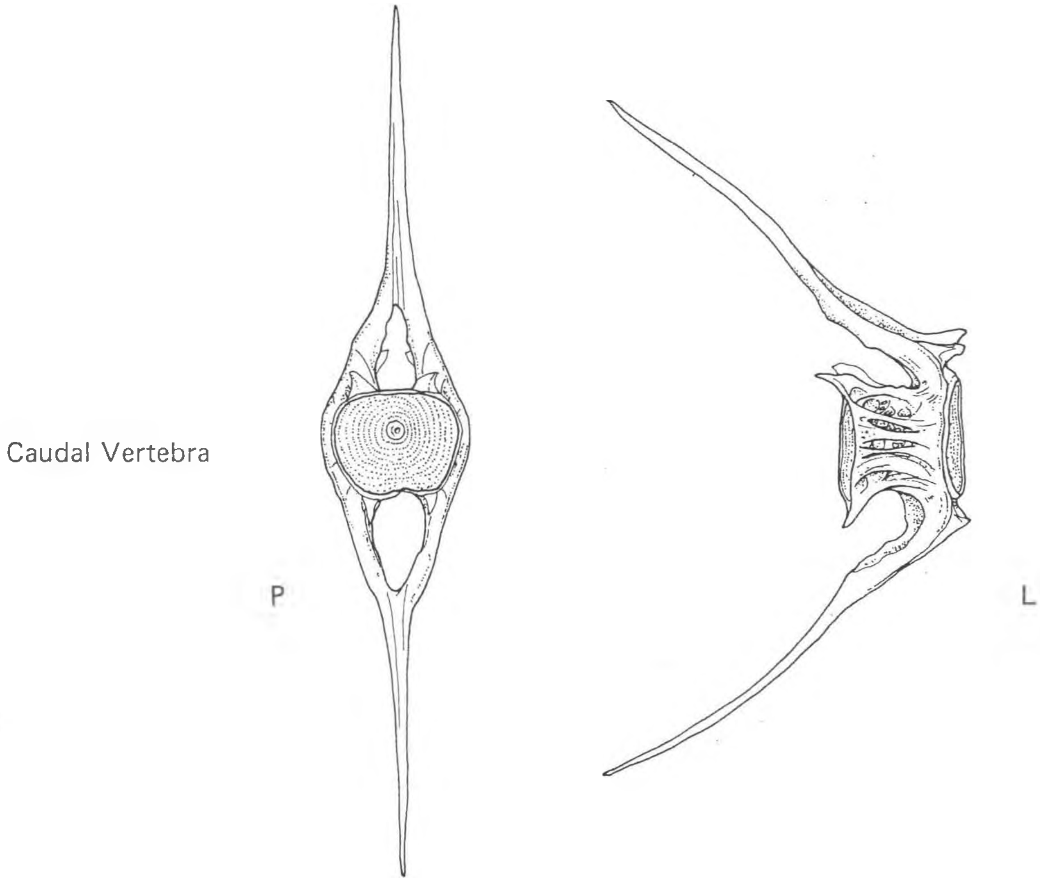
Thoracic Vertebra

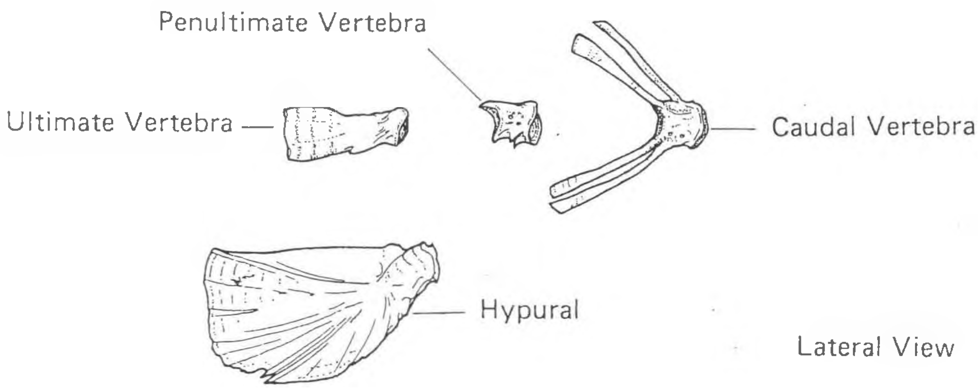


Precaudal Vertebra

GADIDAE *Gadus morhua*

CAUDAL SKELETON

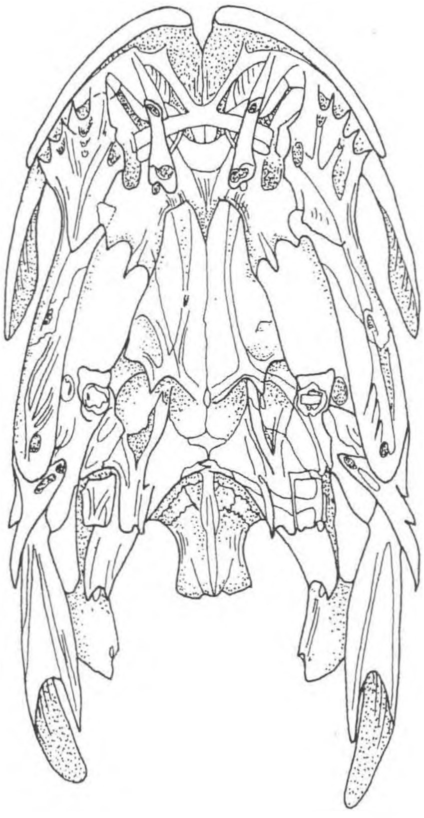




KEY TO ELEMENT VIEW

L Lateral
M Mesial
A Anterior
P Posterior
D Dorsal
V Ventral

FAMILY SCORPAENIDAE



(after Gregory 1933)

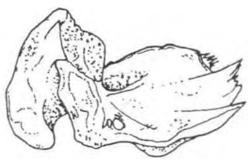
SCORPAENIDAE *Sebastes marinus*

OLFACTORY REGION

D

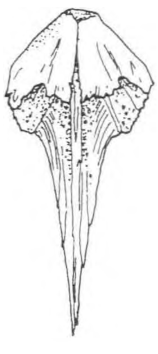
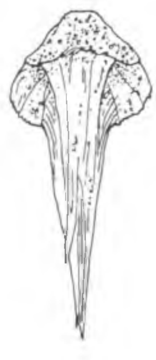

