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MORPHOLOGICAL ASPECTS OF THE VERTEBRAL COLUMN OF THE INDIAN MACKEREL *RASTRELLIGER KANAGURTA* (OSTEICHTHYES: SCOMBRIDAE) COLLECTED FROM THE SEA OF OMAN

SUMMARY

A morphometrical study on the vertebral axis of *Rastrelliger kanagurta* allows dividing its vertebral column into four morphologically distinct regions. This regionalization is more complex than the classical division in truncal and caudal parts only. The biometrical study of the length, height and width of the successive vertebrae allows characteristic-looking vertebral profiles to be drawn. The regionalization in the vertebral column of the species in question could be developed through the difference in length of vertebrae in different regions of the vertebral column. These morphological descriptive parameters express a morphotype that may be linked with the carangiform mode of swimming of the Indian mackerel.

INTRODUCTION

Rastrelliger kanagurta (the Indian Mackerel) is a fish of great commercial importance, which is widely distributed in the Indo-Pacific region. The study of the taxonomy and biology of the mackerel, including skeletal characteristics (Gnanamuttu, 1966; Soiamo *et al.*, 1988, Noble and Geetha, 1992) has received considerable attention in this region during recent years..

The vertebral column varies in degree of regionalization across vertebrates. Such differences in the morphology of vertebrae from different regions of the vertebral column can be revealed by biometrical studies (Kubo and Asano; 1987, 1990; Desse *et al.*, 1989). The vertebral column of actinopterygian fishes has two distinct regions: the pre-anal abdominal region and post-anal caudal region (Grande and Bemis, 1998). Although the actinopterygian vertebral column has two primary regions (i.e. abdominal and caudal), there is diversity in vertebral form within these regions (Ford, 1937; Pietsch, 1978; Grande and Bems, 1998; Bemis and Forey, 2001). The abdominal region may include, from anterior to posterior, occipital vertebrae that are incorporated into the skull through ontogeny, anterior vertebrae that are highly modified (e.g. Weberian apparatus in Ostariphysi and fused vertebrae in Syngnathoidei), and vertebrae that generally bear abdominal ribs. The caudal region includes vertebrae that bear haemal spines and ural vertebrae that bear hypurals. This regional pattern of vertebral structure is probably linked to, and could thus express, the locomotory functions of the vertebral column (Ramzu *et al.*, 1992).

The vertebral column plays a very important mechanical role in fish locomotion (Learn, 1976; Lindsey, 1978; Weifs, 1989). During the developmental stages, this structure is subjected to different types of biological strains which seem to be expressed by local and specific morphological peculiarities (Kubo and Asano, 1987, 1990; Desse *et al.*, 1989). The vertebral column has strong anatomical and functional relationships with the axial musculature (Le Danois, 1958; Lindsey, 1978; Vronskii and Nikolaitchouck, 1989).

Therefore the present work aims to study the biometry of the vertebral column of the Indian mackerel *Rastrelliger kanagurta* and contribute to other morpho-functional data available for teleost species.

MATERIAL AND METHODS

Fishes of *R. kanagurta* (59 specimens) ranging in length 270-301 mm TL were collected from the vicinity of Muscat City at the Sea of Oman in February 2010. To prepare the vertebral columns, fish specimens were boiled and flesh strip off the bone. Additional removal of tissue was done by brushing the vertebral column with soft teeth brush under running water. The columns were dried, and the vertebrae were separated and numbered then measured with a digital 1/100 caliper. Three vertebral variables were selected: the length of the vertebra (VL), which represents the distance along the left mid-ventral line, the anterior height (VH) corresponds to the maximum vertical distance of the anterior side of the vertebrae and width of vertebra (VW), which represents the maximum horizontal of the anterior side of the vertebrae. From these three measurements, it is possible to establish a vertebral profile which reflects the variation of these three variables along the vertebral axis (Desse *et al.*, 1989; Ramzu, 1994; Kacem *et al.*, 1998; Ramzu and Meunier, 1999). To avoid individual variation and to facilitate future comparisons with other samples, even other species, each vertebral measurement was converted into a vertebral index V_i (Ramzu and Meunier, 1999) is calculated separately for VL, VH and VW:

$$V_i = P/SL$$

Where, P is the vertebral parameter (VL, VH and VW) and SL the standard length. Profiles of the vertebral column were drawn by plotting LV, LH and LW against the ordinal number of the vertebrae. Statistical differences between mean values of the three vertebral variables were determined by Student's *t* test ($p < 0.05$).

