THE GROSS ANATOMY OF THE GADOID FISH, UROPHYCIS TENUIS (MITCHELL) 1815, WITH EMPHASIS ON ITS OSTEOLOGY

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THE GROSS ANATOMY OF THE GADOID FISH, UROPHYCIS TENUIS (MITCHILL) 1815, WITH EMPHASIS ON ITS OSTEOLOGY

by

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ABSTRACT

The systematics of the Gadidae is reviewed. Previous references to Urophycis are given. The general biology of Urophycis tenuis is presented. Definitions and synonyms of the teleost skeletal elements are listed.

External characters, internal morphology, and osteology of U. tenuis are described from 17 specimens from Holyrood Pond, St. Mary's Bay, Newfoundland. Viscera, skull, vertebral column and ribs, girdles, and fins are figured.

The upper jaw is longer than the lower jaw and reaches as far back as the rear edge of the orbit. Along the lateral line there are 135 to 139 cycloid scales.

The intestine is relatively long and heavily coiled. The physoclistous swimbladder is well-developed and related to the anterior vertebrae.

The well-formed rostral cartilage performs as a key element in the antorbital portion of the skull. The fused frontals are the largest bones in the cranium. The opisthotics are large and bear moderately sized processes. There are 4 complete branchial arches but only 2 weak basibranchials. The 3rd pair of epibranchials are toothed. The posttemporal and supracleithrum are very weakly developed.

The vertebral column is composed of 49 to 51 amphicoelous vertebrae. The 3rd and 4th vertebrae are modified to associate with the anterior

end of the swimbladder. Parapophyses and ribs are borne by the 3rd and 4th vertebrae and all of the abdominal vertebrae except the last 2. A haemal funnel is formed by the first few anterior caudal vertebrae. Two hypurals, 1 epurals, 2 dorsal radials, and 2 ventral radials are associated with the last 3 vertebrae and support a number of caudal fin rays. The ultimate is of gadoid type. The spinal nerves leave the neural canal via open grooves between the bases of the neural arches and the postzygapophyses. Vertebral abnormalities occur on certain vertebrae in one specimen and are described.

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INTRODUCTION

The order Anacanthini consists of fishes chiefly confined to the cold waters of the oceans and northern seas. Its members include the codfishes and hakes, family Gadidae; the grenadiers or rat-tails, family Macrouridae; the deep-sea fishes of the families Moridae and Bregmacerotidae; and the fishes of the family Muraenolepidae found in Antarctic waters.

The order Anacanthini is first established by Muller (1846:177) for fishes having fins without spinous rays; pelvic fins, if present, jugular or thoracic; and swim-bladder, if present, without pneumatic duct. By these characters, a number of quite different groups of fishes such as codfishes, flounders, and cusk-eels were united in a single order. Gunther (1862:317) accepts Muller's classification of the Anacanthini and divided the order into two suborders, Anacanthini Gadoidei and Anacanthini Pleuronectoidei, based on the structure of the head region.

Cope (1872:341) places only the families Gadidae and Macrouridae in the Anacanthini, which he describes in osteological terms, and places the flounders in a distinct order, the Heterosomata. His classification of the Anacanthini has been accepted by a majority of later workers. Regan (1903:341) generally accepts Cope's views and places the Gadidae, Macrouridae, and Muraenolepidae the order Anacanthini. Jordan (1923:162) accepts Regan's classification of the order with only minor changes.

At present, it is generally agreed that the order Anacanthini comprises mainly the families Gadidae and Macrouridae (Andriyashev, 1954:142, 205; Bailey et al, 1960:22; Berg 1940: 457; Lagler et al. 1962:40), together with three minor families: Muraenolepidae, Moridae and Bregmacerotidae (Svetovidov 1948:67). Norman (1944:191) considers the last two to be genera in the family Gadidae instead of independent families.

Among the order Anacanthini, the Gadidae has the most species, and includes twenty-two or twenty-five genera. With the exception of the genus Lota, all the species inhabit the oceans, mostly the northern seas.

Several recent authors, (Andriyashev 1954:144; Bailey et al. 1960:22; Berg 1940:457; Lagler et al. 1962:40; Svetovidov 1948:74) consider the hakes genus Merluccius Rafinesque 1810 as members of the Gadidae, but others (Breder 1948:280; Bigelow and Schroeder 1953:173; Jordan 1923:164; Jordan and Evermann 1898:2528; Norman 1944:191; Perlmutter 1961:277) do not. The latter group separates them from the Gadidae because of certain characteristics of the skull and vertebral centra. In species of Merluccius the frontal boones are paired with ridges diverging from the occipital crest and bordering a large triangular depression, and all the parapophyses on vertebral centra are broadened. According to certain morphological characteristics of the adults, larvae, and eggs, the family Gadidae can be divided into three subfamilies: Lotinae, Merluccinae and Gadinae (Andriyashev 1954: 142; Svetovidov 1948:72). The subfamily Lotinae is thought to be more primitive than the subfamily Gadinae, while the subfamily Merluccinae is thought to be transitional between the subfamilies Lotinae and Gadinae. Their individual diagnostic characters are as follows:

Subfamily Lotinae: One or two dorsal fins and one anal fin, second dorsal long. Caudal fin rounded, generally in contact with the anal and dorsal, less frequently separated by a narrow space or partly fused. Frontal bones paired in all with the exception of <u>Phycis</u> (Rose 1793) and <u>Urophycis</u> (Gill 1863). Parapophyses not enlarged, dorsal and ventral ribs present. Ventral fins in the larvae consist of only three rays and in the majority greatly elongated. Eggs with an oil globule.

Subfamily Merluccinae: Two dorsal fins and one anal fin, second dorsal and anal fins with a deep notch posteriorly; caudal fin truncate and not connected with anal or second dorsal. Frontal bones paired with a large triangular cavity, bordered on the sides and at the rear by crests, diverging from the rear part of the lateral crests of the supraoccipital. All parapophyses broadened and without ribs except for the shortened first pair possessing a small ventral rib, and dorsal ribs on only three to four anterior vertebrae. Ventral fins in the larvae somewhat elongate. Eggs with an oil globule.

Subfamily Gadinae: Three dorsal and two anal fins either touching at their bases or separated. Caudal fin truncate or with a notch, separated from the anal and dorsal. Frontal bones fused into one unpaired plate. Ventral fins in larvae not elongate, are consisting of more than three rays. Eggs without oil globule.

The Lotinae is the largest subfamily of the Gadidae and consists of nine genera and about thirty species. Certain morphological characters can be used to separate these nine genera into five groups. In one of these groups, composed of the genera Phycis and Urophycis, the frontal bones of the skull are not paired but united as in the subfamily Gadinae, and, thus, it is considered a rather remote tribe within the subfamily Lotinae. Some authors (Jordan and Evermann 1898:2552; Norman 1944:202) consider Urophycis a synonym of Phycis. Breder (1948:284-5) refers simply to all of these species concerned to Phycis, while Bigelow and Schoeder (1953:221-32) refer them to Urophycis. However, as indicated by Svetovidov (1948:109), among this tribe there are sufficient structural differences to divide the members into the two genera, Phycis and Urophycis. Svetovidov's opinion has been accepted by a number of ichthyologists (Bailey et al. 1960:22).

The External features and the general structure of the skull are not good characters for separating _Phycis_ and _Urophycis_. However, the structure of the upper part of the pectoral girdle and the position of the skull to which the pectoral girdle is attached show differences between these two genera. Moreover, all the living species of _Phycis_, except _Phycis chesteri_, are confined to the eastern part of the Atlantic Ocean, while the species of _Urophycis_ are confined to the western Atlantic. The diagnostic key to these two genera given by Svetovidov (1948:73) may be summarized as follows:

Opisthotic with a large process posteriorly for the articulation of the pectoral girdle; posttemporals and supracleithrum normally developed ...._Phycis_ (Rose 1793).

The process posterior to the opisthotic for the articulation of the pectoral girdle not developed; the posttemporals and supracleithrum minute ...._Urophycis_ (Gill 1863).

Urophycis is a bipolar genus with seven species found only in the Atlantic Ocean. Six species are known in temperate waters and at depths in the subtropical North Atlantic Ocean while the other one, _Urophycis brasiliensis_ (Kanp) 1858 is known only from the coasts of South America. The key to the species given below, mainly follows Svetovidov (1948:110):

1. Less than 100 transverse rows of scales 2
   More than 100 transverse rows of scales 3

2. I D 9, II D 47, A 45 ....*U*. *regius* (Walb)1792.
I D 10,II D 66, A 47 ....*U*. *cirratus* (Goodes et Bean) 1896.
3. Nott more than 140 transverse rows of scales 4
140 transverse rows of scales or more 5
4. About 110 transverse rows of scales, third ray of first dorsal fin elongate and threadlike ....*U*. *chuss* (Walb.) 1792.
About 120 transverse rows of scales, third ray of first dorsal fin not elongate ....*U*. *floridanus* (Bean et Dresel) 1884.
5. About 140 transverse rows of scales, third ray of first dorsal fin elongate ....6.
About 155 transverse rows of scales, third ray of first dorsal fin not elongate ....*U*. *earlii* (Bean) 1880.
6. Pelvic fins scarcely reaching origin of anal fin........*U*. *tenuis* (Mitch.) 1815.
Pelvic fins long, reaching far beyond the origin of anal fin ....*U*. *brasilliensis* (Kaup) 1858.

The literature reveals few works on the species of *Urophycis*. Svetovidov (1948:108-118) has made a comprehensive survey of the genus which includes some osteological notes. The external morphology and general biology of certain species is presented by Jordan and Evermann (1898:2552-2556), and Bigelow and Schroeder (1953:221-233). The eggs and larvae of four species occurring in the waters off North Carolina are described in some detail by Hildebrand and Cable (1938:612-629). The early larval stages of squirrel hake, Urophycis chuss, are described by Miller and Marak (1959) who have marked the period of the radical change in the pigmentation pattern of the larvae. Craigie (1916) provides the rate of growth of U. chuss in the Bay of Fundy from scales studies and concludes that the rate of growth is so uniform during the first three years of life as to indicate that spawning does not occur before the fourth year. Unfortunately, the scales of U. chuss do not show annual growth zones as clearly as those of Gadus morhua Linnaeus (1758) and no figure of the scale is given in Craigie's report on U. chuss. Following the work of Linton (1901), Sumner et al (1913:770) list the parasites occurring in two species, ~~Urophycis tenuis and~~ U. tenuis and U. chuss, of the waters of Woods Hole, Mass., and its vicinity. Bardach and Case (1965) have observed the reactions of U. chuss following chemical and mechanical stimulation of its filamentous pelvic fins. Each pelvic receives a well developed ramus lateralis accessorius originating from the geniculate ganglion of the medulla, and also the 4th and 5th spinal nerves. Electrophysiological responses of the isolated fins shows that high mechanical sensitivity is accompanied by chemoreceptor responses to extracts from various marine invertebrates which constitute the food of the fish. The role in behaviour of the various receptors on the modified pelvic fins of squirrel hake has also been discussed. McAllister (1960) notes the sand-hiding behavior in some young white hake, U. tenuis, whose pelvic fins are very similar to those of U. chuss.

It would seem then that a majority of previous investigations on Urophycis concentrated on Urophycis chuss. Urophycis chuss and Urophycis tenuis are similar in appearance, shape of eggs and larvae, spawning, food, habitata, distribution, etc.(Bigelow and Schroeder 1953:223-230; Sumner et al. 1913:770; Svetovidov 1948:113-116). Externally, U. chuss and U. tenuis are indeed similar, but as is mentioned by Bigelow and Schroeder (1953: 223), there are two reliable ways which can be used to distinguish the two fishes. First is the size and number of scales, those of U. chuss are relatively larger than those of U. tenuis, and arrange in about 110 transverse rows along the lateral line as against about 140 transverse rows in U. tenuis. Second, in U. tenuis the maxilla extends back as far as the rear edge of the eye but only as far as the rear edge of the pupil in U. chuss. Another less reliable difference, between these two species is that the pelvic fins of U. chuss overlap generally the vent while those of U. tenuis usually do not reach the vent.

Less is known of the biology of Urophycis tenuis than of Gadus morhua, Pollachium virens Linnaeus (1758) and even Urophycis chuss. The following account of the general biology of this less known species is chiefly summarized from information given by Bigelow and Schroeder (1953:221-226), Sumner _et al_. (1913:770), and Svetovidov (1948:116).

The eggs of _Urophycis tenuis_ are spherical, transparent, buoyant, and 0.72-0.76 mm. in diameter. Immediately after being spawned, they have a few small colorless oil globules which may unite into a large one shortly after fertilization. No definite information concerning conditions for eggs and larvae are available, however, the descriptions of the eggs and early stages of _Urophycis chuss_ by certain authors are highly possible to be applied here to a certain extent. The young fishes, usually live along the coasts at comparatively shallow depths of 4-6 m. Occasionally, they lay on their sides in a substrate of sandy gravel with only their heads showing. This sand-hiding behavior may conceal the fish from not only its predators but also its prey. Another interesting fact is that they sometimes hide themselves within the living shell of the giant scallop (_Pecten magellanicus_) Following the increase in age and size, they move to deeper waters and spend most of their lives in regions of soft mud, sand or shell bottoms. They do not undertake long migrations but do exhibit some seasonal movements. In fall they are present in the shallow waters near the coasts and in summer are found at greater depths away from the coasts.

Urophycis tenuis is a carnivorous bottom-feeder foraging on a variety of smaller marine animals. It feeds mainly on small crustaceans (decapods, amphipods, euphausiids, etc.) found on the bottom, and also prey greedily on small cephalopods as well as a good number of different kinds of small fishes such as herring, flatfish, butterfish, cunner, mackerel and sea-robin. While feeding, their modified pelvic fins and the barbels on lower jaws may be of use to locate the prey as is the situation in Urophycis chuss. They are usually active at night and on dull days.

Nothing exact is known of the rate of growth of Urophycis tenuis, however, it is promising to assume (Bigelow and Schroeder 1953:227), that it grows faster than Urophycis chuss which may reach a length of 38.5 to 44.5 cm. before passing the third birthday. Generally, U. tenuis is abundant at the end of winter and during early spring. Spawning possibly takes place from late winter through spring to late summer. A number of mature and spent fishes of both sexes have been seen in February, April, May and July (Bigelow and Schroeder 1953:230).

Very little is known about the parasites in Urophycis tenuis. Cestodes, nematodes, trematodes, copepods and acanthocephala have been recorded from the body cavity of specimens from the Woods Hole region.

The young fishes are usually found in coastal waters of four to six meters. The adults normally keep to deeper waters, especially in summer, ranging from 119 to 130 meters. Two specimens were caught respectively at the depths of three and 950 meters. Sometimes, they are fonnd at the mouths of rivers and sometimes freshened waters such as Holyrood Pond of St. Mary's Bay, Newfoundland.

Both Urophycis chuss and Urophycis tenuis are common on the continental shelves of North America. U. tenuis occurs from the Gulf of St. Lawrence and the southern part of the Grand Banks of Newfoundland south to North Carolina, and U. chuss even farther south. These two species generally occupy similar habitats where, in some cases, only one of them is dominant in the catch.

As suggested by its body form, Urophycis tenuis is sluggish and inactive, so that it is of no special interest to anglers. However, as a result of their large size, they are fairly important to the Canadian and American fishermen. The largest specimen ever recorded was one caught in the Gulf of Maine, having a length of 134.5 cm. and a weight of 205.5 kg., Scattergood (1953). In 1963, the annual catch of U. tenuis in Canada and the U.S.A. was 2949 metric tons of which 174 tons were landed in the Newfoundland area (ICNAF 1965:17). Pickford (1954) indicates that the pituitary gland of this species may be used as a source of fish growth hormone.

The present study deals with the osteology and gross visceral anatomy of Urophycis tenuis from the southern part of the Avalon Peninsula, Newfoundland. Since osteology constitutes one of the most reliable aspects of teleost taxonomy, and the present classification of the genus *Urophycis* is based mainly on external characteristics, the osteological information of *U. tenuis* may be of some value in establishing the taxonomic status of this group of fishes. Another attempt of this study is to compare the visceral structures of *U. tenuis* with those of *Gadus morhua* which are described in some detail by Parker (1906:107-121).

MATERIALS AND METHODS

Seventeen specimens used in this study of *Urophycis tenuis* were obtained by cod jigs and traps in depths of about 75 m. from Holyrood Pond, Newfoundland, during May, July and September, 1965. Holyrood Pond is a long bay extending deeply into the southern shore end of the Avalon Peninsula. Its outer portion is separated from St. Mary's Bay by a sandy bank with only a narrow access at the east terminal of the bank. The hydrography of Holyrood Pond is not available. It is likely that the water in this bay is rather fresh. The Crossing Place River empties into the northern end of the Pond. The Pond is covered by the ice for more than four months each year.

Measurements and counts of the materials are as suggested by Hubbs and Lagler (1957:18-26) and are given in Tables I and II.

Gross anatomical studies were made of both sexes. The visceral organs were exposed by cutting through the body wall from the vent to near the isthmus. The organs were then fixed in 10% formalin.

A number of fresh specimens were prepared for skeletal study by boiling them for 15 to 25 minutes. The flesh was removed with the aid of forceps. In preparing the bones in the head region, two aspects were considered:

the bones as individual entities; and the structure as a whole with the bones in their respective relationships. In order to meet both of these two requirements, bones on the right side of the skull were removed and separated as functional groups such as the jaw complex, circumorbitals, and opercular group (Nelson, 1963). The left side of the head was left intact. The hyoid and branchial apparatus was kept as a single separate mass. Several specimens were cleared in a solution of KOH and stained with alizarin red S to show the bony structure of median fins and tail. The method followed was as prescribed by Evans (1948).

All the figures in this study are free-hand sketches. A low-power binocular microscope was occasionally used for the purpose of showing the details of certain minute bones.

TABLE I

MEASUREMENTS IN CENTIMETERS OF 17 SPECIMENS OF *UROPHYCIS TENUIS*

Specimen	Standard Length	Predorsal Length	Snout L.	Upper Jaw Length	L., Dorsal Bases 1st	L., Dorsal Bases 2nd	L., Anal Base	Body D.	Head D.	D. of C.P.	Barbel L.
1	87.0	29.5	5.5	12.0	7.5	50.0	36.0	25.0	14.0	4.5	0.7
2	61.5	20.5	5.0	8.0	5.0	32.0	25.0	16.5	12.0	3.0	0.5
3	56.5	19.5	4.8	7.5	4.8	33.5	23.0	15.5	12.5	3.0	0.4
4	63.0	20.5	5.5	8.5	6.0	34.5	28.0	18.5	13.5	3.5	0.4
5*	58.0	20.0	5.0	7.5	4.8	33.0	24.5	16.5	12.5	3.0	0.3
6	56.0	20.0	5.0	8.0	5.0	34.0	25.0	16.0	13.0	4.0	0.3
7	53.0	20.0	5.0	8.0	5.0	34.4	25.0	14.5	13.0	4.0	0.2
8*	55.0	19.0	5.0	7.8	4.0	32.5	24.0	14.5	12.0	3.0	—
9	58.5	18.5	5.0	7.5	4.0	34.5	24.5	15.5	12.0	3.5	0.2
10	62.0	20.0	5.2	8.0	5.0	34.5	28.0	17.5	13.0	3.5	0.5
11	60.0	20.5	5.5	8.0	5.0	35.0	25.5	16.5	12.5	4.0	0.3
12	56.0	20.0	4.8	7.5	5.0	32.5	24.0	15.5	12.0	3.5	0.4
13	58.0	20.5	5.0	7.5	5.0	33.0	25.0	15.5	13.0	4.0	0.3
14	57.5	20.5	5.0	7.5	4.5	34.0	26.0	15.0	12.0	3.5	—
15	56.0	20.0	4.8	7.5	4.5	33.0	25.0	15.5	12.5	3.0	0.3
16*	70.0	23.0	5.8	10.0	7.0	36.0	31.0	21.0	13.0	4.0	0.5
17*	55.0	19.0	4.0	7.5	4.0	33.0	24.0	14.5	12.0	3.0	—

TABLE II
COUNTS OF 17 SPECIMENS OF UROPHYCIS TENUIS

Specimen	First Dorsal Fin Rays	Second Dorsal Fin Rays	Anal Fin Rays	Pectoral Fin Rays	Scales in Lateral Line	Vertebrae
1	10	56	49	16	137	50
2	10	55	48	15	137	50
3	10	55	48	15	137	51
4	10	54	48	15	135	50
5*	10	55	48	15	136	51
6	10	55	49	15	137	51
7	10	55	48	15	137	49
8*	10	55	48	15	137	51
9	10	55	48	15	137	51
10	10	55	48	15	138	51
11	10	55	48	15	137	50
12	10	55	48	15	138	51
13	10	55	48	15	135	50
14	10	55	48	15	135	51
15	10	55	48	15	138	51
16*	10	56	49	15	139	51
17*	10	55	48	15	138	51

*-Male. All the others are females.

Terminology

As complete standardization in the osteological terminology of fish has not yet been established, the most common name for each bone is used here. Unless otherwise specified, this paper follows the terminology of Norden (1961) for the skull, Stokely (1952) for the vertebral column, Barrington (1937)for the caudal fin, Starks (1930) for the paired fins and Eaton (1945) for the median fins.

Synonyms and definitions for the skeletal elements mentioned in this study are as follows:

1. Skull.

Angular. (Articular, Chapman, 1942; Dineen & Stokely 1954; Gregory 1933:90; Parker, 1906:97; Weitzman, 1962, 1964; Dermarticular, Goodrich 1930:303). A pair of lower jaw bones which articulate anteriorly with the dentries, and posteriorly with the quardrates.

Basibranchial. A median ventral ossification forming the floor of the mouth cavity. Its anterior end articulates with the basihyal.

Basihyal. (Glossohyal, Chapman, 1941a, 1941b, 1942; Gregory, 1933:90; Phillips, 1942). An unpaired cartilaginous element forming the base of the tongue.

Basioccipital. A median endochondral bone which forms the posterior part of the base of the skull.

Branchiostegal Rays. A paired series of rod-like bones which articulate with the ceratohyals.

