Distribution of Scleral Ossicles in Teleost Fishes

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Distribution of Scleral Ossicles in Teleost Fishes

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Abstract

Ossicles in the eyeball sclera of 21 teleost species were investigated descriptively. Sclera contained at most two ossicles which occupied anterior and posterior poles of the scleral equator. However, ossicles were not observed in the sclera of the eel *Anguilla japonica*, the bandfish *Trichiurus lepturus* and the grass puffer *Fugu niphobles*, and only anterior ossicle in the flatfish *Limanda herzensteini*. Especially for the marlin *Makaira mitsukurii* and the tuna *Thunnus thynnus orientalis*, a skeletal ring was formed in conjunction of the two developed ossicles. The difference of the sclera was discussed from the standpoint of external muscular system of the eyeball.

The eye is structurally the most complicated sensory organ. According to Harder[1], it is probably most intensively studied as the organ of sight. Most teleostei have special cartilaginous and/or bony sclera in their eyeballs. The sclera protects the eyeball from injury. In small eyes the high interior pressure provides a certain solidity; in larger ones cartilaginous platelets can be embedded in the sclera in some teleostei. Other teleostei such as the tunas have bony lamellae or closed bony rings in the sclera[1]. Generally two platelets of ossicles can be found in teleostean sclera.

The present study was conducted to ascertain the previous workers' observations and add descriptive figures to them relating to the distribution of scleral ossicles in teleostean fishes.

Materials and Methods

The treated teleostei included 8 orders, 11 suborders and 21 species: Anguilliformes, Anguilloidei, *Anguilla japonica* (eel); Cypriniformes, Cyprinidae, *Cyprinus carpio* (carp), *Pseudogobio esocinus* (river dodger), *Zacco platypus* (pale chub); Beloniformes, Exocoetoidei, *Prognichthys agoo* (flying fish); Cyprinodontiformes, Poeciliidae,

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Gambusia affinis (mosquito fish); Perciformes, Mugiloidei, *Mugil cephalus* (mullet), *Sphyraena schlegeli* (red barracuda); Percoidei, *Apogon taeniatus* (cardinal fish), *Atropus atropus* (cleftbelly kingfish), *Coryphaena hippurus* (common dolphin), *Seriola quinqueradiata* (yellow tail), *Sillago japonica* (silver whiting), *Taius tumifrons* (red sea-bream); Xiphioidei, *Makaira mitsukurii* (marlin); Scombroidei, *Pneumatophorus japonicus* (chub mackerel), *Thunnus thynnus orientalis* (tuna), *Trichiurus lepturus* (bandfish); Scorpaeniformes, *Sebastiscus marmoratus* (rockfish); Pleuronectiformes, Pleuronectoidei, *Limanda herzensteini* (flatfish); Tetraodontiformes, Tetraodontoidei, *Fugu niphobles* (grass puffer).

All adult fish were used. For the carp and mullet the scleral conditions according to age were also investigated.

Initially the boiled or 10% formalin-fixed materials of right eyeballs were prepared to remove from the sclera component tissues like muscles, nerve tracts, adipose tissue, retina layer, vitreous humour, lens, etc. The scleral structure was observed to recognize distributions of the cartilage and bone. Their occupation areas on the sclera were then described. Secondly, external muscles of the right eyeball were examined anatomically and clarified their adhered sites on the sclera in tuna, flying fish, and grass puffer, all chosen as representative eyeballs which had different types of sclerae.

Results and Discussion

1. *Anguilla japonica* (Anguilliformes, Anguilloidei) (Plate I)

The sclera consisted of the cartilage only. It possessed specificially many meridional furrows. The bottom foramen of median size was complicated with its intricated margin, and covered with the membranous tissue which contained several cartilaginous islands.

2. *Cyprinus carpio* (Cypriniformes, Cyprinidae) (Plate II)

Two different sizes of sclerae showed almost the same structure, and seemed to maintain typical structures of this species. Two ossicles of a relatively small size were distributed on anterior and posterior poles of the sclera. The bottom foramen developed well and occupied almost all the bottom area.

3. *Pseudogobio esocinus* (Cypriniformes, Cyprinidae) (Plate III)

The sizes of anterior and posterior ossicles were small. The cartilaginous area was thin. The bottom foramen was large and covered with the membranous tissue.

4. *Zacco platypus* (Cypriniformes, Cyprinidae) (Plate III)

The anterior and posterior ossicles were small. The cartilaginous area was flexible. The bottom foramen was large as in the above species, *P. esocinus*.

5. *Prognichthys agoo* (Beloniformes, Exocoetoidei) (Plate IV)

The anterior and posterior ossicles developed well, covering the both sides of the sclera. However the cartilaginous area was broad. The bottom foramen was median size. At the dorso-posterior area near the posterior ossicle, a pore of the nerve to the iris muscle was visible.

6. *Gambusia affinis* (Cyprinodontiformes, Poeciliidae) (Plate Ⅳ)

The anterior and posterior ossicles were small, and the anterior ossicle was larger than the posterior. The bottom foramen was very large, showing a tetrapod shape. The cartilaginous area had a pore of the nerve to the iris muscle at the dorso-median surface.

7. *Mugil cephalus* (Perciformes, Mugiloidei) (Plate Ⅴ)

Structures of small and large sclerae were compared. Each ossicle was small or median size, both showing basically the same construction of the position and shape. The area and rigidity of ossicles slightly increased with the growth. The bottom foramen became larger and distinctly showed a distorted tetrapod or petal shape in the aged fish.

8. *Sphyraena schlegeli* (Perciformes, Mugiloidei) (Plate Ⅵ)

The sclera showed a flattened sphere due to reduction of the length of the principal axis. The anterior and posterior ossicles were median size. The bottom foramen was nearly square and occupied a large portion of its area. At the dorso-posterior of the cartilage, a pore of the nerve to the iris muscle was observed.

9. *Apogon taeniatus* (Perciformes, Percoidei) (Plate Ⅵ)

The anterior and posterior ossicles were small. The sclera was flexible, possessing the bottom foramen which encroached irregularly on the cartilaginous area.

10. *Atropus atropus* (Perciformes, Percoidei) (Plate Ⅶ)

Dorsal view of the sclera was semispheroid. The anterior and posterior ossicles were median size. Their sutural regions against the cartilage slightly thickened. The bottom foramen showed a crescent shape. The dorso-posterior cartilage had a pore of the nerve to the iris muscle.

11. *Coryphaena hippurus* (Perciformes, Percoidei) (Plate Ⅶ)

Dorsal view of the sclera was semispheroid. The ossicles were thick and developed anteriorly and posteriorly. Both were conjugated at the vertical axis of the frontal sclera, forming a skeletal ring which covered only the frontal half of the sclera. The bottom foramen was simply round and relatively small. At the dorsal of the posterior ossicle was situated a pore of the nerve to the iris muscle. It was difficult to observe this pore externally.

12. *Seriola quinqueradiata* (Perciformes, Percoidei) (Plate Ⅷ)

The anterior and posterior ossicles increased their thickness and occupied area. They covered broadly the anterior and posterior sides of the sclera. However, the skeletal ring was incomplete due to the lack of mutual conjunction. The bottom foramen showed a relatively small triangle. The pore of the nerve to the iris muscle was seen at the dorsal of the posterior ossicle.

13. *Sillago japonica* (Perciformes, Percoidei) (Plate Ⅷ)

The anterior and posterior ossicles were median size. The scleral cartilage was soft and flexible. The bottom foramen was a demilunar type. The pore of the nerve to the iris muscle was situated at the dorso-posterior cartilage.

14. *Taius tumifrons* (Perciformes, Percoidei) (Plate Ⅸ)

Both the polar ossicles developed largely, covering the anterior and posterior sides of the sclera. They did not connect each other, yielding a large cartilaginous area between them. The shape of the bottom foramen was distorted and obtuse triangle. The pore of the nerve to the iris muscle was detected dorsally at the posterior ossicle.

15. *Makaira mitsukurii* (Perciformes, Xiphioidei) (Plate Ⅸ)

The pair of ossicles developed largely around the sclera, remaining little cartilaginous area. Structurally they were very thick, and completely conjugated each other, forming a broad skeletal ring of the sclera. The bottom foramen of median size was almost oblong. Backwardly at the dorsal of the posterior ossicle was seen the pore of the nerve to the iris muscle.

