INTRODUCTION

There are, perhaps, 25,000 or more species of fish in existence. Species are grouped into progressively larger categories; genera, families, orders and classes. Theoretically, modern classification reflects phylogeny and relationships. The basis for classification can be considered an inquiry into the origin of species.

Fishes inhabit almost every conceivable aquatic habitat from tiny pools in the desert to the greatest depths of the ocean. The array of adaptations of various species to specific environments results in enormous diversity allowing unlimited possibilities for systematic, ecological and physiological research.

Fossil records of fishes go back more than 400 million years. The great bulk of living species, however, belong to the super order Teleostei which are comparatively modern; radiating contemporarily with the evolution of birds and mammals.

The emphasis and the philosophy of this course is not aimed at classification per se, but on the biological diversity and evolutionary principles forming the basis of classification. More important than knowing the scientific name of every fish encountered is the ability to critically examine an unknown specimen from any part of the world, observing the general external morphology and the internal anatomy and come up with a reasonable interpretation of the species way of life and its role in the ecosystem. Once this level of expertise is achieved, the taxonomic aspects of ichthyology are more readily acquired.

Term Paper

A major term paper is required on some problem of ichthyology (here used in the broad meaning "study of fishes" and not restricted to classification of fishes). The paper may be based on original research or entirely on a synthesis of the literature. It may be possible to write the paper in conjunction with another course such as journalism, if agreeable to all parties. Suitable materials for original research projects are available in our collections.

The subject matter for the term paper should be chosen to complement your interests and to develop an understanding of some area of ichthyology you want to know more about. The problem must be clearly defined and of a degree of complexity allowing adequate coverage for the time available. A topic for the term paper should be selected by the fourth week of the quarter so that the literature review can be gotten underway.

A Soft-rayed Bony Fish Carp (Cyprinus carpio)

External Anatomy

Examine the general body shape. Most streamlined fish exhibit a teardrop or fusiform body shape with the deepest part of the body somewhat anterior to the midpoint. Comparisons should be made of structural peculiarities, such as body shape in different species in relation to habits. The student should think of each structure studied in terms of adaptation to a specific environment. More on this in assigned readings.

Nasal Apparatus: Nostrils are paired in all teleosts. Each is a sac more or less completely enclosed in a cartinlaginous or bony investment and divided into anterior and posterior portions by a fold of skin.

Is there a passage from the nostril into the mouth of the carp? What fishes have "internal nares"?

Barbels in many species of fish are primarily gustatory organs and, to a lesser extent, tactile organs.

Where are the barbels located on the carp? How many are present? What other fishes have barbels? Where located?

Fins. Median fins in the carp include the dorsal, anal, and caudal. Paired fins are the pectorals and pelvics. Note in the carp the long dorsal fin and the short anal fin, and the number of spines anteriorly in each. Numerous soft-rayed fishes have developed spines, but these spines are not considered homologous to spiny-rayed spines. Why? Examine the fin rays to see how they branch distally, are segmented, and are actually paired structures, each being made up of two halves. Fin rays have their origin from modified scales.

Pelvic fins are described for taxonomic purposes as abdominal when located between the anus and the middle of the pectoral and thoracic when located below the pectoral. The position of the pelvic fins is jugular when these are located anterior to the insertion of the pectoral. Know about evolutionary trends in fin position in various groups.

Notice in the trout the fleshy adipose fin and the pelvic appendage at the base of each pelvic fin.

Know how to make fin ray counts. Know formulas for spiny rays, soft rays, branched rays, unbranched rays and principal rays.

The integument consists of a thin outermost epidermis and a thicker inner dermis. Mucuous cells scattered among the epidermal cells provide an osmotic barrier, lubrication to increase streamlining, and protection against bacteria. The dermis is made up principally of connective tissue plus nerves, blood vessels, muscles, and pigment cells. The scales lie in pockets in the dermis and are usually covered by the epidermis. Note how the scales are arranged in diagonal rows. The majority of each scale is covered by other scales. Compare cycloid, ctenoid, ganoid and placoid scales.

What portions of the body are devoid of scales in the carp and in other species on display?

Remove a scale from the region between the anterior end of the dorsal fin and the lateral line, place in water under the dissecting microscope and locate the following structures: (1) focus, (2) radii, (3) circuli, and (4) exposed and unexposed portions. Can you tell how old the fish is from the scale?

Chromatophores are divided into several types based on their pigment. Iridocytes consist of reflecting substance - guanine, a waste product of metabolism. The iridescence of some fishes are from iridocytes.

Detach a carp scale and observe the distribution of the different types of chromatophores. Compare with a goldfish scale.

Mouth: Examine the jaws of the carp by extending them forward. Correlate the subterminal mouth with this fish's mode of life. Compare the jaws of the trout and the carp. Are the trout's jaws protrusible?

Identify the premaxillary, maxillary, and dentary bones in the carp. Examine the maxillary membrane, a fleshy fold of tissue just inside the mouth. Know evolutionary trends in premaxillary and maxillary bones.

Is there a like membrane on the dentary? How might such a membrane function in respiration?

Teeth: Teeth may be found on the following bones in various groups of fishes: Jaws (maxillary, premaxillary, dentary); Roof of mouth - vomer, palatines (paired), pterygoids (endopterygoid, ectopterygoid, mesopterygoid - all paired) and parasphenoid;Floor of mouth - tongue (glossohyal) and basibranchial (on a median plate over basibranchial bones between the gill arches). Also pharyngeal teeth are found on the fifth lower gill arch (5th ceratobranchial) and the pharyngobranchials on the dorsal surface of the pharynx. The presence or absence and relative development of teeth are useful to evaluate evolutionary trends and relationships. During evolution, if teeth are lost on a particular bone, such as the maxillary, no subsequent species developed from this evolutionary line will have these teeth. All species of the family Cyprinidae lack all teeth except pharyngeal teeth. Compare the dentition of a trout and a bowfin (Amia). What clues to feeding habits and way of life can you note from observing the mouth and teeth (size and shapes)?

Opercular Apparatus: Between the head and shoulders of the fish is a series of opercular bones lying in the flap of skin covering the gill region. Locate the large posterior plate, the operculum on either side of the cheek region of the skull. Ventral to this is the subopercle. Ventral and anterior to this is the small interopercle. Anteriormost is the preopercle.

The ventral portion of the opercular region is produced into a thin membranous extension, the branchiostegal membrane, supported by the brachiostegal rays. Note the gular plate in Amia. The branchiostegal membrant joins the operculum and facial bones to the medial fleshy septum (Isthmus) that lies between the gills.

Are the branchiostegal membranes broadly or narrowly joined to the isthmus in the carp? Note the type of membrane morphology in other species.

Gills and Branchial Chamber: Lift the operculum to observe the branchial chamber. Count the number of gill slits and gill arches. These are the common numbers for teleosts; deviations occur by reduction in number or size or both. Dissect out a gill arch from the carp. The anterior and posterior gill filaments (lamellae) of each arch constitute the holobranch. Either set of filaments is referred to as a hemibranch. Notice that the gill filaments project freely into the branchial chamber. In sharks the filaments of each hemibranch are joined to a gill septum and do not project freely into the branchial chamber.

Observe the gill rakers, protuberances on each gill arch opposite the gill filaments. What is their function? Compare the gill rakers in the carp, herring and trout. Does this tell you anything further about the diet of these species? The gill rakers, including all rudiments, are always counted on the first left gill arch; those on the upper half of the arch are given first, followed by those on the lower half of the arch; for example 8+13. The raker at the junction is counted with the lower arch.

Examine the pseudobranch. The pseudobranch in teleosts is considered a vestige of the spiracular gill. It is located on the inner side of the operculum anteriorly. It may or may not retain the gill-like structure. All other gills except the pseudobranch receive blood for aeration directly from the heart by way of the aortic arches. However, in the pseudobranch, as in the hemibranch present in the spiracles of the sharks and sturgeons, blood is received that has been oxygenated by passage through gills behind it. Many advanced groups of teleostean fishes have lost the pseudobranch.

Internal Anatomy

Trunk Musculature: Midway along the length of the carp carefully remove the skin on one side between the dorsal and the mid-ventral line. Care must be taken not to remove any of the muscle. This will expose the great lateral muscle. Observe the transverse septum indicated by the connective tissue band lying immediately under the lateral line. It extends from the under surface of the skin directly down to the lateral ventral surfaces of the centra of the vertebral column. This septum completely divides the great lateral muscle into dorsal (epaxial) and ventral (hypaxial) portions. The extreme dorsal portion of the epaxial muscle on each side has become further differentiated by the separation of a definitive cylindrical bundle, the supracarinalis. Similarly, the extreme ventral portion of the hypaxial muscle is differentiated into the infracarinalis muscle. What are the functions of each of these muscles?

The lateral muscle mass is subdivided into vertical segments (myomeres) which are separated by connective tissue septa (myocormata). The form of the myomere and of the septum varies somewhat in different regions of the body but is always complex and intricate. In the myomeres of the entire side of the carp, the surface markings have the general outline of the letter "W" with the bottom of the letter turned towards the tail.

Make a ventral incision beginning medially between the pectoral fins back to between the pelvic fins and almost to the anus. So as not to damage the urogenital and intestinal openings, continue the incision to the side of the anus and shallow enough not to damage underlying structures.

Reproductive System: In the male, if sexually mature, note the long, white, enlarged testes. Trace out the vas deferens to the genito-urinary pore. In the female note the ovaries. Can you estimate the spawning time from the condition of the gonads and the date of capture? Locate the oviduct. Observe both male and female structures. Would you judge that this species has a high reproductive potential? Compare the ovaries of a trout. What are evolutionary implications of differences in egg size and number?

Note the peritoneum. Do not damage the urinary and genital ducts. Locate the external opening for these ducts and for the rectum. Which is the most anterior, the urogenital papilla or the anal opening?

Alimentary Canal: In order to study the digestive organs and structures dorsal to them, carefully cut the intestine and stomach free from the mesenteries and also the diffuse yellowish structure, taking care not to break this latter structure. The intestinal tract can now be pulled out of the body cavidy for inspection, but do not cut any of its connections. Locate the oesophagus, stomach (cardiac and pyloric ends), the liver, gall bladder, spleen. Can you locate the pancreas? How many pyloric caeca are there (these are finger-like outpocketings of the intestine in the pyloric region)? Note the large air bladder, its constriction, and its pneumatic duct. Trace the connections of this duct. The term describing the condition when the pneumatic duct does not connect with the alimentary canal is physoclistic. When the pneumatic duct does connect, it is called physostomous - the primitive condition. All teleosts are physostomous in the embryonic stage. The air-bladder may be quite alveolar internally (Lepisosteus) or very smooth, or it may act as a functional lung as in the lung fishes. Also it may have other differences such as caecal outgrowths, be adapted for sound production (Sciaenidae) or have a connection with the auditory organ as occurs in the carp. It may even extend into the tail region in some groups of fishes by penetrating for a short distance into the expanded haemal canal of the anterior caudal vertebrae (order Gadiformes) or bifurcate into two lobes, one on each side of the haemal spine (family Embiotocidae). The most important function of the airbladder for teleosts is as a mechanism for detecting changes in water pressures encountered by changes of depths (hydrostatic function).

Circulatory Organs: Below and behind branchial arches, locate the heart. Locate the sinus venosus, auricle or atrium, ventricle, bulbus arteriosus, and ventral aorta.

Locate the kidneys, the urinary duct, urinary bladder and the urogenital sinus. Can fish excrete hypertonic urine?

Skeletal Structures

Pelvic Fin: Remove and discard the digestive and associated organs but leave the air bladder in place. The pelvic fin is situated in the body well below the tips of the ribs. Cut around the base of the pelvic fin skeleton so as to remove it from the body wall. Remove as much of the flesh as possible from the fin skeleton, then hold the fin in boiling water for about one minute. Remove remaining flesh, but take care to keep the fin elements together so as not to lose their relationship. It is seen that the pelvic fin has no girdle, but instead has a large triangular, flat bone, the basipterygium, probably representing fused proximal pterygiophores. To the posterior border of the basipterygium are three partly ossified pieces, the distal pterygiophores. It is on these that the dermal, jointed, fin rays (lipidotrichia) are articulated. The dermal rays are believed to have been derived from long rows of scales that covered the fins of primitive fishes. The horny, dermal unsegmented rays of the elasmobranchs and chimaeras are termed ceratotrichia. The term dermotrichia (a broad term that includes both lipidotrichia and caratotrichia) refers to dermal fin rays of all cartilaginous and bony fishes. Sketch the pelvic fin and label parts.

Caudal Fin: Beginning on the caudal fin, fillet off on each side of the body the flesh for about 3" back towards the end of the dorsal and anal fins. Then cut it off here so that you have the caudal fin and about one inch of caudal vertebrae. Remove as much of the flesh as possible, then hold the fin and vertebrae in boiling water for about 3/4 minute. Do not leave in longer because the bones will come loose and fall apart. Carefully remove the cooked flesh and scales. Holding under a stream of cold water and using the fingers to remove the smaller particles of flesh is a good procedure. This dissection of the caudal fin shows the modification of the posterior end of the vertebral column for the support of the caudal fin. Observe and describe the modifications. The rod-like extension of the last distinct vertebra is the urostyle. The broad, expanded plates attached to the urostyle are the hypural plates. The ventral spine on each distinct vertebra is a haemal spine through which the haemal canal passes. The dorsal spine is the neural spine. Notice how the dermal fin rays articulate on the hypural plates. Sketch and label the caudal end of the vertebral column, showing its modifications for support of the caudal fin. Look up the definition of heterocercal and diphycercal caudal fins and be able to give several examples of each.

Dorsal Fin, Anal Fin, and Vertebral Column: To study these structures, fillet off the flesh from each side, beginning where the tail was cut off and fillet up to about an inch anterior to the front end of the dorsal fin. Cut through the vertebral column at this point, taking care not to remove the air bladder from its connection at the posterior part of the skull. What you now have is one section with the head and the attached air-bladder and a second section, the trunk with the dorsal and anal fins and vertebral column. Remove as much of the remaining flesh as possible. Then place this vertebral and fin section in boiling water for 3/4 minute, then remove the rest of the flesh. Lay the section flat and pick off the flesh from one side, exposing the skeleton of the vertebral column. Time does not allow a study of the musculature of these structures, but notice that there are broad plates for attachment of muscles and tendons connecting the dorsal and anal fins to the trunk and vertebral column. Study the relationships between vertebral column and the median fin skeletons. Each dorsal fin ray has its two halves separated at the base. A small bone, the distal pterygiophore, fits in between the two basal ends of each ray and articulates with a small oblong bone, the middle pterygiophore, which is partly ossified onto the proximal pterygiophore (also called an interneural bone). Sketch a front view of one dermal ray and its pterygiophores. The anal fin structure is similar to that for the dorsal fin, consisting of dermal rays, distal and middle pterygiophores and proximal pterygiophores (interhaemal bones).

Vertebral Column: The vertebral column in the teleosts, unlike the vertebral column of the cyclostomes, sharks, rays and chimaeras, is differentiated into distinct, complete bony vertebrae (except in the chondrosteans - sturgeons, paddlefish). Boil the carp's vertebral column. Remove the flesh. Note that the column is divisible into two distinct portions, the trunk and caudal regions. It is sometimes necessary to count the number of vertebrae in each of these regions in the classification and identification of fish (abdominal and caudal vertebrae).

Abdominal and Haemal Vertebrae: The abdominal vertebrae are identified by the fact that they have a neural canal only and no haemal or ventral canal. Notice the remains of the notochord in the biconvex space between the spool-shaped centra of two vertebrae. On the anterior dorsal surface of the centrum are two processes, the neuropophyses, which join above to give the neural spine, and the neural canal. In contact with the anterior end of each neuropophysis are the paired pre-zygapophyses which articulates with the paired post-zygapophyses of the preceding centrum. From the ventral sides of the centrum there are paired processes, the parapophyses, on which the ribs loosely articulate. The parapophyses remain unjoined below in the abdominal region. In the caudal region these processes unite to enclose a canal, the haemal canal, and are called haemapophyses and extend ventrally as the haemal spine. Vertebrae with both a neural and a haemal spine are haemal or caudal vertebrae. Both ends of the centrum are concave, a condition called amphicoelous. The vertebrae of teleosts are typically amphicoelous. The gar pike (Lepisosteus) has vertebrae with a convex anterior and a concave posterior surface, a condition known as opisthocoelous, a ball and socket type articulation.

Ribs: Dorsal and ventral (Pleural) ribs are present in fishes. The dorsal ribs or intermuscular bones lie between the septa separating the epaxial and hypaxial muscles. These ribs in the carp were removed when the epaxial muscles were filleted off. The ventral or pleural ribs are located internally to the muscles, first outside the peritoneum. In some species of fish the ventral ribs may have secondary branches, the epileurals.

For the next period: Wrap up the carp head with attached air bladder. Put your name on the outside and return it to your instructor.

Pectoral Girdle: In existing sharks, rays, and chimaeras, the pectoral girdle is in the form of a cartilaginous U-shaped bar incomplete dorsally. It is imbedded in the muscles of the body wall close behind the last gill arch. The upper or dorsal portion is called the hypercoracoid (scapula) and the ventral the hypocoracoid (coracoid). Between these two portions is an area with articular surfaces for the basal cartilages of the pectoral fin.

There are notable differences in the pectoral girdle of the teleosts from the condition in the cartilaginous fishes. The teleosts retain the "primary" girdle of the elasmobranchs, that is, the hypocoracoid (coracoid)and hyper-coracoid (scapula), which are both replacement bones, but add a number of dermal bones to these. The scapula and coracoid of teleosts may or may not be homologous with similarly named bones in other vertebrates. These latter bones evolved from modified scales, develop on the outer surface of the primary girdle and are called the secondary girdle. Beginning dorsally and passing ventrally the following bones form each half of the secondary pectoral girdle: (1) the post-temporal usually present, being a forked bone articulating with the epiotic and opisthotic or exoccipital bones of the skull; (2) the supracleithrum, a bone dorsally in contact with the post-temporal and venterally in contact with the (3) cleithrum, a bone laterally and anteriorly in contact with the hyper-coracoid and hypocoracoid; in cyprinoids and ganoids the supracleithra (post-temporal and supracleithrum) may also connect by ligaments, which are sometimes ossified, with the first vertebral centrum; (4) one or two post-cleithra may articulate on the posterior side of the cleithrum.

Other bones may also be associated with the pectoral girdle of other groups of fishes. All chondrosteans (sturgeons, paddlefishes) and all known crossoptery-gians and lungfishes have a clavicle which extends from the cleithrum to the mid-ventral region where it has a union by a symphysis with the clavicle of the opposite side. In some species the coracoids may expand ventrally and unite medially. In some groups of fishes (salmon, trout) there is present a third bone of the primary shoulder girdle, the mesocoracoid. In teleosts the scapula and coracoid are small bones which lie on the inner side of the cleithrum with the scapula dorsal to the coracoid. This primary girdle (cartil-aginous in origin) in teleosts is much reduced in most species compared with the extent and size of the bones of the secondary girdle.

Notice that the pectoral girdle forms the posterior wall of the gill chamber; the anterior face of the cleithrum is the most prominent bone here.

Sketch and label the bones of the pectoral girdle and fin of the carp and trout.

Pectoral Fin: Most teleosts have only a few radials (actinosts), four is the common number but sometimes only 2 or 3, rarely more than 5, in the pectoral fin. They articulate or even unite with the pectoral girdle near the junction of the hypocoracoid (coracoid) and hypercoracoid (scapula). Distally they articulate with the dermal fin rays. Usually the first dermal ray articulates directly with the hypercoracoid.

Two Cephalic Muscles: A series of bones, the infraorbitals or circum-orbitals, forms a ring around the anterior ventral and posterior part of the eye. Immediately ventral to these is a large muscle, the adductor mandibularis, covered by skin. Carefully remove this skin and expose the muscle. It is long and large, the largest muscle in the head. Its main origin is in the angle of the preopercle. Anteriorly it narrows to a tendon which is inserted on the dorsal arc of the mandible. Carefully loosen the circumorbital bones by cutting some of the skin connecting them. A muscle that is seen to spread out from the postorbital region of the skull continues under these bones. It is the levator arcus palatini. Its origin is from the external surface of the sphenotic bone of the cranium (to be studied later) and it fills the space just posterior to the eye. It radiates to its insertion on the antero-lateral face of the hyomandibular.

The Skull, Facial, and Branchial Skeleton: Before proceeding to a dissection of the cephalic skeleton, study the plates available in the laboratory on the cranium, facial bones and branchial arches of *Roccus saxatilis*. Except for a few differences, these bones in *Roccus* will be readily recognizable in the carp. In the classification and study of fishes it is necessary to transfer what one has learned about one fish to a new species that is taken up for examination. To acquaint yourselves with the appearance of fish bones in other groups and species of fish, the student should spend some time looking at the plates in Gregory, W. K., *Evolution Emerging*, and Gregory, W. K., *Fish Skulls*.

Cephalic Skeleton

Cephalic Sensory Canal System: The lateral line continues onto the head in the form of sensory canals. It passes by means of the posttemporal from the trunk onto the head where it becomes a tube enclosed in the dermal bones and gives off several branches. This branching takes on a rather constant pattern throughout most of the groups of the Osteichthyes. The canals open by means of pores into the surface of the head. The first branch given off upon reaching the head is the occipital or supratemporal canal which runs transversely across the occipital region. The next is the hyomandibular branch which runs down onto the lower jaw as the mandibular canal. The main canal continues forward to just behind the eye where it forks to give the suborbital canal which passes below the eye and forward to the nasal area, and a dorsal branch, the supra-orbital canal which runs forward to the nasal region also. Observe what you can of this canal system and sketch. Later, after the flesh has been removed, you will trace the canals and pores on the skull and facial bones.

Tie the carp head in a cloth and place it in boiling water for a few minutes. Then remove all the flesh, taking great care not to lose any of the bones. Some bones will be quite small and are easily missed, so go slowly. Note what muscles fill what spaces as you dissect, even though we are not studying all the muscles. Pay special attention to the removal of the flesh around the pharyngeal teeth area. Note also how oily the flesh and bones are. Oil will come out of apparently cleaned bones for some time.

Bones of the Cranium: The cranium is composed of two types of bones, investing (or membrane or dermal) bones and cartilage (or replacement) bones. The former type composes the secondary cranium and the latter type the primary cranium (or neurocranium or chondrocranium). The membrane bones of the cranium are the parietals, frontals, nasals, parasphenoid, and vomer.

The cartilage bones, formed as ossifications in the chondrocranium, are as follows: the basi-occipital, forming most of the occipital condyle and the posterior region of the basis cranii or skull-floor; and ex-occipitals, which form the sides of the foramen magnum and meet above and below it; the supra-occipital forming the occipital crest; the bones of the auditory capsule, which may number as many as five, but usually only three, which are the prootic in the anterior region of the capsule, quite a large bone, which meets with the prootic from the opposite side in the floor of the braincase, just in front of the basi-occipital; the opisthotic is a tiny bone in the posterior part of the capsule external to the ex-occipital; the sphenotic, above the prootic and beneath the frontal and pterotic; the pterotic, at the postlateral corner of the cranium and with a pointed pterotic process; the epiotic, above the ex-occipital, medial to the pterotic, lateral to the supraoccipital, with a small, sharp epiotic process; the alisphenoid, in front of the prootic, beneath the sphenotic and frontal; the orbitosphenoid, bordered by the frontal dorsally, the alisphenoid posteriorly, the prefrontal anteriorly, the parasphenoid ventrally.

The Membrane Bones: The supraethmoid is the most anterior of the dorsal bones and is pointed and unpaired. The two separate ossifications that form articulating processes on the anterior part of the supraethmoid are the pre-ethmoids. The large paired frontals follow the supraethmoid; then the small, paired parietals. The parasphenoid is the narrow ventral bone joining the vomer and basi-occipital. The vomer is the most anterior ventral bone. The prefrontals are lateral bones placed beneath the ethmoid and frontals just posterior to the vomer.

Hold the freshly cleaned cranium up to the light and trace out the sensory canals. Determine how their course is continued on certain of the facial bones. Sketch and label.

In the Ostariophysi the unpaired basisphenoid bone is missing. It forms the interorbital septum found in other orders of fishes. List which bones Cyprinus and Roccus do not have in common.

Note on the vertebral articulating process of the basioccipital and the horny pad fitting onto it on which the pharyngeal teeth work; the large optic fenestra above the parasphenoid and below the alisphenoid; the foramen for the trigeminis nerve opening between the posterior end of the alisphenoid and the prootic; the foramina for the factalis nerve in the anterior third of the prootic; the large oblong foramen in the anterior lateral part of the exoccipital; the paired foramina for the perilymphatic ducts on the posterior surface of the exoccipitals; the fossa for the hyomandibular bone; the canal for the glossopharyngeal nerve at the posterior border of the prootic, very close to the foramen for the facial nerve.

Sketch and label the cranium.

Facial Bones: Identify the following bones, using the illustrations and demonstrations as aids: the premaxilla and maxilla which enter into the gape and form the upper jaw; the dentary, the articular which articulates with the quadrate, the remains of Meckel's cartilage, and a small bone, the angular. These three bones form the lower jaw; the rostral, a small phlange-like bone connecting by ligaments to the premaxillae and supraethmoid; the intermaxillary, a small, disk-like bone between the dorsal end of the maxilla and the pre-ethmoid articulation; the palatine, dorsal to the intermaxillary, articulating posteriorly with the mesopterygoid; along the anterior border of the mesopterygoid and the quadrate bones is the flat pterygoid which overlaps rather broadly the quadrate. The quadrate bone articulates with the articular of the lower jaw and is connected by cartilage for most of its dorsal border with the metapterygoid and to a much smaller extent with the mesopterygoid. The quadrate has a v-shaped cut in its dorsal edge where the symplectic fits. The symplectic runs for a short distance up the posterior border of the metapterygoid. At its posterior end the symplectic is connected by cartilage to the hyomandibular, a large bone, which extends up to the cranium where it articulates on the sphenotic and prootic bones; the circumorbital bones, six in number, beginning anteriorly where the first one is known as the lacrymal, and the second one sometimes as the jugal. The dermosphenotic is the sixth circumorbital. A small bone, the supra-orbital articulates on the lateral border of the frontal.

The operculum consists of the preopercle which articulates on the dorsal surface of the hyomandibular, the interopercle located ventral and medial to the preopercle, the opercle which articulates on the hyomandibular dorsally, and the subopercle ventral and medial to the opercle.

Mouth Parts: The protrusible, endentulous mouth of the carp is similar in its structure and mechanical operation to that of the sucker but is considerably different from that of the trout, sunfish, or of a fish like the striped bass. Each of the paired premaxillary bones has in most teleosts a backward projecting spine on its anterior, inner surface which works on the supraethmoid in the carp and some other cyprinids and in the suckers the premaxillary spine does not come in direct contact with the supraethmoid. Instead a ligament connects from the premaxillary spine posteriorly to a median, unpaired bone, the rostral. The rostral bone moves from a horizontal position to a vertical position at the head of the supraethmoid as the mouth moves from the protruded position to a closed one. The base of the rostral is connected by a short ligament to the supraethmoid. The paired maxillary bone follows behind the premaxillary and has three processes. The median dorsal one has a small cartilage piece between it and the underside of the lacrymal. The ventral process, articulates laterally to and on the premaxillary. The dorsal process of the dentary is connected by a ligament to the ventral process of the maxillary.

Ventral to the anterior end of the palatine and the post-dorsal end of the maxillary lies the intermaxillary bone, ossified in the carp. It is also known as the cartilaginous rod. It is located between the post-dorsal end of the maxillary and the antero-dorsal surface of the pre-ethmoid on which it articulates. From the anterior end of the palatine there is a ligament connecting to the dorsal end of the maxillary. The palatine has an articulating surface about midway along its length. This articulating surface works on the posterior articulating surface with the pre-ethmoid. The palatine also has a process dorsal to its articulation with the pre-ethmoid. This process is connected by a short ligament to the edge of the supraethmoid. The palatine articulates posteriorly with the mesopterygoid, which has a ligament connecting it to the prefrontal.

The mouth of the carp is protruded by having the lower jaw depressed by the action of several muscles. The premaxillae are then protruded because the lowering of the dentary increases the tension of the ligaments and membranes connecting the upper and lower jaws at the angle of the mouth.

The upper jaw of the shark, the palato-quadrate (or palato-pterygo-quadrate) is carried over into the bony fishes but in these it is much modified in the adult. It has lost most or all of its cartilage and has been broken up into five cartilage bones none of which enter into the gape of the mouth though some may bear teeth. The bones of the primary upper jaw in bony fish are the palatine, pterygoid, mesopterygoid, quadrate, and metapterygoid. These bones, however, are not referred to as forming the upper jaw. Two dermal bones have appeared in bony fish ancestry to form the upper jaw proper, the premaxilla and maxilla. In the lower jaw a similar modification has taken place. The primary jaw consisting of Meckel's cartilage in the embryo practically disappears except for a small rod of cartilage and an ossified cartilage, the articular. The angular and dentary are dermal bones.

Jaw Suspension: In most modern fishes the upper jaw has no direct connection with the brain case except by the hyomandibular. In this type of suspension the thrust of the jaws is transmitted from the quadrate to the brain case by way of the symplectic and metapterygoid to the hyomandibular which relays it to the brain case. Such a type of jaw suspension is called hyostylic or holostylic. Elasmobranch fishes have support for the jaws in two ways; in one the hyomandibular articulates with the brain case and in the other the upper jaw also articulates with the brain case. This type where the hyomandibular takes only part of the jaw support is called amphistylic. A third type of jaw suspension is that in which the hyomandibular takes no part in the support of the jaw. The upper jaw functions as the sole support for both jaws and attaches directly on the skull. This type is called autostylic and is found in the living chimaeras and lung fishes. Land vertebrates all have an autostylic jaw suspension.

Identify and reassemble the bones of the hyoid arch and branchial apparatus.

The hyoid or second arch consists of the hyomandibular, the interhyal, a small bone located at its articulation point in the cartilage between the symplectic and hyomandibular, epihyal, ceratohyal below, and then a small hyophyal. The right and left hyoid arches are connected by an unpaired median bone, the basihyal which supports the base of the tongue. Running forward from on top of the basihyals is the glossohyal or tongue.

Along the posterior border of the epi- and cerato-hyals are the attached branchiostegal rays. Below the basihyal is an unpaired bone, the urohyal.

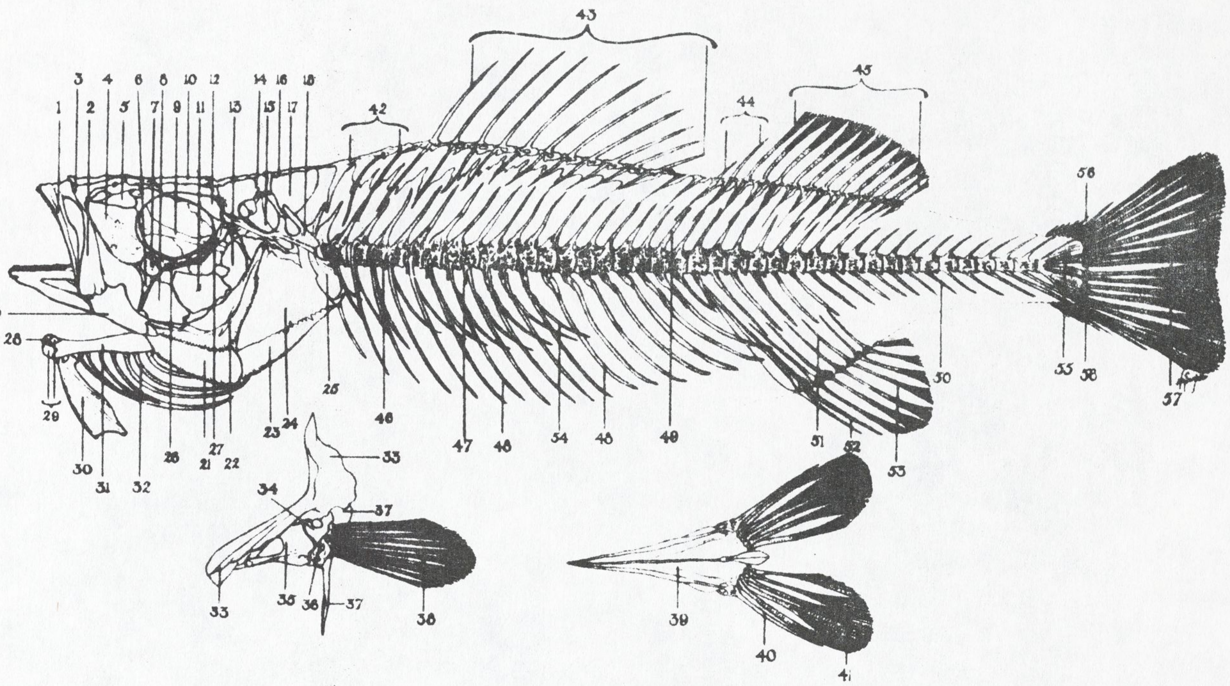
Next come the four branchial arches decreasing in size posteriorly. The dorsal-most segment of each arch is the pharyngobranchial, then the epibranchial, next the ceratobranchial, and most ventrally the hypobranchial. The hypobranchials from each side are joined by an unpaired basibranchial. All bones of the hyoid and branchial arches are cartilage bones.

Sketch and label the facial bones, hyoid and branchial arches.

Turtox Skeleton KEY CARD

for

Perch



1. Premaxilla
2. Maxilla
3. Nasal
4. Infraorbitalis
5. Prefrontal
6. Ectopterygoid
7. Entopterygoid
8. Quadrate
9. Parasphenoid
10. Frontal
11. Metapterygoid
12. Post frontal
13. Hyomandibular
14. Parietal
15. Paroccipital
16. Supratemporal
17. Supraoccipital
18. Post-temporal
19. Dentary
20. Articular
21. Interopercular
22. Preopercular
23. Subopercular
24. Opercular
25. Supra ~~clavicle~~ cleithrum
26. Suborbital
27. Postorbital
28. Basihyoid
29. Hypohyals
30. Urohyal
31. Ceratohyoid
32. Branchiostegal rays (7)
33. ~~Clavicular~~ Cleithrum
34. Scapula
35. Coracoid
36. ~~Pterygials~~ Actinosts
37. Post ~~clavicle~~ cleithrum
38. Dermal rays of pectoral fin
39. ~~Pelvis~~ Basipterygium
40. Hard } Dermal rays of
41. Soft } pelvic fin
42. Ptergiophores or proximal radiacia
43. Anterior dorsal fin rays
44. Hard } Dermal rays of posterior
45. Soft } dorsal fin
46. Vertebrae
47. Parapophysis or Transverse process
48. Ribs
49. Neural spines
50. Haemal spine
51. Radials of ventral fin
52. Hard } Dermal rays of
53. Soft } Anal fin
54. ~~Subperitoneals or false ribs~~ Epipleural ribs
55. Hypural ~~bones~~ plates
56. Hard } Dermal rays of
57. Soft } Caudal fin

23K201
Subject No. 13.14

Bones of the Fish Skull and Their Embryonic Origins*

1. vomer (d)
2. supraethmoid (and preethmoid) (d)
3. prefrontals (d)
4. frontals (d)
5. sphenotic (c)
6. parietals (d)
7. epiotic (c)
8. supraoccipital (c)
9. pterotic (c)
10. opisthotic (c)
11. exoccipital (c)
12. basioccipital (c)
13. parasphenoid (c and d)
14. basisphenoid (c)
15. prootic (c)
16. alisphenoid (c)
17. hyomandibular (c)
18. symplectic (c)
19. quadrate (c)
20. pterygoid (c)
21. palatine (c and d)
22. mesopterygoid (d)
23. metaptergoid (c)
24. preopercle (d)
25. opercle (d)
26. subopercle (d)
27. interopercle (d)
28. articular (c)
29. angular (d)
30. dentary (d)
31. maxillary (d)
32. premaxillary (d)
33. interhyal (c)
34. epihyal (c)
35. ceratohyal (c)
36. basihyal (c)
37. glossohyal (c)
38. urohyal (c)
39. branchiostegal (d)
40. hypobranchial (c)
41. basibranchial (c)
42. ceratobranchial (c)
43. epibranchial (c)
45. pharyngobranchial (c)
49. preorbital (d)
50. suborbital (d)
51. nasal (d)
52. supratemporal (d)
53. posttemporal (d)
54. supracleithrum (d)
55. cleithrum (d)
56. postcleithrum (d)
57. hypercoracoid (scapula) (c)
58. hypocoracoid (coracoid) (c)
59. mesocoracoid (c)
60. actinosts (c)

* d = dermal; c = cartilaginous

Numbers correspond to plates of striped bass skeleton

Selected Annotated Synonmy of Teleost Skull Bones

Abstracted from: Harrington, R.W., 1955. Copeia, No. 4.

Angular, A. (e.t. of de Beer, 1937; Devillers, 1947; Lekander, 1949; demarticular of Goodrich, 1930), the ectosteal (membranous) component of the compound bone known conventionally as "articular." Histology (Haines, 1937) and embryology (Lekander, 1949:83) confirm the invasion of Meckel's cartilage by the angular to the partial or total suppression of the true articular, although Berg (1940:416) preferred to retain the old name, "articular."

Articular, AR. ("true articular" of Haines, 1937), the endochondral and/or perichondral (i.e. endosteal) ossification of the penultimate, posterior segment of Meckel's cartilage. The angular replaces the articular in the more differentiated fishes, but it is often hard to determine whether one, the other, or both angular and articular are present in the compound "articular" (Lekander, 1949:83).

Autopalatine, P. (e.g. of Goodrich, 1930: 284; Gregory, 1933; Ramaswami, 1948:526), the anteriormost bone of the pterygoquadrate arch, as distinct from the sometimes associated dentigerous, membranous component (dermopalatine).

Autopterotic, PTO. (e.g. of Devillers, 1947:29; pterotic of Gregory, 1933; and of de Beer, 1937), the cartilage bone component of the "pterotic," in contact with the lateral semicircular canal. The autopterotic is called opisthotic by Holmgren and Stensio (1936:482, 486, 490) and Lekander (1940), who considered it to be the homologue of the dorsal half of the opisthotic of Polypterus.

Autosphenotic, SPH. (e.g. of Holmgren and Stensio, 1936:490, 494; Lekander, 1949; sphenotic of Gregory, 1933; de Beer, 1937; Ramaswami, 1948), the cartilage bone occupying the postorbital (sphenotic) process, as distinct from the dermosphenotic (see below). Without this distinction much confusion has arisen from the difference.

Basisphenoid, (e.g. of Gregory, 1933:89; suprasphenoid of Kindred, 1919: 37, 73), phylogenetically a cartilage bone but ossifying ontogenetically without cartilage preformation (de Beer, 1937:129, 140). Lacking in Cypriniformes (Ostariophysi) according to Sagemehl (1891:496) and Berg (1940:442); but according to Holmgren and Stensio (1936:489) present in cyprinoids, the pedicel only developing, and often fused to the parasphenoid, e.g. in Abramis. According to Kindred (1919) and de Beer (1937), present also in Ameiurus. Absent in Carassius (Kho, 1931, "basioccipital") and in homalopterids (Ramaswami, 1948:522).

