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# Bone development of the skull, pectoral and pelvic fins in *Seriola rivoliana* (Valenciennes, 1833) larvae

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**Abstract** Skull, pectoral and pelvic fin bone structures in longfin yellowtail *Seriola rivoliana* were studied from 3.43 ± 0.15 to 16.20 ± 0.73 mm standard length (SL) specimens. The *S. rivoliana* skull started to mineralize with the appearance of the parasphenoid and maxillary by 3.43 ± 0.15 mm SL at the neurocranium and jaw regions, respectively. The first pectoral structure to mineralize was the cleithrum at 3.75 ± 0.14 mm SL shortly followed by the supracleithrum and posttemporal. The pelvic fin started by 6.16 ± 0.32 mm SL with the spine and continued with the soft rays and basipterygium. The present study determined the onset of the skull, pectoral and pelvic fin mineralization. These results might be used as a reference for future studies in *S. rivoliana* or related species.

**Keywords** Amberjack · Hatchery · Abnormalities · Osteology · Skeleton

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## Introduction

Longfin yellowtail, *Seriola rivoliana* (Valenciennes 1833) belong to the Carangidae family, the same family as *S. dumerili* (greater amberjack), *S. lalandi* (yellowtail king fish) and *S. quinqueradiata* (Japanese yellowtail). With a high commercial interest due to its fast growth rate (Roo et al. 2012; Mesa-Rodríguez et al. 2014) and worldwide distribution, *S. rivoliana* is one of the species proposed for marine aquaculture diversification. In fact, this species is already commercially produced in Hawaii (Sims and Key 2011) and has been under pilot-scale experimental production in the Canary Islands from 2010.

Nowadays, an increasing amount of literature is available for the *Seriola* genus, particularly in relation to the larval biology (Laroche et al. 1984; Sumida et al. 1985), reproduction (Marino et al. 1995a, b; Kozul et al. 2001; Mylonas et al. 2004; Jerez et al. 2006), culture systems (Papandroulakis et al. 2005; Roo et al. 2012; Cobcroft and Battaglene 2013), feeding requirements and nutrition (Garcia-Gomez 2000; Cobcroft et al. 2004; Tomas et al. 2005; Takakuwa et al. 2006; Papadakis et al. 2007; Hamasaki et al. 2009; Fernández-Palacios et al. 2015) as well as skeletal development and deformities (Kohno 1997; Liu 2001; Cobcroft et al. 2004; Laggis et al. 2010; Cobcroft and Battaglene 2013; Mesa-Rodríguez et al. 2014). However, limited information relating to *S. rivoliana* is available (Blacio et al. 2003; Blacio 2004; Laidley et al. 2004; Roo et al. 2012; Mesa-Rodríguez et al.

2014). In this regard, it is well known that for both commercially produced finfish and diversification candidates for aquaculture the regular ontogeny of the skeletal elements can be altered under aquaculture operations, causing skeletal deformities. Similarly to other *Seriola* species, skeletal anomalies constitute one of the most important bottlenecks during the hatchery phase (Cobcroft and Battaglene 2013). Moreover, the high incidence of deformed teleost fish farmed under intensive culture systems has been previously reported (Boglione et al. 2001, 2003; Gavaia et al. 2002; Hattori et al. 2003; Roo et al. 2010b).

Under these perspectives, skeletal studies are important sources of basic knowledge to characterize and understand the osteological development and mineralization process, which in turn would help to understand and prevent the appearance of skeletal abnormalities (Gavaia et al. 2002; Cobcroft et al. 2004, 2012; Boglione et al. 2009; Cobcroft and Battaglene 2013; Roo et al. 2005, 2009, 2010b; Izquierdo et al. 2010).

The present study aimed to determined the onset of mineralization in the skull, pectoral and pelvic fins of *S. rivoliana* larvae. These results serve as a reference for the staging of bone development in *S. rivoliana* or related species.

## Materials and methods

*Seriola rivoliana* eggs were obtained by induced spawning, using gonadotropin-releasing hormone analog [LHRHa, des-Gly10, (D-Ala6); Sigma-Aldrich, St. Louis, MO, USA] at a dose of 20 µg $kg^{-1}$ body weight, based on the reported dosage for longfin yellowtail (Roo et al. 2012). Larvae were reared in a mesocosm rearing system following the methodology described by Roo et al. (2012) (4.5 eggs $l^{-1}$ were stocked in two 40-$m^3$ tanks), kept under natural photoperiods and filtered natural sea water with 37 g $l^{-1}$ salinity and a temperature of 23.0 ± 0.9 °C. The green water technique was used by adding live phytoplankton (*Nannochloropsis* sp.) to maintain a concentration of 250,000 cells $ml^{-1}$ in the rearing tanks. From 2 to 25 days after hatching (dah) rotifers, *Brachionus* sp., L-strain enriched with DHA Protein Selco (INVE$^{TM}$), were added twice daily (08:00 and 14:00 h). *Artemia* feeding started at 15 dah, enriched with $A_1$ Easy Selco (INVE$^{TM}$). The weaning protocol included manual feeding (Genma Micro, Skretting$^{TM}$) from 20 to 25 dah and automatic feeding afterwards.

Larval growth was assessed by measuring the standard length (SL) of 25 larvae every 2 days using a profile projector (Nikon V-12A, NIKON$^{TM}$). Bone ossification was studied by fixing in buffered formalin from hatching to 33 dah. A total of 200 fixed larvae (3.43 ± 0.15–16.2 ± 0.73 mm SL) were cleared and stained with alizarin red (Vandewalle et al. 1998). Larvae were individually examined using a stereomicroscope. Drawings of the different developmental stages were made using the Adobe Photoshop CS3-10.0 (1990–2007 Adobe System Incorporated, USA) directly from digital photographs. Bone description followed previously described terminology (Cubbage and Mabee 1996). Lists of abbreviations used are detailed in Tables 1 and 2. The structural development sequence is illustrated in Table 4. Thus, the viscerocranial structures were grouped into different regions (Table 1) depending on their functionality (Matsuoka 1985; Collette and Gillis 1992; Cubbage and Mabee 1996; Suda 1996; Faustino and Power 2001). Also, meristic counts performed on *S. rivoliana* juveniles ($n = 10$; weight: 60–120 g) that were soft X-ray monitored (Mod. Senographer-DHR, General Electric, USA) were included (Table 3).