16. *Pneumatophorus japonicus* (Perciformes, Scombroidei) (Plate Ⅹ)

The anterior and posterior ossicles formed an incomplete ring along the frontal sclera. The width of this ring was not wide. The cartilage was distributed on the back area of the sclera. Both ossicles were not so thick as those of the same Scombroidei species. The sclera showed dorsally a flattened semisphere due to its reduction of the principal axis. The bottom foramen was relatively large.

17. *Thunnus thynnus orientalis* (Perciformes, Scombroidei) (Plate Ⅹ)

The paired ossicles developed largely to form a complete and skeletal ring of the sclera. The width of this ring was large as to cover the lateral side of the sclera. The cartilaginous area was observed at the back scleral region only. The bottom foramen of small size showed a distorted square. Two pores were recognized at the dorsal and near the pole of the posterior ossicle.

18. *Trichiurus lepturus* (Perciformes, Scombroidei) (Plate Ⅺ)

The dorsal shape of the sclera was a flattened semisphere, possessing the cartilage to which the bottom foramen invaded largely. The sclera lacked the paired ossicles.

19. *Sebastiscus marmoratus* (Scorpaeniformes) (Plate XI)

The sclera showed dorsally a flattened semisphere due to the developed bottom foramen. The ossicles of median size were situated at the anterior and posterior poles of the sclera.

20. *Limanda herzensteini* (Pleuronectiformes, Pleuronectoidei) (Plate XII)

The dorsal shape of the sclera was conical. Its obtuse apex possessed a relatively small bottom foramen of the cucumber-shape. The position of this foramen was not central but ventral, differing from the case of other species. The ossicle was recognized at the anterior sclera only, and it was small size.

21. *Fugu niphobles* (Tetraodontiformes, Tetraodontoidei) (Plate XII)

The sclera had a specific character of hard adhesion to the thick cornea. The sclera consisted of the cartilage only. No ossicles were distributed.

Around the orbital muscles of the tuna *T. thynnus orientalis* there were many adipose tissues. Musculus rectus medialis (m.r.m.) showed the most thick stem among those bold muscles. M.r.m. was strongly adhered to the sclera. For the flying fish *P. agoo*, although the orbital muscles were thinner as compared to those of the tuna, m.r.m. was thicker as seen in the other members. The orbital muscles were flattened, all showing the same thickness in the grass puffer *F. niphobles* (Fig. 1).

Adhered sites of the orbital muscle on the sclera are shown in Fig. 2. In the tuna *T. thynnus orientalis*, the skeletal ring was broadly adhered by the muscles. Only musculus rectus lateralis (m.r.l.) stuck posteriorly to the margin of the pupil. The origin of m.r.m. was divided into two at the anterior side of the sclera. In the flying fish *P. agoo*, the muscular origin was narrow. M.r.m. adhered to the sclera backwardly at the scleral cartilage. Only this area had rigidity comparable to the osseous hardness. M.r.l. stuck to the posterior margin of pupil. In the grass puffer *F. niphobles*, muscular origins were narrow as in the flying fish *P. aoo*. Their distribution was almost similar to that of the tuna, except the case of m.r.m. M.r.m. was not divided, differing from m.r.m. in the tuna, at its origin on the anterior sclera.

In the teleostean eyeballs a bulbar ellipsoidality was common, and the sclera consisted mostly of a cup of hyaline cartilage which was often calcified. In many teleosts, the frontal part of the sclera was provided with a pair of demilunar ossicles, disposed nasally and temporally around the cornea.

The sclera was very variable in its morphology. Ossicles might occur in one or two components, or none of them in teleostei. The common type had both anterior and posterior ossicles of the small, median or large size (Plates II - VIII). In small-eyed and bottom forms, there was none (Plates I, XI and XII) or only anterior ossicle as in the flatfish (Plate XII). Conversely, the anterior and posterior ossicles might develop enormously and formed a complete skeletal ring in large, large-eyed, swift swimmers

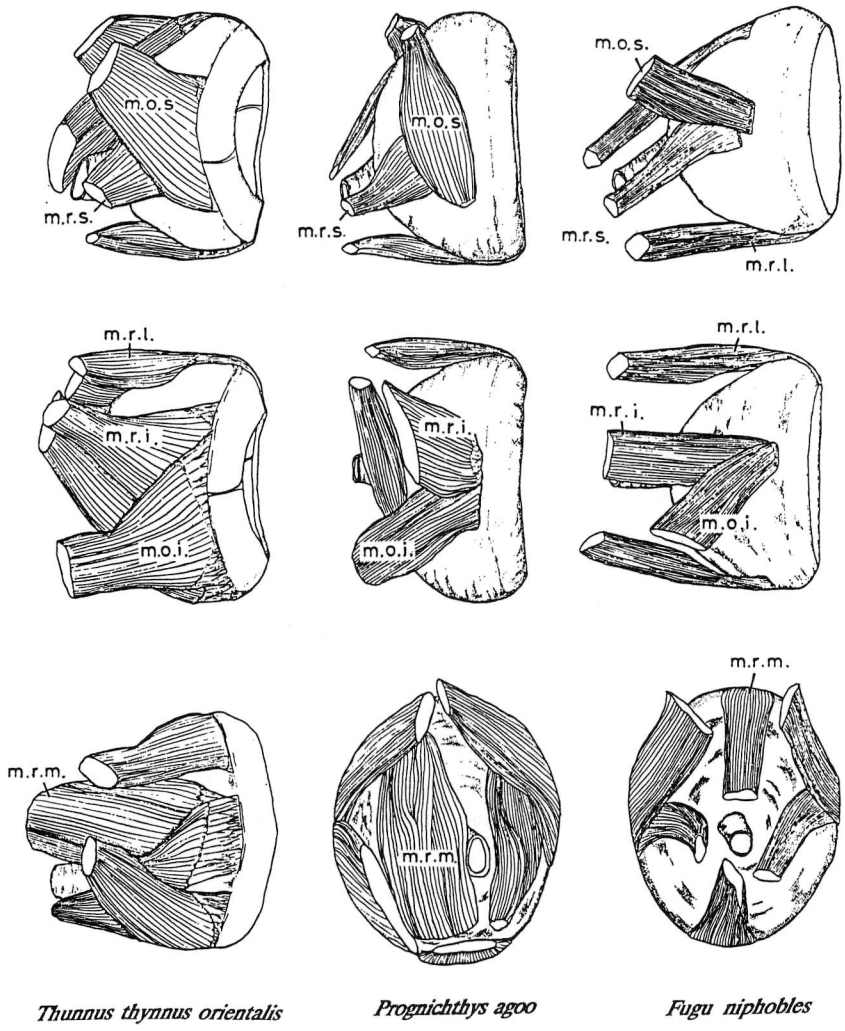

Fig. 1 Arrangements of the external muscles originating from the right eye-ball of three different fishes. Upper, dorsal side; middle, ventral side; lower left, nasal side; lower middle and right, back side. Abbrev., m.o.i., musculus obliquus inferior; m.o.s., musculus obliquus superior; m.r.i., musculus rectus inferior; m.r.l., musculus rectus lateralis; m.r.m., musculus rectus medialis; m.r.s., musculus rectus superior.

as in the tuna (Plate X) and the swordfish (Plate IX).

These demilunar ossicles of modern teleostei were thought to represent the anterior and posterior members of a quartet of ossicles which, in some of the oldest fossil fishes, formed a complete circumcorneal ring[2]. Development of the scleral structure was considered by Walls[3] as follows: primitively, it must have contained a complete cup of hyaline cartilage as in all lower fishes. But the cartilage-cup which initially covered the whole back of the eye-ball, has been replaced by membranous tissue. This

