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Interspecific and intraspecific differences in pectoral-fins spine morphology in Nile River and Lake Nasser catfishes, Siluriformes

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ABSTRACT

The structure of the pectoral fins spine of 4 catfish species *Heterobranchus longifilis*, *Clarias gariepinus*, *Chrysichthys auratus*, *Synodontis schall* and *Synodontis serratus* were described. The fish specimens were collected from Asyut City and Lake Nasser about 319 and 900 Km south of the capital Cairo, Egypt respectively on 10 November 2017 are described. The species examined showed variation in the shape of the spine-shaft tip varies from finely to broadly and rounded pointed; the curvature of the spine-shaft is either straight or curved partially or complete; the anterior serrae varies between is either broad or irregular; the anterior ridge groove is well developed, deep, and curved, with some pores in some species; the anterior dentations varies between short and sometimes are merged together or curved and their number decreased towards the tip; the posterior dentations can vary between absent or long and numerous and sometimes increased in their number towards the tip of the spine; the dorsal, anterior and ventral processes are well developed structures, with rounded, flange-like, and the shape of the basal fossa varies in having narrow, elongated, boat-shape, with high walls at sides; and very wide fossa and lunate in shape. It is usually deep with high walls.

Key words: anatomy, *Chrysichthys*, *Clarias*, development, fins, *Heterobranchus*, taxonomic identification, *Synodontis*

Межвидовые и внутривидовые различия морфологии шипов грудного плавника сомов (Siluriformes) реки Нил и озера Насер

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РЕЗЮМЕ

Описана структура шипов грудного плавника 4 видов сомов *Heterobranchus longifilis*, *Clarias gariepinus*, *Chrysichthys auratus*, *Synodontis schall* и *Synodontis serratus*. Материал собран 10 ноября 2017 г. в Асьют-

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Сити и в озере Насер, соответственно расположенных примерно в 319 и 900 км к югу от столицы Египта Каира. У исследованных видов обнаружена изменчивость формы окончания рукоятки шипов (от тонкого до широкого и закругленного); рукоятка шипов либо прямая, либо частично или полностью изогнутая; передние зазубрины могут быть широкими или нерегулярными; бороздка переднего гребня хорошо развита, глубокая и изогнутая, у некоторых видов с несколькими порами; передние зубчики варьируют от коротких и иногда сливающихся до изогнутых, а их количество уменьшается к кончику шипа; задние зубчики могут отсутствовать или варьируют по длине и числу, иногда их количество увеличивается к кончику шипа; дорсальный, передний и вентральный отростки представляют собой хорошо развитые структуры с округлыми гребневидными формами. Базальная ямка варьирует от узкой, удлиненной, лодкообразной, либо с высокими боковыми стенками до очень широкой и полулунной; обычно она глубокая, с высокими стенками.

Ключевые слова: анатомия, *Chrysichthys*, *Clarias*, развитие, плавники, *Heterobranchus*, таксономическая идентификация, *Synodontis*

INTRODUCTION

Species of catfishes (Siluriformes) are diagnosed in having strong bony and joint-locking pectoral- fin spines. The common attendance of these fin spines through different groups of these fishes may shed light on their early phylogenetic origin (Fine et al. 1997; Sullivan et al. 2006; Lundberg et al. 2014).

The catfish spine represents an association of lepidotrichia as do the spines of acanthopterygian fishes. The dissimilarity exists in how these components are combined into a single structure (Reed 1924). The lepidotrichia which contribute to the formation of the spine first appear as an expansion of the basement membrane as in the case of soft rays described by Harrison (1893) and Goodrich (1904). The catfish fin spines usually have intricate locking joints with the bones of the pectoral girdle ending with sharp tips and with complexly dentate or serrate margins (Reed 1924; Alexander 1966; Fine et al. 1997), and numerous species have venom-producing glandular tissues associated with this spine (Wright 2009, 2012).

The importance of the morphology of the pectoral spines of the catfish species is evident in the identification of both extant and fossil materials as the majority of the catfish fossils are spines. Indeed, the catfish pectoral spines are robust and preserve well. So far, their shape has been used to distinguish families or genera (Gayet and Van Neer 1990; Greenwood 1959).

Ecologically, sound-producing behavior in catfishes is important in reproductive and agonistic behavioral contexts (Teugels 1996; Kaatz 2002; Fine and Ladich 2003; Boyle et al. 2014; Ghahramani et al. 2014; Shine et al. 2021). Pfeiffer and Eisenberg (1965) assumed that catfishes with weapon-like pectoral spines produce disruption sounds as a form of acoustic aposematism. Thus, sound creation is a common and possibly significant feature of catfish performance. Defining the distribution and evolutionary patterns of vocal behavior and morphology in catfishes is vital to understanding communication in these fishes.

Therefore, the taxonomic value of variation of fin spine structure is important in understanding the sonic behaviour of different catfishes based on their differences in spine morphology. The taxonomic usefulness of the spine morphology of the catfishes has been long recognized. Structures of spines have confirmed useful for identifying and differentiating between catfish species and even some higher groups (e.g. Gayet and VanNeer 1990; Rodiles et al. 2010; Egge and Simons 2011).

The present study provides a comprehensive morphological description of the pectoral spines of 4 genera and 3 families (Clariidae, Claroteidae, Mochokidae) collected from the Nile River and Lake Nasser in Egypt. Differences in the shape of the spine and its connections could lead to changes in the stridulation of the catfish and could probably relate to differences in the sonic behaviour between the catfish species examined**.** Specimens of different sizes belonging to the vocal and silent catfish families are considered.