## Results

### Neurocranium

The development of the *S. rivoliana* neurocranium started with the mineralization of the parasphenoid (Ps), a large laterally compressed structure across the length of the skull by 3.75 ± 0.14 mm SL (Fig. 1a). This continued with the vomer (V), situated anterior to the Ps, the frontal (F) and exoccipital (Eoc) by 5.38 ± 0.11 mm SL (Fig. 1b). The nasal (N) and lateral ethmoid (Le) started to develop at the same time as the first otic region structures, with the sphenotic (Sph), supraoccipital (Soc), pterotic (Pto) and intercalar (Ic) by 5.76 ± 0.06 mm SL (Fig. 1c). At 8.78 ± 0.64 mm SL infraorbitals (Inf 2–4) started to develop. After 10.35 ± 0.86 mm SL (Fig. 1d), the otic, basicranial and orbital region structures were in the process of developing: parietal (Pa), epioccipital

**Table 1** Viscerocranial structures and their abbreviations

| Region | Skeletal elements | Abbreviations | Region | Skeletal elements | Abbreviations |
|---|---|---|---|---|---|
| Neurocranium | Basioccipital | Boc | Suspensorium | Ectopterygoid | Ect |
| | Basisphenoid | Bas | | Endopterygoid | En |
| | Ethmoid | E | | Hyomandibula | Hm |
| | Epioccipital | Eo | | Metapterygoid | Mpt |
| | Exoccipital | Eoc | | Palatine | P |
| | Frontal | F | | Palatine teeth | Plt |
| | Infraorbitals | Inf | | Quadrate | Q |
| | Intercalar | Ic | | Symplectic | Sy |
| | Lateral ethmoid | Le | Hyoid arch | Branchiostegals | Brs |
| | Nasal | N | | Ceratohyal | Ch |
| | Parasphenoid | Ps | | Epihyal | Eh |
| | Parietal | Pa | | Hypohyal | Hh |
| | Prootic | Pro | | Urohyal | Uh |
| | Pterotic | Pto | Branquial arches | Basibranchials | Bb |
| | Pterosphenoid | Pts | | Basihyal | Bh |
| | Sphenotic | Sph | | Ceratobranchials | Cb |
| | Supraoccipital | Soc | | Ceratobranchials teeth | Cbt |
| | Vomer | V | | Epibranchials | Eb |
| Jaws | Anguloarticular | Aa | | Hypobranchials | Hb |
| | Dentary | D | | Pharyngobranchials | Pb |
| | Dentary teeth | Dt | | Pharyngobranchials teeth | Pbt |
| | Maxilla | Mx | Opercular series | Interopercle | Iop |
| | Premaxilla | Pm | | Opercle | Op |
| | Premaxilla teeth | Pmt | | Preopercle | Pop |
| | Retroarticular | Ra | | Subopercle | Sop |

(Eo), intercalar (Ic), prootic (Pro) and infraorbitals (Inf 1–5); basioccipital (Boc); basisphenoid (Bas) and pterosphenoid (Pts), respectively. The ethmoid (E) was the last structure of the ethmoid region that started to develop (12.41 ± 0.43 mm SL, Fig. 1d).

## Jaws

The jaw structures differentiated in two regions, the upper maxilla (Mx) and premaxilla (Pm) and the lower jaw (dentary, D; anguloarticular, Aa; retroarticular, Ra). The first visible structure in *S. rivoliana* larvae was the Mx by 3.43 ± 0.15 mm SL (Fig. 2a) followed by the D and Pm (3.75 ± 0.14 mm SL; Fig. 2b), with the last structures to develop being the Aa and Ra by 4.60 ± 0.14 mm SL (Fig. 2c). At this time, small premaxillary teeth (Pmt) were first seen, whereas the dentary teeth (Dt) developed by 5.76 ± 0.04 mm SL (Fig. 2d).

## Suspensorium

The ossification of the suspensorium structures started with the symplectic (Sy), hyomandibula (Hm) and quadrate (Q) followed by the palatine (P), endopterygoid (En) and ectopterygoid (Ect) by 5.76 ± 0.06 mm SL (Fig. 2d). Finally, the metapterygoid (Mpt) and palatine teeth (Plt) began to develop by 10.35 ± 0.86 mm SL (Fig. 2e).

## Opercular series

The four structures that compound the opercular series are closely distributed. The preopercle (Pop) was the

**Table 2** Fins structures and their abbreviations

| Region | Skeletal elements | Abbreviations |
|---|---|---|
| Pectoral fin | Actinost | Act |
| | Cleithrum | Cl |
| | Coracoid | Co |
| | Distal radial | Dr |
| | Propterygium | Prop |
| | Postcleithrum lower | Pcl |
| | Postcleithrum upper | Pcu |
| | Posttemporal | Pt |
| | Soft rays | R |
| | Scapula | Sc |
| | Scapular foramen | F |
| | Supracleithrum | Scl |
| | Supratemporal lower | Stl |
| | Supratemporal upper | Stu |
| Pelvic fin | Basipterygium | Bp |
| | Soft rays | R |
| | Spine | S |

first structure of the opercular series to develop by 3.75 ± 0.14 mm SL (Fig. 2b). The opercle (Op), with a posterior situation, developed afterwards by 4.60 ± 0.14 mm SL (Fig. 2c). Ventrally located, the interopercle (Iop) appeared by 5.76 ± 0.06 mm SL (Fig. 2c) at the same time as the subopercle (Sop), located between the Op and Iop.

