III

Observation of internal morphology

III 1

Formation of viscera

Fresh fish viscera (sg. viscus) have peculiar solidity and touch. These characters are not available from preserved specimens, and need fresh specimens to observe them. The positions of viscera in abdominal cavity are often dislocated by dissection in fresh specimens, so need formalin fixed (and ethanol preserved) are used for such observations. In this chapter digestive organs and other viscera of Blue Mackerel *Scomber australasicus* are shown in line figure (Fig. 1) and color photographs (Fig. 2).

Operation starts from cutting off opercle, by cutting from lower most part of gill membrane (widely united with throat in some species) to both side of joint of lower jaw. Lifting up opercle and cut off the joint with neurocranium, and continuously cut off postorbital region to both joints of upper jaw. Or, just cut off suborbital region by heavy-duty scissors (= bone scissors).

The next is removing lateral muscles, by inexperienced students, cutting from anus (16) to ventral medial line by scissors. Experienced students start cutting around anus by surgical knives without

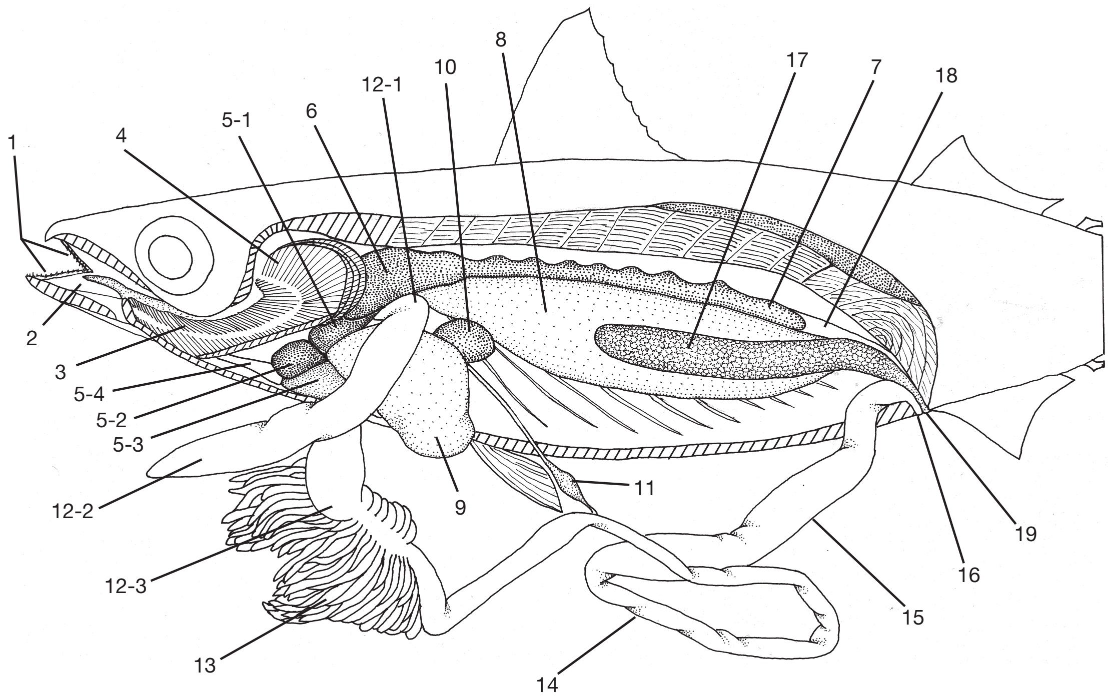

Fig. 1 Viscera of Blue Mackerel *Scomber australasicus*.

1. mouth (jaws)
2. oral cavity
3. gill raker
4. gill filament
5. heart
   - 5-1 venosus sinus
   - 5-2 auricle
   - 5-3 ventricle
   - 5-4 arterial bulb
6. head kidney
7. body kidney
8. air (gas) bladder
9. liver
10. spleen
11. gall bladder
12. stomach
    - 12-1 cardia
    - 12-2 blind sac
    - 12-3 pylorus
13. pyloric caeca
14. intestine
15. rectum
16. anus (=vent)
17. gonad
    - ovary
    - testis
18. urocystis
19. urogenital orifice

damaging digestive organs, and next, with scissors, continue cutting forward. Further, cut with scissors from anus by dorso-anterior angle of left side to near pectoral fin base. Carefully remove kidneys (7) one by one, hidden under lateral process of vertebrae. Before doing this, swim bladder (absent in Atlantic Mackerel *S. scombrus*) appears but is easily broken in dissecting process, and hard to observe or draw.

Fig. 2 Anatomical steps of Blue Mackerel *Scomber australasicus*.
Upper, removing opercula and lateral muscles; Middle, removing pectoral girdle and base of ribs; Lower, Pulling off of gastrointestinal tract.

The last of this serial dissection is removing firm bones of pectoral girdle (Fig. 2, middle). This step should be very careful to avoid injure soft parts connected nearby underside of the bone, such as head kidney (6) or sinus venosus (5-1). Cut off the connection of upper (=dorsal) side of pectoral girdle and neurocranium. Also cut off lower (=ventral) side connection of both side of cleithrum.

Pull down viscera in abdominal cavity for observation and drawing (Fig. 2). To avoid damage by dissecting instruments on viscera, this step should be done by hands, and carefully cut peritoneum by fingers, and keep attaching of start and end of digestive organs with body.

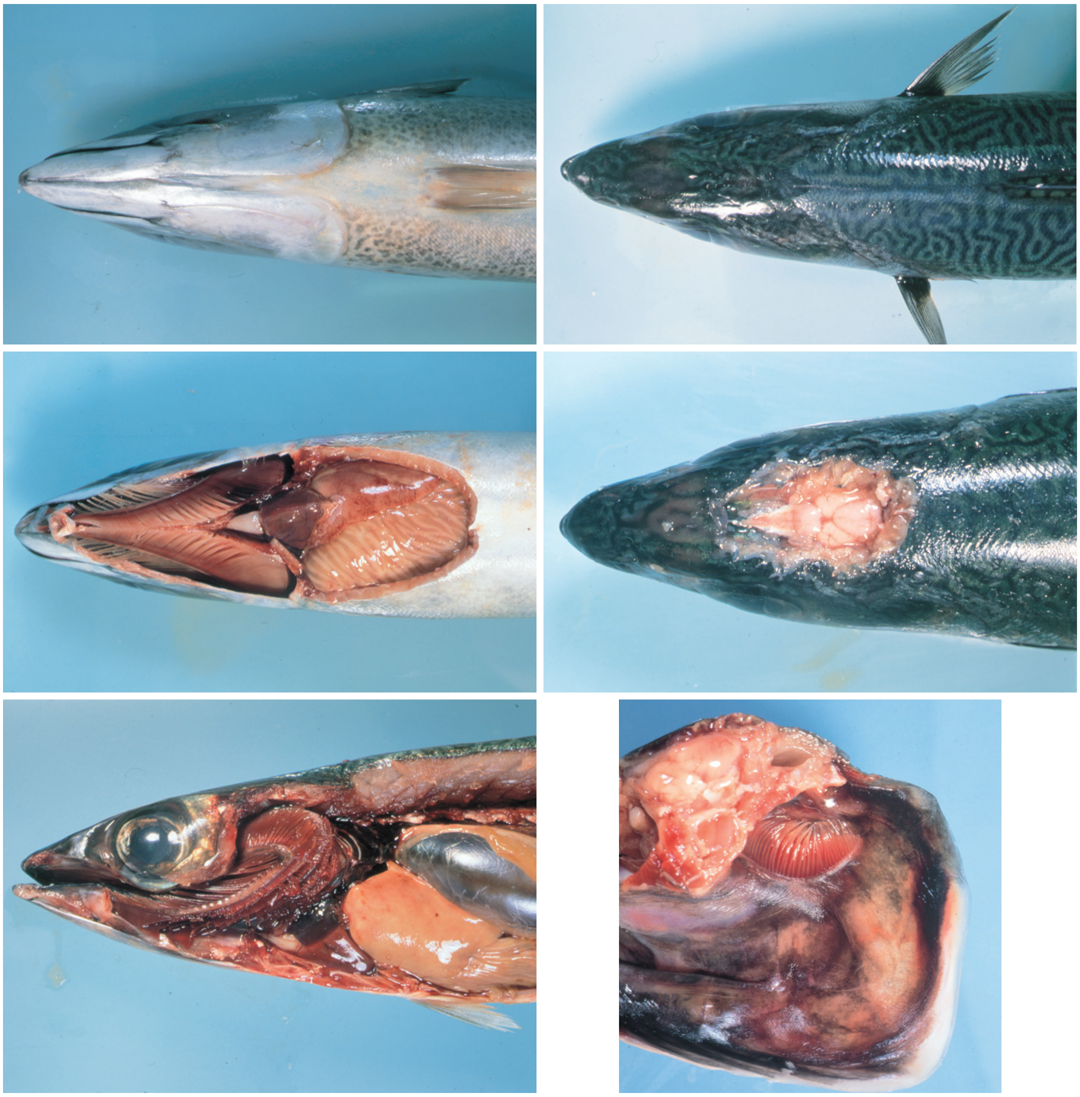

Fig. 3 Dissecting Blue Mackrel Scomber australasicus.
Left upper: ventral view of head and thorax. Left middle: dissection of ventral view of head and thorax. Left lower: lateral view of dissected head and thorax.
Right upper: dorsal view of head and parietal region. Right middle: Dissection of head and parietal region. Right lower: inside of opercula, showing parabranchia.

III 2

Observation of gills

Gills are common in fish, occupy wide space under neurocranium, and are easily recognized red organs by opening gill slit. One set of gill, the main part is thin curved bone, or gill arch, with tubercular or rodlike process on anterior part, or gill rakers. The posterior part is with numerous soft red flaps, or gill filaments.

One gill arch consist of > shaped upper limb, and lower limb. The stem of upper limb is epibranchial (No.60), and the stem of lower limb consists of two bones, hypobranchial (No. 57) for anterior part, and ceratobranchial (No. 58) for posterior part. Both left and right sides of gill arch are connected by a lined several bashibranchials (No. 56), and its anterior tip is homologous with human tang, including basyhyal (No. 48) in hyoid arch. The anterior tip of upper limb is hanged down from neurocranium by suprapharyngobranchial (No.61). On the way of evolution, original 5 pairs of gill arches modified in recent fishes, as upper surface of lower branch of 5th gill arch with lower pharyngeal teeth, and called as lower pharyngeal (No. 59). Also upper branch of 4th and both branch of 5th arches are modified to upper pharyngeal (No. 63) with lower pharyngeal teeth on the lower surface. Pharyngeal teeth of fishes have rich morphological variation, and used important taxonomic keys for some taxon such as the order Cypriniformes and family Scaridae.

Generally there are gill rakers on the anterior surface of 4 pairs of gill arch, generally those on the 1st (most outside, most anterior) are conspicuously developed. Each of gill rakers is covered with densely minute spines on surface, and the epithelium has taste buds. Gill rakers are filtering organs for aspirated water, and plankton feeder has many long rakers, but those of swallowing carnivores are lost or rudimental. The shape or number of rakers related with feeding habitat, and are used for important taxonomic key characters. Count of gill rakers is done on the outside row of 1st gill arch (see II-2).