Ceratobranchial. A pair of slender endochondral bones which articulate with the epibranchials, dorsally, and the hypobranchials ventrally.

Ceratohyal. A pair of large endochondral bones which articulate with the hypohyals, anteriorly, and the epihyals, posteriorly.

Dentary. A pair of large, toothed bones forming the main part of the lower jaw.

Ectopterygoid. (Pterygoid, Chapman, 1941a, 1941b, 1942; Dineen & Stokely, 1954, 1956; Parker 1906:96; Phillips, 1942). A pair of flat thin dermal bones which lie between the palatines and the quadrates.

Epibranchial. A pair of endochondral bones which articulate with the pharyngobranchials dorsally, and ceratobranchials ventrally.

Epihyal. A pair of endochondral bones which articulate with the ceratohyals, anteriorly, and the interhyals, posteriorly.

Epiotic. A pair of endochondral bones which form in the posteriodorsal surface of the chondrocranium and encase the auditory capsule.

Exoccipital. (Lateral Occipital, Berg, 1940:236). A pair of endochondral bones which form in the posterior wall of the chondrocranium and are the lateral boundaries of the foramen magnum.

Foramen Magnum. The opening in the occipital region of chondrocranium through which passes the spinal cord.

Frontal. A pair of large fused shield-shaped dermal bones forming the most part of the roof of the chondrocrium.

Hyomandibular. (Inframandibular, Dineen and Stokely, 1954). A pair of large endochondral bones which suspend the lower jaw from the cranium.

Hypobranchial. A pair of endochondral bones which articulate with the ceratobranchials dorsally, and the basibranchials ventrally.

Hypohyal. A pair of cone-shaped endochondral bones connecting the ceratohyals with the basihyals.

Infraorbital. (Jugal, Gregory, 1933:88; Suborbital, Chapman, 1941a, 1942; Gregory, 1933:88; Harrington, 1955; Koh, 1931; Parker, 1906:100; Phillips, 1942; Vladykov, 1954). Two pairs of tubular dermal bones which present between the lachrymals and the postorbitals.

Interhyal. A pair of small stout endochondral bones which connect the hyoid elements with the symplectic and hyomandibular and preopercle bones.

Infrapharyngeal. (Ceratobranchial, Gregory, 1933:90; Yarberry, 1965; Lower Pharyngeal, Phillips, 1942; Weitzman, 1962, 1964; Pharyngeal Bone, Harrington, 1955; Pharyngeal Plate, Norden, 1963). A pair of horn-like bones which represent the fifth branchial arch.

Interopercle. A pair of triangular dermal bones which are the most ventral element in the opercular group.

Lachrymal. (Antorbital, Lekander, 1949; Weitzman, 1962, 1964; Praeorbital, Berg, 1942:267; Preorbital, Blair and Brown, 1961; Dineen & Stokely, 1954?, 1956? Koh, 1931; Phillips, 1942; Suborbital, Vladykev, 1954; Yarberry, 1965). A pair of dermal bones forming the foremost bones in the circumorbital series.

Lateral Ethmoid. (Ectoethmoid, de Beer, 1937:107; Parethmoid, Gregory, 1933:88; Parker, 1906:95; Prefrontal, Chapman, 1941a, 1941b, 1942; Dineen & Stokely, 1954, 1956; Koh, 1931; Norden, 1961; Phillips, 1942). A pair of bones of cartilage and dermal origin, separating the olfactory capsule from the orbit.

Maxilla. A pair of dermal bones in the upper jaw articulating anteriorly with the premaxilla.

Meckel's Cartilage. A pair of two slender rod-like cartilages extending forward from the mesial surface of the angulars deeply into the dentaries.

Mesopterygoid. (Endopterygoid, Goodrich, 1930:284; Harrington, 1955; Yarberry, 1965; Entopterygoid, Berg, 1940:267; Koh, 1931). A pair of leaf like dermal bones which form a part of the mesial wall of the lower half of the orbit.

Metapterygoid. A pair of somewhat triangular endochondral bones which are bounded by the mesopterygoid, ectopterygoid, quardrate, symplectiic, and hyomandibular bones.

Nasal. A pair of tubular scale-like dermal bones which lie on the dorsal side of the lateral ethmoid bones.

Opercle. A pair of large triangular dermal bones covering the gills.

Opisthotic. (Autopterotic, Yarberry, 1965; Intercalary, Berg, 1940:235). A pair of dermal bones forming the postero-ventral part of the auditory capsule.

Palatine. (Autopalatine, Harrington, 1955). A pair of dermal bones which are the most anterior elements in the hyomandibular-palato-pterygo-quadrate complex.

Parasphenoid. A long, stout, median dermal bone forming the greater part of the base of the skull.

Parietal. A pair of flat dermal bones which form the roof of the braincase.

Pharyngobranchial. (Suprabranchial, Chapman, 1941a, 1942; Suprapharyngeal, Blair & Brown, 1961; Dineen & Stokely, 1954, 1956; Suspensory Pharyngeal, Phillips, 1942; Upper Pharyngeal, Weitzman, 1962, 1964). A pair of irregular bones which present in the dorsal and suspensory pharyngeal of each of the first four gill arch.

Postorbital. (Infraorbital, Weitzman, 1962, 1964; Suborbital, Gregory, 1933:88; Harrington, 1955; Phillips, 1942; Yarberry, 1965; Suborbital Series, Chapman, 1941b). Three pairs of tubular dermal bones which form the posterior rim of the orbit.

Premaxilla. A pair of toothed rod-like dermal bones forming the anterior margin of the upper jaw.

Prootic. A pair of large endochondral bones forming the anteroventral ossification of the otic capsule.

Preopercle. A pair of large curved dermal bones representing the most anterior elements of the opercular group.

Prevomer. (Vomer, Blair & Brown, 61; Chapman, 1941a, 1941b, 1942; Dineen & Stokely, 1954, 1956; Vomer, Gregory, 1933:88; Svetovidov, 47; Koh, 31; Norden, 61; Parker, 06:94). A median, toothed, dermal bone forming the anterior part of the base of the skull.

Pterosphenoid. (Alisphenoid, Chapman, 1941a, 1941b, 1942; Dineen & Stokely, 1954, 1956; Gregory, 1933:89; Koh, 1931; Parker, 1906:94; Phillips, 1942; Pleurosphenoid, de Beer, 1937; Goodrich, 1930:284). A pair of small endochondral bones articulating with the prootics posteroventrally, and the frontals and sphenotic dorsally.

Pterotic. (Autopterotic, Harrington, 1955; Yarberry, 1965; Squamosal, Koh, 1931). A pair of irregular bones forming the posterodorsal ossification of the auditory capsule.

Quadrate. A pair of triangular endochondral bones connecting the lower jaw with the cranium.

Retroarticular. (Angular, Chapman, 1941a, 1941b, Dineen and Stokely, 1954, 1956; Goodrich, 1930:283; Koh, 1931; Parker, 1906:97; Phillips, 1942). A pair of small endochondral bones attaching to the posterior corner of the angular.

Rostral Cartilage. (Ethmoid Cartilage, Chapman, 1941a, 1942; Weitzman, 1962). An almost spherical cartilaginuous mass situated anterior to the supraethmoid.

Sphenotic. (Autosphenotic) Harrington, 1955; Yarberry, 1965). A pair of irregular endochondral bones forming the anterodorsal ossification of the auditary capsule.

Subopercle. A pair of dermal bones lying below the opercles and overlapping the branchiostegal rays.

Supraethmoid. (Dermethmoid, Gregory, 1933:88; Ethmoid, Harrington, 1955; Koh, 1931; Phillips, 1942; Weitzman, 1962, 1964; Mesethmoid, Berg, 1940:234; Chapman, 1941a, 1941b, 1942; Dineen & Stokely, 1956; Goodrich, 1930; Yarberry, 1965). A median dermal bone which is situated immediately above the vomer.

Supraoccipital. A single shield-shaped endochondral bone which forms the posterodorsal ossification of the cranium. A prominent crest of dermal origin is found on the endochondral supraoccipital.

Symplectic. A pair of triangular endochondral bones connecting the hyomandibulars and the quadrates.

Urohyal. (Basibranchiostegal, Blair & Brown, 1961; Dineen & Stokely, 1954, 1956). A median ventral dermal bone which lies in the muscles below the tongue and interpose the hypohyals.

2. <u>Vertebral Column & Caudal Fin.</u>

Antepenultimate. In a restricted sense, this refers to the third last vertebra of the vertebral column.

Centrum. The body of each vertebra, which replaces the embryonic notochord.

Caudal Fin Ray. (Lepidotrichium, Barrington, 1937; Goodrich, 1930:99; Whitehouse, 1910). The dermal ray of the caudal fin.

Epural. This refers to those bony elements which lie dorsal to the terminal caudal vertebrae and are believed to be modified neural spines.

Haemal Arch. An arch under the centrum formed by the union in the middle ventral line of two haemal spines.

Haemal Spine. The posteriorly directed ventral projection formed by the elongation and fusion of the parapophyses.

Hypural. This refers to those bony elements which lie ventral to the terminal vertebrae and are believed to be modified haemal spines.

Neural Arch. An arch over the centrum surrounding the spinal cord.

Neural Spine. The posteriorly directed dorsal projection formed by the fusion of the paired neural arches.

Postzygapophysis. Posterodorsal projections on the centrum functioning as the articular surfaces for the vertebra.

Parapophysis. (Transverse Process, Blair & Brown, 1961; Dineen & Stokely, 1954, 1956; Parker, 1906; Stokely, 1952). Paired, ventral, transverse processes which form the articular surfaces for the ribs.

Prezygapophysis. Anterodorsal projections on the centrum functioning as the articular surfaces for the vertebra.

Radial. (Hypural, Epural, Gosline, 1960; Weitzman, 1962; Yarberry, 1965). This is a dorsal or ventral bony element supporting one or more caudal fin rays, but not making contact with the vertebral column.

Ultimate. (Last Vertebra, Whitehouse, 1910; Terminal Vertebra, Barrington, 1937; Ford, 1937; Gosline, 1960;

Weitzman, 1962; Yarberry, 1965). In a restricted sense, this refers to the last vertebra of the vertebral column. In describing the caudal bony structures, the term 'autogenous' is frequently used as a convenient way of referring to skeletons which are attached to, but not fused with, the vertebral column. Such autogenous processes are easily dissected away from the vertebral column in freshly prepared skeletons.

3. Ribs.

Epipleural. (Dorsal Rib, Goodrich, 1930:71; Lagler et. al., 1962:69; Stokely, 1952; Epicentral, Epimeral, Hypomeral, Phillips, 1942; Intermuscular Bone, Lagler et. al., 1962:69; Intermuscular Rib, Blair & Brown, 1961; Dineen & Stokely, 1956; Hyman, 1942:105; Rib, Ford, 1937). A paired series of ribs projecting into the myosepta from the bases of pleural ribs.

Pleural. (Haemal Rib, Phillips, 1942; Yarberry, 1965; Hypopleural, Chapman, 1941b; Rib, Dineen & Stokely, 1954; Ford, 1937; Parker, 1906:90; Stokely, 1952; Subperitoneal Rib, Blair & Brown, 1961; Hyman, 1942: 105). A paired series of ribs which attach to the parapophyses and surround the abdominal cavity.

4. Girdles and Paired Fins.

Actinost. (Brachial Ossicle, Parker, 1906:101; Radial, Dineen & Stokely, 1954, 1956; Goodrich, 1930: 167; Koh, 1931; Weitzman, 1962; Yarberry, 1965). The four small endochondral bones connecting the scapulae with the pectoral fin rays.

Cleithrum. (Clavicle, Parker, 1906:100; Phillips, 1942). A pair of large, curved, dermal bones forming the main part of the pectoral girdle.

Coracoid. A pair of irregularlly triangular endochondral bones which, together with the scapulae, form the inner surface of the cleithra.

Extrascapula. (Scalebone, Gregory, 1933:89; Supratemporal, Chapman, 1941b, 1942; Goodrich, 1930:283; Tabular, Berg, 1940; Tretiakov, 1945:52). A series of small, tubular bones lying behind the parietals.

Pectoral Fin Ray. (Lepidotrichium, Goodrich, 1930:170). The dermal rays of the pectoral fin.

Postcleithrum. (Postclavicle, Parker, 1906:100; Phillips, 1942). A pair of very slender bony rods which are connected with the inner surface of the cleithra near their dorsal end, and pass backward and downward.

Posttemporal. A pair of forked dermal bones which connect the pectoral girdles to the cranium.

Scapula. A pair of endochondral bones which, together with the coracoids, form the inner surface of the cleithra.

Supracleithrum. A pair of weak, rod-like ossifications connecting the posttemporals and the cleithra.

5. <u>Median Fins.</u>

Anal Fin Ray. (Lepidotrichium, Goodrich, 1930:98). The dermal rays of the anal fin.

Dorsal Fin Ray. (Lepidotrichium, Goodrich, 1930:98). The dermal ray of the dorsal fin.

Pterygiophore. (Basalia, Chapman, 1942; Interhaemal Spine, Interneural Spine, Koh, 1931; Phillips, 1942; Interspinous Bone, Parker, 1906:90; Phillips, 1942). A series of two endoske -letal rods which support the dorsal and the anal fins.

GROSS ANATOMY

I. External Characters (Fig. 1)

Phylogenetically, *Urophycis tenuis* and *Gadus morhua* are closely related. Their general appearances, however, differ distinctly. *U. tenuis* has only two dorsal fins and only one anal fin instead of the three dorsals and two anals of *G. morhua*. Furthermore, the pelvic fins, the shape of the tail, and the length of the barbel are very different between these two species.

The body of *Urophycis tenuis* is cylindrical in front of the vent and the urogenital openings which are situated together in the mid-ventral line, anterior to half-way between the blunt snout and the end of the caudal fin. Behind these openings, the body is flattened and tapered to a thin caudal peduncle and a small rounded caudal fin. The homocercal tail is weak and its length is only about one eighth the body length. The greatest body depth is one fifth to one sixth of the total length.

The head of *Urophycis tenuis* is about one quarter as long as the body. The nostrils are situated a short distance in front of the eyes; they are two small apertures on each side, of which the posterior and lateral is larger and circular, while the anterior and median is smaller and guarded by a tiny flap. The mouth is terminal to below the eyes. The upper jaw is slightly longer than the lower jaw and reaches as far back as the rear edge of the orbit. The eyes are of moderate size with a diameter somewhat larger than the interorbital length. A very small barbel is present on the chin. None of the fishes observed in this study possess a barbel with a length of more than one centimeter.

All of the fins of Urophycis tenuis are composed of only segmented, soft rays. The first dorsal fin originates immediately behind the level of the base of the pectoral fins and has ten rays with the third one elongated as a filament which is about as long as two-thirds of the head length. The rays of the triangular first dorsal fin decrease in length posteriorly. There is a narrow space separating the first and second dorsal fin. The second fin is much longer than the first dorsal and extends to the caudal peduncle. It is about half as high as the first dorsal and has 54 to 56 rays of almost equal lengths. The anal fin, with 54 to 56 rays, extends from a short distance behind the vent to the caudal peduncle and is similar in shape to the second dorsal fin. The caudal fin has about 30 distinct rays and a number of procurrent rays. The pectoral fins are rounded and have 15 or 16 rays. The pelvic fins are situated considerably in front of the pectoral fins and are composed of two elongate rays. The ventral ray is the longer and projects backward nearly reaching the vent.

Minute scales cover both the head and the trunk of Urophycis tenuis, but not the median and paired fins. There are 135 to 139 oblique rows of scales along the lateral line between

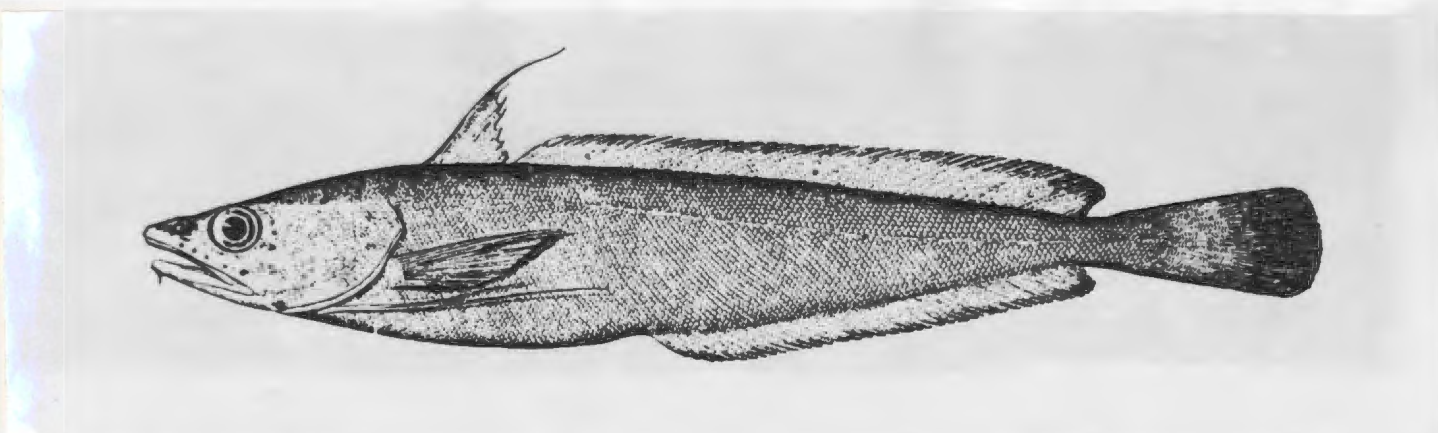


Fig. 1. Lateral view of Urophycis tenuis. From Jordan & Evermann, 'The Fishes of North and Middle America', 1898, Volumn 4, Plate CCCLXV. Drawing by H. L. Todd.

the gill opening and the base of the caudal fin. These scales are cycloid and the circuli are easily seen,but the radii and the annuli are rather difficult to be determined even when stained. The skin is well supplied with mucus. During life, the mucus forms a thin and even film over the body. After death, a thicker layer of slime is present.

The coloration of <u>Urophycis</u> <u>tenuis</u> is variable. Generally, they are darker ~~in~~ dorsally than ventrally. However, the darker coloration is not uniform and many fishes display a blotched pattern. The pattern is composed of small dark patches superimposed in large light areas. The dark patches are not well defined and sometimes shade into the lighter areas. In general they are muddy or reddish-brown on the back, the sides somewhat bronze and the belly is dirty - or yellowish-white with a number of tiny black chromatophores. A narrow and pale stripe is present along the lateral line. The dorsal fins and the anal fin are of the same color as the back and the belly respectively. All of the median fins are edged with black which is wider on the caudal fin. The pectoral fins have a slightly lighter color than that of the dorsal fins. The pelvic fins are as pale or white as the belly and are sometimes tinted with yellow.

<u>Urophycis</u> <u>tenuis</u> may reach a large size. In the present study of 17 fishes, the average total length and weight are 60.18 cm. and 3.04 kg. respectively. The largest specimen observed is 87.0 cm. in total length with a weight of 4.19 kg.; while the smallest one is 53.0 cm. in total length and 2.84 kg.

in weight.

No sexual dimorphism was noted in *Urophycis tenuis* either in external appearance or in the length-weight relationships.

II Internal Morphology (Fig. 2)

The peritoneal cavity of *Urophycis tenuis* extends at the vertical from the first to the 19th or 20th vertebra and is lined by the melanotic parietal peritoneum. A strong fibrous partition, the transverse septum, separates the peritoneal cavity from the anteroventrally situated pericardial sac which is also lined by a layer of pigmented membrane, the parietal pericardium.

1. Peritoneal Cavity and Its Contents

The peritoneal cavity of *Urophycis tenuis* contains most of the visceral organs. These organs are covered by the visceral peritoneum and supported by the mesenteries. For the sake of convenience, the kidneys are described in this section though they are not inside the peritoneal cavity.

ESOPHAGUS -----The esophagus is a short, thick-walled tube connecting the stomach to the pharynx. On the posterior end of its wall is an esopharyngeal sphincter which provides the distensibility of the esophagus.

STOMACH -----The stomach is immediately posterior to the esophagus and has its anterior portion the same diameter as that of the esophagus. It is large, sac-like and thick-walled, about one half the length of the peritoneal cavity. At its median portion, the stomach is divided into two limbs, a proximal cardiac limb and a distal pyloric limb. The cardiac limb is a broad blind sac posteriorly, with its internal epithelium deeply folded and similar to that of the anterior portion of the stomach. The pyloric limb is shorter and smaller than the cardiac limb and connects the intestine with the main part of the stomach. In the natural position, the stomach is largely covered by the liver.