### Hyoid arch

At 3.75 ± 0.14 mm SL (Fig. 3a), three simultaneous pairs of branchiostegal rays (Bsr) started to develop in a caudal-rostral direction up to a total of seven Bsr pairs. The ceratohyal (Ch) expanded anteriorly and posteriorly from 4.60 ± 0.14 mm SL (Fig. 3b). Between the two Chs and with a ventrally situation the urohyal (Uh) started to ossify by 5.00 ± 0.15 mm SL (Fig. 3c). Finally, the hypohyals (Hh) and epihyal (Eh) ossified by 10.35 ± 0.86 mm SL (Fig. 3d).

### Branchial arches

This complex is composed by five pairs of ceratobranchials (Cb1-5), four pairs of epibranchials (Eb1-4) and pharyngobranchials (Pb1-4), three pairs of hypobranchials (Hb1-3), three basibranchials (Bb1-3) and the basihyal (Bh). The first structure of the branchial arches to develop by 3.75 ± 0.14 mm SL was a tiny pair of ceratobranchial teeth (Cbt) at the Cb5, first seen by 4.60 ± 0.14 mm SL. The Cbs followed a caudal-rostral development followed by the Cb4 and Cb3 at 5.00 ± 0.15 mm SL and Cb2 and Cb1 after by 5.38 ± 0.11 mm SL. At the size of 5.76 ± 0.06 mm SL, the upper branchial arches start to develop with the Eb4 and Eb3 first and Eb2 and Eb1 after by 6.16 ± 0.73 mm SL. Simultaneously to the Eb2 and Eb1, the largest Pb (Pb3), the first Hb (Hb3) and the Bb3 start to develop. Gill rakers become evident on the first Cb (Cb1-2) located at the anterior and posterior border of the structure and Cb3 and Cb4 after. Cb4s only present gill rakers at the anterior border. Bb2, Hb2, Hb1, Pb2 and Pb4 develop simultaneously by 7.17 ± 0.3 mm SL. The last structures of the branchial complex to develop were the Bb1, Pb1 and Bh at 10.35 ± 0.86 mm SL. At this stage, the pharyngobranchial teeth (Pbt) are well seen at the Pb's structure (Fig. 4).

### Pectoral fin supports

The first elements that start the ossification of the pectoral fin were the cleithrum (Cl) and supracleithrum (Scl) by 3.43 ± 0.15 mm SL and 4.60 ± 0.14 mm SL, respectively (Fig. 5a). Above the Cl, the Scl and postemporal (Pt) developed dorsally by 5.76 ± 0.06 mm SL (Fig. 5b). At this time, the ossification of soft rays (R) as well as the upper and lower postcleithrum (Pcu and Pcl) occurred. The coracoid (Co) and the scapula (Sc) ossified by 8.78 ± 0.64 mm SL (Fig. 5c), presenting a dorsal and ventral mineralization until they fused by 16.20 ± 0.73 mm SL (Fig. 5e). The first actinost (Act1) started to ossify by 10.35 ± 0.86 mm SL and expanded dorso-ventrally. The group of four Acts presented a gradual ventral development, commencing the mineralization of the third Act by 12.35 ± 0.98 mm SL (Fig. 5d). Finally, supratemporals (Stu and Stl), the fourth Act, the propterygium (Prop) and distal radials (Dr) were ossified by 16.20 ± 0.73 mm SL (Fig. 5e).

### Pelvic fin-supports

At 6.16 ± 0.73 mm SL (Fig. 6a1, 2), the spine (S) started to develop, with a caudal mineralization direction. This was followed by the soft rays (R) and

**Table 3** Meristic counts of *S. rivoliana*(S) single, (P) paired

| Region | Skeletal element | N. structures | Region | Skeletal element | N. structures |
|---|---|---|---|---|---|
| Neurocranium | Basioccipital | 1-S | Opercular series | Interopercle | 1-P |
| | Basisphenoid | 1-S | | Opercle | 1-P |
| | Ethmoid | 1-P | | Preopercle | 1-P |
| | Epioccipital | 1-P | | Subopercle | 1-P |
| | Exoccipital | 1-P | Hyoid arch | Branchiostegals | 7-P |
| | Frontal | 1-P | | Ceratohyal | 1-P |
| | Infraorbitals | 5-P | | Epihyal | 1-P |
| | Intercalar | 1-P | | Hypohyal | 1-P |
| | Lateral ethmoid | 1-P | | Urohyal | 1-S |
| | Nasal | 1-P | Pectoral fin | Actinost | 4-S |
| | Parasphenoid | 1-S | | Cleithrum | 1-S |
| | Parietal | 1-P | | Coracoid | 1-S |
| | Prootic | 1-P | | Distal radial | 19/21 |
| | Pterotic | 1-P | | Propterygium | 1-S |
| | Pterosphenoid | 1-P | | Postcleithrum lower | 1-S |
| | Sphenotic | 1-P | | Postcleithrum upper | 1-S |
| | Supraoccipital | 1-S | | Posttemporal | 1-S |
| | Vomer | 1-S | | Soft rays | 20/22 |
| Jaws | Anguloarticular | 1-P | | Scapula | 1-S |
| | Dentary | 1-P | | Supracleithrum | 1-S |
| | Maxilla | 1-P | | Supratemporal lower | 1-S |
| | Premaxilla | 1-P | | Supratemporal upper | 1-S |
| | Retroarticular | 1-P | Pelvic fin | Basipterygium | 1-P |
| Suspensorium | Ectopterygoid | 1-P | | Soft rays | 5-P |
| | Endopterygoid | 1-P | | Spine | 1-P |
| | Hyomandibular | 1-P | Branquial arches | Basibranchials | 3-S |
| | Metapterygoid | 1-P | | Basihyal | 1-S |
| | Palatine | 1-P | | Ceratobranchials | 5-P |
| | Quadrate | 1-P | | Epibranchials | 4-P |
| | Symplectic | 1-P | | Hypobranchials | 3-P |
| | | | | Pharyngobranchials | 4-P |

*S* single, *P* paired

the basipterygium (Bp) at 7.17 ± 0.3 mm SL (Fig. 6b1, 2). The soft rays developed toward the caudal fin, whereas the Bp mineralized rostrally and caudally (Fig. 6c1, 2). The Bp reached the Cl up to 11.77 ± 0.39 mm SL (Fig. 6d1, 2) when all the pelvic fin structures were developed.