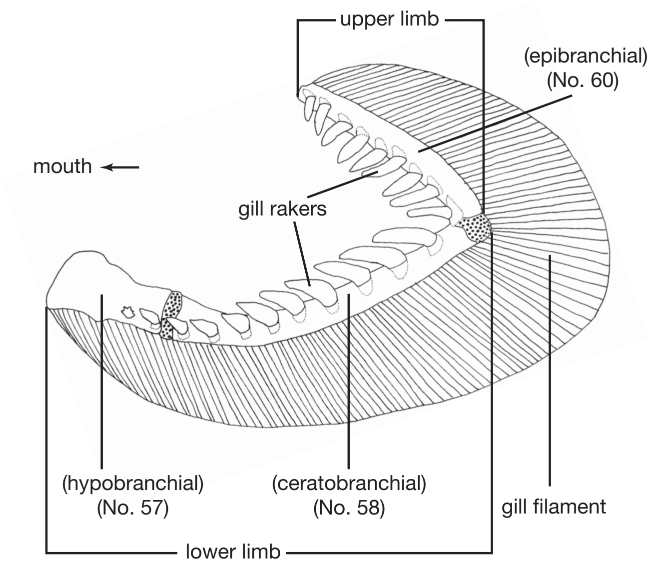

Fig. 1 Anterior most (= external most) gill arch of Red Sea Bream *Pagrus major*. Numbers on figure indicate names of skeletons, III-3. Dotted lines mean joints.

Gill filaments are gas exchanging organs of oxygen and carbon dioxide between brad and environmental water, and also keep salinity balance of body. There are 2 rows of gill filaments on posterior end of 1st to 4th gill arches. In elasmobranchs, 2 rows on each gill arches are divided by interbranchial septum, and 5 – 7 pairs of external gill slits are opened. In teleosts, interbranchial septum are degenerated and lost, and gill filaments are arranged in parallel. Each gill filaments has many vertical (secondary) gill lamella on upper and lower sides, and such expanded surface area is effective for gas and mineral exchanges. Length and number of gill filaments are related with fish activity. Pelagic fishes have developed long filament, and benthic and slow swimming fishes have undeveloped filaments. Thus, relative length of the filaments is a material to consider fish activities.

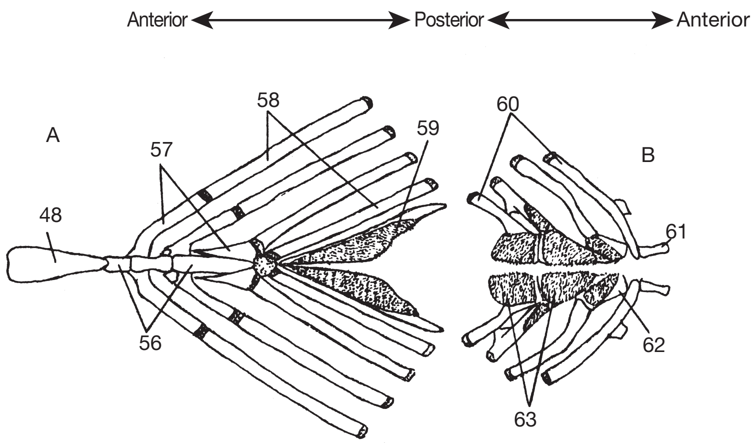

Fig. 2 Gill arch of Japanese Sea Bass *Lateolabrax japonicus*.
A, lower half. B, upper half. From Mastsubara et al. (1979). See III-3 for names and numbers of bones.

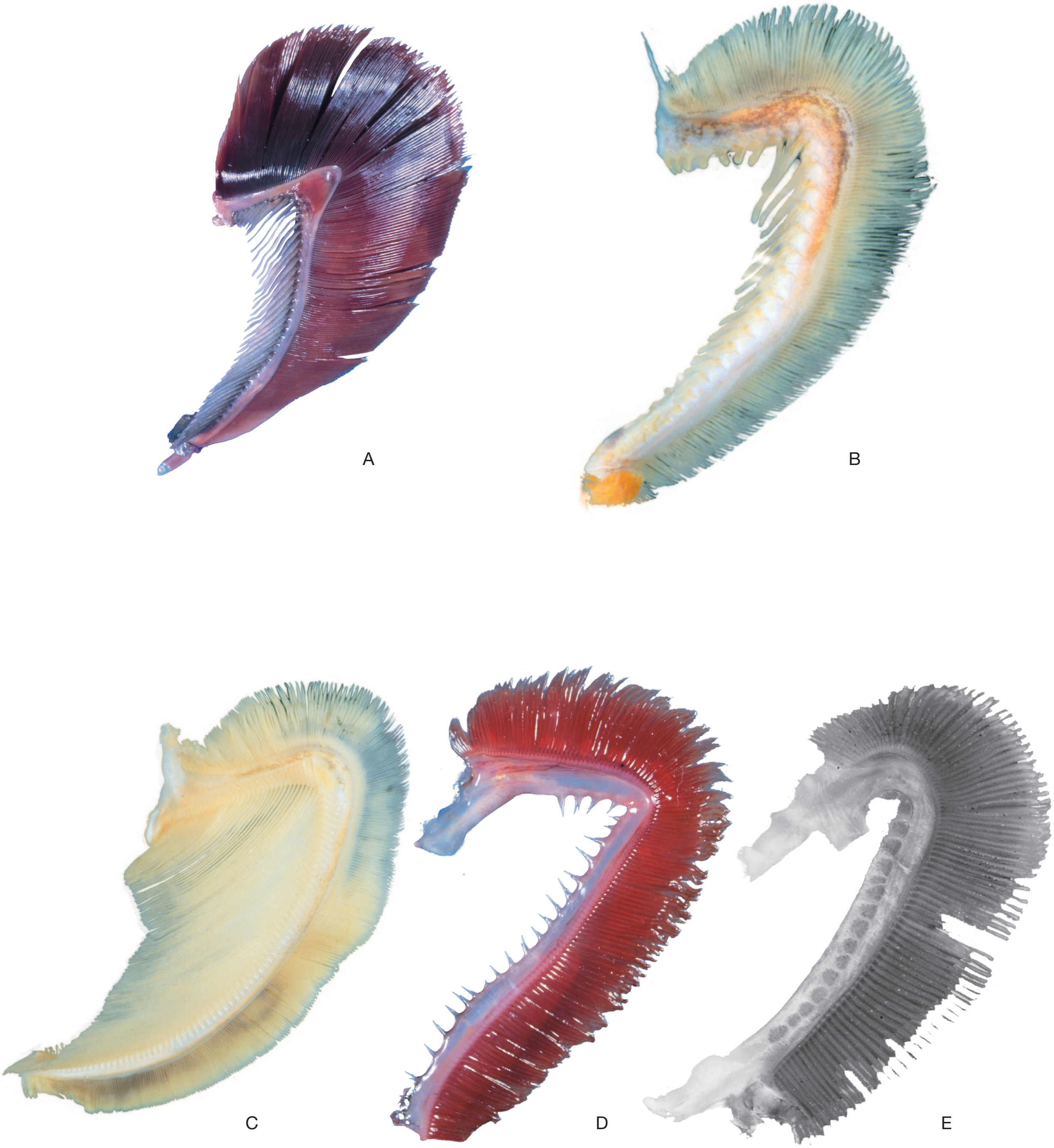

Fig. 3 Gills of various fishes.
A, pelagic fish, Frigate Tuna *Auxis thazard*; B, carnivorous fish, Humpback Red Snapper *Lutjanus gibbus*; C, plankton feeder, Midnight Snapper *Macolor macularis*; D, mesopelagic fish, Long Snouted Lancetfish *Alepisaurus ferox*; E, benthic fish, Yellowfin Stargazer *Uranoscopus chinensis*.

III 3 Names and classification of skeletons

Numbers of text indicate those on figures of III-2~III-7.

- Endoskeleton
  - Axial Skeleton
    - Cranium
      - Neurocranium ………… Nos. 1-23
        Protecting central nerve systems and sensory organs
      - splanchnocranium ………… 24-63
        Supporting and protecting both jaws, hyoid arch, branchial arch, palate, and gills
    - Nothochord
      Running below spinal cord, and supporting it
    - Vertebral Column ………… 64-86
      Covering and protecting spinal cord and notochord
  - Appendicular skeleton
    - Pectoral Girdle ………… 87-96
      Supporting pectoral fin
    - Pelvic Girdle ………… 97
      Supporting pelvic fin
    - Pterigiophore ………… 98-104
      Supporting rays of each fins
- Exoskeletin …………
  - Fin Ray ………… 105-112
  - Scale

No.	English Names
1−23	**neurocranium (= cranium)**
1 (III-6, Fig. 1)	ethmoid
2 (III-6, Fig. 1)	ethmoid cartilage
3 (III-6, Fig. 1)	lateral ethmoid (= prefrontal)
4 (–)	preethmoid
5 (–)	supraethmoid (= mesethmoid)
6 (III-6, Fig. 1)	prevomer
7 (III-5, Fig. 1; III-6, Fig. 1)	nasal
8 (III-6, Fig. 1)	rostral (cartilage)
9 (III-5, Fig. 1)	sclerotic
10 (III-6, Fig. 1)	frontal
11 (III-6, Fig. 1)	pterosphenoid
12 (III-6, Fig. 1)	basisphenoid
13 (–)	orbitosphenoid
14 (III-6, Fig. 1)	sphenotic
15 (III-6, Fig. 1)	pterotic
16 (III-6, Fig. 1)	epiotic
17 (III-6, Fig. 1)	prootic
18 (III-6, Fig. 1)	exoccipital
19 (III-6, Fig. 1)	supraoccipital
20 (III-6, Fig. 1)	parietal