INTESTINE ----- The intestine is a heavily coiled tubular structure comprising the duodenum,the ileum and the rectum. Its anterior portion, the duodenum is slightly swollen and is separated from the ventral end of the pyloric limb of the stomach by the pyloric sphincter. The duodenum extends anteriorly and reaches a little anterior to halfway of the peritoneal cavity where it curves posteriorly and gives rise to the ileum. The ileum has a diameter smaller than that of the duodenum and runs posteriorly to a level a short distance in front of the vent; where it curves anteriorly again to form a sphonal loop and is coiled several times below the middle lobe of the liver. The ileum, then curves strongly posteriorly again and reaches a place in front of the vent where it is separated from the rectum by the ileorectal valve. The thin-walled rectum is relatively short and ends at the vent. The total lengths of the intestine are very great in the specimens observed. In a fish with a standard length of 61.5 cm., the total length of the intestine reaches

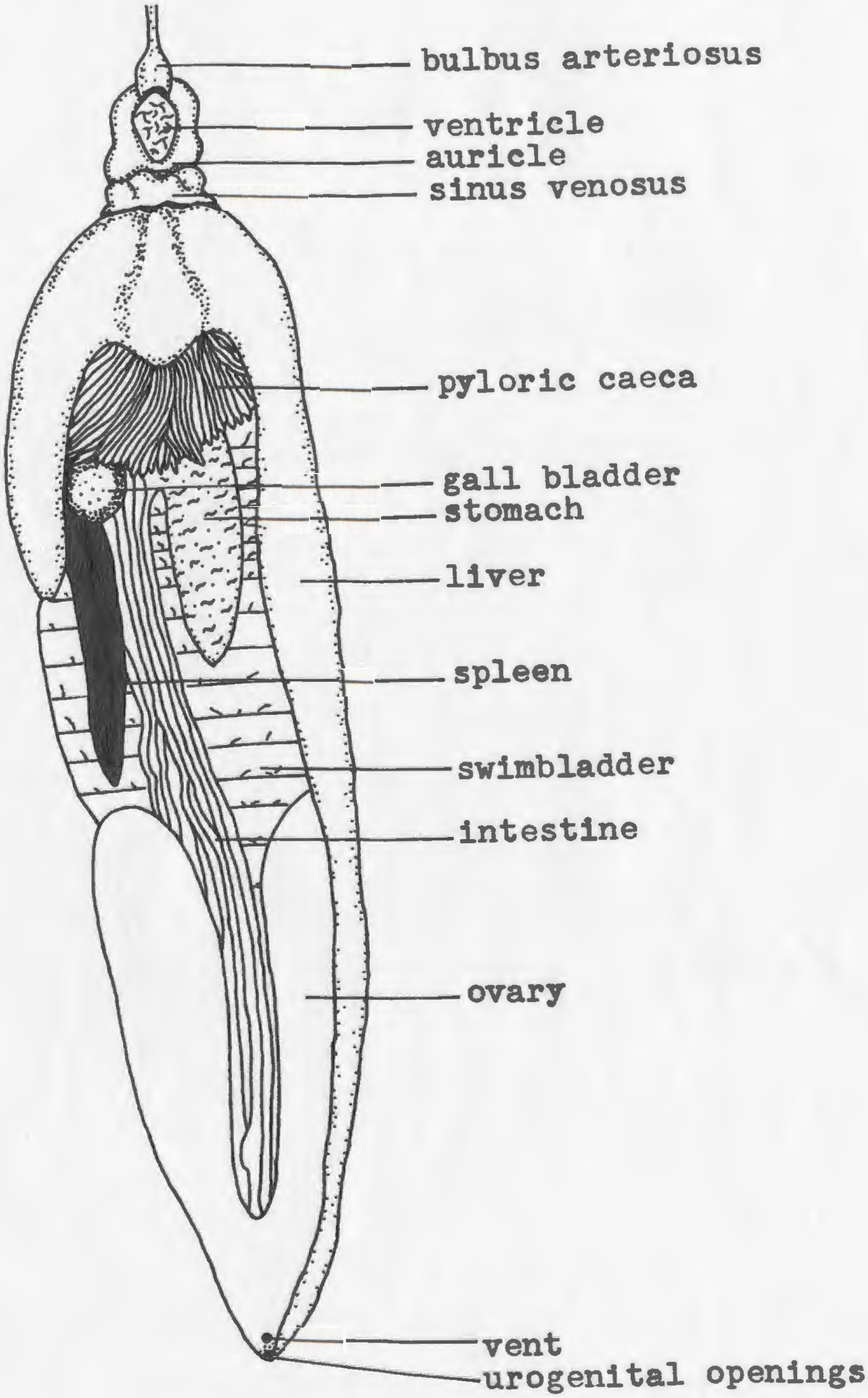


Fig. 2. Internal organs <u>in situ</u> of a female specimen of <u>Urophycis tenuis</u>. X1/4

78 cm.

PYLORIC CAECUM -----There are 45 to 48 pyloric caeca. They are slender, small blind tubes arranged in a circular fashion around the duodeum at its junction with the pyloric limb of the stomach.

LIVER -----The liver is the most prominent organ in the peritoneal cavity. It is brownish, large and tri-lobed, covering either wholly or partially the other organs in the peritoneal cavity. Among the three lobes of the liver, the left one is the largest, extending from the transverse septum to the posterior end of the peritoneal cavity and covering the esophagus, stomach, intestine, swimbladder and gonads. The middle lobe of the liver is short and broad covering the anterior portion of the stomach and a number of the pyloric caeca. The smallest lobe is the right one which is the rightmost organ in the anterior portion of the peritoneal cavity. Within the substance of the liver are numerous hepatic sinusoids which are drained by a pair of hepatic veins. These veins lead to the heart by way of the anterior end of the middle lobe of the liver.

GALL BLADDER -----The gall bladder is a ovoid, thin-walled sac usually filled with greenish bile. It is located at the right ventral side of the peritoneal cavity and is hidden by pyloric caeca, intestine and right lobe of the liver. It is connected to the anterior end of the intestine by the common bile duct which is collapsed and can not be readily seen when the specimen is fixed by formalin.

SPLEEN ----- The spleen is a smooth, reddish, elongate body which is situated lateroventral to the cardiac limb of the stomach and is within the coils of the intestine.

Gonads ----- In the male specimen, the testes are two yellow-brownish, elongate lobes extending below the swimbladder in the posterior half of the peritoneal cavity. Between them are the siphonal loops of the intestine and the rectum. Along the central axis of each testis runs the vas deferens which meets its counterpart of the opposite side at about its posterior fourth to form the common genital canal which is separated by a membrane from the ureter and leads to the genital opening.

In the female specimen, the ovaries are a pair of large, pinkish sacs occupying a position similar to that of the testes in the male. The two ovaries unite with one another posteriorly and form the short oviduct which passes ventrad to the genital opening between the rectum and ureter.

SWIMBLADDER ----- The physoclistous swimbladder is a large, well developed organ extending along the dorsal wall of the peritoneal cavity. Its anterior end is firmly attached to the haemal postzygapophysis of the third vertebra; while most of its dorsal surface is partially enclosed by the parapophyses of the abdominal vertebrae. Two bands of muscle, the sonorific muscles, are found anteriorly and connect the swimbladder to the anterior end of the esophagus. The dorsal and ventral surfaces are smooth, while the lateroventral surface is strongly sacculated and with a number of small projections that are connected by the mesenteries with some other organs. The wall is generally thick and tough, and is composed of two distinct layers, the tunica externa and the tunica interna. The rete mirabile is a reddish, ovid mass situated within the swimbladder on the postero-lateral surface.

KIDNEY ----- The reddish kidneys are a pair of lobed structures which lie immediately dorsal to the peritoneal cavity and ventral to the vertebral column as well as the dorsal aorta. Their anterior portions join one another anterdorsal to the anterior end of the swimbladder. They unite posteriorly with one another and give rise to the ureter which is situated inside the peritoneal cavity and is a thin-walled tube with a small bilobed urinary bladder near its ventral end. The ureter, then, leads to the exterior through the urinary opening.

2. Pericardial Sac and Its Contents

The pericardial sac of *Urophycis tenuis* lies ventral to the gill cavity and is well protected by the pectoral girdle. The organs enclosed in this sac are in a horizontally linear arrangement and covered by the visceral pericardium. Three pairs of muscles extend along the two lateral walls inside the pericardial sac; on each side they are T-shaped with the middle one the broadest.

<u>SINUS</u> <u>VENOSUS</u> ----- The sinus venosus is a thin-walled sac with its posterior margin attached to the transverse septum. It receives the hepatic veins posteriorly and the ducts of Cuvier posterodorsally. A pair of sinuatrial valves are situated at the anterior end of the sinus venosus and separate it from the posterior end of the auricle.

<u>AURICLE</u> ----- The auricle is a large and thin-walled organ. It covers anteriorly the ventricle as well as the posterior portion of the bulbus arteriosus and meets posteriorly the sinus venosus. It is connected with the ventricle at its ventral surface by a short tubular structure in which the atrioventricular valves are located.

<u>VENTRICLE</u> ----- The ventricle is a elliptical, thick-walled and muscular sac lying on the ventral surface of the pericardial sac. It leads anteriorly into the bulbus arteriosus; between them is a pair of semilunar aortic valves.

<u>BULBUS</u> <u>ARTERIOSUS</u> ----- Anterior to the ventricle is the thick-walled and conical bulbus arteriosus which passes anteriorly to the posterior end of the ventral aorta.

III <u>Osteology</u>

1. Axial Skeleton

The axial skeleton of <u>Urophycis</u> <u>tenuis</u> is composed of the skull, the vertebral column, and the ribs. As several of the terminal vertebrae are involved in supporting the caudal rays, the caudal fin is conveniently described in this section; although, in a sense, it is a part of the appendicular skeleton.

A. Skull

One hundred and forty-five skeletal elements, mostly of endochondral or dermal origin, comprise the skull of *Urophycis tenuis*. Among these bones and cartilages, nine are unpaired, each forming a base, a floor, or a roof for the paired elements. For the sake of convenience, the 145 elements are divided into nine groups which are distinguished mainly by their structural functions.

a. Cranium. (Figs. 3 to 6)

The cranium of *Urophycis tenuis* is a moderately elongate and somewhat wedge-shaped structure, formed by a complex of not readily separable elements disposed around the brain and sense organs of the head. The total length of the cranium, measured from the posterior end of the supraoccipital to the tip of the prevomer, is about 2.2 times its greatest width, the distance between two lateral opisthotic processes. Its depth, from the base of the basioccipital to the posterior end of the supraoccipital, is as long as two-thirds its greatest width. The postorbital portion of the cranium is larger than the antorbital portion, as is usual in teleost fishes.

PREVOMER ----- The prevomer is a Y-shaped, median bone forming the most anterior part of the cranium. Its anterior rectangular portion is thickened with a posterodorsal synchondral joint surface on each side for articulation with the ethmoid mass. The anterior margin of this bone is strongly curved, and on its ventral surface are 60 to 70 minute and conical teeth in an irregular, multiple series. The posterior, triangular portion is thin and tapers to slender end inserted into a fossa on the anteroventral surface of the parasphenoid.

ROSTRAL CARTILAGE ----- The rostral cartilage is a large nodule of cartilage forming a part of the septum between the nasal organs. The posterior surface of this cartilage is grooved where it articulates with the anterior edge of the supraethmoid dorsally and the dorsal surface of the prevomer ventrally. Anteriorly the rostral cartilage is between the inner ends of two premaxillae. The rostral cartilage is not noticeable in dried skulls.

SUPRAETHMOID ----- The supraethmoid is a median bone situated behind and above the prevomer, and projects forward from under the anterior edge of the frontals. Its anterior portion is separated ventrally from the prevomer by the posterior part of the rostral cartilage. The anterior margin is truncate with a small triangular depression on top. The dorsal surface of this bone is slightly convex with a foramina over its anterior portion. The posterior portion of the ventral surface of the supraethmoid is thin and concave with two diverging lamellae projecting posterolaterally from the

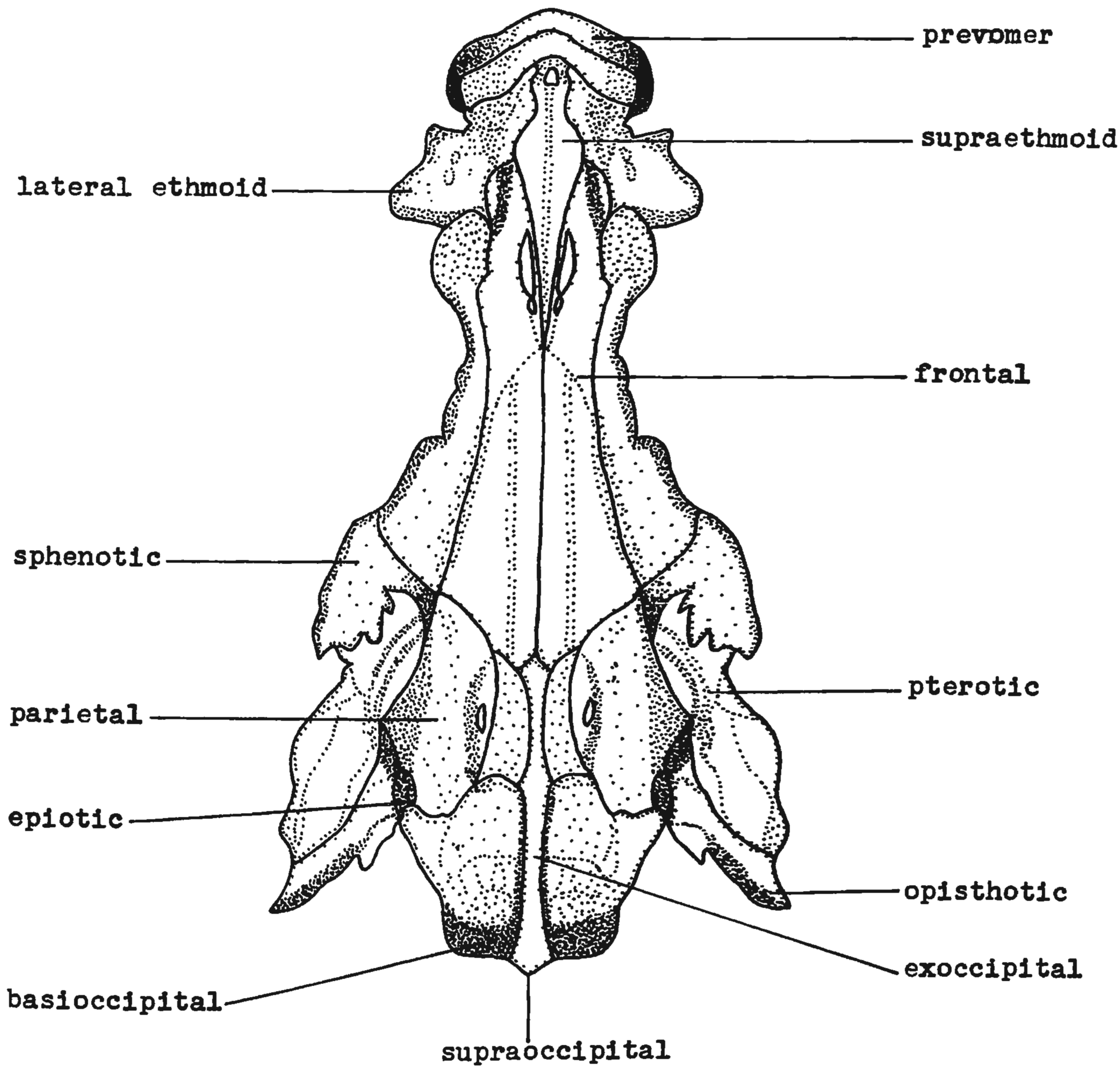


Fig. 3. Dorsal view of the cranium of Urophycis tenuis. X1.5.

central part of the supraethmoid-prevomer articulation. Between these lamellae is a cavity, roofed by a posterior portion of the supraethmoid. The posterior terminal of each ventral lamella contacts the upper proximal portion of its respective lateral ethmoid.

LATERAL ETHMOID ----- The lateral ethmoid is an irregularly shaped bone on each side of the skull separating the olfactory capsule from the orbit, and forming the upper anterolateral projection of the braincase. Each lateral ethmoid articulates with the supraethmoid at its inner anterolateral surface. The lateral ethmoids do not contact each other though they do approach each other medially. The anterior portion of this bone is a strongly constricted region with two expansions on each side, bearing two facets on their ventral surface for articulation with the supraethmoid and the palatine respectively. The posterior portion of the lateral ethmoid is composed of only two grooved projections, of which the upper one is shorter and is inserted to the anteroventral surface of the frontal; while the lower longer one is tapered into a fossa on the anterodorsal surface of the parasphenoid. Near its median line the anterior portion of each lateral ethmoid is pierced by a number of small foramina among which a relatively large one is for the passage of the olfactory nerve.

FRONTAL ----- Posterior to the supraethmoid are the frontals, the largest bones in the cranium, which lie on the dorsal surface of the cranium. Each of the frontals fuses with the other at a suture along the median line. The fused-frontals are shield-shaped with a narrow anterior and a broad posterior portion and form the greater part of the roof of the braincase. Its posterior portion extends to the dorsal surface of the otic capsule where it narrowly overlaps the anterior end of the median supraoccipital. Lateral to the frontal-supraoccipital joint, the frontal also overlaps the anterior end of the pterosphenoid, the pterotic, the sphenotic, and the parietal. Anteriorly, the frontal lies on the posterior end of the supraethmoid and the inner projection of the lateral ethmoid. Both the dorsal and ventral surfaces of the frontals are beset with small crests and grooves in a symmetrical arrangement. Four rather deep grooves for housing the sensory canals are distinct, two on either side of the dorsal surface; and one large depression runs along the median line of the ventral surface. On the anterodorsal surface there are paired, longitudinal and elliptical foraminae, which lead to the muscous cavity.

<u>PARASPHENOID</u> ----- The parasphenoid is a long, stout, median bone forming the greater part of the ventral boundary of the cranium. Its anterior end borders on the two junctures of the prevomers, supraethmoid and lateral ethmoids; while the posterior end terminates in a pair of thin wings, beneath the ventral surface of the otic capsule. The anterior portiom

of this bone is rod-like and grooved on both dorsal and ventral surfaces. It widens out posteriorly and is wedge-shaped. The two thin wings at the posterior end of the parasphenoid underlie the ventral portions of the prootics and the toothpick-like projecting end of the basioccipital.

PARIETAL ----- The parietals are thin, somewhat triangular bones covering part of the posten dorsal surface of the cranium. They do not meet along the midline as do the frontals, but are separated by the medially situated suparoccipital. Each parietal is bounded anteriorly by the frontal, posteriorly by the epiotic, and laterally by the pterotic. The parietals are excluded from contact with the sphenotics externally, however, they do contact each other internally. On the dorsal side of each parietal, there is a longitudinal elevation beneath which is a foramina for the passage of the cutaneous branch of the fifth cranial nerve.

PTEROSPHENOID ----- The pterosphenoids are two irregularly shaped bones which constitute a portion of the anterior wall of the brain capsule. These bones do not meet each other, but are parallel, each surrounded by a series of bone on either side. They articulate posterodorsally with the anterolateral portion of the sphenotics, and postero-ventrally with the mesial margin of the prootics. Their anterior edges lie lateral to the large optic foramen and articulate with the median depression on the ventral surface

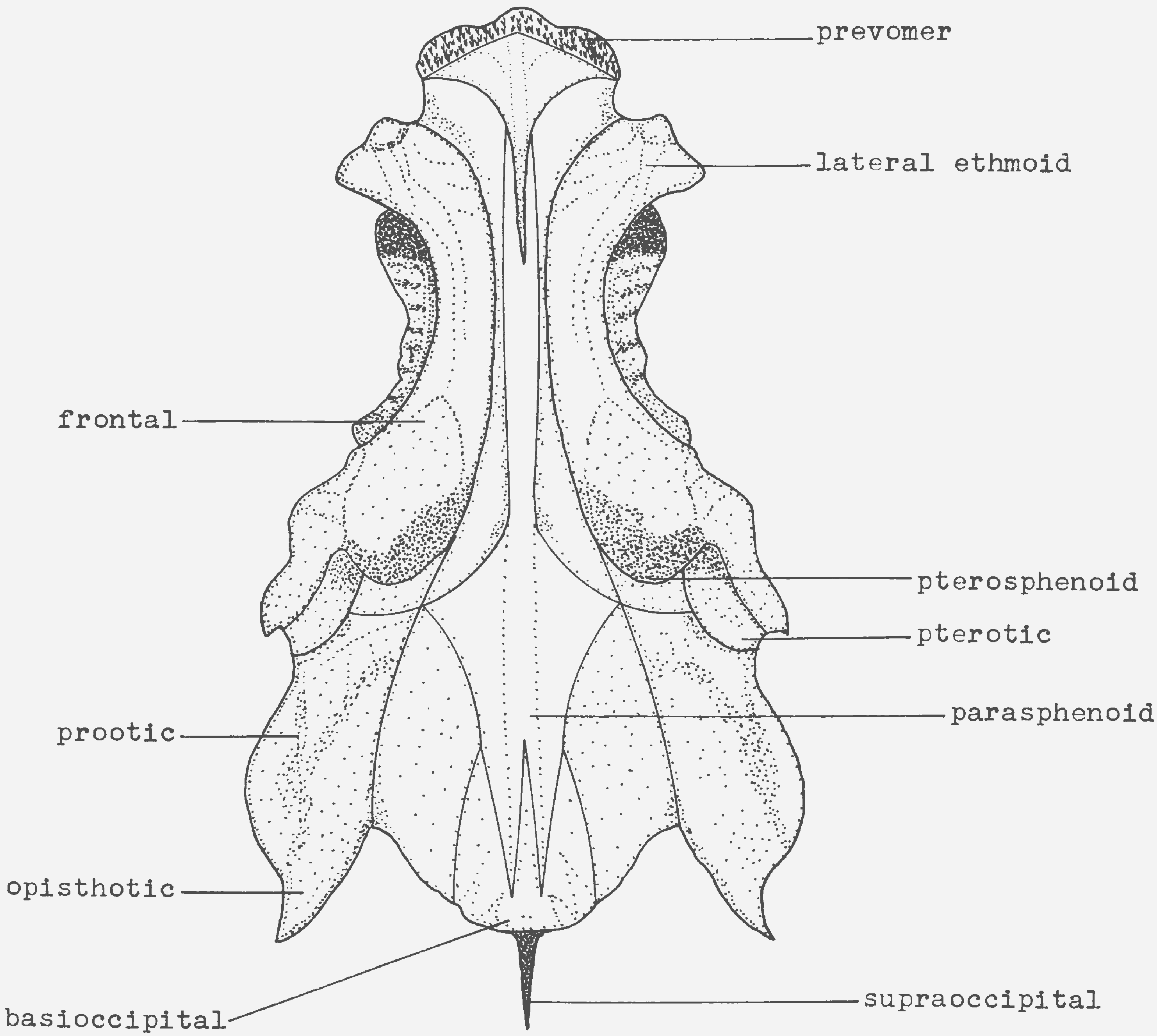


Fig. 4. Ventral view of the cranium of Urophycis tenuis. X1.5.

of the fused frontals.

<u>SPHENOTIC</u> ----- The sphenotics are somewhat square bones forming the anterodorsal surface of the braincase. They are convex dorsally with a medial projection for receiving the posterior portion of the frontal. Their anterior portions are attenuated and articulate with the pterosphenoids. Posteriorly they are bounded by the pterotics and postero-ventrally by the prootics. The posterolateral surface of each sphenotic has a deep fossa for articulation with the hyomandibular. Immediately posterior to this fossa is a second fossa which extends posteriorly to the lateral surface of the pterotic. On its posterodorsal surface is a foramen for the ramus oticus nerve. The sphenotic together with the prootic form a groove around the semicircular canals and their ampullae.