Coronomeckelian, SA. (e.g. of de Beer, 1937; Lekander, 1949:80; sesamoid articular of Ridewood, 1904a; Starks, 1916; Haines, 1937; sesamoid angular of Ramaswami, 1948:528; Os Meckeli of Berg, 1940:427 and fig. 129). Although classified by de Beer and Berg as a cartilage bone, Haines (1937) found it to be a detached portion of the teleost angular (as named here), invariably concerning the insertion of the fibers of the adductor mandibulae, but having no necessary connection with the perichondrium. Coronomeckelian is preferred here to avoid further use of the names articular and angular, although Ramaswami's name is perhaps more apt.

Dentary, D. (dental), the largest dermal bone of the mandible, a part of the bone complex, dental-splenial-mentomandibular, according to Holmgren and Stensio (1936), Pehrson (1944), Lekander (1949). The objection of de Beer (1937:125) to the name dentalo-splenial is overcome with the demonstration by Lekander (1949:125) that splenials in cyprinids may arise separately, either fusing later with the dental or remaining free. The anterior third of the dentary is typically fused with the ossified tip of Meckel's cartilage, known as the mentomeckelian (de Beer, 1937) or mentomandibular ossification (Holmgren and Stensio, 1936; Lekander, 1949).

Dermosphenotic, DSPH. (e.g. of Gregory, 1933:88; Holmgren and Stensio, 1936:494; Devillers, 1947:47; Tretiakov, 1946; Berg, 1940, figs. 58, 72, 92, 98, 111, 122, etc.; the triradiate "post orbital 2" of Ramaswami, 1948), the dermal representative of the autosphenotic, bearing part of the suborbital latero-sensory canal (sometimes the conjunction of temporal, supra- and suborbital canals), contributing by its anteroventral corner to the margin of the orbit, and in its maximum development roofing the lateral temporal fossa. In more active cyprinids, dermosphenotic and adjacent suborbitals tend toward regression and disappearance in connection with the protraction of the lateral temporal fossa to accommodate a more robust adductor mandibulae (Tretiakov, 1946). The name sphenotic has been used for either or both the dermo- and autosphenotic. The names postfrontal and intertemporal are wrongly synonymous with dermosphenotic. de Beer (1937:498) correctly asserted that the postfrontal never was the dermal representative of the sphenotic, since the tetrapod postfrontal was mistakenly homologized with the fish 'sphenotic' before the distinction between membrane and cartilage bones, so that with the distinction, the membrane bone became wrongly named postfrontal. However, he erroneously identified the intertemporal as "the representative of the sphenotic" and the postfrontal as "the uppermost bone in the postorbital series." His intertemporal can be accepted as an intertemporal, but is not the equivalent of the dermosphenotic! It is the dermosphenotic which is the uppermost bone of the post-orbital series, whereas the tetrapod postfrontals are represented in fishes by the supraorbitals (Gregory, 1933:88). In Tarpon (Gregory, 1933, fig. 31), the postfrontal is contiguous anterodorsally with the dermosphenotic. In the figure of Osteolepis (Goodrich, 1930:286) alluded to by de Beer (1937:498), if dermosphenotic is read for postfrontal the discrepancy vanishes. In cyprinids (Tretiakiv, 1946), the apparent uppermost bone in the suborbital series may be either dermosphenotic (SO_6), suborbital 5, or suborbital 4. In Salmo, a dermosphenotic is figured by Gregory (1951:201, fig. 9.33D), although Berg (1940:425) denied its occurrence in the Salmonini. Tretiakov's dermosphenotic is the same as Gregory's and the penultimate bone in Tretiakov's series (our SO_5) seems to be de Beer's postfrontal, the presumption being that the dermosphenotic was lacking in de Beer's as in Berg's specimens of Salmo. That a bone in this position may upon occasion represent at least in part the postfrontal is shown by the paleoniscoid, Coccocephalus (Gregory, 1951:179, fig. 9.6C), in which the penultimate suborbital and hindmost supraorbital series, i.e. through suppression of the dermosphenotic. In Leptolepis bronni (Berg, 1940:418, and figs. 111 and 113, after Rayner), two supraorbitals, a dermosphenotic, and a supratemporal-intertemporal are present, so that dermosphenotic and intertemporal can not be regarded as valid synonyms either.

Dermosupraoccipital, DSOC?. The dermocranial covering of the endocranial supraoccipital (tectum synoticus) according to Gregory (1933:89), who does not equate it with the extrascapulars. Goodrich (1930:283) is less explicit as to its use: "postparietal (dermosupraoccipital) which with (sic) the tabulars may form a transverse row of bones sometimes called supratemporals." Berg (1940, figs. 66 and 68) used the names postparietal and dermosupraoccipital interchangeably for superficial bones of the occipito-parietal region apart from the extraxcapulars (tabulars) and not enclosing the transverse occipital lateral line canal.

Ethmoid, E. The bone ossifying in and around the nasal septum. The name mesethmoid should be rejected because of implications of homology with the mammalian mesethmoid (Gregory, 1933:88; de Beer, 1937:442), and because of its application to a dorsally contiguous dermal element (e.g. by Starks, 1926).

Extrascapular, PP. One of a series of from two to eight bones of the teleost skull, known variously as cervicals, extrascapulars, nuchalia, postparietals, scale bones, supratemporals, or tabulars (cf. review by Tretiakov, 1945:52). Their relations to adjacent bones are diverse and their homologies are not well established. The logical name (supratemporal) of each element of the series is preempted by its application to the dermal (tube bone) representative of the autopterotic, as Tretiakov notes in preferring the name tabular. He identifies them by their connection with the supratemporal commissure (transverse occipital tatero-sensory canal), and infers from their frequently reduced number mutual fusion or growth to subjacent bones. According to him the lateral extrascapular (tabular) retains its independence more often than the others, and may be recognized by the conjunction within it of temporal (postorbital), supratemporal, and posttemporal canals. In cyprinids, the lateral extrascapular has often been called the postparietal, but de Beer (1937) applied the name postparietal in a less restricted sense to the several members of the series, and postparietal seems also to be the synonym of dermosupraoccipital (see above). The names most frequently and unequivocally employed are extrascapular and tabular. Most commonly there are two such bones on either side of the skull, a mesial (or median) extrascapular (middle tabular), and a lateral extrascapular (lateral tabular), such a condition occurring widely, e.g. in *Acentrophorus*, *Chanos* and *Cyprinus*. Among cyprinids, Tretiakov found tube bones free and separate, mutually fused, or fused with parietals or adjacent bones. Ontogenetic studies (Devillers, 1947:31; Lekander, 1949:87) show, moreover, that the extrascapulars often arise *ab initio* as discrete entities, only later fusing with other bones. Thus the old dilemma (cf. Allis, 1904:437; de Beer, 1937:495, 506, 513) concerning the homologies of the components of the "parieto-extrascapular" is resolved.

Intertemporal. (See supratemporal-intertemporal)

Jugal, may be represented by suborbital 2 (SO_2) according to Gregory (1933:88) and de Beer (1937:124). An anatomical criterion is the attachment to the mesial surface of the bone, in conjunction with a ligament from the hyomandibular, of the M. adductor maxillaris, a division of the M. adductor mandibulae (Chabanaud, 1945:570).

Lachrymal (lachrimal, lacrimal, lacrymal, preorbital, SO_1). L. Usually the foremost bone in the suborbital series in teleosts, and the homologue of the lachrymal of *Cheirolepis* and of tetrapods, but not of the antorbital of *Amia* (Gregory, 1933:89, 93). The foremost bone in this series in *Salmo* is called lachrymal-antorbital by Holmgren and Stensio (1936:494), but Devillers (1947:11) objected to this, asserting that it has none of the characteristics of the latter element. On the other hand, Lekander (1949) used the name antorbital for the bone in cyprinids called lachrymal here and by Devillers. Among homalopterids, Ramaswami (1948) described a lachrymal-jugal present simultaneously with an antorbital.

Lateral ethmoid, LE. (parethmoid, ectethmoid, erroneously called prefrontal). The bone arising on each side in relation to the cartilage of the lamina orbitonasalis, according to de Beer (1937:107), who reserved the name extethmoid for the ossification at the same locus independently evolved in birds. Berg (1940:446) mistakenly equated the prefrontal (membrane bone) and lateral ethmoid (cartilage bone).

Membranopterotic. (See under supratemporal-intertemporal)

Mentomeckelian (mentomandibular), M. (See under dentary)

Opisthotic (intercalary), OPIS. Phylogenetically a cartilage bone, often all that remains of it being an ossified ligamentous extension completely excluded from the auditory capsule according to de Beer (1937:130), who accepted the interpretation of Sagemehl (1891:558), who described this condition among cyprinoids. Holmgren, Stensio, and Lekander applied to it the name intercalary, but reserved the name opisthotic for the autopterotic as named here (see under autopterotic). Berg (1940) used the names opisthotic and intercalary both as synonyms (pp. 419, 434) and not as synonyms (pp. 412, 414).

Parasphenoid, PS. Homologue of the mammalian vomer (Gregory, 1933:89).

Postfrontal, (See under dermosphenotic)

Posttemporal, PTT. The bone articulating with the epiotic, suspending the pectoral girdle, and traversed by the posttemporal lateral line canal. de Beer (1937:125) called such a bone "suprascapular (supracleithrum)" in Salmo, "posttemporal" in Ameiurus(p. 139), and "posttemporal (supracleuthrum)" in Amia (p. 105). This confusion stems perhaps from the nomenclature of Haller (1905), in which the upper of the two bones traversed by the posttemporal canal was called the second supracleithrum, and the lower, the first supracleithrum. Haller's first supracleithrum articulates with the cleithrum and should be called simply the supracleithrum; his second supracleithrum is known to most authors as the posttemporal, as named here.

Preethmoid, PE. (e.g. of Starks, 1926; and cf. Ramaswami, 1948:516). The bone called septomaxillary by Sagemehl (1891) but renamed by Swinnerton (1902:530) in view of the dubious homology of these bones with the tetrapod septomaxillaries.

Prefrontal, PF. The membrane bone extending lateral from the lamina orbitonasalis (cartilaginous precursor of the lateral ethmoid) of each side, and which in teleosts may be absent, separate, fused from the beginning with, or developed as an extension of, the lateral ethmoid (de Beer, 1937:500).

Pterosphenoid (pleurosphenoid), PTS. For the so-called "alisphenoid" of teleosts (cf. Gregory, 1933:98). With the recognition of the non-homology of the mammalian alisphenoid with the "alisphenoids" of either teleosts or birds and reptiles, the reptilian "alisphenoid" became known for the teleost "alisphenoid" presumably agreeing with Goodrich (1930:380) that the fish bone was not the exact homologue of that of birds and reptiles. Later (1937:439) he reverted inexplicably to the use of the pleurosphenoid for the fish bone merely with the statement that "the bone in question in these forms has occasionally been known as the pterosphenoid pending the demonstration of its homology with the pleurosphenoid." Unfortunately the name alisphenoid is still often applied to this bone in fishes.

Retroarticular, RA. (e.g. of Boker, 1913·387; Haines, 1937; de Beer, 1937:128; Ramaswami, 1948; dermarticular of Holmgren and Stensio, 1936:496 and fig. 373; demarticular plus retroarticular(?) of Lekander, 1949). The bone conventionally known as the angular. The retroarticular is a mixed ossification, with a core of endochronal bone formed in the ultimate, posterior segment (retroarticular process) of Meckel's cartilage overlain by dermal bone (the latter probably the equivalent of Lekander's demarticular).

"Rostral", RO. (e.g. of Sagemehl, 1884; Starks, 1926; supraethmoid of Koh, 1931; preethmoid of Edwards, 1926). The sesamoid bone typical of cyprinoids and involved in the mechanism for the protrusion of the premaxillaries (cf. Gregory, 1933:185; Easton, 1935). All names so far used for this bone are preempted by their applications to other bones. The name "kinethmoid" (Gr. kinein, to move, plus ethmoid) is therefore proposed here for the cyprinoid "rostral," a movable bone of the ethmoid region.

Squamosal, the name used by Sagemehl (1891:506) for the "pterotic" complex of cyprinoids, and unfortunately still applied occasionally to the teleost skull, although Westoll (1937) and others have shown that the true squamosal is absent from the Actinoptergian skull, having disappeared with the retirement of the jugal canal from the status of lateral-line canal to that of pit line.

Suborbital, SO. (e.g. of Gregory, 1933; de Beer, 1937; Ramaswami, 1948; infraorbital of Holmgren and Stensio, 1936; Moy-Thomas, 1938:307; Lekander, 1949; Devillers, 1947), any one of the series of bones (lachrymal, jugal, postorbital, dermosphenotic, etc) associated with the suborbital (infraorbital) lateral-line canal. Among teleosts, the most usual number in this series is six bones, although departures from this number, even within the same fish, render homologization of individual bones uncertain.

Supracleithrum, SCL. (See under posttemporal)

Supraethmoid, SE. (e.g. of de Beer, 1937; Ramaswami, 1948; dermal ethmoid, dermethmoid, dermal mesethmoid, mesethmoid of various authors). Berg (1940, fig. 127) retained the name mesethmoid for the dermal ethmoid, and used hypethmoid for the "unpaired bone below the dermal mesethmoid" (p. 425), but the name mesethmoid should only be applied fo the mammalian skull (see under ethmoid) and hypethmoid appears to be a synonym for ethmoid as defined above.

Supraorbital, SPO. One of the one or more bones along the upper margin of the teleost orbit, not traversed by a laterosensory canal, and according to Gregory (1933:88) including the postfrontal. The confusion of postfrontal and dermosphenotic becomes understandable from an examination of such skulls as those of Cheirolepis and Coccocephalus (Berg, 1940, fig. 52; Gregory, 1951, fig. 9.6), in which the hindmost supraorbital (postfrontal) seems to be confluent in the one case with the uppermost bone of the suborbital series (dermosphenotic) and in the other, with the bone just beneath the dermosphenotic. Supraorbitals apparently only thus come to acquire relationships with the laterosensory system.

Suprapreopercular, (e.g. of Allis, 1910:152; Holmgren and Stensio, 1936:495; Berg, 1940:403, 413, 423, 428, fig. 146, "s. pr. op."; Tretiakov, 1945; Devillers, 1947:11, 36, 38; Lekander, 1949:69, 102; supraopercular of Bruch, 1861:12; supra-temporal of Parker, 1873:99; "subtemporal or supraopercular" of Ridewood, 1904b:485; subtemporal of Kindred, 1919:94; and of de Beer, 1937:125; "subtemporal" of Gregory, 1933:166, supratemporal, p. 165, "sbtm," fig. 59). The name suprapreopercular is applied to any of from one to several usually small tube bones conducting the dorsal extension of the preopercular laterosensory canal across the gap between the preopercular bone and the supratemporal canal agove. These bones are considered to represent vestiges of the upper half of the bipartite peropercular (suprapreopercular plus infrapreopercular) of, e.g. Paleoniscoids, Bobasatraniidae, Pycnodontiformes, Phractolaemoidel and Chanoidel (Stensio, 1932, 1947:184; Tretiakov, 1945:49), the infrapreopercular being represented by the preopercular as usually understood. Among salmonoids and cyprinoids, suprapreopercular elements tend to be absent or vestigial, and when present in cyprinids, exist as free tube bones or may fuse with the anterodorsal corner of the operculum in the latter condition being peculiar to cyprinids, according to Tretiakov. The skull of Notemigonus c. crysoleucas has such an opercular, and the same condition is recorded for a few other cyprinids (Allis, 1904:437, fig. 17; Devillers, 1944; Tretiakov, 1945).

Supratemporal-intertemporal, ST. (e.g. of Holmgren and Stensio, 1936:490, 494; Berg, 1940:figs. 92, 97, 111; Bamford, 1941; Devillers, 1947:29; Lekander, 1949:69, 71, 85, 103; supratemporal and/or intertemporal of de Beer, 1937:132, 139; "pterotic" or supratemporal of Gregory, 1933:92; squamosal in part of Kindred, 1919; in part, the dermosquamosal of other authors). In cyprinids, the pterotic complex or pteroticum (squamosal of older authors), in addition to the cartilage-preformed autosphenotic (as named here), consists according to Devillers and Lekander of: (1) a flat membranous bone (membranopterotic or dermopterotic), which may be fused from the beginning with the autopterotic or may fuse to it later; and (2) several tubular canal bones (one or two intertemporals and one supratemporal), which either remain free or fuse with the membranopterotic. The extosteal complex might thus be called a supratemporal-intertemporal-membranopterotic but is usually referred to as the supratemporal-intertemporal, as here. The entire pteroticum may, therefore, be designated the supratemporal-intertemporal-autopterotic. Except for their relation to the temporal laterosensory canal and for the more anterior position of the intertemporal, the intertemporal and supratemporal bones have often been only vaguely characterized. The confusion of intertemporal and dermosphenotic has been noted (see under dermosphenotic). Ramaswami (1948:518) identified the intertemporal as the canal bone opposite the sphenotic gap, asserting (p. 520) that in the majority of cases the intertemporal is associated with the sphenotic and the supratemporal either fused with the "pterotic" or located above it. Devillers (1947:30) recalled that phylogenetically the line of demarcation between the two bones was the junction point of preopercular and horizontal canals. In cyprinids, the intertemporal portion of the temporal canal is associated with two neuromasts innervated by the remus aticus facilis, whereas the supratemporal portion is associated with two neuromasts innervated by the glosshpharyngeal (Devillers, 1947; Lekander, 1949).

Remarks on Terminology of Fish Bones

From: Weitzman, S. 1962. Stanford Ichthyol. Bull. 8(1).

The terminology of teleost fish bones adopted here is mostly based on current usage and does not necessarily imply homology with similarly named bones of tetrapods or even other groups of fishes. As Romer (1947) has pointed out, the determination of precise homologies between the skull bones of different groups of fishes presents great difficulties. The homology of many teleost skull bones is in question. For example, according to Westoll (1944, p. 67) the frontals of teleosts may be roughly equivalent to the parietals of tetrapods; however, this did not cause Westoll to propose a change in the name of the bones currently called frontals in teleosts and other fishes. Pending absolute proof that the frontals of teleosts are equivalent to the parietals of tetrapods, it would seem better to retain the old nomenclature for stability's sake. Also, Westoll (1937:570; 1944:76) believed that the premaxillary of teleosts cannot be homologous with that of tetrapods. Even though an old commonly used name may not be used in a strict homologous sense this is no reason to propose a new name until a definite homology can be established. Since accurate homologies have not been determined in many instances, a more or less conventional terminology, based largely, but not completely, on topographic regions is utilized here for the sake of consistency and ease of usage. Where it has been adequately demonstrated that the conventional term is improper or misleading, a substitute term has been accepted and used.

I cannot subscribe to the terminology employed by Harrington (1955) wherein a single bone in the adult is described as though it were composed of two bones simply because developmentally two bone primordia may have contributed to its formation. For example, the bone called lateral ethmoid in this paper may actually be the result of the fusion of two bone Anlagen, the intramembranous prefrontal and the endochondral lateral ethmoid. Definite proof would require study of developmental stages. Calling areas of this bone by two different names, i.e., referring to this bone as though it were two bones, serves no useful purpose and unnecessarily complicates the nomenclature of fish bones. Even if it was definitely established that two bones have contributed to the lateral ethmoid of a certain characid, the complications of using such nomenclature must be considered. If this system of nomenclature is used for all bones of a fish, it would become both difficult and verbose to refer to any of several bones in the adult fish skeleton. Although I firmly believe that, wherever possible and applicable, the developmental origins of bones should be studied and then indicated in the text discussion, especially where they have phylogenetic significance, use of the term "os dentale-mento-mendibulare-spieniale" by Lekander (1949:82) for the dentary of fishes is far too cumbersome. I believe that the advantage such a name has in pointing out developmental origins and possible phylogenetic descent is more than nullified by the loss of brevity. Some writers forget that a name is merely a name, not a description.

There are several systems and variations of terminology in current use for the various parts of the laterosensory system of the head in fishes. Many of these systems were derived irrespective of the associated bony or nervous structures, and often the limits of the various named portions of the continuous canals of the head have been treated very subjectively. For example, the infraorbital canal in the Cyprinidae was described by Illick (1965:209) as extending posteriorly along the side of the head to the supratemporal canal. Robins and Miller (1957:216-217) more correctly described this canal as the lateral canal of the head. They defined this as that portion of the laterosensory canal between the attachment of the gill membrane formed to the orbit.

In general, the terminology employed here follows that utilized by Allis (1889 and 1904), Illick (1956) and Robins and Miller (1957). However, in order to maintain a nomenclature more consistent with the osterological description, I have chosen to define the extent of the various canals in relation to the bones and thus have slightly modified the system. It would probably be more logical to attempt to define the limits of these canals by their innervation. However, the following designations work well for members of the Characidae. See Figure 9 for diagram of head canals.

The supraborbital canal is that portion of the laterosensory canal within or in relation to the dorsal surface of the frontal bone. In characids it has an epiphyseal branch over the epiphyseal bar and a posterior branch which extends posteriorly and is continuous with the parietal canal that lies within the parietal bone. A nasal laterosensory canal lies within the nasal bone and above the nasal capsule. The infraorbital canal lies within or over the six infraorbital bones and rarely over or partially within the adnasal bone. The lateral canal of the head, here called the dermopterotic canal, lies within the dermal portion of the pterotic bone. The supratemporal canal lies within the posterior portion of the parietal bone. The supratemporal canal lies within the posterior portion of the parietal bone. The V-shaped extrascapular canal lies within or over the bone of the same name and the posttemporal canal passes through the posttemporal bone. The supracleithral canal lies within the supracleithrum and the preopercular-mandibular canal extends from the dermopterotic canal across the suprapreopercular region and downward into the suprapreopercular portion of the preoperculum. It continues into the preoperculum, across the mandibularquadrate joint into the ventrolateral border of the dentary almost to the symphysis of the lower jaw.

It should be pointed out that the branches of the main laterosensory canals on the head of *Brycon meeki* are far more extensive than the bony distribution here given. Also, as the size of the specimen increases, the branches of the canals that overlie the bones of the head become more complex and extensive.

Dissection and Study of the Weberian Apparatus of the Carp, Cyprinus carpio

Discussion: In the orders Cypriniformes and Siluriformes (Ostariophysi) there is a unique modification of the anterior vertebrae called the Weberian apparatus. This apparatus consists of 4 ossicles in close association with the first four modified vertebrae. They form a series on each side of the vertebral column that connect the anterior end of the air-bladder and the internal ears.

The internal ears, each of which consists of three semi-circular canals, a sacculus, and a utriculus, are connected by the endolymphatic sac in the posterior part of the cranium. This sac meets the perilymphatic sac medially, which extends a short distance posteriorly and then divides, each half leaving the cranium on both sides through a lateral foramen. Just anterior to the first vertebra each branch of the perilymphatic sac enlarges to form the atrium sinus imparis. The wall of each atrium is partly membranous and is in part formed by the two cup-shaped ossicles, the claustrum and scaphium. Continuing in the anterior-posterior direction is the intercalarium, a thin, forked bone whose two processes rest on the second vertebra. An interossicular ligament connects this ossicle with the next posterior one, the tripus, a much larger triangular bone with a long anterior process and a long thin medially curving posterior process, the transformator. The tripus has a central process that extends into the second vertebra. This process acts as a fulcrum in its articulation on the second vertebra. The transformator process of each tripus is imbedded in the tendonous outer layer of the anterior portion of the air-bladder. The end of each transformator process is attached anteriorly to the ossa suspensoria by a small triangular muscle consisting of unstriated fibres, the tensor tripodis muscle. The tripus and intercalarium lie in a cavity, the saccus paravertebralis which is membranous and filled with a semi-gelatinous fluid. In the more generalized members of the order this sac communicates anteriorly with the atrium sinus imparis, a condition present in the carp but a careful dissection is necessary to show it.

Development of the Weberian apparatus: The neural arches and spines of the compound vertebra (the fused second the third centra) are formed from the basidorsals of the second, third, and fourth vertebrae fused with the first three interspinous bones and possibly also the neural spine of the first vertebra.

The transverse processes of the first and second vertebrae are dorsal ribs. The ossa suspensoria are modified haemapophyses. The claustrum arises as an ossification of the connective tissue forming the wall of the atrium sinus imparis. The scaphium arises partly from the basidorsal of the first vertebra and partly from an independent mesenchymatous rudiment. The intercalarium is also dual in origin, deriving partly from an ossification in the interossicular ligament and partly from the second basidorsal. The tripus arises from three sources, from the third basidorsal, from an independent mesenchymatous rudiment and from a small ossification in the outer coat of the air-bladder. These conclusions on the embryonic origin of the Weberian ossicles and anterior vertebrae are those given by Watson (Ref. 8) for the goldfish. Some of these may be in conflict with the findings of earlier workers but these conflicts may be due to the less complete observations of the earlier workers.

Evolution in Weberian structure: In the Siluriformes (catfishes), the apparatus is direct, that is, the intercalarium does not articulate with the vertebral column and the tripus does not possess a transformator process which reverses the direction of motion of the ossicular chain as it does in the order Cypriniformes where the system is termed indirect. Since the embryonic condition of the Weberian chain in the goldfish (*Carassius auratus*) is so similar to the adult condition in the catfishes, it is assumed that most likely the indirect cypriniform system has evolved from the direct siluriform system.

Dissection for Weberian apparatus: Carefully remove the musculature from the anterior end of the vertebral column on one side of the carp. If you damage the sacs on one side, you still have the opposite side to dissect after you finish the side on which you are working. Study the structures described in the discussion part of this exercise. Sketch the ossicles *in situ*. Then remove the section of the vertebral column bearing the apparatus, place in boiling water for a minute or two, remove all flesh from the vertebra, glue the ossicles of one side in place on the vertebrae and keep the ossicles from the other side in a small vial. Sketch and label the cleaned vertebrae with ossicles in place. Sketch the separated ossicles and label.

Function of Weberian apparatus: Experimental work definitely shows that it is a mechanism for the transmission of vibrations to the internal ear. The attachment of the air-bladder to the tripus is such as to make the apparatus a very sensitive one for reception of rapid vibrations of small amplitude. It has been shown that the sacculus and lagena in the ear of the *Cyprinidae* and *Siluridae* are especially adapted to receive sound vibrations conveyed to it by the Weberian apparatus.

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Suggested Reading

Romer, Vertebrate body, pg. 513-520.

Norman, Chapter 7.

Section II

Systematic Arrangement of Fishes

The next several laboratory periods will consist of examining representatives of various classes, subclasses, orders and families of fishes. We will proceed phylogenetically from the class Agnatha to the advanced groups of teleostean fishes. The bulk of the time will be devoted to the teleosts.

The student should know the diagnostic characters of each taxa taken up in lab. For example, learn the characters distinguishing the class Agnatha from Chondrichthyes and Osteichthyes; then the characters separating the orders Petromyzontiformes and Myxiniformes. In some cases we may proceed down through families to genera and species. Other important information should be noted such as any general statements concerning the ecology, life history, geographical distribution and approximate number of species of each of the taxa considered. The next few pages will serve as an outline leading up to the teleostean fishes. For the subsequent laboratory periods, prepare your own outline of significant information characterizing the representative taxa.

For the systematic arrangement of the Teleostei, you should have some understanding of Regan's 1929 classification, the modifications introduced in 1940 by Berg and particularly the 1966 revisions of Greenwood, Rosen, Weitzman and Myers. What characters have been favored to assess phylogenetic relationships? How is the primitive or derived state of a character determined? Why is there still such uncertainty in plotting the phylogenetic branching sequences leading to the living orders of teleosts?

PHYLUM CHORDATA

Characters: Animals with an internal skeleton, including at some point in their life history a dorsal supporting notochord, gill clefts, and dorsal, tubular nerve cord. These features are all formed in the early embryo and they may persist or be altered and disappear in the adult stage.

CLASS AGNATHA

Characters: The Agnatha includes both armored fossil forms which were widely distributed in Europe and America in the Silurian. There is only one living subclass, the Cyclostomi. In this group the body is eel-shaped and lacks scales. The notochord is persistent and the skeleton is cartilaginous and ribless. Paired fins and limb girdles are absent. There are no jaws and the mouth is surrounded by a sucking disk. The absence of jaws and fins is regarded as the primitive feature of Cyclostomes. However, the absence of a bony skeleton is a degenerate character since the ostracoderms were covered by a bony armor and some had a well-developed internal bony skeleton.

ORDER PETROMYZONTIFORMES, THE LAMPREYS

FAMILY PETROMYZONIDAE

Characters: Lampreys have a single median nostril which does not communicate with the pharynx. There are seven pairs of spherical gill pouches. Each pouch is connected by a narrow opening to the exterior and opens internally to a common branchial basket. The circular mouth is surrounded by horny teeth, the number and arrangement of which is characteristic for the species. The tongue is also fitted with horny teeth. Usually two dorsal fins are present. The vertebral column is represented by a notochord and rudimentary cartilaginous neural arches.

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Ecology: Adults of some lampreys, such as the sea lamprey, *Petromyzon marinus*, are parasitic on fish. They attach to other fish by means of the sucking disk, rasp on opening in the flesh with their horny cusps and suck the body fluids. A well-developed musculature which constricts and expands the gill pouches serves to circulate water over the gills when the mouth is attached to the prey. Other species, such as the brook lamprey, *Lampetra planeri*, possess a degenerate alimentary tract and do not feed after becoming adults. Adult lampreys spawn in streams where they excavate a shallow nest. During the spawning act the female attaches by means of the mouth to a stone and the male attaches to the head of the female. All lampreys die shortly after spawning. The eggs are numerous and small, approximately 1 mm in diameter. Larval lampreys (ammocoetes) possess rudimentary eyes, an oral hood, a single dorsal fin, and lack teeth. Ammocoetes bury themselves in mud and filter feed on small particles of organic debris. After several years in this stage, metamorphosis occurs. The eyes become functional, teeth appear, and the oral hood is lost. Single family with 8 genera and about 30 species.

The larval stages of all living species of Petromyzontiformes occur in freshwater. The adults of some species enter the marine environment.

Distribution: Freshwater and anadromous. Temperate parts of both hemispheres.

ORDER MYXINIFORMES, THE HAG FISHES

Characters: Single semi circular canal, nasal sac opens to pharynx, barbels around mouth, 1-16 gill openings. About 15 species arranged in 3 families; eyes degenerate; 50 cm in length.

Ecology: All species are entirely marine (with isotonic blood) in all stages of life. Scavenger feeding habits; burrow into dead and dying fish, consuming the flesh and viscera.

Distribution: Temperate and subtropical waters of Atlantic and Pacific Oceans.

CLASS CHONDRICHTHYES (sharks, rays, and chimaeras)

Characters: These fishes are distinguished by a cartilaginous skeleton in which the notochord is partially replaced by calcified centra without bone cells; placoid scales. Jaws consist of the palato-quadrate and Meckle's cartilage. The tail, except in the chimaeras, is heterocercal. Cartilaginous fishes resemble the class of true bony fishes in having jaws, paired nasal organs, gill arches, and paired fins. They differ from the bony fishes in lacking an air bladder, pyloric caecae, a true operculum and bone cells. Two subclasses, several orders and about 600 species.

Ecology: The chondrichthyes retain many primitive characters. The spiral valve of the intestine, which increases absorptive area, is best developed in this group, although it is also present in lampreys, sturgeons, bowfins, gars, and lungfish. Most species are large and predaceous.

Fertilization in all living forms is internal. Adult males can be recognized by the myxoptergia or claspers, modifications of the inner margins of the pelvic fins. Embryo development is oviparous, ovoviviparous, or viviparous. In oviparous forms, for example the skates and ratfish, the eggs develop externally after being laid in horny cases. These cases are spindle-shaped or rectangular and often bear tendrils at the corners which attach them to weeds or stones. In ovoviviparous forms the eggs develop within the body of the mother, but the embryos are not connected directly with the body of the mother. The large egg yolk provides food. In viviparous forms, the young are connected to the mother by a placenta-like structure through which they draw nourishment. Due to the increased protection afforded by internal development, fecundities in the group are low.

SUBCLASS ELASMOBRANCHII, THE SHARKS AND RAYS

SUPERORDER "A", THE SHARKS

Characters: Sharks have a body which is elongate and round in cross-section and 5-7 slit-like lateral gill openings. The margin of the eyeball is free from the skin for some distance all the way around (on the rays the upper margin is adnate to the skin). The caudal fin is heterocercal. A cloaca is present. A spiracle (vestigal gill slit) is usually present. The pectoral fins have narrow bases and are not attached to the head anteriorally or to the pelvic fins posteriorally, as in the rays. In sharks, as well as rays and most bony fish, the jaw suspension is hyostylic. The jaw structure here has no direct connection with the braincase and the jaw joint is braced entirely by the hyomandibular. Sharks are a difficult taxonomic group due to the relatively few external features on which distinction may be based.

Ecology: Most sharks live along coasts in relatively shallow water, although some forms are found at very great depths and in the open ocean. They are primarily scavengers, the sense of smell being specially well developed. Vision is not especially keen, except in the pelagic forms. The largest living fish is the whale shark, Rhineodon typus, which reaches a length of 70 feet. Shark fins are used by the Chinese in cooking. Shagreen, used for polishing, is the skin of those species with small, close-set placoid scales. The vitamin-rich liver oil previously supported a commercial fishery for two Pacific Coast species, the soupfin shark (Galeorhinus zyopterus) and the dogfish (Squalus suckleyi) but the manufacture of synthetic vitamins has largely replaced this.

Distribution: Typically marine, cosmopolitan. A few species occasionally enter fresh water and some are entirely freshwater. The greatest number of species occur in tropical and subtropical waters.

SUPERORDER "B" THE RAYS

Characters: Rays have five gill openings on the under surface of a depressed body. The anterior margin of the enlarged pectoral fin is joined to the side of the body or head to provide a continuous flat surface and the anal fin is absent. The spiracles, through which water is taken in for respiration, are located dorsally.

Ecology: Rays are highly modified for life on the bottom. They are well protected from potential enemies. Poison glands are associated with the spines of stingrays which can inflict severe wounds on unwary waders. The large organs derived from muscle tissue and located on each side of the head of electric rays are capable of voluntarily emitting shocks up to 220 volts. Many forms are equipped with pavement teeth (hexagonal plates) which are adapted for feeding on shellfish. "Ray" is a general term; the term "skate" is restricted to members of the family Rajidae.

Distribution: Typically marine, cosmopolitan. A freshwater genus inhabits the Amazon.

Procedure: Observe other adaptations of this group for a bottom-living existence.

SUBCLASS HOLOCEPHALI

ORDER CHIMAERIFORMES (chimaeras)

Characters: Chimaeras have five gill arches protected by a gill cover which is a flap of skin without membrane bones. The teeth, at least partially, are in the form o grinding plates and there may also be prominent incisor-like teeth. The teeth lack enamel. The tail is diphycercal. The jaw suspension, in common with the lungfish, is autostylic, since the upper jaw is fused to the braincase. Spiracle absent. On males there is a cephalic appendage, the tenaculum possibly useful in copulation, but don't ask how.

Ecology: Hydrolagus colliei, a common Pacific species, is a relatively shallow water form compared to other members of the family. Teeth fused into bony plates give rise to the common name "ratfish." The eggs are laid in elongate, rigid, brown cases. This fish is little utilized although the liver oil is rich in vitamins and the flesh is said to be palatable.

Distribution: Marine, cosmopolitan, principally in deep water. A single family, Chimaeridae; about 30 species.

CLASS OSTEICHTHYES (bony fishes)

Characters: In this class are included the vast majority of fishes. The bony fishes have many structural features which distinguish them from the lampreys, sharks, and rays. The endoskeleton and vertebral column are wholly or partly ossified. Neural and haemal arches are present. Membrane bones are present. The jaw is well developed with premaxillary, maxillary, and dentary elements. A bony operculum covers the gill clefts and either gular plates or branchiostegal rays are present. There is an air bladder present, except in certain specialized groups. The well-developed secondary pectoral girdle is connected dorsally with the posterior part of the skull (except in many eel-like fishes). The body is covered with rhomboid plates, cycloid or ctenoid scales, bony plates, or naked skin. There are typically four respiratory gill arches.

SUBCLASS DIPNOI

ORDER DIPTERIFORMES (lungfishes)

Characters: In the living lungfishes the paired fins are lobate with a jointed median axis. The scales are overlapping and cycloid in shape, but not true cycloid. An operculum is present but the opercular elements are not differentiated. Internal nares, a cloaca, and a spiral valve are present. The air bladder possesses a duct opening to the ventral side of the esophagus and is lung-like and cellular. All of these forms must secure air at the surface of the water even during periods when the water is not stagnant. Peculiar grinding teeth are present. In all living forms the median fins are confluent to form a continuous symmetrical diphycercal tail. Anatomical features which resemble those of amphibians include the internal nares, an autostylic jaw and fleshy, lobed fins which are suitable for development into terrestrial limbs. Living lungfishes are survivors of a fossil group which was moderately abundant in the late Paleozoic and early Mesozoic. There are three living genera one each in tropical regions of Australia, South America, and Africa.

FAMILY CERATODONTIDAE (Australian lungfish)

Characters: In *Neoceratodus* the air bladder is an unpaired sac, divided into right and left lobes by a band of connective tissue.

Ecology: The Australian lungfish, unlike the lungfishes of Africa and South America, does not build a cocoon in the mud. If the pool in which it is living dries up, it cannot survive. However, the air-breathing habit enables it to live in the mud during periods of drought in shallow ponds polluted by decaying organic matter and deficient in oxygen. It is a sluggish fish, feeding on aquatic vegetation and small invertebrates. Eyesight is poor and food is located principally by the sense of smell. Spawning occurs in the spring months (Aug-Oct). Each egg, placed among aquatic vegetation, is surrounded by a heavy gelatinous coat. The embryological development has many amphibian characteristics. The lungfish is the only undoubted primary freshwater fish in Australia. What zoogeographical implications can you draw from this?

Distribution: Northern Queensland, Australia. Freshwater.

FAMILY LEPIDOSIRENIDAE (South American and African lungfishes)

Characters: In *Lepidosiren* the endocranium is largely membranous. The paired fins are reduced. The air bladder is paired. The pelvic fins are fringed.

Ecology: This fish lives in swamps along rivers but never in the rivers themselves. The nest burrow is in the muddy bottom and the male guards the eggs. Separate burrows for aestivation are constructed in impervious clay. These burrows are mucous-lined and are closed at the surface with a loose clay plug. It feeds mainly on snails.

Distribution: Amazon basin, South America. Freshwater.

GENUS *Protopterus* (African lungfishes)

Characters: The African lungfishes are similar to the South American form with the exception that the pelvic fin is elongated into a barbel-like structure.

Ecology: *Protopterus* builds an aestivation chamber which is lined with mucous. The entrance of the chamber is not closed as in *Lepidosiren*. Special nest burrows are built which are lined with leaves and sticks. The male guards the eggs. The larvae have four pairs of plume-like external gills and are equipped with the ventral suckers in order to attach to rootlets in the burrow.