No.	English Names
21 (–)	intercalar (= opisthotic)
22 (III-6, Fig. 1)	basioccipital
23 (III-6, Fig. 1)	parasphenoid
24–63	**splanchnocranium (= visceral skeleton)**
24 (–)	supraorbital
25 (III-5, Fig. 1)	lachrymal (= preorbital)
26 (III-5, Fig. 1)	infraorbital
27 (–)	suborbital
28 (III-5, Fig. 1)	premaxillary
29 (III-5, Fig. 1)	maxillary
30 (–)	supramaxillary
31 (III-5, Fig. 1)	dentary
32 (III-5, Fig. 1)	angular
33 (III-5, Fig. 1)	retroarticular
34 (–)	articular
35 (–)	coronomeckelian
36 (III-5, Fig. 1)	mentomeckelian cartilage
37 (III-5, Fig. 1)	palatine
38 (III-5, Fig. 1)	ectopterygoid (= pterygoid)
39 (III-5, Fig. 1)	endopterygoid (= mesopterygoid)
40 (III-5, Fig. 1)	metapterygoid
41 (III-5, Fig. 1)	quadrate
42 (III-5, Fig. 1)	symplectic
43 (III-5, Fig. 1)	hyomandibular
44 (III-5, Fig. 1)	preopercle
45 (III-5, Fig. 1)	opercle
46 (III-5, Fig. 1)	subopercle
47 (III-5, Fig. 1)	interopercle
48 (III-2, Fig. 2; III-5, Fig. 1)	basihyal (= glossohyal)
49 (III-5, Fig. 1)	upper hypohyal lower hypohyal
50 (III-5, Fig. 1)	ceratohyal
51 (III-5, Fig. 1)	epihyal
52 (III-5, Fig. 1)	interhyal
53 (III-5, Fig. 1)	branchiostegal
54 (–)	gular plate
55 (III-5, Fig. 1)	urohyal
56 (III-2, Fig. 2)	basibranchial
57 (III-2, Fig. 1; III-2, Fig. 2)	hypobranchial
58 (III-2, Fig. 1; III-2, Fig. 2)	ceratobranchial
59 (III-2, Fig. 2)	lower pharyngeal
60 (III-2, Fig. 1; III-2, Fig. 2)	epibranchial
61 (III-2, Fig. 2)	suprapharyngobranchial (= suspensory pharyngeal)
62 (III-2, Fig. 2)	infrapharyngobranchial (= pharyngobranchial)
63 (III-2, Fig. 2)	upper pharyngeal
64–86	**vertebral column**
64 (III-7, Fig. 1)	abdominal vertebra
65 (III-7, Fig. 1; III-7, Fig. 4)	caudal vertebra
66 (III-7, Fig. 4)	preuralcentrum 2, 3

No.	English Names
67 (III-7, Fig. 4)	urostyle (=preural centrum 1 + ural vertebra)
68 (III-7, Fig. 4)	hypural
69 (III-7, Fig. 4)	uroneural
70 (III-7, Fig. 4)	epural
71 (III-7, Fig. 4)	Parhypural
72 (III-7, Fig. 3)	neural spine
73 (III-7, Fig. 3; III-7, Fig. 4)	neural arch
74 (III-7, Fig. 3)	neural zygapophysis
75 (III-7, Fig. 3)	centrum
76 (III-7, Fig. 3)	hemal zygapophysis
77 (III-7, Fig. 3)	hemal arch
78 (III-7, Fig. 3)	parapophysis (=transverse process)
79 (III-7, Fig. 3; III-7, Fig. 4)	hemal spine
80 (III-7, Fig. 3)	neural canal
81 (III-7, Fig. 3)	hemal canal
82 (III-7, Fig. 3)	pleural rib (=rib)
83 (–)	epipleural
84 (–)	epineural
85 (III-7, Fig. 3)	epicentral
86 (–)	myorhabdoi (=myorabdoi)
87–96	**pectoral girdle**
87 (III-5, Fig. 1)	supratemporal (=extrascapular)
88 (III-5, Fig. 1)	posttemporal
89 (III-5, Fig. 1)	supracleithrum
90 (III-5, Fig. 1)	cleithrum
91 (III-5, Fig. 1)	scapula
92 (–)	mesocoracoid
93 (III-5, Fig. 1)	coracoid
94 (III-5, Fig. 1)	postcleithrum
95 (–)	clavicle
96 (III-5, Fig. 1)	actinost
97	**pelvic girdle**
97 (III-5, Fig. 1)	basipterygium
98–104	**pterygiophore**
98 (III-7, Fig. 1)	free interneural spine (=predorsal bone)
99 (III-7, Fig. 1; III-7, Fig. 2)	interneural spine
99, 102 (III-7, Fig. 1; III-7, Fig. 2)	proximal pterygiophore
100, 103 (III-7, Fig. 2)	median pterygiophore
101, 104 (III-7, Fig. 2)	distal pterygiophore
102 (III-7, Fig. 1; III-7, Fig. 2)	interhemal spine
105–112	**exoskeleton**
105 (III-7, Fig. 1)	dorsal spine
106 (III-7, Fig. 1; III-7, Fig. 2)	dorsal soft ray
107 (III-7, Fig. 1)	anal spine
108 (III-7, Fig. 1; III-7, Fig. 2)	anal soft ray
109 (III-7, Fig. 1; III-7, Fig. 4)	caudal soft ray
110 (III-5, Fig. 1)	pelvic spine
111 (III-5, Fig. 1)	pelvic soft ray
112 (III-5, Fig. 1)	pectoral soft ray

III 4

How to observe skeletons

1. **Studies on skeletons** are called osteology. Osteology is peculiar to Vertebrata and is essential for studies on their phylogenic evolution and species identification. This is because osteology has the following advantages.
   1) Highly objective data can be obtained because a stable and consistent result can be obtained regardless of when or who observes and measures a skeletal trait, due to its very low deformation in long-term storage.
   2) Because bones, in particular, are likely to be preserved as fossils among skeletons, osteology allows us to directly compare and examine historical taxa. In other words, in terms of the traceability of evolutionary history, this is an advantage over studies on muscles, visceral organs, chromosomes, genes, proteins, etc. from which no data can be obtained unless the specimen is contemporary, due to the difficulty in preservation.
2. **How to study skeletons of contemporary fish**
   1) X-ray photography: This has the advantage that individual variation in the counted values, including the number of the vertebrae and the number of the pterygiophores, can be reduced because many specimens can be relatively easily examined non-destructively if the specimens are unpaired skeletons (vertebral column, vertical fins, etc.). However, disadvantages include that the outline of cartilages and bone pieces with a thin periphery are not clear, and that it is impossible to understand the shape of paired skeletons due to overlap in the image.
   2) Separation of skeletons: Separate the skeleton from the body by boiling the raw or salted specimen or letting insects (Dermestidae, etc.) eat the fleshy parts. Preservation by dehydration is convenient for studies on the shape of individual bones and using the skeletons as educational materials due to ease of handling, but cartilages can be so deformed that their original shape is not preserved, and even bones will be a little deformed. Preservation of picked skeletons in alcohol can preserve the shape, but it has the disadvantage that the linkage between bones is not preserved because the bones will eventually disassemble.
   3) Preparation of double-stained transparent specimens: Stain the bones of specimens in red with alizarin red and their cartilages in blue by alcian blue, make the skin and the muscles of the specimens transparent using potassium hydroxide and trypsin, and observe the bones and cartilages. This method allows us to observe the best condition because the shape of the fish body is maintained unchanged, preserving the linkages between the bones and causing no deformation of bones and cartilages. However, it takes days to prepare a specimen, and the protocol requires skill. In addition, the handling of specimens is a little troublesome because they are preserved in glycerin. I have omitted this preparation method in this book because many informative books that have been recently published discuss this. (References: Osamu Fukuhara, Masaru Tanaka. 1987. Techniques for studies on the early life history of marine fish 1 - How to stain hard tissues of larvae and juveniles. Aquabiology, 9 (2): 97-99; Koichi Kawamura, Kazumi Hosoya. 1991. A modified double staining technique for making a transparent fish-skeletal specimen. Bulletin of Natural Research Institute of Aquaculture, (20): 11-18)
3. **Experimental method according to 2) above**
   1) Wrap the specimen with a sheet of gauze to prevent the loss of small bones and cartilages.
   2) Boil the specimen in dilute potassium hydroxide (KOH, below 0.1%) aqueous solution. Stop

the boiling at the point when a little of the redness of blood remains in the skeleton when you peel off the muscle in the vicinity of the most anterior part of the vertebral column. Excessive boiling can cause the neurocranial members to be dislocated at the joints. Once dislocated, they can never be restored. Although KOH makes it easy to remove flesh, excessive use is harmful because bones, particularly soft rays, will be fragile.

3) Collect the external skeletons in the vicinity except scales (I postpone this to another occasion) in the following order in general. Because most of the bones except for the axial skeletal are in a right-to-left pair, preserve those on the left side, and put those on the right side aside for supplementation.
4) Find the name of each bone, and note the mutual relationship through a joint by sketching the bones in a way that indicates their top and back as well as four quarters.
5) Draw an outline of the fish on another Kent paper prepared beforehand, and temporarily place the picked bones on a place equivalent to their *in vivo* location. Avoid paying too much attention to cleaning in this step and complete the procedure soon. Because the skeletons are arranged three-dimensionally, you need to be creative in arranging the bones two-dimensionally.
6) First, pick up the nasal bone (No. 7), the circumorbital [there are the lacrimal bone (No. 25), the infraorbital bone (No. 26), and, depending on the species, the supraorbital bone (No. 24) and the subinfraorbital bone (No. 27)], and the supratemporal bone (No. 87). Because the supratemporal bone is very likely to be lost, be sure to pick it up in this step. (A→B in the foldout figure.)
7) Remove the muscles for moving the jaws and the muscles at the pectoral fin base, and then pick up the bones forming the upper jaw [there are the premaxillary (No. 28), the maxillary (No. 29), and, depending on the species, the supramaxillary (No. 30)]. (B→C in the foldout figure)
8) After picking up the dentary (No. 31) and the angular bone (No. 32) forming the lower jaw, pick up the palatine arch (Nos. 32–43) and the opercular arch (Nos. 44–47) together and disassemble them later. (C→D in the foldout figure)
9) Pick up the basihyal (No. 48, only one at the center) from the position equivalent to the human tongue, and then the following hyoid arches (Nos. 48–53) together, and disassemble them later. (D→E in the foldout figure)
10) After picking up the urohyal (No. 55, only one at the center) which was between the bilateral hyoid arches, pick up all the branchial arches from both the right and left sides together, and disassemble them later. (No foldout figure. See the branchial arches of Japanese sea *Lateolabrax japonicus* in Figure 2 in III-2)
11) Disassemble and pick up the pectoral girdle (Nos. 88–96) and the pelvic girdle (No. 97) inferiorly in order. At this time, combine the soft rays together because they are fragile.
12) Remove the upper part of the dorsal muscle, and then pick up the dorsal-fin pterygiophores (Nos. 99–101) and rays (Nos. 105–106) by recording the positional relationships with the neural spine (No. 72). (See Figure 1 on p. 58.)
13) Collapse the contact plane (horizontal septum) between the myomeres of the dorsal and ventral muscles, record the position of the joints between the vertebra (Nos. 64–81) and the rib (No. 82) as well as the intermuscular bone (Nos. 83–86), and pick up the set except the vertebra. Repeat this for the following sets of myomeres.
14) Remove the lower half of the ventral muscle, and then pick up the anal-fin pterygiophores (Nos. 102–104) and rays (Nos. 107–108) by recording the positional relationships with the hemal spine (No. 79). (See Figure 1 on p. 58.)
15) Finish this procedure by picking up the neural cranium (Nos. 1–23) and the vertebral column (Nos. 64–81) together.

16) Carefully remove muscles, blood vessels, bone marrow, etc. from each of the picked skeletal elements. Then, clean the element and arrange and tape it on thick paper or in a wooden box, or preserve it in 70% ethyl alcohol solution.
17) You need to be extremely careful not to disassemble the caudal skeleton at the terminus of the vertebral column.

Observation of the splanchnocranium, pectoral girdle, and pelvic girdle

The major skeletal arranged in the axial part of a fish body is called the axial skeleton. The axial skeleton is composed of the cranium or the skull (neurocranium and splanchnocranium) followed by the notochord and the vertebral column to which the pleural ribs are attached, and a variety of intermuscular bones.