<u>PTEROTIC</u> ----- The pterotics are irregularly shaped bones forming the posterodorsal and lateral sides of the auditory capsule. Anteriorly the pterotics abut on the sphenotics, mesially on the parietals and posteriorly on the epiotics and the opisthotics. Their ventral sides articulate with the prootics, and contribute to the upper portion of the wall of the auditory capsule. On the upper surface of each pterotic is the temporal groove which extends from the pterotic forward past the sphenotic to the anteriolateral portion of the frontal. Behind the pterotic-parietal juncture is a series of tubular extrascapulae which connect with the

temporal groove forming a part of the laterosensory system. On the anterolateral surface is a concave area which forms a portion of the second sphenotic fossa mentioned above. The posterior portion of the pterotic terminates in an attenuated projection, uniting with the opisthotic process posteriorly.

PROOTIC ----- The prootics are a pair of pentagonally shaped bones on the lower sides forming the anterior and lateral surfaces of the braincase. On the anterior wall of the braincase they provide the ventral and lateral borders of the large trigeminofacial foramina, while the pterosphenoids form the medial and dorsal borders. They are bordered dorsally by the pterotics and anterodorsally by the sphenotics. Posteriorly, together with the opisthotics, they constitute the lateral wall of the braincase. Along the median line, the prootics join ventrally but this suture is hidden by the parasphenoid. At the anterolateral angle of the braincase, each prootic joins the sphenotic to form a deep fossa for the reception of the head of the hyomandibula.

OPISTHOTIC ----- The opisthotics are large triangular bones forming the lateroventral boundary of the braincase. They articulate with the prootics anterodorsally, the epiotics posteromesially, the exoccipitals posteroventrally, and the basioccipital ventrally. At its dorsolateral end each opisthotic terminates in a process which forms the outmost boundary of the cranium. The area between the epiotic and

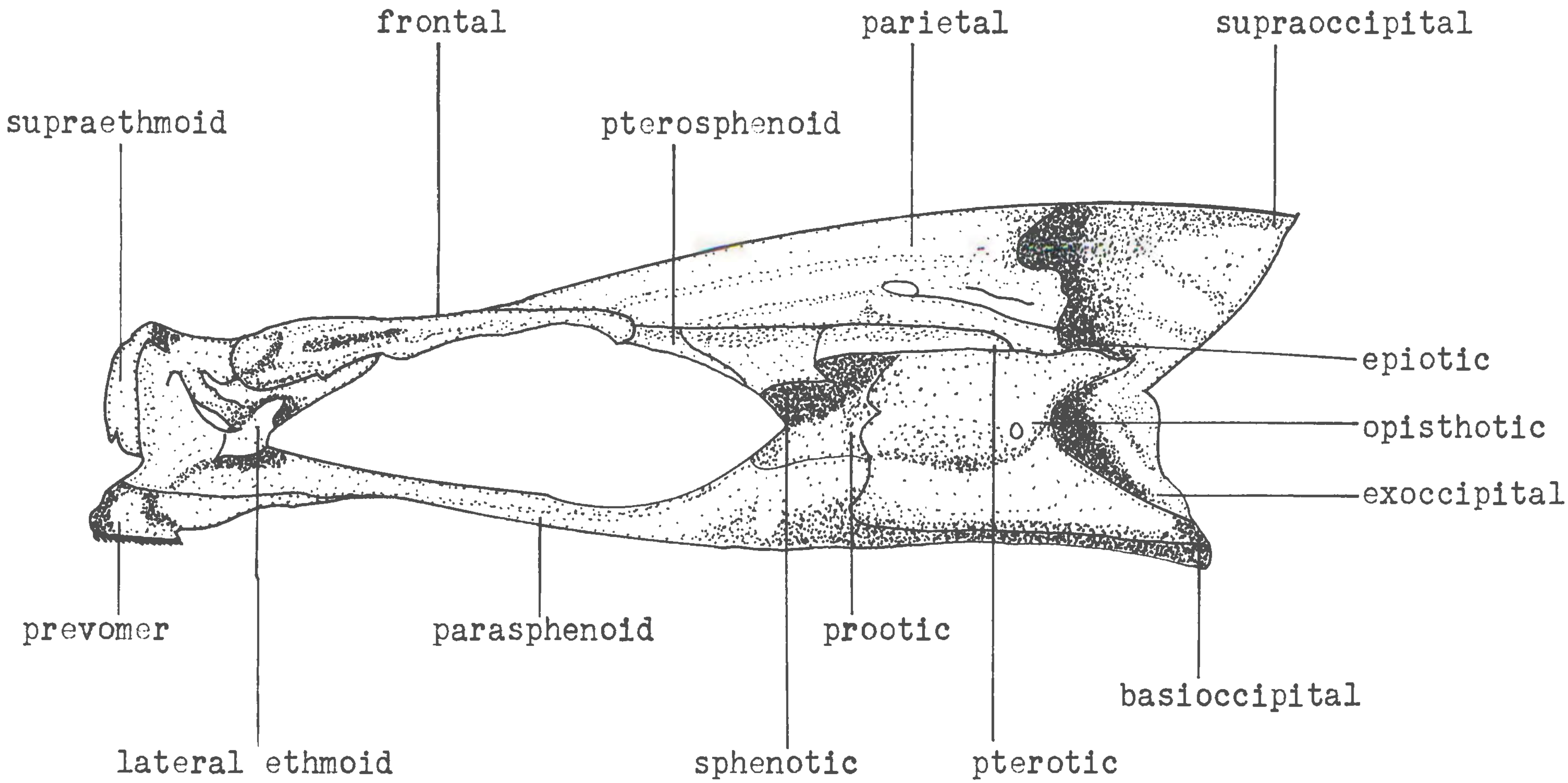


Fig. 5. Lateral view of the cranium of Urophycis tenuis. X1.5.

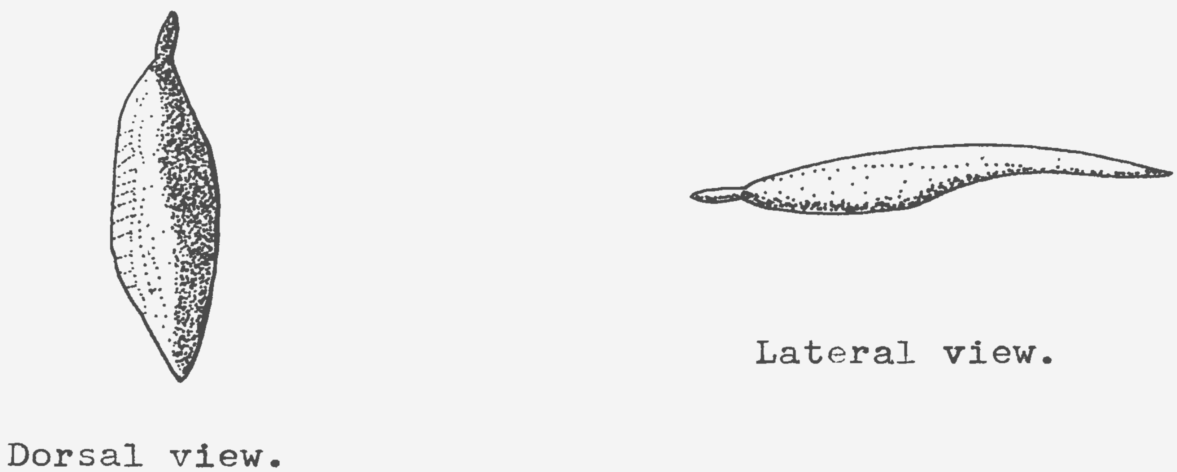
the posterior portion of the opisthotic is deeply concave and forms the temporal fossa where the pectoral girdle articulates with the cranium by a small forked bone, the posttemporal. On the upper lateral surface, near the posterior end, the opisthotic is perforated by a foramina for the exit of the glossopharyngeal nerve.

<u>EPIOTIC</u> ----- The epiotics are the smallest bones in the cranium. They are cone-like projections forming the upper, posterolateral part of the cranium. Each epiotic is bodered anteriorly by the parietal and the pterotic, mesially by the supraoccipital, and ventrally by the exoccipital. Internally, the epiotic forms a small cavity for housing the posterior vertical semi-circular canals. Immediately distal to each epiotic is the temporal fossa at the juncture of the epiotic, pterotic and opisthotic, which is very distinct on the posterolateral surface of the cranium.

<u>OTOLITH</u> ----- The otoliths are present in each auditory labyrinth. Two of these, the sagittae, are prominent and are enclosed in the membranous sacs, the sacculi, on either side of the braincase. Each sagitta is calcareous and leaf-like with a projected anterior end and lies on the floor of the braincase between the prootic and the basioccipital. Its greatest length is about 3.5 times its greatest width. Its dorsal surface is slightly convex. The ventral surface is concave with a number of short, transverse lines.

<u>SUPRAOCCIPITAL</u> ----- The supraoccipital is a median, rhombic bone along the posterodorsal portion of the mid-line of the cranium. It separates the parietals and the epiotics laterally, and touches the frontals anteriorly. It articulates with the exoccipitals ventrally and forms the roof of the elliptical foramen magnum. On its posterodorsal surface is a large, median, laterally compressed crest, the occipital spine, which extends backward to a level somewhat behind the basioccipital and meets the neural spine of the first vertebra, the atlas.

<u>EXOCCIPITAL</u> ----- The exoccipitals are a pair of irregularly shaped bones forming most of the posterior wall of the braincase and providing a floor for it. Posteriorly, their medial edges are arched comprising the lateral walls of the foramen magnum. They meet each other above the foramen magnum where they are narrowly overlapped by the posteroventral end of the supraoccipital. Each exoccipital is bounded anterodorsally by the central portion of the supraoccipital, laterally by the opisthotic, and ventrally by the basioccipital. On its posterior surface is an articular facet for the corresponding surface on the neural arch of the atlas. Its lateral surface is perforated by two foramina; the larger one is for the exit of the 10th. (vagus) nerve, and the smaller one for the occipital nerve. The exoccipital is concave laterally and convex ventrally, where it makes a contribution to the formation of the otolith bulla.



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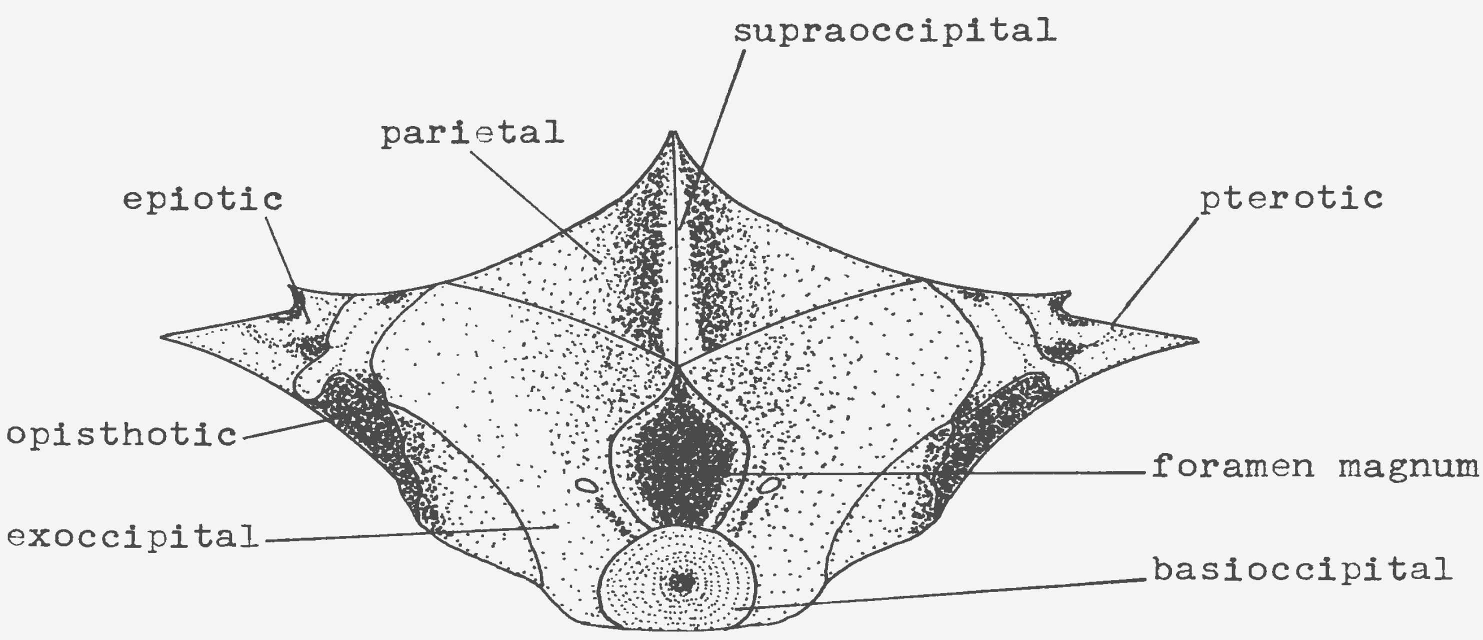

B

Fig. 6. A. Otoliths (sagittae) of Urophycis tenuis. X1.5.
B. Posterior view of the cranium of Urophycis tenu-
X1.5.

BASIOCCIPITAL ----- The basioccipital is a median bone beneath the foramen magnum, forming the posteroventral end of the cranium. It is bordered by the posterior portion of the parasphenoid anteriorly, laterally by the exoccipitals and anterodorsally by the opisthotics. Its posterior face, the occipital condyle, is concave for articulation with the centrum of the atlas. The dorsolateral portion of this bone serves as the rear part of the floor of the braincase where the otoliths are situated.

b. Nasals and Circumorbital Series (Fig.7)

A number of loosely attached bones, chiefly in the ethmoid and the orbital regions, are related to the cranium of the Urophycis tenuis. These bones are integral parts of the cranium though they do not firmly ankylose to it.

NASAL ----- The nasals are elongate, scale-like bones suspending in the ethmoid regions on two lateral sides of the skull. Their dorsal surfaces are grooved for housing the laterosensory canals. The anterior end of each nasal lies lateral to the median rostral cartilage and dorsal to the external surface of the premaxilla; the posterior end is dorsal to the lateral ethmoid and mesial to the supraethmoid. Posteriorly, it is expanded and abuts against the anterior end of the frontal, from which it receives a branch of the laterosensory system.

LACHRYMAL ----- The lachrymals are the anteriormost elements of the circumorbital series on both sides of the skull. They are large, thin and somewhat rhombodial, with their lateral surfaces grooved for the laterosensory canals. Each lachrymal extends anteriorly to form the anterior border of the semicircularly shaped circumorbital chain,and disposes its anterior end behind the upperportion of the maxilla and below the nasal. On the middle portion of its dorsal surface is a mesially projecting process which touches the anterior portion of the palatine. Posteriorly, it meets the first infraorbital to comprise the anterolateral rim of the circumorbital chain.

<u>INFRAORBITAL</u> ----- The infraorbitals are 4 small scale-like bones. Two are present in the inferior portion of the circumorbital chain on either side of the skull. They are somewhat square in shape, and contain the laterosensory canals along their dorsal edges. In each circumorbital chain, the first infraorbital, the anterior one, connects with the posterior end of the lachrymal; while the second infraorbital meets the ventral edge of the third postorbital posteriorly. Both the infraorbitals approach the mesopterygoid mesially and form the ventral rim of the circumorbital chain.

<u>POSTORBITAL</u> ----- There are 6 postorbitals. Three constitute the posterior rim of the circumorbital chain on either side of the skull. They are small, scale-like and are grooved along their mesial edges for housing the laterosensory canals. On either side of the skull, the three bones are arranged vertically; the upper one, the first postorbital,

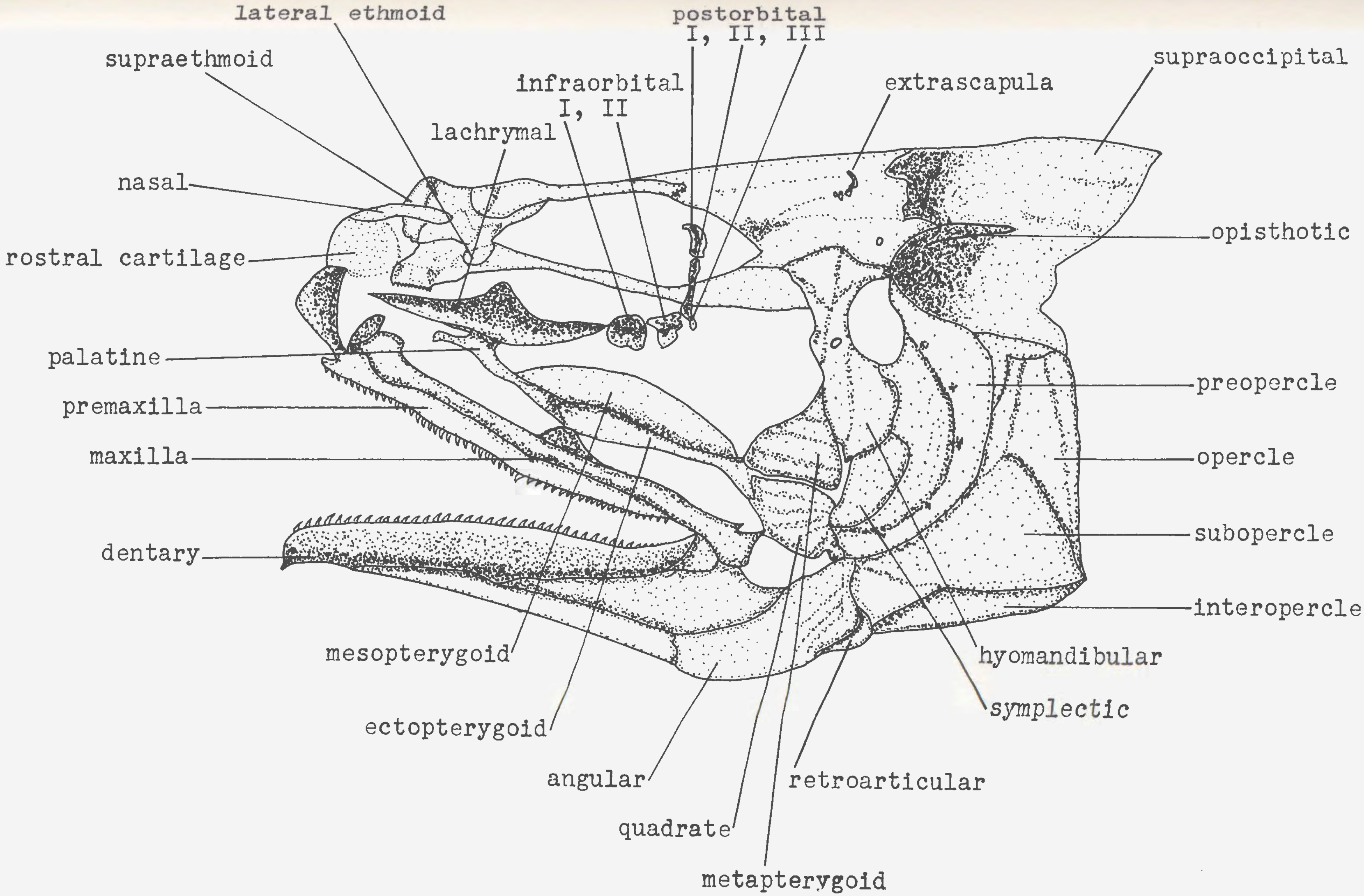

Fig. 7. Lateral view of the skull of _Urophycis tenuis_. X1

being the largest while the second and the third ones are of equal size and connected to each other by connective tissue. Each postorbital series is connected to the cranium at the juncture between the frontal and the sphenotic by the first postorbital. Ventrally, the third postorbital meets the second infraorbital to form the posterolateral margin of the circumorbital chain.

Unlike the articulation between two bones of the cranium, the members of the circumorbital series lie widely separated from one another and are supported only by the connective tissue.

c. Upper Jaw (Fig. 7)

The upper jaw of Urophycis tenuis consists of a pair of premaxillae and a pair of maxillae.

PREMAXILLA ----- The paired premaxillae are stout, curved, rod-like bones forming the anterior margin of the upper jaw. They meet each other anteromesially along a convoluted joint. Throughout most of their lengths, they are bounded loosely to the underlied maxillae by the fibrous connective tissue. Their posterior ends do not join the maxillae but are connected to them by ligaments. Each premaxilla carries a dorsal process on its anterior portion, the end of which is dorsally directed and lies on the anterior part of the rostral cartilage. Immediately posterior to the dorsal process is a second process which is lower and is provided for articulation with a fissure in the anterior end of the maxilla. On its posterodorsal surface , the premaxilla bears a flange which overlaps the mesial surface of the maxilla. Its ventral surface bears about 130 minute, canine-like teeth which are set in shallow depressions and are irregularly arranged.

<u>MAXILLA</u> ----- Lying behind and parallel to the premaxillae are the longer, paddle-like, toothless maxillae. They curve anteromesially to approach each other but do not directly contact one another. Each maxilla is expanded in its anterior end with a deep notch anteromesially for articulation with the second process of the anterior end of the premaxilla. Around this notch are two raised flanges; the proximal one passes mesial, and the distal one extends lateral to the second process of the premaxilla. Dorsally, its anterior end articulates firmly with the rostral cartilage and the anterodorsal surface of the prevomer. Median to its anterior shank, the maxilla is connected to the anterior end of the palatine by a pair of slender ligaments. Its posterior portion is flattened and curves posteroventrally to a point under the second infraorbital, nearly reaching the quadrate. The posterior tip of each maxilla is connected with the posterodorsal limb of the forked dentary by a large ligament which allows considerable flexibility in the juncture.

d. Lower Jaw (Figs. 7 & 8)

On either side of the lower jaw of <u>Urophycis</u> <u>tenuis</u> are 4 elements of which one, Meckel's Cartilage, is cartilaginous, and is not illustrated in Fig. 7 .