Distribution: Central West Africa. Freshwater. What orders and families of teleosts occur both in Africa and South America?

SUBCLASS ACTINOPTERYGII
SUPERORDER CHONDROSTEI
ORDER ACIPENSERIFORMES

Characters: The primitive chondrosteans possess characters which closely resemble those of sharks and rays. The caudal is heterocercal. The endocranium is cartilaginous, never ossifying as a complete box. Spiracles are present in most forms. The opercular apparatus is only partially developed. The notochord is not replaced by vertebral centra and the otoliths are not calcified. The fins have numerous close-set rays, and these rays outnumber the radials. This group also has certain unique characters, such as an elongate snout and a body naked or covered with 5 rows of bony scutes.

FAMILY ACIPENSERIDAE (sturgeons)

Characters: The body is covered with five rows of bony scutes which form a partial armor. The mouth is ventral and protractile. Teeth are present only in very young fish. The opercular membranes are joined to the isthmus and there are no branchiostegal rays. The dorsal and anal fins are inserted far back on the body.

Ecology: Sturgeons are sluggish fishes which feed on aquatic insects, crustaceans, and molluscs. In the Columbia River part of the diet consists of salmon, smelt, and lamprey carcasses. They are long-lived; ages up to 50 years have been determined by study of cross sections of the first pectoral fin rays. Growth of the fish is extremely slow. Females reach maturity at an age of between 15 and 20 years. Males become ripe somewhat earlier. Individuals up to 20 feet in length and 1800 pounds in weight have been taken in the Columbia River basin. Sturgeon spawn in freshwater in the spring and early summer. Fecundity is high with up to four million eggs being produced by a 50 year old female. The flesh is esteemed as food and caviar is prepared from the eggs. A high quality isinglass is prepared from the air bladders.

Distribution: Anadromous and freshwater. Temperate parts of North America and Eurasia.

FAMILY POLYODONTIDAE (paddlefishes)

Characters: In paddlefishes the snout is prolonged into a thin, flexible projection whose length may be one-third of the body length. The inner portion of the paddle is formed by produced nasal bones and it is surrounded by a reticulate bony framework. The jaws have small teeth. The body is naked except for a few small scales at the base of the upper lobe of the caudal fin. The caudal fin is heterocercal, although the lower lobe is well developed so that the fin is nearly equally forked. There is one pair of broad branchiostegal rays. The air bladder is cellular and is connected by a duct with the esophagus. The gills are covered by a large soft operculum which extends far posteriorly to a point above the base of the ventral fins.

Ecology: Paddlefishes feed by stirring up the mud with their snouts and by straining plankton from the water through the sieve-like gill rakers. They have been called "animated plankton nets". Adults spawn in the spring when they are found associated in schools along sandy lake shores. As in the sturgeons, eggs are small and numerous. The newly-hatched young do not possess the paddle-shaped snout.

Distribution: Freshwater. *Polyodon*, eastern North America; *Psephurus*, China.

SUPERORDER HOLOSTEI
ORDER LEPISOSTEIFORMES OR SEMIONOTIFORMES

FAMILY LEPISOSTEIDAE (gars)

Characters: Gars are characterized by the thick, ganoid scales that cover the body. The jaws are extremely elongate with sharp teeth and the nostrils are located at the end of the upper jaw. There are also teeth on the palatines and the paired vomer bones. Three branchiostegal rays are present. The caudal fin is abbreviate heterocercal, although it may appear superficially symmetrical. The dorsal and anal fins are located opposite each other towards the posterior end of the body. The air bladder is cellular, connected with the esophagus, and may be used as a lung. The gill rakers are very short. Pseudobranchia are present. There are no spiracles or gular plate.

Ecology: Gars are a remnant of an ancient and abundant family. Fossil gars are known from Europe. Gars and the bowfin, discussed below, are among the most predatory fishes in freshwater. They often drift lazily at the water surface but are capable of swift movements to capture prey. They are warm-water fishes and inhabit sloughs and quiet backwaters.

Distribution: Freshwaters of eastern North America, Central America, and Cuba.

ORDER AMIIFORMES

FAMILY AMIIDAE (bowfins)

Characters: In the bowfin the head is covered with smooth plates. The jaws have an outer series of conical teeth and an inner band of rasp-like teeth. There are also teeth on the vomer, palatines, and pterygoids. The tail, as in the gars, is abbreviate heterocercal. There is a gular plate and 10-12 branchiostegal rays. The dorsal fin is long and low. The median fins have equal numbers of dermal rays and endoskeletal supports in contrast to the sturgeons and paddlefishes where the number of dermal rays is greater than the number of endoskeletal supports. The scales are cycloid-like. The gill rakers are short and stout. There is no pseudobranch.

Ecology: There is only one living species, *Amia calva*, in this order which has many fossil representatives. This is a predacious fish which feeds on crayfish and small fish. The males are smaller than the females and can be distinguished from the latter by the ocellus rimmed with orange-yellow located at the base of the caudal fin. Bowfins can live a long time out of water, breathing air with their lung-like air bladder. Spawning occurs in the late spring in streams or shallow bays. The eggs are laid in a shallow depression prepared by the parents. On hatching the young adhere to roots on the bottom of the nest by an adhesive organ on the snout. The young are guarded for a time after hatching by the male.

Distribution: Freshwater. North America. Mississippi River and Great Lakes, south to Florida.

Name: ______________________________

FW 492A

The Role of Fish Hatcheries in Modern Fisheries Management

1. In the nineteenth century the main thrust of government fish propagation programs was to hatch tremendous numbers of eggs from food and game fishes (also oysters, lobsters, etc.) and stock out the fry soon after hatching in the belief that by such means the abundance of valuable species could be increased virtually without limit, and species could be readily established where they did not occur naturally (Pacific salmon were stocked into the Mississippi River near New Orleans and great salmon runs were eagerly awaited from their return from the Gulf of Mexico). What is basically wrong with the assumptions on which early fish propagation were based?

2. Artificial propagation still plays a major role in both state and federal fisheries management programs (some critics believe the role is "too major" and all out of proportion from cost/benefits in comparison to other management options). What are some similarities and some basic differences between modern and nineteenth century methods, goals and objectives of artificial propagation?

3. In your opinion, under what circumstances is the artificial propagation of a species justified? That is, where favorable cost/benefits are derived to justify the use of license monies as a "good investment?"

4. Discuss the types of studies and data necessary to evaluate cost/benefit ratios of a stocking program.

5. What is interspecific and intraspecific diversity? How might the intelligent and innovative use of these genetic based diversities maximize cost/benefit ratios and make stocking programs more effective (what is interactive segregation)?

6. What role might interspecific and intraspecific hybrids play to increase the effectiveness of fisheries management? List some hybrid combinations you have heard of used in stocking programs in the United States.

7. In your opinion, what is the role of catchable trout in a states' overall fishery program? What data are necessary to evaluate catchable stocking and maximize cost effectiveness?

8. No matter how effective, in terms of return to the creel, a catchable program proves to be, the fact remains that the majority of license buyers, highly subsidize a minority of "catchable specialists." Studies in California and Colorado (Poudre River) both demonstrated that 50% of all catchable trout caught were caught by less than 10% of the anglers. What can you suggest toward the development of long range goals, objectives and guidelines of a fisheries management policy that would treat the inequities of catchable stocking and keep a catchable program in its proper perspective? Obviously, there is no simple answer or it would have been instituted long ago. What pressures are exerted from certain groups that make it difficult to establish a more rational approach to catchable stocking and hold the line on the vicious circle of ever increasing demand?

michigan fisheries

No. 5
January, 1962

DEPARTMENT OF FISHERIES, SCHOOL OF NATURAL RESOURCES
THE UNIVERSITY OF MICHIGAN ANN ARBOR

ATLAS OF FISH ANATOMY [1]

by

Karl F. Lagler

This atlas is prepared as a teaching aid in fish biology. Multiple copies are available from the Department of Fisheries at cost. I would welcome the contribution of useful anatomical drawings by others. These would be included in future editions, with full credit as to source. Suggestions would be welcome regarding desirable inclusions, either to be originated or to be borrowed from published sources.

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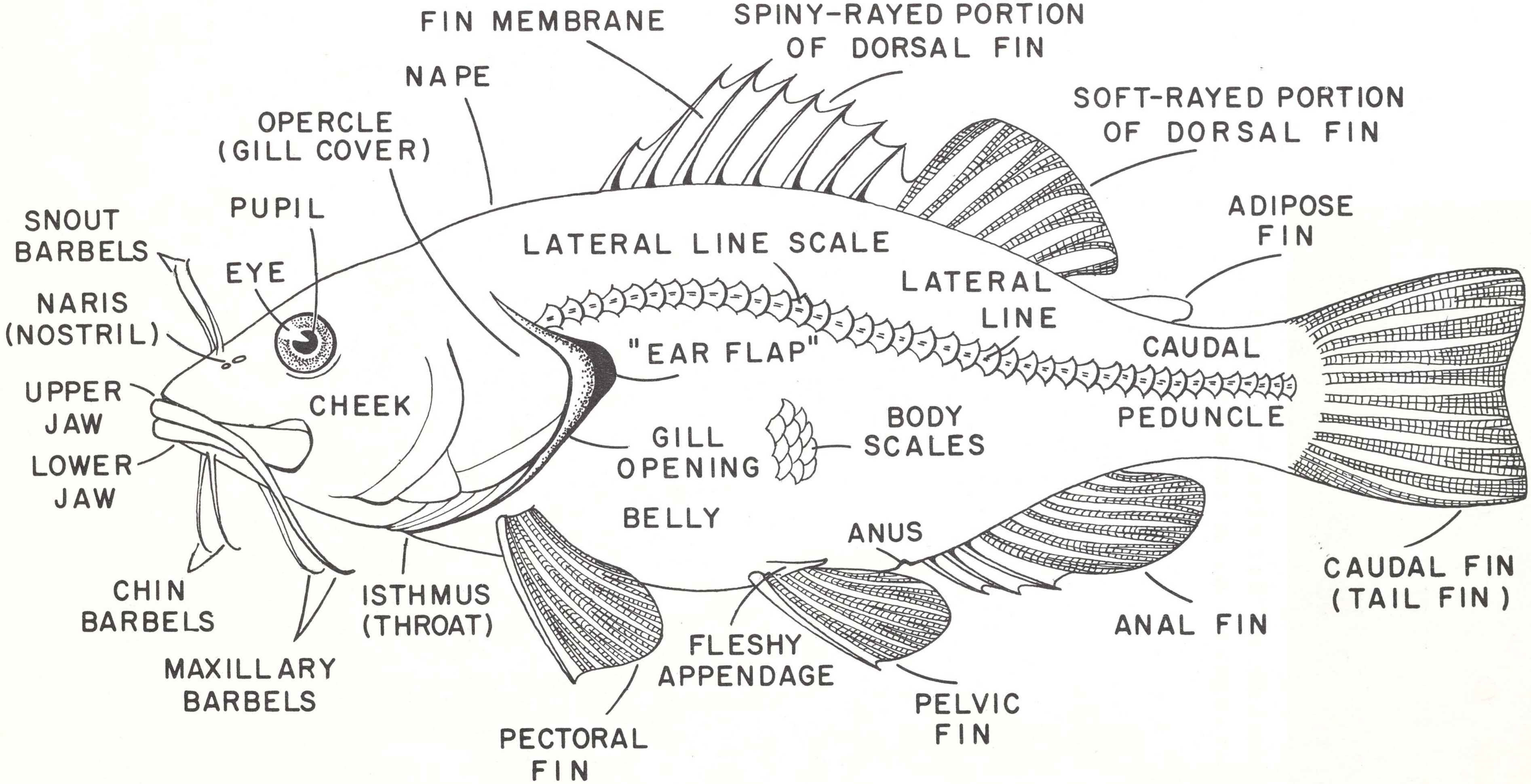
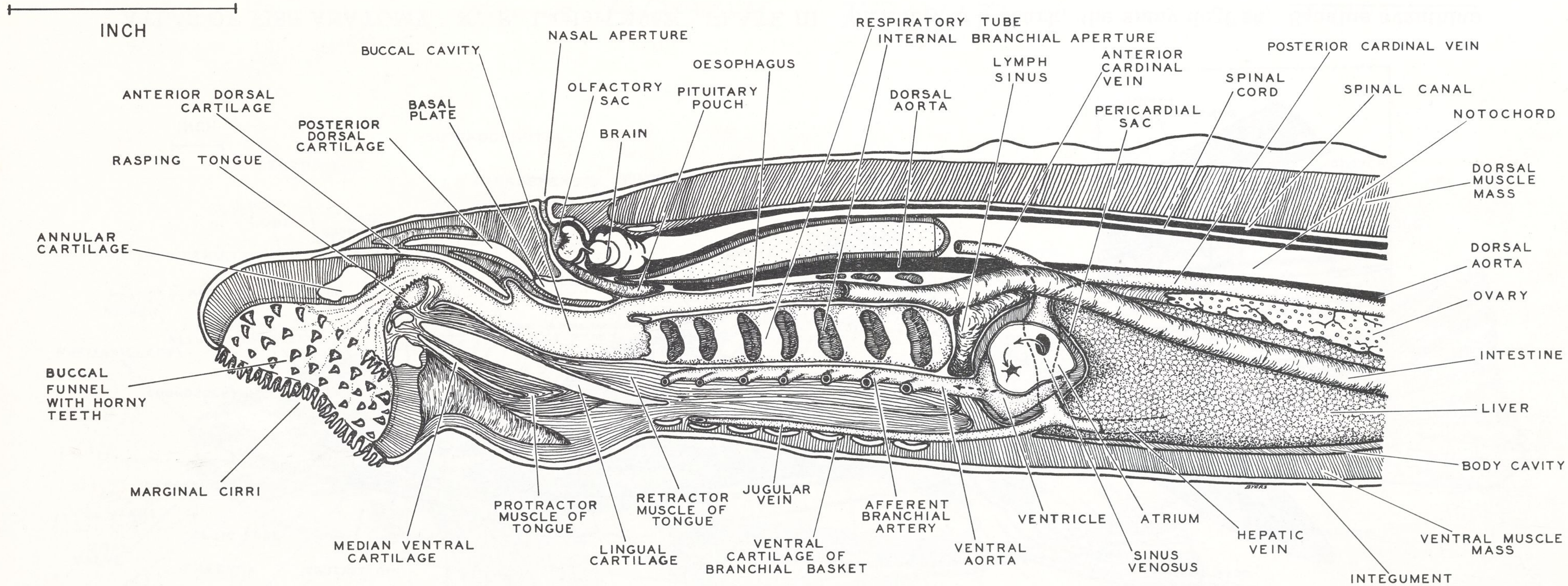
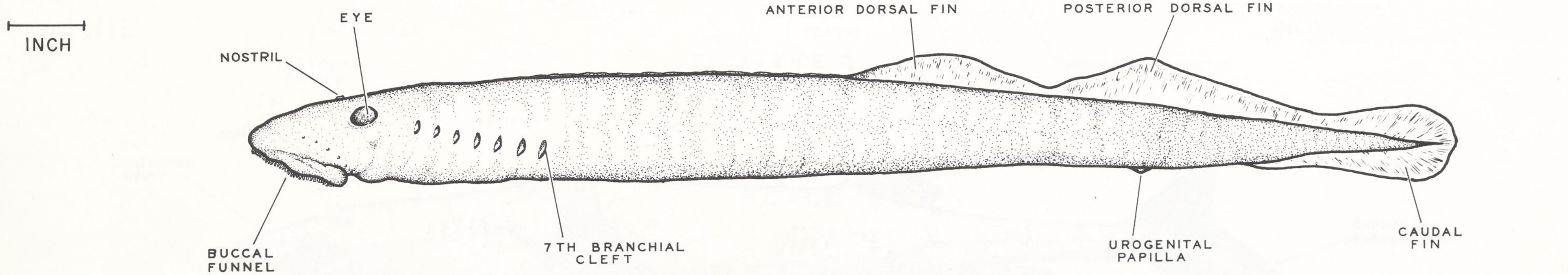


ATLAS OF FISH ANATOMY. K. F. Lagler, 1962. PLATE I. External features of a composite fish (Q. Carlson, del.)





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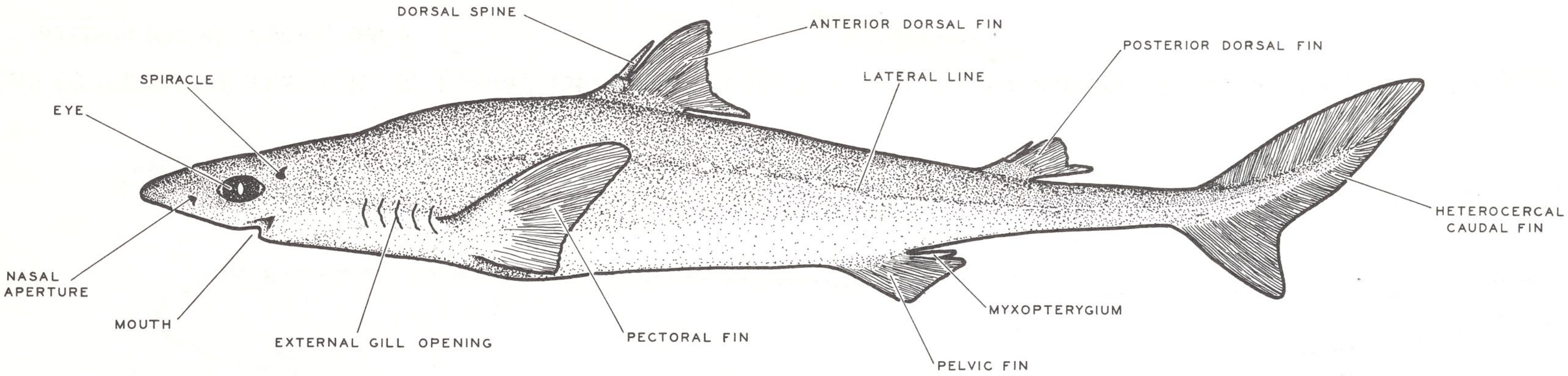

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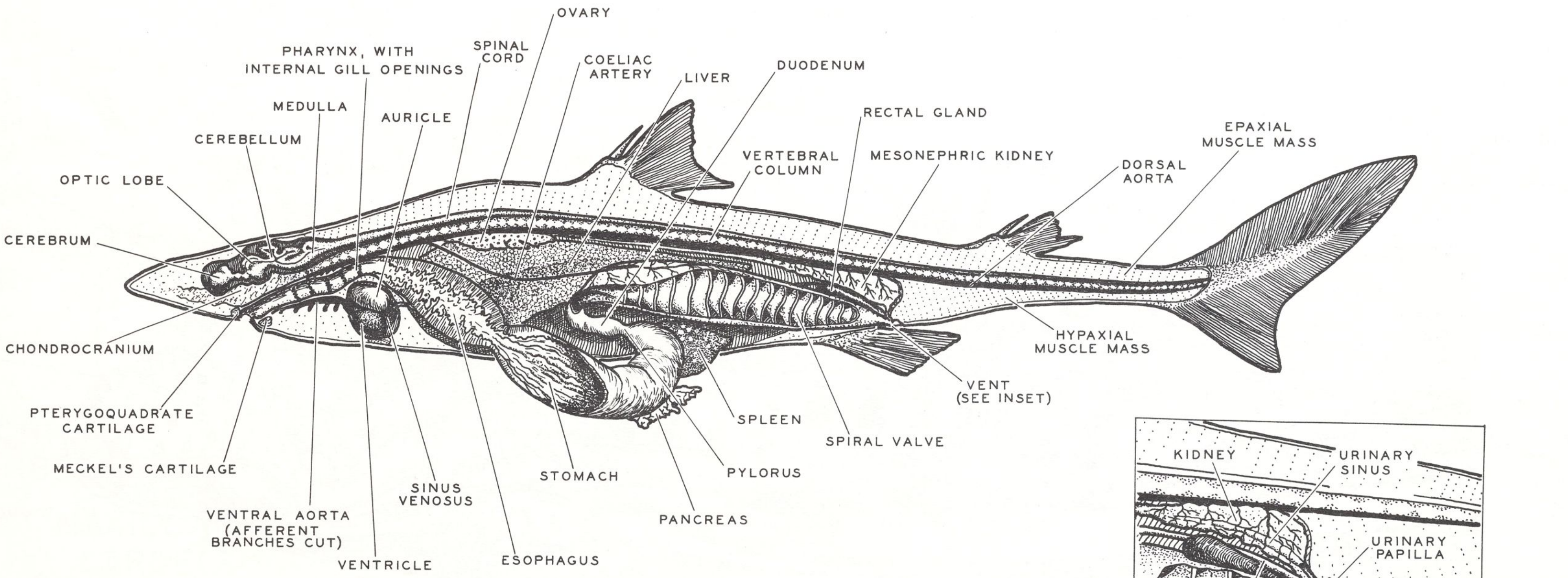

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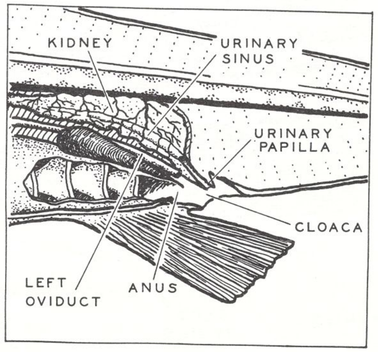

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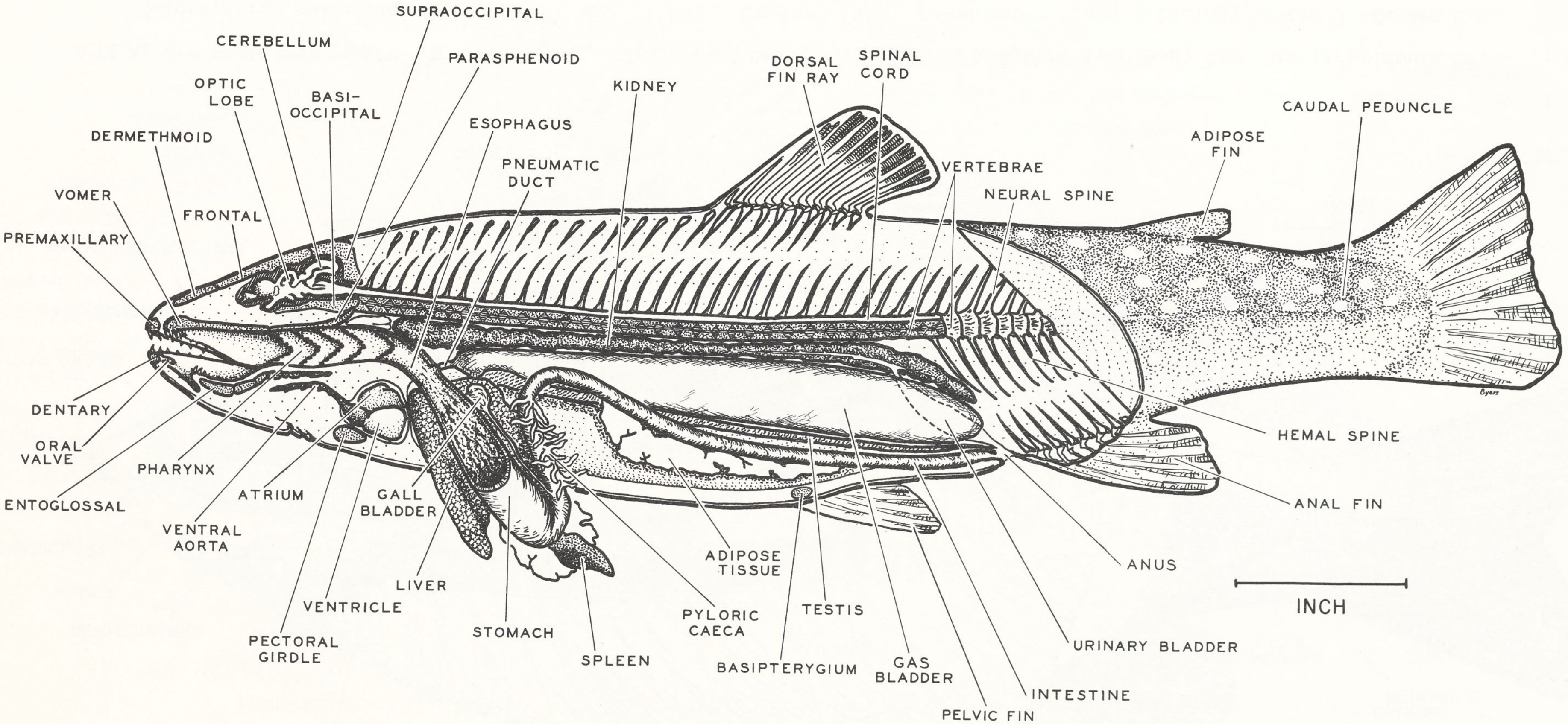
ATLAS OF FISH ANATOMY. K. F. Lagler, 1962. PLATE III. Anatomy of a shark, the spiny dogfish, Squalus acanthias (G. W. Byers, del.)

INTERNAL ANATOMY OF THE BROOK TROUT



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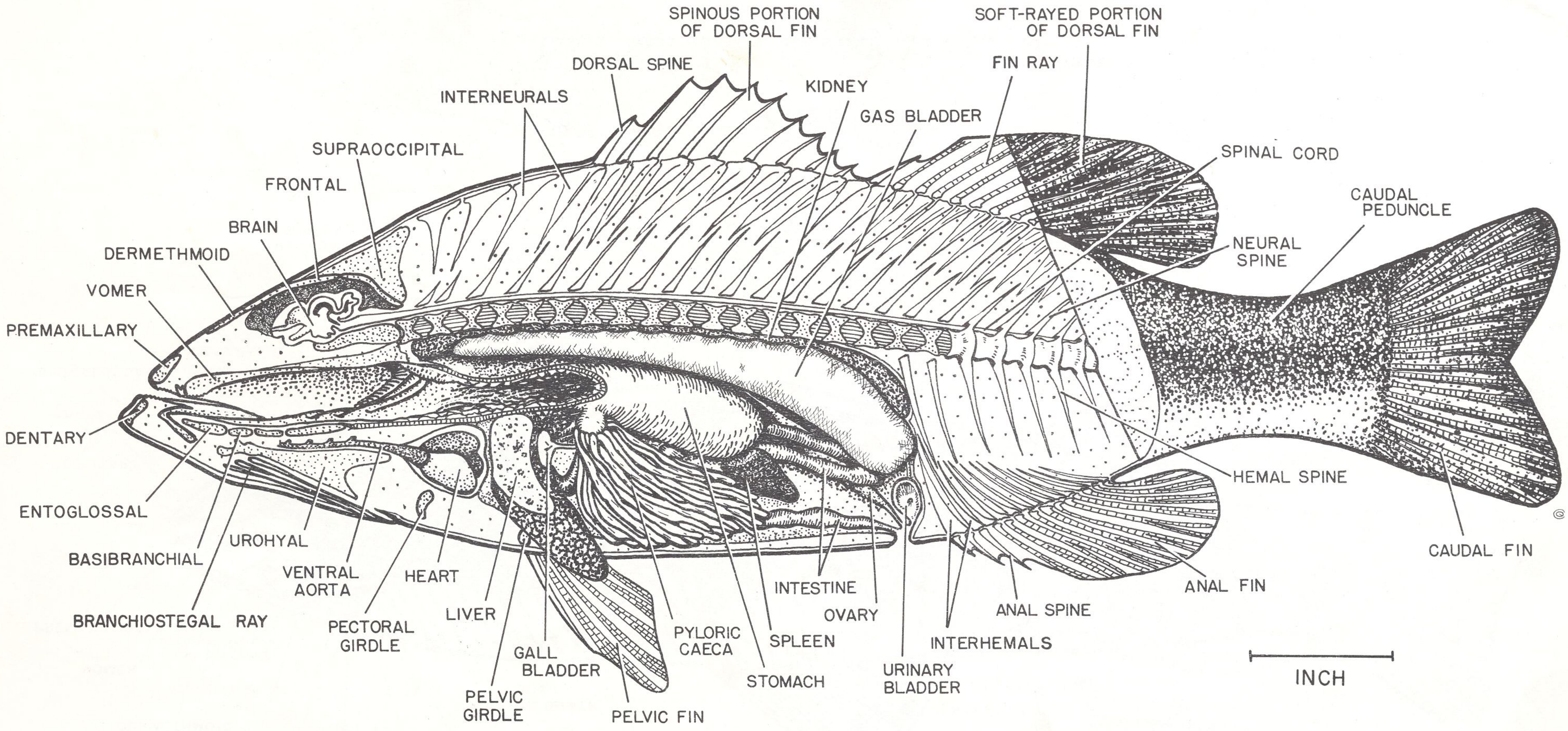
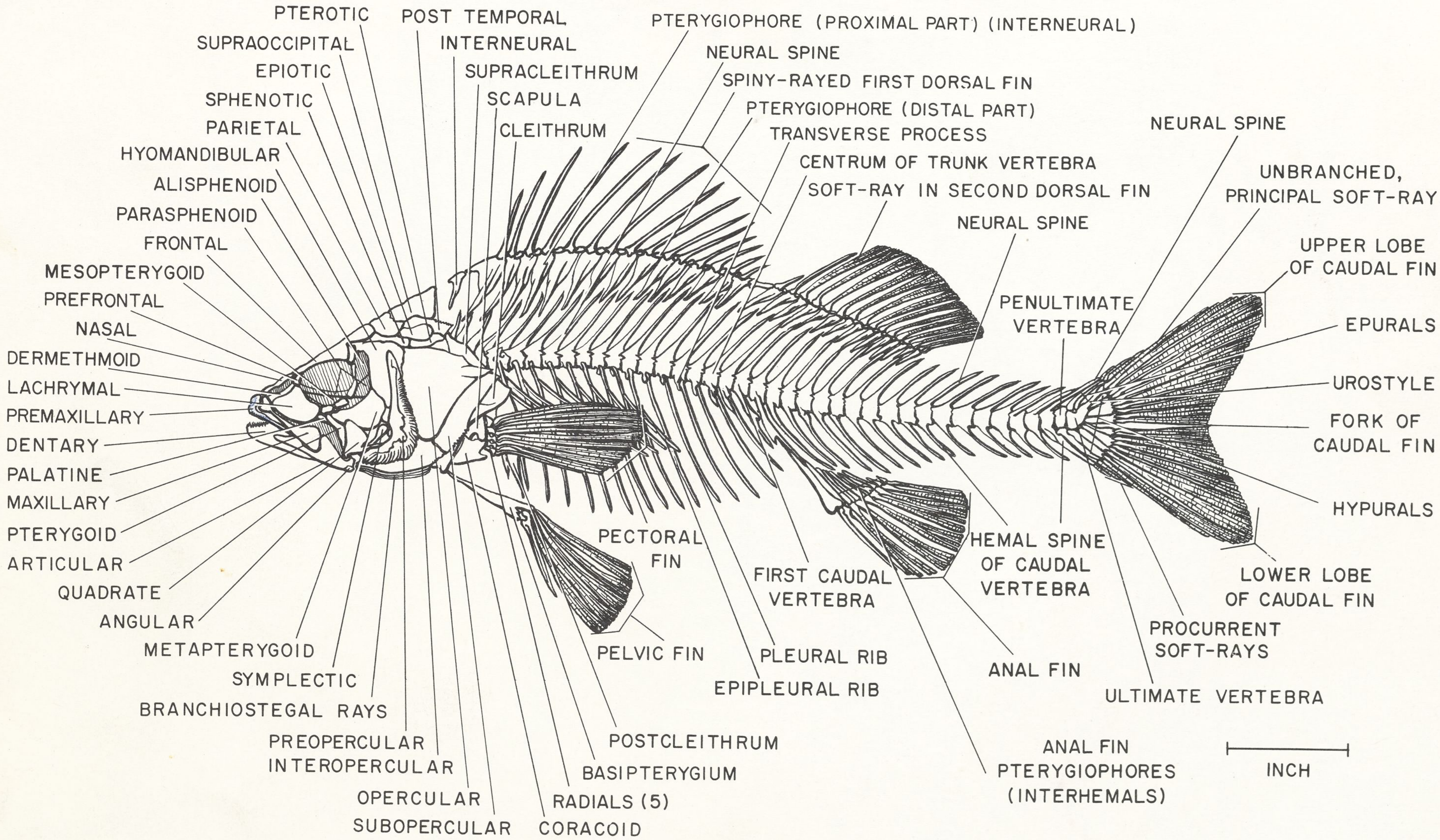
ATLAS OF FISH ANATOMY. K. F. Lagler, 1962. PLATE IV. Anatomy of a soft-rayed bony fish, the brook trout, Salvelinus fontinalis (G. W. Byers, del.) (From Lagler, 1956, Freshwater Fishery Biology, Wm. C. Brown Co., Dubuque, Iowa)



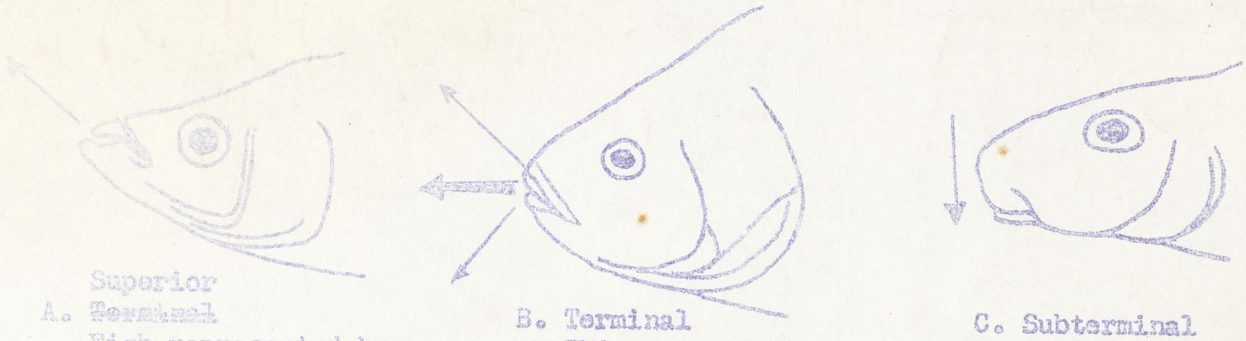
ATLAS OF FISH ANATOMY. K. F. Lagler, 1962. PLATE V. Anatomy of a spiny-rayed bony fish, the largemouth bass, Micropterus salmoides (Q. Carlson, del.) (From Lagler, 1956, Freshwater Fishery Biology, Wm. C. Brown Co., Dubuque, Iowa)



ATLAS OF FISH ANATOMY. K. F. Lagler, 1962. PLATE VI. Skeleton of a spiny-rayed bony fish, the yellow perch, Perca flavescens (J. N. Richman, del.)

FISH MORPHOLOGY

Mouth position — indicates where a fish feeds — surface, mid-water, or bottom.

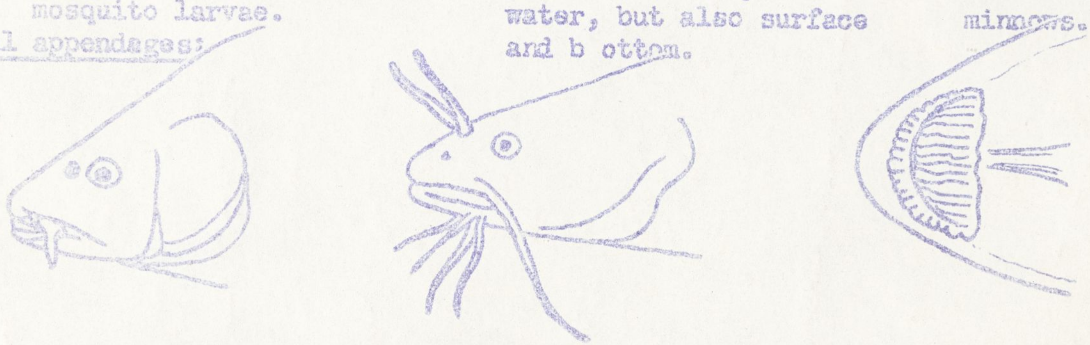


A. ~~Terminal~~ Superior
Fish represented here is the mosquitofish; a surface feeder on mosquito larvae.

B. Terminal
This type is the most flexible in use — primarily mid-water, but also surface and b ottom.

C. Subterminal
Adapted for bottom feeding; includes the sucker and sucker-like minnows.

Oral appendages:



A. Maxillary barbel of the carp.

B. Maxillary and chin barbels of a cat-fish.

C. Fleshy lips of a sucker; bear sensory papillae.

Pharyngeal teeth:

A. Pharyngeal archesof a minnow; tooth formula 2,5—4,2; teeth may be highly variable in shape.

B. Pharyngeal teeth of a sucker; note only 1 row, with teeth of a uniform shape.

C. Unfused, lower pharyngeal arches of a predatory fish(perch)

D. Fused lower pharyngeals of a surf perch; note molariform teeth.

Dentary teeth are absent in minnows and suckers; in these two groups, the pharyngeal teeth are the functional teeth. Molariform teeth crush the carapaces of crustaceans and various invertebrates. In the vast majority of fishes, the lowere pharyngeals are unfused, narrow and elongate, and covered with villiform(hair-like) teeth.

Gill rakers:

Gill rakers are tooth-like projections on the anterior surface of the gill arches. In fish that feed on phytoplankton, the ~~teeth~~ rakers are wedge-shaped and possess a brush-like surface. In fish that feed on zooplankton, the rakers are many in number, closely spaced, and extremely long. Predatory fish have small or reduced rakers which sometimes are transformed into tooth-bearing plates. Differences in gill raker number between two species or subspecies often reflect differences in feeding habits and general ecology.