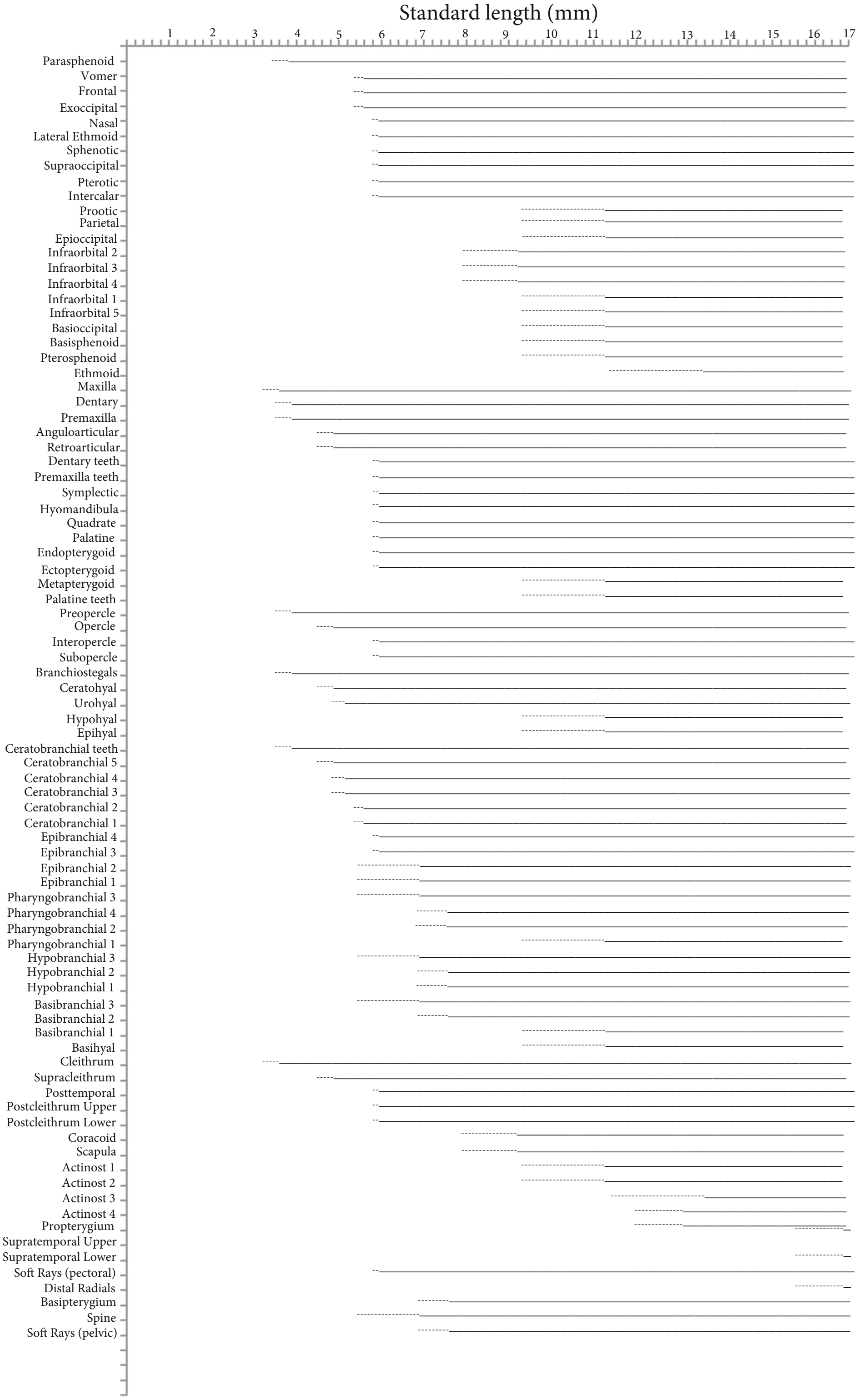
## Meristic characters

Meristically, major viscerocranial structures of *S. rivoliana* larvae were presented as one pair of each structure (1-P), with the exception of Boc, Bas, Ps, Soc, V and Uh, which were presented as a single structure (1-S), while seven pairs of Bsr (7-P) developed at the hyoid arch. In the pectoral and pelvic fins, a final count of 20/22 and 5 ossified soft rays were identified, respectively (Table 3).