L

Ethmoid

D


V

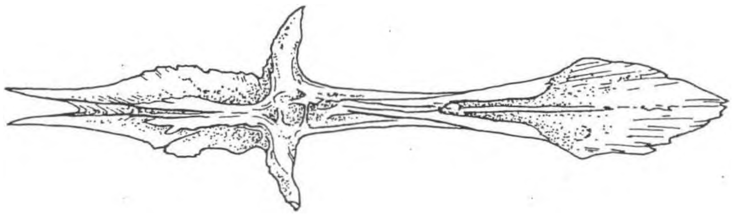
Prefrontal

D


V

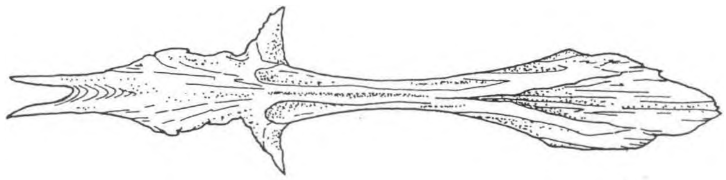
Vomer

SCORPAENIDAE *Sebastes marinus*

ORBITAL REGION



D



V

Parasphenoid

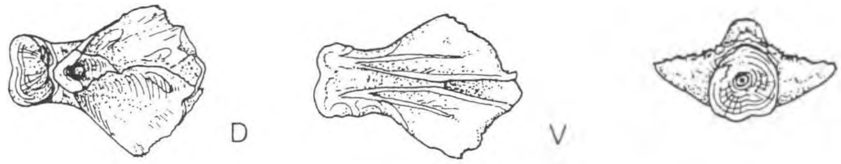
Alisphenoid

SCORPAENIDAE *Sebastes marinus*

OCCIPITAL REGION

Supraoccipital

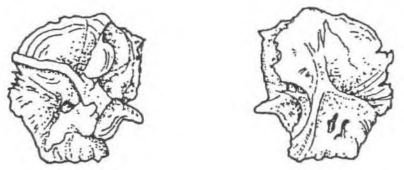
Exoccipital



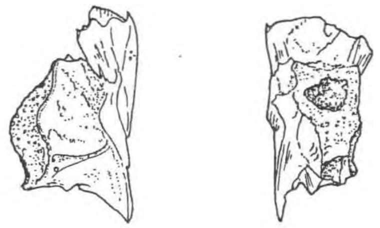
Basioccipital

SCORPAENIDAE *Sebastes marinus*

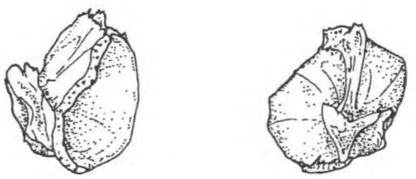
OTIC REGION



Sphenotic

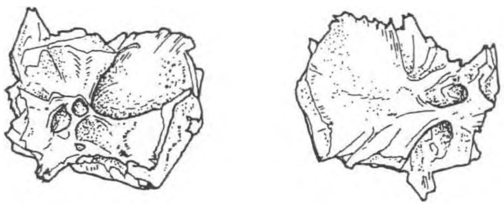


Pterotic



Epiotic

Opisthotic

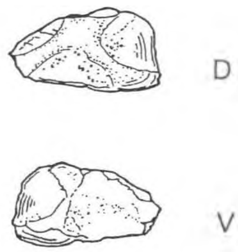


Prootic

Otolith

SCORPAENIDAE *Sebastes marinus*

INVESTING BONES



Nasal

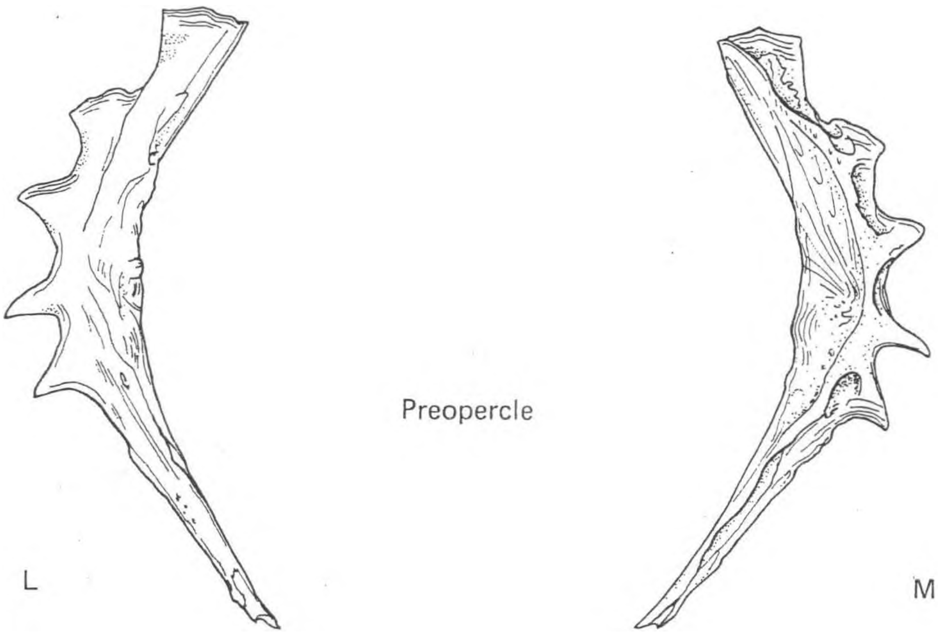
Supratemporal

Frontal

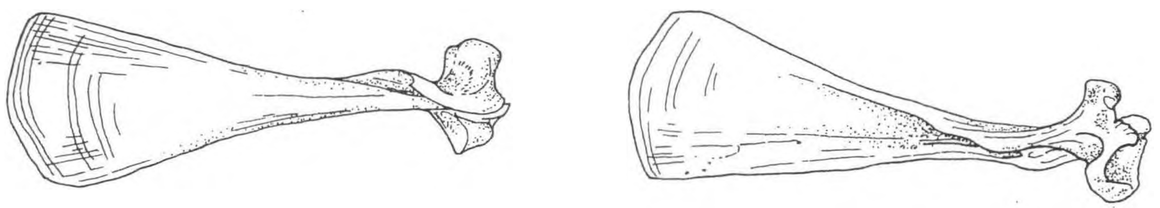
Parietal

SCORPAENIDAE *Sebastes marinus*

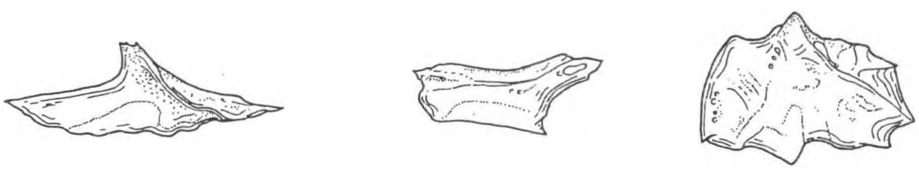
LATERAL SKULL BONES



L Preopercle M



L Maxilla M



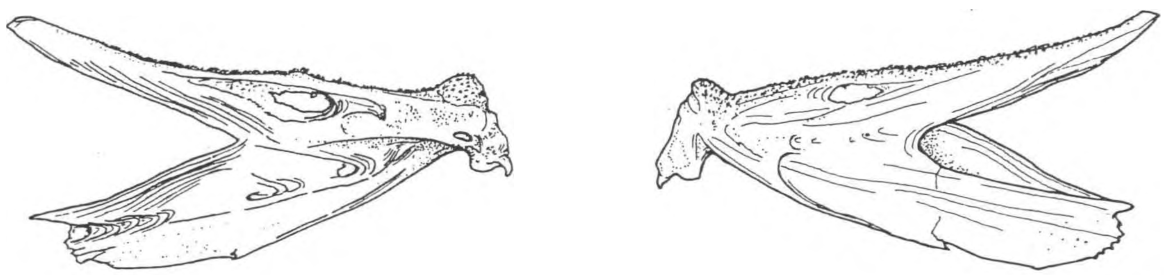
3 Suborbitals 2 1 Lachrymal

Circumorbital Series

SCORPAENIDAE *Sebastes marinus*

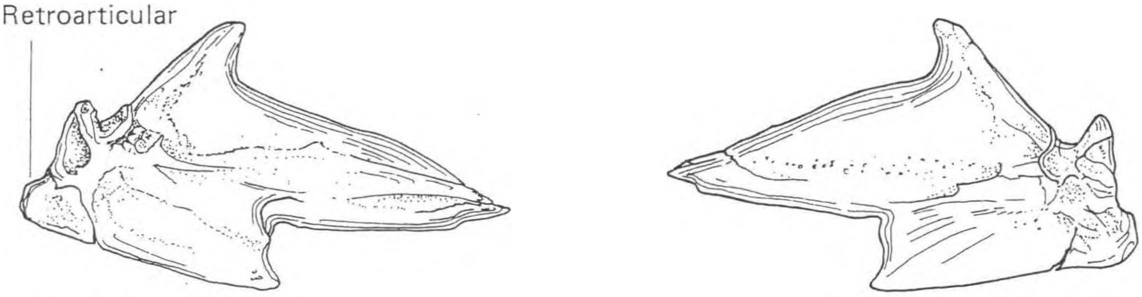
LATERAL SKULL BONES

L Premaxilla M



L Dentary M

Retroarticular

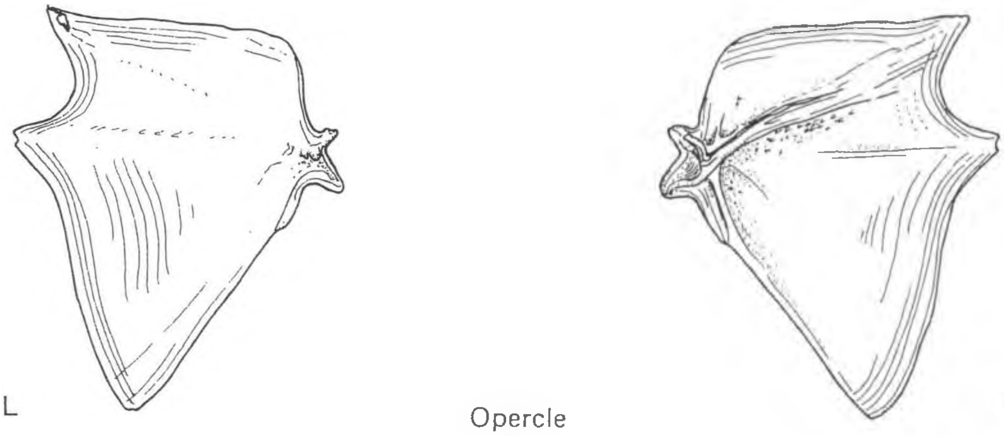


L M

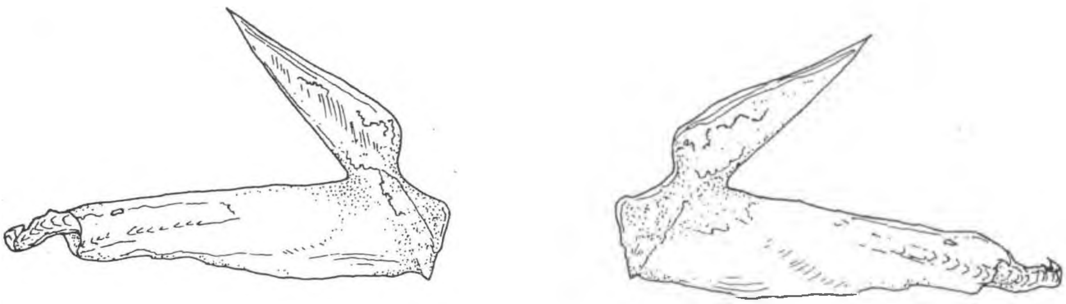
Angular

SCORPAENIDAE *Sebastes marinus*

OPERCULAR SERIES



L Opercle M

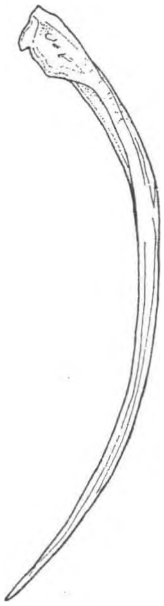


L M
Subopercle

L M
Interopercle

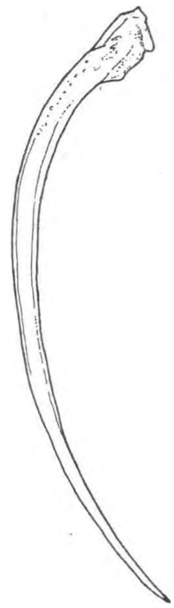
SCORPAENIDAE *Sebastes marinus*

OPERCULAR SERIES



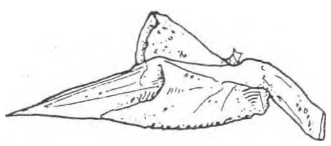
L

Branchiostegal Ray



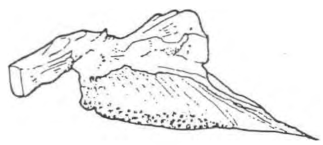
M

MANDIBULAR ARCH

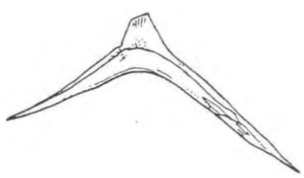


L

Palatine

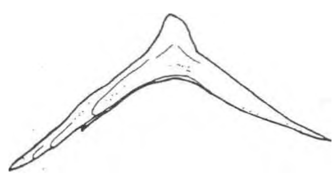


M



L

Ectopterygoid



M

SCORPAENIDAE *Sebastes marinus*

MANDIBULAR ARCH

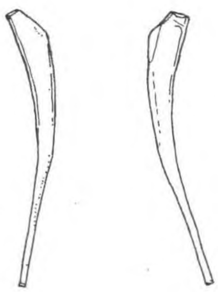
Quadrate

Metapterygoid

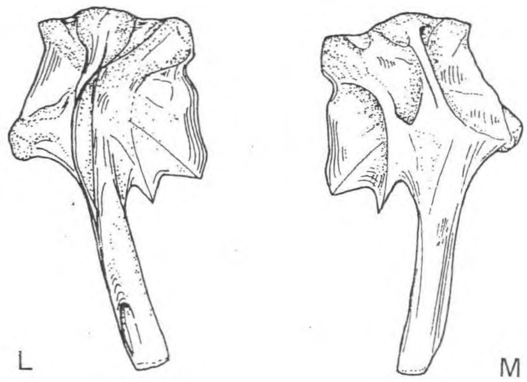
Mesopterygoid

SCORPAENIDAE *Sebastes marinus*

HYOID ARCH

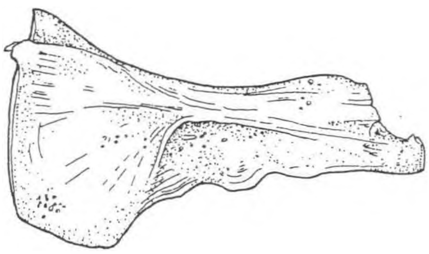


Symplectic



L M

Hyomandibular



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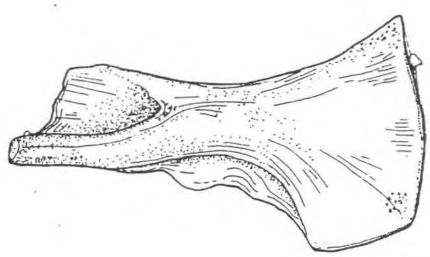
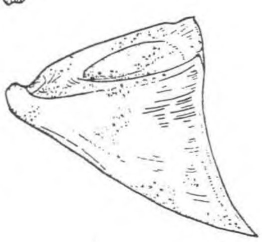