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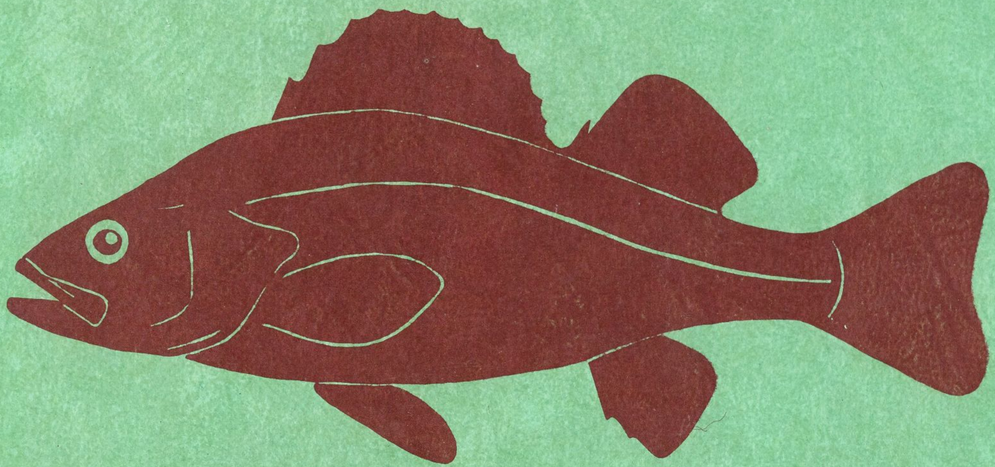
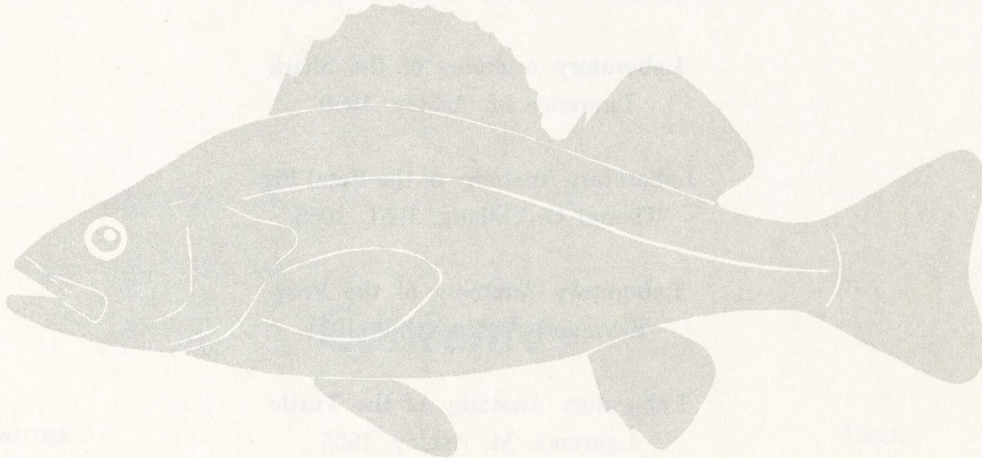


LABORATORY ANATOMY OF THE PERCH

ROBERT B. CHAISSON

LABORATORY ANATOMY OF THE



PERCH

ROBERT B. CHIASSON

Professor of Zoology
University of Arizona
Tucson, Arizona

Illustrated by THE AUTHOR

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Contents

Preface

Although the yellow perch (*Perca flavescens*) has long been a common form for laboratory dissection, there is no complete description of the anatomy of the perch in the English language.

Many elementary zoology and comparative anatomy laboratory manuals treat the perch superficially but the dogfish shark is usually considered as the "fish" to be treated in detail. While it is true that the dogfish is easily dissected, it is not representative of the majority of fishes nor of a "primitive" fish. Indeed the dogfish is a highly specialized form quite distinct from all bony fishes. The perch is a representative of the largest vertebrate class, *Osteichthyes*.

Thus, in spite of the fact that bony fishes make up the largest living class of vertebrates their anatomy is virtually ignored or at best, glossed over by the authors of textbooks and laboratory manuals. Hopefully, this manual will help to fill some of the void in this area.

In addition to a systematic description of the anatomy of the perch, certain structures of other fishes are included in this manual for comparison. The other fishes which are included are available from biological supply houses and help to show the diversity of form in this vast group of vertebrates.

As in the other manuals of this series, more descriptive material is included than is usually covered in an undergraduate course. This provides some latitude of choice on the part of the laboratory instructor.

DISSECTION TECHNIQUES

Some special materials will be necessary if all of the dissections and investigations described in this manual are to be covered.

Microscope slides of the skin and of entire scales are available from biological supply firms. The study of these slides will require a compound microscope with magnification to 400x. Investigation of some of the dissections (brain, for example) may require a dissecting microscope.

Prepared skeletal material is available from most biological supply firms. Generally this material is not thoroughly cleaned and unless the instructor carefully cleans the skeletons the student will not be able to see many of the skull bones. If a thorough dissection is desired it might be best to have an early cursory examination of the prepared material and a later, complete, study of the skull of the students' dissection specimen. If so, the second study of the skull should precede the study of the nervous system but should follow the study of the muscular, respiratory and circulatory systems.

It is assumed that injected specimens will be available for the study of the circulatory system. Specimens with four separate injections (1. prebranchial arteries, 2. post branchial arteries, 3. post caval veinous, and 4. hepatic portal veinous) would be helpful for demonstration if they can be obtained.

Skinning is usually a simple procedure. However, connective tissue of the skin may adhere to the underlying muscles and may tear the muscles as you pull the skin away. Extreme care should be taken to avoid destruction of the small fin muscles during skinning. A study of the head muscles may require removal of the opercular shield and a portion of the lower jaw. These bones should be removed from one side *only*. The latter restriction will preserve the opposite side for later study.

Additional, specific directions for dissection will be found at appropriate places in the text.

Deep appreciation is extended to Dr. Donald A. Thomson, Department of Zoology, University of Arizona, for his critical review of the manuscript. This critique was directly responsible for preventing the inclusion of several errors and for updating the section on classification. I also wish to express my thanks to Mr. John Gerdes for drawing Figure 10 in this manual.

CHAPTER 1

Introduction

SYSTEMATIC POSITION

Bony fishes are the largest group of vertebrate animals living today, both in numbers of individuals and in numbers of species. They occur in both fresh and sea water, from the North Pole to the South Pole, and completely around the world. They live at depths in the oceans as great as seven miles and in mountain streams or lakes as high as three miles above sea level.

Such great diversity has produced many problems in the classification of fishes and even more problems to those workers attempting to discover the evolutionary interrelationships of fishes. These problems have led to considerable argument among icthyologists as to the classification and evolution of fishes.

The most widely used classifications of fishes may be found in the following:

BERG, L. S. 1940. Classification of fishes both recent and fossil. Trav. Inst. Zool. Acad Sci. URSS, 5:87-517. Reprinted 1947 by Edwards Brothers, Ann Arbor, Mich.

GRASSE, P. 1958. Agnathes et poissons anatomie, ethologie, systematique. *In* Traite de Zoologie. Tome XIII, vols. Masson et Cie, Paris.

GREGORY, W. K. 1933. Fish skulls: A study of the evolution of natural mechanisms. Trans. Amer. Philos. Soc. 23:75-481.

JORDAN, D. S. 1923. A classification of fishes including families and genera as far as known. Stanford Univ. Publ. Biol. Sci., 3(2):79-243.

REGAN, C. T. 1929. Fishes. *In* Encyclopedia Brittanica, 14th ed., 9:305-328.

The consensus of opinion of most contemporary workers is to group all bony fishes in the class, *Osteichthyes*. The class in turn is subdivided into four subclasses, *Actinopterygii, Crossopterygii, Brachiopterygii,* and *Sarcopterygii*. The following outline will illustrate the arrangement of the major groupings:

Class *Osteichthyes*
- Subclass *Crossopterygii*
  - Order *Crossopterygii*
- Subclass *Sarcopterygii* (Dipneusti)
  - Order *Dipteriformes*
- Subclass *Brachiopterygii*
  - Order *Polypteriformes*
- Subclass *Actinopterygii*
  - Superorder *Chondrostei*
    - Order *Acipenseriformes*
  - Superorder *Holostei*
    - Order *Amiiformes*
    - Order *Lepidosteiformes*
  - Superorder *Teleostei*
    - Order *Clupeiformes*
    - Order *Cypriniformes*
    - Order *Anguilliformes*
    - Order *Perciformes*

A classification (including all the possible categories) of the yellow perch is as follows:

Phylum: Chordata
Subphylum: Vertebrata
Class: Osteichthyes
Subclass: Actinopterygii
Superorder: Teleostei
Order: Perciformes
Suborder: Percoidea
Family: Percidae
Genus: Perca
Species: *Perca flavescens*
Common name: Yellow Perch

CHAPTER 2

External Anatomy and Skin

The body of a fish is divided into three parts, *head, trunk,* and *tail.* The head and trunk are separated from each other by the gill openings which are covered laterally by a bony *operculum.* The posterior edge of the operculum provides a good, practical posterior border for the head. The posterior limit of the trunk in the perch is marked by the ventral, *anal* and *urogenital* openings.

THE HEAD

The head of the perch has three notable structures; a *mouth,* two *nostrils* and two *eyes.*

The overall shape of the perch is fusiform or torpedo-shaped. Consequently, the head is smaller than the trunk. There is a taper (in side view) from the mouth to the deepest part of the trunk, just behind the appendages. The slope is more abrupt on the dorsal side than it is on the ventral.

The mouth of the perch is *terminal* on the head but in some other fishes it may be *superior* (dorsal) or *inferior* (ventral). The position of the mouth on the head reflects the manner in which the fish feeds. If the mouth is superior, the fish is usually a surface feeder. If the mouth is inferior, the fish is usually a bottom feeder. If the mouth is terminal as in the perch, the fish usually feeds by overtaking prey while swimming.

The lips of the perch are membranous with teeth on the lower edge of the mouth (mandible) and on the most anterior portion of the upper lip (premaxillary). The maxillae, which are excluded from the gape in the perch, are toothless (see Chapter 3).

There are four nasal apertures in the perch; two on each side of the midline just above the mouth. Water enters each nasal sac through the anterior nasal aperture and leaves by the posterior aperture. Lidless eyes are situated on each side of the perch head so that binocular vision is impossible. Some other fishes have a nictating membrane covering the eye.

THE TRUNK

The trunk increases in size posteriorly from the head to the dorsal median fin. Posteriorly, the tail tapers down from the trunk to the caudal fin. The overall shape of the perch body is *fusiform* (torpedo-shaped). In cross-section the trunk is "tear-drop" shaped.

Another term for describing the perch body (especially in cross-section) is, *compressed.* There are four categories of fish body shapes, *compressed, depressed, truncated,* and *attenuated.*

The perch has two sets of paired appendages, called *pectoral* and *pelvic* fins. In spite of the fact that the two sets of paired fins are at the anterior end of the perch trunk they are still homologous to the paired appendages of tetrapods.

The paired pectoral fins are located high on the sides of the trunk and just behind the gill openings. In fact, the bones on which the pectoral fins are based are attached directly to the skull (see Chapter 3).

The pelvic fins are set far anterior on the trunk, just posterior to the pectoral fins. The two pelvic fins are close together on the anterior ventral surface of the trunk in the thoracic position as compared to the posterior abdominal pelvics of more primitive bony fishes.

In addition to paired fins the perch has four median, unpaired, fins. The names of these fins indicate their position on the body. The anterior dorsal fin begins at the anteriormost point of the trunk on the dorsal side. The posterior dorsal fin is directly behind the anterior dorsal fin. The anterior dorsal fin is supported by spiny fin rays but the posterior dorsal fin is *soft* and spineless.

The posterior end of the trunk and the beginning of the tail are marked by the external orifices, *anal* and *urogenital* (urinary and genital openings are separate in the male; see Chapter 8). Just posterior to these openings is a ventral *anal fin.*

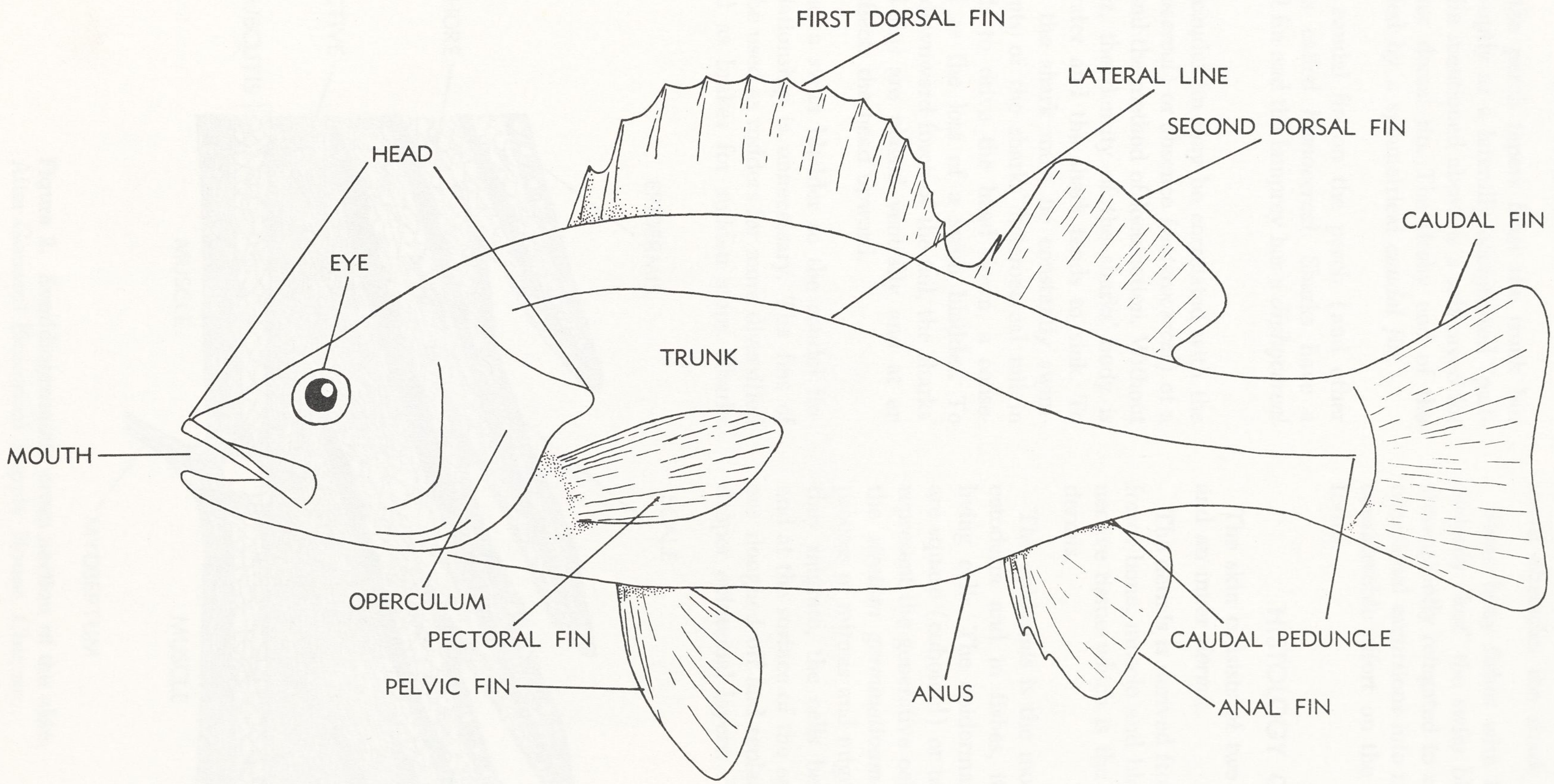

Figure 1. External anatomy of the Perch. Modified after Hubbs and Lagler, Fishes of the Great Lakes Region. Cranbrook Inst. Sci., Bull. 26 (1949).

THE TAIL

The tail of the perch tapers from the trunk but ends rather abruptly as a laterally compressed "paddle." The anal fin mentioned above is a soft rayed fin like the posterior dorsal fin. The fleshy end of the tail is surrounded by a symmetrical *caudal fin.*

The type of caudal fin on the perch (and other bony fishes) is called *homocercal.* Sharks have a *heterocercal* tail fin and the lamprey has a *diphycercal* tail.

The type of caudal fin may be correlated with the presence (*homocercal*) or absence (*heterocercal*) of a swim bladder and the method of locomotion. Without a swim bladder, the density of the sharks' body is greater than water and the shark tends to sink. To counteract this the shark must be constantly swimming. Movements of the sharks' heterocercal tail in swimming tends to drive the head down, a consequence as bad as the loss of a swim bladder. To counteract the downward force of the tail, the sharks' paired pectoral fins are placed ventrally and at an angle which deflects the head upward.

The perch has a swim bladder so the caudal fin-pectoral fin relationship is unnecessary. The fins of the perch may be used as rudders for more diversified movements and as brakes for sudden stops. Sharks cannot brake their forward movement. In order to avoid obstacles the shark must turn sharply.

Some bony fishes with homocercal tails have secondarily "lost" the swim bladder (or lungs) and are consequently relegated to a bottom dwelling life. The occasional excursions into more shallow levels require considerable effort on the part of these buoyantless forms.

HISTOLOGY OF THE SKIN

The skin consists of two parts, an outer *epidermis* and an inner *dermis.*

The dermis is derived from mesenchyme which also forms bone, muscle and blood vessels as well as connective tissue which is the predominant tissue of the dermis.

The epidermis is the most prominent derivative of ectoderm and in fishes, it is composed entirely of living cells. The epidermal cells nearest the dermis are square (cuboidal) or tall (columnar). These cells represent the generative cell layer of the epidermis or the *stratum germinativum.* New cells form by the process of mitosis and migrate toward the surface. As they migrate, the cells become progressively flatter and at the surface of the epidermis the flattened cells are sloughed off and replaced by new cells from the deeper epidermal layers.

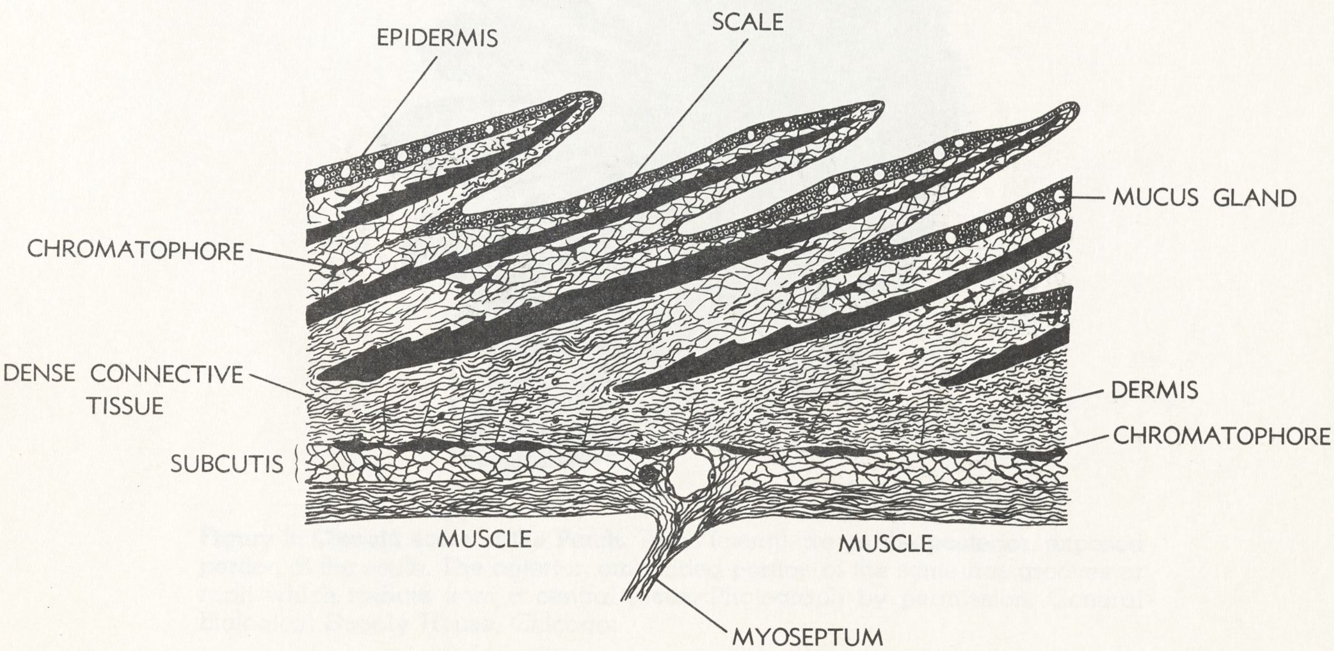

Figure 2. Semidiagramatic cross section of the skin.
After General Biological Supply House, Chicago.

In several epidermal cells the cytoplasm of the cell undergoes a decomposition to form mucus. To some small extent this mucus may help to restrict the passage of water through the skin.

The dermis is composed of a dense fibrous connective tissue containing bony scales and attached to the underlying muscles by a *subcutis*. The subcutis is a loose network of connective tissue. Pigment (color) cells are present in both the epidermis and subcutis.

The scale of the perch is a thin, flexible, plate composed of two parts. The outer portion of the scale is the so-called "bony" portion. Presumably the bony portion of the scale has most of the inorganic material but there are exceptions. The deeper or inner portion of the scale is called the fibrous layer and it is composed of several layers of fibrous connective tissue. Each connective tissue layer is arranged at right angles to each of the layers adjacent to it. The result is a crisscross of fibers which make the scale strong but flexible. In a few species of fish the fibrous layer may be imbedded with some calcium salts but this is not usually the case in the perch.

The scale of the perch is called *ctenoid* because the exposed, posterior portion bears small spiny structures called *ctenii*. In *most* instances ctenoid scales are found on those fishes with stiff spines in their fins. Soft rayed fishes have scales which usually lack ctenii and this type of scale is termed *cycloid*.

Fish scales are useful in age and growth studies of fishes.

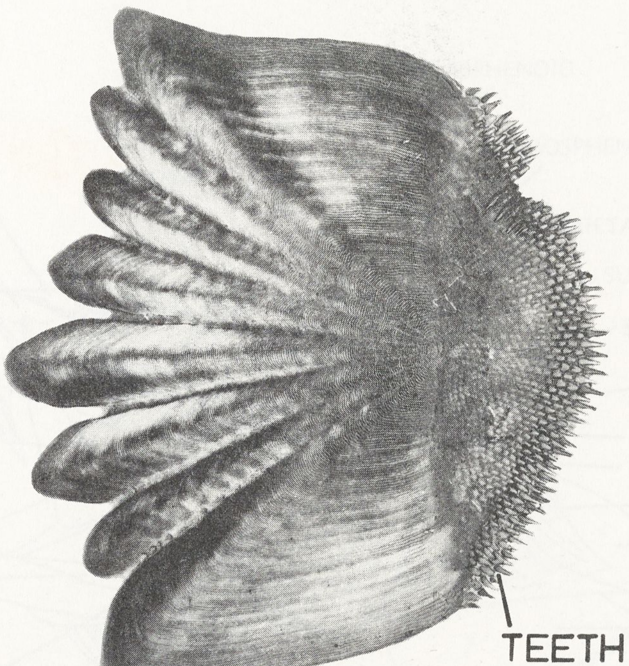

Figure 3. Ctenoid scale of the Perch. Teeth (ctenii) are on the posterior, exposed portion of the scale. The anterior, embedded portion of the scale has grooves or radii which radiate from a central **focus.** Photograph by permission, General Biological Supply House, Chicago.

CHAPTER 3

The Skeleton

The skeleton of the perch is composed of bone and consists of axial and appendicular parts. Prepared skeletons of the perch will be necessary for this study. The bones of the prepared skeletons are delicate and easily broken. Be especially careful in handling these skeletons. Do not use pencils or pens for pointers. Use a mounted needle or metal probe when pointing out bones to your neighbor or to the instructor.

THE AXIAL SKELETON

The axial skeleton includes the bones of the skull, the vertebrae and the ribs.

THE SKULL

The skull of the perch is actually a double skull. The outer skull which you will see first is an outer armour of *dermal* bone. Dermal bone forms in the dermis of the skin in a manner somewhat similar to the formation of scales, that is, the bone forms directly from the embryonic cells of the dermis and is not preceded by a cartilage structure.

The inner skull is composed of bone formed deep in the body (subdermal) and the individual skeletal structures are usually preceded in development by a

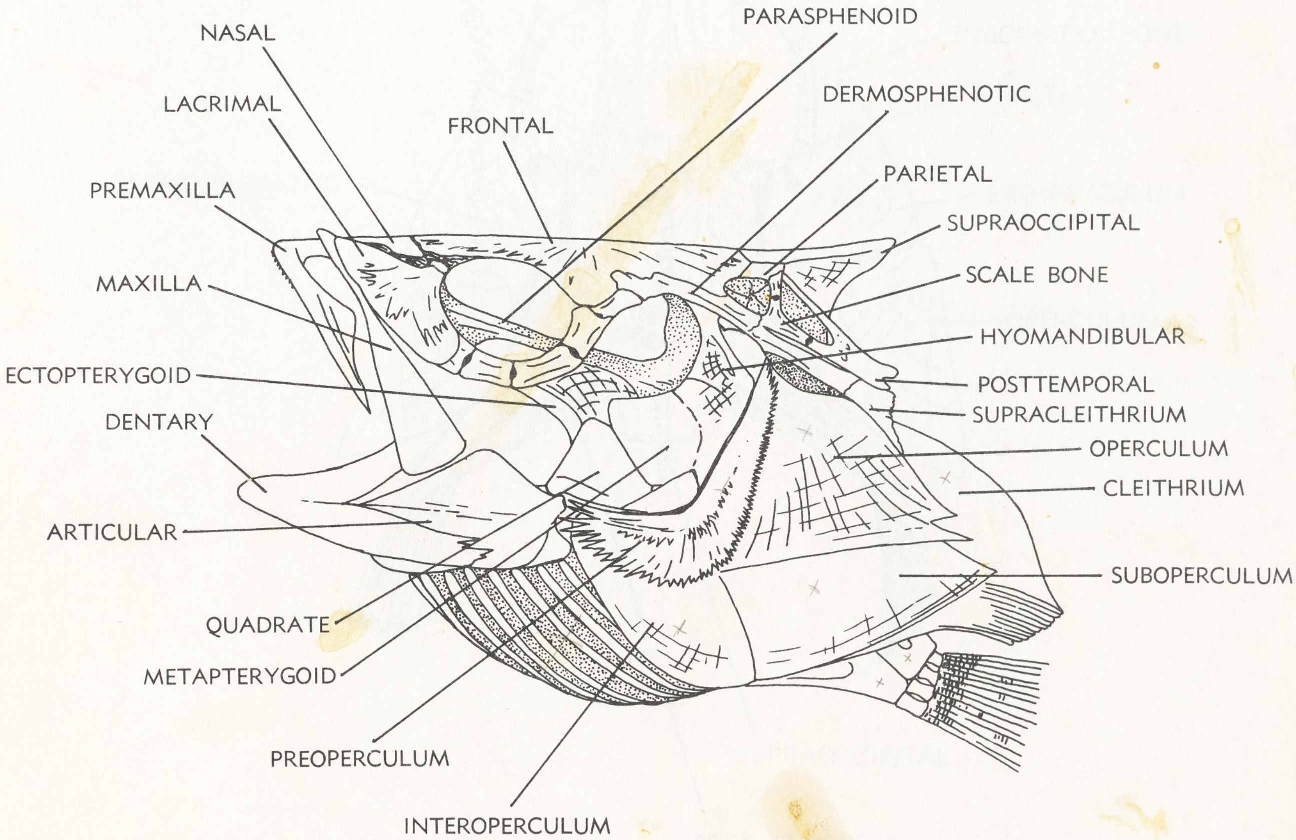

Figure 4. Lateral view of the skull.

corresponding cartilage structure, hence the name *endochondral* or *cartilage* bone.

I. The Dermoskeleton of the Head.

A. The Skull Roof.

1. *Nasal* bones are small, paired, anterior bones bordering the nasal capsule. These small bones are widely separated in the midline. Prepared skulls should be carefully cleaned of dried connective tissue in the region of the nasal bones. In most preparations these bones are completely obscured by dried tissues.

2. *Frontal* bones are also paired dermal bones. These are the largest bones of the dermal skull roof. The frontals make up most of the head shield including the dorsal border of the orbit. Some authors call these bones the parietals and the following set of bones are then called postparietals.

3. *Parietal* bones are very small paired bones just posterior to the frontals. These bones are separated in the midline by the dorsal spine of the supraoccipital.

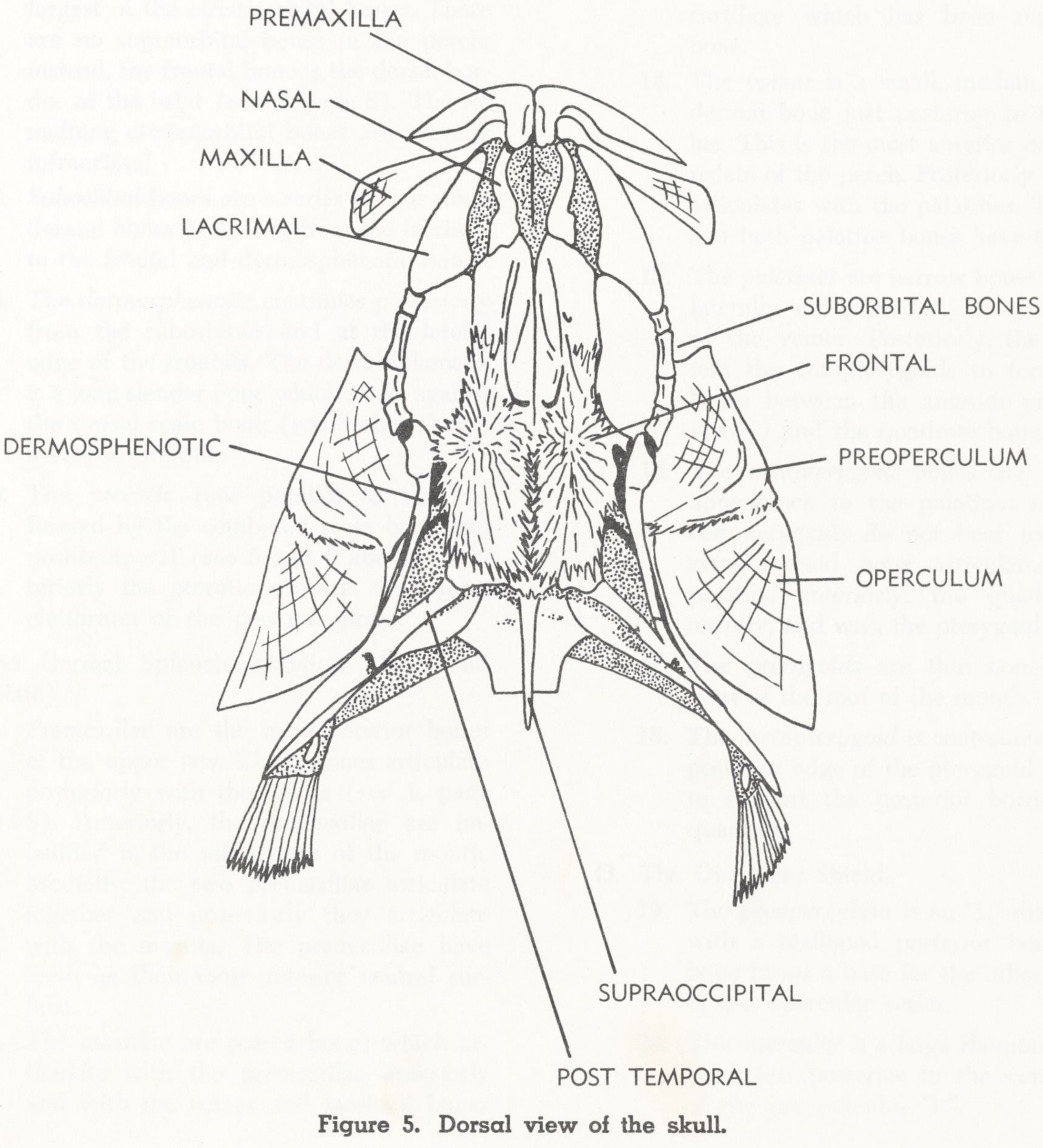

Figure 5. Dorsal view of the skull.

4. A *dermal epiotic* bone abuts against each parietal bone. Each dermal epiotic bone together with a scale bone and a post-temporal make up a system of posterior struts which arch laterally from the parietal and supraoccipital.
5. *Scale bones,* one on each side, form an angle which unites the dermal epiotic with one arm of the Y-shaped post-temporal.
6. *Post-temporals* form the dorso-posterior corner of the dermocranium.

B. Circumorbital Bones.

7. The *lacrimal* is the most anterior and the largest of the circumorbital bones. There are no supraorbital bones in the perch; instead, the frontal bone is the dorsal border of the orbit (see 2, page 8). The remaining circumorbital bones are actually infraorbital.
8. *Suborbital* bones are a series of four small dermal bones extending from the lacrimal to the frontal and dermosphenotic bones.
9. The *dermosphenotic* continues posteriorly from the suborbitals and at the lateral edge of the frontals. The dermosphenotic is a long slender bone which abuts against the dorsal scale bone (see 5 above) and a ventral pterotic.
10. The *pterotic* runs parallel to the bar formed by the combined scale bone and post-temporal (see 5 and 6 above). Posteriorly the pterotic contacts the supracleithrium of the pectoral girdle.

C. The Dermal Splanchnocranium (Jaws and Palate).

11. *Premaxillae* are the most anterior bones of the upper jaw. These bones articulate posteriorly with the nasals (see 1, page 8). Anteriorly, the premaxillae are imbedded in the soft tissues of the mouth. Medially, the two premaxillae articulate together and posteriorly they articulate with the maxilla. The premaxillae have teeth on their most anterior ventral surface.
12. The *maxillae* are paired bones which articulate with the premaxillae anteriorly and with the vomer and lacrimal bones posteriorly. Laterally, the maxilla is buried in soft tissues. Both the premaxilla and maxilla are partially covered by the lacrimal (see 7 above). The three bones, premaxilla, maxilla, and lacrimal overlap one another somewhat like shingles on a roof. With this arrangement, each bone gains some strength from each of the others. The maxilla do not bear teeth.
13. The *angular* bone is a small bone at the posterior inferior angle of the lower jaw. Three bones; *dentary, articular,* and *angular* make up the lower jaw of the perch. The articular is not a dermal bone but represents the posterior half of Meckel's cartilage which has been replaced by bone.
14. The *vomer* is a small, median, unpaired dermal bone just posterior to the maxillae. This is the most anterior bone of the palate of the perch. Posteriorly the vomer articulates with the palatines. The vomer and both palatine bones have teeth
15. The *palatines* are narrow bones extending laterally and posteriorly from either side of the vomer. Posteriorly, the palatines join the ectopterygoids to form a solid brace between the anterior palate (the vomer) and the quadrate bone.
16. The *ectopterygoid* bones are similar in appearance to the palatines except the ectopterygoids do not bear teeth. Each ectopterygoid bone articulates with a palatine anteriorly, the quadrate posteriorly, and with the pterygoid medially.
17. The *pterygoids* are thin bones forming most of the roof of the mouth.
18. The *metapterygoid* is continuous with the posterior edge of the pterygoid and helps to support the posterior border of the quadrate.

D. The Opercular Shield.

19. The *preoperculum* is an "L"-shaped bone with a scalloped posterior border. This bone forms a base for the other members of the opercular series.
20. The *opercular* is a large rhomboid shaped bone just posterior to the vertical limb of the preopercular "L".

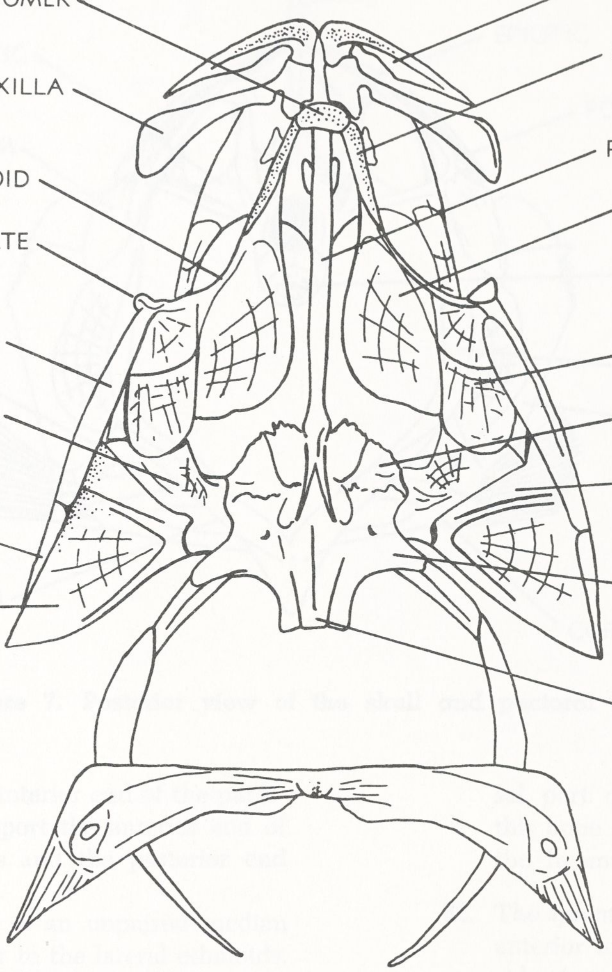

Figure 6. Ventral view of the skull with lower jaws, hyoid and branchial arches removed.

21. The *interopercular* forms the anterior ventral border of the operculum.

22. The *subopercular* forms the posterior ventral border of the operculum.

II. The Endoskeleton of the Head.

A. The Cranium.

23. The *parasphenoid* is a long slender unpaired bone extending from the vomer to the endocranium (basioccipital) between the two pterygoids (see 17, page 9).

24. The *basioccipital* is the true floor of the braincase. The slender parasphenoid separates the basioccipital and the toothed palate (vomer and palatines). Laterally the two exoccipitals join the basioccipital and form the walls of the cranial box.

25. The *exoccipitals* (see 24 above) in posterior view (Figure 7) resemble the transverse processes of vertebrae. The posterior face of each exoccipital is expanded to receive the expanded anterior face of the prezygopophyses of the first vertebra (see Figure 11).

26. The *supraoccipital* serves as the roof of the braincase and provides a large spine for the attachment of trunk muscles.

27. *Lateral ethmoid* bones extend dorsally from the anterior end of the parasphenoid

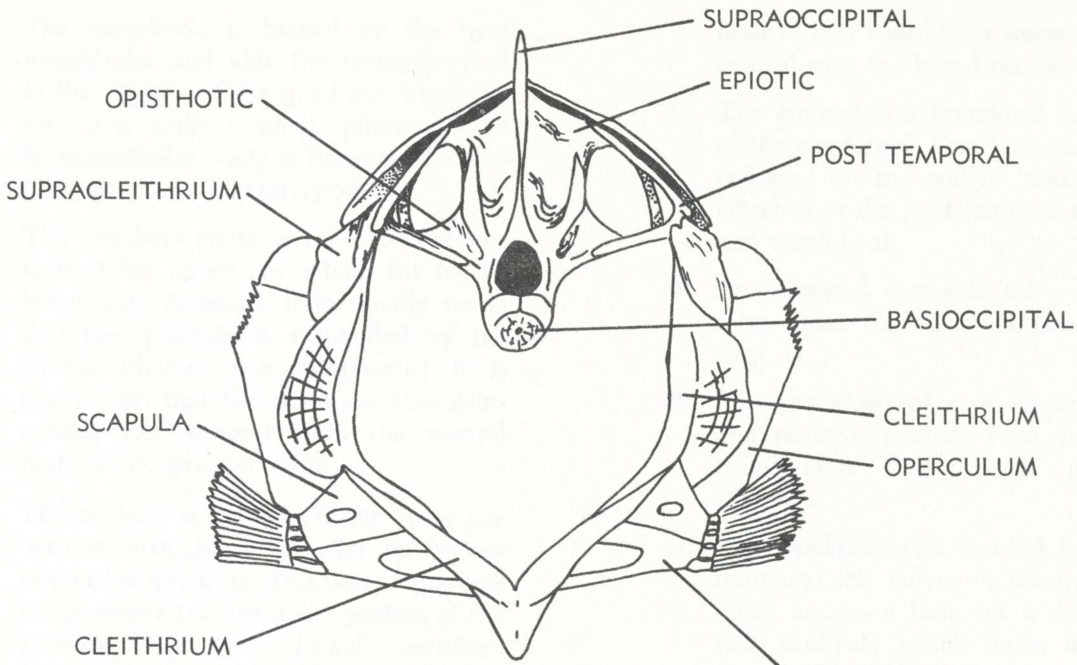

Figure 7. Posterior view of the skull and pectoral girdle.

and support the anterior end of the parasphenoid and support the anterior end of the frontal bones and the posterior end of the lacrimaals.