## Discussion

Due to the wide variability between marine teleosts, determination of a common developmental pattern becomes complex. However, a similar skeletal

**Table 4** Structure sequence of *S. rivoliana*



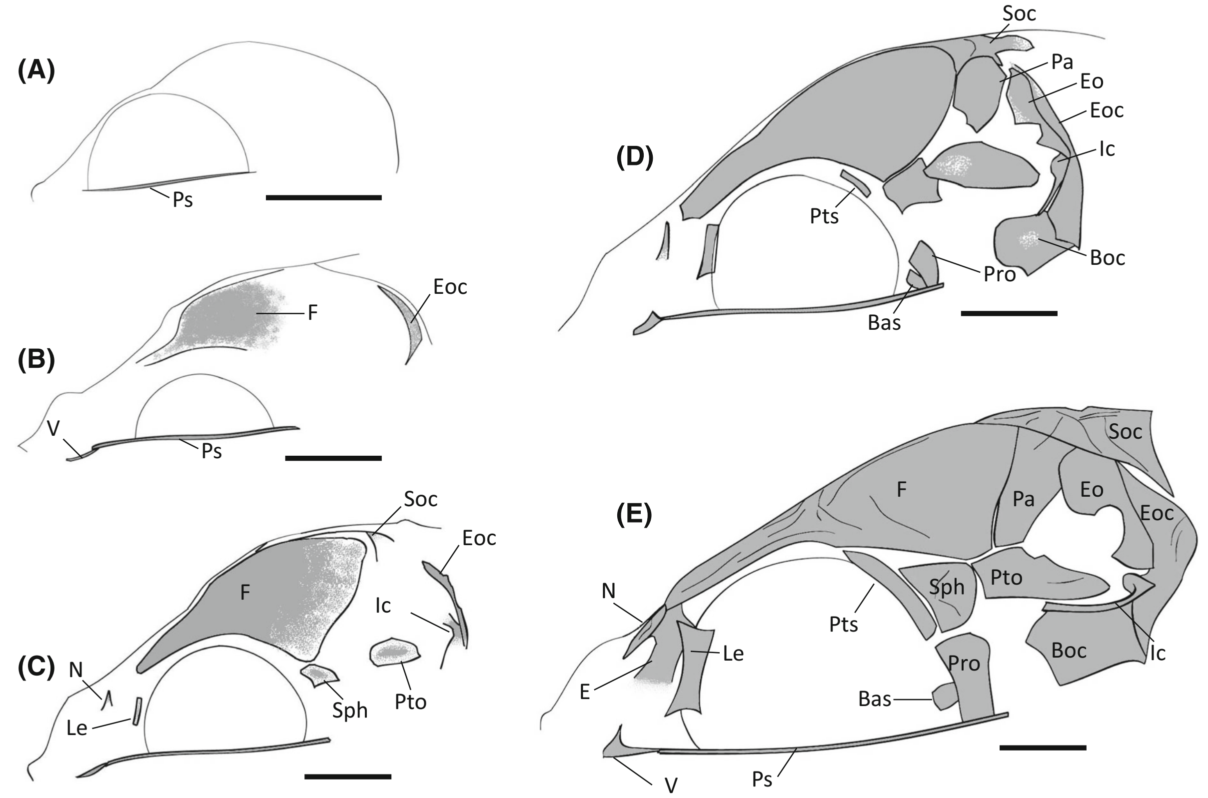


**Fig. 1** Neurocranium development (**a**–**e**) of *S. rivoliana* (painted areas, mineralized structures). *Boc* basioccipital, *Bas* basisphenoid, *Eo* epioccipital, *E* ethmoid, *Eoc* exoccipital, *F* frontal, *Ic* intercalar, *Le* lateral ethmoid, *N* nasal, *Ps* parasphenoid, *Pa* parietal, *Pro* prootic, *Pto* pterotic, *Pts* pterosphenoid, *Sph* sphenotic, *Soc* supraoccipital, *V* vomer

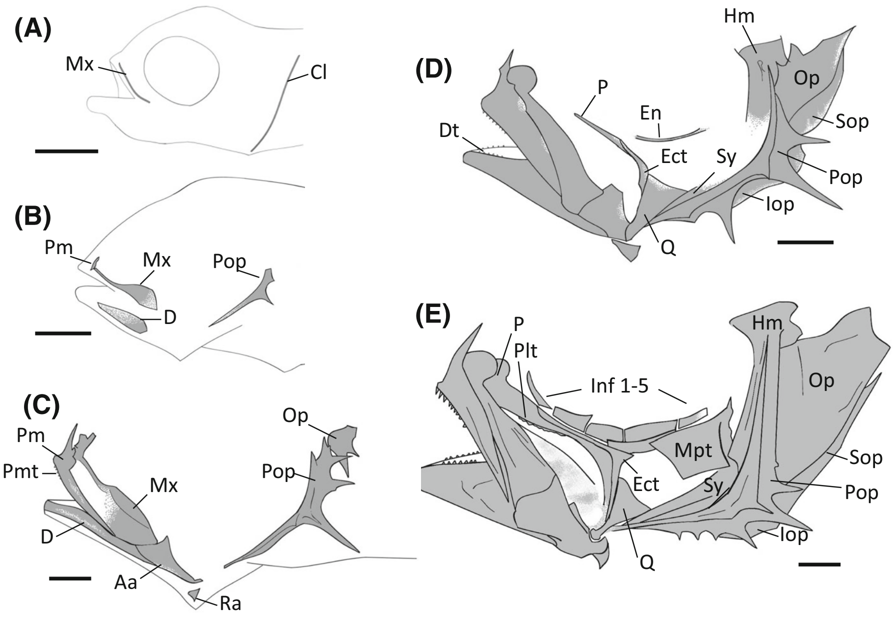


**Fig. 2** Jaws and opercular series development (**a**–**e**) of *S. rivoliana* (painted areas, mineralized structures). *Aa* anguloarticular, *D* dentary, *Dt* dentary teeth, *Ect* ectopterygoid, *En* endopterygoid, *Hm* hyomandibular, *Inf* infraorbitals, *Iop* interopercle, *Mpt* metapterygoid, *Mx* maxillary, *Op* opercle, *P* palatine, *Pm* premaxillary, *Pmt* premaxillary teeth, *Pop* preopercle, *Plt* palatine teeth, *Q* quadrate, *Ra* retroarticular, *Sop* subopercle, *Sy* sympletic