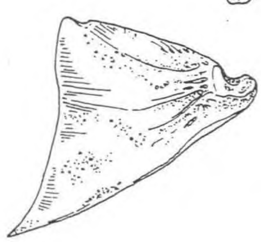
M

Ceratohyal

Interhyal



L

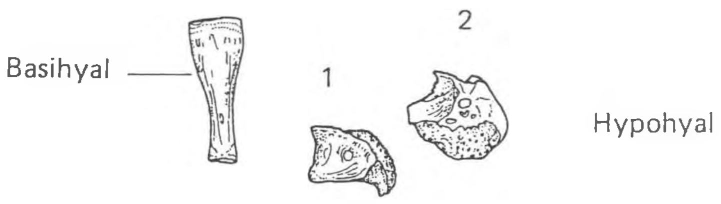


M

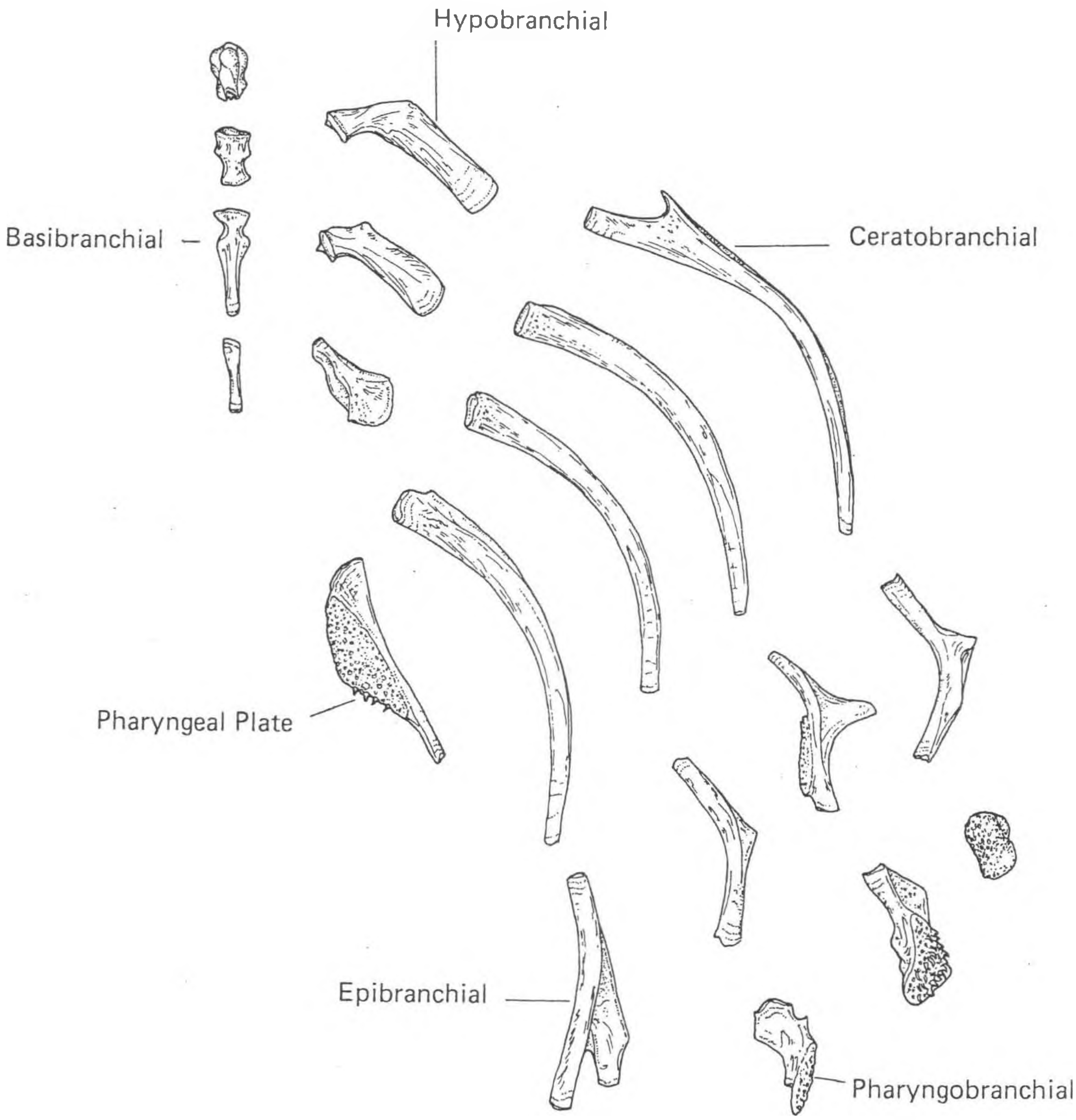
Epihyal

SCORPAENIDAE *Sebastes* sp

HYOID ARCH

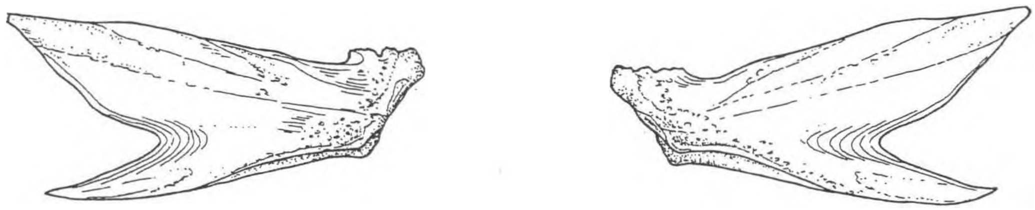


BRANCHIAL ARCH



SCORPAENIDAE *Sebastes marinus*

BRANCHIAL ARCH



Urohyal

PECTORAL GIRDLE

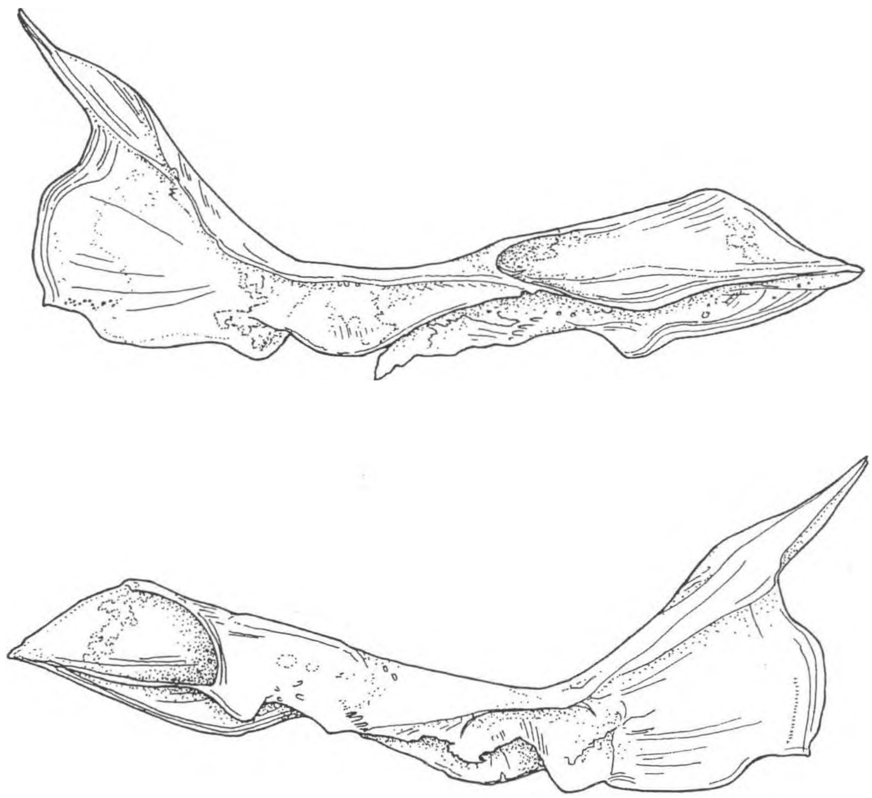
L M

Posttemporal

Supracleithrum

SCORPAENIDAE *Sebastes marinus*

PECTORAL GIRDLE



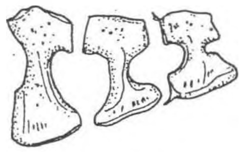
L

M

Cleithrum

SCORPAENIDAE *Sebastes marinus*

PECTORAL GIRDLE

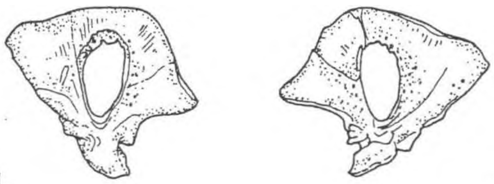


Radials

1 upper

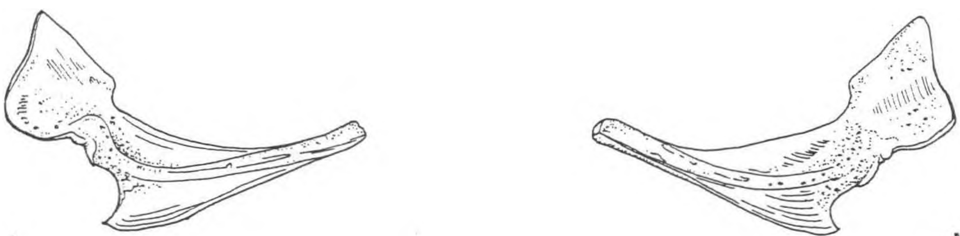
2 lower

Postcleithrum



L M

Scapula

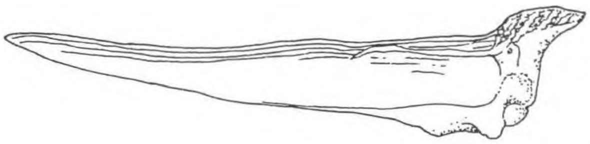


L M

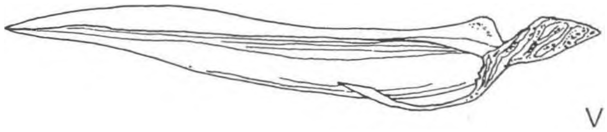
Coracoid

SCORPAENIDAE *Sebastes marinus*

PELVIC GIRDLE

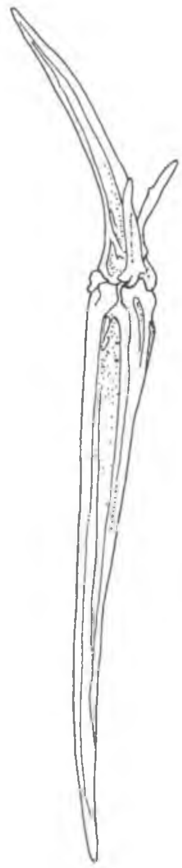


D



V

Basipterygium



Interhaemal Spine

VERTEBRAL COLUMN

A

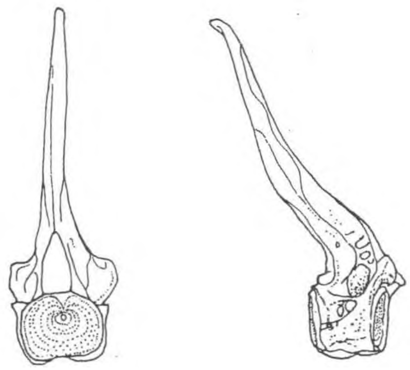
P

L

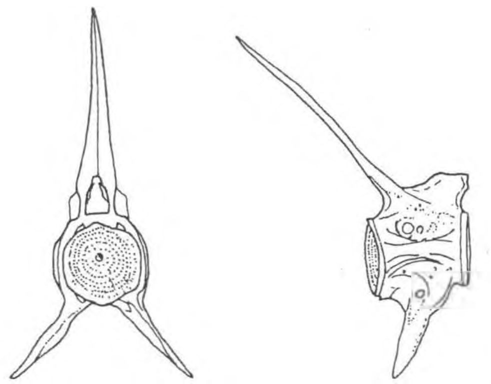
Atlas Vertebra

SCORPAENIDAE *Sebastes marinus*

VERTEBRAL COLUMN

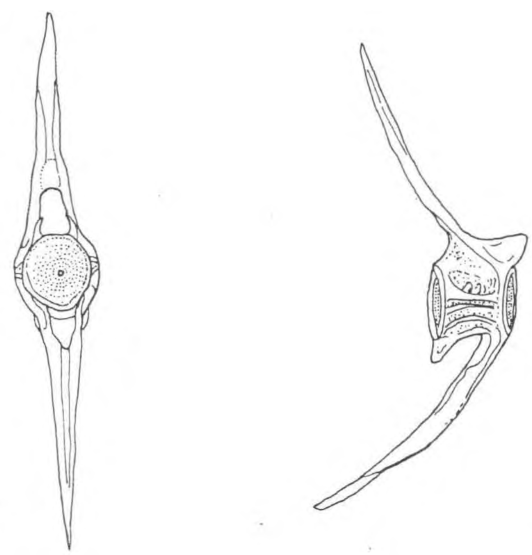
P  L