MATERIALS AND METHODS

This study utilized 50 specimens collected from the Nile River at Asyut City and Lake Nasser about 319 and 900 Km south of the capital Cairo respectively on 10 November 2017. All specimens were collected at a depth range 3–7 m. Individuals of *Clarias gariepinus* were collected from the Nile River using

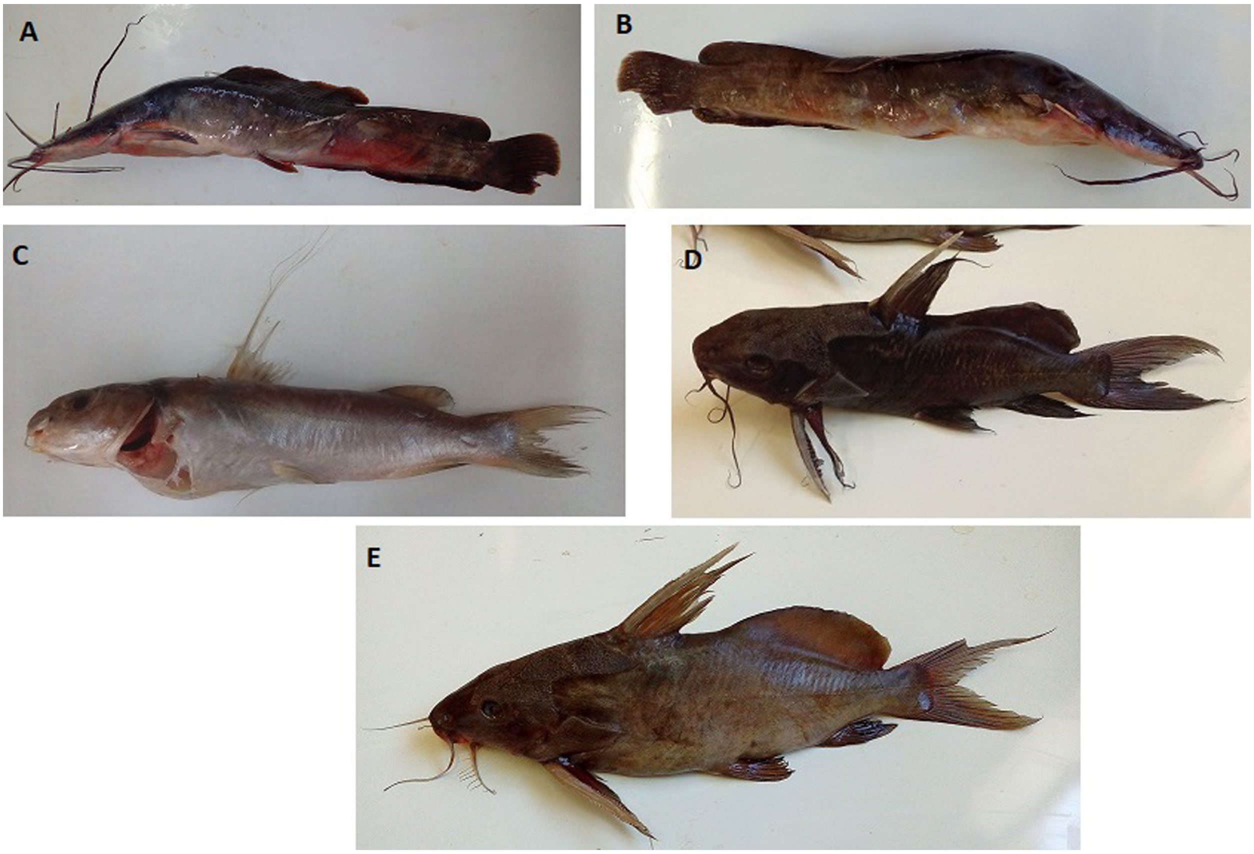

Fig. 1. Images of the catfish species studied: A – *Heterobranchus longifilis*, 470 mm TL; B – *Clarias gariepinus*, 410 mm TL; C – *Chrysichthys auratus*, 270 mm TL; D – *Synodontis schall*, 400 mm TL; E – *Synodontis serratus*, 400 mm TL.

long line. Samples of *Heterobranchus longifilis* (using long lines), *Synodontis serratus* and *S. schall* (using trammel net) were collected from the Lake Nasser. Specimens of *Chrysichthys auratus* were obtained from both the Nile River and the Lake Nasser using long lines. In order to decide if there were any differences in the surface structures on the pectoral spine between species, we performed a close camera examination of these structures for the individuals. Fish specimens were skeletonized by water maceration. The cleaned bones were then air-dried. Morphology of the pectoral spine base was observed in 10 specimens of each of the five species. Images of the pectoral spines were captured using Leica 210 camera fitted on a stereo microscope model LED5000 SLI. Surface morphology of the lateral, anterior and posterior surfaces of the pectoral spine were imaged following Kaatz et al. (2010) and Vanscoy et al. (2015). Spines were observed in their erect location at a right angle to the longitudinal axis of the fish with the fin spread in the horizontal plane (in contrast to the withdrawn fin position with the fin folded with the spine tip directed posteriorly). The indicator terms dorsal, ventral, anterior and posterior are related to the edges of the spine in its erect position. Spine length, spine-shaft length and other length measurements were taken along the proximodistal (mediolateral) axis of the spine. Pectoral-spine length is the straight-line distance between the most proximal point on the spine base to the distalmost point on fully co-ossified spine shaft so as not to contain any distal fin-spine segments that may be partially ossified but not fused to the spine tip. Pectoral- spine shaft length is the straight-line distance between the points of source of the dorsal articular process on the spine shaft to the distalmost point on fully co-ossified spine shaft. Spine-shaft width is the straight-line distance along the anteroposterior axis through the midpoint of the shaft; spine depth is a straight-line dorsoventrally distance through the midpoint of the shaft.

