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Early Osteological Development of the Yellow Tail *Seriola dumerili* (Pisces: Carangidae)

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Chen-Hsiang Liu (2001) Early osteological development of the yellow tail *Seriola dumerili* (Pisces: Carangidae). *Zoological Studies* **40**(4): 289-298. The osteological development of *Seriola dumerili* was studied in a series of 15 cleared-and-stained specimens (6.6-32 mm). The dorsal spine began to ossify by 12.7 mm, and its soft rays by 27.2 mm, and all elements (VII-I, 32) were completed by 23.5 mm. Ossification of dorsal pterygiophores occurred initially by 15.9 mm. Anal fin ray formation (II-I, 20) was completed by 12.7 mm, and soft rays began to ossify at 24.5 mm. Ossification of the anal pterygiophores occurred initially by 15.9 mm. The cartilaginous caudal complex appeared by 6.6 mm NL, and its ossification was completed by 27.2 mm. The fusing of the 1st and 2nd, and the 3rd and 4th hypurals occurred by 8.1 mm. The pectoral girdle contained 5 dermal bones which ossified by 6.6 mm NL, and 3 cartilage replacement bones which ossified by 27.2 mm. The hyoid arch contained 2 dermal bones, six cartilage replacement bones, and 7 branchiostegals (dermal bone) which began to ossify by 15.9 mm. Ossification of the neural and haemal spines was completed by 23.5 mm. Notochord flexion occurred and formed an individual centrum by 6.6 mm NL, and all 24 centra had completely ossified by 12.7 mm. It was previously believed that the hypural complex fusing at a small size at 16.8 mm was an advanced condition. There were 2 plesiomorphic characters, i.e., three predorsals of the back and 3 epurals of the caudal complex, found in *S. dumerili*. In addition, there were also 2 apomorphic characters, i.e., a stay on the proximal radial and a double fin-ray on the last distal radial of the 2nd dorsal and anal fins, found in *S. dumerili*. http://www.sinica.edu.tw/zool/zoolstud/40.4/289.pdf

Key words: Osteological development, *Seriola dumerili*, Dermal bone.

The carangid yellow tail, *Seriola dumerili* (Risso, 1810) is distributed in tropical and subtropical waters worldwide, except in the eastern Pacific Ocean (Laroche et al. 1984). The yellow tail is an important commercial fish in Taiwan. Their juveniles aggregate under floating objects and were caught by a small seine net for an environmental survey (Liu 1985). Its early life history has been studied by many authors (e.g., Hildebrand and Cable 1930, Sanzo 1933, Padoa 1956, Johnson 1978, Okiyama 1988). However, little is known about its early osteological development. Recent papers dealing with development of morphometrics and osteology in the early stages of percoid fishes have been increasing (see Potthoff 1974 1975 1980, Potthoff et al. 1984 1988, Matsuoka 1982 1985, Watson and Walker 1992, Kelley 1995, Faustino and Power 1999), and are providing basic knowledge for larval taxonomy and systematics from such families as the Sparidae, Haemulidae, Lutjanidae, Pomacanthidae, and Coryphaenidae, but not the Carangidae.

The purpose of this study was to describe the osteological development of the jaws, suspensorium, hyoid arch, opercular series, branchial arch, fins, pterygiophore, neurocranium, and vertebral column in *S. dumerili*. In addition, ossified structures in all the above skeletal components were classified according to their origin, as being either dermal or cartilage replacement bone (Faustino and Power 1999). This study will form the basis of future experimental work aimed at comparing with other families in the suborder Percoidei.

MATERIALS AND METHODS

Fifteen specimens (6.6-32 mm) examined in the present study were collected by use of larval and small seine nets in the coastal waters of Taiwan from 1984 to 1988. These materials are deposited at

Fisheries Research Institute (TFRI), Council of Agriculture. They were observed, and photographed were under a light microscope, while others were fixed in buffered 10% formalin. Later they were stained (Taylor and Van Dijk 1985) for osteological observation. Only cleared-and-stained specimens were used for body length measurements. Each measurement consisted of the notochord length (NL, from the anterior tip of the snout to the posteriormost

Table 1. Developmental sequence of skeletal and bony structures in *Seriola dumerili* (6.6 mm NL to 32 mm SL)