Because many fish crania are exposed medially and/or laterally, their morphological characteristics are often seen in descriptions of fish species. Therefore, to avoid missing bones that can be examined in species identification, it is important to know the site and morphological characteristics of individual bones.

It is not the case that all of the bones presented in the table in III-3 are present in a species used as the experimental material, and that the figures on p. 45–62 show all bones. In addition, you should pay close attention to the collection of individual bones because bones may have become soft and cartilages may have become hard.

Splanchnocranium; Nos. 24–63 (= visceral skeleton): This is present in the periphery of the neurocranium and composed of many of the very slender bones. When picking these up, refer to the foldout figure to determine from where to pick them up. Temporarily place the removed bones on a sheet of paper by determining their arrangement based on Figure 1 below, and enter the name. Clean

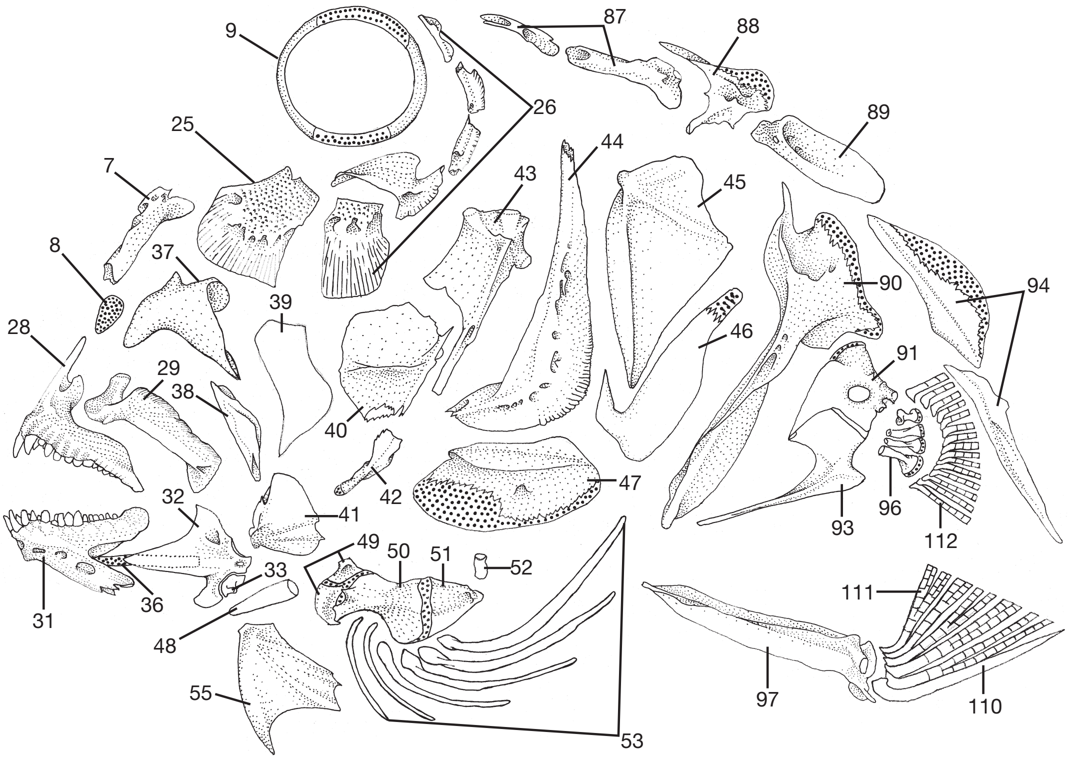

Fig. 1 Splanchnocranium of Red Sea Bream *Pagrus major*.
Large dots indicate cartilages. See table of III-3 for bone names and numbers.

the bones individually after observation and sketching, tape them to their original position, and make a clean copy of the names. Be careful to avoid an error in the anterior–posterior, top–bottom, and top–back orientations of each bone. Also, pay attention to the bones through which the lateral line canals on the head run (lacrimal bone; No. 25, infraorbital bone; No. 26, dentary; No. 31, premaxillary; No. 44, etc.) and the route, opening, and arrangement of tunnels through which vessels or nerves run. In addition, because there are not only the two jawbones but also the bones on which teeth are present (palatine: No. 37, etc.), follow the procedures below with careful observation.

Circumorbital; Nos. 24-27: The orbit of some splanchnocrania is constituted of a large lacrimal bone (No. 25) anterior to the eye and a series of infraorbital bones (No. 26) surrounding the posterior margin of the eye from immediately posterior to the lacrimal bone via the infraorbital part. The splanchnocranium of ancient fish has a supraorbital bone (No. 24) fringing the upper margin of the eye in some cases. Naturally, these are in a left-to-right pair. The inner margin contacting the eye is thick because sensory canals pass through it, and it has scattered openings for branched canals on the outer surface. In fish belonging to Perciformes, etc., the first and second anterior infraorbital bones have an overhang facing medially like it is supporting the eyeball, which is called the suborbital shelf. The position and number of the suborbital shelf are a clue for investigating relationships. Scorpaeniformes fish show a common peculiar specific trait that the posterior margin of the second infraorbital bone extends to form a joint with the preopercle (No. 44) on the surface. [In the anterior margin of the snout, there is a pair of thin plate-like nasal bones (No. 7) inside the right and left nostrils. This is free from the neurocranium, but considered a part of neurocranium instead of the splanchnocranium.]

Upper jaw; Nos. 28–30: Inside the nasal bone, there is an ascending process of the premaxillary (No. 28), and inferior (posterior) to the processes of the right and left bones, there is an oval or rice-ball-shaped rostoral bone (No. 8) (unpaired). After taking out the bones forming the upper jaw in conjunction with the premaxillary, the bone adjacent superiorly is the maxillary (No. 29), and, depending on the species, 1–2 slender supramaxillary bones (No. 30) run in parallel in its posterior dorsal part. On the inferior margin of the premaxillary, there are a variety of small to large teeth depending on the species. In ancient fish including Clupeidae, the premaxillary is small and the oral margin is formed by the maxillary, etc., where some species such as Amia, gars, and deep-sea fish in Argentiniformes and Stomiidae have teeth. In many of the advanced fish groups, such as Perciformes and Scorpaeniformes, the mouth is formed by only the premaxillary extending highly to the posterior direction, and the maxillary is recessive and does not face the oral margin. The developmental level of the ascending processes in the anterior superior part of the premaxillary varies remarkably depending on the species, from those in which it moves like it is rotating using the short rostoral bone (No. 8) immediately inferior as a fulcrum to the species in which the upper jaw can greatly protrude by sliding the long process.

After removing the upper jaw, removal of the muscle, etc. of the cheek allows you to observe a series of bones linked from the lower jaw to the posterior terminus of the operculum. Cut these bones, keeping the joints where possible off the hyoid arch inside (below of observation angle) them, cut the left-to-right jointing part of the lower jaw and temporarily place the whole piece longitudinally. After such preparation, disassemble and clean them step-by-step as follows.

Lower jaw, Nos. 31–36: The dentary (No. 31) located at the most anterior part of the selected bones is the only bone constituting the oral margin of the lower jaw. Because the dentary and teeth on the premaxillary have various morphologies associated with their feeding habit, you need to observe them sufficiently. The arrowhead-like bone sticking into the deep notch of this dentary anteriorly is called the angular bone (No. 32). Inside the dentary and angular, there is the slender Meckel's cartilage (No. 36) connecting the two bones. Because this will accompany either one when the bones are pulled apart, do not further disassemble it. The minute bone called the coronomeckelian (No. 35) at the base of this cartilage on the angular side has been gaining phylogenic attention recently. Do not cut off a small bone called the retroarticular bone (No. 33), either, which is seen at the lateral side of the posterior inferior part of the angular.

Suspensorium, Nos. 37–47: These are a series of bones suspending the mandibular arch from the neurocranium, and composed of the opercular arch (Nos. 44–47), commonly called the gill cover, and the palatine arch (Nos. 37–43) constituting the inner wall of the oral cavity. The opercular arch is the main organ at the time of gill ventilation for gas exchange. In addition, because the four types of membrane bones constituting the arch can be observed from the surface, these are also valued as taxonomic characters. The large membrane bone at the upper right is called the opercle (No. 45). This forms a joint with the hyomandibular bone (mentioned below) at the anterior supra corner, and the presence or absence of any spine at the posterior margin is an important characteristic. The V-shaped thin subopercle (No. 46) contacts the opercle such that it supports it from the bottom. There is a large semilunar preopercle (No. 44) widely contacting the anterior margin of the opercle. The interopercle (No. 47) contacts the inferior side of both the preopercle and subopercle. The anterior margin of the preopercle forms a joint with the palatine arch. It is particularly frequent that the shape of the lateral margin of the preopercle is used as a taxonomic character.

The palatine arch is little exposed to the outside. However, if it has teeth, the teeth are exposed to the inner wall of the oral cavity, and are used as a taxonomic character. The somewhat T-shaped firm bone forming a joint with the upper part of the preopercle posteriorly is called the hyomandibular bone (No. 43). The hyomandibular forms a joint with the neurocranium at the upper condyle, and also with the opercle at the posterior condyle. Between the inferior terminus of the hyomandibular and the quadrate mentioned below is the slender rod-like symplectic (No. 42). There is a very thin, plate-like metapterygoid (No. 40) forming a joint with the anterior inferior part of the hyomandibular bone and the endopterygoid (No. 39) anterior to it. The fan-shaped quadrate (No. 41) forms a joint with the inferior part of the metapterygoid, endopterygoid, and symplectic. The quadrate forms a joint with the angular of the lower jaw at the condyle on the part equivalent to the fulcrum of a fan. At the anterior margin of the angular and the endopterygoid, there is the ectopterygoid (No. 38). There is the palatine arch (No. 37), the anterior tip of which is like a hook, attaching to the anterior half of this ectopterygoid and the endopterygoid. The hook-like part is exposed in the form of an inverted V beside the prevomer, the anterior terminus of the neurocranium, on the ceiling of the oral cavity. The presence of any tooth there and the shape of the tooth are important taxonomic characters.

Hyoid arch; Nos. 48–55: There are several curved, sword-like slender branchiostegals (No. 53) inside the lower part of the opercular arch. The bones supporting them are composed of the relatively wide bone, the ceratohyal (No. 50), with a large hole at the center or in a saddle shape; the epihyal (No. 51) sutured to the ceratohyal anteriorly; and the hypohyal (No. 49; composed of top and bottom ones) sutured to the ceratohyal posteriorly. These three types of four bones cannot be restored once disassembled. Because the number and shape of the branchiostegals and the arrangement of the attachment to the inferior margin of the ceratohyal and the epihyal vary greatly among fish species, these are important taxonomic characters and powerful factors for considering phylogenic relationships. There is a small, rod-shaped interhyal (No. 52) superior to the posterior terminus of the epihyal, which helps to form a joint with the symplectic in the palatine arch from the inner surface of the operculum. All of the above are left-to-right paired. A sheet of the triangular urohyal (No. 55) inferior to the most anterior basibranchial bone (No. 56 in the branchial arch below) sandwiched by the bilateral hypohyals, and the unpaired baseball-bat-shaped basihyal (No. 48) forming a joint with the anterior terminus of the basibranchial bone are the hyoid arch. The basihyal is the part equivalent to the human tongue. Some fish have teeth here as well.