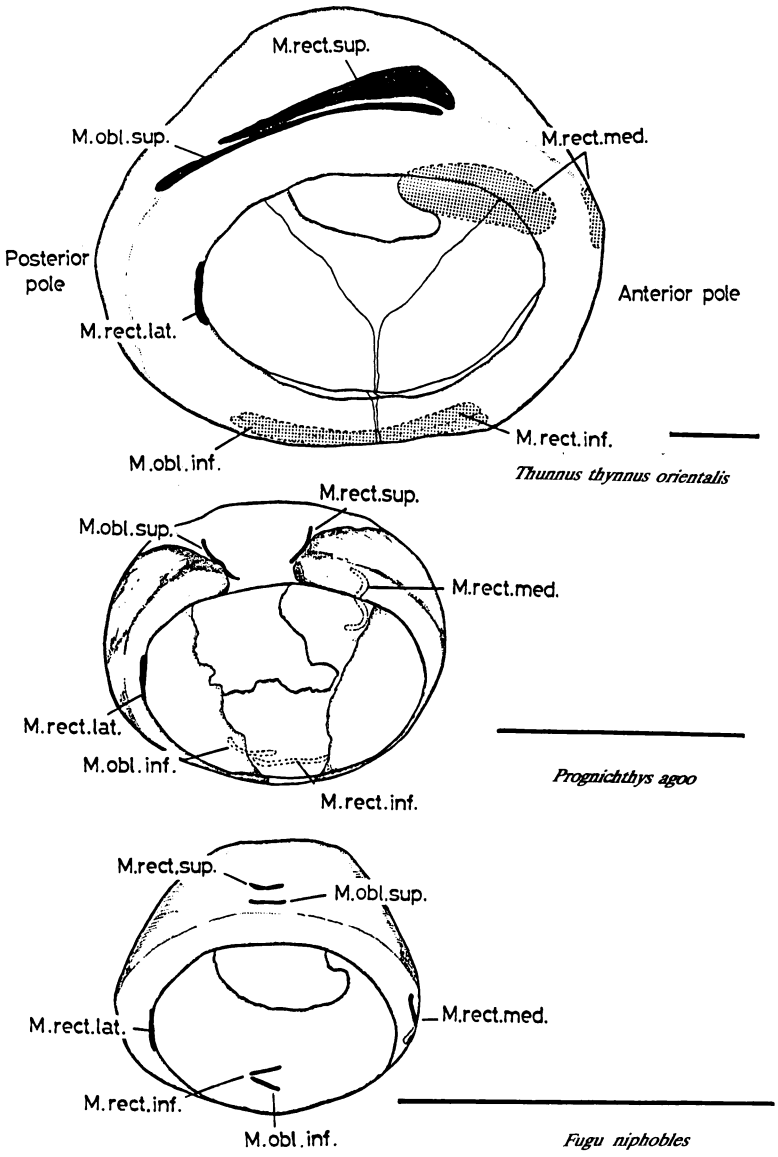

Fig. 2 Original sites of the orbital muscles on the right sclera, viewed dorsofrontally. Dark areas are in visible condition. The dotted means invisible. Scale = 1 cm. Abbrev., M.obl.inf., musculus obliquus inferior; M.obl.sup., musculus obliquus superior; M.rect.inf., musculus rectus inferior; M.rect.lat., musculus rectus lateralis; M.rect.med., musculus rectus medialis; M.rect.sup., musculus rectus superior.

membranous tissue had a window, the bottom foramen, which was often so large that the cartilage and/or ossicle became to be restricted to a broad equatorial area.

As differently specialized sclerae, both extremes correspond to those of the tuna *T.*

thynnus orientalis and the grass puffer *F. niphobles*. The former had well developed ossicles, contrary to the complete absence in the latter. For the muscular system of the eyeball, especially the musculus rectus medialis in the tuna developed its size, and was divided into two fulcura on the sclera, indicating an anterior motion of the eye to perform a very important role in this species. The muscular size was different among species, though distribution patterns of the muscular origin on the sclera were generally similar. Size difference of these muscles might reflect the area size of the adhered site. Thus anatomical results of the muscular system seemed to suggest a functional inevitability of the occurrence of the ossified ring in the eyeball.

Acknowledgement

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Explanations of Plates

Plate I : *Anguilla japonica*, Anguilliformes, Anguilloidei; the horizontal diameter of the sclera(ϕ) = 5mm.

Plate II : *Cyprinus carpio*, Cypriniformes, Cyprinidae; left, body length = 13cm, ϕ = 8mm; right, body length = 24cm, ϕ = 16mm.

Plate III : left, *Pseudogobio esocinus*, Cypriniformes, Cyprinidae, ϕ = 7mm; right, *Zacco platypus*, Cypriniformes, Cyprinidae, ϕ = 8mm.

Plate IV : left, *Prognichthys agoo*, Beloniformes, Exocoetoidei, ϕ = 19mm; right, *Gambusia affinis*, Cyprinodontiformes, Poeciliidae, ϕ = 5mm.

Plate V : *Mugil cephalus*, Perciformes, Mugiloidei; left, body length = 14cm, ϕ = 8mm; right, body length = 26cm, ϕ = 19mm.

Plate VI : left, *Apogon taeniatus*, Perciformes, Percoidei, ϕ = 8mm; Sphyraena schlegeli, Perciformes, Mugiloidei, ϕ = 8 mm.

Plate VII : left, *Atropus atropus*, Perciformes, Percoidei, ϕ = 15mm; right, *Coryphaena hippurus*, Perciformes, Percoidei, ϕ = 28mm.

Plate VIII : left, *Seriola quinqueradiata*, Perciformes, Percoidei, ϕ = 27mm; right, *Sillago japonica*, Perciformes, Percoidei, ϕ = 8mm.

Plate IX : left, *Taius tumifrons*, Perciformes, Percoidei, ϕ = 16mm; right, *Makaira mitsukurii*, Perciformes, Xiphioidei, ϕ = 57mm.

Plate X : left, *Pneumatophorus japonicus*, Perciformes, Scombroidei, ϕ = 20mm; right, *Thunnus thynnus orientalis*, Perciformes, Scombroidei, ϕ = 55mm.

Plate XI : left, *Trichiurus lepturus*, Perciformes, Scombroidei, ϕ = 18mm; right, *Sebastiscus marmoratus*, Scorpaeniformes, ϕ = 12mm.

Plate XII : left, *Limanda herzensteini*, Pleuronectiformes, Pleuronectoidei, ϕ = 10 mm; right, *Fugu niphobles*, Tetraodo ntiformes, Tetraodontoidei, ϕ = 8mm.

Abbreviations, ao, anterior ossicle (nasal pole); bf, bottom foramen; ca, cartilaginous area; ma, membranous area; pn, pore of the nerve to the iris muscle; po, posterior ossicle (caudal pole).