DENTARY ----- The paired dentaries are large bones forming the main part of the lower jaw. Each dentary curves anteromesially to join its counterpart of the opposite side through a synchonsis. Posteriorly,the dentry is forked to form the dorsal and ventral limbs by a V-shaped angle into which the anterior end of the angular and Meckel's Cartilage are disposed. It is connected dorsally with the posterior end of maxilla by a ligament from the posterodorsal end of its dorsal limb. The lateral surface of its ventral limb has a deep groove along which runs a branch of the laterosensory canal. At the posterior end of its ventral limb, the dentary meets the ventral portion of the angular, with a narrow space between them. On the dorsal edge of this bone are about 100 minute teeth.

MECKEL'S CARTILAGE ----- Meckel's Cartilages are two slender rods forming the axes for the bones of the lower jaw. Each cartilage extends anteromesially from the place dorsal to the retroarticular, passing through the angular and the dentary, to join its counterpart of the opposite side in the mid-line. It remains unossified throughout its length.

ANGULAR ----- The angulars are a pair of large, irregularly shaped bones forming the posterior part of the jaw. Anteriorly, each angular is pointed, with its end inserting into the angle between the dorsal and ventral limbs of the dentary.

Its anteroventral edge is overlapped by the dorsal edge of the ventral limb of the dentary. On its dorsal edge is a process situated immediately behind the posterior end of the dorsal limb of the dentary. Posterodorsally, it is connected with the ventral end of the quadrate through a facet at its posterior end. From its posterior end a plate extends anteroventrally, with an anterior surface approaching the posterior end of the ventral limb of the dentary. It joins Meckel's Cartilage along its mesial surface, and the retroarticular at its posteroventral end.

RETROARTICULAR ----- Lying on the posteromesial surface of the angulars are the small retroarticulars which form the posteroventral angles of the lower jaw. Each retroarticular is L-shaped, with the dorsal and ventral arms. The dorsal arm approaches the posterior end of Meckel's Cartilage dorsally, while the ventral arm firmly joins the ventral plate of the angular. Posterodorsally, the retroarticular is connected with the interopercle by a large ligament.

e. Opercular Series (Figs. 7 & 8)

The opercular series of Urophycis tenuis consists of 4 pairs of fairly large bones occupying the posterolateral regions of the skull.

PREOPERCLE ----- The preopercles are large, crescentic bones, forming the anterior and dorsal parts of the opercular series. Each preopercle serves as a principal connection between the opercular series and the corresponding suspensorium. At its dorsomesial surface is a facet where the preopercle meets the ventral portion of the hyomandibular, the dorsal portion of the symplectic, and the anterior end of the interhyal. Anteroventrally, it joins the quadrate at the latter's posterodorsal process. The posterior portion of this bone is thin and scale-like, overlapping dorsally the anterior limb of the opercle, the anterior part of the subopercle and the dorsal margin of the interopercle ventrally. Its anterior portion is evenly curved, and is flanged with five small processes to touch the lower posterior portion. The operculomandibular laterosensory canal leaves the cranium at the lateral edge of the pterotic and runs down the flanged anterior portion of the preopercle, continuing on into the juncture between the quadrate and the angular.

<u>OPERCLE</u> ----- Lying beneath and behind the preopercle is the A-shaped opercle. Each opercle is plate-like, with two thick limbs extending posteroventrally and anteroventrally from its anterodorsal end. The ventral tip of the posterior limb abuts against the posterodorsal edge of the subopercle; while the anterior limb reaches the anterior edge of the subopercle and is overlapped by the posterior border of the preopercle. At its anterodorsal end there is a fairly large socket for articulation with the posterior, or opercular process of the hyomandibular.

Broadening ventrally from this articulation, the opercle runs posteriorly to overlie the region of the supracleithrum and the dorsal portion of the cleithrum.

SUBOPERCLE ----- The subopercles are thin, somewhat triangular bones, each lying below the two limbs of the opercle. It is connected anterodorsally with the posteroventral angle of the preopercle and anteriorly with the posterior portion of the interopercle by loose connective tissue. Its ventral and posterior margins are jagged and rounded, forming the posterior edge of the whole opercular series and overlying the lower dorsal portion of the cleithrum.

INTEROPERCLE ----- The interopercles are obtuse-angle-shaped, with their long axes horizontal. Each interopercle has its dorsal surface overlapped by the ventral portion of the preopercle, and in turn the posterior portion of the interopercle overlaps the anterior end of the subopercle. On its ventromesial surface is a small process which is connected with the posterior angle of the retroarticular by a large ligament. It is the ventral edge of the opercular series and in a position dorsal to the first three or four branchiostegal rays.

f. Palatine Arch (Figs. 7 & 8)

Each half of the palatine arch of Urophycis tenuis consists of 3 elements which form the anterior part of the hyomandibulo-quadro-pterygo-palatine complex (the jaw suspension).

PALATINE --- The palatines are a pair of toothless, irregu-

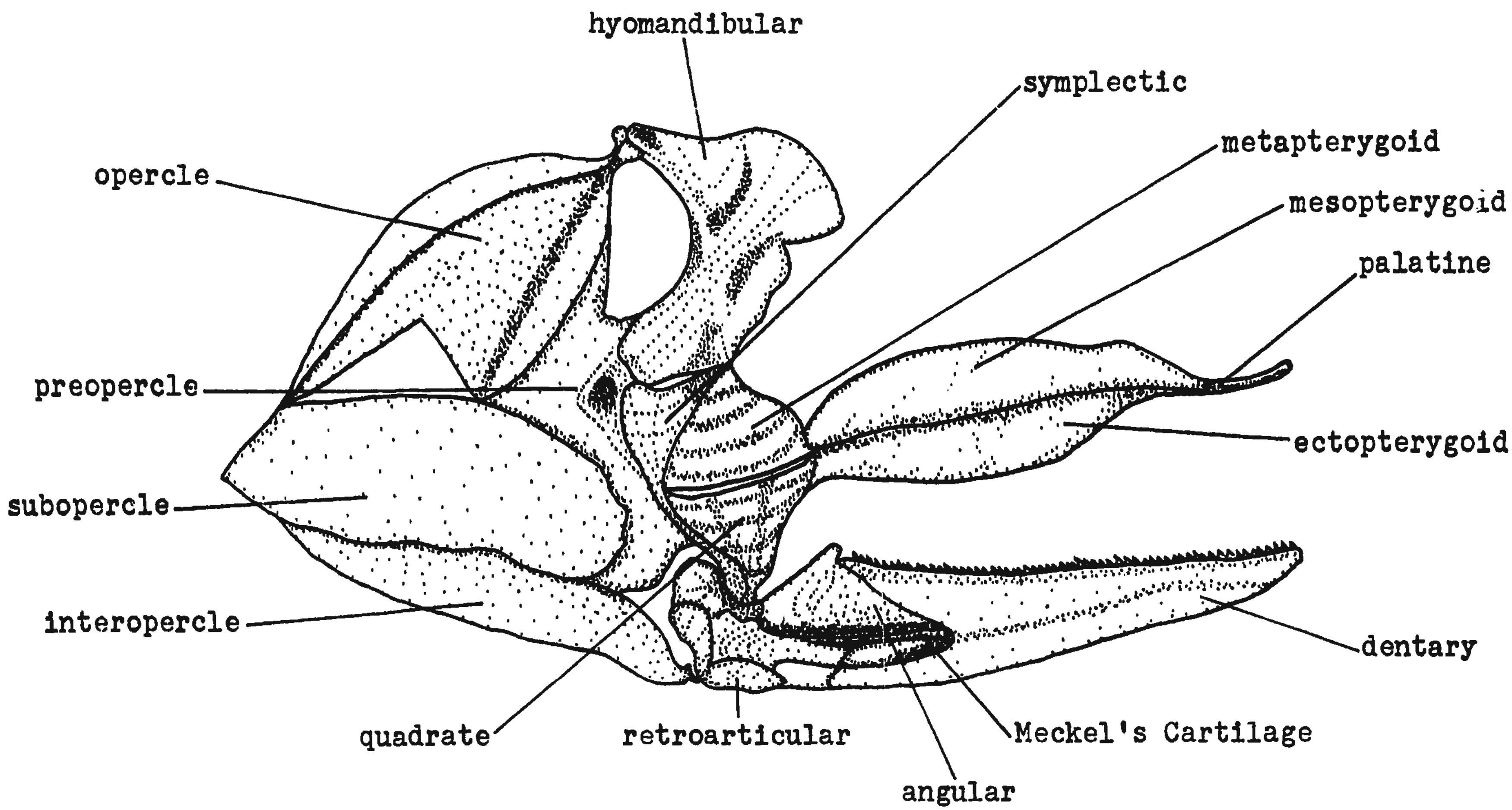

Fig. 8. Lateral bones of the face of <u>Urophycis</u> <u>tenuis</u>. X1.5.
Mesial view of the left side.

larly shaped bones, being the anteriormost elements of the jaw suspension. Each of them is in a position mesial to the nasal and the lachrymal. Its anterior portion is stout, rod-like and is connected with the anterior shank of the maxilla by a pair of slender ligaments. Its posterior portion is very expanded with an irregular end to join the anterior extremities of the mesopterygoid dorsally and the ectopterygoid ventrally. About halfway between its two ends is an articular facet where the palatine joins the lateral expansion of the lateral ethmoid.

ECTOPTERYGOID ----- The ectopterygoids are a pair of toothless splint-shaped bones forming the ventral boundary of the palatine arch. Each ectopterygoid articulates anteriorly with the posteroventral end of the palatine. From its articulation with the palatine, it extends posteroventrally to form a thickened homocercal terminal which articulates by suture with the anterior surface of the quadrate and the anteroventral end of the metapterygoid. It contacts the ventral edge of the mesopterygoid along most of its thickened dorsal edge.

MESOPTERYGOID ----- Lying over the ectopterygoids are the thin, leaf-like mesopterygoids. Their upper surfaces are rounded, and form the main floor of the orbital cavity. Each mesopterygoid joins the posterior end of the palatine anteriorly; and approaches the anterior angle of the metapterygoid with a narrow open space posteriorly.

g. Mandibular Arch (Figs. 7 & 8)

Each half of the mandibular arch of <u>Urophycis tenuis</u> consists of 4 bones and serves as a connection between the cranium and the hyomandibulo-quadro-pterygo-palatine complex.

<u>METAPTERYGOID</u> ----- The paired metapterygoids are triangular bones and the smallest elements of the mandibular arch. The dorsal end of each metapterygoid is rod-like, articulating with the anterior margin of the hyomandibular. Its posterior edge lies along the anteroventral margin of the hyomandibular and the anterior margin of the symplectic. Ventrally, it is separated from the straight part of the dorsal edge of the quadrate by a thin synchondrosis. Its anteroventral end rests on the posterodrosal angle of the ectopterygoid and approaches the posterior end of the mesopterygoid. On its lateral surface are several distinct stripes which run transversely along most of its width.

<u>QUADRATE</u> ----- The quadrates are two triangular bones, each serving as a junction between the lower jaw and the corresponding jaw suspension. On its ventral end is a saddle-shaped socket where the posterior angle of the angular is joined. It meets the posteroventral end of the ectopterygoid anteriorly; the ventral edge of the metapterygoid dorsally. Its posterior end is prolonged dorsoposteriorly into a long process which borders on the anteroventral edge of the preopercle. On its posteromesial surface is a groove where the ventrally projected end of the symplectic is inserted. Several transverse stripes

same as those on the metapterygoid are formed on its lateral surface.

<u>SYMPLECTIC</u> ----- The symplectics are a pair of Y-shaped bones, each forming the lower posterior portion of the mandibular arch. Each symplectic has its anterior edge articulated with the posterior edge of the metapterygoid. Its dorsoposterior end rims a large facet where it meets the anteromesial surface of the preopercle. Dorsally, its dorsal edge is connected to the straight border of the hyomandibular by a fairly large synchondrosis. Its ventral end is rod-like and fits into the groove near the posterior edge of the mesial face of the quadrate.

<u>HYOMANDIBULAR</u> ----- The large hyomandibulars are irregularly shaped bones, each comprising several ridges and grooves with few flat areas. Each consists of a strut of bone running dorsally into a flattened head. The head has three finger-like thickenings radiating from its base, each of which ends in an articular surface. Two of these articular surfaces are on the dorsal margin: articulating respectively with two fossas formed by the sphenoid, pterotic and prootic as previously described. The third articular surface is directed posteriorly forming the opercular process, and serves as the attachment of the anterior socket of the opercle. At its ventral portion, the hyomandibular terminates in anteriorly a jagged process lying on the posterior edge of the metapterygoid, and posteriorly a straight-edge connection with

the dorsal side of the symplectic by a synchondrosis. Near its center, the hyomandibular is perforated by a large foramen for the exit of the hyomandibular branch of the facial nerve.

H. Hyoid Arch (Figs. 9 & 10)

The hyoid arch of Urophycis tenuis represents the posteroventral portion of the skull. Each half of the arch consists of 11 elements, and makes an angle with its counterpart of the opposite side of about 65 degrees. Between the paired halves are two median elements: the urohyal and the basihyal.

UROHYAL ----- The urohyal is a median, vertical plate, deeply imbedded in the muscle of the isthmus. Its anterior portion is high and thick and is attached by ligaments to the mesial portion of the dorsal parts of the hyohyals. Its lateral surfaces are very compressed, serving as the insertion for certain muscles. Posteriorly, it approaches the joint of cleithra of the pectoral girdle.

BASIHYAL ----- The basihyal is so poorly ossified that it is difficult to locate in some specimens. It is a toothless, paddle-like ossification, forming the anterior part of the floor of the tongue. Its posterior end occupies a position anterodorsal to the posteromesial parts of the hypohyals and articulates with the anterior end of the first basibranchial.

HYPOHYAL ----- The hypohyals are somewhat triangle in shape

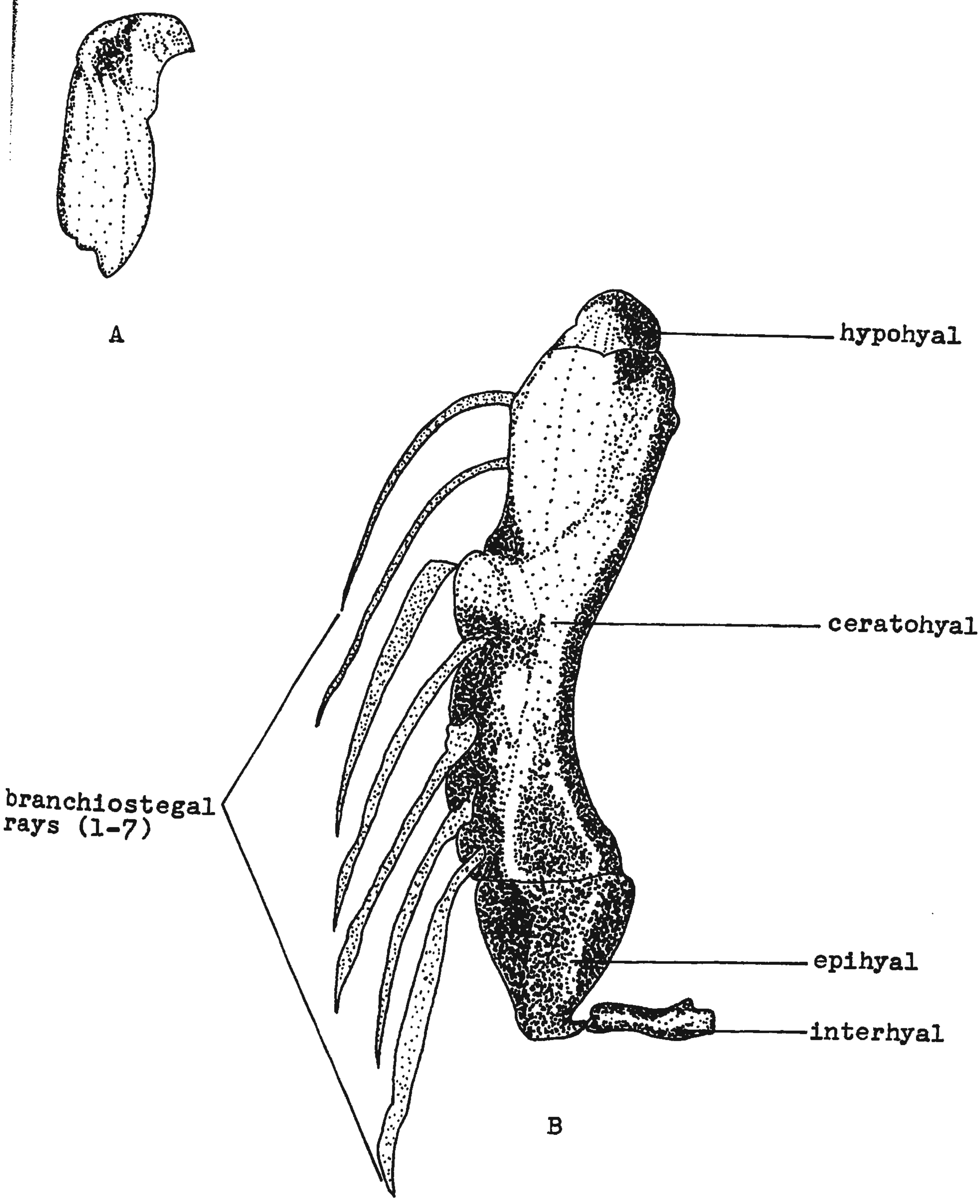

Fig. 9. A. Lateral view of the urohyal of <u>Urophycis tenuis</u>. X1.5.
B. Dorsal view of the right portion of the hyoid arch of <u>Urophycis tenuis</u>. X1.8.

and the anteriormost elements of each half of the hyoid arch. Each hypohyal is composed of two parts which are partially hollow. The pyramidal dorsal part is larger and connected with the anterior portion of the urohyal by a ligament medially. The ventral part is cone-like, articulating with the lateral edge of the dorsal part and bearing a large foramen on its ventral surface. The posterior edge of the hypohyal is formed by the rear ends of both parts, and is joined to the anterior edge of the ceratohyal by a narrow suture. No branchiostegal rays are borne on the hypohyal.

<u>CERATOHYAL</u> ----- The ceratohyals are two large bones forming main parts of the hyoid arch. Each ceratohyal meets anteriorly the posterior edge of the hypohyal, and posteriorly the anterior edge of the epihyal. Its mesial portion is compressed with several concave areas where the branchiostegal rays are attached.

<u>EPIHYAL</u> ----- The epihyals are somewhat triangular, each with a laterally curved posterior end for the reception of the ventral end of the interhyal. Anteriorly, it is connected with the posterior edge of the ceratohyal by a narrow suture. Its median mesial portion is convex, corresponding with that of the ceratohyal.

<u>INTERHYAL</u> ----- The interhyals are small, rod-like bones, connecting the hyoid arch to the suspensora. The anterior end of each interhyal extends dorsally to articulate in cartilage in a facet at the juncture of the mesial surfaces of the pre-

opercle, hyomandibular and symplectic. Posteromesially, it is connected with the posterior end of the epihyal.

BRANCHIOSTEGAL RAY ----- There are 14 branchiostegal rays: 7 on either half of the hyoid arch. The anterior 3 are attached to the concave areas of the distal surface of the ceratohyal, and the remaining 4 are attached to its mesial surface. Each branchiostegal ray has its anterior end enlarged and facet-like for more effective attachment to the ceratohyal. These branchiostegal rays increase in length and width posteriorly, with the first 3 being small and thin; the last four thick and long with their posterior ends nearly reaching the position below the third vertebra. The posterior 4 branchiostegal rays extend posterodorsally with their anterior portions under the interopercle and the subopercle.

(9) Branchial Arches (Fig. 10)

The branchial arches of Urophycis tenuis support the posterior portion of the floor of the mouth cavity and the roof as well as the floor of the pharyngeal cavity. They are composed of 4 complete arches, each with a double row of gill filaments, and a rudimentary 5th arch bearing no filaments. With the exception of the first one, each complete arch bears 26 or 28 small, toothed patches arranged in two rows on its mesial surface. On the mesial surface of the 1st branchial arch are two rows of differently shaped structures: the outer is composed of 13 or 14 short, conical gill rakers; the inner is formed by 13 or 14 small, toothed patches similar to those of the other 3 complete arches.

Each complete branchial arch is composed of the paired hypobranchials, ceratobranchials, epibranchials, and pharyngobranchials which are separated by a median basibranchial in the ventral surface of the branchial chamber. The branchial arches are suspended from the cranial base, in the posterior portion of the parasphenoid, by the pharyngobranchials.

<u>BASIBRANCHIAL</u> ----- There are 2 basibranchials. The 1st branchial is shield-shaped, lying in the mid-ventral line. Its anterior end is attenuated, and articulates with the posterior end of the basihyal. It provides laterally the articular surfaces for the proximal ends of the first 3 hypobranchials on either side. Posteriorly, it loosely contacts the second basibranchial which is very small and entirely cartilaginous, being the median juncture for the 4th pair of the hypobranchials.

<u>HYPOBRANCHIAL</u> ----- Laterodorsal to the basibranchials are the bilaterally paired hypobranchials of the 1st through the 4th branchial arches. The first pair of hypobranchials are curved and rod-like each connecting through synchondrosis with the 1st ceratobranchials superiorly and the anterolateral surface of the 1st basibranchial inferiorly. The 2nd hypobranchials resemble the first ones in general but are only half as long as the latter. The 3rd pair of hypobranchials are the smallest among the 4 pairs of hypobranchials. Each 3rd hypobranchial is hollow and fan-shaped with a slender mesial end

which articulates with the posterolateral surface of the 1st basibranchial. The 4th pair of hypobranchials are similar in shape to the 3rd pair hypobranchials except that their mesial ends are longer and articulate with the cartilaginous 2nd basibranchial. Both the 3rd and the 4th hypobranchials have mesially curved distal ends which join their corresponding ceratobranchials superiorly.

CERATOBRANCHIAL ----- The 4 pairs of the cerarobranchials are of approximately same length. They are slender and rod-like, with their anteroventral surfaces deeply concave for housing the branchial arteries. Together with the 4 pairs of the hypobranchials, they form the ventral portions of the branchial arches. Each ceratobranchial articulates with the mesial ends of the epibranchials superiorly, and the distal ends of the hypobranchials inferiorly.