Branchial arch; Nos. 56–63 (see Figure 2 in III-2): After removal of the upper and lower jaws, the suspensorium, and the hyoid arch, the branchial arch appears. Pick these all up together, then remove the arch individually from the lateral side in order on both the right and left sides, clean them, and place them in a row symmetrically on the paper. In the arrangement, I advise you to extend them in a shape that is formed in a widely opened mouth if seen posteriorly. Lastly, arrange the multiple basibranchial bones (No. 56) in the middle of the lower branches of the branchial arch. The structure of each branchial arch is mentioned in detail in "III-2. Observation of gills".

Appendicular skeleton: This refers to the skeletons supporting the rays of the dorsal fin, anal fin, and paired fins from inside of the body. Here we can observe the pectoral girdle supporting the pectoral fin and the pelvic girdle supporting the pelvic fin, both of which are paired fins.

Pectoral girdle; No. 87–96: Removal of the skin and the muscle from the lateral surface of the occipital region to the start point of the pectoral fin will let you find one or two slender supratemporal bones (No. 87) in some species but none in other species. This bone has a groove where the lateral line runs, which in the posterior part branches in a Y-shape. In the fish in Sparidae, this bone looks like a rain gutter and is easily lost because it is smaller than a scale. Depending on the fish species, it is treated as a part of the neurocranium because it firmly fastens itself to the cranium. Following the supratemporal bone, the crab-claw-like posttemporal bone (No. 88) is seen. An oval supracleithrum (No. 89) forms a joint with the inferior part of the posttemporal bone from inside. After collecting these, remove them up to the most anterior cleithrum (No. 90) with the accompanying soft rays of the pectoral fin (No. 112) in a group without collapse. Consequently, the two relatively thin postcleithra (No. 94) remain at the most anterior part of the ventral muscle.

Next, remove the muscle at the base of the picked pectoral fin and remove all rays of the pectoral fin (No. 112) from the attachment base in a group. In the remaining attachment base, four hand-drum-shaped actinosts (No. 96) are generally seen, but these are easily lost because they are very small in some species. The actinosts are supported by two thin, plate-like bones. The one occupying the upper half is the scapula (No. 91), with a hole near the center, whereas the lower half is occupied by the hammer-shaped coracoid (No. 93). Both bones form a joint with the posterior margin of the cleithrum (No. 90), a very large and rigid bone covering the entire area from the upper to the lower terminus of the posterior margin of the gill slit. In the ancient fish groups, such as Clupeiformes and Cypriniformes, there is a special bone connecting the cleithrum and the coracoid called the mesocoracoid (No. 92).

Pelvic girdle; No. 97: Pick up the basopterygium (No. 97) supporting the pelvic fin in conjunction with the pelvic fin rays (No. 111 and 112). The pelvic girdle is composed of only a pair of basopterygia in many of the advanced fish, and directly supports 1 spine and 5 soft rays. However, in the ancient fish groups such as Salmoniformes, it only supports many soft rays through the radials.

III 6

Observation of the neurocranium

Head of Agnatha is only a cluster of several cartilages. The neurocranium of extant advanced Chondrichthyes is called the chondrocranium and is composed of a mass of cube-type cartilages. The neurocranium of Teleostei is composed primarily of many cartilaginous bones and membranous bones (= membrane bones) sutured together, and a minor cartilaginous part. Such a neurocranium is called an osteocranium. The neurocranium protects the brain, the most anterior part of the spinal cord.

At the time of the observation, remove the left half of the splanchnocranium, pectoral and pelvic girdles, etc. in the vicinity of the head you observed earlier, cutting the remaining neurocranium (called the skull in some cases) off the joint with the first vertebra to pick it up. If possible, I advise you to use two individuals of the same species in the observation of the neurocranium to disassemble one and sketch the other in parallel. Once it is disassembled, it can never be restored.

As the arrangement of bones constituting the neurocranium is three-dimensional and complicated, it is difficult to represent all parts unless you sketch the observation results not only from the lateral sides but also from five directions, including the lateral, dorsal, ventral, anterior, and posterior directions.

At the center of the apex of the neurocranium is a prevomer (No. 6), the apex of which has a horseshoe shape in its inferior surface. This horseshoe-like part is located immediately posterior to the joint part of the right and left premaxillaries (No. 28) among the already observed splanchnocranium, and can be identified without anatomy. The presence or absence of teeth in this part and, if there are teeth, the number and shape are important taxonomic characters and helpful for predicting the feeding habit. You can see that, from both sides, the palatine arch (No. 37) among the splanchnocranium connects to the prevomer anteriorly. There is a slender, plate-like parasphenoid (No. 23) covering nearly all of the central part of the cranial base following the prevomer. This is located at the center of the ceiling of the oral cavity. Ancient fish groups are also equipped with teeth here in some cases. The basioccipital (No. 22) at the posterior terminus of the cranial base forms a joint with the vertebral column. Being surrounded by four bones, basioccipital, exoccipitals (No. 18) dorsal bilateral to the basioccipital, and dorsal supraoccipital (No. 19), the foramen magnum is formed at the posterior terminus of the cranium through which the central nerve runs. This foramen magnum connects to the neural canal of the vertebra.

An ethmoid (No. 1) is sutured to the posterior dorsal part of the prevomer. The posterior terminus of the ethmoid, which is like a cartilage and penetrates the inter-orbital part, is called the ethmoidal cartilage (No. 2). A rostoral bone (No. 8) forms a joint with it posteriorly, and a pair of slice-like nasal bones (No. 7) forms a joint with the rostoral posteriorly. Because these are free from the main body, they are picked up at the time of observation of the splanchnocranium. A pair of lateral ethmoids (No. 3) overhangs on both lateral sides of the ethmoid. On the dorsal surface, a pair of longitudinally long plate-like frontals (No. 10) hangs on the dorsal surface of the binocular part. In fish species with large eyes, this bone is highly indented from the lateral surface to be narrow. Between the right and left frontals, a supraoccipital (No. 19) is inserted anteriorly, and the mid-dorsal line bulges like a plate. On the lateral sides of the supraoccipital, the parietal (No. 20), the epiotic (No. 16), and the exoccipital (No. 18) lie on a line in this order posteriorly, and are sutured to the supraoccipital.

The largely overhanging autopterotic (No. 15) is sutured to the lateral side of each parietal, and the autosphenoid (No. 14) is sutured to the anterior. [Because the supratemporal bone (No. 87) forms a joint with or is adjacent in the vicinity of the posterior part of the autopterotic, the supratemporal bone is treated as a part of the neurocranium in some cases. However, in this book, it was mentioned above as a part of the pectoral girdle.]

Between the posterior lateral side of the parasphenoid and the exoccipital, the prootic (No. 17) is sutured, and the auditory and static organs, including the otolith, are protected inside. There is a small opisthotic (No. 21) posterior superior to the prootic and superior to the exoccipital, but its presence cannot be shown unless you sketch it from the posterior surface.

There is a basisphenoid (No. 12) that is sandwiched by the right and left prootics and vertically protruding to the posterior inferior part between the eyes. On the superior part, the foramen magnum sandwiched by the right and left autosphenoids on the anterior surface of the cerebral ventricle is the route of the optic nerve and eye-moving muscle. There is a pterosphenoid (No. 11) dorsal to the basisphenoid.

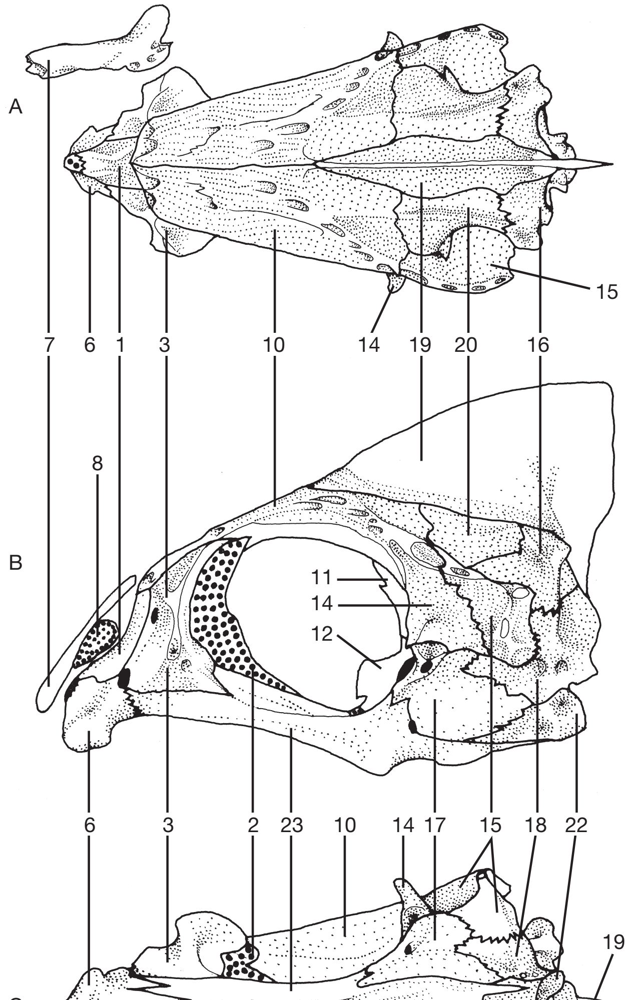

Fig. 1 Neurocranium of Red Sea Bream *Pagrus major*. A, dorsal view; B, left lateral view; C, ventral view. Large dots indicate cartilages. See table of III-3 for bone names and numbers.

III 7

Observation of the vertebral column and vertical fins

In the axial skeleton of Agnatha, the notochord is developed in the median, being accompanied by a very small number of cartilage pieces on the dorsal side, and several clusters of cartilages that only gather in the head. In extant advanced Chondrichthyes and Teleostei, the notochord in the embryonic stage similar to that of Agnatha is subsequently replaced by the vertebra that has developed from the circumference, and consequently remains rudimentarily at the joint part of each vertebra as the fish grows. A series of vertebrae that are consecutive in a segmental manner from immediately posterior to the cranium, called the vertebral column (Nos. 64–86), is attached by a variety of intermuscular bones, including ribs and myorhabdoids.