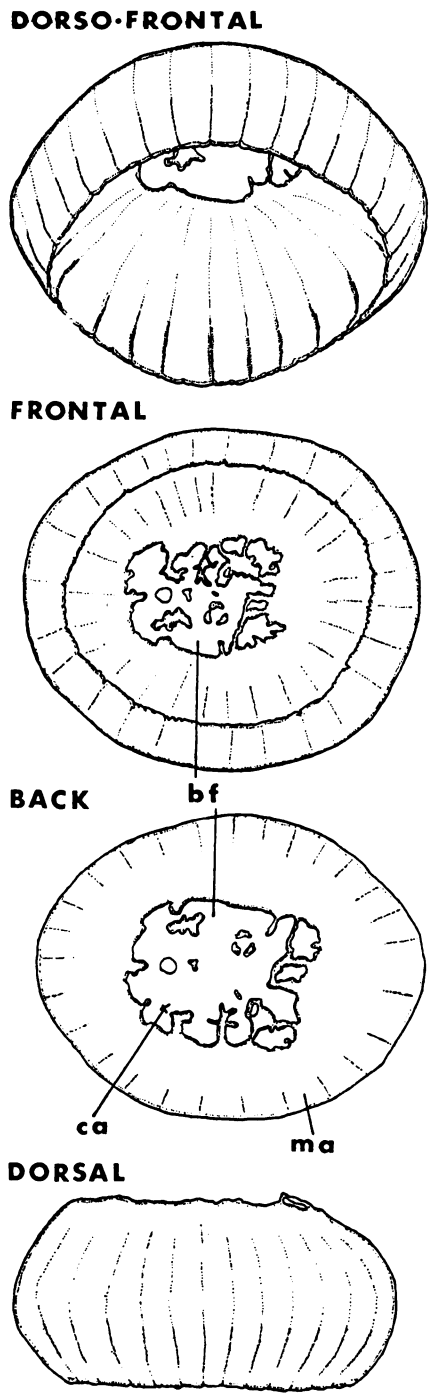
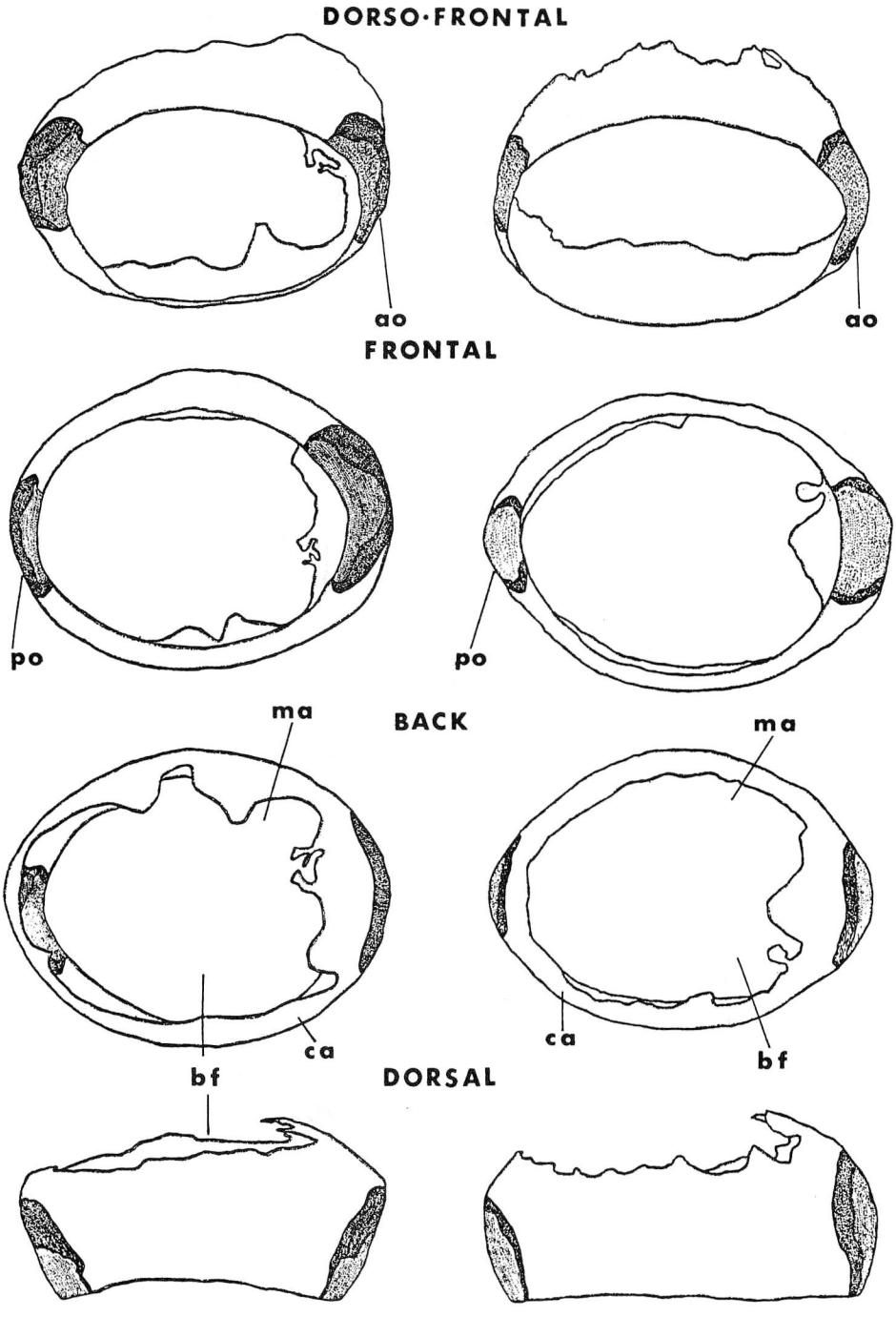
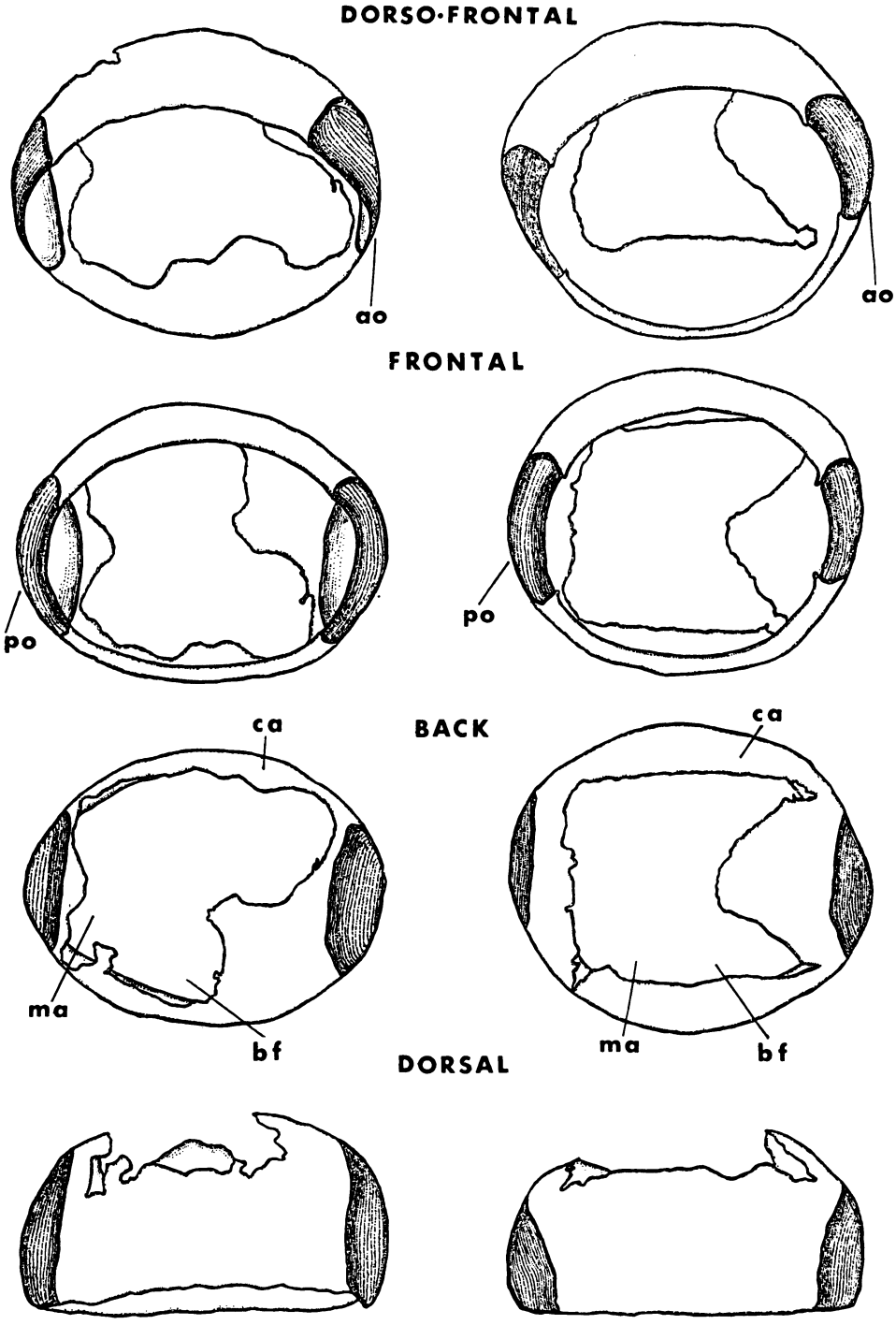