Structure	Length (mm) 6 15 24 33	Bone type C or D
1. Jaws		
Premaxilla		D
Maxilla		D
Supramaxilla		D
Meckel's cartilage		C
Dentary		D
Retroarticular		C
Angular		D
2. Suspensorium		
Palatine		C
Ectopterygoid		D
Endopterygoid		D
Metapterygoid		C
Quadrate		C
Symplectic		C
Hyomandibular		C
3. Hyoid arch		
Urohyal		D
Interhyal		C
Epihyal		C
Ceratohyal		C
Dorsal hypohyal		C
Ventral hypohyal		C
Basihyal		C
Branchiostegal ray		D
4. Opercular series		
Opercle		D
Preopercle		D
Interopercle		D
Subopercle		D
5. Bracnchial arch		
Upper pharyngeal teeth		C
Lower pharyngeal teeth		C
Pharyngobranchial 2-3		C
Pharyngobranchial 4		C
Suspensory pharyngeal		C
Lower pharyngeal		C
Gill raker		C
Hypobranchials 1-3		C
Epibranchials 1-4		C
Ceratobranchials 1-4		C
Basibranchials 1-3		C
6. Pectoral fin and girdle		
Cleithrum		D
Scapula		C
Coracoid		C
Proximal radials 1-4		C
Distal radials		C
Propterygium		C
Upper supratemporal		D
Lower supratemporal		D
Posttemporal		D
Supracleithrum		D
Post cleithrum 1 (upper)		D
Post cleithrum 2 (lower)		D
Rays		D
7. Pelvic fin and girdle		
Basipterygium		C
Spine		D
Rays		D
8. Anal fin and pterygiophore		
Proximal radials		C
Distal radials		C
Stay		C
Spines		D
Rays		D
9. Dorsal fin and pterygiophore		
Proximal radials		C
Predorsals		C
Distal radials		C
Stay		C
Spines		D
Rays		D
10. Caudal fin and complex		
Parhypural		C
Preural centra 2-4		D
Urostyle		D
Uroneurals 1-2		D
Epurals 1-3		C
Hypurapophysis		C
Hypurals 1-4		C
Hypural 5		C
Neural spine (PU_2)		C
Neural spine (PU_3)		C
Haemal spine (PU_2)		C
Haemal spine (PU_3)		C
Distal cartilage		C
Radial cartilage (dorsal)		C
Radial cartilage (ventral)		C
Specialized neural arch (PU_2)		C
Rays		D
11. Neurocranium		
Nasal		D
Ethmoid		C
Lateral ethmoid		C
Vomer		D
Frontal		D
Parasphenoid		D
Sclerotic		C
Infraorbitals 2-4		D
Lachrymal		D
Parietal		D
Sphenotic		C
Pterotic		C
Epiotic		C
Preotic		C
Supraoccipital		C
Exoccipital		C
Basioccipital		C
12. Vertebral column		
Neural arches and spine		C
Haemal arches and spine		C
Centra		D
Pleural ribs		C

C: Cartilage replacement bone D: Dermal bone
○: Cartilaginous △: Ossifying □: Ossification completed

tip of the notochord) for preflexion and early flexion larvae or standard length (SL, from the anterior tip of the snout to the posteriormost edge of the hypural bones) for late flexion and postflexion larvae. The terms preflexion, flexion, and postflexion (Ahlstrom et al. 1976) are used to describe the larval stages.

All specimens were examined and photographed under a dissecting microscope. Cartilage was determined by the presence of blue staining. The central urostyles of older fish stained light blue by alcian blue, and an observer may consider them to be cartilage. However, according to Kohno et al. (1983), alcian blue stain indicates both uncalcified bone or bone in early-stage larvae. Alcian blue is specific for mucopolysaccharides (Dingerkus and Uhler 1977), leaving bones stained light blue. The origin of ossified tissue in fish is complex but can be subdivided into 2 principal types, intramembranous (achondral) which occurs with the absence of a cartilage matrix and gives rise to dermal bone (Cormack 1984, Junqueira et al. 1995), and cartilage replacement bone in which an earlier matrix of cartilage is progressively substituted by bone.

Meristic counts include the numbers of fin rays, teeth, spines, and gill rakers (Table 2). Terminology for the neurocranium and caudal complex follows Gosline (1961a b), Nybelin (1963), and Monod (1968). Body length is presented as standard length in millimeters (mm) if not otherwise specified.

RESULTS

Osteological development (Table 1)

Jaws (Fig. 1a)

The premaxilla, maxilla, and all dermal bone, began to ossify by 6.6 mm NL, and their ossification was completed by 16.1 mm. The supramaxilla (dermal bone) began to ossify by 12.6 mm, and its ossification was completed by 21.8 mm. Meckel's cartilage was fully developed by 6.6 mm NL, and framed the lower jaw. The dentary (dermal bone) bagan to ossify by 6.6 mm NL, and its ossification was completed by 15.9 mm. The angular (dermal bone) and cartilaginous retroarticular began to ossify by 6.6 mm NL, and its ossification was completed by 15.9 mm. The premaxilla (upper jaw) and dentary (lower jaw) had 9 and 8 teeth, respectively, by 6.6 mm NL, and the numbers of teeth on the jaws gradually increased with growth (Table 2).

Suspensorium (Fig. 1a)