EPIBRANCHIAL ----- Dorsomesial to the posterior ends of the ceratobranchials and forming the lateral portions of the branchial arches are 4 pairs of short, rod-like epibranchials. They are similar to each other in length and shape, and each has an expanded posterior portion. On the anterior surface of the 3rd epibranchial are 15 to 20 minute, dorsally projecting conical teeth. No teeth are borne on the 1st,2nd, and 4th epibranchials. Each epibranchial articulates superiorly with the anterolateral end of its corresponding pharyngobranchial.

PHARYNGOBRANCHIAL ----- There are 4 pharyngobranchials on either side, forming the dorsal portion of the branchial

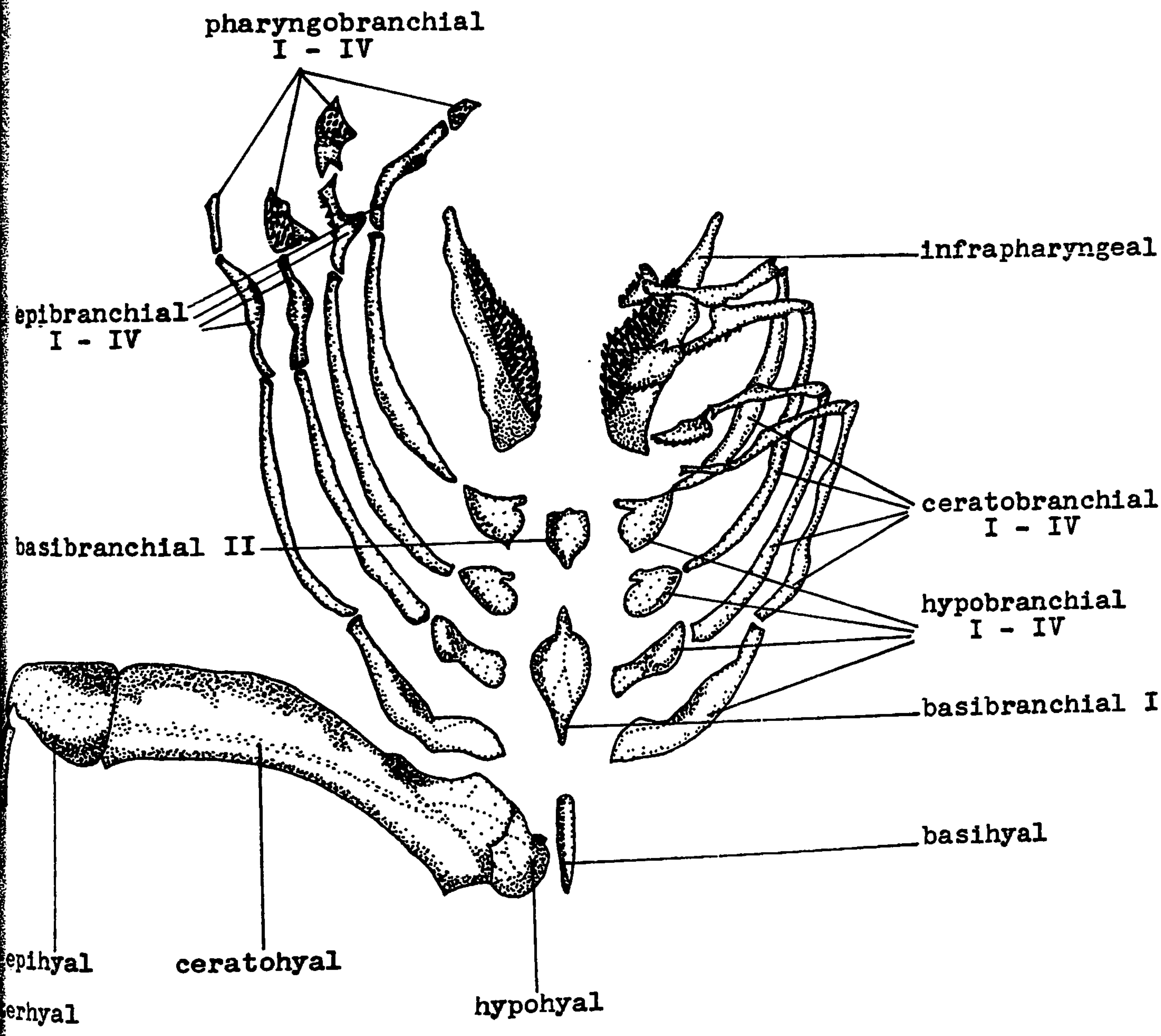

Fig. 10. Dorsal view of the hyobranchial system of <u>Urophycis tenuis</u>. (except upper portion of the right arches - ventral view) X1.5.

arches. They are small bones and differ in shape. All of their posterior ends are articulated inferiorly with the anteroventral ends of their corresponding epibranchials. Each pharyngobranchial bends mesially and approaches its counterpart of the opposite side in the dorsal mid-line. The 1st pharyngobranchials are short, rod-like, poorly ossified, and bear no teeth. The 2nd pharyngobranchials are larger than the first ones and of right-angle triangle in shape, each bearing about 20 minute, canine-like teeth on its anteroventral surface. The paired 3rd pharyngobranchial is irregularly shaped, and is the largest bone among the pharyngobranchial series. On its anteroventral surface are 20 to 23 minute, canine-like teeth which are irregularly arranged and slightly larger than those of the second pharyngobranchial. The 4th pharyngobranchials are smaller, triangular and each bears 12 to 15 minute, canine-like teeth.

INFRAPHARYNGEAL ----- The paired infrapharyngeals represent the fifth branchial arch. They meet each other at their ventral ends, but diverge markedly dorsally. Neither infrapharyngeal has a connection with the medial basibranchial but each is connected laterally to its corresponding ceratobranchial by a sheet of connective tissue. On the ventromesial surface of each infrapharyngeal are 45 to 50 minute, canine-like teeth which are arranged roughly in four rows.

B. Vertebral Column

The vertebral column of *Urophycis tenuis* has 49 or 51 vertebrae including the terminal segment, the ultimate. The column is divisible into 4 sections: (1) post-cranial, (2) abdominal, (3) anterior caudal, and (4) posterior caudal, based on the presence or absence of haemal arches.

a. Post-cranial Section (Fig. 11)

The post-cranial section is composed of the first 4 vertebrae. On the 1st vertebra, the centrum is shorter than that of the succeeding ones, and is deeply concave at its anterior surface for articulation with the posterior surface o f the basioccipital. It bears a pair of large neural prezygapophysis lying on the posterolateral edges of the exoccipitals, and well-developed neural spine articulating with the posterior edge of the occipital spine. The stout neural postzygapophys of the 1st vertebra are placed laterally and directed posteriorly. The 2nd vertebra is smaller but similar in shape to the first one and has a pair of tendon on either side of its centrum. The haemal postzygapophyses of the 3rd vertebra are unique in this column. Each projects posteroventrally slightly beyond the posterior level of the centrum of the 4th vertebra. The centrum of the 4th vertebra carries dorsally a pair of normally placed neural postzygapophysis, and ventrally a pair of haemal prezygapophysis as well as a pair of haemal postzygapophysis. On both sides of the 4th vertebra the haemal pre-and postzygapophyses are firmly fused and lie on the haemal postzygapophyses of the 3rd vertebra.

The post-cranial section of the vertebral column may be re-

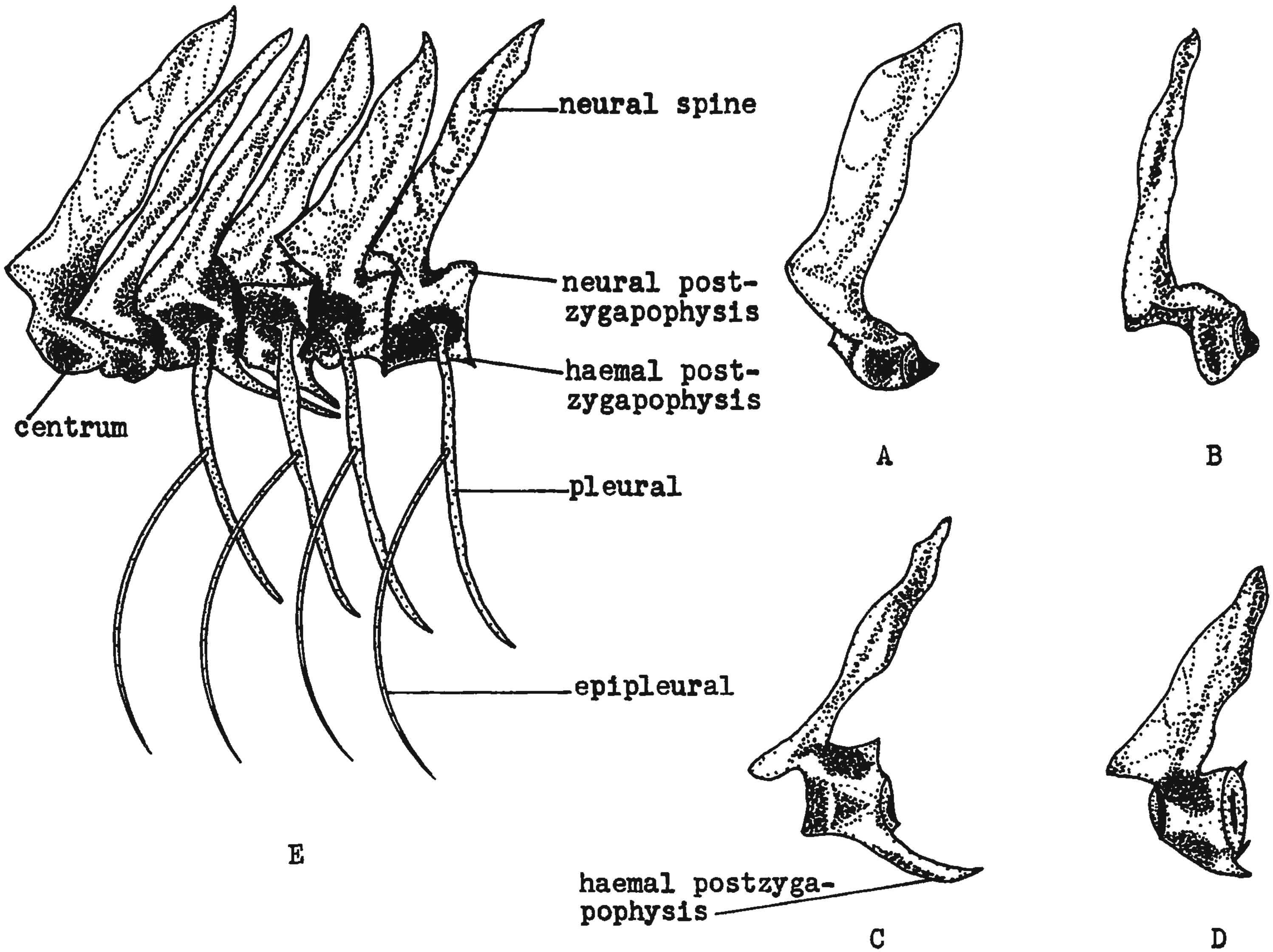

Fig. 11. A - D. Lateral view of the 1st to 4th vertebrae of <u>Urophycis tenuis</u>. X1.8.

E. Lateral view of the 1st to 6th vertebrae of <u>Urophycis tenuis</u>. X1.5.

garded as a gradual transition in form between the occipital segment of the skull and the typical abdominal vertebrae. The neural spines of the first 4 vertebrae are similar in height and are as high as the occipital spine of the supra-occipital. The position of the neural postzygapophyses on the post-cranial vertebrae are ascent posteriorly, being the lowest on the 1st one and the highest on the 4th one. On either lateral side of the first 4 vertebrae there is a deeply concave area which ascends in position in a manner similar to the neural postzygapophysis. Neither haemal spines nor the parapophyses are present on any of the post-cranial vertebrae.

b. Abdominal Section (Fig.12)

The abdominal section of the vertebral column of Urophycis tenuis is composed of the next 12 vertebrae behind the 4th. All of the abdominal vertebrae have centra which are nearly uniform in shape and size. Their neural prezygapophyses are short processes directed anterodorsally from the neural arches, and articulate with the preceding vertebrae by the neural postzygapophyses which are directed posterodorsally from the centra. The typical haemal prezygapophysis is formed at the base of the parapophysis and articulates anteriorly with the haemal postzygapophysis of the preceding vertebra. Parapophyses occur on all of the abdominal vertebrae. On the 5th vertebra, they are small and projected anterolaterally. Caudad the parapophyses gradually become laterally projected and larger in each successive vertebra, and reach

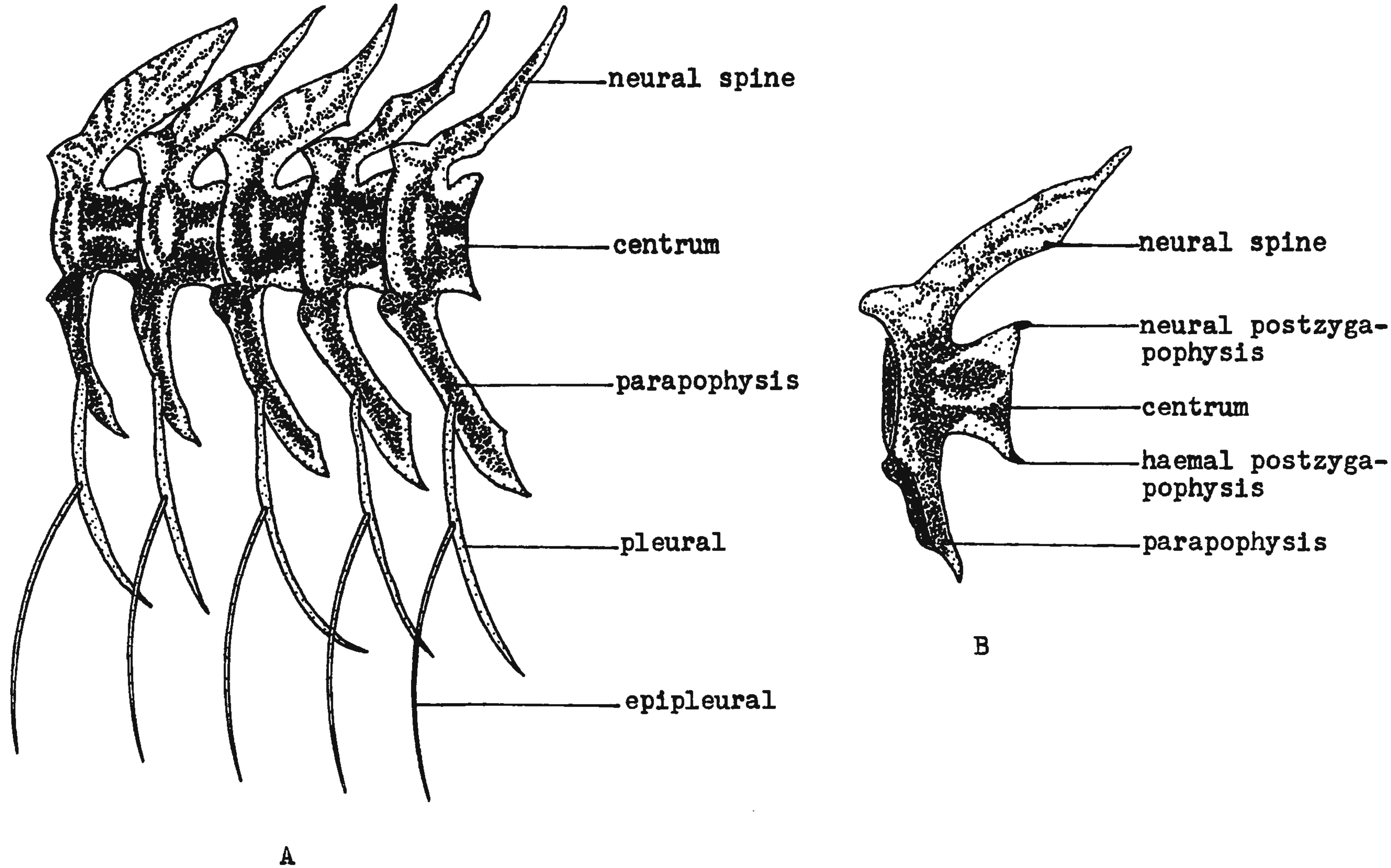

Fig. 12. A. Lateral view of the 12th to 16th vertebrae of <u>Urophycis tenuis</u>. X1.5.

B. Lateral view of the 9th vertebra of <u>Urophycis tenuis</u>. X1.8.

their largest size on the last vertebra of the abdominal section. Neural spines are presented on all of the abdominal vertebrae and furnish the support for the first dorsal fin and the anterior portion of the second dorsal fin. On the 14th, 15th and 16th vertebra, the neural spines decrease in size and each tapers to a dorsoposterior end. No haemal spines are formed on the vertebrae of this section.

c. Anterior Caudal Section (Fig. 13)

The anterior caudal section of the vertebral column of Urophycis tenuis is the longest of the 4 sections and is composed of the 27 vertebrae between the 16th and 44th vertebrae. The size of the centra of the vertebrae of this section decrease caudad and are generally smaller than those of the vertebrae of the abdominal section. On the typical anterior caudal vertebra, the short prezygapophyses project anterodorsally and anteroventrally from the bases of the neural and the haemal arches respectively; and the corresponding shorter postzygapophyses project posterodorsally and posteroventrally from the upper and lower parts of the posterior edge of the centrum. The neural spines in this section provide the support of most of the second dorsal fin. They are slender, attenuated at their distal ends and are progressively smaller and more curved caudally. On the anterior caudal vertebrae, the parapophyses are replaced by the haemal spines, the first pair of which occurs on the 16th vertebra and are much longer as well as thicker than the others. The haemal

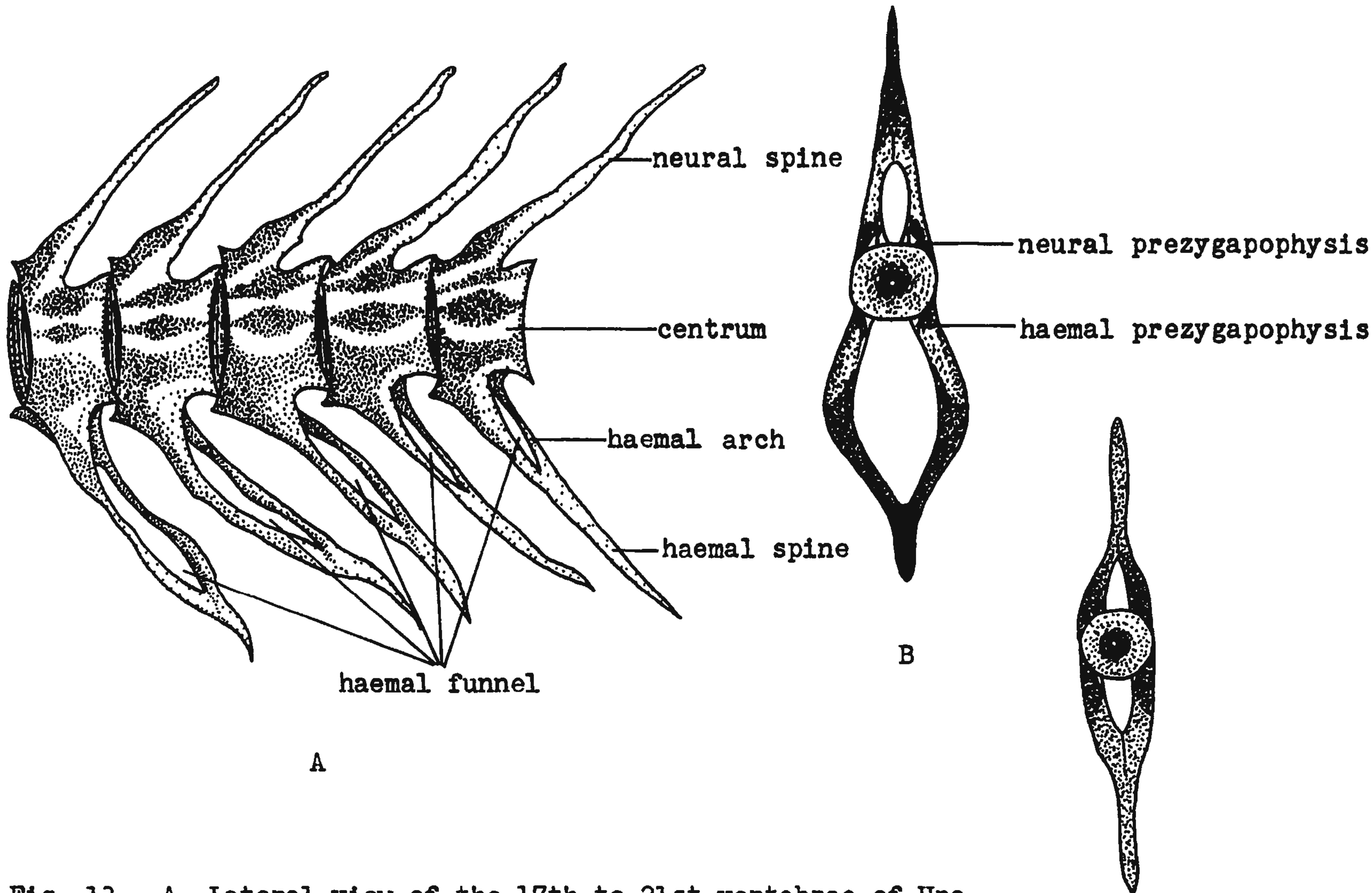

Fig. 13. A. Lateral view of the 17th to 21st vertebrae of *Urophycis tenuis*. X1.5.