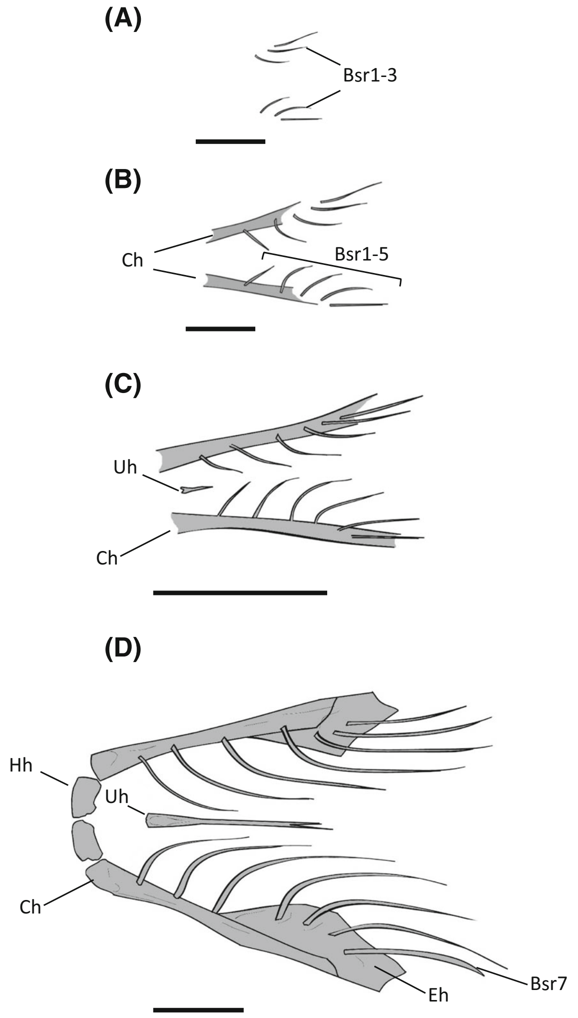


**Fig. 3** Hyoid arch development (**a–d**) of *S. rivoliana* (painted areas, mineralized structures). *Bsr* branchiostegals, *Ch* ceratohyal, *Eh* epihyal, *Hh* hypohyal, *Uh* urohyal

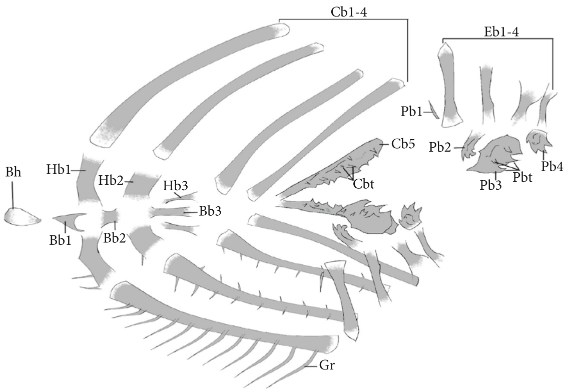


**Fig. 4** Branchial arches development of *S. rivoliana* (painted areas, mineralized structures). *Bb* basibranchial, *Bh* basihyal, *Cb* ceratobranchial, *Eb* epibranchial, *Hb* hypobranchial, *Pb* pharyngobranchial

development and mineralization in the neurocranium structures have been found in *S. rivoliana* in comparison with those reported in different species such as *Pagrus major* (Matsuoka 1985), *Spondyliosoma emarginatum* (Beckley 1989), *Dentex dentex* (Koumoundouros et al. 2000), *Sparus aurata* (Faustino and Power 2001), *Anisotremus davidsonii* and *Xenistius californiensis* (Watson and Walker Jr 1992). These findings could be related to the same functional requirements for larval survival at early life stages (Faustino and Power 2001). For example, the structures associated with the first feeding, including the jaws, neurocranium, suspensorium and gill arches are the first to develop in many different species (Roo et al. 1999), although the timing of mineralization may differ between species. Thus, some skeletal elements in the neurocranium structure (E, Bas and Pts) and suspensorium (Hm, Sy and Q) share a common developmental pattern with *P. major* (Matsuoka 1985), *A. davidsonii X. californiensis* (Watson and Walker Jr 1992), *D. dentex* (Koumoundouros et al. 2000) or *S. aurata* (Faustino and Power 2001). Furthermore, in addition to the previously mentioned species, jaw skeletal structures are also common in species such as *S. emarginatum* (Beckley 1989), *S. setapinnis* (Katsuragawa 1997), *Gadus morhua* and *Pseudopleuronectes americanus* (Hunt von Herbing 2001), *Solea solea* (Wagemans and Vandewalle 2001), *S. dumerili* (Liu 2001) and *Epinephelus septemfasciatus* (Nagano et al. 2007). The tiny variations observed in the ossification timing or sequence of jaw structure ossification may be a consequence of different functional requirements (Faustino and Power 2001), feeding habits or even ways of feeding.

Regarding the skeletal elements directly related with breathing action, such as the opercular series and the hyod arch development, these seem to be common in several marine finfish, identifying minor differences in the mineralization timing with species such as *P. major* (Matsuoka 1985), *A. davidsonii* (Watson and Walker Jr 1992) or *S. aurata* (Faustino and Power 2001). On the contrary, other cranial structures, such as the Soc crest, which is common in many carangid species (Katsuragawa 1997) such as (*Caranx crysos*, McKenney et al. (1958); *S lalandi, Chloroscombrus orqueta, Caranx caballus and Caranx sexfasciatus*