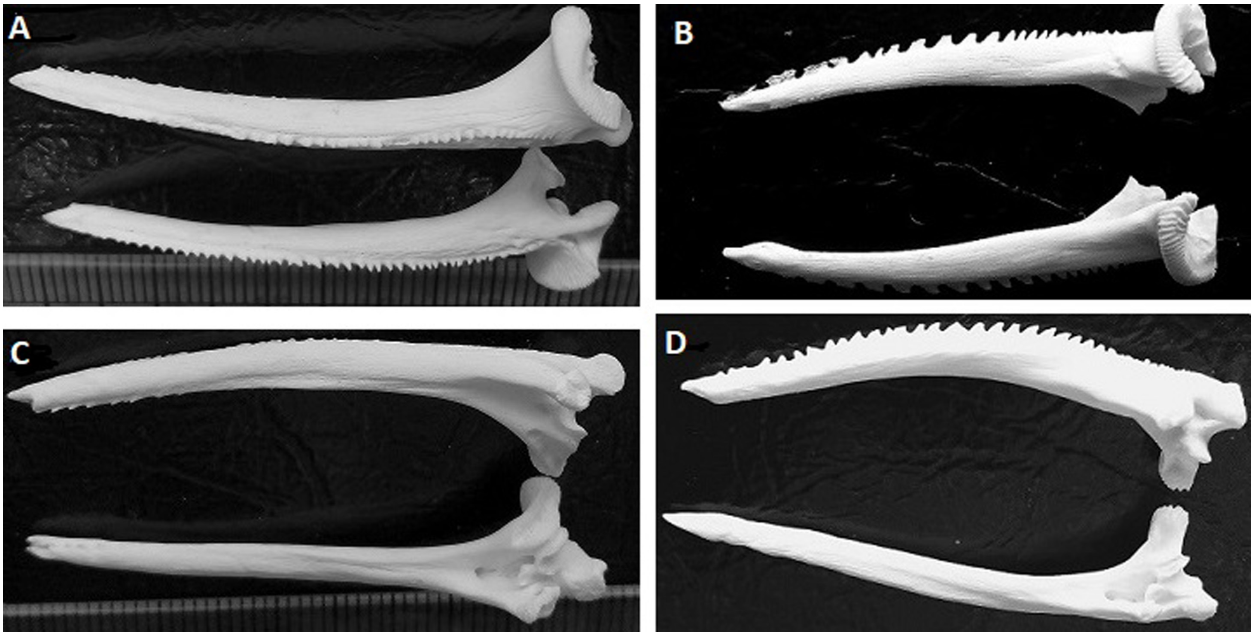

Fig. 2. Left and right pectoral fin spine of *Heterobranchus longifilis*, 470 mm *TL* (A, C); *Clarias gariepinus*, 410 mm *TL* (B, D). Each image showing the dorsal side (above) and the ventral side (below).

Material examined**.** Family Clariidae: *Heterobranchus longifilis* Valenciennes, 1840, 10 specimens, 400–470 mm total length (*TL*); *Clarias gariepinus* (Burchell, 1822), 10, 350–410 mm *TL*. Family Claroteidae: *Chrysichthys auratus* (Geoffroy Saint-Hilaire, 1809), 10, 180–270 mm *TL*. Family Mochokidae: *Synodontis schall* (Bloch et Schneider, 1801), 10, 220–400 mm *TL*; *S. serratus* Rüppell, 1829, 10, 250–400 mm *TL* (Fig. 1).

RESULTS

Anatomy of the pectoral-fin spines

The anatomy of the pectoral-fin spines of the five species is pictured in Figs 2–4. We illustrate spines of the *S. serratus* as a typical pectoral spine with the basic diagnostic characters (Fig. 5).

The pectoral-fin spine is a solid, unitary bone formed from a densely co-ossified, single, unbranched lepidotrichium (i.e. the first, marginal or leading pectoral-fin lepidotrichium) with an articular base and a thick, sharp-tipped shaft.

The proximal part of the pectoral fin is equipped with three bony articular processes on the base with intervening notches that articulate with the cleithrum and scapulocoracoid and that also connect with the tendinous muscle insertions (Diogo et al. 2001; Miano et al. 2013). The dorsal articular process is usually greatly expanded, rounded and flange-like and articulates with a matching deep, internal groove on the medial face of shoulder of the cleithrum.

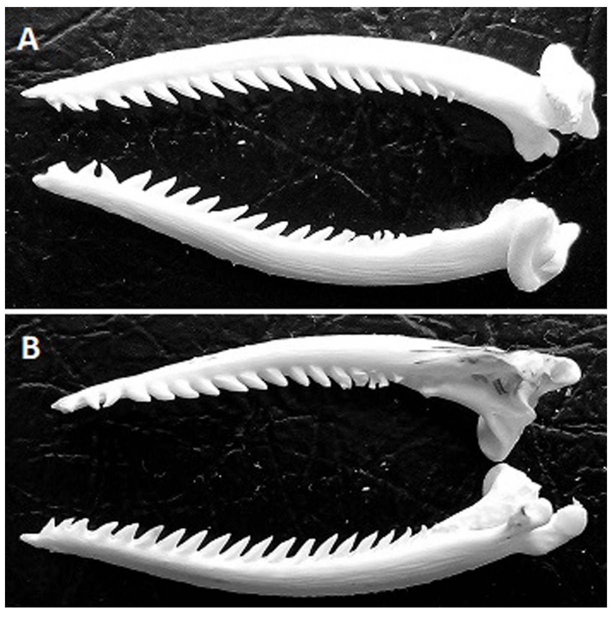

Fig. 3. Left and right pectoral fin spine of *Chrysichthys auratus*, 270 mm *TL*: A, dorsal view; B, ventral view

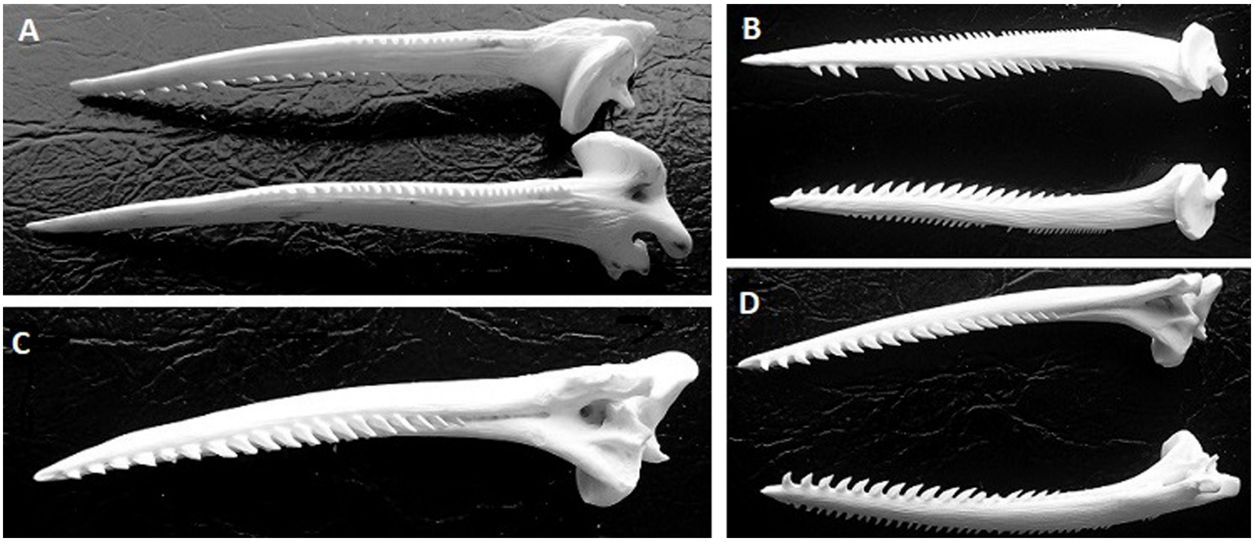

Fig. 4. Left and right pectoral fin spine of *Synodontis schall*, 400 mm *TL* (A, C) and *Synodontis serratus*, 400 mm *TL* (B, D) showing dorsal and ventral sides.