The cartilaginous palatine began to ossify by 6.6

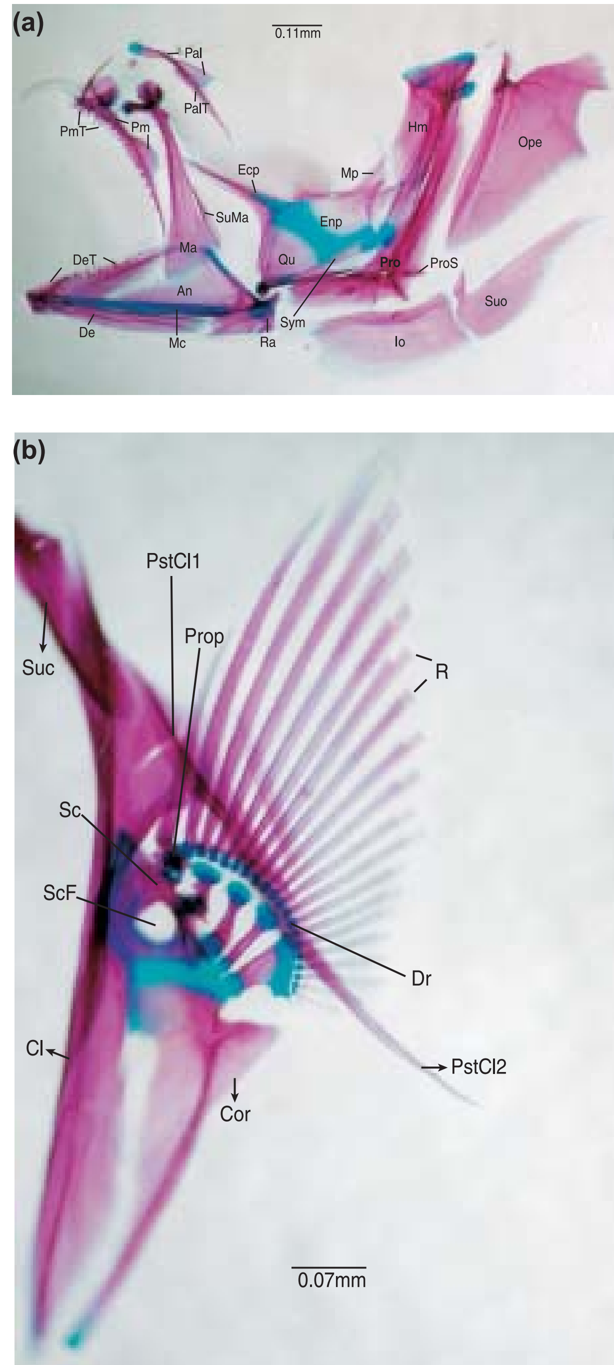

Fig. 1. Osteological features of (a) upper and lower jaws, suspensorium, opercular series and (b) pectroral girdle of *Seriola dumerili* at 27.2 mm SL. An, angular; Cl, cleithrum; Cor, coracoid; De, dentary; DeT, dentary teeth; Dr, distal radial; Ecp, ectopterygoid; Enp, endopterygoid; Hm, hyomandibular; Io, interopercle; Ma, maxilla; Mc, Meckel's cartilage; Mp, metapterygoid; Ope, opercle; Pal, palatine; PalT, palatine teeth; Pm, premaxilla; PmT, premaxilla teeth; Pr, proximal radial; Pro, preopercle; Prop, propterygium; Pros, preopercle spine; PstCl1, postcleithrum 1; PstCl2, postcleithrum 2; Qu, quadrate; R, ray; Ra, retroarticular; Sc, scapula; ScF, scapula foramen; Suc, supracleithrum; Suo, subopercle; SuMa, supramaxilla; Sym, symplectic.

mm NL, and its ossification was completed by 21.8 mm. The 7 palatine teeth were present by 21.8 mm, and increased in number with growth. The ectopterygoid (dermal bone) began to ossify by 8.1 mm, and its ossification was completed by 21.8 mm. The endopterygoid (dermal bone) began to ossify by 12.6 mm, and its ossification was completed by 27.8 mm. The cartilaginous metapterygoid began to ossify by 27.8 mm, and its ossification was still incompleted by 32 mm. The cartilaginous quadrate began to ossify by 27.8 mm, and its ossification was still incompleted by 32 mm. The cartilaginous symplectic began to ossify by 21.8 mm, and its ossification was completed by 27.8 mm. The cartilaginous hyomandibular began to ossify by 12.6 mm, and its ossification was completed by 21.8 mm.

Hyoid arch (Fig. 2a)

The urohyal (dermal bone) had formed as a thin rod by 12.7 mm, and its ossification was completed by 31 mm. The cartilaginous interhyal was presented by 6.6 mm NL, and began to ossify by 16.1 mm. The cartilaginous epihyal was presented by 6.6 mm NL, and began to ossify by 16.1 mm. The cartilaginous ceratohyal began to ossify by 16.1 mm, and its ossification was completed by 21.8 mm. A big foramen (= berciform foramen) of the ceratohyal gradually extended with growth. The cartilaginous dorsal hypohyal was presented by 6.6 mm NL, and began to ossify by 16.1 mm. A small foramen of the dosal hypophyal gradually extended with growth. The cartilaginous ventral hypohyal began to ossify by 16.1 mm, and its ossification was completed by 21.8 mm. The cartilaginous basihyal was presented by 6.6 mm NL, and began to ossify by 16.1 mm. The full complement of 7 branchiostegal rays (dermal bone) were presented by 6.6 mm NL, and their ossification was completed by 8.1 mm.

Opercular series (Fig. 1a)

All elements of the opercular apparatus were formed as dermal bone. The opercle began to ossify by 6.6 mm NL, and its ossification was completed by 16.1 mm. Ossification of the preopercle was completed by 6.6 mm NL. The interopercle and subopercle began to ossify by 12.6 mm, and their ossification was completed by 21.8 mm.

Branchial arch (Fig. 2b)

The 3 pairs of cartilaginous hypobranchials, the 4 pairs of cartilaginous epibranchial, the 4 pairs of cartilaginous ceratabranchial, and the 3 isolated pieces of cartilage of the basibranchial began to ossify by 21.8 mm. The 3 pairs of cartilage of the 2nd, 3rd, and 4th pharygobranchials began to ossify by 8.1 mm, and their ossification was completed by 12.6 mm. The upper pharyngeal teeth (with 4 counts) began to ossify by 6.6 mm NL, and 23 pharyngeal teeth had completely ossified by 12.7 mm. The lower pharyngeal teeth (with 5 counts) began to ossify by 6.6 mm NL, and 18 pharyngeal teeth had completely ossified by 12.7 mm. One pair of cartilages of the suspensory pharyngeal (= 1st pharyngobranchial) began to ossify by 8.1 mm, and its ossification was completed by 12.7 mm. One pair of cartilages of the lower pharyngeal began to ossify by 8.1 mm, and ossification was completed by 12.7 mm. The cartilaginous gill rakers (with 3+13 counts) began to ossify by 6.6 mm NL, and their (with 4+13 counts) ossification was complete by 8.1 mm.