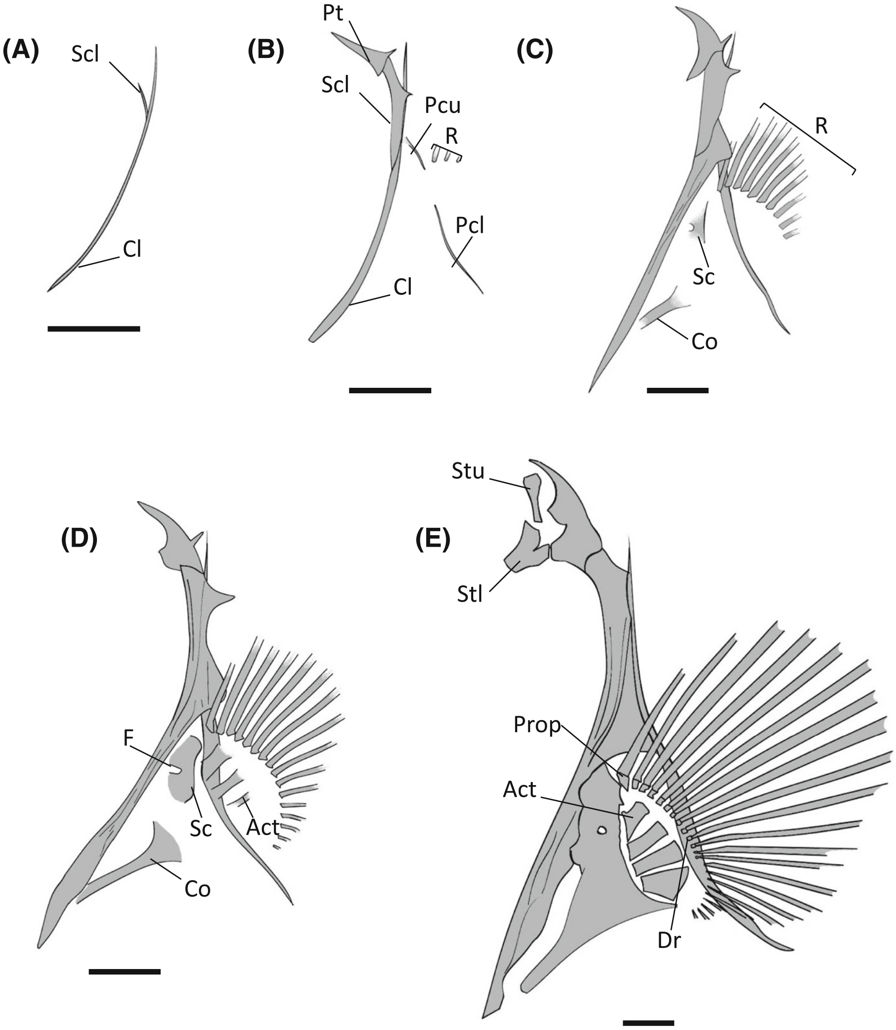


**Fig. 5** Pectoral fin development (**a**–**e**) of *S. rivoliana* (painted areas, mineralized structures). *Act* actinost, *Cl* cleithrum, *Co* coracoid, *Dr* distal radial, *F* scapular foramen, *Pcl* postcleithrum low, *Pcu* postcleithrum up, *Prop* propterygium, *R* soft rays, *Sc* scapula, *Scl* supracleithrum, *Stl* supratemporal lo, *Stu* supratemporal up

(Sumida et al. 1985); *Selene setapinnis*, Katsuragawa (1997) and *Hemicaranx amblyrhynchus* (Flores-Coto et al. 1998); and *Parastromateus niger* (Hilton et al. 2010), were not identified;they were also not identified in *S. rivoliana* (present study) or in similar species such as *S. dumerili* (Liu 2001). This type of skeletal element together with opercular spines has been identified as a protective structure (Morgan 1989) and might greatly differ between species particularly related to aspects such as the type of environment where the larvae grow (estuarine, open ocean) or predator pressure and the need for predator avoidance.

Concerning the ossification timing, even within the same species or genus many differences could be addressed. Thus, Liu (2001) described the start of the neurocranium development at 6.6 mm ($L_N$) with the mineralization of the F, Inf, Ps and V simultaneously in *S. dumerili*, whereas *S. rivoliana* (present study) began neurocranium mineralization by 3.75 ± 0.14 mm (SL) starting with Ps and followed by V, F and Exo at 5.38 ± 0.11 mm (SL). Besides, at 16.8 mm ($L_N$), the Sph, Pto, Eoc, Pro, Soc, Exo and Bo were the last structures to mineralize in *S. dumerili* (Liu 2001), whereas in *S. rivoliana* larvae the E was the last structure that started to develop by 12.41 ± 0.43 mm (SL). These developmental patterns and mineralization timing are clearly different between *S. dumerili* (Liu 2001) and *S. rivoliana*

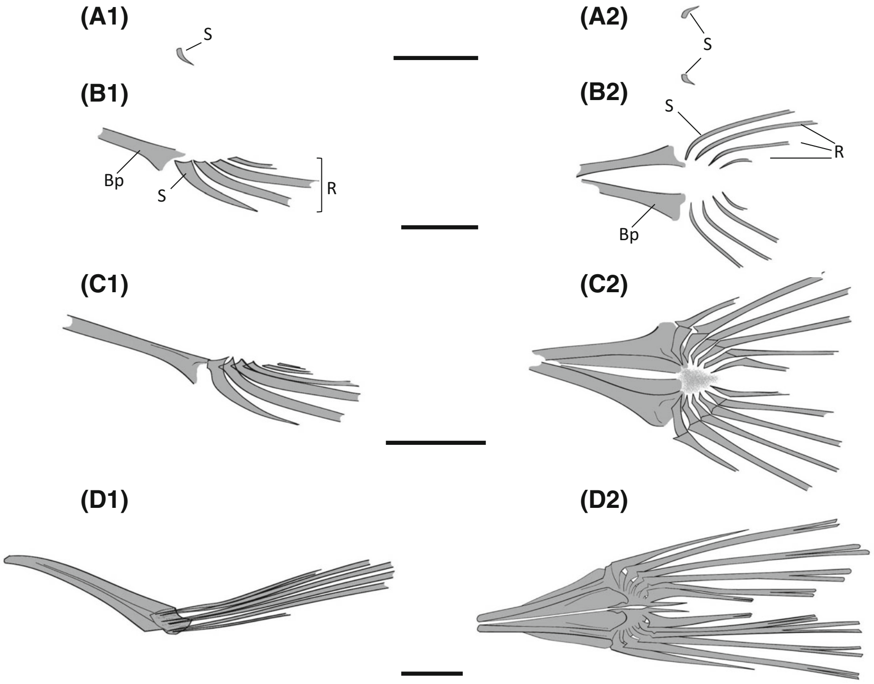


**Fig. 6** Pelvic fin development (**a**–**d**) of *S. rivoliana* (painted areas, mineralized structures). Ventral and lateral view. *Bp* basipterygium, *R* soft rays, *S* spine