For observation, after the lifting of the pectoral and pelvic girdles, remove the left lateral muscle to expose the vertebral column. Individual detachment of the sarcomeres from the anterior will let you find curved, sword-like intermuscular bones running along the horizontal septum separating the lateral muscle top and bottom. These are called the supraneural bones (No. 85). The one at the anterior terminus attaches to the transverse process (No. 78) of the first centrum (No. 75). The more posterior, the lower the attachment position becomes, such as near the rib base, or, depending on the species, the lateral side of the inferior part of the centrum or even the hemal arch (No. 77). The sword-like firm bone that forms a joint with the transverse process of the abdominal vertebra (No. 64) in the vicinity of the third centrum or posterior and runs along the peritoneum as if wrapping the viscera is called the

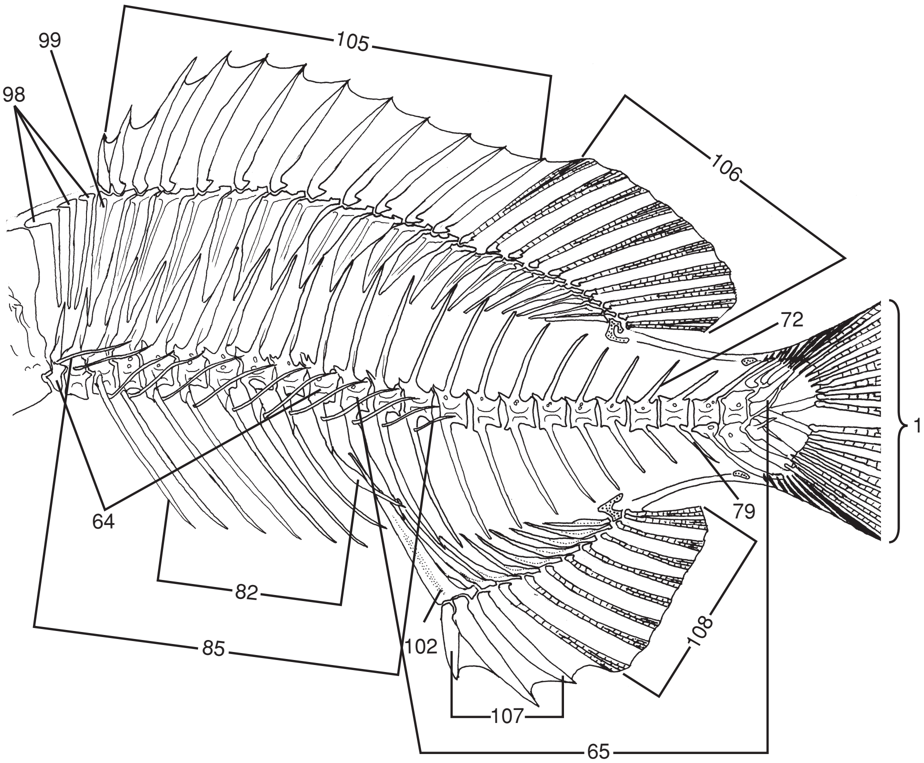

Fig. 1 Vertebrae and vertical fins of Red Sea Bream *Pagrus major*.
See table of III-3 for bone names and numbers.

rib (No. 82). In more ancient fish groups, apart from these, there are intermuscular bones including the epipleural ribs (No. 83) and the epicentrum (No. 84) running from the ribs and the centrum laterally. Moreover, the slender bones called the myorhabdoids (No. 86) are added to the inside of the diaphragm in some cases without attaching to the axial skeleton. When there are many types and a high number of bones like this, it is referred to as “bony”.

After recording the positional relationships above in a rough sketch, expose the vertebral column. At the same time, expose the pterygiophores (Figure 2) of the dorsal and anal fins as well, and sketch the positional relationships between these bones and the neural spines/hemal spines of vertebrae in particular by outline. Thereafter, pick up the free interneuron spine at the start of the dorsal fin (No. 98) from the posterior of the neurocranium existing to the base, then pick up the interneuron spines (Nos. 99–101) in order posteriorly in combination with the ray (No. 105 or 106) supported by the spine, and clean them. Similarly, pick up the interhemal spines (Nos. 102–104) in combination with a ray (No. 107 or 108) in the anal fin. Each of the interneuron/interhemal spines is composed of three parts, the proximal pterygiophore (Nos. 99 and 102), median pterygiophore (Nos. 100 and 103), and distal pterygiophore (Nos. 101 and 104), in order posteriorly. All proximal pterygiophores are ossified. The median pterygiophores are also ossified and distinct in the anterior, but the ones in the posterior are difficult to find because they are cartilaginous. The distal pterygiophores are even more difficult to find because they are all small cartilages. In addition, it is impossible to completely pick up the soft

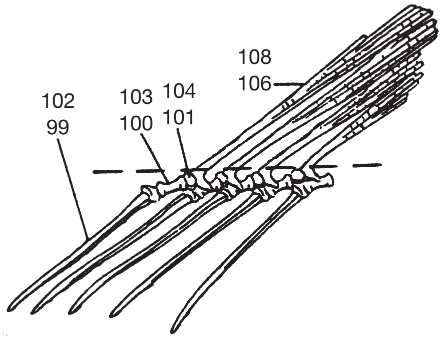

Fig. 2 Dorsal and anal fins and their supporting bones of teleost. From Bond (1979).

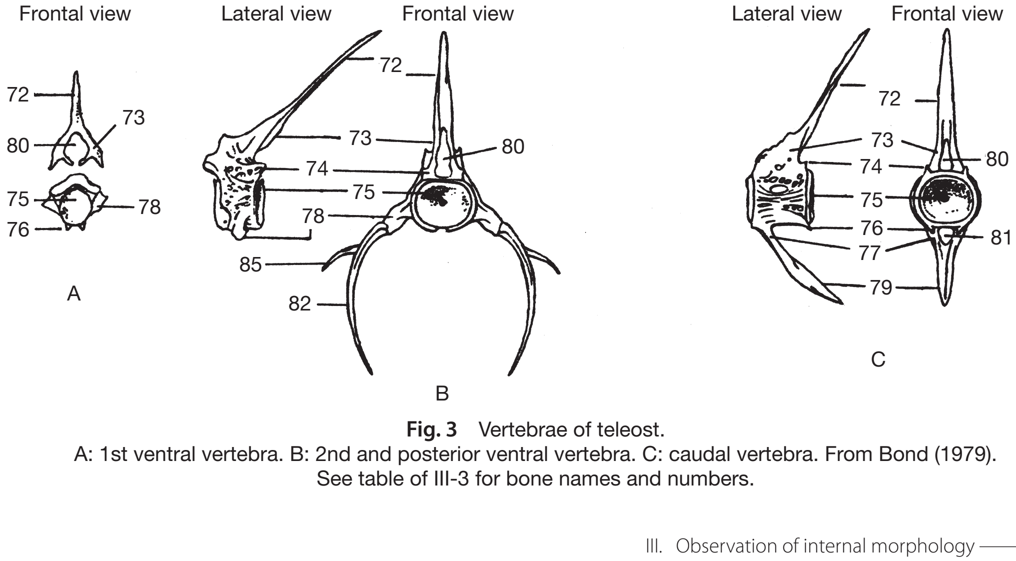

Fig. 3 Vertebrae of teleost.
A: 1st ventral vertebra. B: 2nd and posterior ventral vertebra. C: caudal vertebra. From Bond (1979).
See table of III-3 for bone names and numbers.

rays (Nos. 106 and 108) because they are slender and fragile. Do not disassemble the soft rays of the caudal fin (No. 109) because the rays form a direct joint with the terminus of the vertebral column.

Lastly, cut the vertebral column at the joint parts to observe the individual vertebrae (Figure 3).

1) The vertebral column is composed of a series of vertebrae, and broadly classified into the abdominal vertebrae (No. 64) in the trunk and the caudal vertebrae (No. 65) lining the tail.
2) The drum-shaped part forming the central part of each vertebra is called the centrum (No. 75). All centra have the neural spine (No. 72) (called neurapophysis in Chondrichthyes) on the dorsal side. The caudal vertebrae (No. 65) have the hemal spine (No. 79) (hemopophysis likewise) on the ventral side. In each basal part, the neural canal (No. 80) and the hemal canal (No. 81), holes through which the spinal cord or the blood vessel runs, are formed by the neural arch (No. 73) and the hemal arch (No. 77), respectively. Some of the anterior vertebrae sometimes form a joint with the centrum without fusion of their neural arch. The number is generally one in fish of Perciformes, but multiple in the ancient fish groups.
3) Each centrum has 8 zygapophyses (Nos. 74, 76) at a maximum paired between right and left on the anterior, posterior, dorsal, and ventral sides. However, missing items vary depending on the place and species.
4) The abdominal vertebrae (No. 64), except for several anterior ones, have the transverse process (No. 70) on both the right and left ventral sides, where the rib (No. 82) forms a joint. Each rib is attached by the supraneural bone (No. 85). The transverse processes of the anterior vertebrae protrude nearly laterally, whereas the more posterior the position is, the more inferiorly they

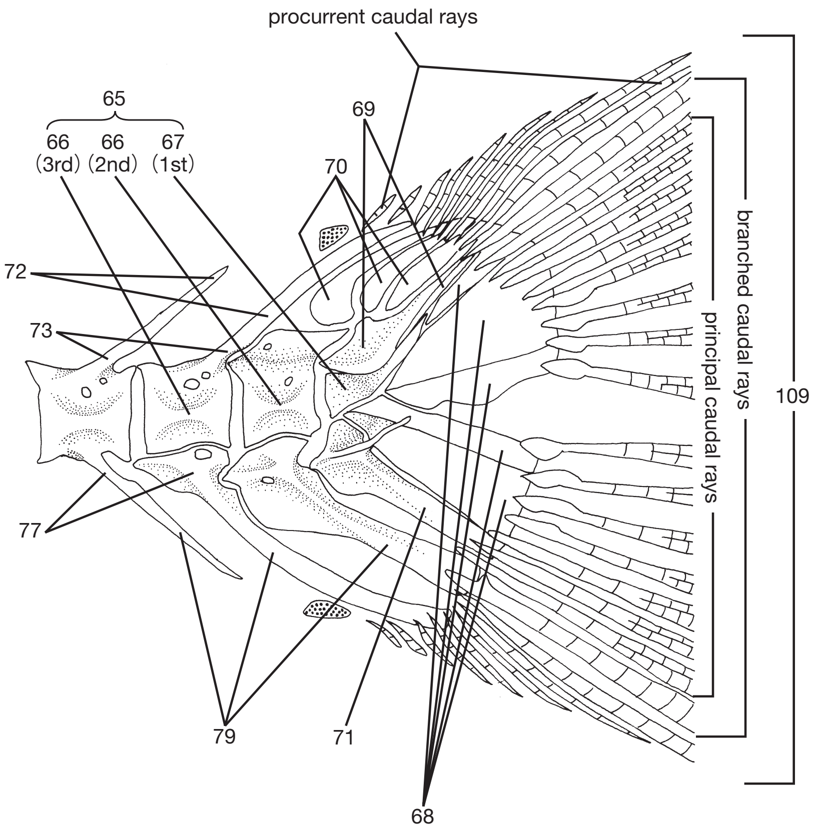

Fig. 4 Caudal skeletons of Red Sea Bream *Pagrus major*.
Large dots indicate cartilages. See table of III-3 for bone names and numbers.

protrude, and eventually the right and left transverse processes fuse, making a hollow. This fused skeletal part is the hemal arch (No. 77), and the hollow part is the hemal canal (No. 81). Even if there is a process in both sides inferior to the hemal canal or the processes are fused to form a short spine, it is still considered an abdominal vertebra (No. 64). However, the clearly elongated spine is judged to be a caudal vertebra (No. 65).