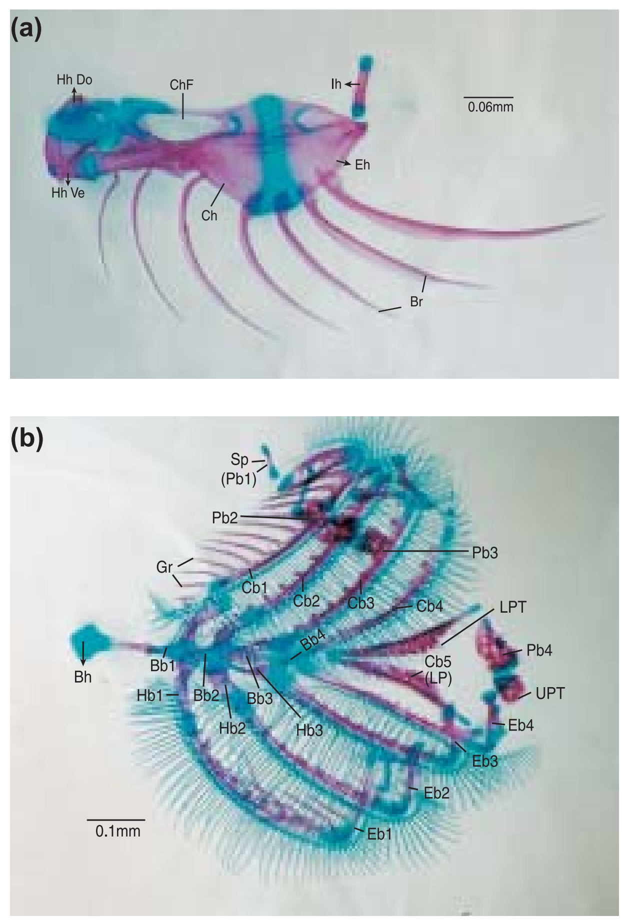

Fig. 2. Osteological features of (a) hyoid and (b) branchial arches of *Seriola dumerili* at 27.2 mm SL. Bb1-4, basibranchials 1-4; Bh, basihyal; Br, branchiostegal ray; Cb1-5, ceratobranchials 1-5; Ch, ceratohyal; ChF, beryciform foramen; Eh, epihyal; Eb1-4, epibranchials 1-4; Gr, gill raker; HbDo, hypohyal (dorsal); HhVe, hypohyal (ventral); Ih, interhyal; Lp, lower pharyngeal; LPT, lower pharyngeal teeth; Pb1-4, pharyngobranchials 1-4; Sp, suspensory pharyngeal; UPT, upper pharyngeal teeth.

Table 2. Meristic characters of *Seriola dumerili* (6.6 mm NL to 32 mm SL)

Item \ Length (mm)	6.6	8.1	12.6	12.7	15.9	16.1	16.8	21.8
1. Dorsal fin rays	VII-I, 26	VII-I, 28	VII-I, 28	VII-I, 28	VII-I, 29	VII-I, 28	VII-I, 28	VII-I, 31
2. Anal fin rays	17	II-I, 16	II-I, 19	II-I, 20	II-I, 20	II-I, 20	II-I, 20	II-I, 20
3. Pectoral fin rays	18	18	18	18	20	20	20	20
4. Pelvic fin rays	5	I, 5	I, 5	I, 5	I, 5	I, 5	I, 5	I, 5
5. Caudal fin rays								
2ndary (upper)	8	9	9	9	11	12	11	12
Principal (upper/lower)	9/8	9/7	9/9	9/9	9/10	10/8	9/8	9/7
2ndary (lower)	7	7	8	8	9	10	10	12
6. Centra	24	24	24	24	24	24	24	24
7. Gill rakers	3+13	4+13	5+15	5+13	6+13	6+13	6+13	7+14
8. Teeth (upper jaw)	9	10	28	21	30	27	27	30
9. Teeth (lower jaw)	8	6	17	15	16	19	18	22
10. Pharyngeal teeth (upper)	4	18	25	23	24	21	23	16
11. Pharyngeal teeth (lower)	5	10	17	18	25	17	20	20
12. Preopercular spines	6	5	7	7	6	7	6	5
13. Palatine teeth	–	–	–	–	–	–	–	7
14. Vomer teeth	–	–	6	8	10	5	6	8
15. Branchiostegal rays	7	7	7	7	7	7	7	7