B. Anterior view of the 17th vertebra of *Urophycis tenuis*. X1.8.

C. Anterior view of the 28th vertebra of *Urophycis tenuis*. X1.8.

spines of the last few anterior caudal vertebrae are very slender and weak, but still provide the support of the anal fin as do the preceding caudal vertebrae. The haemal arches of the first 5 to 7 anterior caudal vertebrae are well-developed forming a haemal funnel which is very prominent throughout the length of this section of the vertebral column.

d. Posterior Caudal Section and Caudal Fin (Fig.14)

The last 6 or 7 vertebrae comprise the posterior caudal section of the vertebral column of *Urophycis tenuis*, and contribute to the support of the soft branched and segmented caudal-fin rays.

Except for the last 3 vertebrae, all of the posterior caudal vertebrae are similar in both size and shape, and do not differ significantly from the last few anterior caudal vertebrae. Their neural and haemal spines are elongate helping to support a total of 15 caudal fin rays and a number of procurrent rays.

The antepenultimate has a centrum slightly smaller than that of the preceding vertebra. Its neural spines are shorter and thicker than the typical neural spines of the posterior caudal vertebrae and support only one caudal fin ray. Anterior to these neural spines is a splint-shaped dorsal radial which helps to support another fin ray. The haemal spines of the antepenultimate are replaced by an autogenous hypural which makes a loose contact with the ventral surface of the centrum

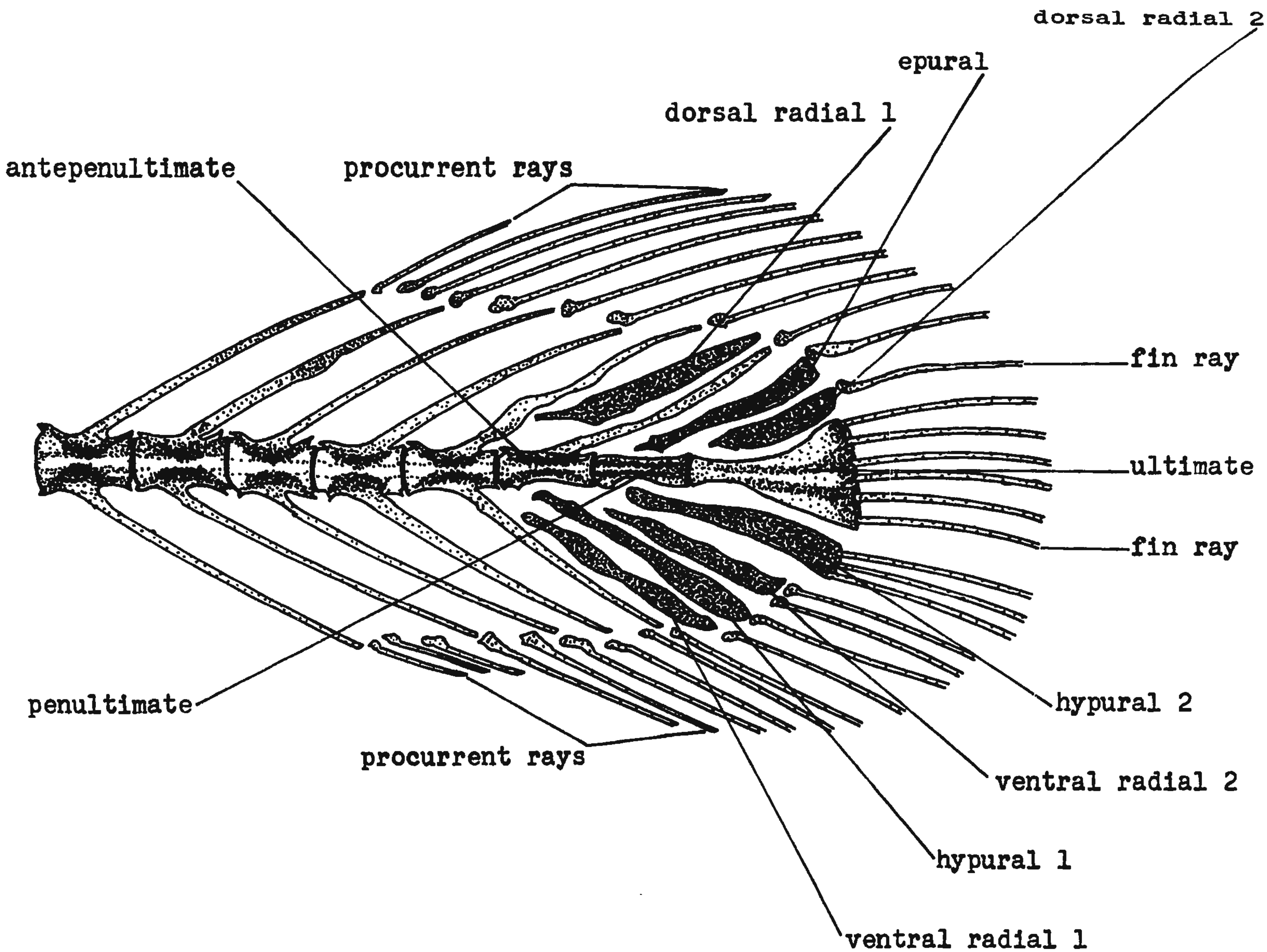

Fig. 14. Lateral view of the 44th to 51st vertebrae of <u>Urophycis</u> <u>tenuis</u>. X1.5.

and supports a caudal fin ray. Corresponding the dorsal radial is a ventral radial which occurs anterior to the autogenous hypural and also supports only one fin ray.

The centrum of the penultimate is the smallest one among all the centra of the vertebral column. The neural and haemal spines of this vertebra are replaced respectively by the autogenous epural and hypural; the former supports one caudal fin ray while the latter supports as many as 3 rays. Anterior to the large autogenous hypural is the paddle-shaped second ventral radial which contributes to the support of 2 rays.

The ultimate is a fan-like bony plate with its anterior concave end ankylosed to the posterior end of the penultimate. No vestige of either the neural or the haemal spines occurs on this vertebra. Its posterior margin is smooth bearing 6 caudal fin rays. Lying above its dorsal edge is the splint-like second dorsal radial which supports only one ray.

e. Vertebral Abnormalities (Fig. 15)

In the vertebral column of a specimen with a standard length of 53 cm, some vertebrae of abnormal structure were found. On the 14th vertebra, each of the neural spines projects dorsally and fails to meet its counterpart of the opposite side to develop a neural arch. This abnormality of the neural spines also occurs on the 15th, 22nd, 23rd, and 24th

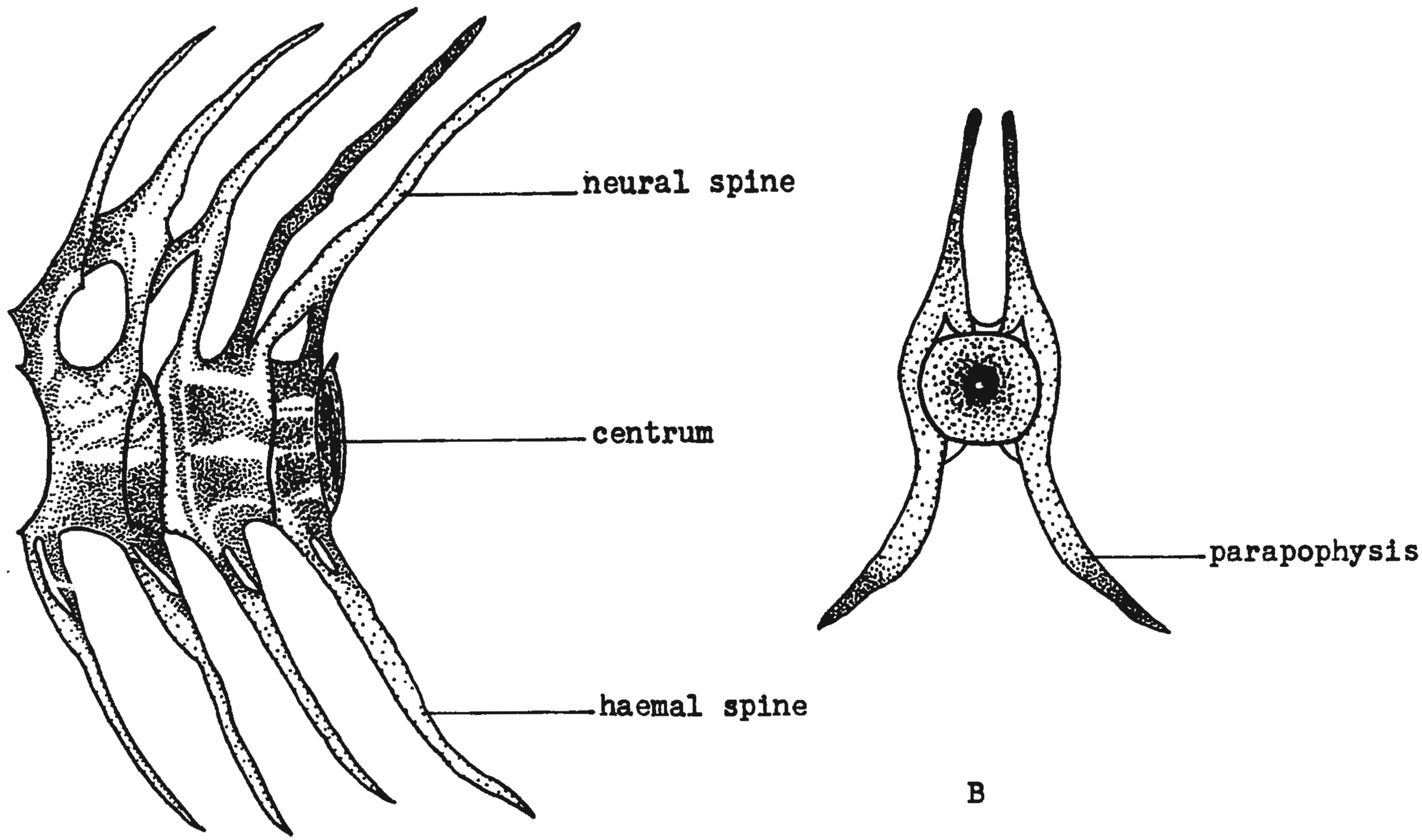

Fig. 15. Vertebral abnormalities of <u>Urophycis</u> <u>tenuis</u>. X1.5.

A. Lateral view of the 25th to 28th vertebrae.

B. Anterior view of the 14th vertebra.

vertebrae. Furthermore, the centra of the 25th to 28th vertebrae are shorter than those of the normal vertebrae and are fused firmly to each other. The left neural spine of the 25th vertebra does not unite with its right counterpart which, however, unites posteriorly with the left spine of the 26th vertebra. The right neural spine of the 26th vertebra, in turn, unites with the left spine of the 27th vertebra and leaves the right spine of the 27th vertebra not united as is the left neural spine of the 25th vertebra.

f. General Remarks

All the vertebrae of *Urophycis tenuis* have amphicoelous centra except the ultimate which is composed of only half of a typical centrum. These centra are developed around the notochord, and each is pierced by a small foramen which together with the concavities of both ends are filled with the remnent of the notochord. The two concavities of each typical centrum display distinct rings. These may be annual growth rings. The concave lateral surfaces are sculptured with several horizontal bridges running between the two ends. Between the bases of the neural arches and the neural postzygapophyses are open grooves, several of which provide the exits of the spinal nerves. Except for the parapophyses, all of the structures of the vertebrae along the vertebral column decrease in size caudad.

C. Ribs (Figs. 11a and 12a)

Two types of ribs are associated with certain vertebrae of

Urophycis tenuis. The pleurals occur from the 3rd to the 14th vertebra, and each is external to the parietal peritoneum between the coelomic wall and hypaxial muscles. They are slender, flattened bones with small knob-like proximal ends for articulation with the lower lateral surfaces of the centra from the 3rd to the 6th vertebra and the distal bases of the parapophyses from the 7th to the 14th vertebra. They project lateroventrally, and increase in size from the 3rd to the 9th vertebra and decrease slightly in size from the 10th to the 14th vertebra. There are 12 pairs of epipleurals. They are more slender and longer than the pleurals and project dorsolaterally to insert into the horizontal skeletogenous septum. Each epipleural has its proximal end slightly enlarged to articulate with the middle of the anterior surface of the corresponding pleural.

(2) Appendicular Skeleton

The appendicular skeleton of *Urophycis tenuis* comprises the paired and median fins, and their bony supports.

A. Paired Girdle and Paired Fin

There are two girdles supporting the paired fins of *Urophycis tenuis*: the pectoral girdle and the pelvic girdle.

a. Pectoral Girdle and Pectoral Fins (Fig. 16)

The pectoral girdle is composed of 15 elements, 4 of which are responsible for supporting 15 or 16 pectoral fin rays.

EXTRASCAPULA ----- Between the posterior portions of the parietal and the pterotic there is a group of 5 loosely attached extrascapulae. They are very small and difficult to find in some specimens. All of them are entirely grooved for housing the supratemporal canal of the laterosensory system.

POSTTEMPORAL ----- The posttemporals are Y-shaped bones connecting thepectoral girdles with the posterior portions of the cranium. They are minute and weakly developed. None of the posttemporals examined in this study of 17 fishes has a length of more than half a centimeter. Each posttemporal articulates anteriorly by its large limb with the latero-posterior surface of epiotic and by its small limb with the posteromesial surface of the pterotic. Posteriorly, the posttemporal is connected by a ligament with the dorsal end of the supracleithrum.

SUPRACLEITHRUM ----- The supracleithra are small, rod-like elements which connect the posttemporals to the main parts of the pectoral girdle. They are deeply embedded in the muscles and easily overlooked in some specimens. The dorsal end of each supracleithrum is pointed and contacts the posterior end of the postemporal. The ventral end is slightly enlarged and overlaps the dorsal portion of the cleithrum without any modifications for articulation.

CLEITHRUM ----- The cleithra form the main parts of the pectoral girdle. They are large, L-shaped, each with a

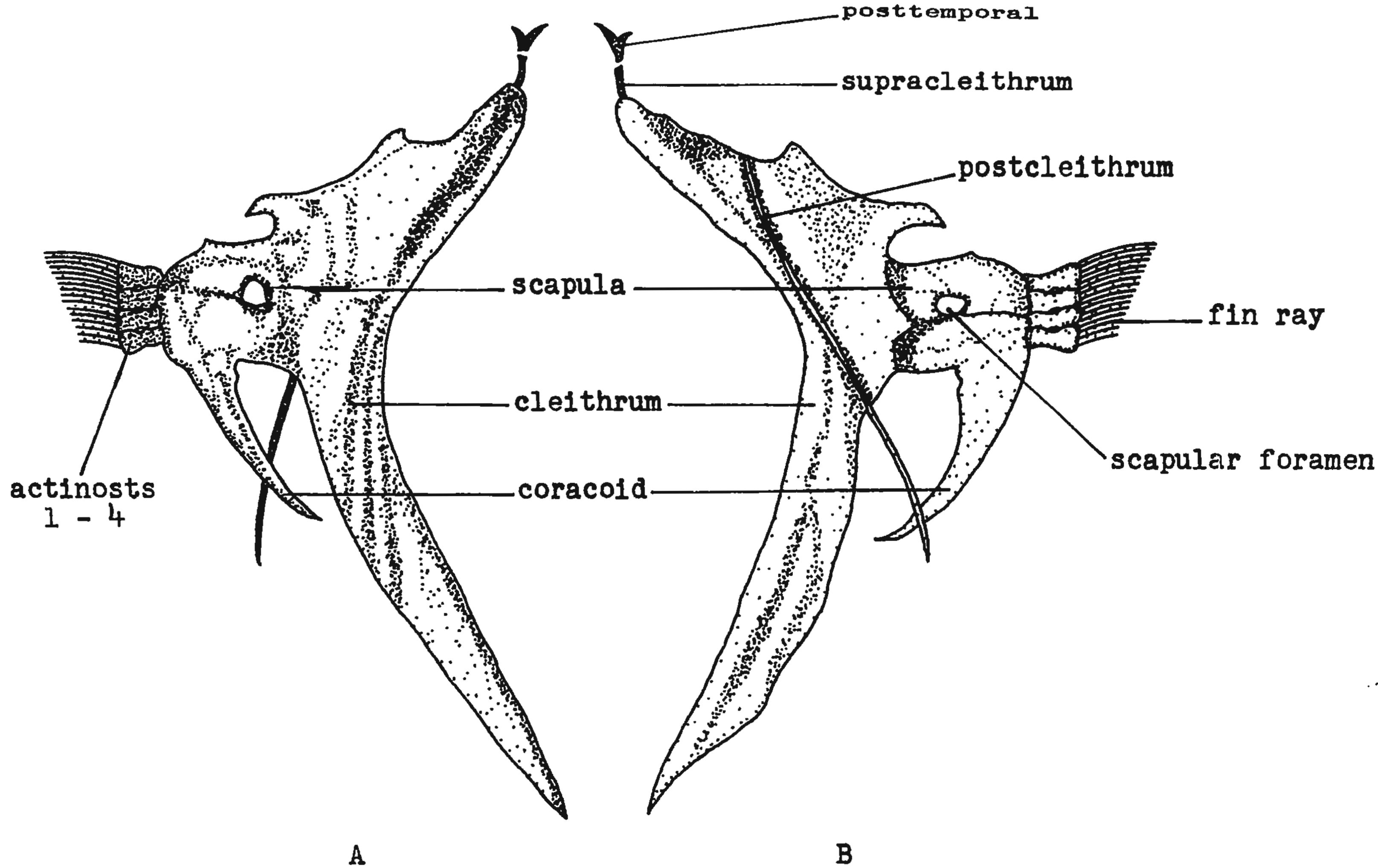

Fig. 16. Right pectoral girdle and fin of <u>Urophycis tenuis</u>. X1.5. A. Lateral view. B. Medial view.

shorter, vertical dorsal portion and a longer, nearly horizontal ventral portion. The vertical, dorsal portion is broad and has a thickened dorsal end which is overlapped by the ventral end of the supracleithrum and is attached mesially to the postcleithrum. The longer ventral portion curves anteromesially and tapers to an end which is connected by a short ligament with its counterpart of the opposite side. The joint of two cleithra, left and right, is on the mid-ventral line of the body and is a short distance below the posterior end of the urohyal. On the mesial surface of the cleithrum is a flange which extends the whole length of the dorsal margin of this bone. Posterior to the middle portion of this flange are the scapula and the coracoid which attach loosely to the cleithrum.

<u>POSTCLEITHRUM</u> ----- The postcleithra are two slender, rod-like bones which are attached to the dorsal portion of the cleithra and run posteroventrally through the muscles mesial to the scapulae and the coracoids.

<u>SCAPULA</u> ----- The scapulae are thin, irregularly-shaped bones lying on the mid-mesial surface of the cleithra. Each scapula contains most portion of the scapular foramen and postero-ventrally is attached by connective tissue to the posterodorsal margin of the coracoid. Posteriorly, the scapula serves for the attachment of the two dorsal actinosts.

<u>CORACOID</u> ----- The coracoids are plate-like bones; each of them is composed of two portions. The broad posterodorsal

portion is connected anteriorly by connective tissue with the posteroventral portion of the cleithrum, and borders dorsally the ventral margin of the scapular foramen as well as the posteroventral margin of the scapula. The posterodorsal edge of this portion is rather smooth and 2 ventral actinosts are attached to it. The anteroventral portion of the coracoid is rod-like and projects anteriorly to approach the antero-ventral surface of the cleithrum.

ACTINOST ----- On each side of the pectoral girdle are four small, hourglass-shaped actinosts. They decrease in size dorsally, with the most dorsal one the smallest. Anteriorly they articulate by connective tissue with the posteroventral and the posterodorsal portions of the scapula and the cora-coid. Posteriorly they form the supports of the pectoral fin rays; each of them is associated with about 4 rays.

PECTORAL FIN RAY ----- Each pectoral fin is composed of 15 or 16 soft, branched and segmented rays. They are attached to the posterior ends of the actinosts and diminish in size ventrally.

d. Pelvic Girdle and Pelvic Fins (Fig. 17)

The pelvic girdle of *Urophycis tenuis* comprises a pair of basipterygium closely associated with the cleithra. The pelvic fins are much reduced.

BASIPTERYGIUM ----- The basipterygia are V-shaped elements forming the main parts of the pelvic girdle. The slender

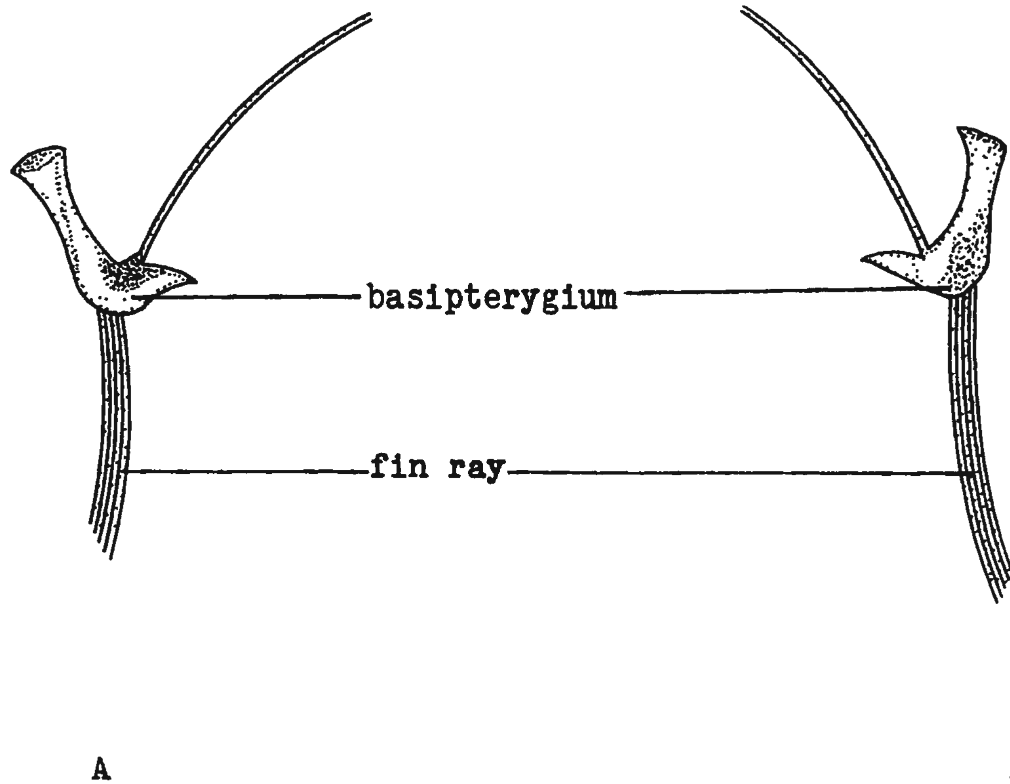

Fig. 17. Left pelvic girdle and fin of <u>Urophycis</u> <u>tenuis</u>. X1.5. A. Medial view. B. Lateral view.

ventral limb of each basipterygium projects anteromesially to meet its counterpart of the opposite side a short distance behind the joint of the left and right cleithra.