5) The caudal vertebrae near the posterior terminus are remarkably deformed/fused to support the caudal fin. The vertebrae in this vicinity are generically named the caudal skeleton (Figure 4). Because the difference in these fusing conditions varies depending on the evolutionary level of the species, it is valued for determining phylogenic relationships. Because the variation is remarkable even in extant Teleostei, I explain it by focusing on red seabream *Pagrus major* here.

The centrum of the terminal vertebra is called the urostyle (No. 67), and it plays a central role in the caudal skeleton. This is a small triangle if seen laterally, but a thick round bone if seen posteriorly. Therefore, it can be distinguished from the surrounding plate-like bones. The plate-like bone that forms a joint with the bottom of the urostyle and is equipped with a wire-like process bilaterally on the base is the parhypural (No. 71). There are two hemal spines specialized to a similar thickness immediately anterior to it, but they are not fused with the centrum (No. 79). The hemal spines with a normal thickness located more anterior are fused with each centrum.

A large and a small uroneural bone (No. 69) are seen to contact the dorsal side of the urostyle. These are left-to-right paired, distinguishing them from others. Between them and the last neural spine (No. 73), there is a boomerang-shaped thin bone followed by the 2 epurals, for a total of 3 epurals (No. 70). Because the epurals come off by adhering to the caudal fin rays when lifted, removal of the rays requires care.

Posterior to the urostyle, there are 5 flat bones named hypurals (No. 68) that are extended in a fan shape. This is composed of several fused hemal spines. Those in red sea bream exhibit typical morphology of fish in Perciformes. The hypurals are further fused with each other or with other bones in the vicinity depending on the species.

All of the branched caudal rays are supported by the parhypural and 5 hypurals (3 in the upper half and 2 in the lower half). Superior to them, there is an unbranched soft ray that nearly reaches the posterior terminus of the caudal fin and is supported by the fifth hypural. Also inferior to the rays, there is an unbranched soft ray that reaches nearly to the posterior terminus of the caudal fin and is supported by the parhypural. These two unbranched soft rays and all branched soft rays are collectively called the principal caudal rays. The rays located more anterior (superior and inferior) to the principal caudal rays are not included in the number of caudal fin rays in usual counting because the anterior ones are embedded beneath the skin and become small rudimentarily (see the counting method in II-5). However, these are valued in phylogenic studies, and counted using transparent specimens in which the skeletons are double-stained.

6) The number of fish vertebrae is an important taxonomic character expressed by the formula: total number of vertebrae (V) = number of abdominal vertebrae (AV) + number of caudal vertebrae (CV). It is counted by estimating the urostyle as the last caudal vertebra. When discussing the shape of vertebrae, it is occasionally convenient if we count the bones anteriorly, like preural centrum 1, 2, …, n, in addition to expressing the bones by the posterior ordinary number of the abdominal vertebrae and caudal vertebrae separately. At this time, the urostyle is estimated as the first preural centrum. This is based on the concept that the ural vertebra and the first preural centrum separately seen in the primitive fish are fused in the advanced fish groups.

III 8

Observation of the muscular system

The muscular system of fish controls their various life activities, including the movement of various organs, swimming, respiration, and the ingestion and digestion of food. The muscles are broadly classified into striated muscle and smooth muscle based on their cellular morphology. Another classification is based on the organ where the muscles are arranged, which broadly divides the muscles into three types. The striated muscle constituting the heart wall is called the cardiac muscle. The striated muscles moving fins and bones are skeletal muscles. The smooth muscles constituting the visceral organs are called visceral muscles. Moreover, there are also physiological categories of involuntary muscle and voluntary muscle. The cardiac muscle and the visceral muscle are involuntary muscles that are unconsciously governed by the autonomic nervous system to act at all times. The skeletal muscle is the voluntary muscle governed by the brain to consciously adjust activity. The skeletal muscles are described below.

The cells constituting the skeletal muscle are called muscle fibers because they have a slender shape. These are multinucleated cells in which a large number of myofibrils are assembled.

Lateral muscle: The lateral muscle is an assembly of muscle fascicles arranged regularly on both sides of the trunk and tail. Extension and shrinkage of the lateral muscle give the fish the power to swim. In many cases, the lateral muscle is composed of W-shaped myomeres (Figure 1-7, 8) subcutaneously lining the lateral side. The anterior and posterior myomeres are separated by the diaphragm (Figure 1-6). In addition, in Chondrichthyes and Teleostei, each myomere is divided into a right and left

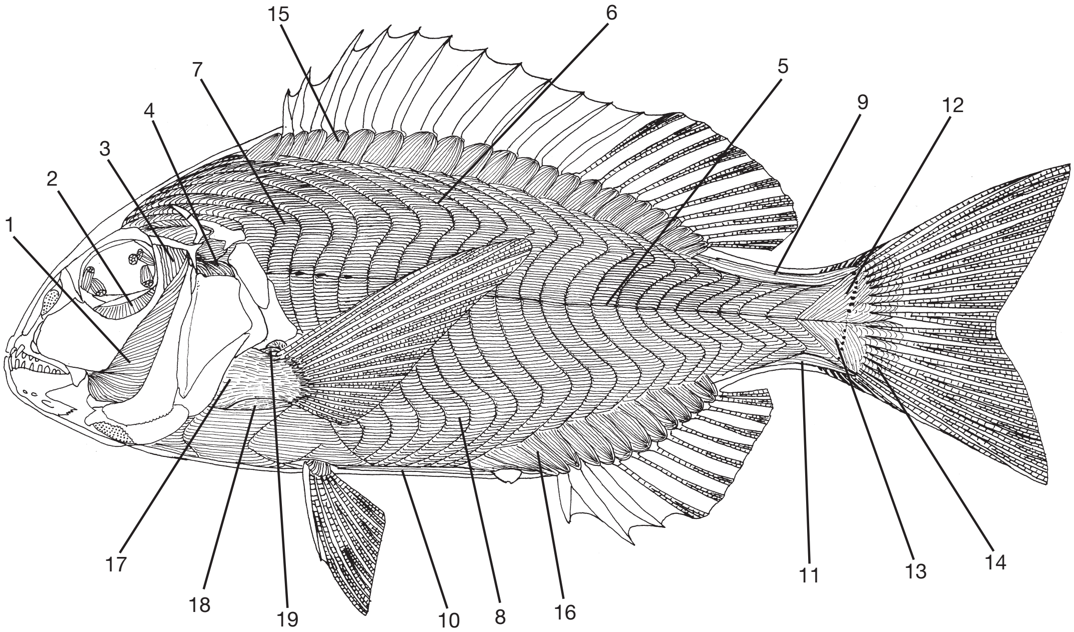

Fig. 1 Muscle system of Red Sea Bream *Pagrus major*.
1. adductor mandibulae; 2. adductor arcus palatine; 3. levator arcus palatine; 4. levator operculi; 5. horizontal septum; 6. myoseptum; 7. epaxialia; 8. hypaxialis; 9. supracarinalis posterior; 10. infracarinalis medium; 11. infracarinalis posterior; 12. flexor dorsalis; 13. flexor ventralis; 14. intermedialis; 15. inclinator dorsales; 16. inclinator anales; 17. abductor superficialis; 18. aductor profundus; 19. arrector ventralis

side by the medium septum or the vertical septum, composed of a tendon-like membrane connecting vertebra, and by the abdominal cavity, and divided into the dorsal muscle (Figure 1-7) and the ventral muscle (Figure 1-8) by the horizontal septum (Figure 1-5) lying between the vertebrae and the body surface. No horizontal septum is seen in Agnatha.

When observing the lateral muscle of Chondrichthyes and Teleostei, in many cases, each myomere is W-shaped on the body surface but has complicated morphology in the deep layer because it is equipped with two anterior muscle cones protruding anteriorly (Figure 2-5) and a posterior muscle cone protruding posteriorly (Figure 2-4), separately on the top and bottom of the centra. In sharks, the W-shaped myomeres are bent even more posteriorly in the dorsal part, and another anterior muscle cone develops in the deep layer of this part. In Agnatha, the shape of each myomere has a dull bending part, relatively simple and arched, and lacks the anterior muscle cone and the posterior muscle cone.

In the surface of the lateral muscle, muscular fascicles have a reddish brown color due to the abundant myoglobin and dense distribution of capillary vessels running longitudinally in a zonal manner along the horizontal septum (Figure 2-6). This is called the surface dark muscle (Figure 2-1), and its developmental level varies considerably depending on the species. The surface dark muscle is generally well developed in surface swimmers such as Japanese sardine *Sardinops melanostictus*, flying fish, Pacific saury *Cololabis saira*, mackerel, and Japanese Spanish mackerel *Scomberomorus niphonius*, and poorly developed in bottom-dwellers including wrasse, sargassum fish *Histrio histrio*, lizardfish *Saurida* sp., Platycephalidae, and sea robin *Chelidonichthys spinosus*.

Moreover, highly migratory surface swimmers such as skipjack/tuna, shortfin mako shark *Isurus oxyrinchus*, and salmon shark *Lamna ditropis* have paired red muscle fascicles running bilaterally along the vertebral column. This is called the true dark muscle (Figure 3-4). The true dark muscle is the part medial to the anterior muscle cone of the lateral muscle, and in the shortfin mako shark *Isurus oxyrinchus* it is apart from the vertebrae and embedded in the lateral muscle. In frigate/bullet tuna *Auxis* (Figure 3) and skipjack *Katsuwonus pelamis*, the dark muscle is remarkably developed and accounts for around 1/5 of the ordinary muscles.

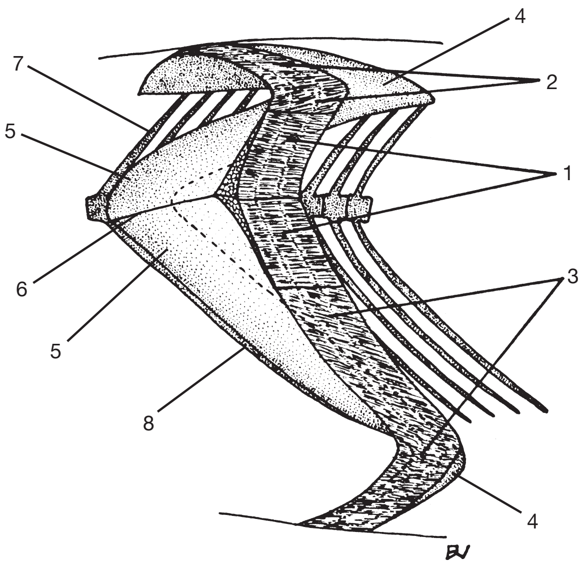

Fig. 2 One myoseptum of lateral muscle of a salmonid fish, King Salmon *Oncorhynchus tschawytscha*.
1, superficial dark muscle or lateralis superficialis; 2, epaxial; 3, hypaxialis; 4, posterior cone; 5, anterior cone; 6, horizontal septum; 7, neural spine & medium septum; 8, hemal spine & medium septum. From Winterbottom (1974).