Item \ Length (mm)	22	23.5	24.5	27.2	31	31.5	32
1. Dorsal fin rays	VII-I, 31	VII-I, 32	VII-I, 32	VII-I, 32	VII-I, 31	VII-I, 32	VII-I, 32
2. Anal fin rays	II-I, 20	II-I, 20	II-I, 21	II-I, 20	II-I, 20	II-I, 20	II-I, 20
3. Pectoral fin rays	20	20	20	20	20	20	20
4. Pelvic fin rays	I, 5	I, 5	I, 5	I, 5	I, 5	I, 5	I, 5
5. Caudal fin rays							
2ndary (upper)	12	12	12	11	12	12	12
Principal (upper/lower)	9/9	9/9	9/7	9/9	9/7	9/7	9/7
2ndary (lower)	11	10	11	9	11	11	11
6. Centra	24	24	24	24	24	24	24
7. Gill rakers	7+13	7+14	6+15	7+14	7+14	6+12	6+19
8. Teeth (upper jaw)	31	35	37	50	45	50	32
9. Teeth (lower jaw)	25	27	30	30	38	50	36
10. Pharyngeal teeth (upper)	18	18	17	20	abound	abound	abound
11. Pharyngeal teeth (lower)	17	14	15	14	abound	abound	abound
12. Preopercular spines	5	5	5	5	3	2	4
13. Palatine teeth	8	7	10	10	17	21	18
14. Vomer teeth	6	7	8	7	10	12	13
15. Branchiostegal rays	7	7	7	7	7	7	7

A dash (–) indicates that teeth were not developed.

Pectoral fin and girdle (Fig. 1b)

The 18 ossifying pectoral fin rays were presented by 6.6 mm, and their ossification was completed by 8.1 mm; 20 fully completed rays were presented by 15.9 mm (Table 2). The needle-like cleithrum (dermal bone) had completely ossified by 6.6 mm NL. The cartilaginous coracoid began to ossify by 16.8 mm, and its ossification was completed by 27.2 mm. The 4 cartilaginous proximal radials began to ossify by 21.8 mm, and their ossification was completed by 27.2 mm. The cartilaginous distal radials and propterygium were still unossified by 32 mm. The 4 dermal bones, upper supratemporal, lower supratemporal, posttemporal, and supracleithrum had completely ossified by 6.6 mm NL. The upper and lower posttemporals (dermal bone) began to ossify by 6.6 mm NL, and their ossification was completed by 8.1 mm. The cartilaginous scapula, with a foramen, began to ossify by 15.9 mm, and its ossification was completed by 21.8 mm.

Pelvic fin and girdle

The rudimentary fin spine (Table 2) had formed and was ossified by 8.1 mm. The fully complete 5 rays were presented by 6.6 mm NL, and their ossification was completed by 8.1 mm. The cartilaginous basipterygium gradually elongated and began to ossify by 6.6 mm NL; ossification was completed by 8.1 mm.

Anal fin and pterygrophore (Fig. 3)

Anal fin spines and rays began to develop with completion of II-I, 20 by 12.7 mm (Table 2). The 2nd anal spine began 1st to ossify by 8.1 mm, and all 3

Table 3. Development of pterygiophore and vertebral column counts in *Seriola dumerili* (6.6 mm NL to 32 mm SL)

Item \ Length (mm)	6.6	8.1	12.6	12.7	15.9	16.1	16.8	21.8	22	23.5	24.5	27.2	31	31.5	32	Total
1. Neural arches and spines																
No. C	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	
No. O	17	21	22	22	22	22	22	22	22	22	22	22	22	22	22	22
2. Haemal arches and spines																
No. C	9	2	1	0	0	0	0	0	0	0	0	0	0	0	0	
No. O	13	20	21	22	22	22	22	22	22	22	22	22	22	22	22	22
3. Predorsals																
No. C	0	3	3	3	3	3	3	0	0	0	0	0	0	0	0	
No. O	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3
4. Dorsal fin																
No. proximal radials (C)	17	35	34	35	29	27	30	30	30	26	22	0	10	0	0	
No. proximal radials (O)	0	0	0	0	8	8	8	8	8	12	16	38	28	38	38	38
No. spines (C)	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	
No. spines (O)	0	4	8	8	8	8	8	8	8	8	8	8	8	8	8	8
No. rays (C)	27	29	28	28	29	27	28	31	32	23	0	0	0	0	0	
No. rays (O)	0	0	0	0	0	0	0	0	0	9	32	32	32	32	32	32
5. Anal fin																
No. proximal radials (C)	16	18	19	19	19	18	19	19	19	14	12	0	0	0	0	
No. proximal radials (O)	0	0	1	2	2	2	2	2	2	7	9	21	21	21	21	21
No. spines (C)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
No. spines (O)	0	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
No. rays (C)	17	16	19	20	20	20	20	20	20	14	0	0	0	0	0	
No. rays (O)	0	0	0	0	0	0	0	0	0	6	20	20	20	20	20	20
6. No. ossifying centra	19	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24

C: cartilaginous O: ossifying

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spines had completely ossified by 12.7 mm. The 20 rays began to ossify by 23.5 mm, and ossification was completed by 32 mm. It seemed that the 1st anal proximal radial resulted from the fusion of 2 pieces of cartilage, which supported the first 2 spines and began to ossify by 12.7 mm; however, the 21 proximal radials were still incompletely ossified by 32 mm (Table 3). The cartilaginous distal radials began to ossify by 12.7 mm, and their ossification was still incompleted by 32 mm. The stay was presented by 12.7 mm as a separate cartilage mass (Fig. 5c), but later fused with the anterior proximal radial by 16.8 mm (Fig. 5e); and a single posterior ray (Fig. 5d) moved forward, between 12.7 and 16.8 mm, thus forming a double fin-ray on the last distal radial (Fig. 5e) by 16.8 mm.