Thoracic Vertebra

P  L

Precaudal Vertebra

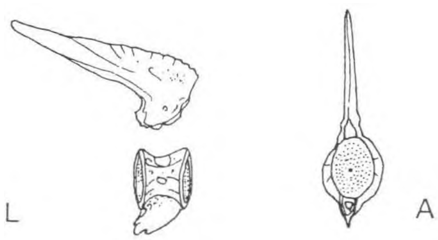
CAUDAL SKELETON

P  L

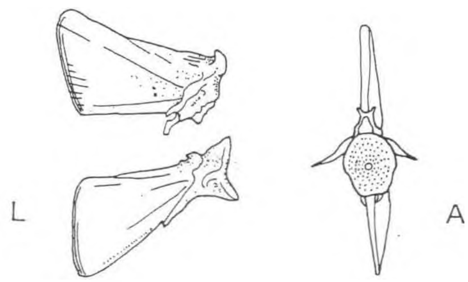
Caudal Vertebra

SCORPAENIDAE *Sebastes marinus*

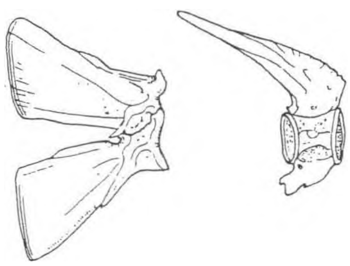
CAUDAL SKELETON



Penultimate Vertebra



Ultimate Vertebra

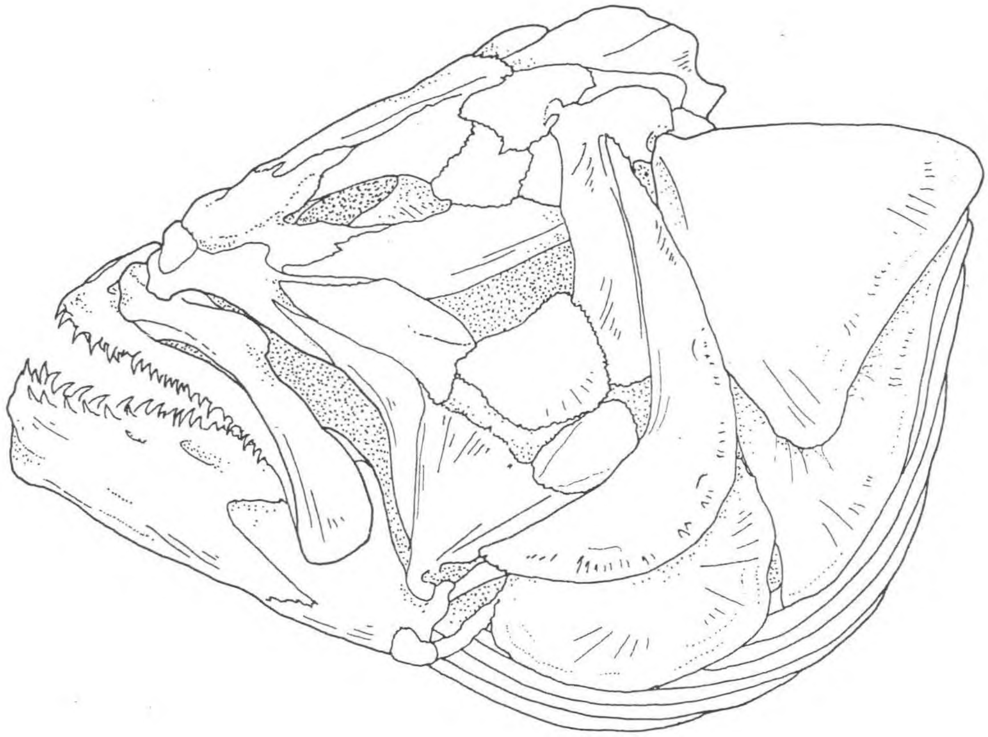


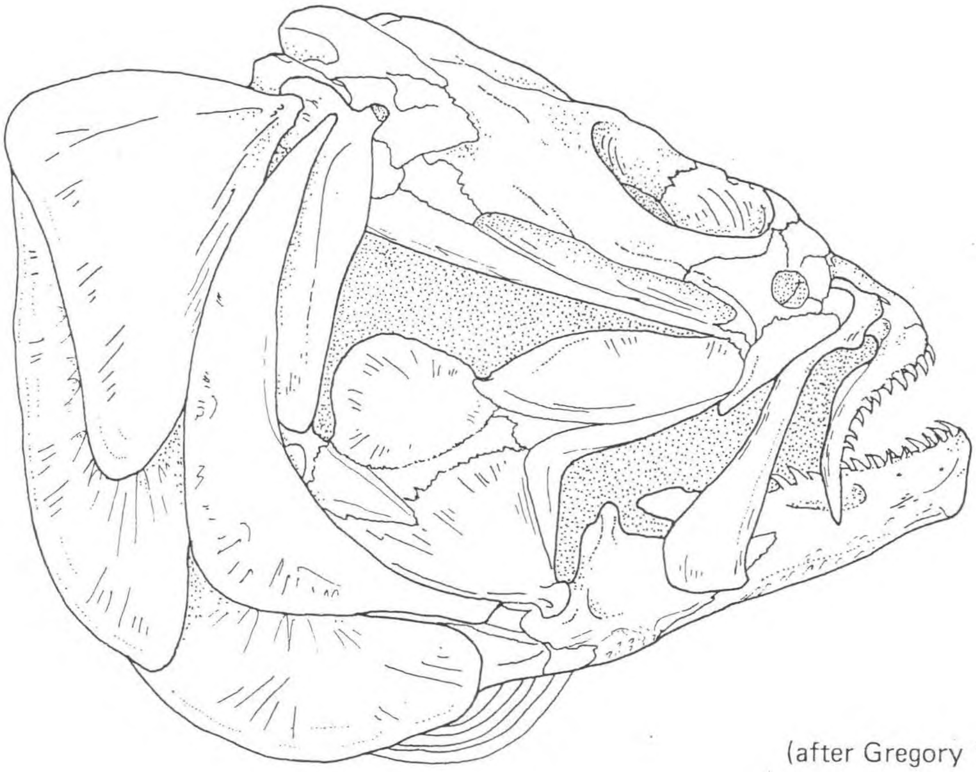
Lateral View

KEY TO ELEMENT VIEW

L Lateral
M Mesial
A Anterior
P Posterior
D Dorsal
V Ventral

FAMILY PLEURONECTIDAE

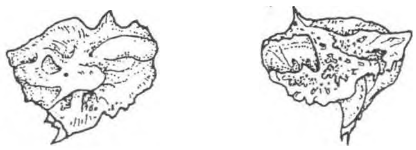




(after Gregory 1933)

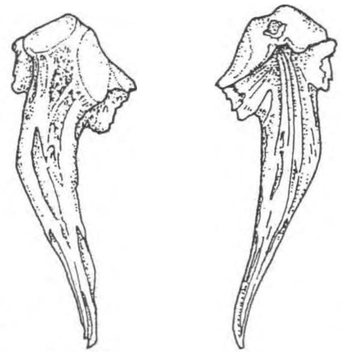
PLEURONECTIDAE *Hippoglossus stenolepis*

OLFACTORY REGION



D V

Ethmoid



D V

Vomer

L M

right

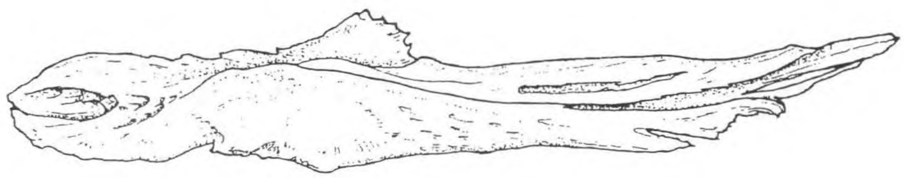
Prefrontal

L left M

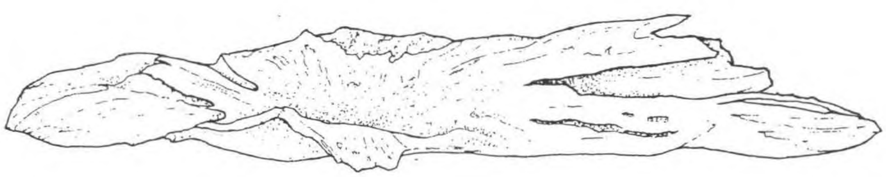
PLEURONECTIDAE *Hippoglossus stenolepis*

ORBITAL REGION

Alisphenoid



D

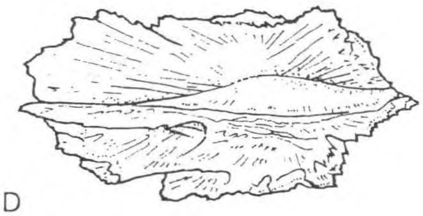


V

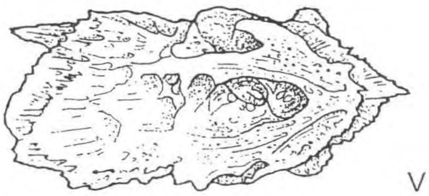
Parasphenoid

PLEURONECTIDAE *Hippoglossus stenolepis*

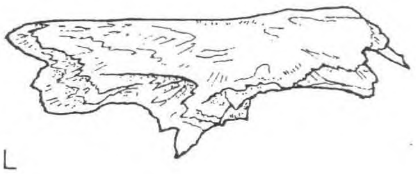
OCCIPITAL REGION



D



V



L

Supraoccipital

from larger specimen - *Hippoglossus stenolepis* (b)