Dorsal process. In *H. longifilis,* the dorsal articular process is well-developed, dorsally tilted and expanded, rounded, flange-like about 1¼ of the depth of the spine shaft, dorsally spanning the entire spine-shaft width from anterior to posterior margins of the spine. This process is equipped with course ridges on the medial rim of the dorsal articular process. In addition, a honeycomb structure is present on the medial surface of the dorsal articular process. No pores were noted. The dorsal articular process in *C. gariepinus* is similar to that of *H. longifilis* width from anterior to posterior margins of the spine, dorsolateral and the dorsomedial margins with few incomplete acentric ridges that do not reach the centre of the process; the inner wall of the radiations have pores. In *C. auratus*, the dorsal articular process is well-developed and similar in the basic structure of that of *H. longifilis.* Fine ridges on the medial rim of the dorsal articular process and honeycomb structure occur on its proximal surface. For *S. schall*, it is also well-developed, but it is large, with length about 1¼ of the depth of the spine shaft. Absence of ridges on the dorsolateral and the dorsomedial margins. No honeycomb surface occurs on the medial surface of the dorsal articular process. The neck area is well developed. The general structure of the dorsal articular process in *S. serratus* is similar to those of the other species, except that it is shorter (about equal to ¼ of the depth of the spine shaft). No ridges or honeycomb structure occur on the dorsomedial margins.

Anterior process. The anterior articular process is beak-like and articulates with the dorsal surface of the coracoid anterior and ventral to the cleithral internal groove. In all the five catfish species, the anterior articular process was thick, broad and projected ventrally beyond the spine shaft.

Ventral process. The club-shaped ventral articular process of the spine base develops from the base of the ventral hemitrichium and articulates with the ventral surface of the abductor bridge of the coracoid. In *H. longifilis*, the ventral articular process long (size is equal to ½ length of the dorsal articular process), strongly curved ventrally, presence of a broad neck, shallow constriction separating this process into symmetrical parts, presence of deep grooves on its anterior and the posterior sides, widely separated from the dorsal and the lateral articular processes, shallow and wide grooves on its ventral side. The ventral process is short, triangular in-shape, well developed and noticeable, proximal end with rounded end not reaching the ventral edge of the dorsal articular process in *C. gariepinus*. For *C. auratus* it is thick, small (size is equal to ½ length of the lateral process), constricted with double rounded proximal ends, no neck, presence of deep grooves on its anterior and posterior sides. In *S. schall* it is broad, curved, hammer-shaped, with curved ventral edge, presence of deep grooves on its anterior and posterior sides. For *S. serratus*, this process is broad with a straight end connected to the shaft distally and similar length to the anterior articular process.

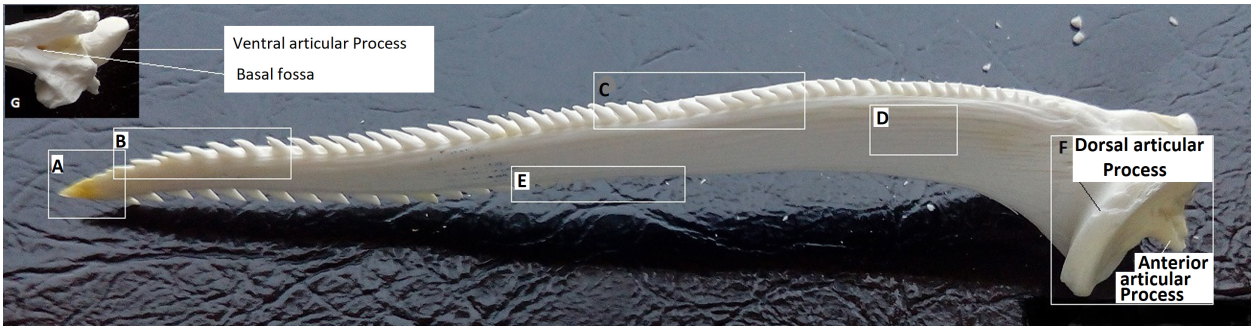

Fig. 5. Pectoral-fin spine of *Synodontis serratus*, 400 mm TL, left spine in the elevated position in dorsal view, showing enlarged details of its subparts. Inserts: A. anterior distal serrae, B. anterior ridge, C. anterior dentations, D. shaft surface texture of ridges and grooves, E. posterior dentations, F. base, dorsal view, G. base, posterior view.

Distal to the spine base on the posterior side of the spine is a deep basal fossa that internally opens into the lumen of the spine shaft. In *H. longifilis*, the basal fossa is wide, deep, and oval in shape, traversing on the most basal area of the spine. It is narrow, elongated, boat-shape, with sloping distal end and high wall at the proximal end, deep, traversing on most of the ventral area of the spine in *C. gariepinus*. As to *C. auratus*, it is deep, elongated, with the proximal end wider than the distal and traversing over most the basal area of the spine. In *S. schall,* it has a semicircular shape, very deep distally and shallow proximally, traversing on most of the ventral area of the spine, with the proximal area have no wall and sloping. For *S. serratus*, it is very narrow, elongated, boat-shape, with high walls at sides, deep at both proximal and distal ends. The latter is narrower than the proximal end.