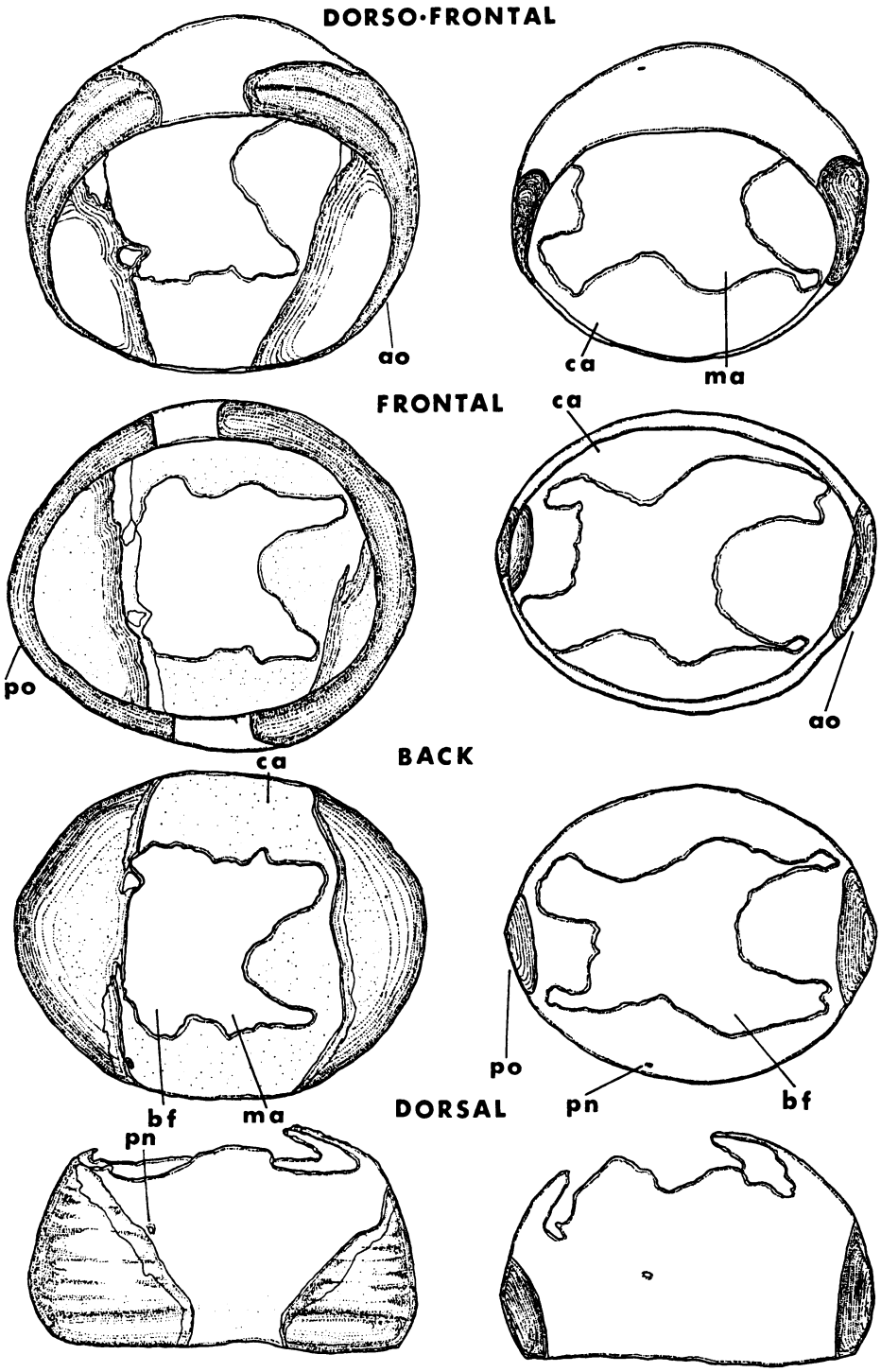
Plate I *Anguilla japonica*



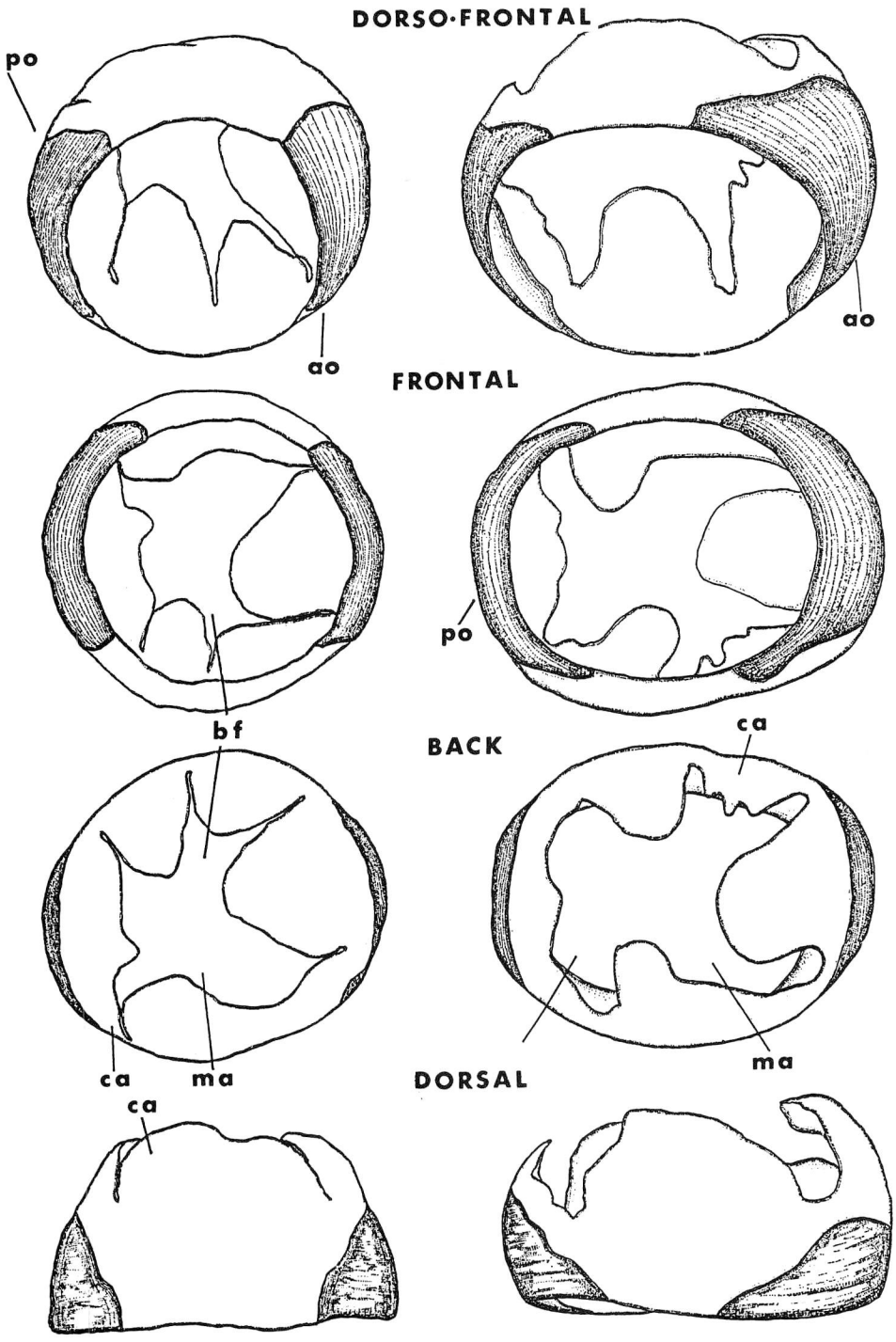
Cyprinus carpio Plate II *Cyprinus carpio*



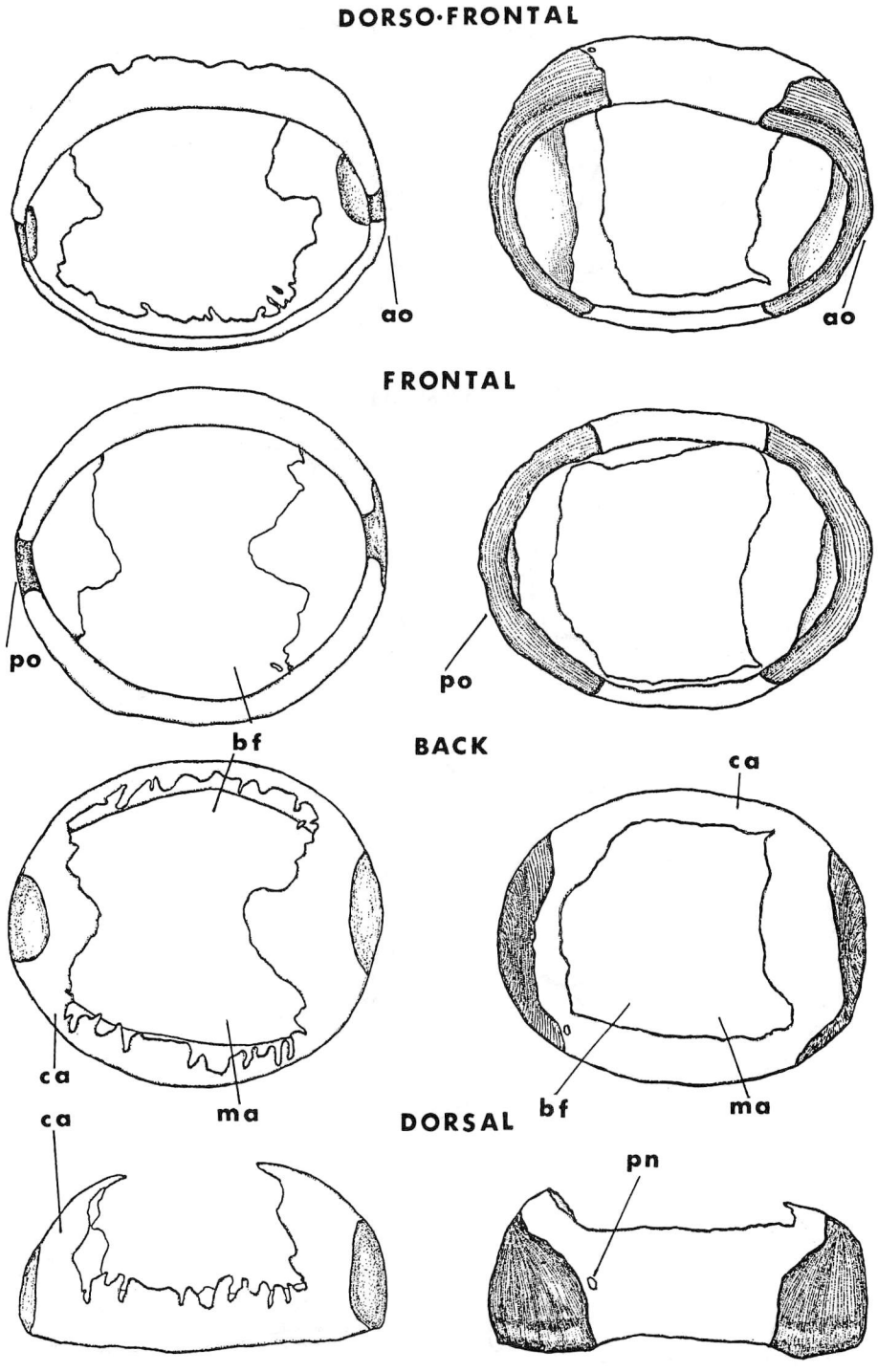
Pseudogobio esocinus Plate III *Zacco platypus*