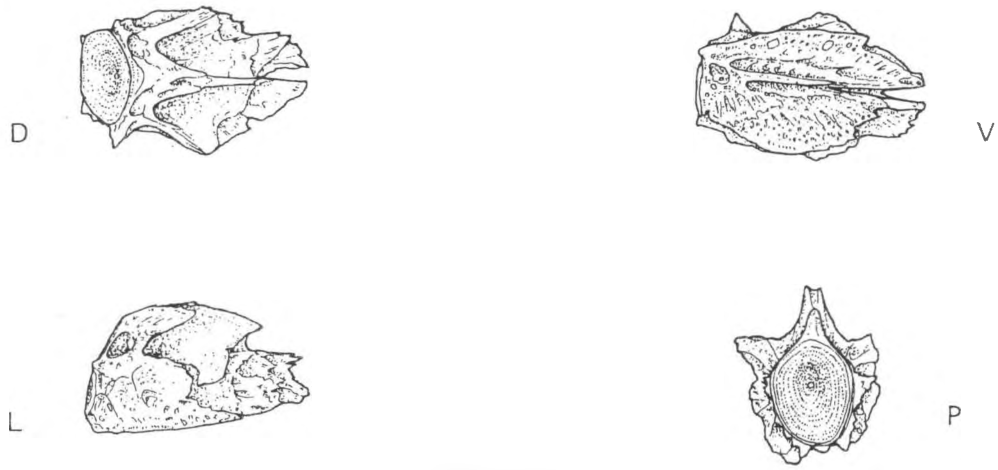
right

Exoccipital

left

PLEURONECTIDAE *Hippoglossus stenolepis*

OCCIPITAL REGION



Basioccipital

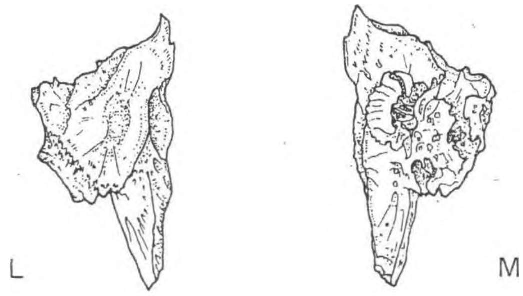
OTIC REGION

Sphenotic

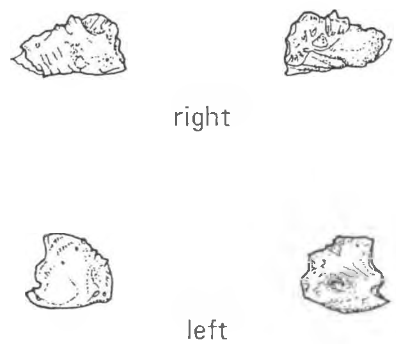
from larger specimen - *Hippoglossus stenolepis* (b)

PLEURONECTIDAE *Hippoglossus stenolepis*

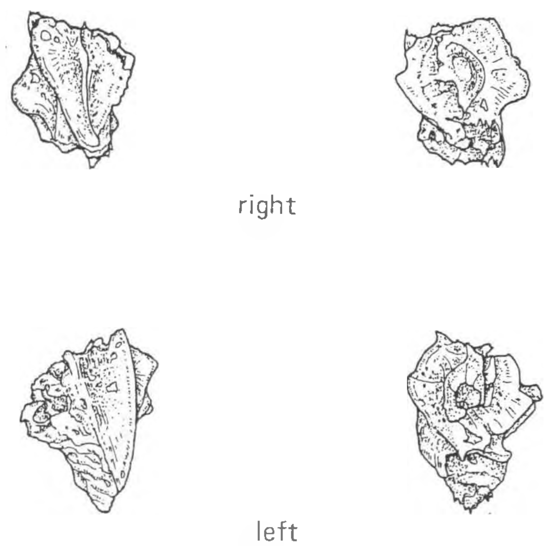
OTIC REGION



Pterotic



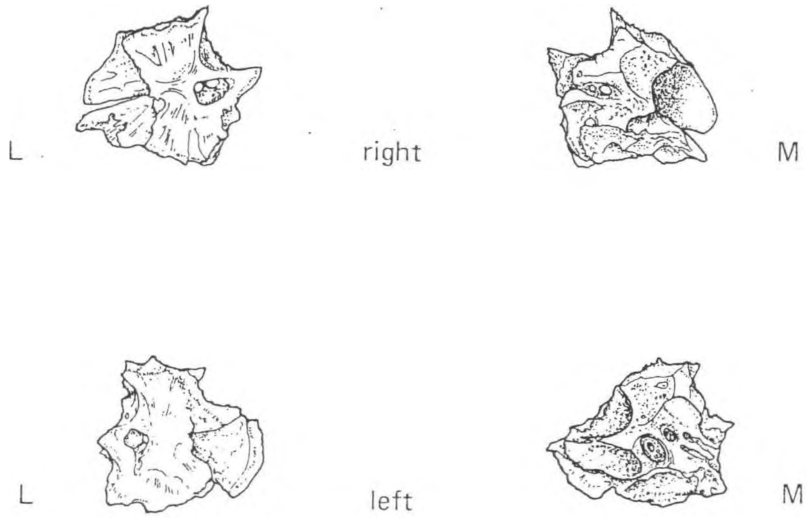
Opisthotic



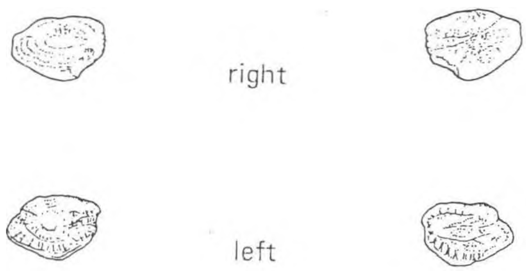
Epiotic

PLEURONECTIDAE *Hippoglossus stenolepis*

OTIC REGION



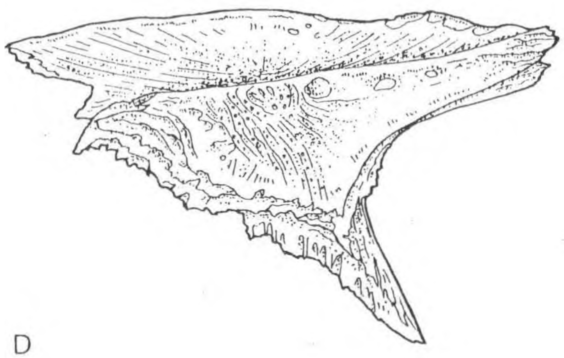
Prootic

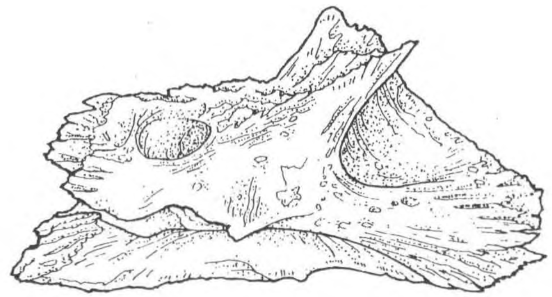


Otolith

PLEURONECTIDAE *Hippoglossus stenolepis*

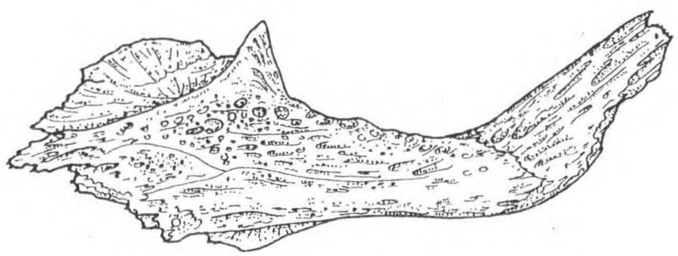
INVESTING BONES

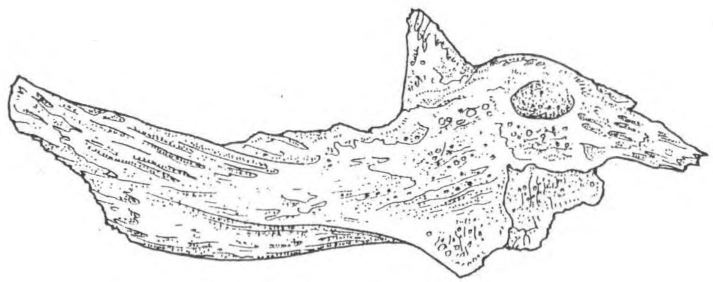




D left V

Frontal





right

D V

from larger specimen - *Hippoglossus stenolepis* (b)

PLEURONECTIDAE *Hippoglossus stenolepis*

INVESTING BONES

L M

Nasal

right

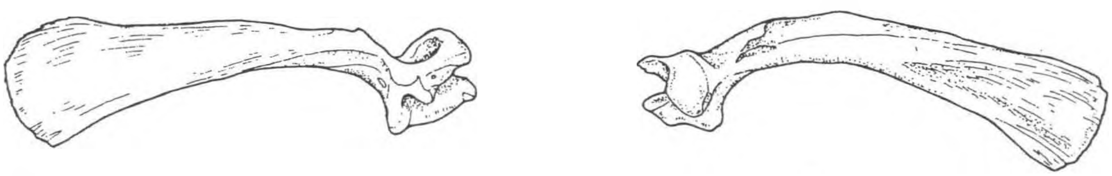
Parietal

left

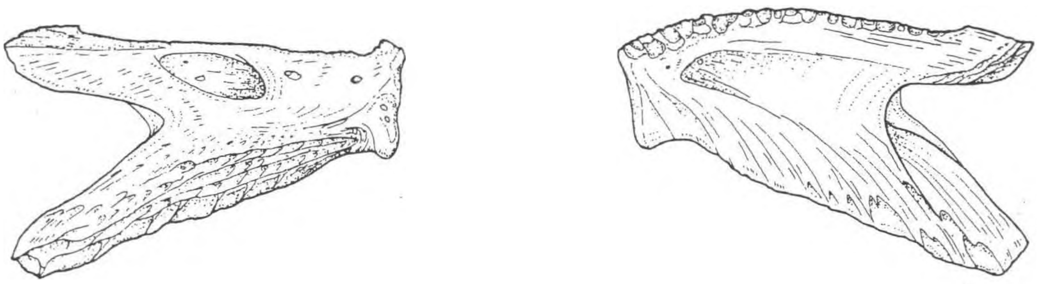
PLEURONECTIDAE *Hippoglossus stenolepis*