Abdominal vertebrae were defined as those that were cranial to vertebrae with fused haemal arches. The caudal region was defined as the region from the first fused haemal arch posterior to the last centrum including the ural centrum. The mean vertebral aspect ratio (AR= centrum length/ centrum height) for each region was calculated for each individual. The means were then calculated for abdominal aspect ratio (AAR) and caudal aspect ratio (CAR).

RESULTS

There are 30 vertebrae in the vertebral column of *R. kanagurta*. The general appearance of each vertebra looks like a cylinder with each vertebra comprising an amphicoelous (hour-glass shape) centrum, whose chordal cavities connected by a thin hole. Outside these chordal cavities, no bony deposit masks this structure (Fig. 1).

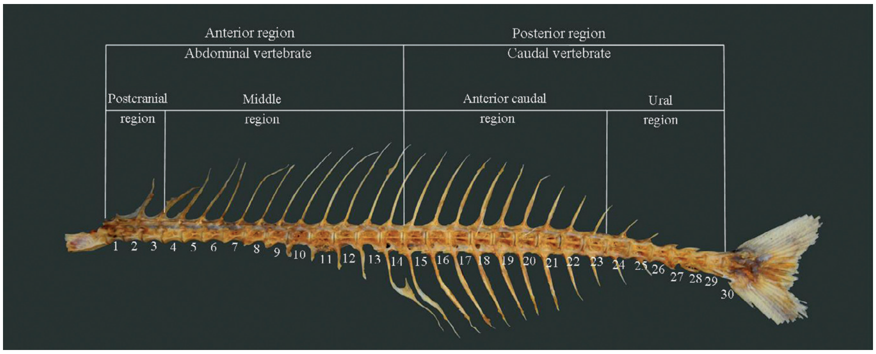

Fig. 1. Vertebral column of *Rastrelliger kanagurta* showing different regions

It is possible to divide the vertebral column of *R. kanagurta* into two main regions: an anterior region made of abdominal vertebrae without haemal spine and posterior region with caudal vertebrae where the two haemal arches are joined and prolonged by a haemal spine. The anterior region is divided into two regions, the postcranial (V1-V3) and the middle region (V4-V14). Similarly, the posterior region is divided into anterior caudal (V15-V23) and ural regions (V24-V30). Such division and differences in the length and height of vertebra of the four regions of the vertebral column is supported by the *t*-test results ($t \geq 1.96$; $p \leq 0.05$).

Table 1. Average values (M) (mm) of length (LV), height (LH) and anterior width (LW) for the successive vertebrae if the vertebral column of Rastrelliger kanagurta (SD = standard deviation)

Ordinal number of vertebrae	LV		HV		WV	
	M	SD	M	SD	M	SD
1	20.64	3.39	21.32	3.61	6.30	3.60
2	21.33	2.51	18.96	3.24	5.29	3.23
3	21.53	2.22	17.35	2.78	4.39	2.76
4	21.87	2.00	17.82	2.77	5.07	2.75
5	22.29	2.23	17.94	2.90	4.34	2.88
6	22.92	2.35	18.28	2.90	4.73	2.87
7	23.83	1.76	18.44	2.32	4.33	2.31
8	24.03	2.25	18.44	3.15	4.81	3.14
9	24.62	2.10	17.61	3.48	4.96	3.47
10	24.87	2.70	16.57	3.71	4.44	3.70
11	25.23	2.21	16.61	3.31	4.65	3.30
12	25.17	2.33	16.45	2.49	4.80	4.79
13	25.29	2.41	16.83	2.73	4.75	2.74
14	25.58	2.33	16.75	2.55	4.65	2.54
15	24.76	2.38	17.18	2.66	4.93	2.65
17	24.90	1.60	17.12	2.78	4.98	2.77
18	25.10	1.83	17.15	3.69	4.98	3.68
19	25.32	2.14	17.27	2.92	5.06	2.91
20	24.73	2.33	17.12	3.33	5.61	3.32
21	25.46	2.35	17.22	3.15	5.20	3.14
22	25.05	2.69	17.16	3.17	5.14	3.15
23	25.17	2.55	17.61	3.31	5.30	3.30
24	23.99	3.11	17.49	3.59	5.32	3.58
25	23.20	3.24	18.17	3.58	5.44	3.57
26	22.32	3.04	18.67	3.97	5.35	3.96
27	20.27	3.00	18.87	3.65	5.32	3.64
28	19.91	2.97	18.18	3.48	5.31	3.47
29	18.40	3.40	15.45	4.52	4.10	4.50
30	16.43	5.69	14.42	3.06	3.23	3.05