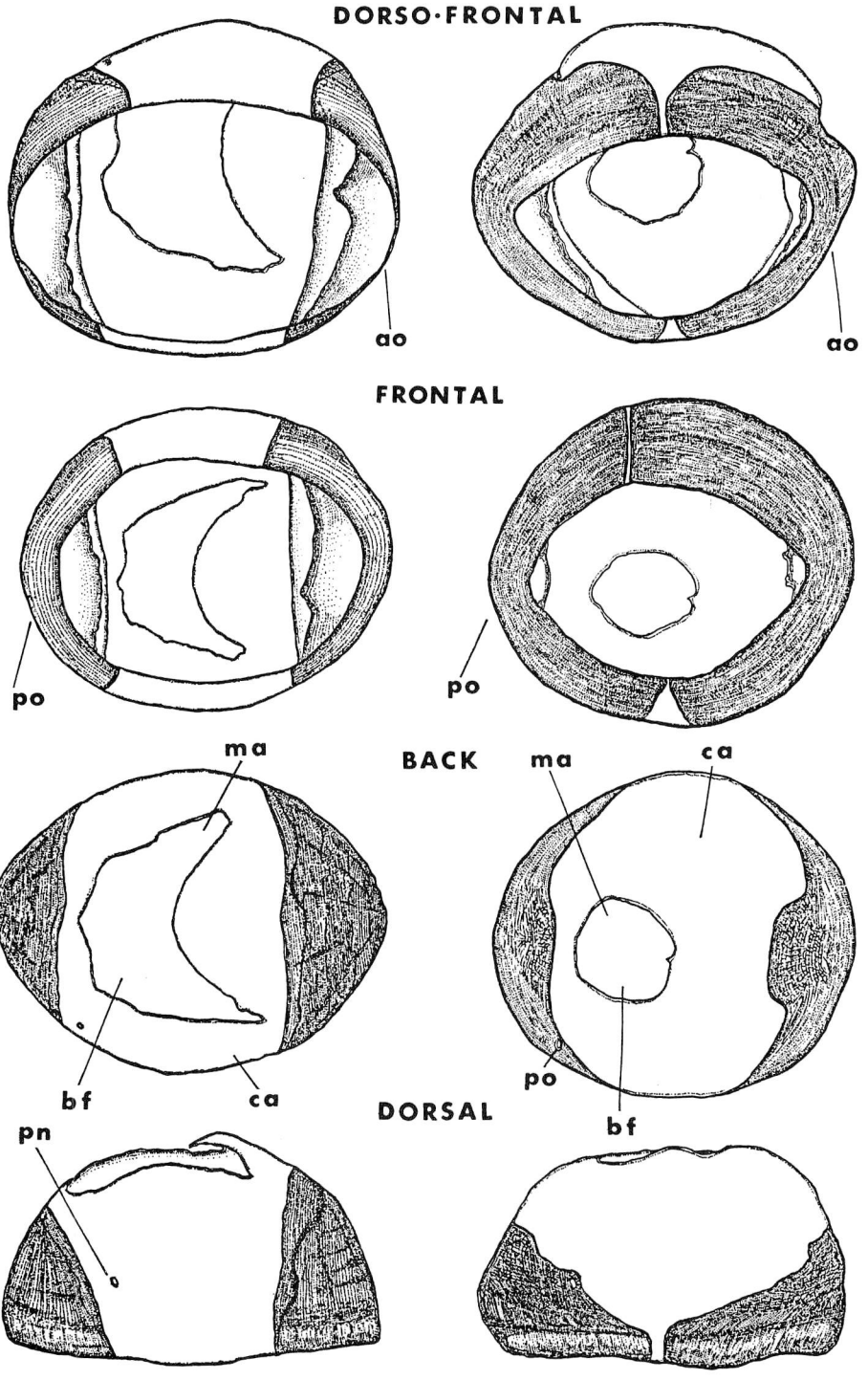
Prognichthys agoo Plate IV *Gambusia affinis*