LATERAL SKULL BONES

L Premaxilla M



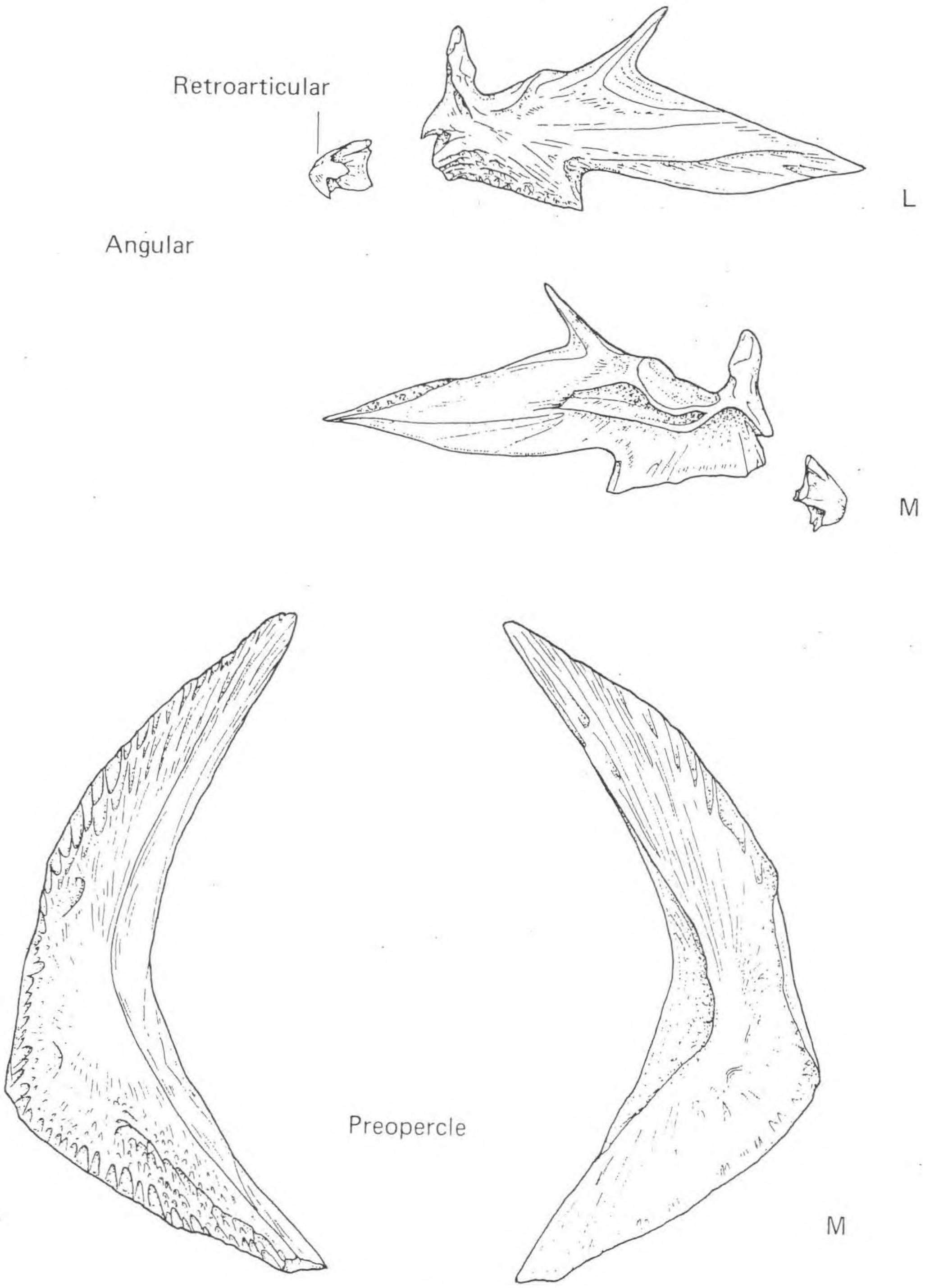
L Maxilla M



L Dentary M

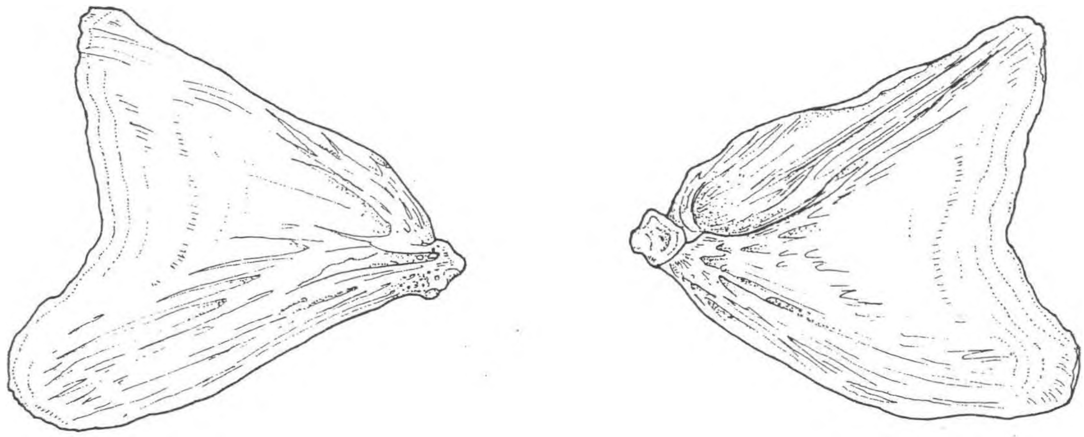
PLEURONECTIDAE *Hippoglossus stenolepis*

LATERAL SKULL BONES

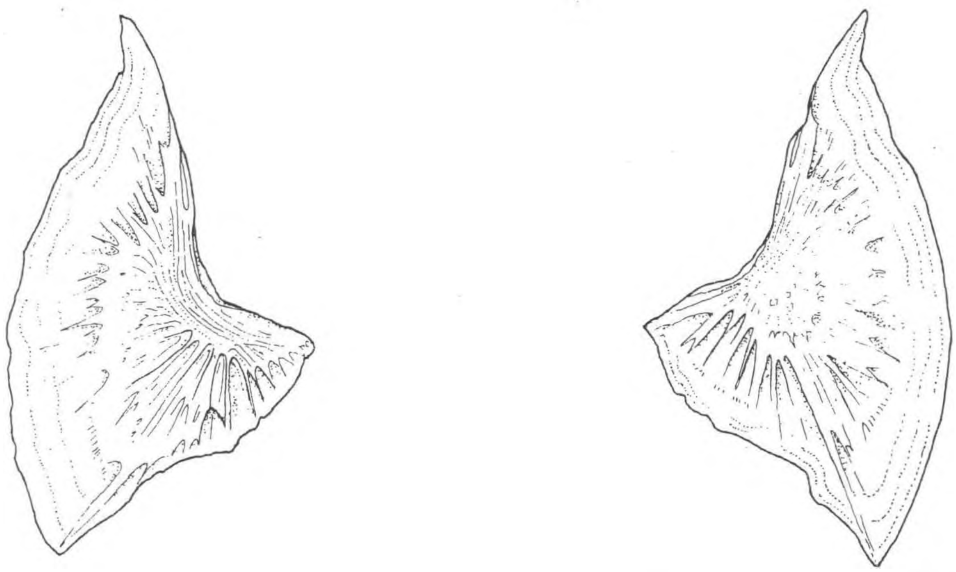


PLEURONECTIDAE *Hippoglossus stenolepis*

OPERCULAR SERIES



L Opercle M

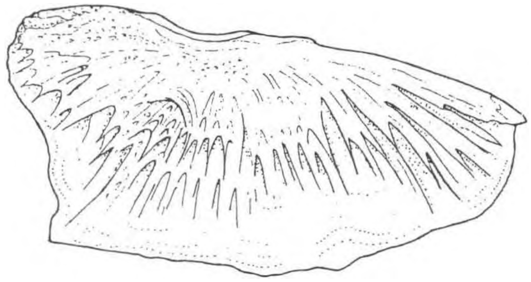


L Subopercle M

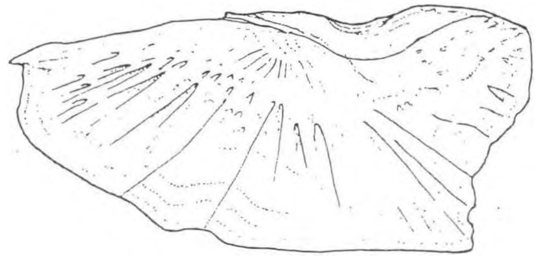
PLEURONECTIDAE *Hippoglossus stenolepis*

OPERCULAR SERIES

Interopercle

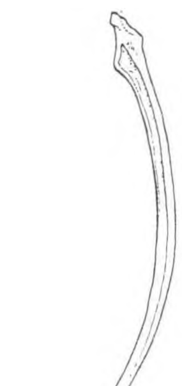


L

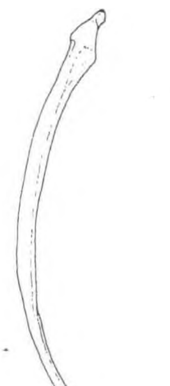


M

Branchiostegal Ray



L



M

PLEURONECTIDAE *Hippoglossus stenolepis*

MANDIBULAR ARCH

L M

right

Palatine

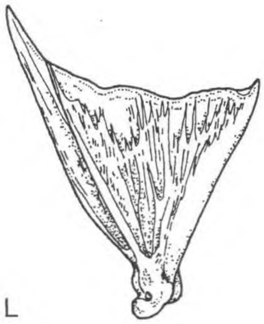
L left M

L M

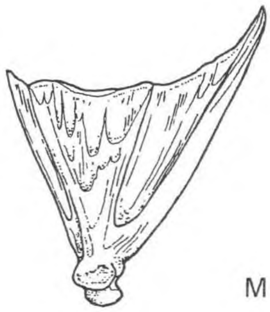
Ectopterygoid

PLEURONECTIDAE *Hippoglossus stenolepis*

MANDIBULAR ARCH



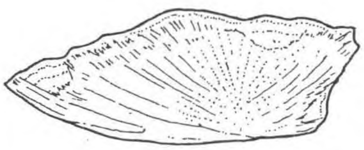
L

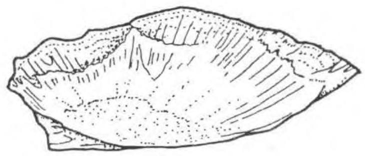


M

Quadrate

L



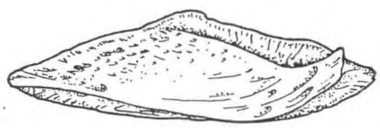


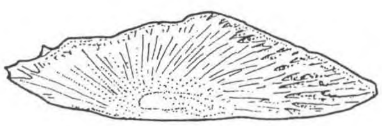
M

right

Mesopterygoid

L





M

left

PLEURONECTIDAE *Hippoglossus stenolepis*

MANDIBULAR ARCH

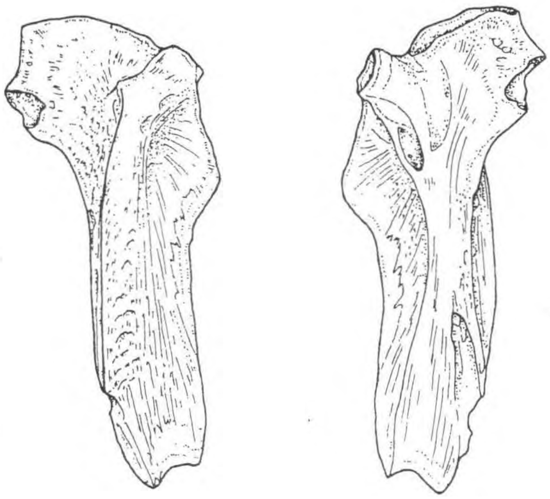
L

M

Metapterygoid

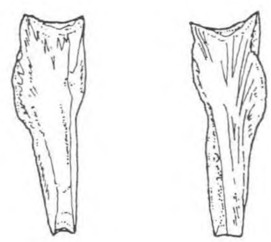
HYOID ARCH

L



M

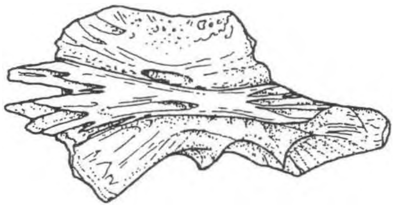
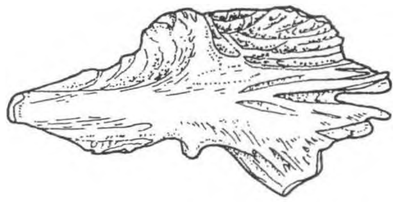
Hyomandibular