The limit between abdominal and caudal vertebrae is located at the level of vertebra number 15. The 14 anterior vertebrae, or precaudal vertebrae (V1-V14), define the abdominal region or truncal, delimited by the presence of the gut. The next vertebrae or caudal vertebrae (V15-V30) belong to the tail; their haemal arches are fused from the 15th vertebra and prolonged by a haemal spine. This latter spine showed variation in both its length and shape. It is long and curved backward in vertebrae number 15-17 and reached its maximum length at vertebra number 18 after which it starts to decrease in length and reaches its minimum length at vertebra number 25. In the five most posterior vertebrae (V26-V30), the haemal spine is short, lies parallel to the axis of the vertebral column, and directed is posteriorly. The anterior surface of the haemal arch is smooth and no concavity is present. There was no intraspecific variation in the shape of vertebrae.

The vertebral column of *R. kanagurta* showed characteristic regionalization (Table 1). The anteriormost three vertebrae appear differently from the remaining precaudal vertebrae. The first vertebra is a small vertebra and fits into the anterior part of the second vertebra. There are no anterior zygapophyses in the first vertebra as this vertebra supports the skull; instead, it has two facets for the skull to rest on. The lateral processes of vertebrae number 1-3 are well developed and lie parallel to the axis of the vertebral column. The development of the lateral paraphysis decreases posteriorly. Four to five vertebrae (V4-V7) following the first three can be considered as transitional vertebrae that form a connection between the above mentioned first three vertebrae and the trunk because they increase or decrease regularly in their biometrical parameters (Figure 2). Secondly, the middle region appears to be made up of two morphological entities: the middle region (V4-V14) and the anterior caudal (V15-V23). Here the length of the trunk vertebrae increases until a maximum is attained around the 23rd vertebra. V4-V14 bears ribs that extend on the sides of the fish body. Thirdly, the ural region includes vertebrae V24-V30. It corresponds to the caudal peduncle and is characterized by a fall of the vertebral length and width. Vertebral length falls between V24-V30, while vertebral width falls between V28-V30.

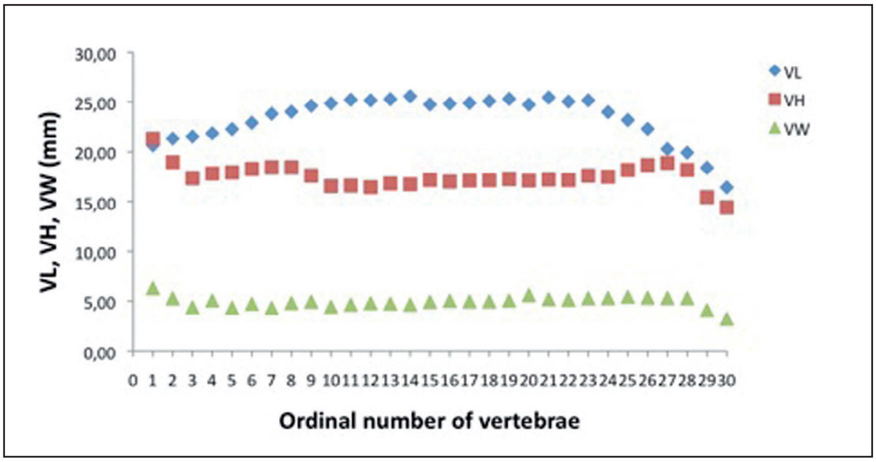

Fig. 2. Vertebral profiles of *Rastrelliger kanagurta*. VL, central length; VH, central height; VW, central width

The profiles corresponding to the three variables measured on all the vertebrae were the same in all the specimens studied. The morphometric analysis shows that the vertebral axis of the Indian mackerel, *R. kanagurta* has complex division. Four regions can be characterized along the vertebral axis according to the changes of the two parameters measured from one vertebra to another.

The vertebral profile given by the variation of the vertebral length along the axis shows two minima: one anterior at V1, the other at posterior end at V30. Between V2 and the maximum vertebral length value, the vertebral length increases regularly; then it decreases sharply and then increased steadily again between V15 and V19. It fluctuates in decreasing and increasing until V24 where the slope accentuates.

The vertebral profile revealed by the vertebral height shows the following changes along the axis of the vertebral column: a sharp decrease between V1 and V3, a steady increase is shown until V8, sharp decrease between V8 and V10, steady increase between V10 and V24, sharp increase between V25 and V27 and finally dramatic decrease from V28 until V30.