Dorsal fin and pterygiophore (Fig. 3)

Dorsal fin spines and rays began to develop with completion of VII-I, 32 by 23.5 mm (Table 2). The spines began to ossify by 8.1 mm, and their ossification was completed by 12.6 mm. The unossified dorsal fin spines appeared by 6.6 mm NL, and all spines had completely ossified by 12.7 mm. The rays began to ossify by 8.1 mm, and their ossification was completed by 23.5 mm. The 3 cartilaginous predorsals were presented by 8.1 mm, and began to ossify by 21.8 mm; however, they were still incompletely ossified by 32 mm. The 38 cartilaginous proximal radials began to ossify by 15.9 mm, and they were still incompletely ossified by 32 mm. The cartilaginous distal radials began to ossify by 12.7 mm, and they were still incompletely ossified by 32 mm. The stay was presented as a separate cartilage mass as the anal fin stay in the last distal radial by 12.7 mm, and it was still incompletely ossified by 32 mm. A double fin-ray was presented on the last distal radial by 12.7 mm.

Caudal fin and caudal complex (Fig. 4)

The principal caudal ray with a count of 9/8 and the rudimentary ray with counts of 8 (upper) and 7 (lower) were presented by 6.6 mm NL (Table 2). Maximum caudal fin ray counts were attained between 15.9 and 32 mm. The principal caudal rays were supported by the 1st to 5th hypurals and by the parhypural. The upper rudimentary rays were supported by bones articulating with 3 centra, (the 2nd to 3rd preural centrum and urostyle) and by radial cartilage. The lower rudimentary rays were supported by the haemal spine of the 2nd to 3rd preuralcentrum and by radial cartilage. The caudal fin rays (dermal bone) began to ossify by 6.6 mm NL, and their ossification was completed by 16.8 mm. The bony caudal complex consisting of the urostyle, the 2nd and 3rd preural centra, one neural spine, three epurals, and parhypural was presented by 6.6 mm NL (Fig. 5a). The urostyle (dermal bone) and 2nd and 3rd preural centra (dermal bone) were presented and began to ossify by 8.1 mm. The 1st and 2nd, and 3rd and 4th hypurals had fused by 8.1 mm (Fig. 5b); the cartilaginous 5th hypural was presented and had fused with the 4th hypural by 12.7 mm. The ossification of all 5 hypurals was completed by 27.2 mm. The 2 pairs of uroneurals (dermal bone) began to ossify by 6.6 mm NL, and their ossification was completed by 16.1 mm. The

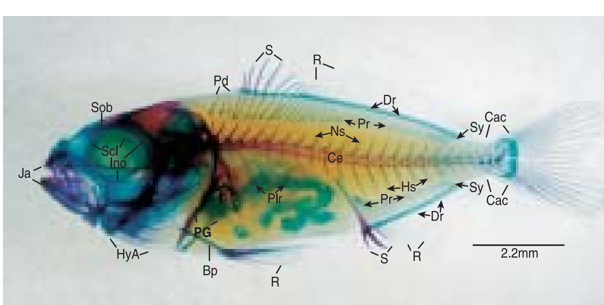

Fig. 3. Osteological features of a cleared-and-stained *Seriola dumerili* larva at 16.1 mm SL. Bp, basipterygium; Cac, caudal complex (see fig. 4); Ce, centrum; Dr, distal radial; Hs, haemal spine; HyA, hyoid arch (see fig. 2a); Ino, infraorbital; Ja, jaws (see fig. 1a); Ns, neural spine; Pd, predorsal; PG, pectoral girdle (see fig. 1b); Plr, pleural rib; Pr, proximal radial; R, ray; S, spine; Scl, sclerotic; Sob, supraorbital bone; Sy, stay.

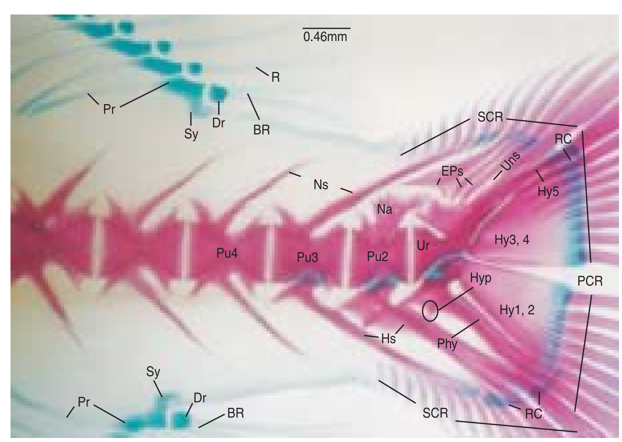

Fig. 4. Osteological features of fin-supports at 31 mm SL. BR, double fin-ray; Dr, distal radial; Eps, epurals; Hs, haemal spine; Hy1-5, hypurals 1-5; Hyp, hypuralpophysis; Na, specialized neural arch; Ns, neural spine; PCR, principal ray; Phy, parhypural; Pr, proximal radial; Pu2-4, preural centra 2-4; R, ray; RC, radial cartilage; SCR, rudimentary ray; Sy, stay; Uns, uroneurals; Ur, urostyle.

cartilaginous hypurapophysis began to ossify by 12.7 mm, and its ossification was completed by 16.1 mm. The cartilaginous neural spine and haemal spine of the 3rd preural centrum began to ossify by 12.7 mm, and their ossification was completed by 23.5 mm. The cartilaginous neural spine of the 2nd preural centrum began to ossify by 12.7 mm, and its ossification was completed by 16.8 mm. The cartilaginous haemal spine and specialized neural arch of the 2nd preural centrum began to ossify by 12.7 mm, and their ossification was completed by 21.7 mm. The distal cartilage was presented by 6.6 mm. The dorsal and ventral radial cartilages were presented by 12.7 mm.