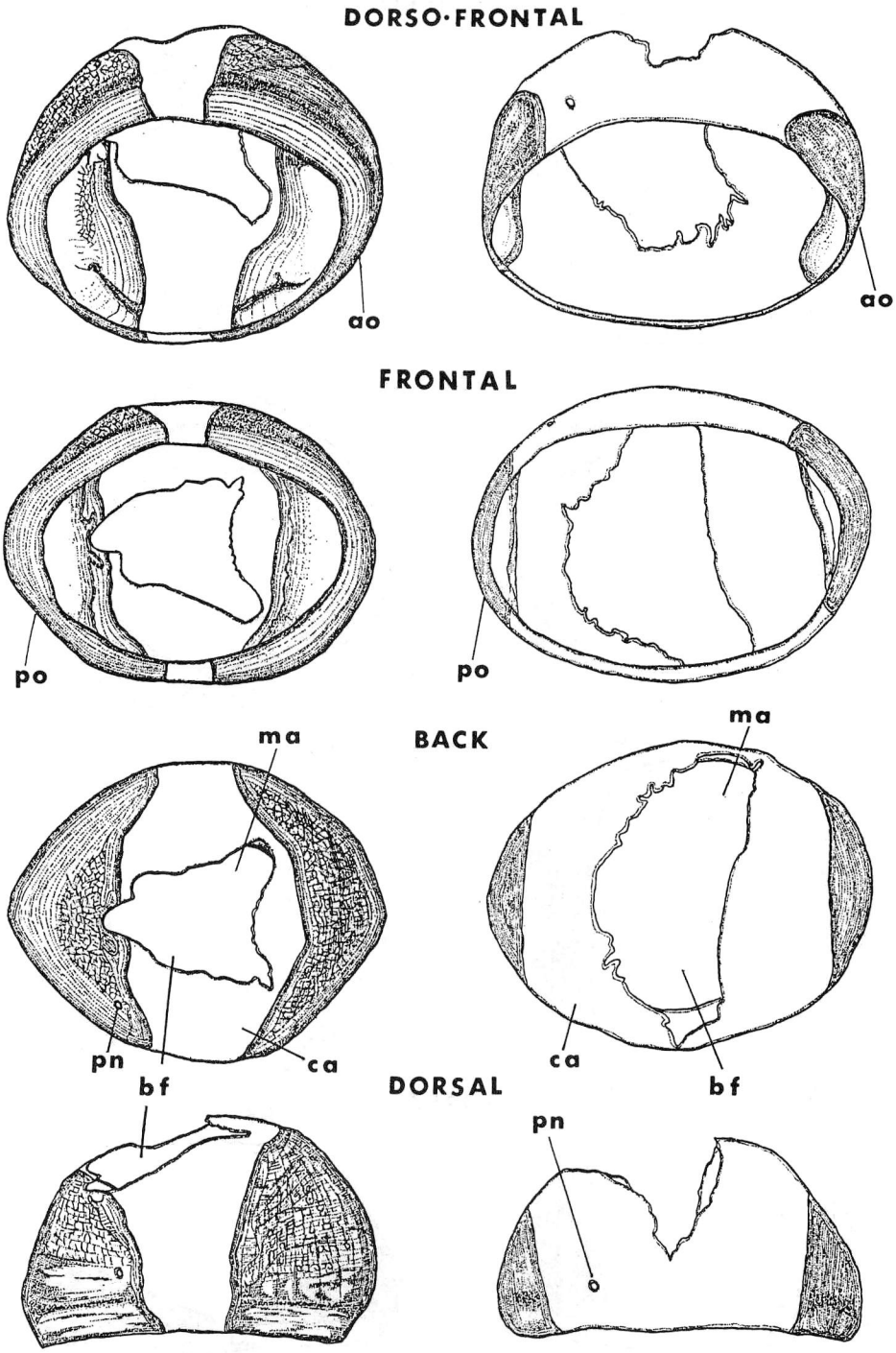
Mugil cephalus Plate V *Mugil cephalus*



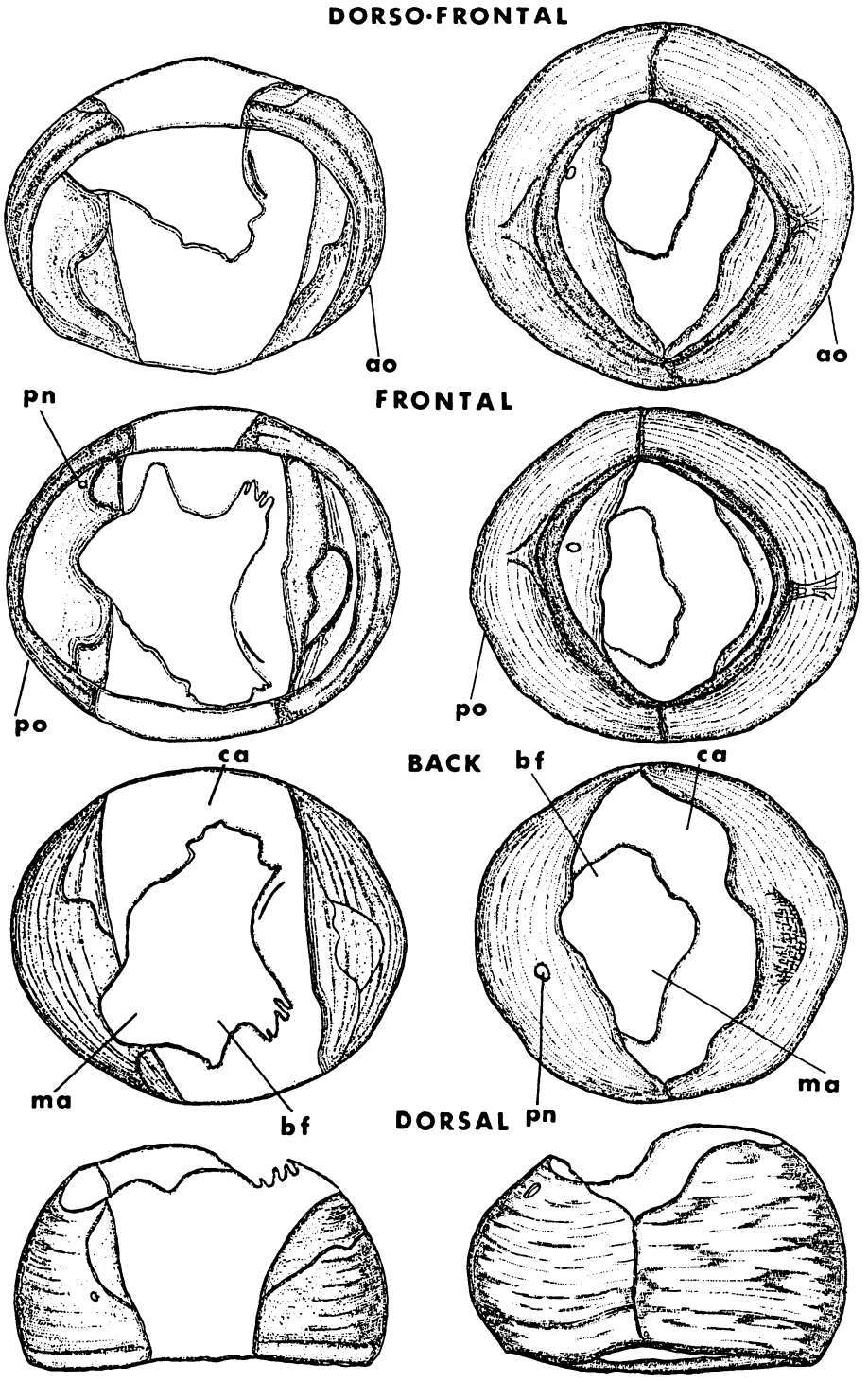
Apogon taenitus Plate VI *Sphyraena schlegeli*



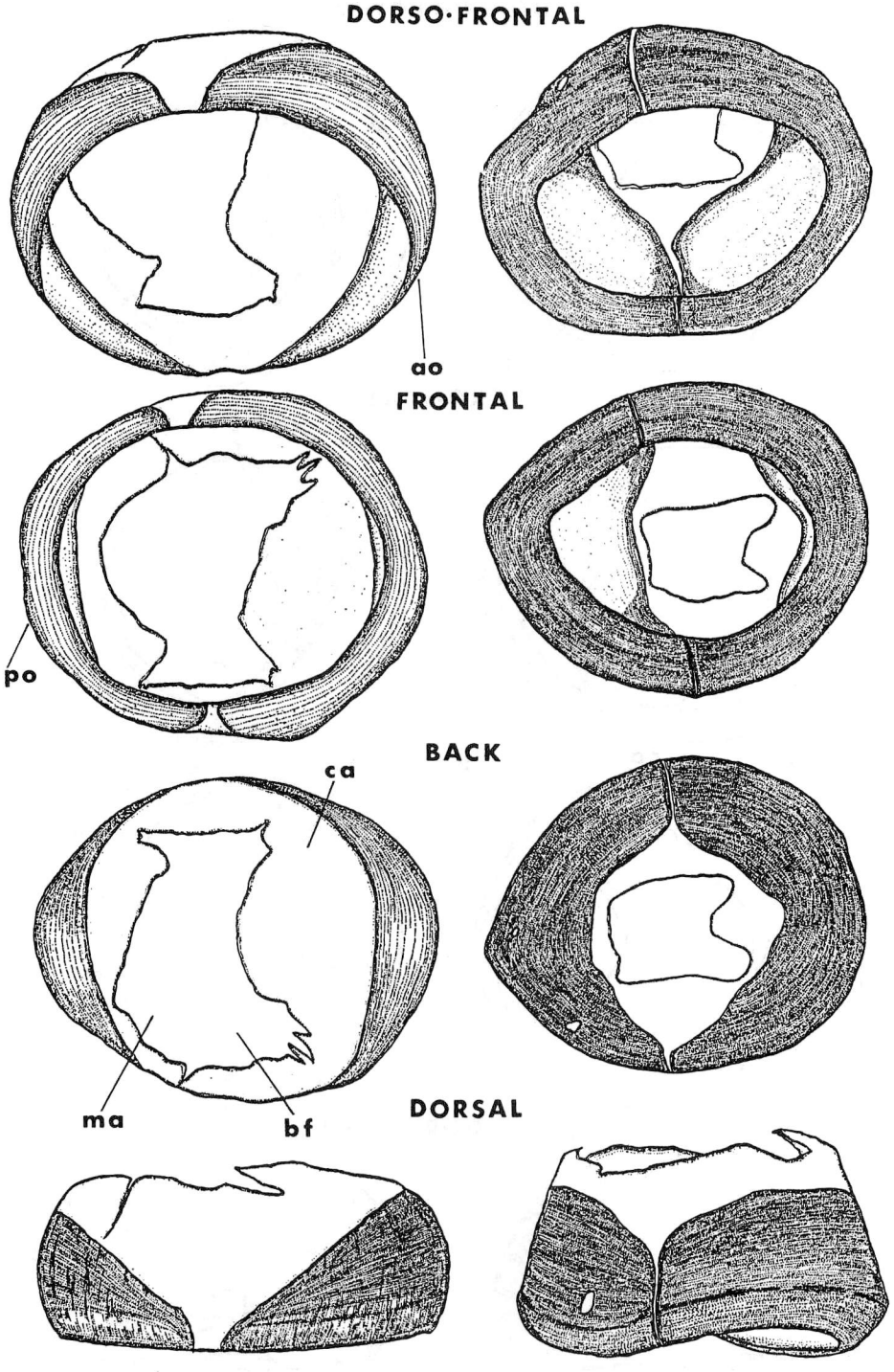
Atropus atropus Plate VII *Coryphaena hippurus*