The shaft of the pectoral spine protrudes distally from the spine base, arising from the body ventral to the cleithral shoulder and posterior (“humeral”) process and the shaft attenuates to its ossified tip. The dorsal and ventral surfaces of the shaft are textured with fine, plaited ridges and grooves. In all five species, the shaft of the pectoral spine is stout and fully ossified. The shaft is straight to the tip in *C. gariepinus*, *S. schall* and *S. serratus*, while it is curved forward in *H. longifilis* and *C. auratus*. In the species *H. longifilis* and *S. serratus*, deep elongated grooves running parallel to the length of the shaft are present. In the remaining three species the grooves are shallow. In addition to the elongated grooves, the surface of the shaft is equipped with pores. In *H. longifilis*, *C. gariepinus*, *S. schall* and *S. serratus* the pores are shallow, and there are no pores on the surface of *C. auratus*.

Three types of ornamentation are present along the anterior margin of the spine shaft, all of which are median structures. 1) At the spine tip there are proximally directed distal serrae. 2) At about one-sixth of shaft length from the tip the anterior distal serrae appear to unite to form the elevated sharp-edged anterior ridge. 3) Further proximally, at about one-third of shaft length from the tip, the anterior ridge becomes increasingly dentate with the formation of unpaired, median anterior dentations. The anterior dentations can be hooked slightly but are mostly distally directed, regularly or irregularly spaced. The posterior margin of the spine shaft is ornamented with large posterior dentations.

The number of the anterior serrae ranges from 2–5. The lowest number is observed in In *S. schall* (2–3), and the highest was noted in the remaining four catfish species examined. The anterior serrae are either merged or have irregular spacing. The former condition was observed in *H. longifilis*, *C. auratus* and *S. schall*, while in *C. gariepinus* and *S. serratus*. In *C. gariepinus*, the anterior serrae are armed with granules.

The anterior ridge groove is either present, prominent, deep or absent. Except for *C. gariepinus*, where there is no groove, the remaining four species have deep, curved grooves. Pores were present in *H. longifilis*. The anterior groove usually maintains a similar depth along the shaft of the spine, but in *S. schall* it is deep near the proximal end and shallower at the tip of the spine.

Except for *C. auratus*, where they are few, the anterior dentations are numerous in the remaining 4 species. They are usually shorter and narrower near the tip of the shaft. The anterior dentations are closely spaced in *H. longifilis*, irregular in *C. auratus*, *S. schall* and *C. gariepinus*, while in *S. serratus*, the spacing increased toward the tip.

Table 1. Characteristic features of the spine of the pectoral fin of the five catfish species examined.

Characters	*Synodontis serratus*	*Clarias gariepinus*	
Shape of the spine-shaft tip	Finely pointed	Broadly pointed	
Texture of the spine-shaft tip	Shallow grooves decreasing in number and depth towards the tip of the spine; large pores present near the proximal end of the spine.	Deep, irregular grooves getting more irregular towards the tip of the spine; short grooves present near the tip; pores present	
Curvature of the spine-shaft	Straight	Broad curved at the proximal end and backward curved at the distal end of the spine	
Number, shape, spacing of the anterior serrae	4, irregular, rounded in shape, flat, directed laterally	4, broad base, blunt tip serrae, with shallow spacing, equipped with granules	
Anterior ridge groove	Prominent, with groove	Enlarged, elongated, anterior ridge groove	
Number, shape, size, distribution of the anterior dentations	Numerous near the proximal end, decreased towards the tip, regular spacing increased distally	Some of the dentations are doubled, those at the proximal end are curved distally, while those at the middle of the shaft are curved towards the proximal end	
Number, shape, size, distribution of the posterior dentations	Numerous, very long, located in the ⅔ of the length of the spine, increased in length towards the tip of spine, those at the distal end of the spine are merged and with irregular form and uniform spacing	Absent from the most length of the posterior side of the spine-shaft except for short dentations located in the ⅓ length of the spine-shaft toward the tip of the spine. Dentations are fused together forming an emarginated posterior edge	
Dorsal articular processes	Well-developed and dorsally tilted, expanded, rounded flange-like, with no ridges or honeycomb structure on the dorsomedial margins	Well-developed, dorsally tilted and expanded, rounded, flange-like, dorsally spanning the entire spine shaft. Dorsolateral and the dorsomedial margins with few incomplete acentric ridges that do not reaching the centre of the dorsal articular process. The inner wall of the radiations provided with pores	
Anterior articular processes	Prominent, projecting ventral medially beyond body of the spine base	Thick, broad, projecting ventrally beyond the body of the spine shaft	
Ventral articular processes	Broad, with broad neck and rounded edge, contiguous with the shaft. Two heads present, one irregular in shape and the other is broad and blunt; the area between the two heads is curved	Short, triangular-shape, well developed and produced; large number of irregular ridges present locating on the rim of the dorsal articular process	
Basal fossa	Narrow, elongated, boat-shape, with high walls at sides, deep and very wide at both proximal and distal ends. Presence of small opening	Very wide fossa, with narrow and deep distal end and wide and shallow proximal end, traversing on most of the basal area of the spine; proximal end with no wall and slopping toward the body of the fish	