Neurocranium and infraorbitals

The 7 cartilage replacement bones, i.e., the sphenotic, pterotic, epiotic, preotic, supraoccipital, exoccipital, and basioccipital began to ossify by 16.8 mm, and their ossification was completed by 21.8 mm. The nasal (dermal bone) and lachrymal (dermal bone) began to ossify by 12.7 mm, and their ossification was completed by 27.2 mm. The 2 cartilaginous ethmoids and lateral ethmoid began to ossify by 21.8 mm, and their ossification was completed by 27.2 mm. The frontal (dermal bone) began to ossify by 6.6 mm NL, and its ossification was completed by 21.8 mm. The parietal (dermal bone) began to ossify by 12.7 mm, and its ossification was completed by 21.8 mm. The 3 infraorbitals (dermal bone) began to ossify by 6.6 mm NL, and their ossification was completed by 21.8 mm. The para-sphenoid (dermal bone) began to ossify by 6.6 mm NL, and its ossification was still incompleted by 32 mm. The cartilaginous sclerotic began to ossify by 27.2 mm, and its ossification was still incompleted by 32 mm. The vomer (dermal bone) began to ossify by 6.6 mm NL, and its ossification was completed by 12.7 mm. The vomer had counts of 5-13 teeth between 15.9 and 32 mm.

Vertebral column (Fig. 3)

The 19 centra (dermal bone) began to ossify by 6.6 mm NL, and more centra gradually appeared in-

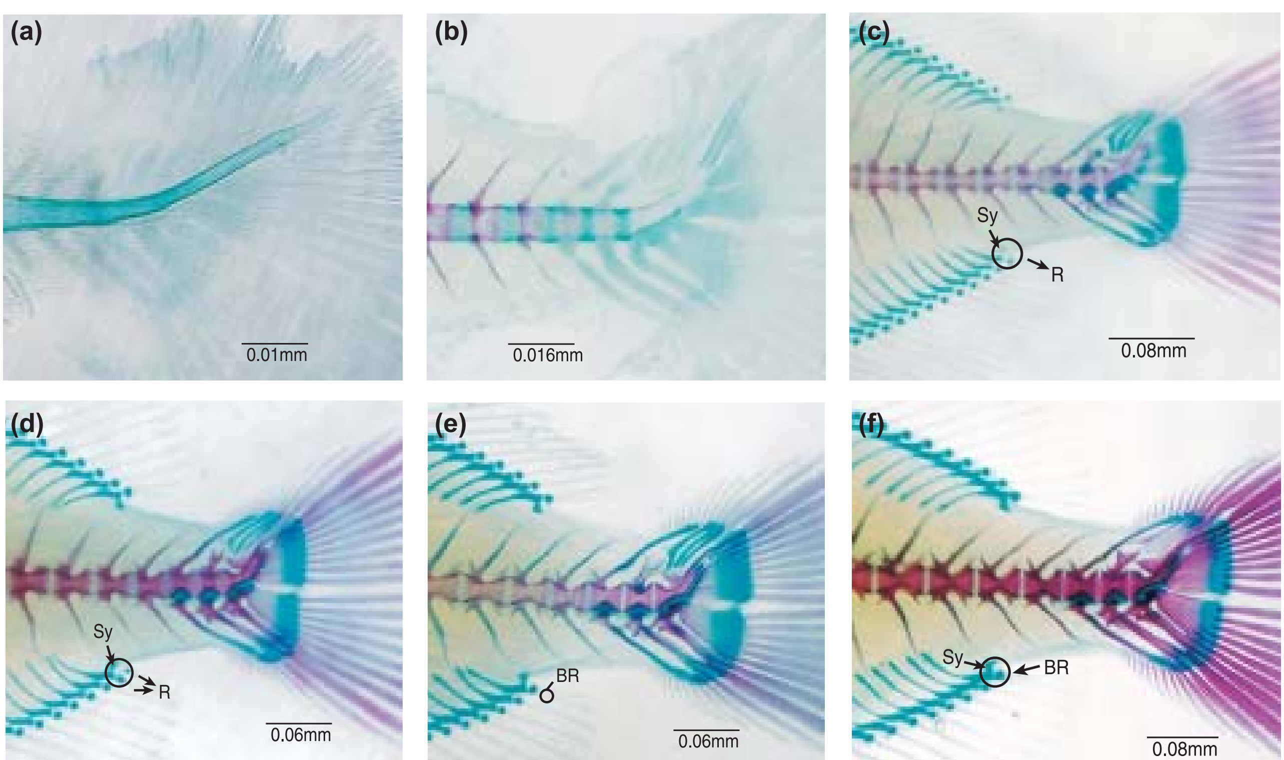

Fig. 5. Osteological development of caudal, dorsal, and anal fins-support in *Seriola dumerili*.
(a) Notochord flexion occurring at 6.6 mm NL. (b) The 1st and 2nd, and 3rd and 4th hypurals fused at 8.1 mm. (c) Stay as a separate cartilage mass at the posterior of the dorsal and anal fins at 12.7 mm. For symbols, see figure 4. (d) Stay fused with the anterior proximal radial and a single posterior ray on the last distal radial of the anal fin moved forward at 16.1 mm. For symbols, see figure 4. (e) Caudal complex beginning to ossify and a double fin-ray forming on the last radial of the anal fin at 16.8 mm. For symbols, see figure 4. (f) Ossification of the caudal complex complete at 21.7 mm. For symbols, see figure 4.