Symplectic

PLEURONECTIDAE *Hippoglossus stenolepis*

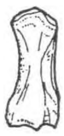
HYOID ARCH

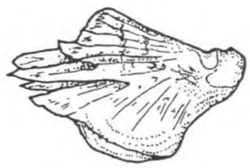
L

Ceratohyal

M



Interhyal

Epihyal

L

M

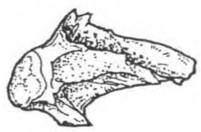
1

upper

Hypohyal

2

lower



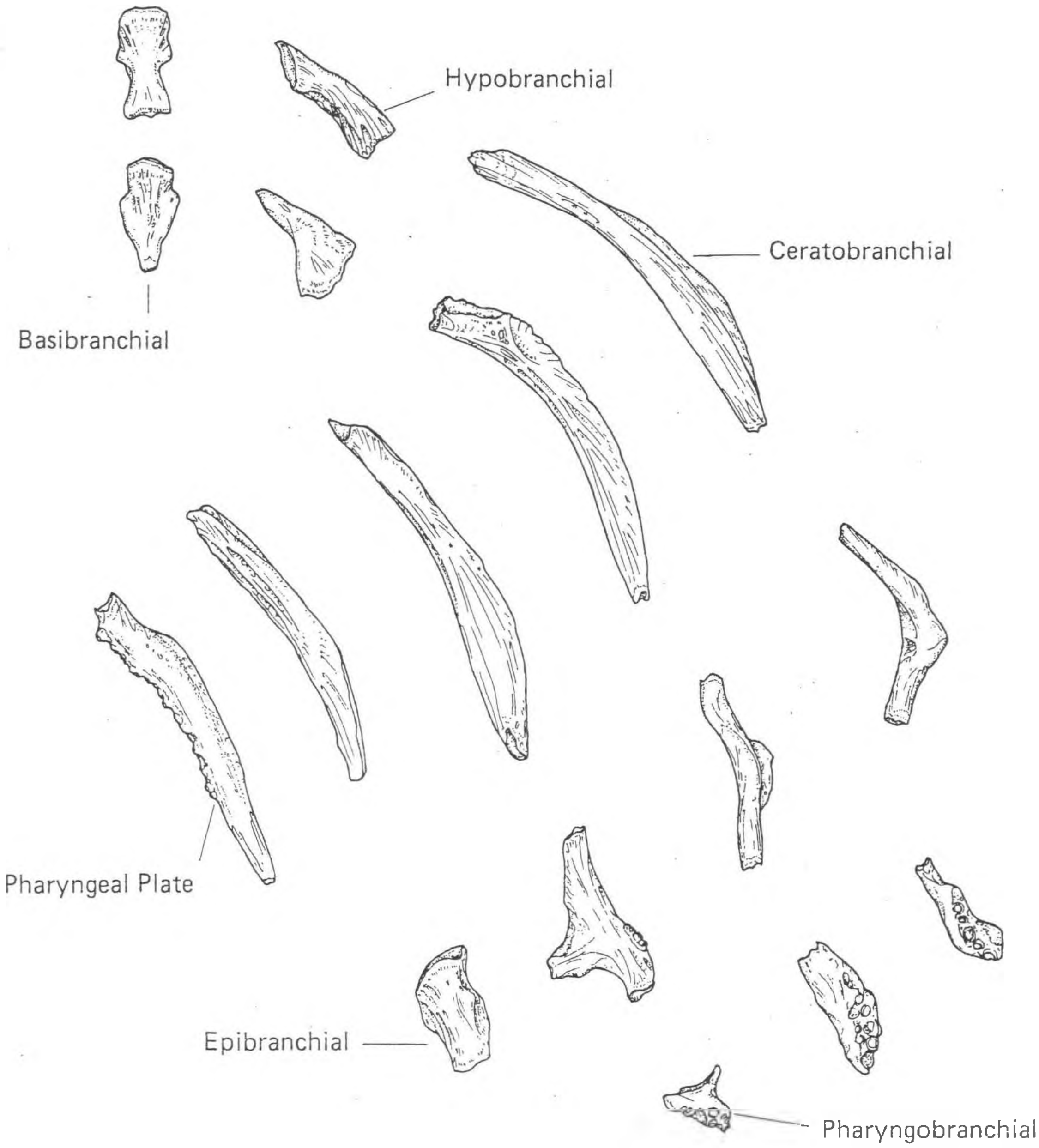
L

M

PLEURONECTIDAE *Hippoglossus stenolepis*

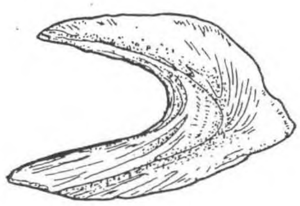
HYOID ARCH

BRANCHIAL ARCH

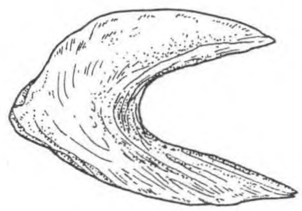


PLEURONECTIDAE *Hippoglossus stenolepis*

BRANCHIAL ARCH



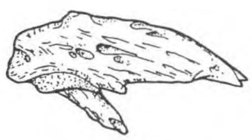
L



M

Urohyal

PECTORAL GIRDLE



L

M

Posttemporal

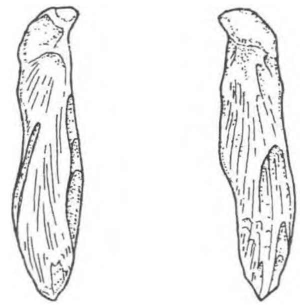
Postcleithrum

PLEURONECTIDAE *Hippoglossus stenolepis*

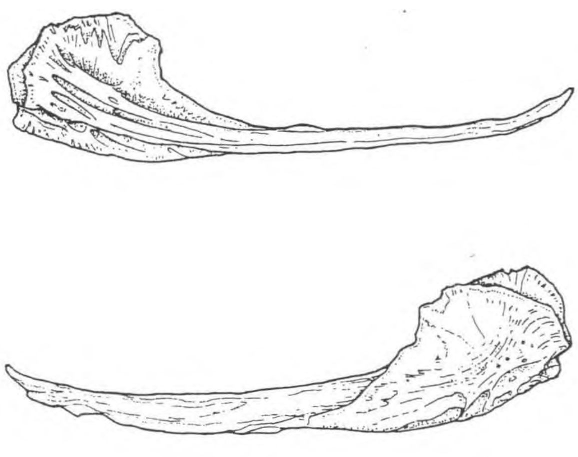
PECTORAL GIRDLE

L  M

Scapula



Supracleithrum



L

M

Coracoid

Radials

PLEURONECTIDAE *Hippoglossus stenolepis*

PECTORAL GIRDLE

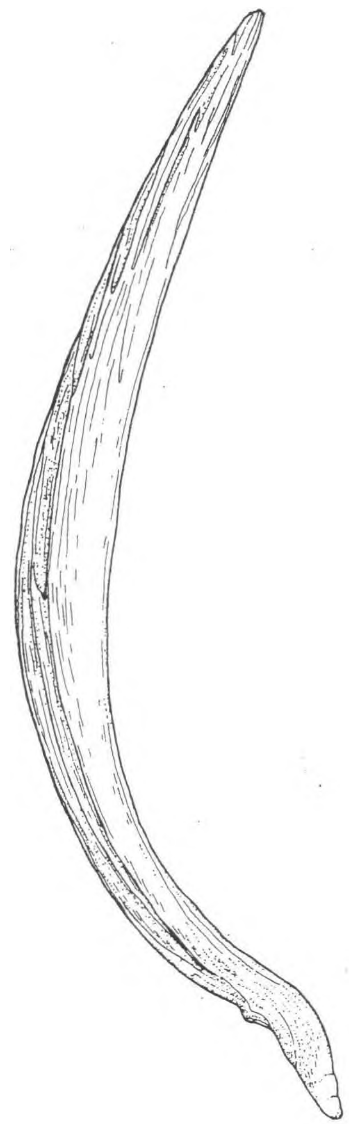