28. The *mesethmoid* is an unpaired median bone just anterior to the lateral ethmoids. This bone is based on the vomer and contacts the posterior end of the nasals and the anterior end of the frontals.
29. The *epiotic* bone may be seen on skulls in which the occipital region is fairly well cleaned. Both the epiotic and opisthotic bones are contacted by the post-temporal (see 6) which is a V-shaped bone with the point of the V directed posteriorly and the two arms arranged so one arm is dorsal and the other is ventral. The dorsal arm contacts the epiotic and the ventral arm contacts the opisthotic.
30. The *opisthotic* (see 29 above) is the most posterior portion of the otic capsule. This bone and the preceding (epiotic) are probably the only bones of this series which you will be able to see.
31. The *prootic* is at the ventro anterior corner of the cranial "box". The anterior dorsal part of the hyomandibular contacts this bone and the posterior dorsal part of the hyomandibular contacts the epiotic.
32. The *sphenotic* is dorsal to the prootic and anterior to the epiotic. This bone lies inside (medial) the dermosphenotic (see 9). These bones (epiotic, opisthotic, prootic, and sphenotic) contain the semicircular canals.

B. The Endochondral Jaws and Suspensorium.

33. The *hyomandibular* is located between the quadrate and the cranium (see 29 and 31 above). This bone represents a partial remnant of the primitive first branchial arch which, together with a ventral portion (ceratohyal and basihyal), forms the hyoid arch. In tetrapods the hyomandibular is associated with the ear to conduct sound vibrations from the tympanum to the inner ear. In these vertebrates the bone is known as the stapes. Ventrally, the hyomandibular of the perch contacts two bones, an anterior metapterygoid (see 18) and a posterior symplectic.

34. The *symplectic* is braced by the hyomandibular and aids the metapterygoid in the support of the quadrate. The symplectic is really a small splinter of the hyomandibular wedged between the preoperculum and metapterygoid.

35. The *quadrate* contains the articular surface of the upper jaw which fits in the lower jaw. Although it is usually noted that the quadrate is suspended by the hyomandibular (and symplectic) it is easily seen that the quadrate also gains considerable support from the ventral limb of the preoperculum.

36. The *articular* is the bone of the lower jaw with an articular surface for the reception of the quadrate. This bone represents the posterior (or proximal) portion of the primary lower jaw, *Meckel's cartilage.* This juncture between the quadrate and articular is the jaw articulation of all vertebrates except mammals.

C. The Hyoid Apparatus and Gill Arches.

A part of the hyoid apparatus has been described as a part of the jaw suspensorium. The remainder of the hyoid serves as a base for the gills. Most of this apparatus is of endochondral bone but a few exceptions are noted.

37. The *ceratohyals* are the main body of the hyoid apparatus. These bones are separated in the anterior midline by the hypohyal. Posteriorly they have an attached epihyal and ventrally a series of branchiostegal rays are based on the ceratohyal.

38. The *epihyal* is a functional continuation of the ceratohyal. One branchiostegal ray is based on the epihyal and another is attached at the joint between the epihyal and ceratohyal.

39. An *interhyal* suspends the entire apparatus from the hyomandibular (see 33 page 11).

40. Six *branchiostegal* rays extend ventrally and posteriorly from each side of the hyoid arch. These bones are dermal structures.

41. The *hypohyal* serves as a link between the right and left halves of the hyoid apparatus, and as a base for a dermal bone (the urohyal) which forms in the connective tissues between the long throat muscles.

42. The *urohyal* is a dermal, not endochondral bone, but it is intimately associated with the hyoid apparatus.

43. The *gill apparatus* is a complicated series of four bony arches which support the gills. Each arch is based ventrally on a basibranchial and consists of (from ventral to dorsal) a *hypobranchial,* a *ceratobranchial,* and an *epibranchial.* Dorsally each epibranchial is attached to a fused *pharyngobranchial* complex. The first three pharyngobranchials are fused

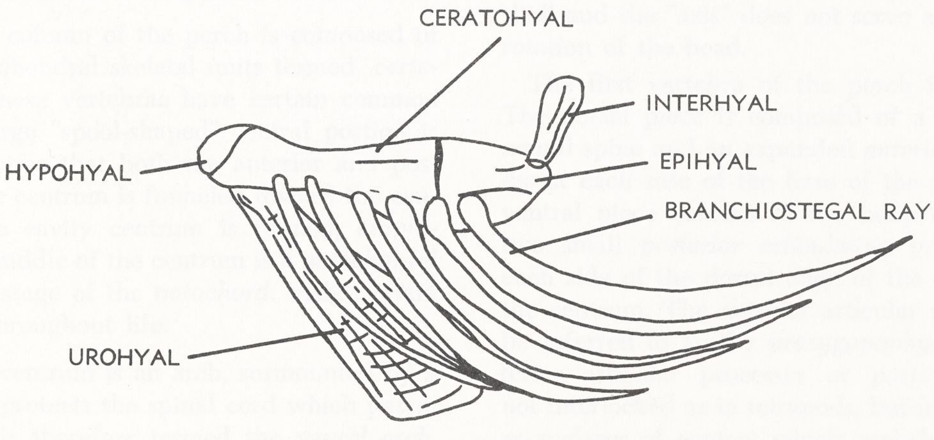

Figure 8. Lateral view of the hyoid apparatus.

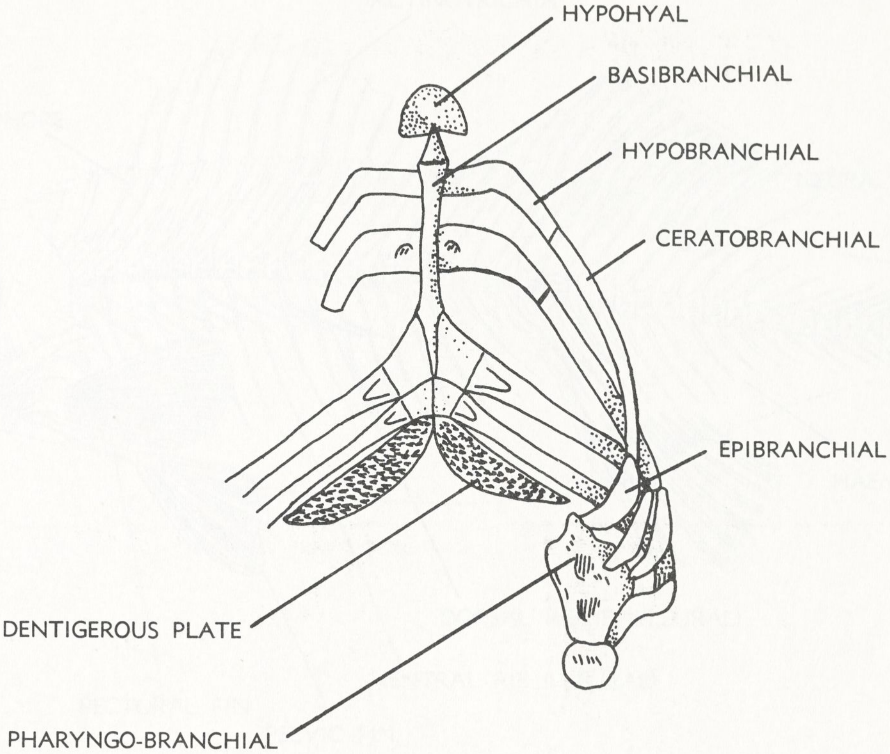

Figure 9. Dorsal view of the branchial apparatus.

together and the last pharyngobranchial articulates with the anterior mass. Dermal, tooth bearing bones are fused to the ventral surface of the pharyngobranchials. At the posterior end of the last gill arch, a dermal tooth-bearing plate is attached to each terminal hypobranchial.

THE VERTEBRAL COLUMN

The vertebral column of the perch is composed of a series of endochondral skeletal units termed, *vertebrae.* Each of these vertebrae have certain common features. The large "spool-shaped" central portion is the *centrum.* Notice that both the anterior and posterior face of the centrum is funneled toward the center. This double cavity centrum is termed, *amphicoelous.* At the middle of the centrum is a *notochordal canal* for the passage of the *notochord.* Fishes retain the notochord throughout life.

Dorsal to the centrum is an arch, surmounted by a spine. The arch protects the spinal cord which passes through it and is therefore termed the *neural arch.* The spine is called the *neural spine.*

The remaining features are characteristic of the vertebrae of particular regions of the column. The two major subdivisions of the fish vertebral column are the trunk and the tail. Although there is no neck in the fish, the first two trunk vertebrae are modified and appear quite different from the remaining vertebrae. Although some authors have referred to these vertebrae as the *atlas* and *axis* the terms seem to be presumptive. The "atlas" does not "support" the fish skull and the "axis" does not serve as a pivot for the rotation of the head.

The first vertebra of the perch is in two pieces. The dorsal piece is composed of a neural arch and neural spine and an expanded *anterior articular process* at each side of the base of the neural arch. The ventral piece consists of the body or centrum with two small *posterior articulating processes*: one on each side of the dorsal edge of the posterior face of the centrum. The anterior articular process may also be referred to as the *prezygopophyses* and the posterior articular processes or *postzygopophyses* are not interlocked as in tetrapods, but instead, serve only as surfaces of contact which probably restrict movement.

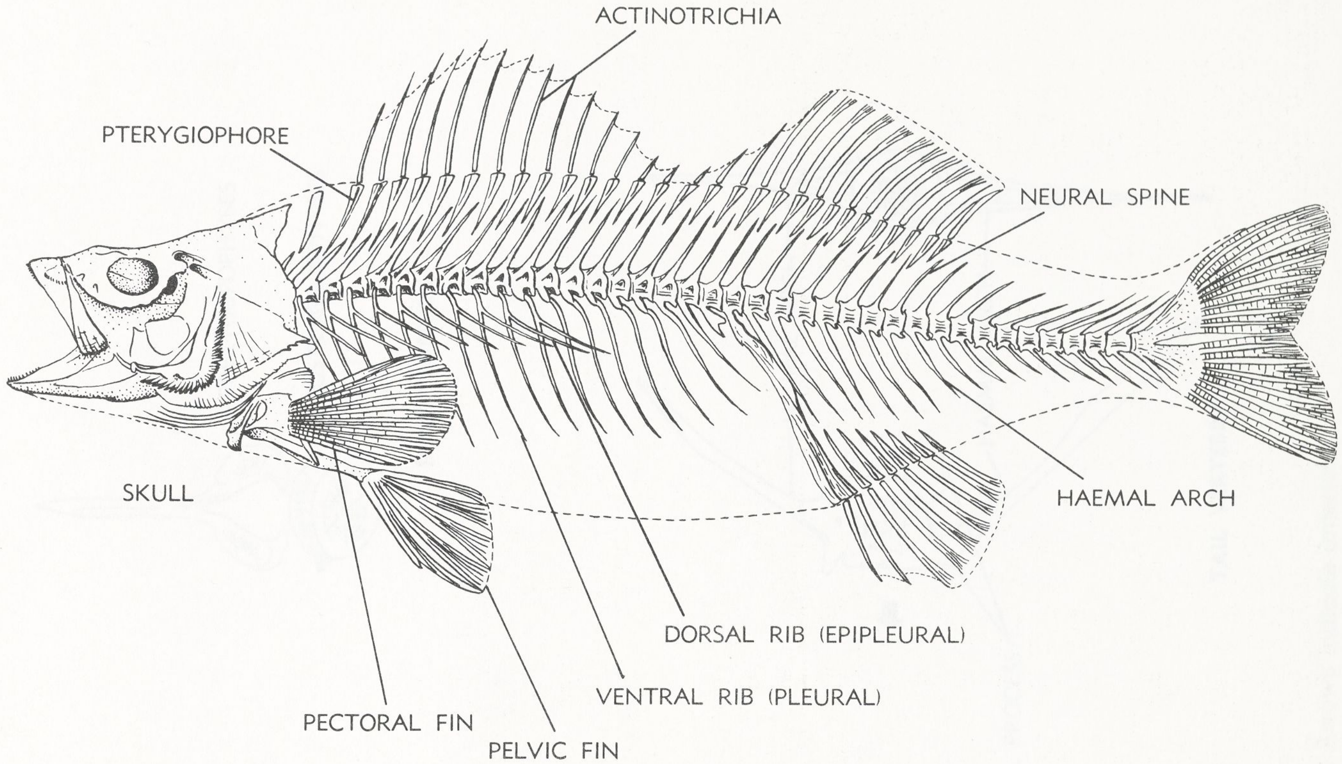

Figure 10. Lateral view of the entire skeleton.

The second vertebra of the perch is a single unit but aside from this difference the two vertebrae are very similar. The second vertebra, like the first, has a large prezygopophysis and a small postzygopophysis. Both lack transverse processes and ribs and they are both the same size.

The zygopophyses of the remaining vertebrae are all small structures and in many instances fail to make contact. The transverse processes look like a tiny leaf extending laterally from the anterior ventral corner of the connective tissues. There are no joints or articular surfaces involved in rib attachments.

The ribs of the perch are of two types, a *pleural* or *ventral* rib develops in the myosepta just lateral to the pleuroperitoneal lining (see Chapter 5). The *epipleural* or *dorsal* rib develops in the horizontal septum and attach to the posterior surface of the pleural ribs by ligaments. Since the epipleural rib is between the epaxial and hypaxial muscle masses (see Chapter 4) it is sometimes called an *intermuscular bone*. The epipleural ribs are only attached to the first half of the pleural ribs; the last seven or eight pairs of pleural ribs do not have epipleurals attached to them. Some teleosts have an additional set of ribs based on the upper portion of the centrum or on the base of the neural arch.

In the tail the ribs and transverse processes are replaced by a haemal arch similar to the neural arch. The haemal arch surrounds blood vessels rather than nerves. Haemal arches of the *caudal* vertebrae are equipped with processes similar to the pre-and post-zygopophyses but they do not contact one another. These processes may be referred to as *basal processes* of the haemal arch.

THE APPENDICULAR SKELETON AND FINS

I. The Medial Fins.

A. Dorsal.

1. The *anterior* or *first dorsal* fin has dermal structures for fin support as do all the fins. These dermal structures are known as fin rays and are thought by some authors to be evolved from scales (see Chapter 2, *Histology of the Skin*). In bony fishes these structures are of two types. Some fin rays are ossified providing a stiff bony support for the fin and are known as *acti-*

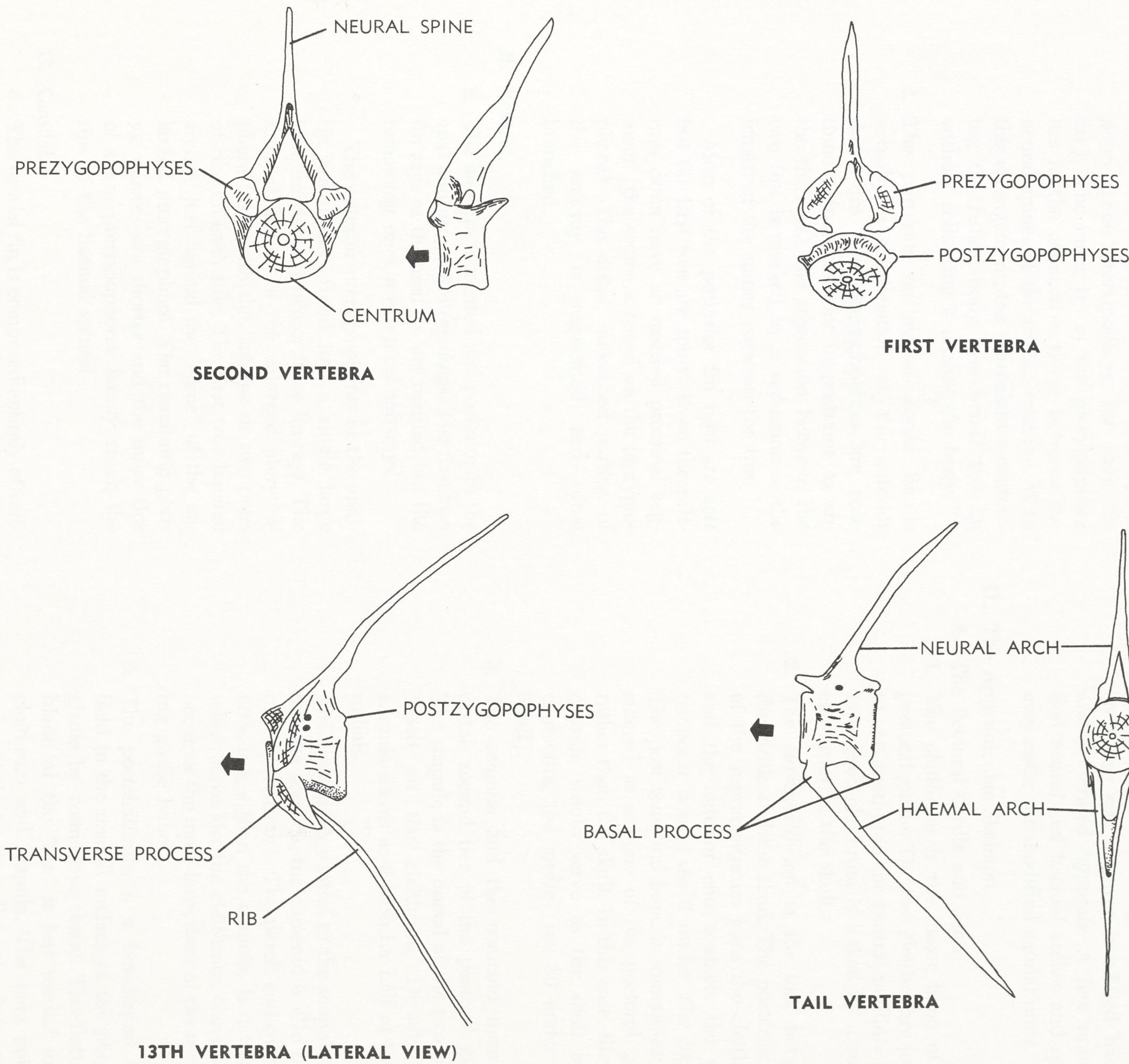

Figure 11. Representative vertebrae. Arrows indicate anterior.

notrichia or "spines". Others are not ossified but are flexible, typically segmented and often branched. The anterior dorsal fin of the perch consists of spines only. The base of each spine or soft-ray is supported by a bony structure known as a *pterygiophore* (one pterygiophore for each fin ray). The inner tip of the pterygiophore lies in the connective tissue between the neural spines of the trunk vertebrae. With this arrangement, the musculature contorting the fishes' body also bends the fin without collapsing it against the body.

2. The *posterior* or *second dorsal* fin is actually a continuation of the anterior dorsal fin. The pterygiophores are continuous from anterior to posterior as are the fin rays. The separation between the two fins is marked by a reduction in the length of the spines between the fins.

   Most of the posterior fin rays are soft but the first two are spiny. Even the soft-rays often have an ossified proximal segment (the segment based on the pterygiophore). The distal, unossified portion of the soft-ray is segmented and often branched.

B. Ventral.

3. The *anal fin* is located just posterior to the anal and urogenital openings. The first two fin rays of the anal fin are ossified but the remaining ones are typical soft-rays.

   The anterior pterygiophores of the anal-fin are usually fused into a single large base for the first two or three fin rays. The internal "spine" of the enlarged pterygiophore fuses with the last one or two pairs of ribs on each side. The first true haemal arch is just behind the "spine" of the enlarged pterygiophore. The remaining pterygiophores are shorter and the inner tips of these pterygiophores barely reach the tips of the haemal spines!

C. Caudal.

4. The *caudal* fin is composed entirely of soft-rays. The caudal fin rays are based on modified parts of the caudal vertebrae, not on pterygiophores. All of the major parts of the caudal vertebrate seem to be involved in the formation of the fin base. In general, the neural spines of the vertebrae are compressed into two or three plates called *epurals*. The last caudal vertebra is modified into a dorso-posteriorly directed plate, the *urostyle*. Below the urostyle are six or seven modified haemal arches, termed *hypurals*. A few unmodified neural and haemal arches and spines may assist the modified caudal units.

II. The Appendicular Skeleton.

A. The Pectoral Girdle and Fins.

1. The *cleithrum* is the major bone of the pectoral girdle. The two cleithra are joined to one another in the ventral midline. Dorsally each cleithrum is linked by a supracleithrum to the skull.

2. The *supracleithrum* is the link between the girdle and the skull. The posterior end of the supracleithrum joins the cleithrum and the anterior end contacts the post-temporal bone (see 6 under *The Skull*). The post temporal bone is sometimes considered as a bone of the pectoral girdle rather than the skull. In this case, the otic capsule would serve as the skull bones contacting the girdle (see 30 under *The Skull*).

3. The *scapula* and the coracoid form the distal, second tier of the pectoral girdle. The scapula is the dorsal of the two bones based on the cleithrum. Distally, the scapula serves as a base for half of the fin radials.

4. The *coracoid* is ventral to the scapula and, like the scapula, the coracoid is also based on the cleithrum. The perch coracoid is a little larger than the scapula. In tetrapods which have lost the cleithrum, the scapula becomes the more important of the remaining girdle bones.

5. The *postcleithrum* is a fan-shaped bone held to the medial surface of the pectoral girdle by connective tissue. The flattened blade of the "fan" is just medial to the cleithrum and scapula. The long pointed spine of the "fan handle" extends ventrally, toward the pelvic girdle.

6. *Radials* are bones of the fin with two joints. One joint allows movement between

the radial and the scapula or coracoid and the other joint allows movement between the radial and the fin rays. There may be some variation in the number of radials but there are usually only four in the perch pectoral fin. Soft-rays support the remainder of the fin.

B. Pelvic Girdle and Fins.

7. The paired *pelvic plates* or *basipterygia* make up the entire pelvic girdle of the perch. The two plates may be fused to each other in the midline. The anterior tips of the pelvic plates extend forward between and dorsal to the joined cleithra.

Some authors have attempted to homologize these bones with the *pubic* bones of tetrapods. The basis for this theory is very questionable.

There are no radials at the base of the pelvic fin. Without radials, the fin rays are based directly on the posterior ends of the pelvic plates. The fin rays are of the typical soft-rayed non-ossified type except for the first (most medial) which is spiny.

CHAPTER 4

The Muscular System

The muscles of the perch are not as complex as the muscles of land vertebrates; and yet, considering relative body sizes, the fish probably has twice the muscle mass of most tetrapods. The reasons for this difference in the amounts of muscle are evident if we consider two important differences between tetrapods and fishes. First, the fish moves by body contortions not limb movements; and, second, the fish muscles are not separated units producing specific movements of a specific structure as in tetrapods. The contractions of the muscle fibers within a fish myotome exert their action indirectly upon the vertebral column. Thus the relative inflexibility of the fish trunk and the indirectness (hence, inefficiency) of the fish muscles demand more muscle mass to perform less action than in tetrapods.

A. *Body Musculature.*

Each perch myotome looks like a large "W" tilted on its side. The two bottom points of the W are directed posteriorly and the center upper point is anterior (see Figure 15). Each of the three points of the W is related to the corresponding point of the preceding or succeeding myotome like one of a stack of paper cups is related to a preceding or succeeding cup (see Figure 12). That is, the myotome does not extend directly from the midline to the surface; but angles, anteriorly on the dorsal and ventral points; and posteriorly on the middle point. Thus if a horizontal section is cut so the myotome is divided at any of these three points, we would find the muscle segment shaped as in Figure 13.

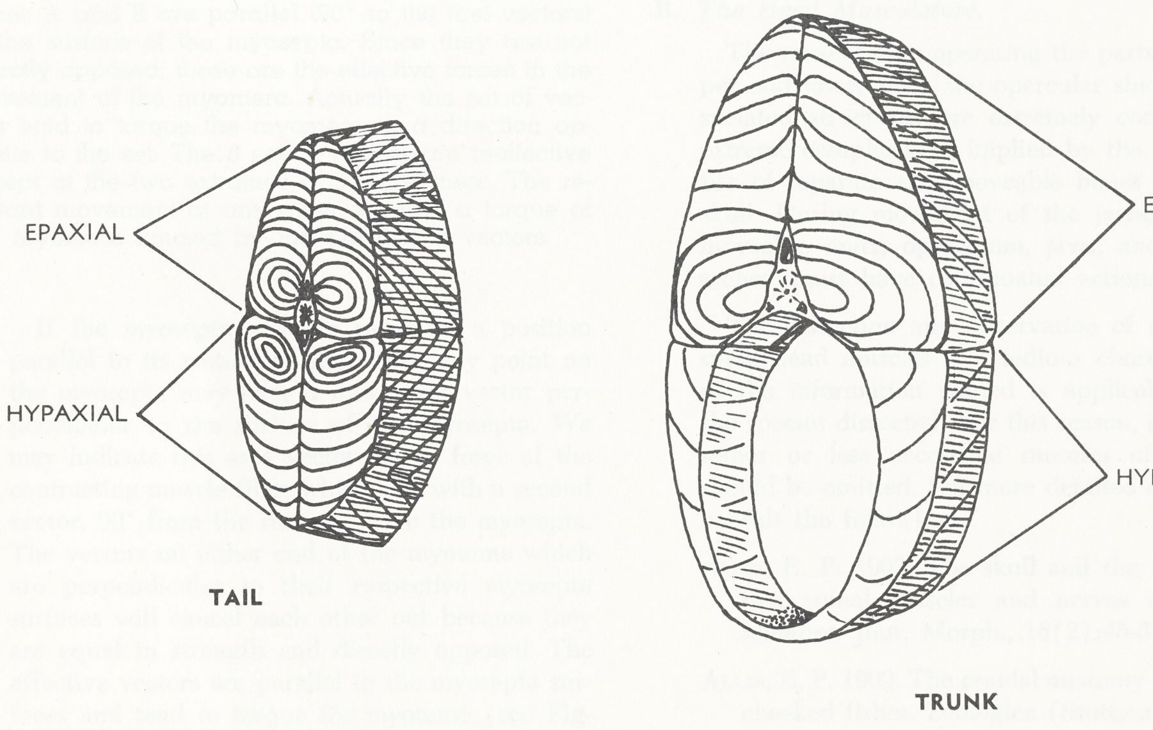

Figure 12. Cross section of the trunk and tail regions.

Each muscle fiber is arranged parallel to the midline and extends from one myosepta to the next (see Figure 13). The simultaneous contraction of all the fibers at this level tend to move the two myosepta towards one another. This actually may happen to a slight extent but several factors work against it.

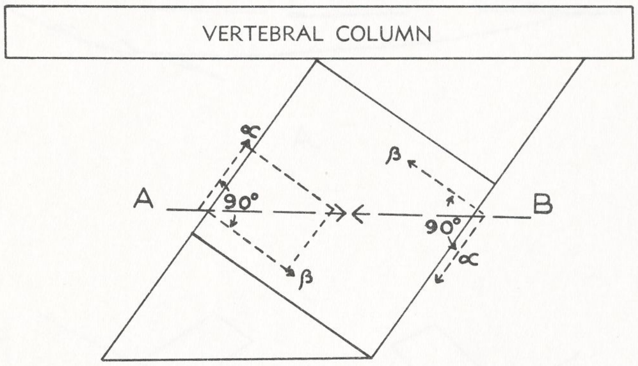

Figure 13. Diagram of myomere movement. Since each myosepta is drawn toward the other, A and B indicate the forces in the myomere which draw the myosepta together. These forces are produced by the contraction of the muscle fibers. One of the vectors (β) of each of the forces A or B may be perpendicular to each of the myosepta. The vectors are equal but opposed to similar vectors of other myofibrils and are cancelled out. The other vectors (α) for forces A and B are parallel (90° to the first vectors) to the surface of the myosepta. Since they are not **directly** opposed, these are the effective forces in the movement of the myomere. Actually the set of vectors tend to torque the myomere in a direction opposite to the set. The β set of vectors are ineffective except at the two extremes of the myomere. The resultant movement at any given level is a torque of the myomere caused by the parallel α vectors.

If the myosepta were to move to a position parallel to its resting position then any point on the myosepta may have a movement vector perpendicular to the surface of the myosepta. We may indicate this as a vector of the force of the contracting muscle fiber which acts with a second vector, 90° from the first, to move the myosepta. The vectors on either end of the myotome which are perpendicular to their respective myosepta surfaces will cancel each other out because they are equal in strength and directly opposed. The effective vectors are parallel to the myosepta surfaces and tend to torque the myotome (see Figure 13).

If a posterior medial myotome segment is opposed to an anterior dorsal (or ventral) myotome segment; the opposing torques will bend the midline of the body at a point midway between the two myotomes (see Figure 14).

By alternating the body twists the fish is able to move through the water (see Figure 14). As the number of opposing myotome segments increase, the animal is better able to control its movements and perhaps to also increase the force with which each movement is made. In the tail (which is the prime mover of the animal) the medial myotome segment is divided into two separate parts both directed as the more anterior single segment. In this way the tail is effectively quartered with opposing myotome segments in each quarter (see Figure 12). A variety of movements are possible with this arrangement.

Each myotome is divided into dorsal and ventral halves by a *transverse septum* of connective tissue. These muscles or myotome segments dorsal to the transverse septum are referred to as *epaxial;* and, those ventral to the septum are *hypaxial.* The anterior hypaxial muscles seem to play only a minor role in locomotion. Their main function is probably to support the body viscera.

B. *The Head Musculature.*

The musculature operating the parts of the upper and lower jaws, the opercular shield, and associated structures are extremely complex. This extreme complexity is implied by the great number of separate and moveable bones in the fish skull. During movement of the jaws, all of the moveable units; operculum, jaws, and branchial arches, must have coordinated actions.

The dissection and observation of all of these small head muscles is a tedious chore and most of the information gained is applicable only to the species dissected. For this reason, some of the minor or less accessible muscles of the head should be omitted. For more detailed descriptions consult the following:

Allis, E. P. 1903. The skull and the cranial and first spinal muscles and nerves in *Scomber scomber.* Jour. Morph., 18(2):45-328.

Allis, E. P. 1909. The cranial anatomy of the mail-cheeked fishes. Zoologica (Stuttgart), 22(57): 1-219.

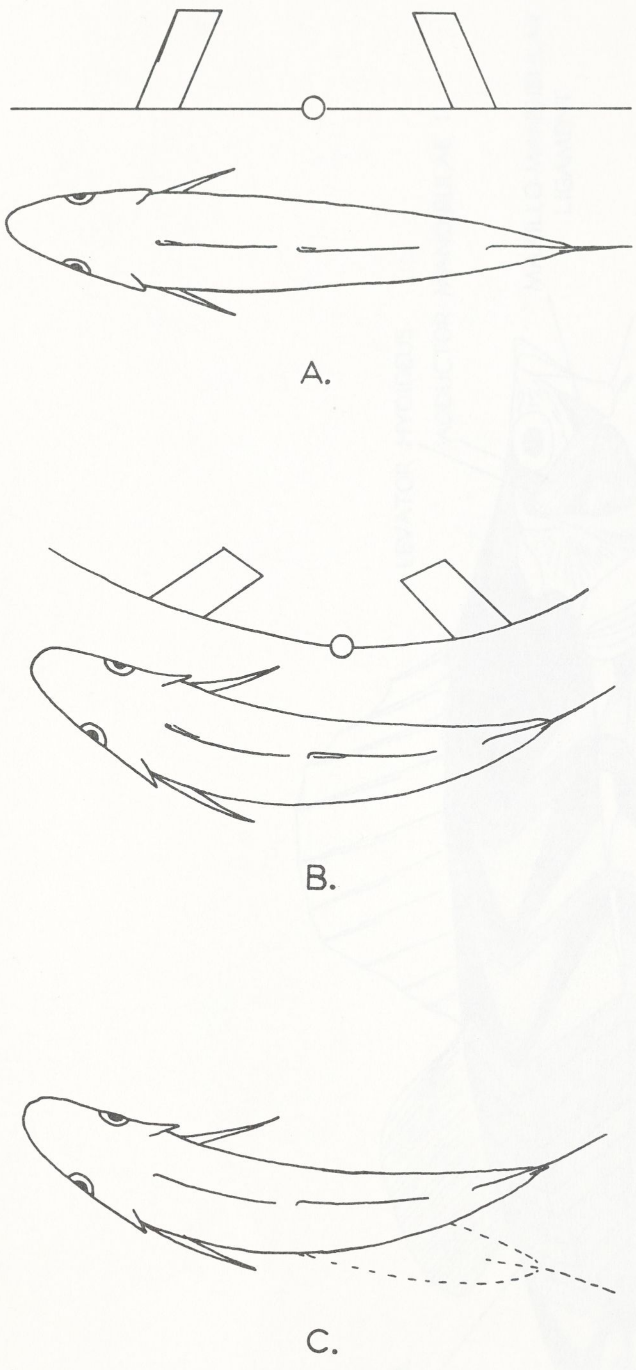

Figure 14. Diagrams illustrating fish movements based on myomere contractions. In A., the vector forces cause the myomere segments to rotate rather than constrict. In B., the rotation of anterior and posterior myomere segments cause the fish's body to bend about a point midway between the two segments.

Alternate bends of the posterior end of the body propell the fish forward (as in C.).

Vetter, B. 1874. Untersuchungen Zur Vergleichenden Anatomie der Kiemen-und Kiefermusculatur der Fische. I. Jean Zeitschr f. Naturw., 8:405-458.

Vetter, B. 1878. Untersuchungen zur Vergleichenden Anatomie der Kiermen-und Kiefermusculatur der Fische, II. Jena. Zeitschr. f. Naturw., 12:431-550.

To expose the head musculature, insert the tip of a scalpel blade (No. 10) under the skin at the upper leading edge of the preopercular bone. Cut the *skin* carefully along the entire edge of the preopercular. Grasp the cut skin flap with forceps and pull the flaps forward. The anterior attachment will tear loose without damage to the underlying structures if you pull strongly enough. Note that the maxilla and its skin cover form a flap over the posterior part of the lower jaw. This flap may be cut off with scissors. A small area of skin just above and posterior to the dorsal tip of the preopercular bone should be cleared away. A pair of blunt forceps will be useful for this chore.

This dissection will expose the following muscles.

1. *Adductor mandibulae* is the most complicated muscle in the perch. This muscle is divided into four parts and includes a rather complicated tendon. *Adductor mandibulae, part 1,* originates on the dorsal half of the vertical arm of the peropercular bone. This portion of the muscle inserts at the center of the *maxillo-mandibular ligament.* The maxillo-mandibular ligament attaches to the proximal end of the maxilla and the opposite end attaches to the angular bone near the quadrato-articular joint. Between the two extreme attachments, a third, deeper, portion of the maxillo-mandibular ligament attaches to the coronoid processes of the dentary and angular bones and then passes into the lower jaw. The third portion of the ligament serves as an origin for the fourth part of the adductor mandibulae. *Adductor mandibulae, part 2,* originates on the ventral half of the vertical arm of the preopercular bone and inserts on the maxillo-mandibular ligament beneath (medial to) the insertion of part 1.

Cut the adductor mandibulae, part 1, near its insertion and pull the muscle posteriorly. This procedure will expose adductor mandi-

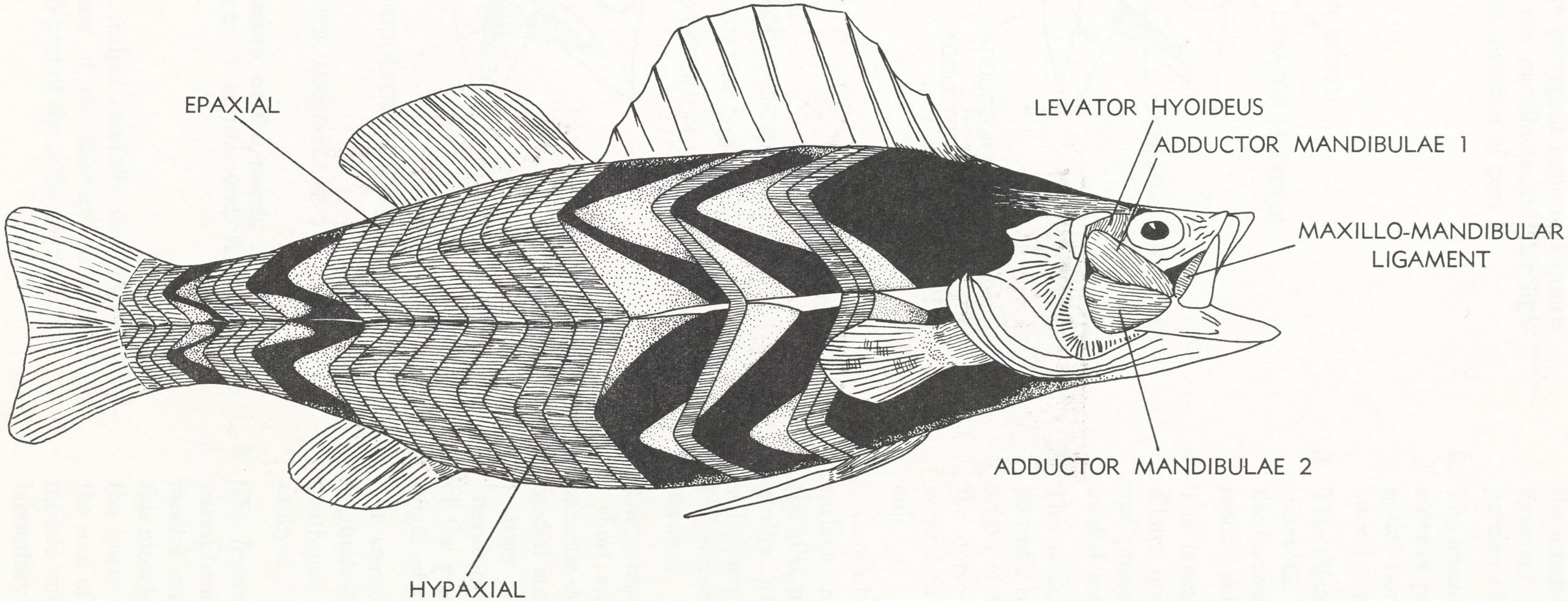

Figure 15. Lateral view of the perch musculature.

bulae, part 3. *Adductor mandibulae, part 3* originates on the pterygoid bone and inserts with part 2 on the maxillo-mandibular ligament beneath the insertion of part 1.