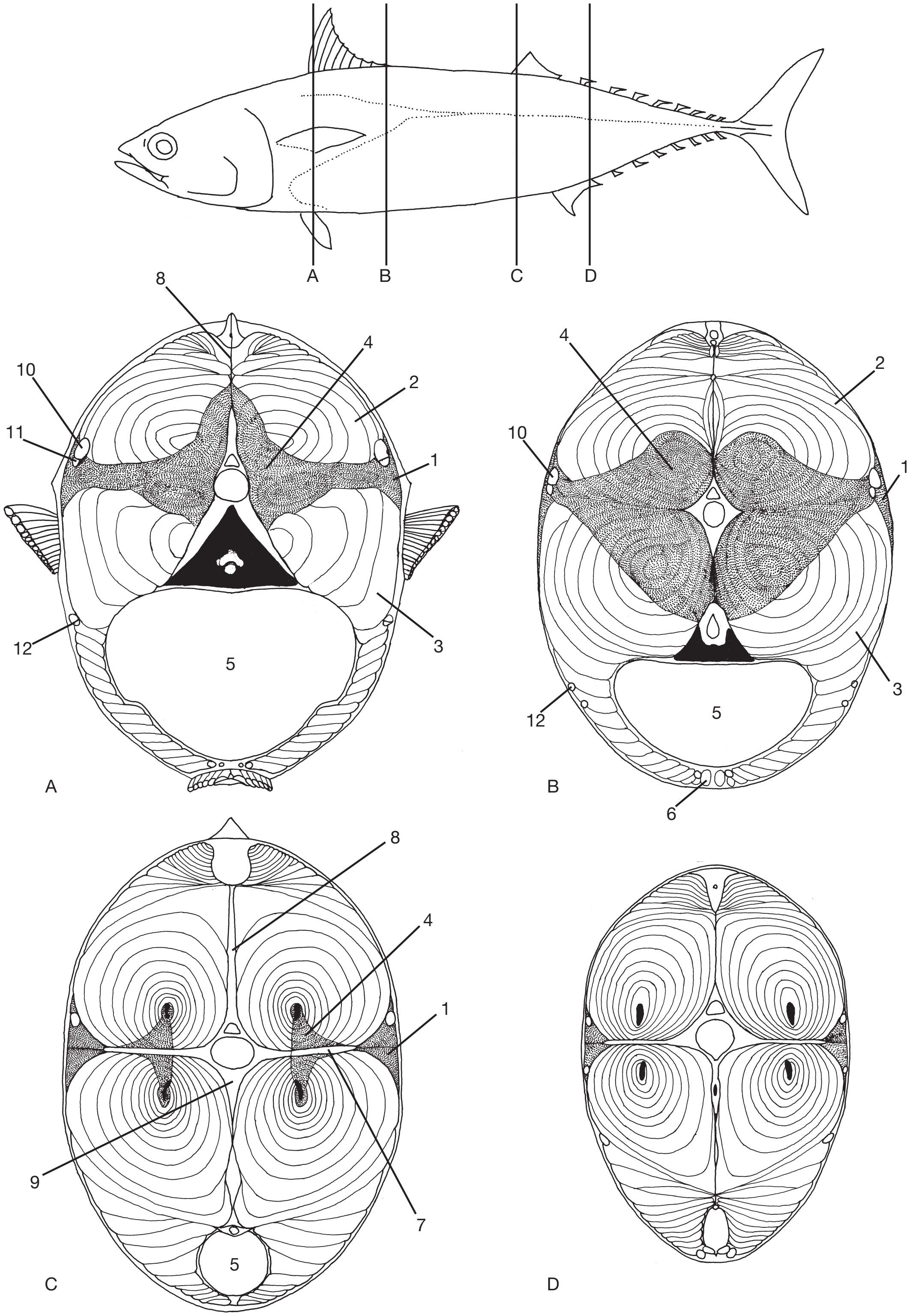

Fig. 3 Cross section of muscle of Frigate Tuna *Auxis thazard*. A-D on upper figure indicate section place of lower figures. 1, superficial dark muscle; 2, epaxial; 3, hypaxialis; 4, true dark muscle; 5, abdominal cavity; 6, infracarinalis medius; 7, horizontal septum & epineural; 8, medium (vertical) septum & neural spine; 9,medium septum & hemal spine; 10, lateral line canal; 11, dorsal cutaneous vessel; 12, ventral cutaneous vessel.

Jaw muscles and opercular muscles: The most remarkable muscle among the muscles for closing the mouth is the adductor mandibulae (Figure 1-1). Normally, this muscle is broadly divided into three muscles that arise from the palatine arch centering the quadrate and connect the medial and posterior surfaces of the dentary and the upper jaw, and the muscle fascicles lying in the inner cavity of the lower jaw, a total of four groups. The developmental status of the muscle fascicles of these parts varies depending on the species. The major muscles to open the lower jaw include the protractor hyoidei. This is a pair of slender muscle fascicles that arise from the medial surface near the joint between the right and left dentaries and reaches nearly all of the hyoid arch (excluding the urophyal and the interhyal) including the branchiostega.

Dorsal posterior to the adductor mandibulae, there is the dilator operculus connecting vertically toward the posterior part of the orbit of the neurocranium and the dorsal surface of the anterior part of the opercle. Posterior to this is the levator operculi (Figure 1-4) connecting vertically toward the dorsal surface of the posterior part of the opercle. In addition, there is the adductor operculi connecting horizontally the medial lateral wall of the neurocranium and the medial surface of the dorsal part of the opercle. All of these control opercular movement.

Muscles to move fins: The muscles for moving the dorsal fin and the anal fin among vertical fins are symmetrically arranged and share a basic structure, whereas the muscles for moving the caudal fin are very distinct.

Dorsal fin: The inclinator dorsalis (Figure 4-1) arises bilaterally from each ray base toward the medial surface of the skin. This acts to inclinate the ray right and left. In puffers, this muscle is remarkably developed and wraps the lateral muscle to act not only as an inclinator but also as a flexor and extensor for the body. This appears to have been developed in relation to the fact that a puffer

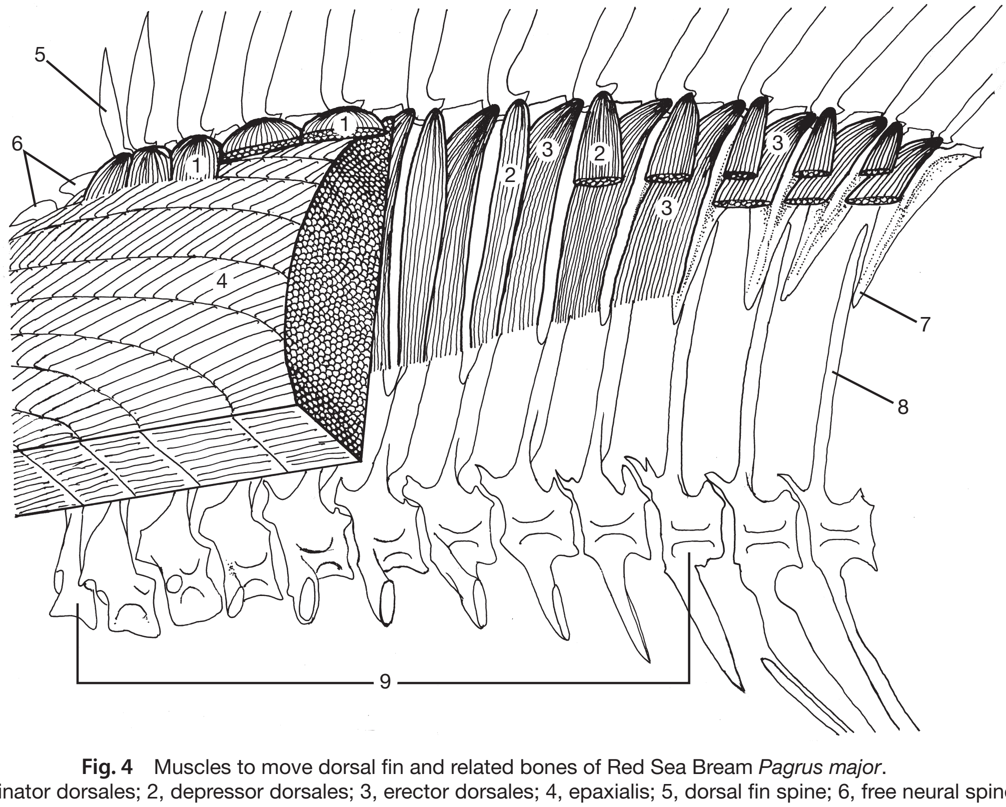

Fig. 4 Muscles to move dorsal fin and related bones of Red Sea Bream *Pagrus major*.
1, incinator dorsales; 2, depressor dorsales; 3, erector dorsales; 4, epaxialis; 5, dorsal fin spine; 6, free neural spine; 7, proximal pterigiophores; 8, neural spine; 9, abdominal vertebrae.

moves forward by the movement of the dorsal and anal fins. Inside the lateral muscle (Figure 4-4) are the erector dorsalis (Figure 4-3), running from the anterior terminus of the base of each ray (Figure 4-5) toward the distal pterygiophore (Figure 4-7) immediately anterior; the neural spine (Figure 4-8), or the medium septum; and the suppressor dorsalis (Figure 4-2), running from the lateral surface of the posterior terminus of the base toward the distal pterygiophore immediately inferior, the neural spine, or the medium septum. The former functions to erect the ray and the latter functions to fold the ray posteriorly, and both are left-to-right paired. In addition, these are fixed posteriorly and anteriorly by the supracarinalis anterior connecting the neurocranium and the most anterior pterygiophore and the supracarinalis posterior connecting the last neural spine and the last pterygiophore.

Caudal fin (see the foldout figure): The posterior terminus of the vertebral column has complicated muscles involved in the movement of the caudal fin. The major ones include the flexor dorsalis and the flexor ventralis, which arise from a wide range of the lateral surface of the caudal skeletal and are arranged radically mainly at the base of the branched soft rays of the caudal fin, the adductor caudalis connecting the lower central soft rays of the caudal fin and the urostyle as well as the hypurals, and the interradialis caudalis between the caudal rays. Among them, the muscles with the most important function are the flexor dorsalis and the flexor ventralis, which are separately composed of the muscle fascicles that are further divided into, again, top and bottom.

Pectoral fin (see the foldout figure): The muscles for moving the pectoral fin also include many types of muscles that contract medially, laterally, superiorly, or inferiorly. Major ones include the triangle abductor superficialis that lies on the posterior and ventral surfaces of the cleithrum and attaches to the anterior surface of the lateral side of the ray base through its posterior terminus, and the abductor profundus that lies on the medial lateral surface of the coracoid and attaches to the posterior inferior process of the base of all soft rays.

Pelvic fin: In the pelvic fin, the major muscles are the abductor profundus pelvicus, which is located on the ventral surface of the pelvic girdle and is associated with the pelvic fin ray through its posterior terminus, the arrector ventralis pelvicus, which arises from the ventral surface of the lateral side of the pelvic girdle to connect to the lateral surface of the first pelvic ray, and the adductor profundus pelvicus, which lies on the dorsal side of the pelvic girdle and adheres to the dorsal surface of the pelvic ray base.

A detailed explanatory review of fish muscle that is highly recommended is: Winterbottom, R. (1974) A descriptive synonymy of the striated muscles of the Teleostei. Proc. Acad. Nat. Sci. Philad., 125 (12): 225-317.