L

M

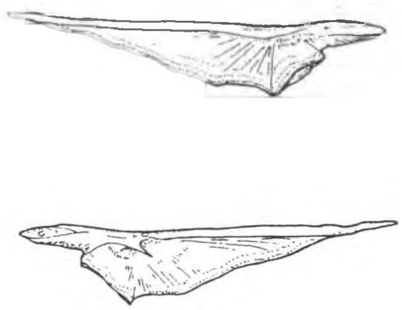
Cleithrum

PLEURONECTIDAE *Hippoglossus stenolepis*

PELVIC GIRDLE



Interhaemal Spine



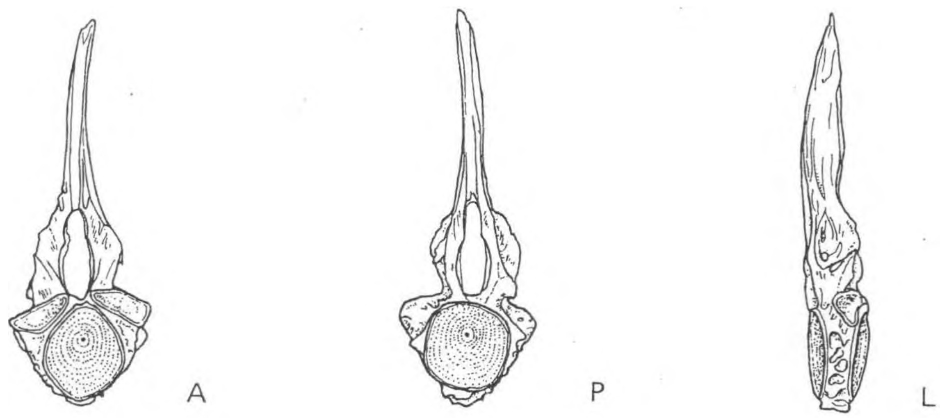
L

M

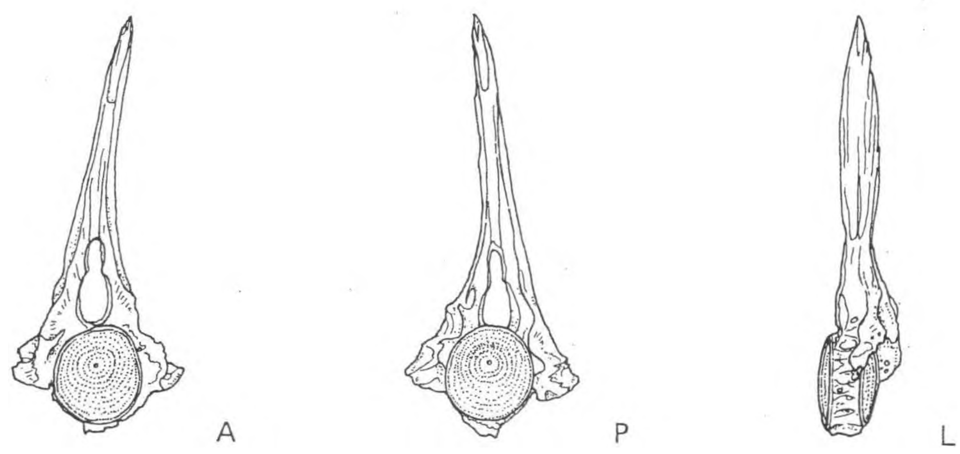
Basipterygium

PLEURONECTIDAE *Hippoglossus stenolepis*

VERTEBRAL COLUMN



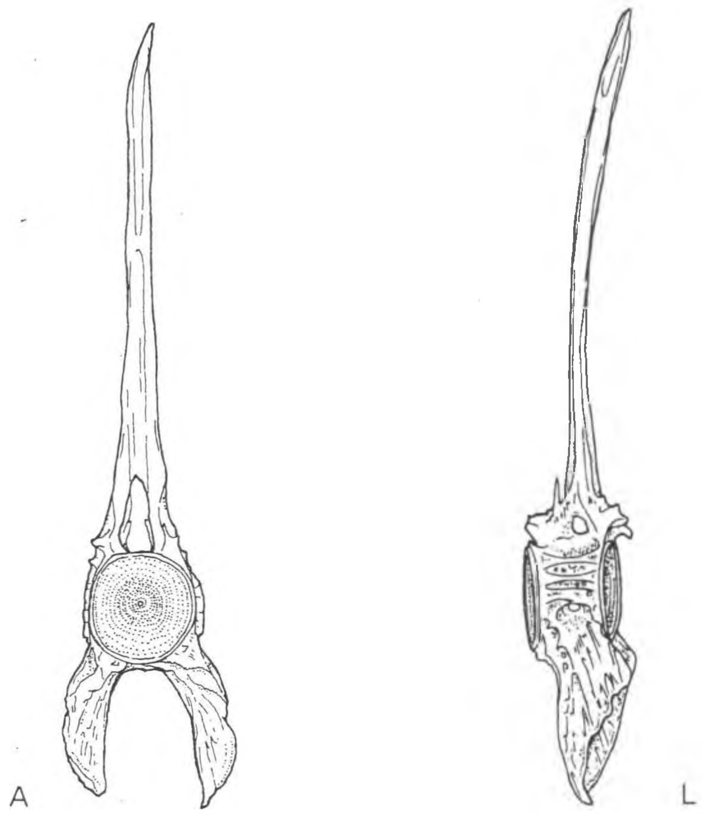
Atlas Vertebra



Thoracic Vertebra

PLEURONECTIDAE *Hippoglossus stenolepis*

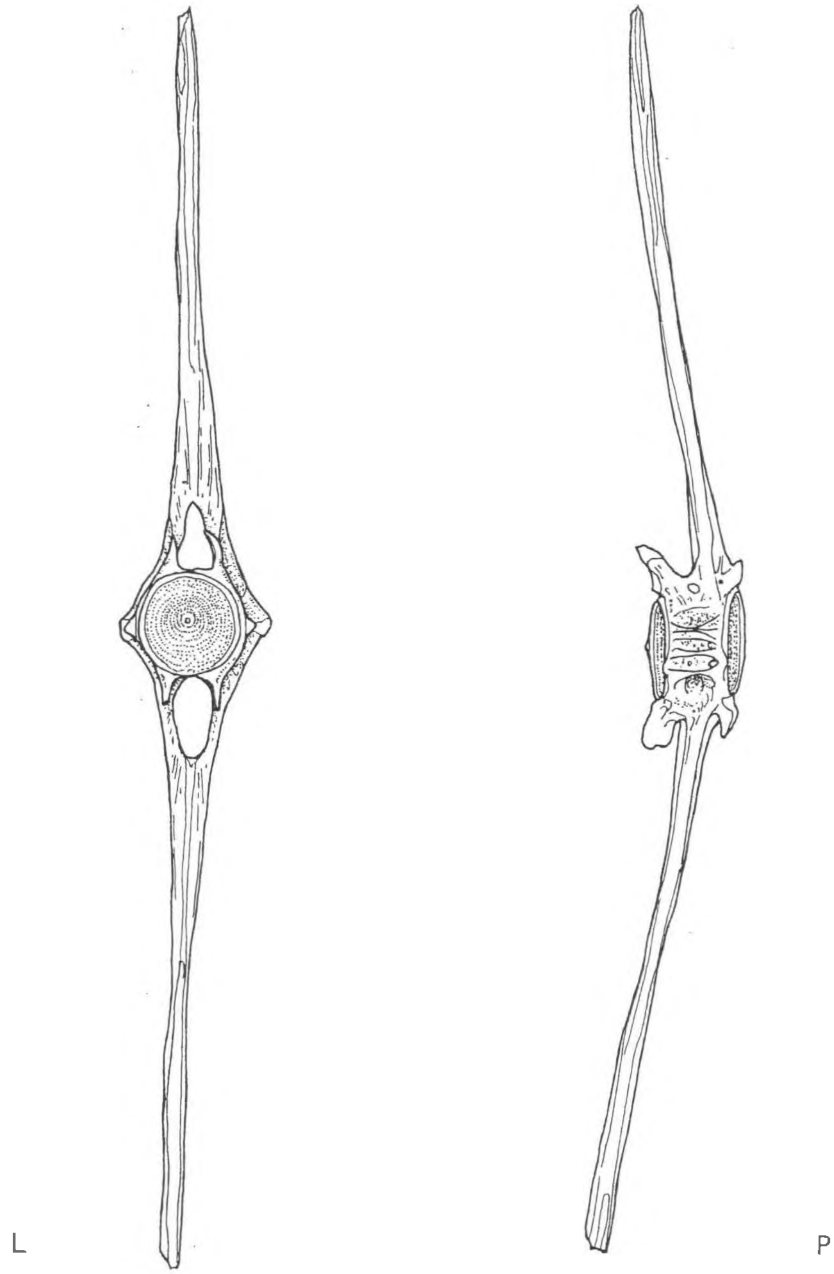
VERTEBRAL COLUMN



Precaudal Vertebra

PLEURONECTIDAE *Hippoglossus stenolepis*

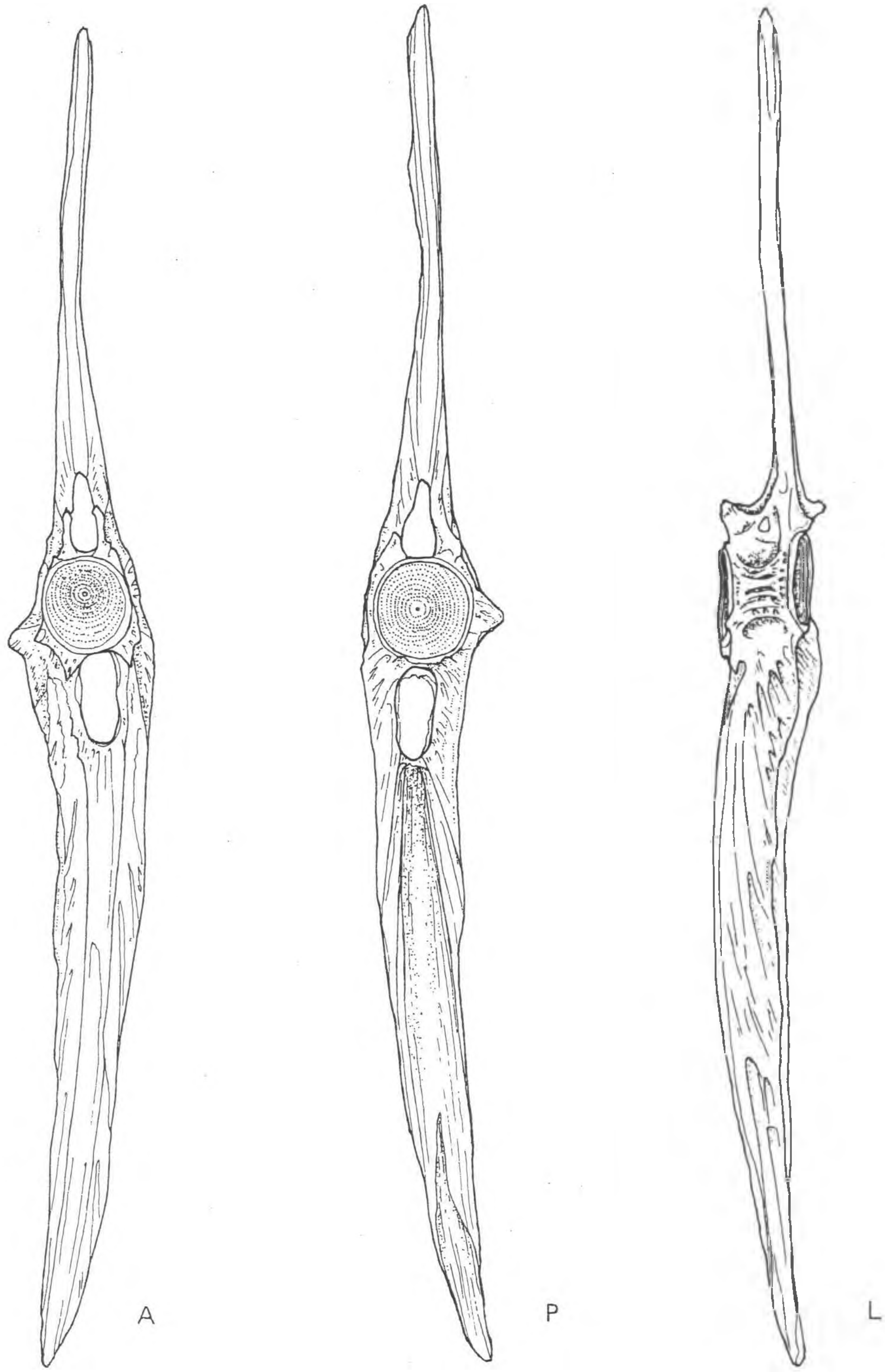
CAUDAL SKELETON



Caudal Vertebra

PLEURONECTIDAE *Hippoglossus stenolepis*

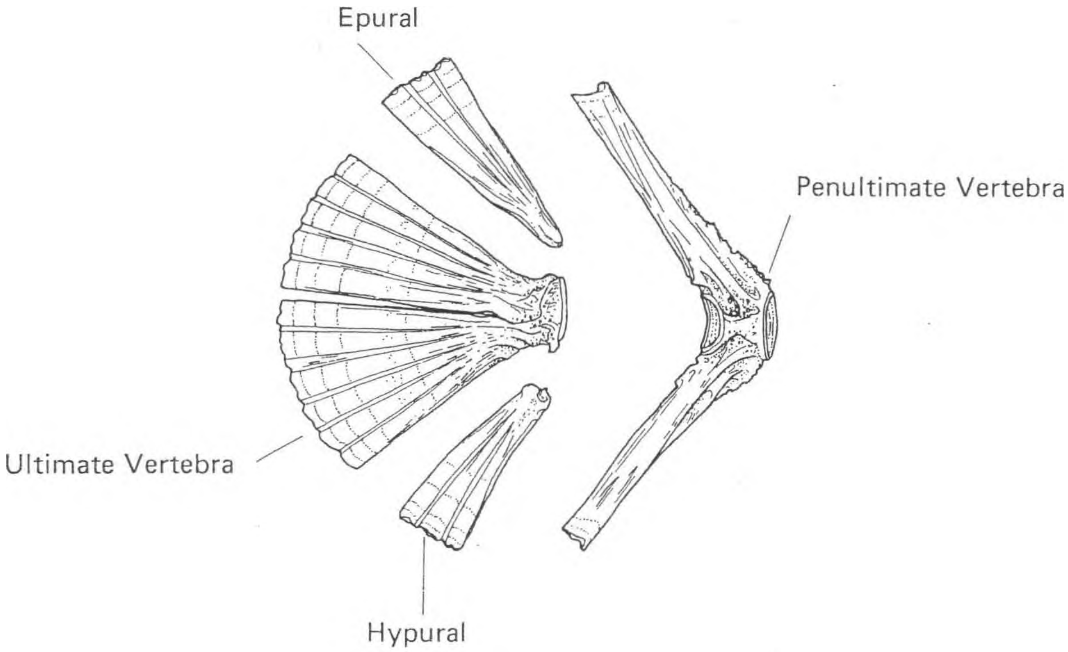
CAUDAL SKELETON



Caudal Vertebra - articulates with Interhaemal Spine

PLEURONECTIDAE *Hippoglossus stenolepis*

CAUDAL SKELETON



Lateral View

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