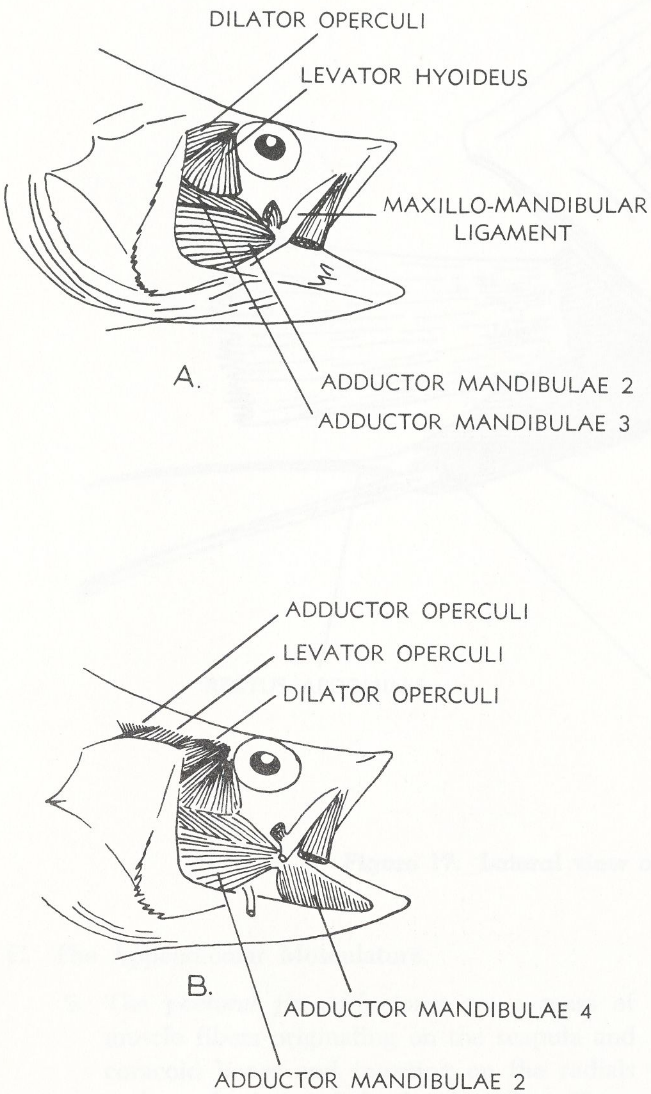

Figure 16. Jaw musculature of the perch. A. The adductor mandibulae, part 1 is removed. B. Deep musculature of the jaws.

With a sharp scalpel carefully slice away the lateral portion of the dentary bone to expose the fourth part of the adductor mandibulae.

Adductor mandibulae, part 4, originates on the internal portion of the maxillo-mandibular ligament and inserts on the ventral, internal portion of the dentary bone.

2. The *levator hyoideus* originates from the most anterior part of the sphenotic (or dermosphenotic) bone and inserts, fanlike, on the upper lateral surface of the hyomandibular.
3. The *dilator operculi* also originates on the sphenotic but just posterior to the origin of the levator hyoideus. Insertion is to the dorsal medial surface of the operculum.
4. The *levator operculi* is just posterior to the dilator operculi and originates from the dermal pteriotic bone. Insertion is to the dorsal medial surface of the operculum.
5. The *adductor operculi* originates from the pteriotic bone just posterior and medial to the origin of the levator operculi. Insertion is to the dorso-medial surface of the operculum ventral to the insertion of the levator operculi.

Carefully tear the skin away on the ventral surface and expose the musculature between the gills, posteriorly to the pectoral and pelvic girdles. At the symphasis of the lower jaws, with forceps, pick away the skin on the ventral surface of the lower jaw and hyoid apparatus.

6. The *geniohyoideus* is divided into two parts, a short anterior muscle extending from the anterior dorsal surface of the basihyal to the medial surface of the dentary symphasis and a larger posterior mass taking origin from the lateral surface of the ceratohyal. The insertion of the posterior segment is to the tendon of origin of the anterior segment.
7. The *sternohyoideus* is a large ventral muscle originating on the ventral spine of the postcleithrum and inserting on the sides of the urohyal.
8. The *levator arcus palatini* originates on the parasphenoid bone and inserts on the entire medial surface of the pterygoid. To expose this muscle it will be necessary to cut through the lower jaws and remove the tissue lining the roof of the oral cavity. Do not dissect this muscle until you are directed to do so by the laboratory instructor.

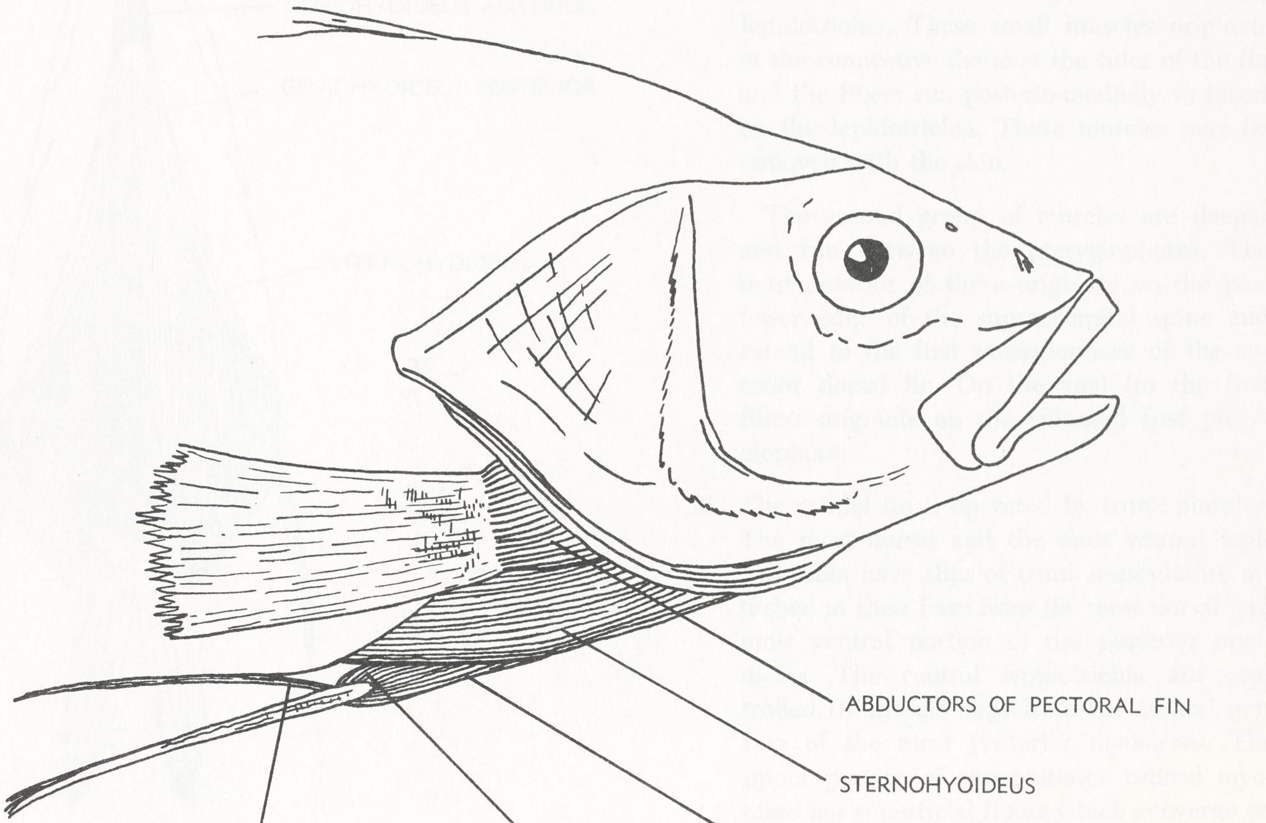

Figure 17. Lateral view of appendicular musculature.

C. The Appendicular Musculature.

9. The *pectoral fin adductores* are a mass of muscle fibers originating on the scapula and coracoid bones and inserting on the radials and on the base of the lepidotrichia. These muscles are located on the anterior face of the fin and girdle but the fibers are continuous with those on the edges and posterior face of the girdle.

10. The *pectoral fin abductores* originate on the medial surface of the scapula and coracoid and insert on the medial surface of the radials.

11. The *pectoral fin rotatores* are muscle fibers on the leading and trailing edges of the fin. Actually these fibers are continuations of the adductores and abductores.

12. The *pelvic fin adductores* originate on the medial surface of the pelvic plates and insert on the medial surface of the fin radials.

13. The *pelvic fin abductores* originate on the outer surface of the pelvic plates and insert on the outer surface of the fin radials. No rotatores fibers are evident on the pelvic fin.

14. The median fins (anterior dorsal, posterior dorsal, and anal) have two sorts of muscles

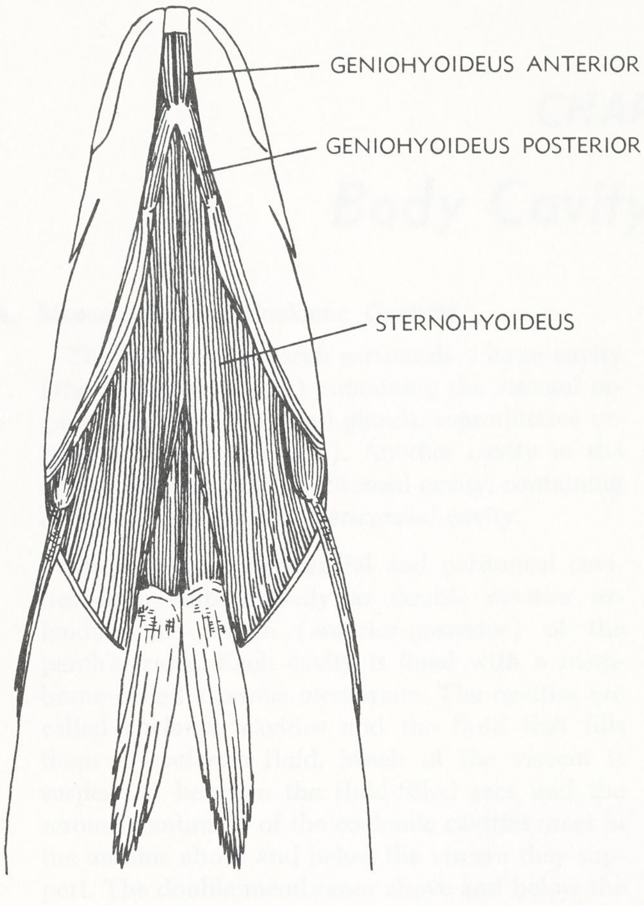

Figure 18. Ventral view of appendicular musculature.

controlling their movements. The first set are small skin muscles inserting at the base of the lepidotrichia. These small muscles originate in the connective tissue at the sides of the fin and the fibers run posterio-medially to insert on the lepidotrichia. These muscles may be removed with the skin.

The second group of muscles are deeper and run between the pterygiophores. The most anterior of these originate on the posterior edge of the supraoccipital spine and extend to the first pterygiophore of the anterior dorsal fin. On the anal fin the first fibers originate on the enlarged first pterygiophore.

15. The caudal fin is operated by trunk muscles. The most dorsal and the most ventral lepidiotrichia have slips of trunk musculature attached at their base from the most dorsal and most ventral portion of the posterior myomeres. The central lepidotrichia are controlled by muscle slips from the central portion of the most posterior myomeres. The upper portion of the posterior central myomere has superficial fibers which converge on the tip of the urostyle.

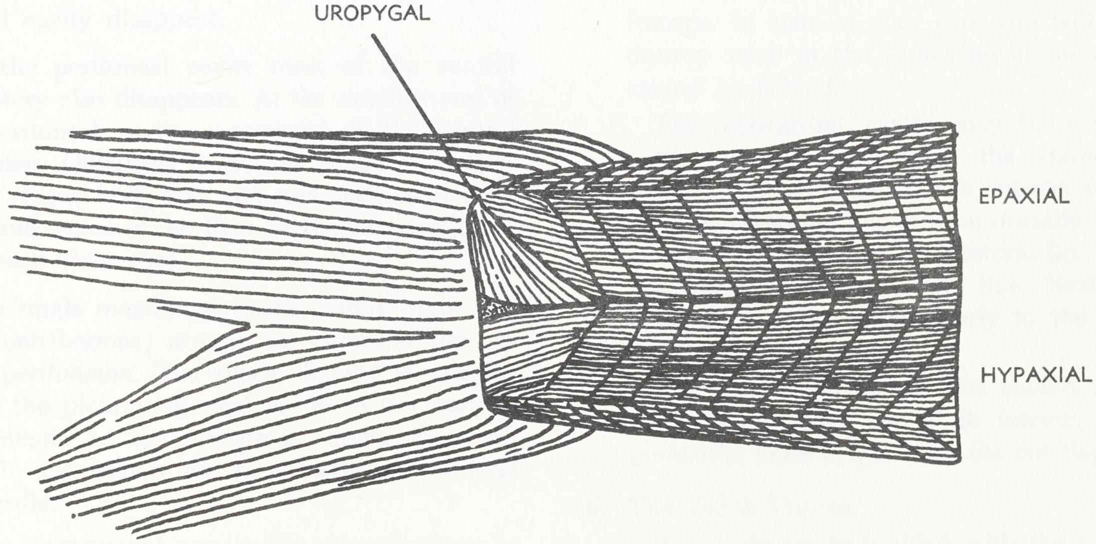

Figure 19. Musculature of the tail.

CHAPTER 5

Body Cavity and Viscera

A. Mesenteries and Coelomic Cavities.

The body of the perch surrounds a large cavity (the *peritoneal* cavity) containing the visceral organs (digestive tract and glands, reproductive organs, and swim bladder). Another cavity in the throat, anterior to the peritoneal cavity, containing the heart, is called the *pericardial* cavity.

The combined pericardial and peritoneal cavities form embryonically as double cavities extending the length (anterior-posterior) of the perch's trunk. Each cavity is lined with a membrane called a *serous* membrane. The cavities are called *coelomic* cavities and the fluid that fills them is *coelomic* fluid. Much of the viscera is suspended between the fluid-filled sacs and the serous membranes of the coelomic cavities meet in the midline above and below the viscera they support. The double membranes above and below the viscera are termed *dorsal* and *ventral* mesenteries respectively.

As embryonic development continues the pericardial and peritoneal cavities become separated from one another and the mesenteries of the pericardial cavity disappear.

In the peritoneal cavity most of the ventral mesentery also disappears. At the anterior end of the peritoneal cavity a remnant of the ventral mesentery (*falciform ligament*) attaches the liver to the ventral body wall and continues around the liver and attaches the liver to the stomach (*gastrohepatic ligament*).

The single membrane (with double, right and left, contributions) around the viscera is the *visceral peritoneum.* The single layered membrane lining the pleuroperitoneal cavity is the *parietal peritoneum.* In the pericardial cavity the comparable membranes are the *parietal* and *visceral pericardia.*

This arrangement permits the visceral organs to move about and to be lubricated at the same time. This is especially important for violently moving organs such as the heart, stomach and intestines. In addition, the coelomic fluid serves as a medium for the passage of wastes and, in the female, for the passage of eggs.

Structures which are not suspended by mesenteries in the trunk cavity are called *retroperitoneal.* This means that the structures are behind (retro-) the peritoneum.

In order to study the internal organs it will be necessary to cut out a portion of the trunk wall. Make an incision along the ventral trunk wall beginning just in front of the anal opening and continue the incision anteriorly to the pelvic girdle. At the anterior and again at the posterior end of the ventral incision, make cuts dorsally, ending your incisions just ventral to the lateral line. Be very cautious in making your incisions. A deep cut may destroy some of the underlying organs. If you are sufficiently careful the parietal peritoneum will remain with the coelom rather than with the body wall that you remove. Layers of fat will be found both retroperitoneal and in the mesenteries. Carefully remove the fat with forceps. In spite of your care you will tear and destroy some of the serous membranes but this cannot be helped.

The pericardial cavity may be exposed by cutting transversely across the sternohyoideus muscles approximately 1 inch anterior to the pelvic fins. Continue this incision dorsally to a point anterior and dorsal to the pectoral fin. Again, do not cut through the lateral line. Next. make a mid-ventral incision posteriorly to the trunk incision you made earlier.

The pericardial membranes should adhere to the flap you have cut. With forceps, work the pericardia loose as you raise the cut flap.

B. The Trunk Viscera.

The body cavity is filled with the various visceral structures: *digestive tract, gonads* (*testis* or

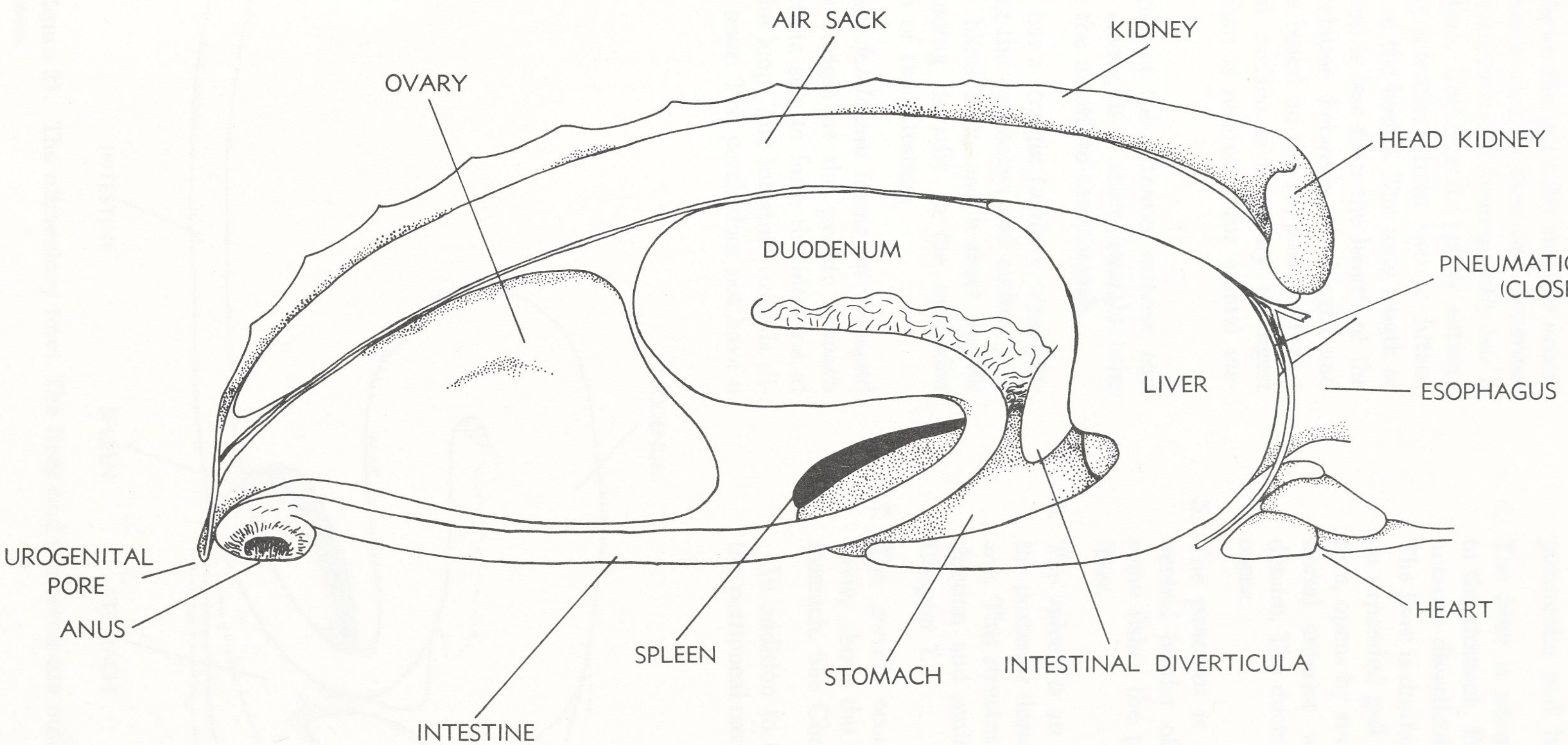

Figure 20. Lateral view of body viscera.

ovaries), *spleen, kidneys,* and *air sack.* All of these visceral structures are covered by thick layers of fat contained by the serous membranes. The digestive tract includes the gut tube and the accessory digestive glands such as *liver* and *pancreas.* The perch is a carnivore and consequently has a very short intestine. Herbivorous (plant eating) fish have a long intestine (from two to fifteen times the length of the body). The total length of the perch intestine is less than the length of the body. This correlation between gut length and feeding habits is based on the supposition that a greater intestinal surface is necessary to digest plant material than is necessary for animal material.

1. The *esophagus,* at the extreme anterior end of the body cavity, is a short, straight tube leading from the mouth to the stomach.
2. The *stomach* has a straight *fundic* ventral portion, receiving the esophagus and ending posteriorly as a blind sack, and a short *pyloric* portion extending dorsally to the expanded proximal end of the intestine.
3. The expanded *duodenum* forms an S-shaped loop from its origin at the pyloric stomach then constricts in size to form the *intestine* at the end of the loop. The intestine extends directly to the *anus.* The perch does not have a cloaca. There are three intestinal diverticula (*pyloric caeca*) at the most anterior part of the duodenum as well as openings from the pancreatic and bile ducts.
4. The *liver* is situated just anterior and dorsal to the stomach. Portions of the liver cover the anterior diverticulum and the ventral stomach. The liver is drained by a system of tubules into an expanded *gall bladder.* The gall bladder in turn, opens by several (4-6) ducts through the dorsal anterior wall of the expanded duodenum. The ducts open posterior to the pyloric caeca.
5. The *pancreas* is a small folded tissue at the ventral border of the expanded intestine. In some fishes the pancreas is embedded in the liver.
6. The *spleen* is an elongated structure lying on the posterior dorsal surface of the fundic stomach. This structure is concerned with the production and maintenance of blood cells. See Chapter 7.
7. The *gonads* occupy the space in the trunk cavity above the intestine and posterior to the stomach. See Chapter 8.

In addition to those structures contained in the peritoneal cavity, the *kidneys* and the *swim*

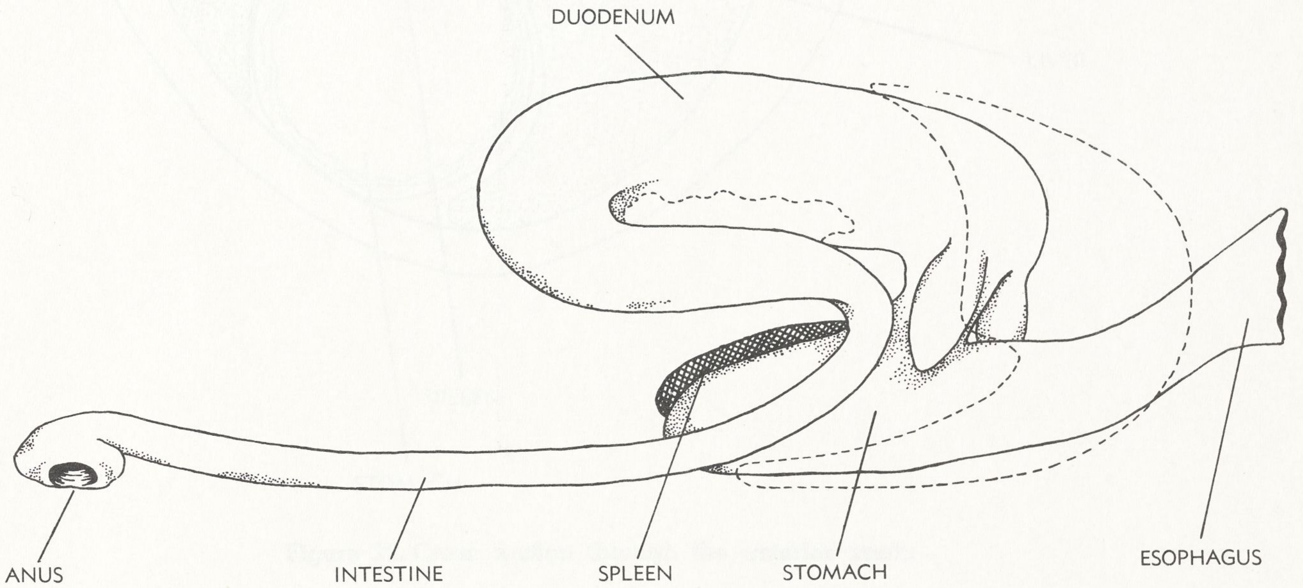

Figure 21. The alimentary tract. The liver and pancreas are outlined by dotted lines.

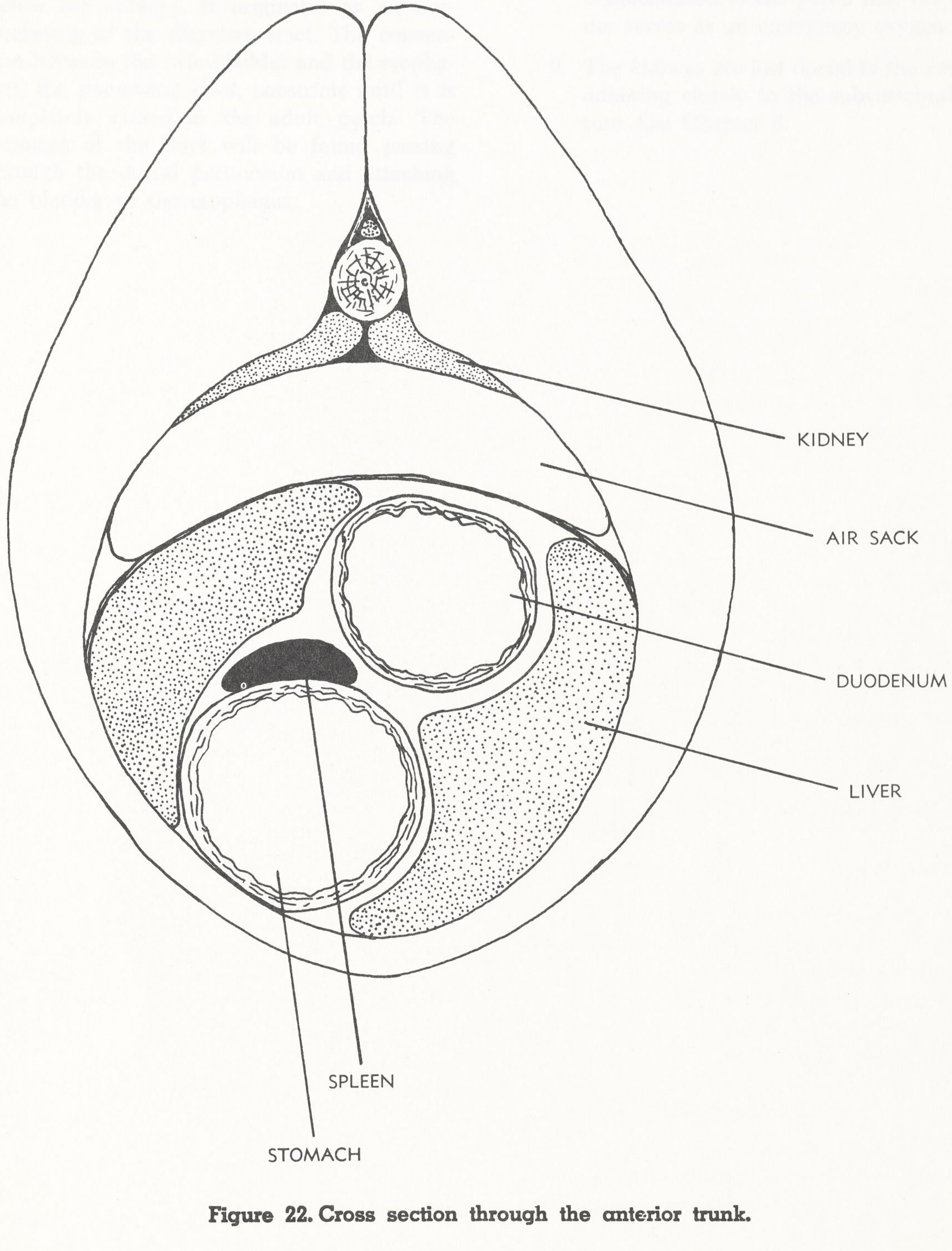

Figure 22. Cross section through the anterior trunk.

bladder will be found retroperitoneally, above the peritoneal cavity. Notice that the dorsal peritoneum is thick and pigmented.

8. The *swimbladder* of the perch lies just below the kidneys. It originates as an outpocketing of the digestive tract. The connection between the swimbladder and the esophagus, the *pneumatic duct,* constricts until it is completely closed in the adult perch. The remnant of the duct will be found passing through the dorsal peritoneum and attaching the bladder to the esophagus.

The swimbladder serves as a hydrostatic organ in that its inflation will increase the bouyancy of the body and its deflation will increase the specific gravity. It has also been demonstrated in the perch that the swimbladder serves as an emergency oxygen store.

9. The *kidneys* are just dorsal to the swimbladder adhering closely to the subvertebral musculature. See Chapter 8.

CHAPTER 6

Mouth, Pharynx and Respiratory System

A. Mouth and Pharynx.

1. The *mouth* of the perch is bordered by the premaxilla and maxilla above and the dentary below. Teeth are present only on the premaxilla and dentary. The maxilla serves only as a lateral wall, channelling water and prey into the oral cavity.

2. The *oral cavity* is a shallow vestibule arbitrarily separated from the more posterior pharynx. The gill rakers and gill slits may be considered as parts of the pharynx (see 4 below) so the oral cavity is between the first row of gill rakers and the mouth.

3. The *palate* forms a relatively solid roof for the oral cavity and pharynx. Palatal teeth are present on the central vomer and lateral palatine bones thus forming an anteriorly directed arch of anterior palatal teeth.

4. The *pharynx* contains the branchial complex of hyoid apparatus and gill arches (see Chapter 3, *The Skull*). Pharyngeal teeth are present on both the roof and floor of the pharynx. The pharyngo-branchial bones serve as a base for the pharyngeal teeth in the roof of the pharynx and a dentigerous plate attached to the medial portion of the most posterior branchial arch bears the teeth of the pharynx floor. The pharyngeal teeth are in the most posterior part of the pharynx and probably serve to hold the struggling prey just prior to swallowing. The act of swallowing will constrict the pharynx and the posteriorly directed pharyngeal teeth will then assist in driving the prey into the esophagus.

5. The pharynx wall is perforated by five pairs of *gill slits*. The first slit is between the last branchiostegal ray and the first branchial arch. The last slit is between the last branchial arch and the lateral portion of the dentigerous plate. The three middle gill slits are between the successive branchial arches. The mid ventral floor of the pharynx is composed of basibranchials based anteriorly on the hypophyal.

B. The Respiratory System.

The *gills* are attached to each of the four pairs of branchial arches. The gills are on the aboral surface of the branchial arch and *gill rakers* are on the oral surface. Laterally, the gills are covered by the opercular shield. (see Chapter 3, *The Skull*). Ventrally the "fan-like" branchiostegal apparatus completes the opercular chamber.

Each gill arch has two sets of filaments, one set extending into the slit in front of the branchial arch and one set extending into the slit behind the arch. The anterior set of filaments are *postrematic* (at the posterior border of the slit) and the posterior filaments are *pretrematic* (at the anterior border of the slit). Since all of the gills have a double set of filaments they are known as *holobranchs*. The holobranch filaments extending into one gill slit are known as hemibranchs (one-half of a holobranch) and non-functional gill filaments (as in the spiracle of the shark) are called pseudobranchs.

C. The Mechanism of Respiration.

Water passes into the fish mouth to the pharynx and from the pharynx through the gill slits into the opercular chamber. A backflow of water, out of the mouth, is prevented by the *oral valves*. The water passes out of the opercular chamber at the posterior, free edge of the opercular flap. The opercular chamber is closed when the free edge of the operculum is held against the body.

Actually, the flow of water is virtually continuous over the perch's gills. The mechanism which "pumps" this water is akin to a continuous flow pump.

Contraction of the sternohyoideus and geniohyoideus open the mouth and draw the floor of

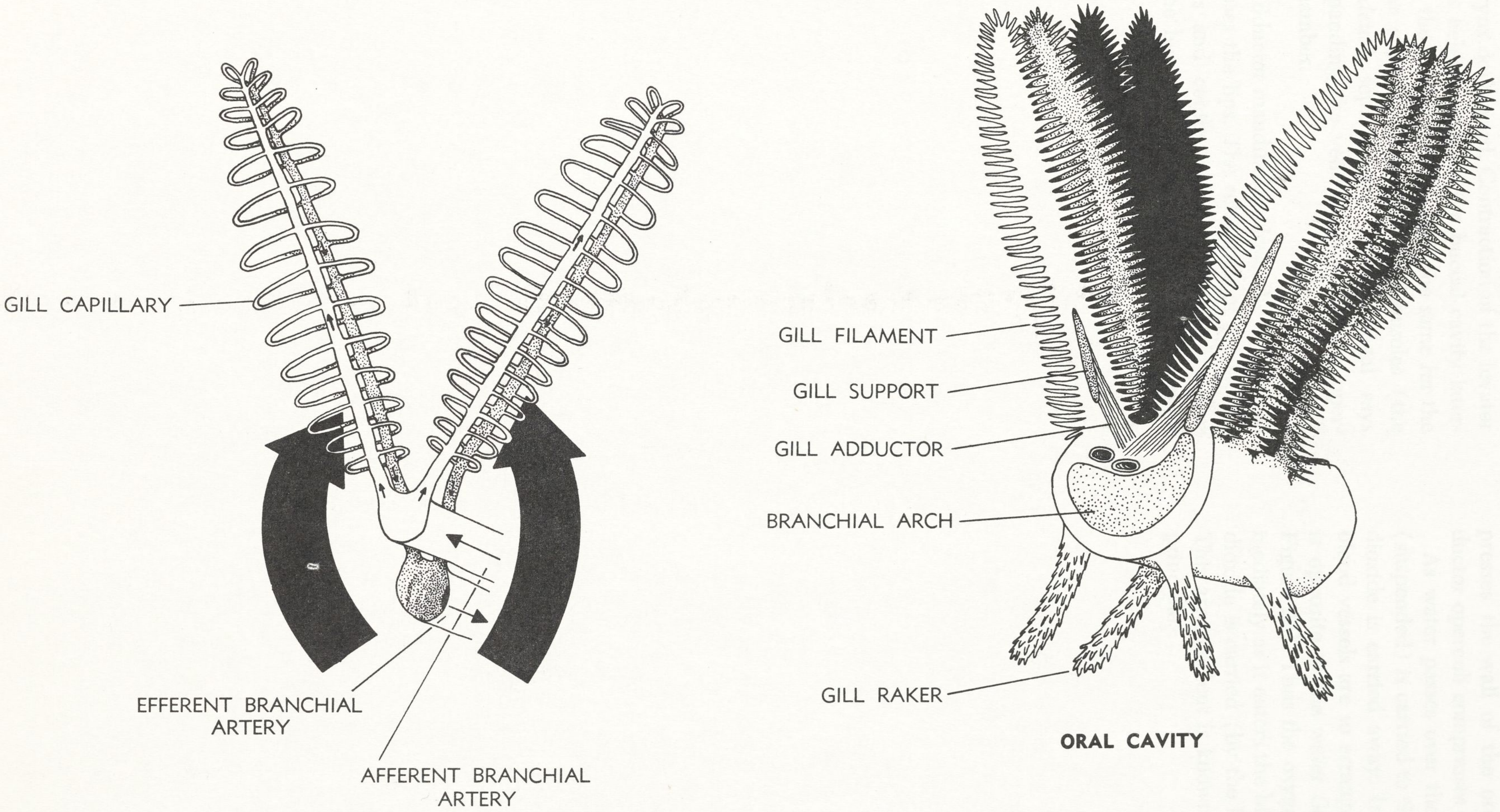

Figure 23. Diagram of the gills and gill circulation. Note that blood and water flow in opposite directions. Water flow is indicated by the large solid arrows.

the pharynx downward. Contraction of the levator hyoideus helps to expand the buccal cavity laterally and the dilator operculi does the same for the opercular chamber. Branchiostegal muscles (the *hyohyoideus*) separate the branchiostegal rays thus expanding the ventral portion of the opercular chamber.

The adductor mandibulae closes the mouth and compresses the lips. The relaxation of the sternohyoideus and contraction of the geniohyoideus raises the hyoid. The levator arcus palatini compresses the wall of the oral cavity and the adductor operculi compresses the opercular chamber.

As water passes over the gill filaments oxygen (suspended) is carried to the filament and carbon dioxide is carried away. Inside the filament, the blood vessels are so arranged that the blood flow is opposite to the water flow over the gills (see Figure 23). Thus the oxygen is carried away immediately as it enters the blood stream and carbon dioxide is carried (by the blood) to the filament. This arrangement is known as the countercurrent principle.

CHAPTER 7

The Circulatory System

If the circulatory system of the perch is singly injected, only the branches associated with the dorsal aorta will receive the injection mass. The venous system, ventral aorta, afferent arteries, and vessels to the head will not be injected. Some of these vessels may be studied without the benefits of an injection mass but most of the venous system will probably be impossible to find.

A. The Heart.

As was mentioned earlier, the *pericardial cavity* is originally formed as an anterior continuation of the posterior peritoneal cavity. The membrane on the surface of the heart being the *visceral pericardium* and that on the wall of the cavity is the *parietal pericardium.* The pericardial mesenteries disappear at a very early embryonic stage.

The heavy membrane separating the pericardial and peritoneal cavities is the combined posterior parietal pericardium and anterior parietal peritoneum. These combined membranes are termed the *transverse septum.*

The heart of the perch is in four chambers; *sinus venosus, atrium, ventricle,* and *bulbus arteriosus.* The chambers are arranged, from posterior to anterior, as listed above so blood passes from one chamber to the next in that order.

1. The *sinus venosus* receives blood from two, right and left, *common cardinal veins* or *ducts of Cuvier.* In the perch the sinus venosus is a flattened vessel, enlarged slightly from the diameter of the common cardinal veins and opening directly into the large atrium.

2. The *atrium* is a single, large chamber extending on both sides of the ventricle. On the right side of the ventricle a portion of the atrium extends as far forward as the ventral aorta. There is no discernable valve between the sinus venosus and atrium but there is a very efficient bicuspid valve between the atrium and the ventricle. This valve is actually a part of the ventricle rather than the atrium and it may best be seen on the dorsal side of the ventricle if the atrium is carefully removed with a pair of small forceps. The valve is very similar in operation to the mammalian semilunar valve. As the ventricle contracts, the anterior and posterior cups of the valve fill up on the ventricle side and occlude the opening. As the ventricle relaxes, blood flows from the atrium into the ventricle.

3. The *ventricle* is a thick muscular structure with a single internal chamber. Anteriorly, the ventricle has a small opening into the bulbus arteriosus. The opening is protected from backflow by an elongated valve extending into the bulbus and attached to the inner wall of the bulbus by muscular slips. If the bulbus is carefully torn loose from the ventricle the cusps of the valve will be seen adhering to the ventricle. Some of the bulbar muscular slips will have torn loose from the bulbus and will be seen attached to the bulbar surface of the valves.

4. The *bulbus arteriosus* is the enlarged base of the ventral aorta. More primitive vertebrates may have a conus arteriosus in this position. A conus is capable of muscular pulsation but the bulbus arteriosus is not.