creasing to the full complement of 24 ossified centra by 12.7 mm. The cartilaginous neural arches and 17 spines began to ossify by 6.6 mm NL, and more spines appeared gradually, increasing in mumber to the full complement of 22 by 21.8 mm, at which time all 22 neural spines had completely ossified. The cartilaginous haemal arches and 13 haemal spines began to ossify by 6.6 mm NL, and more spines appeared gradually increasing to the full complement of 22 by 21.8 mm, at which time all 22 haemal spines had completely ossified. The 8 cartilaginous pleural ribs were presented by 12.7 mm, and began to ossify by 21.8 mm. There were no epipleural ribs in the early stage. Notochord flexion had occurred and individual centra had formed by 6.6 mm NL (Fig. 5a).

DISCUSSION

A fusion of the caudal skeleton of about 5 hypurals and the parhypural forms a cartilaginous plate in various stages among percoids. The cartilaginous hypural plates 1+2 and 3+4+5 were completely formed at the early stage of 8.1 mm in *Seriola dumerili* (Carangidae, Figs. 4, 5b). In contrast, such cartilaginous fusion occurred at later stages as found at 13 mm in *Lutjanus campechanus*, (Lutjanidae; Potthoff et al. 1988), 14.9 mm in *Anisotremus davidsonii* (Haemulidae; Watson and Walker 1992), 23 mm in *Pagrus major* (Sparidae; Matsuoka 1982), 31.6 mm in *Pomacanthus arcuatus* (Pomacanthidae; Kelley 1995), and 55.5 mm in *Coryphaena equiselis* (Coryphaenidae; Potthoff 1980). However, the cartilaginous parhypural fuses with the 1st cartilaginous hypural to form a cartilaginous plate from early stages in Pomacanthids, Coryphaenids, and Haemulids. However, there are several families in which these do not fuse at later stages even in adults as in carangids, lutjanids, and sparids. The fusion of the caudal skeleton occupies an important position in phylogenetic studies. It was previously believed that the advanced condition was when the hypurals fused to form a plate at an early stage. Gosline (1961b) emphasized the necessity of studying ontogenetic fusion of the caudal skeleton.

Our observations in *Seriola dumerili* suggest that the "stay" differs from the last pterygiophore, such that the anal stay is presented as a separate cartilage mass, but later fuses with the anterior proximal radial between 12.7 and 16.8 mm. The stay for the posteriormost dorsal and anal pterygiophores was considered to be a vestigial fin support. This view agrees with the opinions of Potthoff (1974) and Kohno et al. (1983) in respect to the opinion that the stay is a reduced proximal radial. Percoids, except coryphaenids, all have a stay, such as in carangids, lutjanids, haemulids, sparids, and pomacanthids. The loss of the stay in coryphaenids represents an advanced character (Potthoff 1980). When the stay is present, a single posterior anal ray moves forward to form a double fin-ray on the last distal radial between 12.7 and 16.8 mm in *Seriola dumerili*. Whereas, such a double fin-ray on the posteriormost dorsal and anal distal radials has been commonly found in such diverse fishes as carangids, lutjanids, scombrids, sparids, pomacanthids, and haemulids. The double fin-ray and the stay are 2 important apomorphic characters in *Seriola dumerili*.

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紅甘鰺仔稚魚之骨骼發育研究

劉振鄉

從 1984 年到 1988 年間，在臺灣沿岸海域的仔稚魚調查，於稚魚及扒網的漁獲物中，選用 15 尾紅甘鰺標本，以透明魚體和骨骼染色方式研究其仔稚魚骨骼發育情形：上下顎骨的發育較早也硬骨化較快，在 15.9-21.8 mm 時就已完成；懸垂骨則較緩，約在 21.8-27.2 mm 時完成硬骨化；屬於膜性硬骨的鰓蓋骨則早在 6.6 mm 時便完全硬骨化；鰓弧大都是軟骨性硬骨，所以硬骨化的情形最為緩慢，在 32 mm 時仍在硬骨化中；各鰭因運動需要，骨骼硬骨化的情形也較早，約在 8.1 mm 左右；脊柱及頭顱的硬骨化均在 21.8 mm 時就完成，第一、二塊及第三、四、五塊下尾軸骨在 16.8 mm 時就完全融合，屬進化型的特徵。本研究發現紅甘鰺具有兩個祖徵(plesiomorphy) 為三根背前棘 (predorsal) 和三根上尾軸骨 (epural)；以及兩個衍徵 (apomorphy) 為擔鰭骨突 (stay) 及分叉軟條 (double fin-ray)，它們都是類緣關係及進化過程的重要分類形質，本研究的模式更提供人工養殖魚類成長分析的精確方法。

關鍵詞：骨骼發育，紅甘鰺，膜性硬骨。

行政院農業委員會水產試驗所