There are two minima shown by the vertebral width profile, one at V3 and the other at the posterior end of the vertebral column at V30. A sharp decrease between V1 and V3, The fluctuation of the vertebral width between V4 and V28 can be divided into three sectors, the first sector, V4-V10, showed clear and variable fluctuation of the vertebral width. The second, V11-V19, and third sectors, V20-V28 are separated by the increased value of vertebral column occurs at V20. The fluctuation of vertebral width value in the second and third sector is steady. This value drops dramatically at V29 and reached its minimum value at V30.

Out of the 30 vertebrae of *R. kanagurta*, there are 15 abdominal vertebrae and a similar number of caudal vertebrae. The vertebral aspect ratio is 4.93 and 4.62 for the abdominal and caudal regions respectively and the index of vertebral column elongation.

DISCUSSION AND CONCLUSION

The analysis of the variation in length, height and width of vertebrae along the vertebral column of *R. kanagurta* indicate that its structure is more complex than simple division in two areas, precaudal and caudal. This biometric study suggests the division of the vertebral column in four regions: 1) a postcephalic (anterior truncal); 2) a middle region; 3) anterior caudal region; and 4) ural region. The regions 1 & 4 are characterized by strong variation in vertebral parameters; in the regions 2 & 3, these variations are more regular and characterized by a cline on both side of the maximum value of the length and width of vertebrae.

The post-cephalic region (or post-cranial), immediately at the back of the head, ensures the articulation with the skull. The first three vertebrae V1-V3 form a morphological set resulting mainly into specific parameters of vertebral length and width. However these three vertebrae do not show completely different morphological characteristics compared to the other vertebrae (except for the first one). For *R. kanagurta*, the first vertebra plays as anterior ventral concavity which is articulated with the basioccipital. This first post-cephalic vertebra is designed to articulate with the posterior region of the skull, forming with the next vertebra a link between the two main elements of the axial skeleton, which is a function that requires some morphological specificity (Videler, 1993). The four vertebrae beyond V1-V3 could be considered transition vertebrae as they show an increase in the vertebral biometric parameters (Ramzu and Meunier, 1999).

The middle regions include the limit between the precaudal and caudal regions (V4-V14 and V15-V23) which corresponds to the haemal arch closing. It is therefore composed of truncal vertebrae and caudal vertebrae and forms morphological units. In these regions the increase is regular until a maximum value before decreasing progressively.

The ural region starts with the 24th vertebra. It corresponds to the tail and is characterized by a decrease of the two values of the analyzed parameters. The ural vertebra has different anatomy as it lacks real haemal arches, but it has hypural elements that support the lepidotrichia of the caudal fin.

As in other teleost fish (Ramzu *et al.*, 1992), the substitution of classical anatomical precaudal and caudal region by more than two regions is probably linked to the mechanical constraints of swimming. . Moreover, the anterior-posterior development of the two morphological parameters found in *R. kanagurta* together with the sudden variations of the postcephalic and ural regions on the one hand, and the maximum of the middle regions on the other, support this hypothesis (Ramzu *et al.*, 1992). The Indian mackerel is known to present a carangiform mode of swimming (Breder, 1926; Lindsey, 1978; Webb, 1978) in which the vast majority of movement is concentrated in the very rear of the body and tail. Carangiform swimmers generally have rapidly oscillating tails. The maximum length of the vertebra (VL) occurs around the vertebrae V14-V18; this can be the structural response of these vertebrae to the local occurrence of maximal mechanical constraints.

Regarding the fourth region of the vertebral column, its specific parametrical variation might express the major role performed by the caudal vertebrae in the motor process of swimming. The caudal skeleton responds to the alternate contraction of the intrinsic muscles on the lateral sides of this region, thus a torsion of the caudal peduncle is created, when they slightly increase or decrease the surface area of the caudal fin at different phases of one beat (Bainbridge, 1963), thereby creating a support on water.

The morphometric analysis of the vertebral column has revealed no significant difference between the variation within the length, height and width of each vertebra. Therefore, characterization of one vertebra along the vertebral column would be sufficient if it was based only on one of these two parameters (Desse *et al*., 1989). Furthermore, the morphology of the vertebrae of males and females are similar. This result supports that of Kacem *et al*. (1998) on the morphology of the skeleton of *Salmo salar*.

The regionalization in the vertebral column of R. kanagurta could be developed according to the difference in length of the vertebrae in different regions of the vertebral column, that in turn is determined by the presence of mechanical constraints due to the swimming activity, but could potentially be related to several different forms of costraint, as found for other fish species (see FJELLDAL et al., 2005). The similarity in the value of the aspect ratio of both abdominal and caudal region obtained in this study may indicate that the changes in the vertebral length in abdominal and caudal regions are closely linked (Ward and Brainerd, 2007).

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