According to some authors, the muscle slips and the valvular cusps they adhere to (when the bulbus is separated from the ventricle), together represent the *conus arteriosus.* This view is not accepted by all workers.

B. The Branchial Circulation.

5. The *ventral aorta* receives blood from the bulbus arteriosus and distributes it to the afferent branchial (gill) arches. There are only three pairs of branches from the ventral aorta. The first and second afferent arches

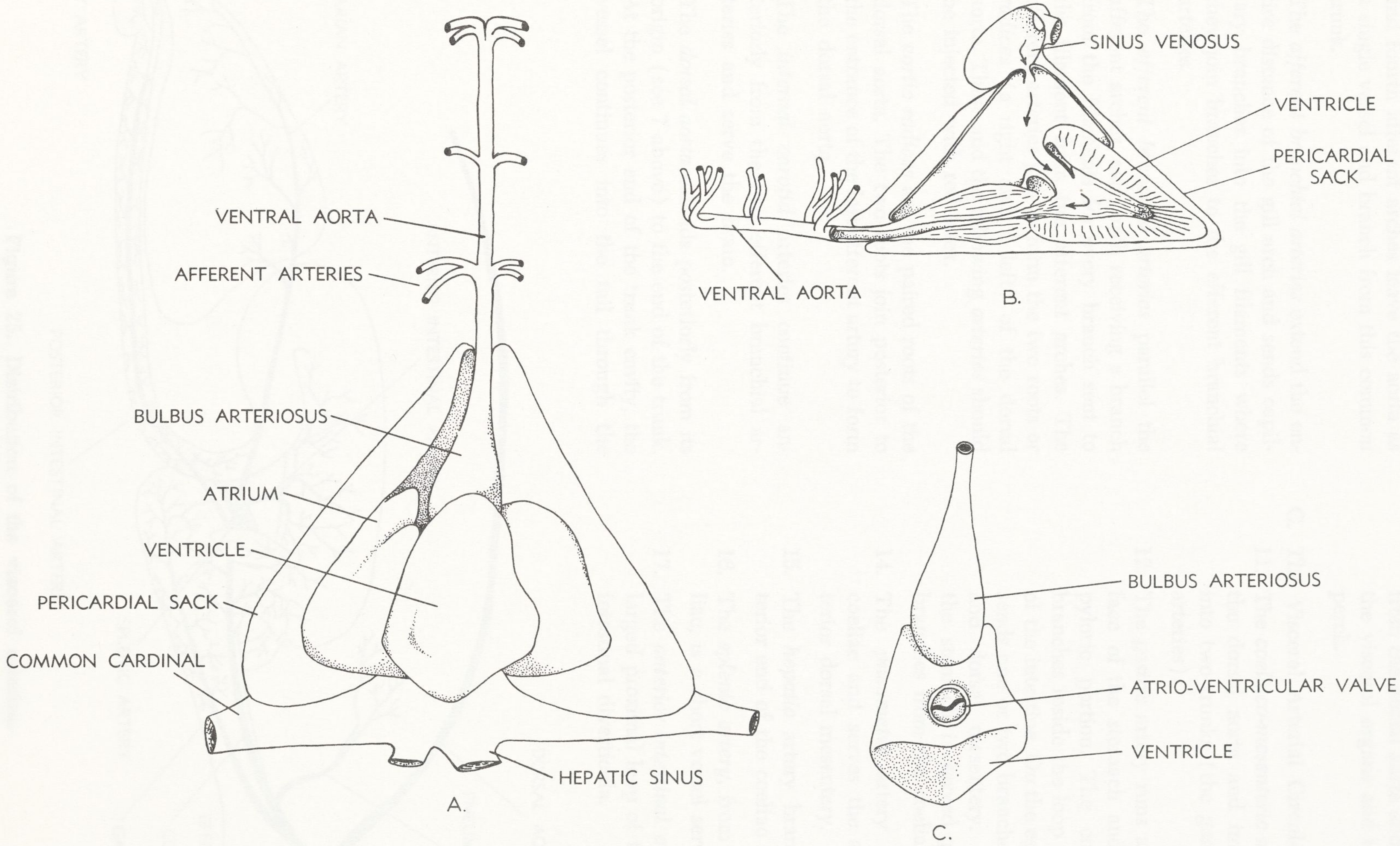

Figure 24. A. Ventral view of the heart and associated vessels. B. Sagittal section of the heart. C. Dorsal view of ventricle and bulbus arteriosus with atrium removed.

branch directly from the aorta but the third and fourth afferent arches leave the aorta as a single vessel and branch from this common trunk.

6. The *afferent branchial arteries* extend the entire distance of the gill arch and sends capillary branches into the gill filaments where they join branches to the efferent branchial arteries.

7. The *efferent branchial arteries* parallel the afferent arches, each arch receiving a branch from the filaments for every branch sent to the filament from the afferent arches. The efferent arteries join to form the two roots or *radices* (a right and a left) of the dorsal aorta. These and the following *arteries* should be injected with red latex.

8. The *aortic radices* are the paired roots of the dorsal aorta. The two roots join posterior to the entrance of the last efferent artery to form the dorsal aorta.

9. The *internal carotid* arteries continue anteriorly from the first efferent branchial arteries and serve the brain.

10. The *dorsal aorta* extends posteriorly from its origin (see 7 above) to the end of the trunk. At the posterior end of the trunk cavity, the vessel continues into the tail through the haemal arches as the *caudal artery*. Branches from the dorsal aorta and caudal artery serve the visceral organs and body muscles of the perch.

C. The Visceral Arterial Circulation.

11. The *coeliaco-mesenteric* artery branches from the dorsal aorta and immediately branches into two trunks (the *gastric* and the *coeliac* arteries).

12. The *gastric* artery runs along the dorsal surface of the stomach and to the left of the pyloric portion. The coeliac ends in five branches inside the loop of the proximal end of the intestine. On the esophagus, the coeliac sends one or two branches to the air bladder and dorsal mesentery. The right side of the stomach is served principally by short branches from the coeliac.

14. The *pneumatic* artery branches from the coeliac and serves the air bladder and anterior dorsal mesentery.

15. The *hepatic* artery branches from the posterior end of the coeliac and serves the liver.

16. The *splenic artery,* from the end of the coeliac, is a short vessel serving the spleen.

17. The *anterior intestinal artery* serves the enlarged proximal loop of the intestine and the intestinal diverticula.

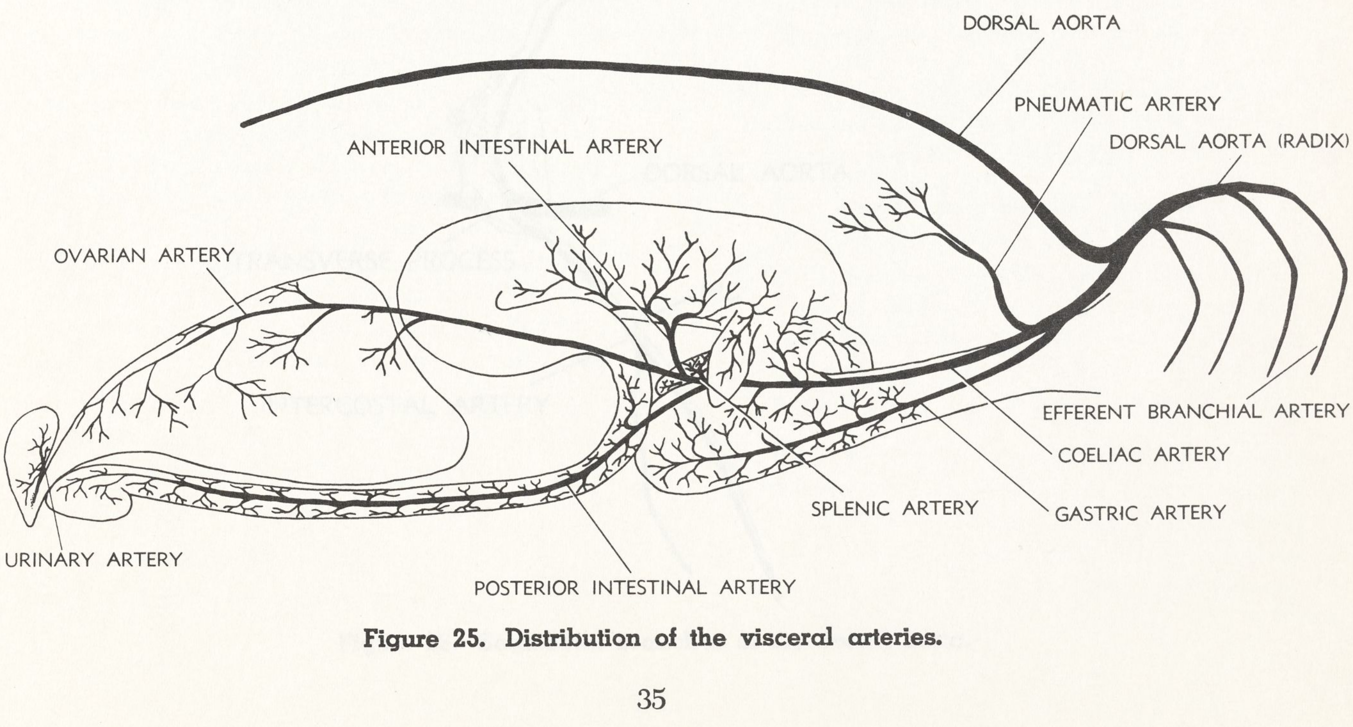

Figure 25. Distribution of the visceral arteries.

18. The *posterior intestinal artery* serves the straight, posterior, terminal portion of the intestine.

19. The *ovarian artery* (in the female) extends on the left side of the intestine from the coeliac to the dorsal surface of the ovary.

The *spermatic artery* (in the male) extends from the coeliaco-mesenteric to the testis on the left side and from the gastric artery to the right testis.

D. The Somatic Arterial Circulation.

At each vertebra the dorsal aorta sends out two pairs of branches. One pair goes dorsally to the interspinous and interpterygiophore muscles and the other pair of arteries serve the muscles between the ribs or haemal arches.

20. *Interspinal* arteries are paired branches of the dorsal aorta which fuse and extend dorsally to the dorsal tip of each neural spine. Each pair emerges from the aorta (or caudal artery in the tail) and joins a *supraspinous* artery which runs from anterior to posterior at the dorsal tips of the neural arches.

21. *Interpterygiophore* arteries branch dorsally from the supraspinous artery and serve the interpterygiophore muscles.

22. *Intercostal* arteries extend ventro-laterally from the aorta and serve the intercostal muscles. Superficial branches extend laterally from the intercostal arteries and pass through the intermuscular septum which separates the epaxial and hypaxial muscles.

Branches of the intercostal arteries in the region of the pectoral and pelvic appendages also serve these structures.

23. The *cutaneous* artery forms by a recombination of the superficial branches of the intercostals. The cutaneous artery runs horizon-

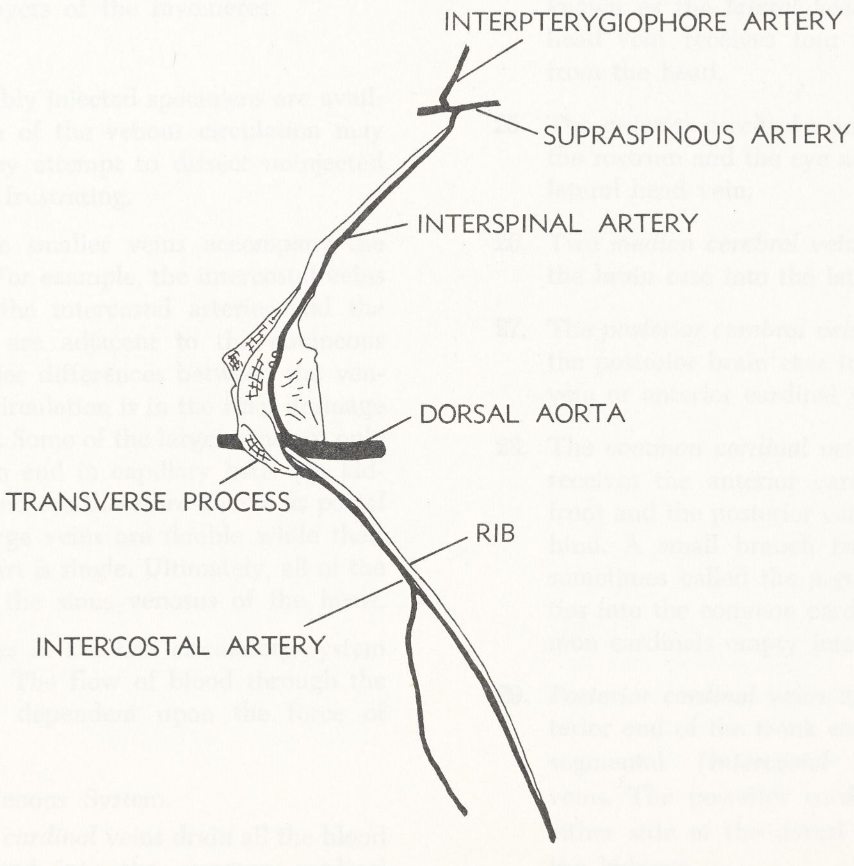

Figure 26. Segmental branches of the dorsal aorta.

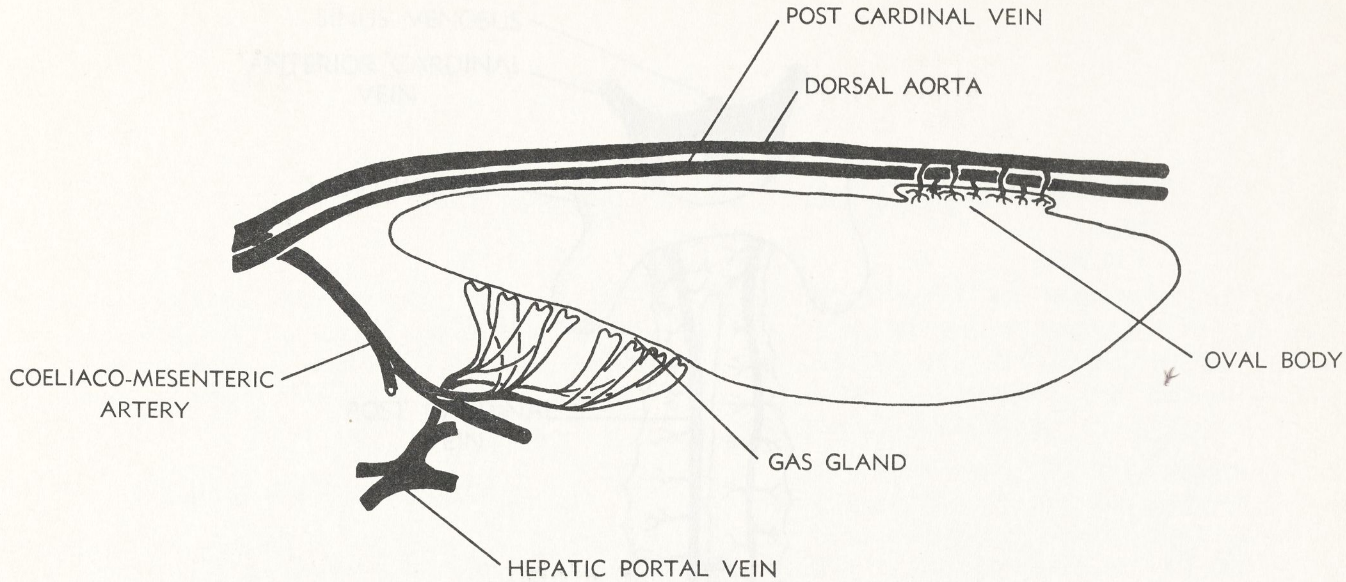

Figure 27. Diagram of a teleost air bladder and its associated circulatory system. After Goodrich, 1930. Studies on the structure and development of vertebrates. Macmillan Co., London.

tally near the lateral line and serves the superficial layers of the myomeres.

E. The Veins.

If triply or doubly injected specimens are available, a dissection of the venous circulation may be profitable. Any attempt to dissect uninjected veins will prove frustrating.

In general, the smaller veins accompany the smaller arteries. For example, the intercostal veins are adjacent to the intercostal arteries and the cutaneous veins are adjacent to the cutaneous arteries. The major differences between the venous and arterial circulation is in the final drainage of the large veins. Some of the large veins not only originate but also end in capillary beds (in kidneys and liver) and are therefore known as *portal* vessels. Other large veins are double while their arterial counterpart is single. Ultimately, all of the veins drain into the sinus venosus of the heart.

The only valves in the fish circulatory system are in the heart. The flow of blood through the veins is entirely dependent upon the force of gravity.

F. The Cardinal Venous System.

24. The *anterior cardinal* veins drain all the blood from the head into the common cardinal veins. Beside the endocranium this vessel is known as the *lateral head vein.* The lateral head vein receives four principal branches from the head.

25. The *anterior cerebral* vein drains blood from the rostrum and the eye and empties into the lateral head vein.

26. Two *median cerebral* veins drain blood from the brain case into the lateral head vein.

27. The *posterior cerebral vein* drains blood from the posterior brain case into the lateral head vein or anterior cardinal vein.

28. The *common cardinal vein* (duct of Cuvier) receives the anterior cardinal vein from in front and the posterior cardinal vein from behind. A small branch from the lower jaw, sometimes called the *jugular vein,* also empties into the common cardinal. The two common cardinals empty into the sinus venosus.

29. *Posterior cardinal* veins originate at the posterior end of the trunk cavity from *renal* and segmental (*intercostal* and *interspinous*) veins. The posterior cardinals are found on either side of the dorsal aorta and between the kidneys.

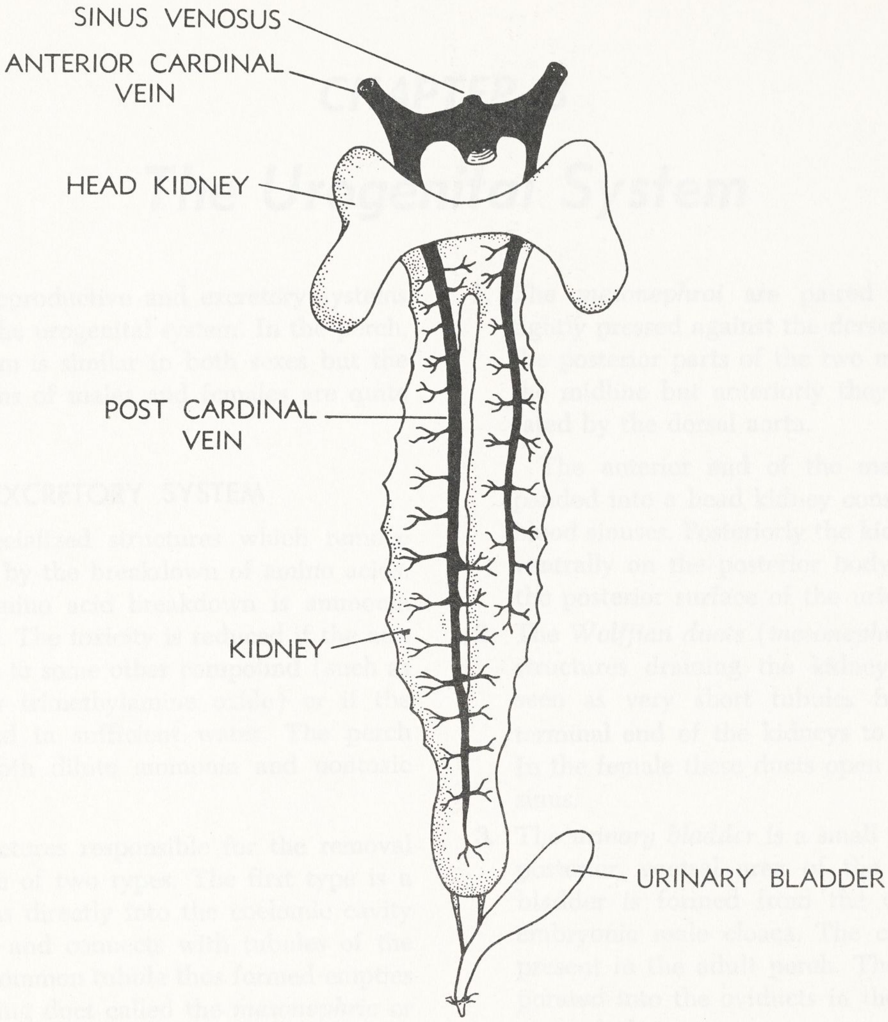

Figure 28. Postcardinal veins and kidneys. After Haller, from Kingsley, 1926, Outlines of Comparative Anatomy of Vertebrates, Blakiston's Son & Co.

30. The *renal* veins are short vessels draining the kidneys and opening into the posterior cardinals.

G. The Hepatic Sinus and Hepatic Portal System.

31. The *hepatic sinus* receives blood from the liver and opens directly into the sinus venosus.
32. The *hepatic portal* vein receives blood from the spleen, intestines, stomach, pancreas, and swim bladder and distributes blood to the capillaries of the liver.
33. The *splenic* vein drains the spleen and adjacent parts of the stomach and empties into the hepatic portal vein.
34. A *gastric* vein from the stomach empties into the hepatic portal.
35. The *pancreaticoduodenal vein* drains blood from the capillaries of the pancreas, the pyloric caecae, and from the adjacent duodenum into the hepatic portal.
36. The *intestinal vein* drains the posterior intestine and empties into the hepatic portal vein.
37. Several *cystic* and *duodenal* veins drain the capillaries of the gall bladder and adjacent duodenum into the hepatic portal.
38. *Gonadal veins* from the ovary or testes extend from the dorsal surface of the gonad to the hepatic portal vein.

CHAPTER 8

The Urogenital System

The combined reproductive and excretory systems are referred to as the urogenital system. In the perch, the excretory system is similar in both sexes but the reproductive systems of males and females are quite different.

THE EXCRETORY SYSTEM

Kidneys are specialized structures which remove the wastes formed by the breakdown of amino acids. The product of amino acid breakdown is ammonia which is very toxic. The toxicity is reduced if the ammonia is converted to some other compound (such as urea, uric acid, or trimethylamine oxide) or if the ammonia is diluted in sufficient water. The perch kidney removes both dilute ammonia and nontoxic compounds.

The kidney structures responsible for the removal of these wastes are of two types. The first type is a tubule which opens directly into the coelomic cavity by a *nephrostome* and connects with tubules of the second type. The common tubule thus formed empties into a long collecting duct called the *mesonephric* or *Wolffian* duct. The second type of tubule ends blindly rather than opening to the coelomic cavity. The blind end of the tubule encapsulates a knot of blood vessels called the *glomerulus* and waste material in the blood of these capillaries is filtered from the blood into the blind tubule. This combined tubule drainage is termed a *mesonephros*.

The more posterior mesonephric tubules do not have nephrostomes and in some other fishes the more anterior tubules may not have capsules around glomeruli. In the latter case the tubules are called *pronephros*.

The tubules have a capillary bed around them which helps to resorb water from the excretory material in the tubule. This capillary bed is from branches of the renal portal vein and the capillaries empty into vessels which drain into the renal vein. The glomeruli are formed from branches of the renal artery and drain (eventually) into the renal veins.

1. The *mesonephroi* are paired elongated masses tightly pressed against the dorsal body wall. Often the posterior parts of the two masses are fused in the midline but anteriorly they are usually separated by the dorsal aorta.

   The anterior end of the mesonephroi are expanded into a head kidney consisting primarily of blood sinuses. Posteriorly the kidneys are deflected ventrally on the posterior body wall and end on the posterior surface of the urinary bladder.
2. The *Wolffian ducts* (*mesonephric ducts*) are long structures draining the kidney but they may be seen as very short tubules from the posterior, terminal end of the kidneys to the male bladder. In the female these ducts open into the urogenital sinus.
3. The *urinary bladder* is a small vesicle at the most posterior, ventral area of the body cavity. The bladder is formed from the dorsal wall of the embryonic male cloaca. The cloaca is no longer present in the adult perch. The bladder is incorporated into the oviducts in the female to form a *urogenital sinus*.
4. The *urinary papilla* is the external projection of the male urinary bladder. Waste materials are extruded through a *urinary pore* of the papilla. In the female the excretory materials are extruded through a *urogenital pore*.

REPRODUCTIVE SYSTEMS

MALE

5. The *testes* are paired, lobulated structures, posterior to the duodenum and stomach, ventral to the air bladder and dorsal to the intestine. Longitudinal folds run the length of testes and the *vas deferens* will be found inside of the largest and most central of these folds. With the help of a dissecting microscope, pick away the tissue of the testes and expose the vas deferens.
6. The *vas deferens* (see above) of the two sides join in the posterior midline to form a genital

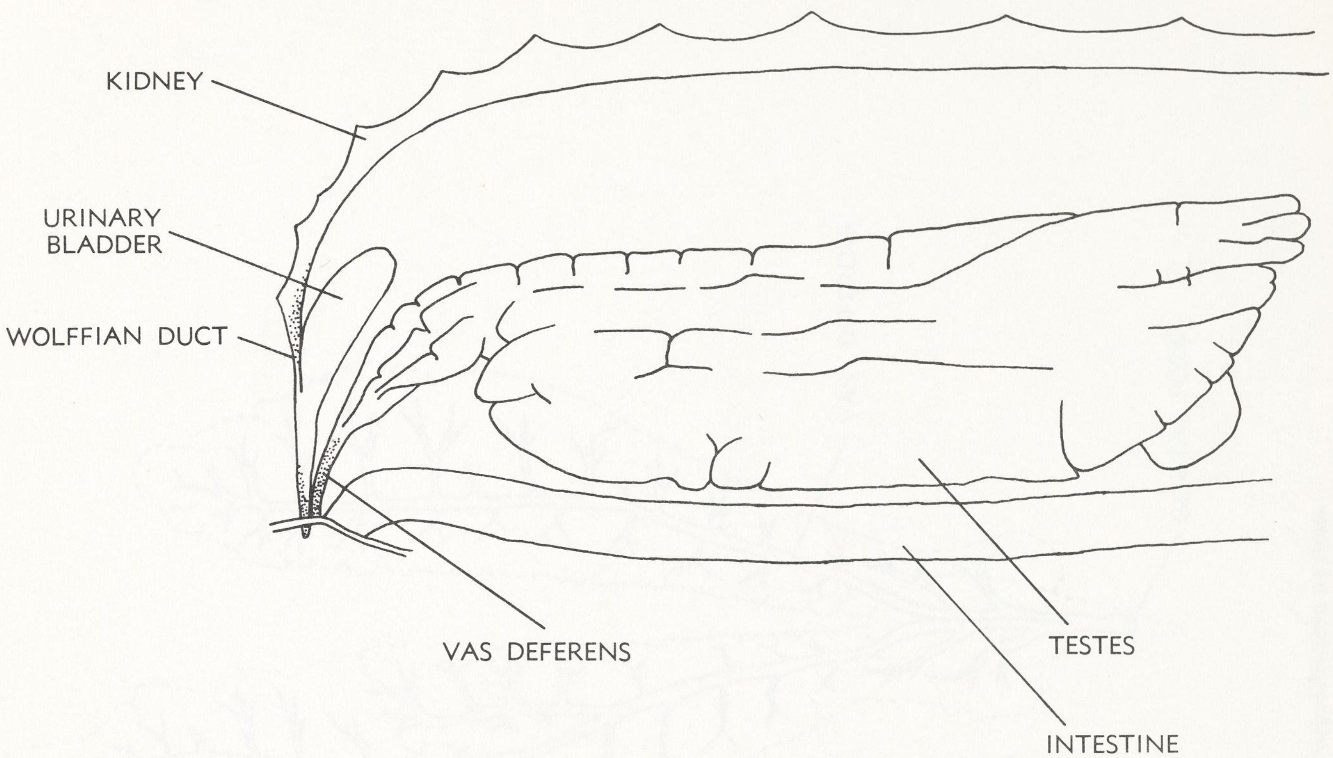

Figure 29. Lateral view of the male urogenital organs.

sinus which opens to the exterior between the urinary papilla and the anus. The vas deferens will be located adjacent to the spermatic artery.

7. The *genital pore* is the external opening of the combined vas deferens.

FEMALE

8. The *ovary* of the female is a single large sack of eggs located in the same position in the trunk cavity as were the testes in the male. The single sack probably represents a single ovary and oviduct but there is some evidence the ovaries are fused together.

9. The *oviduct* in the perch is in two parts. The eggs are actually expelled from the female through an abdominal pore just posterior to the anus. The lining of the pore is folded, internally, into a funnel-like structure which meets the coelomic portion of the oviduct.

The coelomic part of the oviduct is formed during embryonic development by a fold of the peritoneum which envelopes the ovary and forms a "tunnel" from the ovary to the abdominal pore. Figure 31 illustrates the oviduct of the perch.

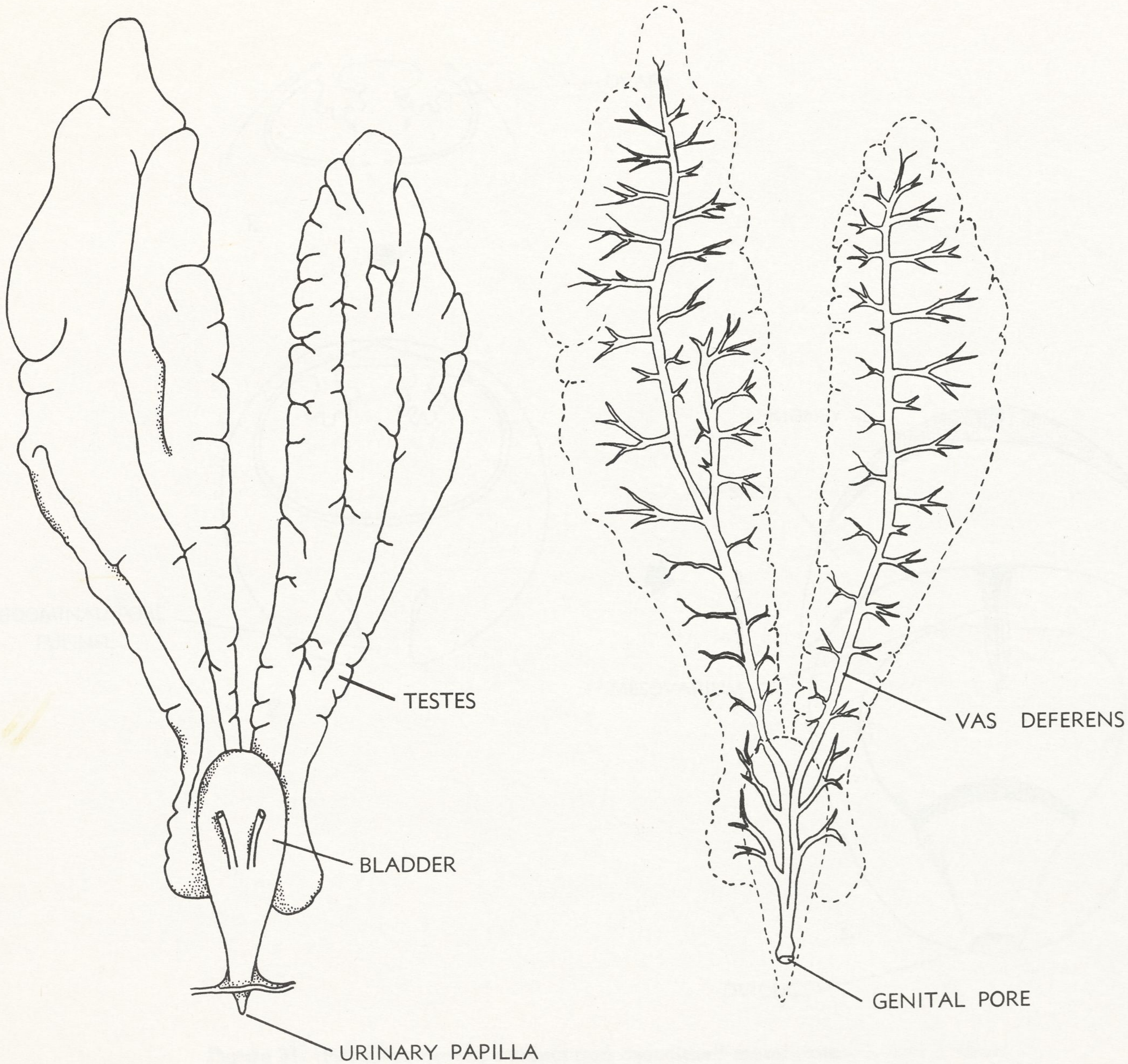

Figure 30. Dorsal view of the male reproductive system.

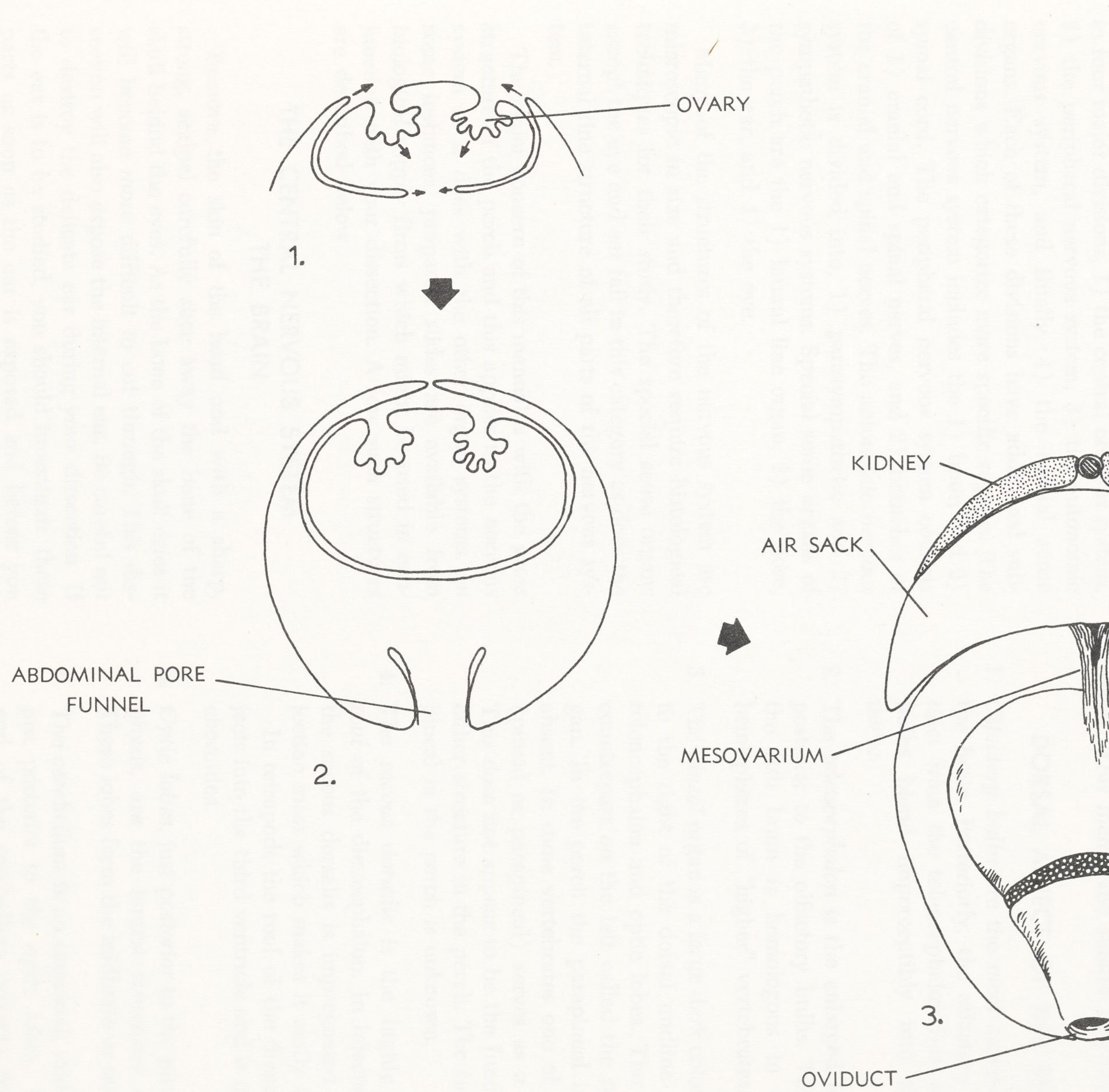

Figure 31. Posterior view of oviduct and associated membranes. 1. and 2. show stages in the development of the ovarian membranes.

CHAPTER 9

The Nervous System

The vertebrate nervous system is usually arranged in four major divisions, 1) the central nervous system, 2) the peripheral nervous system, 3) the autonomic nervous system, and finally, 4) the special sense organs. Each of these divisions have additional subdivisions which categorize more specific regions. The central nervous system includes the 1) brain and 2) spinal cord. The peripheral nervous system consists of 1) cranial and spinal nerves, and 2) branches of the cranial and spinal nerves. The autonomic nervous system is divided into, 1) parasympathetic and 2) sympathetic nervous systems. Special sense organs of the perch are the 1) lateral line organ, 2) the nose, 3) the ear, and 4) the eye.

Many of the structures of the nervous system are microscopic in size and therefore require histological techniques for their study. The special sense organs except the eye and ear fall in this category as does the internal fine structure of all parts of the nervous system.

The major concern of this manual is with the gross structure of the perch and this applies to the nervous system as it does with the other organ systems. In some instances, prepared slides are available from biological supply firms which might be used in conjunction with your dissection. A few such structures are described below.

THE CENTRAL NERVOUS SYSTEM
THE BRAIN

Remove the skin of the head and with a sharp, strong, scalpel carefully slice away the bone of the skull behind the eyes. As the bone of the skull dries it will become more difficult to cut through. This dissection will also expose the internal ear. Be careful not to destroy the delicate ear during your dissection. If the ear is to be studied, you should investigate these parts as soon as the ear is exposed and before you expose the brain.

The brain is embedded in a gelatinous mass which must be removed before the brain can be studied. A pigmented membrane, the *meninx,* covers the brain directly. This membrane should be removed.

DORSAL ASPECT OF THE BRAIN

1. *Olfactory bulbs* are the most anterior portion of the brain. Posteriorly, the olfactory bulb is distinct from the telencephalon but anteriorly the bulbs blend imperceptibly into the olfactory nerve.
2. The *telencephalon* is the enlarged forebrain just posterior to the olfactory bulbs. This portion of the fish brain is homologous to the cerebral hemispheres of "higher" vertebrates.
3. The *pineal* organ is a large dark colored body just to the right of the dorsal midline between the telencephalon and optic lobes. The pineal has a counterpart on the left called the *parapineal* organ. In the perch the parapineal is reduced or absent. In some vertebrates one of these organs (pineal or parapineal) serves as a median *eye.* This does not appear to be the functional role of either structure in the perch. The function of the pineal in the perch is unknown.
4. The *saccus dorsalis* is the highly vascularized roof of the diencephalon. In injected specimens, the saccus dorsalis is impregnated with the injection mass which makes it easily distinguished.