	Synodontis schall	*Chrysichthys auratus*	*Heterobranchus longifilis*
	Broad, with rounded end	Broad, with rounded end	Broad, with rounded end
	Deep grooves, discontinuous, with pores present at proximal end of the spine; fully covered with very deep, wavy grooves	Shallow, elongated grooves, reaching the tip of the spine; no pores	Deep, elongated grooves, reaching the tip of the spine; pores present; grooves near the proximal end are curved around the dorsal process
	Uniformly curved	Shaft curved anteriorly near the proximal end and posteriorly at the tip of the spine-shaft	Broad, regularly curved anteriorly
	No serrae, except of a double, broad and low sera	4–5, with irregular shape, broad base, blunt, low merged together	4–5, low, merged, no spacing
	Very deep, with pores at the proximal end getting shallower at the tip of the spine	Very deep anterior ridge	Very deep and curved ridge groove near the proximal end, with pores at the middle part of the spine-shaft
	Few, extending on the ⅓ proximal length of the spine-shaft, size increased towards the tip and decrease again, regular spacing	Very few located at the middle part of the spine-shaft, spacing irregular, forming a wavy anterior ridge	Numerous, getting shorter towards the proximal end, narrow spacing, presence of pointed and blunt cusps, those near the tip of spine-shaft are merged
	Size increased towards the tip of the spine-shaft and decreased again, the longest dentation present at the middle of the spine-shaft, width, regular spacing, rounded cusp	Numerous, variable in size, the first 2 dentations near proximal end are the smallest, the rest are large, length is equal to ½ width of the spine-shaft, dagger-shape, broad base, broadly pointed, irregular spacing increased distally	Few located in the far part of the proximal end, irregular spacing, straight, directed distally
	Well-developed, dorsally tilted and expanded, rounded, flange-like. Dorsolateral and the dorsomedial margins with no ridges or honeycomb. Prominent neck present	Well-developed, dorsally tilted and expanded, rounded, flange-like. Fine ridges present on the medial rim of the dorsal articular process and honeycomb structure is on its proximal surface	Well-developed, dorsally tilted and expanded, rounded, flange-like about 1¼ of the depth of the spine shaft. Course ridges present on the medial rim of the dorsal articular process; honeycomb structure is on the medial surface. No pores
	Thick, broad, projecting ventrally beyond the body of the spine shaft	Thick, broad, projecting ventrally beyond the body of the spine shaft	Thick, broad, projecting ventrally beyond the body of the spine shaft
	Broad, curved, hammer shaped, with curved ventral edge, presence of deep grooves on its anterior and posterior sides. No ridges.	Thick, small (size is equal to ½ length of the lateral process), constricted with double rounded proximal ends, with long neck; deep grooves present on its anterior and posterior sides	Long (size is equal to ½ length of the dorsal articular process), strongly curved ventrally; presence of a broad neck; constriction shallow separating this process into symmetrical parts; presence of deep grooves on its anterior and the posterior sides, widely separated from the dorsal and the lateral articular processes; shallow and wide grooves on its ventral side
	Lunate in shape, deep; proximal end with rounded high wall; distal end with sloppy edge and traversing on most of the basal area of the shaft	Deep, very wide at both distal and proximal ends, with deep distal and proximal ends	Wide, deep, oval in shape, traversing on the most basal area of the spine

The serrae are few in number in *H. longifilis* and *C. gariepinus*, but they are numerous in the remaining 3 species. These dentations are straight directed distally (*H. longifilis*, *S. schall*), triangular in shape, with single pointed cusps (*C. gariepinus*), dagger-shape, broad base and broadly pointed (*C. auratus*) and curved toward the proximal end of the spine (*S. serratus*). The spacing of the serrae was regular (*S. schall*), irregular (*H. longifilis*, *C. gariepinus*, *C. auratus*) or increased towards the tip of the spine (*S. serratus*). In *C. gariepinus* the serrae are confined to the distal ⅓ of the length of the shaft. In *C. auratus*, the first 2 dentations near the proximal end are the smallest, but the rest are large, length is equal to ½ width of the spine-shaft. In *S. schall* the longest dentation located at ⅓ of the length of the spine-shaft, length is equal to ½ width of the shaft-spine. In *S. serratus*, length of the largest dentation is equal to width of the shaft of the spine.

Intraspecific variation in the morphology of the spine of the pectoral fin

There is little variation with size in *H. longifilis* except for the shape of the spine-shaft tip, the developmental changes can be seen in all the remaining characters examined. For the texture of the spine-shaft, it is shallow, straight and elongated groove, no pores in small sized specimens, while it is deep and with pores. For the curvature of the spine-shaft, it is narrow, while in the large sized specimens it is broad. The number of the anterior serrae ranging between 3 and 4 in the small individuals, while there are 4–5. The anterior ridge groove is shallow, with no pores in specimens of 400 mm *TL*, while in specimens of 450 mm *TL* it is shallow with a few pores. In large specimens (470 mm *TL*), the anterior ridge shown to have very deep and curved ridge groove near the proximal end, with pores at the middle part of the spine-shaft. For the anterior dentations, they appeared to be few. The posterior dentations are few, with uniform spacing in small sized individuals (400–450 mm *TL*), while they are also few, but with irregular spacing in the large sized specimens (470 mm *TL*). In the small sized specimens, the dorsal, anterior and ventral processes are poorly develop, oblong in shape, fine ridges on dorsal articular process, presence of honeycomb, no pores, while they are well-developed, rounded in shape, presence of course ridges on the medial rim of the dorsal articular. The basal fossa was narrow, deep, circular in shape, traversing on the most basal area of the spine in specimens with total length ranging between 400 and 450 mm *TL*, but it is wide, deep, oval in shape, traversing on the most basal area of the spine.

The pectoral spine of *C. gariepinus* has developmental variations in certain minor characters. Except for spine-shaft tip and shape, the remaining 8 minor characters change during growth. The elongated groove present on the spine-shaft becomes deeper and irregular and develops deep pores with increased in size. A slight changes can occur in the curvature of the spine shaft in the large specimens (410 mm) of *C. gariepinus* and became curved forward after being straight in smaller specimens (350 mm). Minor changes occur in the shape, number and spacing of the anterior serrae. Slight increase in the number of serrae and presence of granules occur in smaller individuals. The anterior ridge groove becomes prominent in larger individuals. There are differences between the large and small individuals in regard to the number, shape, size, and distribution of anterior dentations especially at the proximal end of some large specimens as they got doubled and curved. After being confined to the distal ⅓ of the length of the shaft in young specimens, the serrae are no longer present from most of the length of the spine-shaft, and the remaining dentations fuse together forming an emarginated posterior edge in larger individuals. As to the dorsal, anterior and ventral processes, they vary little between smaller and larger individuals except large specimens have a large number of irregular ridges on the rim of the dorsal process. Finally, the basal fossa is narrow in smaller individuals and very wide in larger ones.

Except near the tip of the spine, shape and texture, number and spacing of the anterior serrae, the remaining 6 characteristics of the pectoral spine of *C. auratus* display variations in their morphology. Some of these variations are clear between the smaller and larger individuals, while others disappear in large specimens. The anterior ridge groove increases in size with fish growth: no groove is present in 180 mm *TL* individuals, while a deep groove is present in specimens of 260 and 270 mm *TL*. Except for number, shape and size of anterior dentations remain conservative with size. The number of anterior dentations becomes smaller in large specimens (260, 270 mm *TL*), and they were confined to the middle part of the spine-shaft. As with anterior dentations, the posterior dentation morphology was conservative with fish size. However, dentations curved distally in larger specimens.