PELVIC FIN RAY ----- There are only two soft, branched, segmented rays in each pelvic fin. They attach directly to the posterior end of the basipterygium and project posterolaterally. Owing to the anteriorly situated position of the pelvic girdle, the pelvic fins are inserted considerably in front of the pectoral fins. The dorsal ray of the pelvic fins is shorter than the ventral one and may reach almost to the vent.

B. Median Fins and Their Supports

The median fins of *Urophycis tenuis* consists of the dorsal fins, the anal fin, and the caudal fin; the last of which has been described previously.

a. Dorsal Fins and Their Supports (Fig. 18)

The dorsal fins of *Urophycis tenuis* are composed of a short first dorsal fin and a much longer second dorsal fin. The first dorsal fin consists of 10 soft rays, with the 3rd one much elongate, and extends from the 3rd to the 7th vertebra. The second dorsal fin consists of 54 to 56 soft rays of almost equal length, and extends from the 8th to the 40th vertebra. Except for the first and the last rays of each dorsal fin, the rays are branched and segmented and have their proximal ends enlarged for attachment of the muscles and for articulation with the distal pterygiophores. The distal pterygiophores are a series of small cartilaginous elements along the midline at the bases of the fins, and in direct contact with the distal ends of the proximal pterygiophores. The proximal pterygiophores lie in the dorsal skeletogenous septum and are spoon-shaped with the handles interdigitating with the neural spines. They articulate dorsally with the proximal edges of the distal pterygiophores.

b. Anal Fin and Its Support (Fig.19)

The anal fin of Urophycis tenuis comprises 48 or 49 soft, branched, segmented rays of approximately equal length, and extends from the 10th to the 40th vertebra. The structure of the anal fin is essentially similar to that of the second dorsal fin. The proximal pterygiophores of this fin are slightly smaller than those of the dorsal fins, and are hockey-stick shaped rather than spoon-shaped. The proximal ends of the first 10 to 12 proximal pterygiophores lie below the pleurals of the last 6 abdominal vertebrae. The remaining proximal pterygiophores interdigitate with the haemal spines of the anterior caudal vertebrae.

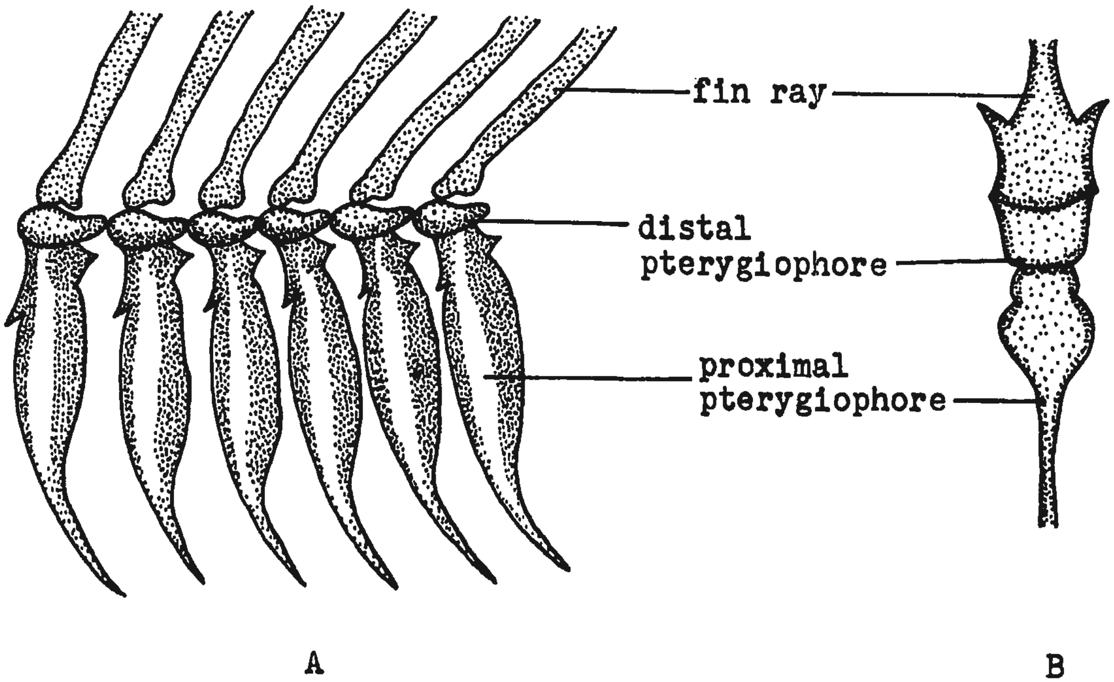

Fig. 18. Dorsal fin of Urophycis tenuis.

A. Lateral view of the middle portion of the 2nd dorsal fin. X3.

B. Anterior view of the articulation of the 27th second fin ray with its pterygiophores. X3.5.

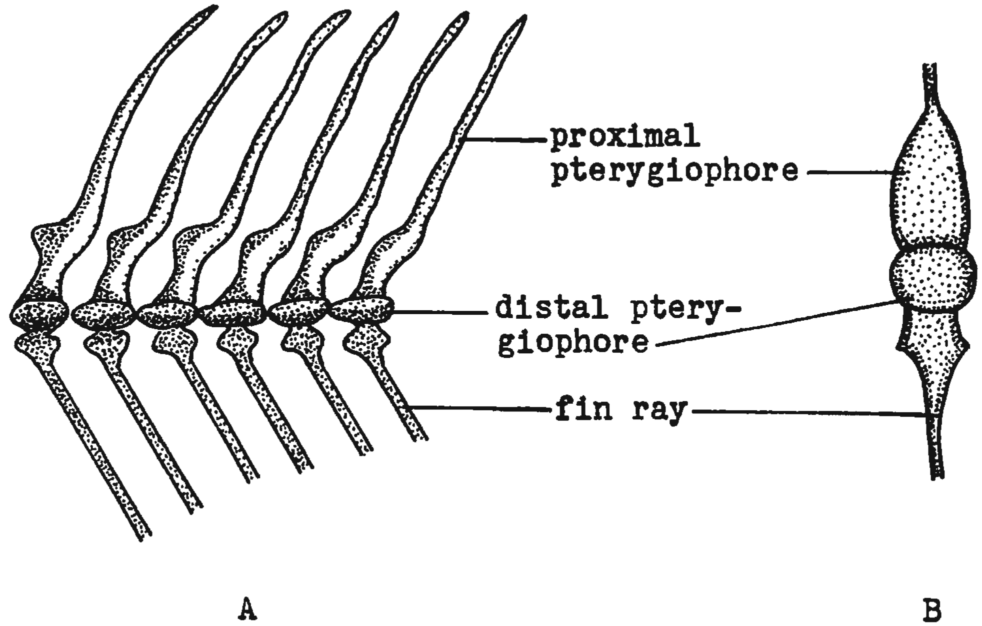

Fig. 19. Anal fin of <u>Urophycis tenuis</u>.

A. Lateral view of the middle portion of the anal fin. X3.

B. Anterior view of the articulation of the 4th anal fin ray with its pterygiophores. X3.5.

DISCUSSION

Svetovidov (1948:109) states that the current classification of the genus Urophycis is based mainly on external characters. Detailed osteological information concerning the species of this genus may therefore be of value in establishing their taxonomic positions. However, at present it is not possible to discuss the status of the species in this genus and the position of *Urophycis* from the standpoint of osteology because detailed studies of the other species are not available. For this reason, the author will discuss various aspects of the anatomy of *U. tenuis* mainly in relation to *Gadus morhua*.

Urophycis tenuis exhibits some features usually considered to be 'primitive': the presence of cycloid scales, the absence of spinous fin rays, the presence of large opisthotic processes. It also shows some characteristics of specialization: the anterior position of pelvic fins, the swimbladder of physoclistous type, and the absence of orbitosphenoids. All these structural features are also found in *Gadus morhua* (Parker, 1906:86-129).

The relative lengths of the pelvic fins in *Urophycis tenuis* and *U. chuss* is often used as a character to separate these species. However, as Bigelow and Schroeder (1953:222) have said, this character is not a reliable one.

The general plan of the visceral organs of Urophycis tenuis is similar to that of Gadus morhua (Parker 1906:107-119). The relative length of the intestine, viz. the total length of the intestine divided by the standard length of the fish, of U. tenuis reaches about 1.27 which is comparatively great. Al-Hussaini (1949) demonstrates that among three species of different feeding habits the relative length of the intestine is the longest, 1.84 to 1.87 in a herbivorous carp and the shortest, 0.68 to 0.85, in a carnivorous gudgeon. His conclusion of the relationships between the lengths of the intestines and the diets in the teleost fishes seems not to be applied to U. tenuis, a carnivorous fish (Bigelow and Schroeder 1953:224-225; Breder 1948:285; Perlmutter 1961:319; Svetovidov 1948:114). The relative length of the intestine of U. tenuis also provides an example of supporting Barrington's view (1957:121) on these relationships of diets and intestines.

The anterior end of the well developed swimbladder of Urophycis tenuis is closely associated with the 3rd vertebra. Relationships between the swimbladders and the modified anterior vertebrae have been found in some other teleost fishes such as certain species of Catostomidae, Cyprinidae, and Ameriuridae (Dobbin, 1941), and Ophidion holbrooki (Rose, 1961). The role of sonorific muscles of the swimbladders in production of sound by some fishes has been reviewed by a number of workers (Jones, 1957; Jones and Marshall, 1953). The relative position of these muscles in U. tenuis differs from those in some gadoid fishes such as Raniceps ranius, Gadus callarias, Molva molva, and Lota lota, but resembles the situation encountered in some others such as Brosme brosme, Gadus pollarchius, G. aeglefinus, G. virens, and Phycis mediterraneus (Hagman,1921).

Lagler et al. (1963:219) states that in Gadus there are 3 hepatic veins, but Goodrich (1930:516) and Parker (1906:113) find only 2. Like many fishes, Urophycis tenuis has only 2 hepatic veins.

The rostral certilage of Urophycis tenuis is well-developed and similar in position to that of Melanostigma pammelas (Yarberry, 1965). It provides a meeting place for the supraethmoid, the prevomer, and the paired premaxillae as well as nasals and is a key element in the anterior end of the cranium.

Some fishes have no opisthotics (Chapman, 1942; Dineen and Stokely, 1952; Yarberry, 1965) or small opisthotics (Blair and Brown, 1961; Harrington, 1955; Koh, 1931; Norden, 1961). In Urophycis tenuis, the opisthotics are large and bear moderately developed processes that provide in part articulations for the minute and weak posttemporals. The sizes of opisthotic process, posttemporal, and supracleithrum are reliable osteological characteristics distinguishing Urophycis from Phycis. (Svetovidov, 1948:73).

The maxillae of Urophycis tenuis are toothless and large but do not enter into the gape. As indicated by Berry (1964), during the development of Merluccius the maxillae at first form the only elements of the upper jaw. They are pushed out of the gap by the subsequently formed premaxillae that grow posteriorly under the maxillae and become toothed.

The angular and the retroarticular described in this paper are frequently termed the articular and the angular. However, histologically (Haines, 1937) and embryologically (Lekander, 1949:82), the true articular is the endochondral and/or perichondral ossification of the posterior portion of Meckel's Cartilage which is suppressed partially or totally by the invasion of the angular and is not noticeable in Urophycis tenuis. Furthermore, the retroarticular is a mixed ossification with a core of endochondral bone formed by the posterior end of Meckel's Cartilage.

In some of the specimens of Urophycis tenuis examined in this study, the preopercles are closely associated with the hyomandibulars. This situation is similar to that of Amia calva and it is probable that the preopercle is a member of hyomandibular group rather than opercular series (Hubbs, 1919). There are seven similar branchiostegal rays in U. tenuis as is the case in Gadus morhua (Parker,1906:98) The branchiostegal rays are usually variable in number and form within the lower groups and constant within the higher groups of fishes (Hubbs, 1919).

Le Cren (1947) and Hooper (1949) determine respectively the ages of Perca fluviatilis and Schibeodes mollis by reading the marks on their opercles and vertebrae. Ford (1937) urges the study of the bony structures of some species, such as the parapophyses of Gadus aeglefinus, in regard to their possible use in age determination. As the scales and otoliths of Urophycis tenuis do not show clear annual growth rings, it is suggested that the marks on its metapterygoids and quadrates be investigated, as well as the vertebral centra, as a means of age determination.

Urophycis tenuis has only two basibranchials as does Gadus morhua (Parker, 1906:99). The second of these is very small and entirely cartilaginous. Corresponding to their four complete branchial arches, most fishes have 3 to 4 basibranchials in which the posteriormost one is usually toothed (Blair and Brown, 1961; Chapman, 1942; Dineen and Stokely, 1954, 1956; Norden, 1961, Harrington, 1955; Phillips, 1942; Yarberry, 1965). The number of the paired pharyngobranchials of U. tenuis differs from that of G. morhua which has only two pairs (Parker, 1906:98).

In Urophycis tenuis, the minute, posteriorly directed teeth are borne by the premaxillae, dentaries, prevomer, infrapharyngeals, the 3rd pair of epibranchials, and 2nd to 4th pairs of the pharyngobranchials. Except the first two sets of elements all of these support either the floor or the roof of the mouth cavity and have their teeth are said to be oral teeth. The prevomer teeth are found in a majority of fishes except in some cypriniformes such as Carassius auratus (Koh, 1931), Notropis bifrenatus (Harrington, 1955), Brycon meeki

(Weitzman, 1962), and *Poecilobrycon harrisoni* (Weitzman, 1964). The infrapharyngeals are considered by several authors as the 5th pair of the ceratobranchials (Harrington, 1955, Koh, 1931; Weitzman, 1962) and are toothed in many species. Teeth are not found on the epibranchials of *Gadus morhua* (Parker, 1906: 98) and the above mentioned cypriniformes but are found on these elements in a number of fishes (Blair and Brown, 1961; Dineen and Stokely, 1956; Norden, 1961). The Pharyngobranchial teeth again are not borne by those cypriniformes except *Brycon meeki* whose upper pharyngeals (4th pair of the pharyngobranchials) lie close together to form a single tooth-bearing pad (Weitzman, 1962). Also supporting parts of the roof and floor of the mouth cavity are the palatine, the mesopterygoids, and the basihyal. The palatine teeth do not develop in the cypriniformes mentioned but occur in a great number of species. The mesopterygoid teeth are only found in a relatively few fishes such as *Osmerus* (Chapman, 1941b) and *Thymallus* (Norden, 1961). The basihyal teeth are borne by some groups of fishes but, again, not by those cypriniformes. It seems that the development of certain oral teeth in some species at least is determined ecologically (Barrington, 1957:114; *Lagler et al.*, 1963:147) rather than phylogenetically.

The anterior 2 vertebrae of *Urophycis tenuis* are closely related to the occipital segment of the cranium and perform as a functional neck in fishes as has been pointed out by Ford (1937). The haemal pre-and postzygapophyses of the 3rd and the 4th vertebrae are peculiarly developed to associate with the swimbladder, and are one of the most marked features found in this species. The parapophyses of the abdominal vertebrae are well developed, partially enclosing the swimbladder. Thus, it is obvious that there is a relationship between the swimbladder and the anterior part of the vertebral column which would tend to support Ford's view that a correlation may be presented between the vertebral column and the form and function of the viscera.

The haemal arches of the first few anterior caudal vertebrae form a haemal funnel which is unique in the gadiformes (Ford, 1937). The shape of the ultimate is similar to that of Gadus (Barrington, 1937; Ford, 1937; Whitehouse, 1910). In connection with the last three vertebrae are a epural, 2 hypurals, 2 dorsal radials, and 2 ventral radials, all of which are arranged in a manner similar to that described for Gadus morhua by Barrington (1937).

Generally, the spinal nerves of fishes leave the neural canal via foramina in the walls of the neural arches (Ford, 1937; Yarberry, 1965). However, in Urophycis tenuis, as most other gadoid fishes, the spinal nerves leave the neural canal by open grooves between the bases of the neural arches and the neural postzygapophyses.

Structural abnormalities of the vertebral column in Clupea harengus have been recorded by Ford (1937). The vertebral abnormalities in one specimen of Urophycis tenuis are of two types. First, there is the incomplete growth of the neural spines which occurs on the 14th, 15th, and 22nd to 24th vertebrae. Second is the fusion of the centra as in the 25th to 28th vertebrae. It is hard to say whether these abnormalities are due to the change of environmental factors during the larval stage of the fish, although it is well known that the growth of the vertebrae and other meristic characteristics of fishes depend greatly on the ecological factors (Lagler *et al*., 1963:322; Taning, 1952).

As a whole, the vertebral column of *Urophycis tenuis* used in this study is more like that of *Urophycis brasiliensis* than *U. tenuis* as figured by Svetovidov (1948:301). As stated by Svetovidov (1948:110), the only diagnostic difference between *U. tenuis* and *U. brasiliensis* is the length of the pelvic fins which is not always constant in *U. tenuis*. The taxonomic relationship between these two species is therefore not clear.

The epipleurals of *Urophycis tenuis* project dorsolaterally into the horizontal skeletogenous septum from the corresponding pleurals as do those of *Micropterus coosae* (Blair and Brown, 1961). However, in a number of fishes, **including** *Gadus morhus*, the epipleurals project ventrolaterally from the corresponding pleurals or the ventral portion of the centra (Norden, 1961; Phillips, 1942; Weitzman, 1962).

Starks (1930) states that the scapular foramen in fishes is usually contained wholly within the borders of the scapula, but sometimes it is between the scapula and the coracoid or between the scapula and cleithrum. In Urophycis tenuis, the scapular foramen is relatively larger than that of Gadus morhua and notches the scapula much more deeply than it does the coracoid.

Svetovidov (1948:114) indicates that Urophycis tenuis does not enter the mouths of rivers and the freshened waters. However, the specimens for the present study were collected from Holyrood Pond which is a long bay representing the mouth of the Gross Place River in the Avalon Peninsula, Newfoundland.

SUMMARY

1. The systematics of the cold-water fish family Gadidae is reviewed.

2. *Phycis* and *Urophycis* are restricted to the Atlantic Ocean and resemble one another externally but can be separated osteologically.

3. Present classification of *Urophycis* is based mainly on external characters that are not always constant in *Urophycis tenuis*.

4. Previous references to *Urophycis* are summarized.

5. The general biology of the less known *Urophycis tenuis* is briefly presented.

6. Definitions and synonyms of the teleost skeletal elements are listed.

7. Externally, *Urophycis tenuis* is distinguished from the other species of *Urophycis* by its length of the upper jaw, scales on the lateral line and length of the pelvic fins. The last character is not reliable.

8. The relative position of the viscera of *Urophycis tenuis* is of typical teleost type. The intestine is long and coiled, and the swimbladder is well-developed and closely associated with the anterior vertebrae.

9. In the cranium of *Urophycis tenuis*, the frontals are

fused and are the largest bones. The opisthotics are well formed; each bears a moderately sized process. The rostral cartilage is large and is a key element in the antorbital portion.

10. Each circumorbital series of Urophycis tenuis comprises 6 dermal bones, and attaches to the palatine anteriorly and the anterior end of the sphenotic posteriorly.

11. The upper and lower jaws, and the opercular series of Urophycis tenuis are normally developed. The preopercle is the element which connects each opercular series to the suspensorium, and in turn to the cranium.

12. The hyomandibulo-quadro-pterygo-palatine complex of Urophycis tenuis is normally formed, and serves as a bridge to connect the opercular series and the lower jaw to the cranium.

13. Urophycis tenuis has 7 branchial rays on either half of the hyoid arch. They attach only to the ceratohyal.

14. There are 4 complete and a rudimentary branchial arches in Urophycis tenuis. Only 2 basibranchials are present with the 2nd one weakly developed. The infrapharyngeals, 3rd pair of epibranchials, and 2nd to 4th pairs of the pharyngobranchials are toothed.

15. The vertebral column of _Urophycis tenuis_ is composed of 49 to 51 vertebrae which can be grouped morphologically into four categories. The post-cranial section comprises the first four vertebrae. The 3rd and 4th vertebrae are modified and related to the anterior end of the swim-bladder. There are 12 abdominal vertebrae; except the last 2 each bears a pair of pleural and a pair of epi-pleural ribs. The haemal arches of the first 5 to 7 anterior caudal vertebrae are well-developed forming a marked haemal funnel. The last 6 or 7 vertebrae contribute to the support of the caudal fin rays. The neural spines of the antepenultimate are retained; but its haemal spines are replaced by an autogenous epural. The neural spines and haemal spines of the penultimate are replaced by the epural and hypural respectively. The ultimate is of typical gadoid type.

16. The spinal nerves of _Urophycis tenuis_ leave the neural canal via open grooves between the bases of the neural arches and the neural postzygapophyses.

17. Structural abnormalities are found on the 14th, 15th, 22nd to 24th and 25th to 28th vertebrae of a specimen of _Urophycis tenuis_.

18. The pectoral girdle on either side of _Urophycis tenuis_ comprises 15 elements, 4 of which are responsible for supporting 15 or 16 fin rays. The posttemporals and supracleithra are minute and weakly developed. The

scapular foramen notches the scapula much more deeply than it does the coracoid.

19. The pelvic girdle of Urophycis tenuis is reduced and supports only 2 fin rays on either side.

20. The structure of the dorsal fins and the anal fin of Urophycis tenuis are similar. Each unit within these fins is organized by a proximal pterygiophore, a distal pterygiophore, and a soft fin ray. The distal pterygiophore is small and entirely cartilaginous.

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