   In tetrapods the roof of the diencephalon projects into the third ventricle and is called the tela choroidea.
5. *Optic lobes,* just posterior to the pineal and paraphysis, are the largest structures of the brain. These lobes form the midbrain or *mesencephalon.*
6. The *cerebellum* is an unpaired, midline structure just posterior to the optic lobes. The posterior end of the cerebellum projects dorsally, above the fourth ventricle. Laterally the cerebellum has rounded enlargements which project partially into the fourth ventricle.

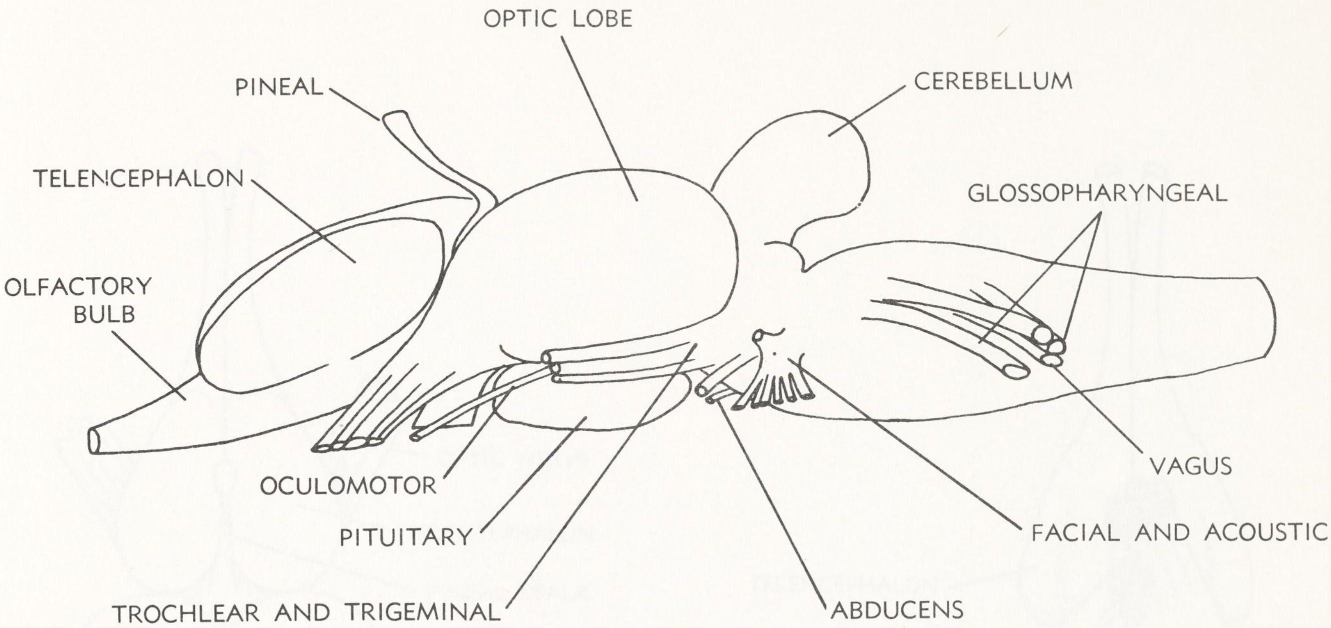

Figure 32. Lateral view of the brain.

The cerebellum is formed from the embryonic metencephalon.

7. The *medulla oblongata* is the most posterior division of the brain. The posterior *fourth ventricle* is the open chamber in the dorsal half of the medulla. This chamber is roofed by a *tela choroidea* which was probably removed during your dissection.

The lateral middle walls of the fourth ventricle are expanded into two lobes, the *tuberculi impar,* which meet in the midline to separate the fourth ventricle into anterior and posterior divisions.

The medulla is formed from the embryonic myelencephalon.

VENTRAL ASPECT OF THE BRAIN

Some of the structures described under the dorsal aspect of the brain will also be seen here. These descriptions will not be repeated.

8. The *optic nerves* will be seen emerging from the anterior ventral corner of the optic lobes. The nerves cross beneath the telencephalon so the nerve from the left optic nerve extends to the right eye and the nerve of the right optic lobe serves the left eye. There is no optic chiasma in the perch.

9. The *pituitary* is very large in the perch and is located just posterior to the crossed optic nerves. The pituitary is an endocrine gland which secretes several different hormones.

10. The *medulla oblongata* (see 7 above) has all of the cranial nerves except the first two, emerging from it. The cranial nerves are described in the chart on page 46.

SAGITTAL VIEW OF THE BRAIN

One of the primary characteristics of the vertebrate central nervous system is that it is hollow. The cavity of the spinal cord is the *central canal.* In the brain, the central canal is expanded into a series of ventricles; one ventricle being located in each major portion of the brain.

The two lobes of the telencephalon contain the two most anterior ventricles. The diencephalon contains the third ventricle and an optic ventricle forms the interior of each of the mesencephalic lobes. Posteriorly, a fourth ventricle is located in the dorsal half of the myelencephalon. The first two ventricles will be seen if the telencephalon is cross sectioned but they will not be seen in sagittal section.

1. The *optic ventricles* are found inside the optic lobes. The outer tissue of the optic lobes forms the optic tectum.

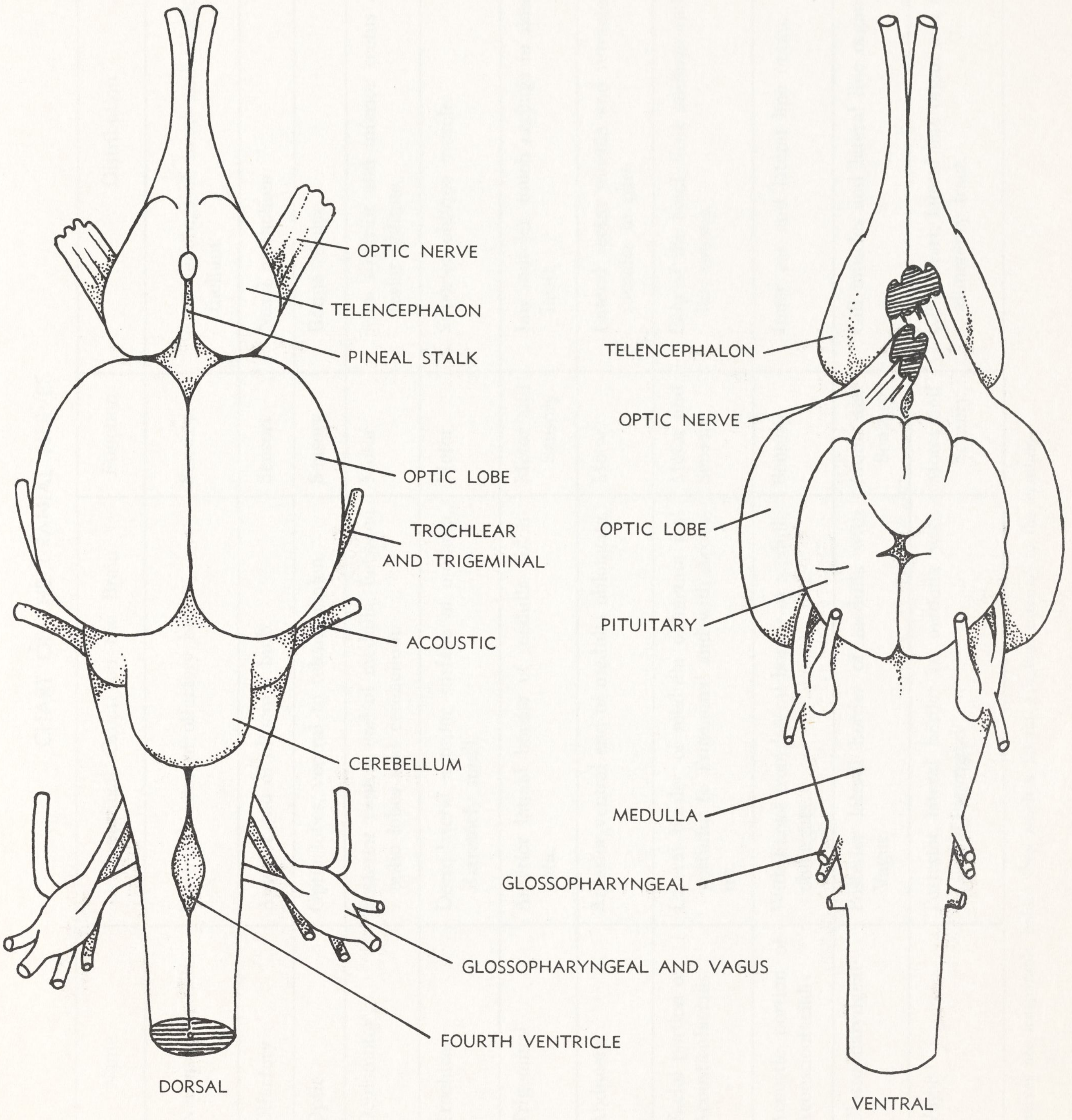

Figure 33. Dorsal and ventral views of the brain.

CHART OF THE CRANIAL NERVES

Name	Superficial Origin on the Brain	Function	Distribution
O. Nervus terminalis	Ventral border of olfactory bulb.	Sensory	Sense endings of snout and olfactory epithelium.
I. Olfactory	Anterior end of olfactory bulb.	Sensory	Nasal epithelium.
II. Optic	Optic lobes, ventral to telencephalon.	Sensory	Retina of eye.
III. Oculomotor	Posterior ventral end of medulla, between optic lobes and cerebellum.	Motor	Mm. superior and inferior rectus and inferior oblique.
IV. Trochlear	Dorso-lateral anterior surface of medulla. Extremely small.	Motor	Superior oblique muscle.
V. Trigeminal	Anterior lateral border of medulla oblongata.	Motor and Sensory	Jaw muscles, touch endings in skin of the head.
VI. Abducens	Anterior ventral end of medulla oblongata.	Motor	Lateral rectus muscle and retractor bulbi muscles in part.
VII. Facial portion of Acousticofacialis	Lateral border of medulla oblongata just posterior to Trigeminal and with Acoustic.	Motor and Sensory	Skin of the head, taste endings and lateral line organs.
VIII. Acoustic portion of Acousticofacialis	With Facial from lateral border of medulla oblongata.	Sensory	Inner ear and lateral line organ.
IX. Glossopharyngeal[1]	Posterior lateral border of medulla with Vagus.	Motor and Sensory	Gill muscles and lateral line organ.
X. Vagus[1]	Posterior lateral border of medulla with Glossopharyngeal	Motor and Sensory	Gills, heart, lateral line organ and anterior alimentary tract.

[1]These nerves are inseparable before they reach a lateral ganglion external to the cranium.

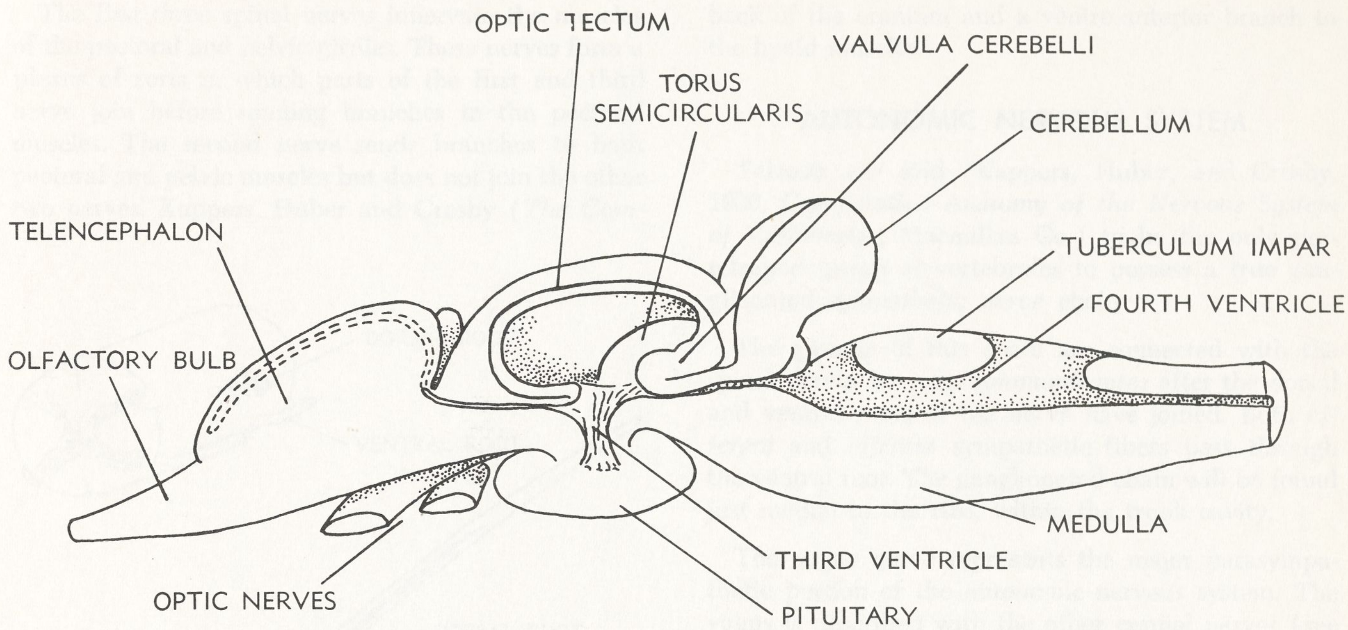

Figure 34. Midsagittal view of the brain.

2. The *valvula cerebelli* is a midline structure projecting anteriorly into the area of the posterior floor between the two optic ventricles. This structure appears to be a continuation of the base of the cerebellum. Fish which have a large valvula cerebelli also have a better developed lateral line organ.
3. The *torus semicirculari* are enlargements of the posterior floor of each optic ventricle. The two tori semicirculari are separated from each other by the valvuli cerebelli. The *tori semicirculari* are homologous to the *corpus quadrigeminum posterius* (auditory reflex centers) of mammals.
4. The *third ventricle* is a narrow midline channel projecting ventrally from between the two optic ventricles toward the pituitary gland. A narrow passage runs forward from the central chamber to the telencephalic ventricles and a posterior channel joins the third ventricle with the fourth. The posterior channel is termed the *aqueduct of Sylvius*.
5. The *infundibulum* is a short stalk from the floor of the diencephalon to the pituitary. A portion of the third ventricle is in the center of the infundibulum.
6. The *fourth ventricle* is the cavity of the dorsal half of the myelencephalon.
7. The *tuberculum impar* is formed by enlargements on the lateral walls of the fourth ventricle which fuse with each other in the midline. This structure is associated with fibers of the facial nerve (7th cranial nerve) and is sometimes referred to as the *facial lobe.*

THE SPINAL CORD

The spinal cord of the perch requires histological techniques for its proper study. Even what might be referred to as a "gross" dissection will require a dissecting microscope.

The major features of the typical vertebrate spinal cord are (1) a central spinal nerve cord extending posteriorly from the brain and passing through the vertebral neural arches and, (2) a series of paired spinal nerves emerging from the spinal cord and serving various somatic structures.

In the perch, the paired spinal nerves pass through vertebral foramina as they emerge from the spinal cord. As a result of this arrangement the nerves are destroyed as the vertebrae are removed. A study of these nerves is therefore extremely difficult. Figure 35 will illustrate the typical spinal nerves and indicate their relationship to the vertebral column. Figure 36 illustrates the arrangement of the first three spinal nerves and a typical spinal nerve of the trunk.

The first three spinal nerves innervate the muscles of the pectoral and pelvic girdles. These nerves form a plexus of sorts in which parts of the first and third nerve join before sending branches to the pectoral muscles. The second nerve sends branches to both pectoral and pelvic muscles but does not join the other two nerves. Kappers, Huber and Crosby (*The Comparative Anatomy of the Nervous System of Vertebrates,* Vol. I. Macmillan Co., New York, 1936) state, "The more anterior of the two nerves is represented almost entirely by a ventral ramus. . ." . In the perch, all three of the spinal nerves concerned in the pectoral-pelvic plexus appear to lack dorsal roots.

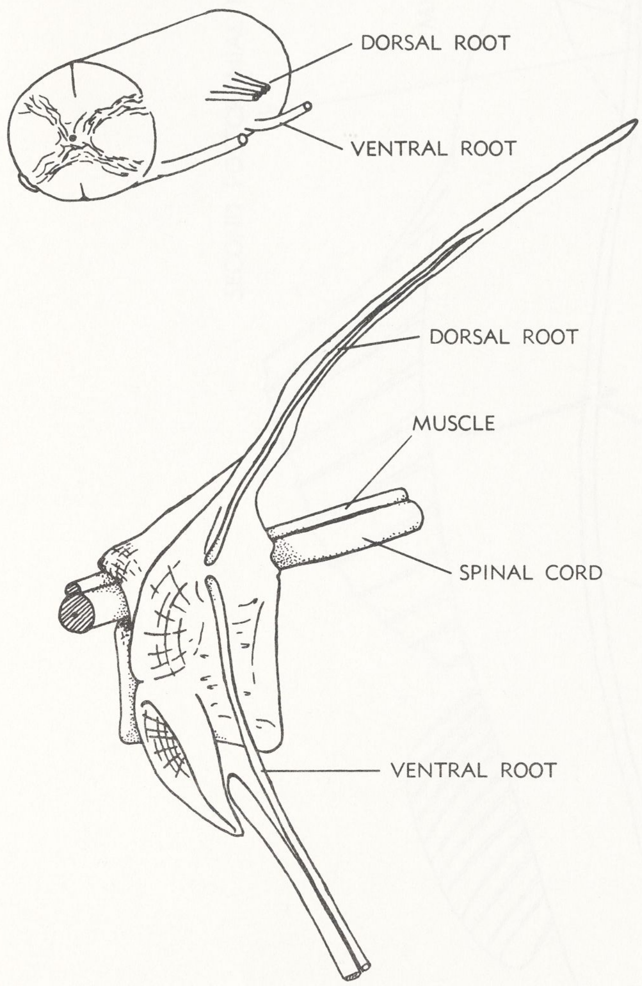

Figure 35. Spinal cord and the arrangement of spinal nerves.

In addition to serving the fin muscles, the first spinal nerve has a dorsal (*occipital*) branch to the back of the cranium and a ventro-anterior branch to the hyoid muscles.

AUTONOMIC NERVOUS SYSTEM

Teleosts are said (Kappers, Huber, and Crosby, 1936, *Comparative Anatomy of the Nervous System of Vertebrates,* Macmillan Co.) to be the only pretetrapod group of vertebrates to possess a true ganglionated *sympathetic nerve* chain.

The ganglia of this chain are connected with the spinal nerves by *rami communicantes* after the dorsal and ventral roots of the nerve have joined. Both *afferent* and *efferent* sympathetic fibers pass through the ventral root. The ganglionated chain will be found just medial to the ribs, within the trunk cavity.

The *vagus nerve* represents the major parasympathetic portion of the autonomic nervous system. The vagus is described with the other cranial nerves (see the chart of cranial nerves, page 46).

THE SPECIAL SENSE ORGANS
THE LATERAL LINE ORGAN

The lateral line organs of the perch consist of a series of interconnected tubules in the dermis of the skin. One long tubule runs the length of the body on either side, just lateral to the juncture of epaxial and hypaxial muscles. It is these portions which give the organ its name.

In the head, the lateral line structures run through passageways in the dermal bones of the skull. These passages can be found in the bones around the orbit and in the lower jaw as well as on the top of the skull.

As the tubule passes through a scale (or scale bone) a branch of the tubule opens to the surface. In the horizontal portion of the tubule between the lateral branches are groups of ciliated cells called *neuromasts.* The ciliated end of the neuromast cells project into the lateral line canal and the opposite end is innervated by branches of the *vagus* (*lateral line* branch) on the trunk and by the *facial* and *glossopharyngeal* nerves on the head. The difference between the glossopharyngeal and vagus is questionable, thus the fibers from these two nerves might be considered as coming from the same nerve trunk.

Experimental evidence shows that the lateral line organ is sensitive to pressure (acoustic waves) and temperature changes. Several other, as yet unsubstantiated, functions have been claimed for this organ.

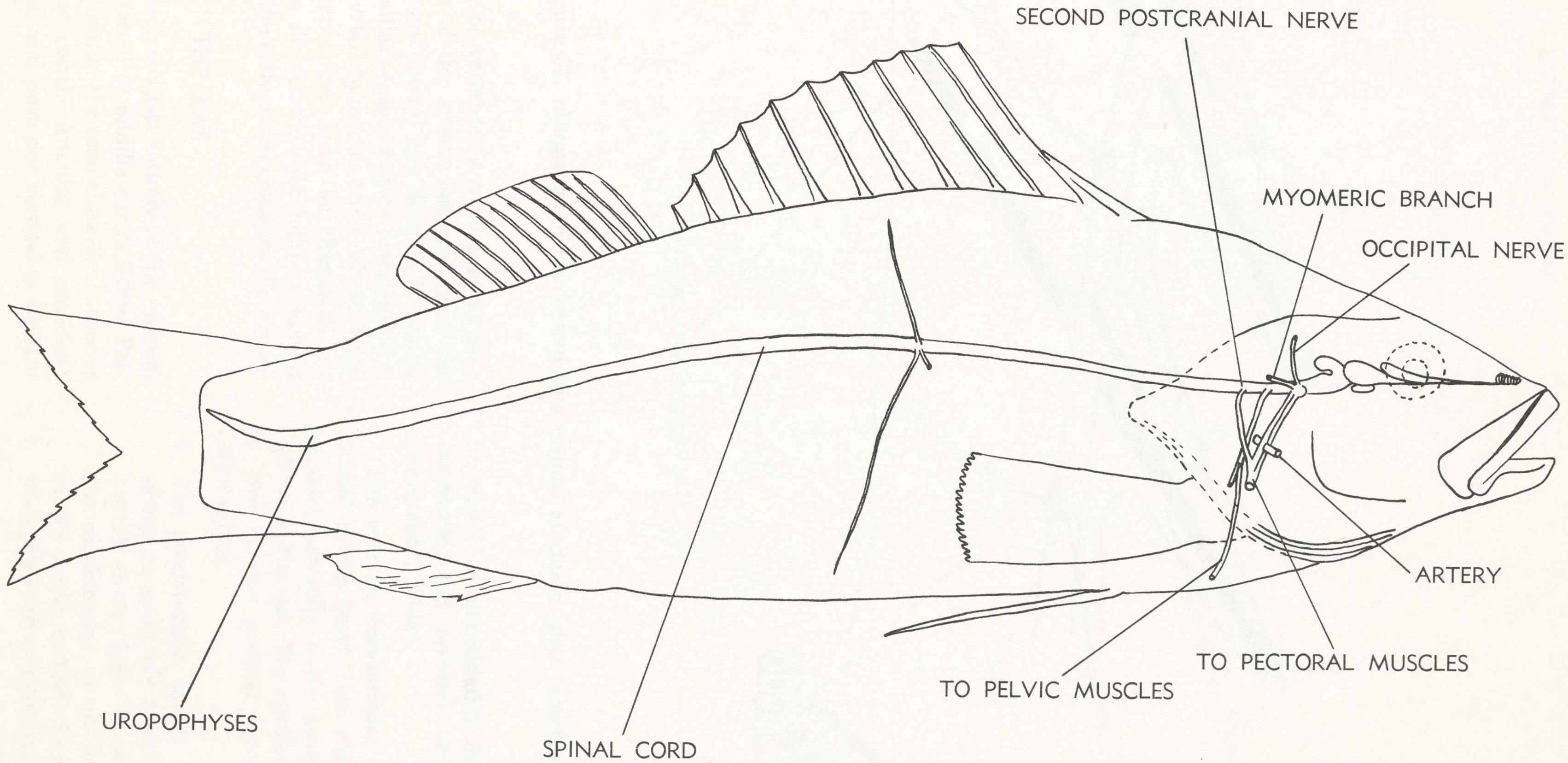

Figure 36. The central nervous system and appendicular plexus.

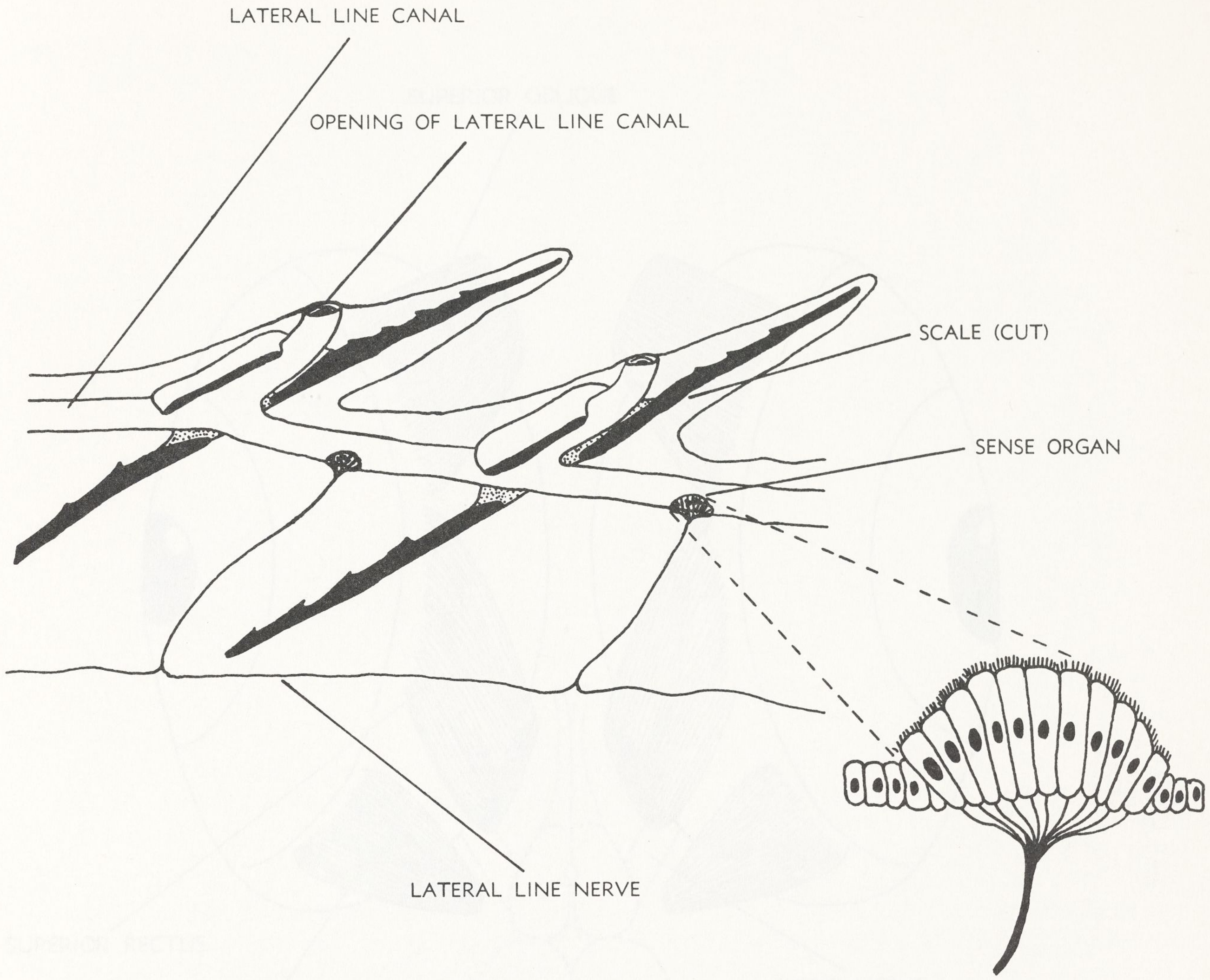

Figure 37. Diagram of the lateral line organ. Modified after Goodrich, 1930.

The internal ear of vertebrates is thought to be a specialized portion of the lateral line system of the head. Both the ear and lateral line develop in similar ways; both have similar sensory organs (neuromasts); and both are innervated by nerves from related brain centers. If the internal ear is to be dissected, the student should also dissect the suborbital portion of the cranial lateral line system and compare the canals.

THE EAR

The ear of the perch consists entirely of the internal ear. There is no external or middle ear in fishes. Portions of the ear are inside the cranial cavity (anterior vertical semicircular canal, utriculus and sacculus) and part (horizontal and posterior vertical semicircular canals) is embedded in the cartilagenous (*prootic, opisthotic,* and *epiotic*) skeleton (see Chapter 3; paragraphs, 30-32).

The anterior semicircular canal will be seen just lateral to the brain (see Figure 39). With a sharp scalpel, carefully shave away the dermal bone just lateral to the ear. The cartilage can be removed with a pair of fine pointed forceps under a dissecting microscope.

1. The *semicircular canals* are arranged in three planes on each side of the head. Figure 39 will illustrate these planes as well as the relationship of the semicircular canals to the brain. The names of the canals indicate their position; *anterior vertical, posterior vertical,* and *horizontal semicircular*

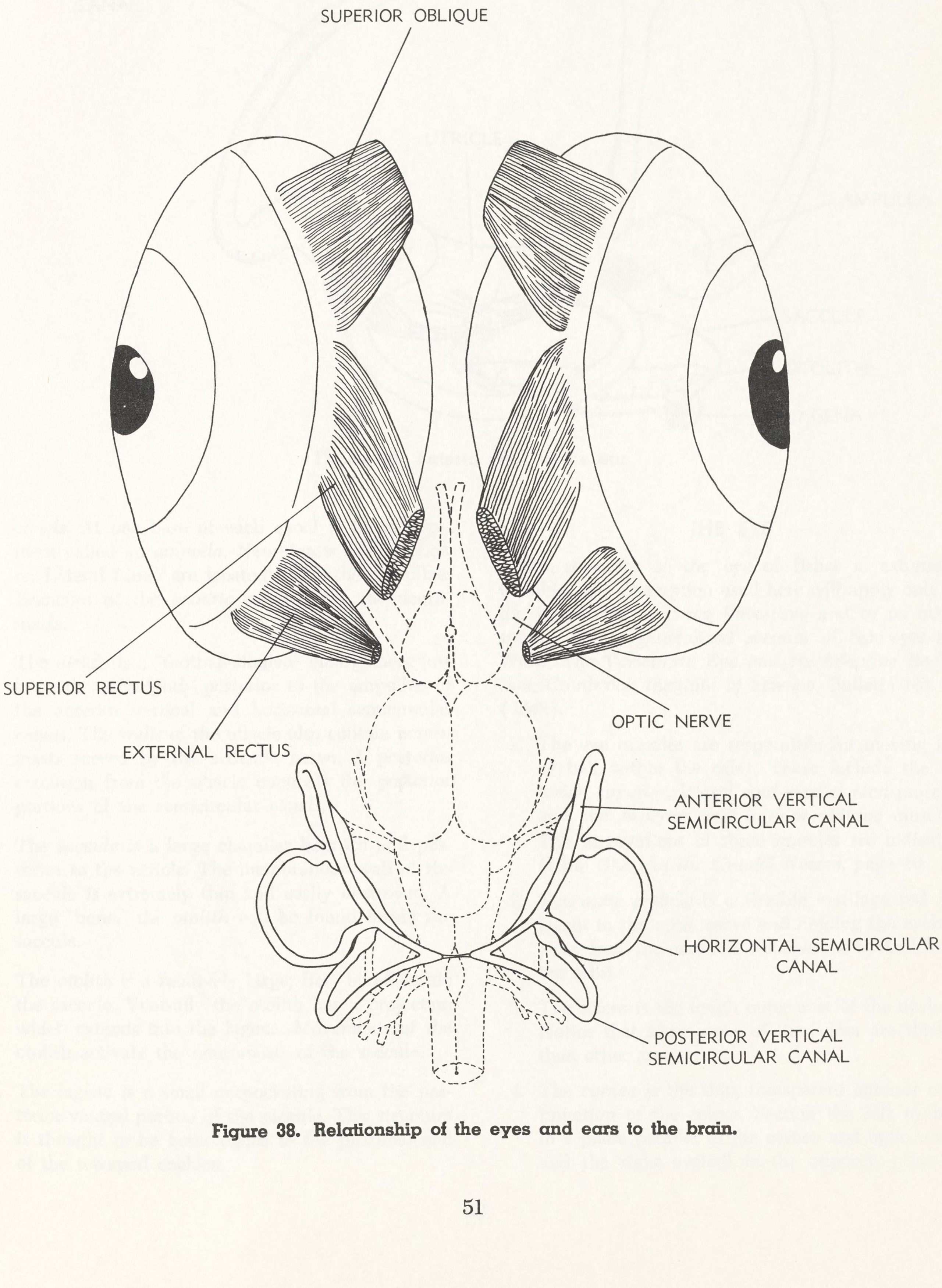

Figure 38. Relationship of the eyes and ears to the brain.

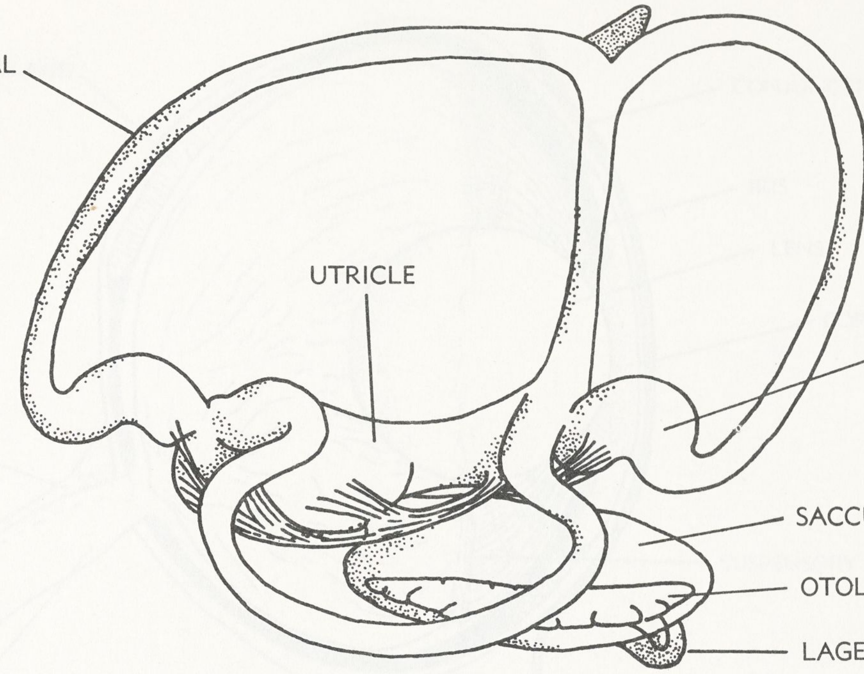

Figure 39. Lateral view of the ear.

canals. At one base of each canal is an enlargement called an *ampulla.* Neuromasts (see section on Lateral Line) are located inside the ampullae. Branches of the *acoutic* nerve serve the neuromasts.

2. The *utricle* is a "football-shaped" enlargement just beneath and slightly posterior to the ampullae of the anterior vertical and horizontal semicircular canals. The walls of the utricle also contain neuromasts served by the acoustic nerve. A posterior extension from the utricle connects the posterior portions of the semicircular canals.

3. The *saccule* is a large chamber beneath and posterior to the utricle. The membranous wall of the saccule is extremely thin and easily destroyed. A large "bone," the *otolith* will be found inside the saccule.

4. The *otolith* is a relatively large, flat "bone" inside the saccule. Ventrally the otolith has a projection which extends into the lagena. Movements of the otolith activate the neuromasts of the saccule.

5. The *lagena* is a small outpocketing from the posterior ventral portion of the saccule. This structure is thought to be homologous to the proximal end of the tetrapod cochlea.

THE EYE

The structure of the eye of fishes is extremely variable. The description used here will apply only to the yellow perch, *Perca flavescens* and to no other species. For a generalized account of fish eyes see Walls, *The Vertebrate Eye and Its Adaptive Radiation, Cranbrook Institute of Science,* Bulletin No. 19 (1942).

1. The eye muscles are responsible for moving the eyeball within the orbit. These include the *inferior, superior, lateral,* and *medial recti* muscles and the *superior* and *inferior oblique* muscles. The innervations of these muscles are indicated in the *Chart of the Cranial Nerves,* page 46.

2. The *optic pedicle* is a flexible cartilage rod adjacent to the optic nerve and holding the eyeball away from the cranium. Remove the eyeball from the orbit.

3. The *sclera* is the tough outer coat of the eyeball. Notice that some areas of the sclera are thicker than other areas.

4. The *cornea* is the thin, transparent anterior continuation of the sclera. Section the left eyeball in a plane parallel to the cornea and optic nerve and the right eyeball in the opposite plane in

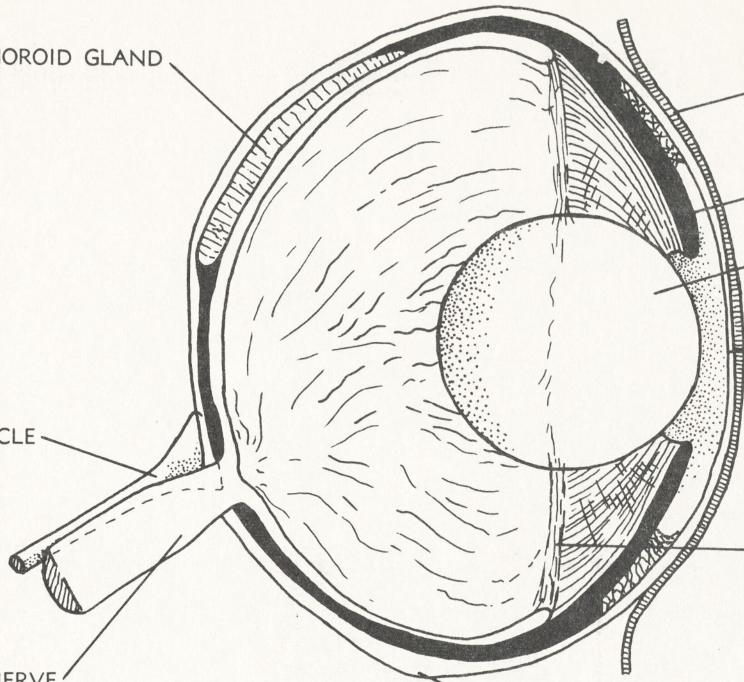

Figure 40. Sagittal view of the eye.

order to separate it into external and internal halves.

5. The *choroid* layer is the black pigmented tissue between the sclera and retina of the internal half of the eyeball. The iris is the anterior continuation of the choroid layer. The perch has a greyish brown *choroid gland* on the dorsal half of the eyeball in the choroid layer.

6. The *iris* is the heavily pigmented continuation of the choroid layer just internal to the cornea. Fibers connect the iris with the anterior cornea.

7. The *pupil* is the large opening in the center of the iris.

8. The *anterior chamber* of the fish eye is a very small chamber between the iris and the cornea.

9. The *posterior chamber* of the eye is between the iris and the lens. The anterior and posterior chambers are connected by the pupil.

10. The *lens* of the perch is a spherical body, suspended from the anterior edge of the retina by a *suspensory ligament*.

11. The *retina* is a greyish tissue lining the interior of the posterior half of the eyeball. Posteriorly, the retina is continuous with the optic nerve. The thickness of the retina is very uneven.

12. The *vitreous body* is the viscous fluid filling the chamber between the lens and the retina.