Seriola quinqueradiata Plate VIII *Sillago japonica*

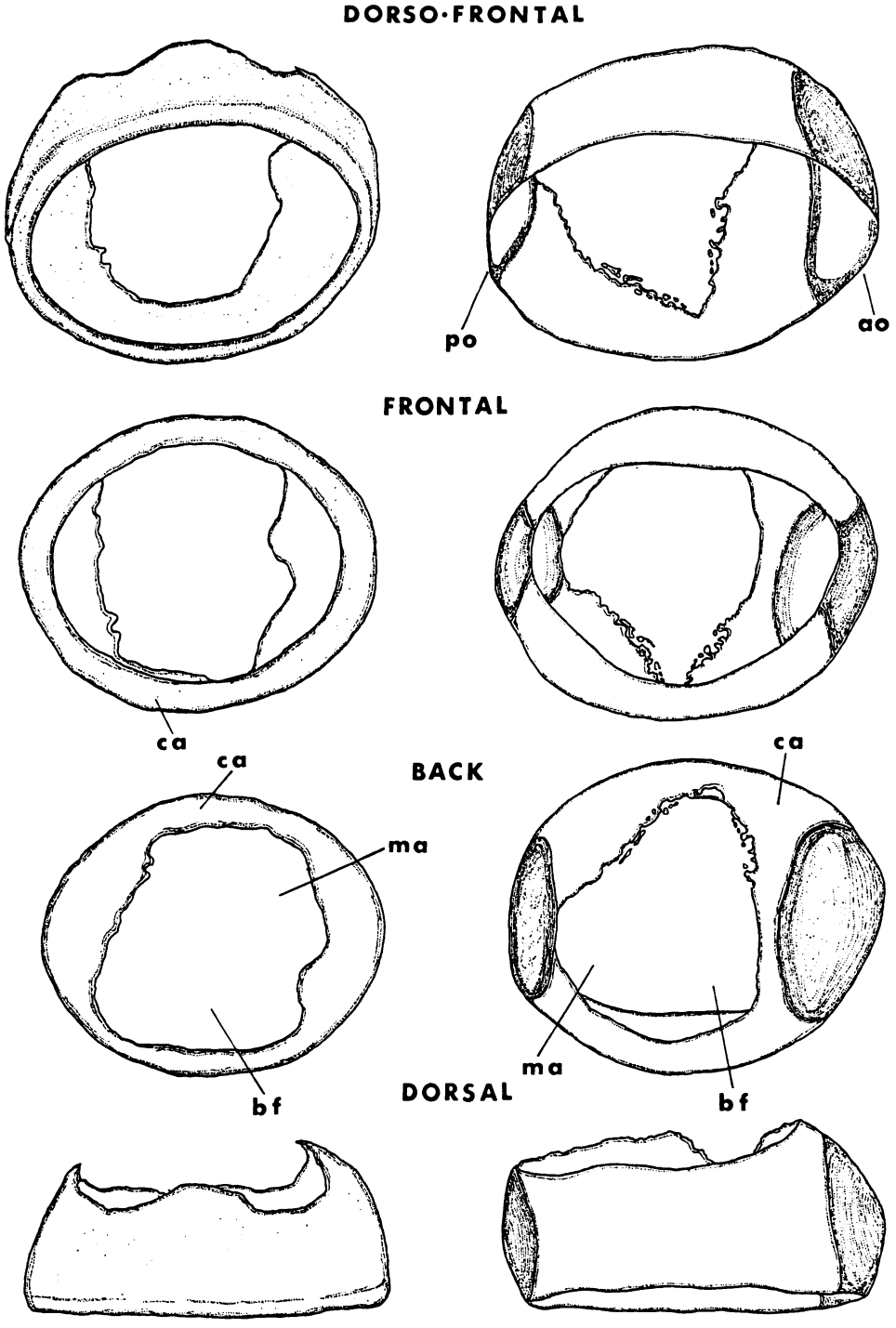


Taius tumifrons Plate IX *Makaira mitsukurii*

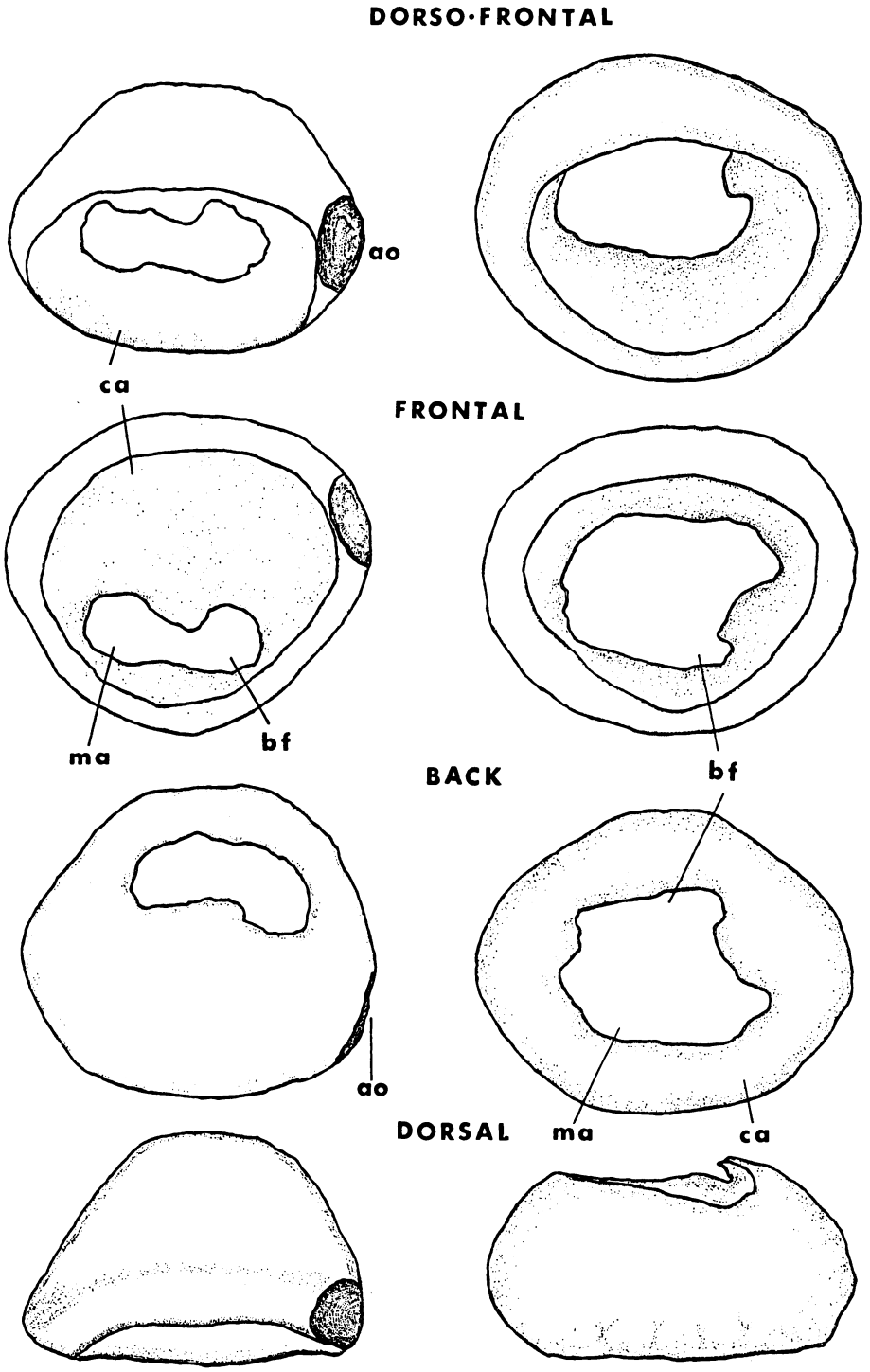


Pneumatophorus japonicus *Thunnus thynnus orientalis*

Plate X



Trichiurus lepturus Plate XI *Sebastiscus marmoratus*



Limanda herzensteini Plate XII *Fugu niphobles*