The morphology of the pectoral spine of *S. schall* is variable between smaller and larger individuals except for the shape of the tip of the spine-shaft, which was conservative. The groove present on the surface of the spine-shaft became deeper, shorter and wavy in larger specimens. Also, pores increased in size in larger individuals. The spine-shaft, straight distally in smaller specimens becomes uniformly curved in larger fish. The number of anterior serrae increases with fish size, but they are mostly eroded in larger specimens. In some cases, serrae appeared to fuse. The anterior ridge-groove is usually deep in all individuals, but in smaller specimens, it is shallow toward the tip of the spine-shaft. Pores are present in larger individuals. In the smaller individuals, they reach to ⅓ of the length of the spine-shaft, while in the larger specimens, they cover ⅔ of the spine-shaft length. The anterior dentations are uniformly spaced and curved towards the proximal end in smaller specimens, while those of the larger individuals are merged, with a broad base and rounded cusps. Posterior dentations, are long and increased in number distally but decreased at the tip of the spine- shaft tip. They have regular spacing and their tips are directed proximally. In both smaller and larger individuals, the dorsal articular process is well-developed and dorsally tilted. No honeycomb structure, ridges and bony tissues are present in the dorsal articular process of the smaller individuals, but they were observed in larger specimens. The anterior and the ventral and articular processes, getting bigger and thicker in larger individuals may be due to the normal growth steps. The shape of the basal fossa changes from semicircular in specimens of 220 and 310 mm *TL* to circular in individuals of 330 mm *TL* to lunate shape in larger specimens of 350 mm *TL*. The fossa is usually deep to very deep at distal end and shallow at proximal end traversing over the most surface of the basal area.

The shape and curvature of the shaft of the pectoral spine remain unchanged during development in *S. serratus*. The morphology of the other 7 characters of the pectoral spine appeared to vary between smaller and larger specimens. Within the specimens of *S. serratus*, the following characters were incorporated: the number of the anterior serrae, the shape of the anterior ridge groove, the number of the anterior dentations and the shape of their tip, the shape, number and location of the posterior dentations, the shape and location of the dorsal, anterior and ventral processes, and the shape and width of the basal fossa. The latter group contains the remaining characters of the pectoral spine.

The characteristic features of the pectoral fin spine in the catfish species examined

The five catfish species investigated have a diagnostic characters as follows: *Heterobranchus longifilis*, head long and broad, somewhat rectangular in dorsal outline; snout broadly rounded; large premaxillary and vomerine toothplate width; toothplates width very large; premaxiliary teeth conical; vomerine and mandibular teeth sub-granular to granular; lateral line appearing as thin white line extending from posterior end of head to middle of caudal fin base. *Clarias gariepinus*, one hundred and thirty five gill rakers on the 1st gill arch; distance between dorsal and caudal fin not greater than the eye diameter; clavicle striated and distinct under the skin. *Chrysichthys auratus*, large eye; short adipose dorsal fin; caudal fin deeply forked, with acutely pointed lobes; first dorsal soft ray produced; upper surface of head not smooth; premaxillary teeth ban broad. *Synodontis schall*, twenty four – thirty six movable mandibular teeth; interorbital width not half length of head; skin villose on the side of body; ventral and anal fins obtusely pointed. *Synodontis serratus*, snout longer than the postocular part of the head, spine of dorsal fin serrated anteriorly, 30-48 movable mandibular teeth.

The results showed that the five catfish species examined have shown some characteristic features of the morphology of the pectoral fin spine that can separate these species with. These characters are distributed in the five species studied as shown in Table 1.

DISCUSSION

Pectoral spines of catfishes have been known for their function as anti-predators (Recher and Recher 1968; Bunkley-Williams et al. 1994; Werner et al. 2001) and this suggestion is supported by experimental evidence (Bosher et al. 2006; Sismour et al. 2013). With the large range in size, habitats and predators of catfishes, several limitations are likely to affect spine development within and across species. Duvall (2007) suggested that several factors can affect spine size: to survive attacks by aquatic and aerial predators, use in locomotion (primary breaking and turning), and a signaling device to produce acoustic signals (Fine and Ladich 2003). These thoughts suggest several postulations for pectoral spine and girdle development as fish grow. Among these considerations that Duvall (2007) mentioned are: (1) spine morphology, adapted for locomotion and sound production is under the effect of convergent evolution so that the chief features of the spines in different species are likely to be conservative; (2) spine size will increase with fish size within each species. However, since the chances of predation decrease with fish size, it may not be necessary for spine size to increase linearly with fish body length. The above considerations given by Duvall (2007) were noted and observed in the present study on the pectoral spine morphology of five catfish species collected from Egyptian waters.

Pectoral spine morphology varies slightly within and across catfish species studied making it difficult to distinguish species. On the other hand, minor characters may allow individual species to be identified. The general morphology of the pectoral spine of the 5 species is similar and also similar to the spines of other catfish species described by others (Gayet and Van Neer 1990; Fine et al. 1997; Parmentier et al. 2010; Kaatz et al. 2010; Miano et al. 2013; Vanscoy et al. 2015).

The pectoral spine of the two clariid species, *H. longifilis* and *C. gariepinus* have similarity in 3 characters: shape and texture of the spine-shaft; and shape of the dorsal, ventral and anterior articular processes. Considerable differences were noted in 4 characters shaft curvature and shape, number, size and distribution of the anterior serrae. Slight differences were observed in only 2 characters: the shape, number, size and distribution of the anterior dentations; and shape of the basal fossa.

The pectoral spine of the two species belonging to the family Mochokidae, *S. schall* and *S. serratus* has shown similarity in 5 characters: the shape of the tip of the spine-shaft; the shape of the anterior ridge groove; the shape, number, size and distribution of the anterior dentations; the shape, number, size and distribution of the posterior dentations; and the shape of the dorsal, ventral and anterior articular processes. They are slightly different in the shape, number and spacing of the anterior serrae, but there are a considerable differences in 3 characters: the texture of the spine-shaft; the curvature of the spine-shaft; and shape of basal fossa.

Comparing the morphology of the pectoral spine of the claroteid species *C. auratus* with those of the 2 species of the family Mochokidae, *S. schall* and *S. serratus*, it appears that *C. auratus* is similar to the 2 mochokids species in 4 characters: shape and texture of the spine-shaft; shape of the anterior ridge groove; and the shape, number, size and distribution of the posterior dentations. On the other hand, claroteid species *C. auratus* indicated variations from the 2 mochokids species in 3 characters: the shape, number, size and distribution of the anterior dentations; the shape, number, size and distribution of the posterior dentations; and shape of the basal fossa. Still, the claroteid species *C. auratus* has shown slight differences to the 2 mochokids species in 2 characters: the curvature of the spine-shaft; and the shape, number and spacing of the anterior serrae.