(present study). In this regard, not only the species but also the environmental conditions (Boglione et al. 2009; Cobcroft et al. 2012) and zootechniques applied (Roo et al. 2010a, b) might delay or advanced the larval ontogeny, promoting differences in the larval stages of stained specimens that would explain these differences.

The ontogeny and mineralization of feeding and breathing structures should be combined with those skeletal elements involved in swimming activity, related to prey capture and escape abilities. Thus *S. rivoliana* larvae initiated the ossification of the dorsal and anal fin at 8.01 ± 0.26 mm SL (Mesa-Rodríguez et al. 2014) and were shortly followed by the pelvic fins at 8.60 ± 0.66 mm SL during the notocord post-flexion stage. This developmental pattern occurs after the mineralization of the main jaw and breathing structures between 3.75 ± 0.14 mm SL and 6.16 ± 0.73 mm SL, supporting the importance of feeding and breathing. Moreover, bones involved in main functions such as feeding and breathing have been conserved among many different Teleost (*Danio rerio*, Cubbage and Mabee 1996; *Betta splendens*, Mabee and Trendler 1996; *G. morhua* and *P. americanus*, Hunt von Herbing 2001; *S. solea*, Wagemans and Vandewalle 2001; *E. septemfasciatus*, Nagano et al. 2007). The onset of a similar ossification pattern in swimming structures such as the dorsal, anal and pelvic fins among *S. dumerili* (Laggis et al. 2010), *S. lalandi* (Sumida et al. 1985) and *S. rivoliana* (Mesa-Rodríguez et al. 2014) at the post-flexion stage suggests that this characteristic is common for the *Seriola* genus. Therefore, identification of the pre- and post-flexion stages is a useful external indicator of the initiation of internal column mineralization (Mesa-Rodríguez et al. 2014) and fins. This fact improves the larval swimming ability to capture prey and predator avoidance. In addition, notochord flexion is paired with the appearance of the first gastric glands and new photoreceptors in the eye (rods) providing a higher digestive capacity and improving visual acuity, respectively (Roo, personal communication), which is probably related to changes in feeding habits and environmental needs, as happens with other species (Roo et al. 1999).

Furthermore, notochord flexion was also an indicator to distinguish different genera from the carangid family during the formation of pelvic fin elements (Laroche et al. 1984; Ahlstrom and Sumida 1985). For example, the presence of single Scl and Pt spines in the pectoral fin support of *S. rivoliana* is in concordance with that found for *S. setapinnis*, *S. vommer* (Katsuragawa 1997) and *C. sexfasciatus* (Sumida et al. 1985), but differs from *Trachurus lathami*, *Decapterus punctatus*, *Chloroscombrus chrysurus* (Katsuragawa 1990), *C. caballus*, *C. orqueta* and *S. lalandi* (Sumida et al. 1985), in which the number of spines of each structure varies. According to the presence and number of spines, there is no tendency between carangid species. In this regard, obtention of meristic data of *S. rivoliana* is also relevant to identify deviation from the regular pattern under culture conditions. In fact, meristic counts are considered quality descriptors of reared juveniles (Boglione et al. 2001). Generally, cultured juveniles display a higher variability of meristic characters than natural populations. In this study, *S. rivoliana* were cultured under semi-intensive system conditions, a condition where juvenile finfish were previously reported to be more prone to present similar characteristics to wild juveniles (Roo et al. 2009). The meristic data obtained for *S. rivoliana* identified a number of seven paired Bsrs, similar to other carangid species such as *S. dumerili* (Liu 2010) and *P. niger* (Hilton et al. 2010) and in common with *A. davidsonii* and *X. californiensis* (Watson and Walker Jr 1992). Also, the numbers of spines in the pelvic fin ($I + 5$) and soft rays in the pectoral fin (20–23) are common in several carangids such as *S. setapinnis* (Katsuragawa 1997), *S. dumerili* (Liu 2001; Laggis et al. 2010), *P. niger* (Hilton et al. 2010), *S. lalandi* (Sánchez-Ramírez and Flores-Coto 1993), *S. rivoliana* (Castriota et al. 2004; present study), *Seriola fasciata* (Bañón and Mucientes 2009), *C. caballus* and *C. orqueta* and *C. sexfasciatus* (Sumida et al. 1985), whereas for many other marine finfish the soft rays from the number of pectoral fin varies from 14 to 22 (*S. emarginatum*, Beckley 1989; *A. davidsonii* and *X. californiensis*, Watson and Walker Jr 1992; *Dicentrarchus labrax*, Marino et al. 1993; *D. dentex*, Koumoundouros et al. 2000; *S. aurata*, Faustino and Power 1999; *D. sargus*, Koumoundouros et al. 2001; *P. erythrinus*, Sfakianakis et al. 2004). These results may indicate that the total number of 20–23 pectoral fin soft rays is characteristic for the carangid fish.

Results from the present study determined that the onset of structure ossification is directly related with the main functionalities of the different structures, suggesting that some developmental events during the mineralization process may be common for many different species. In addition, the first description of meristic data and mineralization timing for this species might be a useful practical guide for future studies in this field with the *Seriola* genus or related species.

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