The claroteid species *C. auratus* pectoral fin spine exhibits similarity with the two clarid species, *H. longifilis* and *C. gariepinus*: shape of the spine-shaft shape; the shape, number, size and distribution of the anterior serrae; the shape of the anterior ridge; the shape, number, size and distribution of the anterior dentations; and the shape of the dorsal, anterior and ventral processes. They are noticeably different in 2 characters: the texture of the spine-shaft; and the shape of the basal fossa. There are minor differences in regard to two characters, the curvature of the spine-shaft; and the shape, number, size and distribution of the serrae.

As far as the author's knowledge, there is no description for the pectoral fin spine of the catfish *C. auratus*, but Gayet and Van Neer (1990) have described *C. furcatus*, which appears to have a similar shape of the head and the shaft of the spine of *C. auratus* given in the present study.

The two mochokids species, *S. schall* and *S. serratus* have shown more similarity in the morphology of their pectoral fin spine (5 characters), while those of the family Clariidae, *H. longifilis* and *C. gariepinus*, and were less similar. This is may be due to the fact that the two mochokids species belong to the same genus, *Synodontis*, while the two clariid species, *H. longifilis* and *C. gariepinus*, share only 3 characters, which might be due to the taxonomic position of each species.

The morphology of the pectoral spine of *H. longifilis* agrees with Gayet and Van Neer (1990) and Kaatz et al. (2010) as both the general feature of the spine-shaft and the minor characters of the spine's head appear similar. For *C. gariepinus*, the pectoral spine of the larger individuals are in agreement in their morphology to those described by Gayet and van Neer (1990). In addition, the morphology of the pectoral fin spine of the smaller specimens varies considerably. There is a full agreement in the morphology of both species of the genus *Synodontis* and the 6 synodontid species described by Parmentier et al. (2010). The only differences are in the shape of the pectoral spine of individuals in different developmental stages that appeared to show slight variations from the adult. The general description and the minor characters of the pectoral spine given by Gayet and Van Neer (1990) for *S. schall* fit well with those given by the present study for the same species.

The present study is also comparing the morphology of the pectoral spine of the claroteid species *C. auratus* with those of the 2 species of the family Mochokidae, *S. schall* and *S. serratus*. It appears that *C. auratus* is similar to the 2 mochokids species in 4 characters: shape and texture of the spine-shaft; shape of the anterior ridge groove; and the shape, number, size and distribution of the posterior dentations. On the other hand, claroteid species *C. auratus* indicated variations from the 2 mochokids species in 3 characters: the shape, number, size and distribution of the anterior dentations; the shape, number, size and distribution of the posterior dentations; and shape of the basal fossa. Still, the claroteid species *C. auratus* has shown slight differences to the 2 mochokids species in 2 characters: the curvature of the spine-shaft; and the shape, number and spacing of the anterior serrae.

Within teleosts, catfish are distinctive in having two sonic organs: spine stridulation and sonic swimbladder muscles (Fine and Ladich 2003). There are profound differences of the morphology of both types of organs. Differences in the pectoral sound-producing apparatus are mainly limited to the relative size of the pectoral spines; doradids have larger spines than mochokids, and pimelodids' are even smaller. On the other hand, swimbladder mechanisms differ generally in the insertion and origin of muscles as well as sonic structures.

Stridulation of the pectoral spine within the pectoral girdle revealed in diverse catfish taxa. The phylogenetic dendrogram of catfish families given by Kaatz et al. (2010) exhibits vocal and silent catfish families. Among the three catfish families examined in this study, the family Claroteidae is the only one with silent species.

Sweep movement of the pectoral spine contains a number of separate pulses, each with a discrete waveform (Fine et al. 1997). According to Vance (2000), they are formed by the ridges lining the base of the pectoral spine as they pass over the rough surface of the spinal fossa of the cleithrum. According to Fine et al. (1997), the degree to which the spine is pressed against the groove during abduction seems to be the most possible explanation for sound production. Therefore, the relative spine size, which is a family characteristic seems here to be the controlling factor. In the present study, the size of the pectoral fin spine of the members of the vocal families, Clariidae and Mochokidae were showed to be large.

Mohajer et al. (2015) studied the sound generation in blue catfish *Ictalurus furcatus* Lesueur, 1840, the largest catfish in North America and found that this species gives pectoral stridulation sounds (distress calls) when confronted and seized. They concluded that it is uncertain whether their sounds evolved to function in air or water and stridulation sounds contain of a flexible series of pulses produced during abduction of the pectoral spine. Pulses formed as a result of a quick rapid spine rotations (jerks) of the pectoral spine that do not change with fish size although larger individuals generate longer, higher amplitude pulses with lower peak frequencies. In larger fish, Mohajer et al. (2015) suggested that there are longer pauses between jerks, and therefore fewer jerks and fewer pulses in larger fish that take longer to abduct their spines and therefore produce a longer series of pulses per abduction sweep. Sounds couple more effectively to water and have lower peak frequencies than in air.

Pulse periods are usually correlated to distances between ridges and thus spine sizes long as spines are moved at similar velocity, but since there is multiple ridges are likely to contact the cleithrum at the same time the main factor will be here the speed of the abduction. Significantly larger maximum pulse periods of abduction and adduction movement (AB- and AD-sounds) in doradids compared to both other families indicate larger maximum distances between ridges in doradids. The members of the vocal families investigated in the present study, Clariidae and Mochokidae have ridges on the dorsal process that causes the sound. These ridges are spaced differently in different species, therefore may produce different kinds of sound characteristic of the species. On the other hand, *C. auratus*, the silent catfish species, has fine ridges, which due to their size may not enable them to be sonic. The ictalurid, *Ameiurus nebulosus* (Lesueur, 1819), is known to produce sounds in agonistic contexts (Rigley and Muir 1979). Individuals of this species tested by Kaatz et al. (2010) were silent in disturbance as well but did have dorsal process ridges. For such fishes, morphology may be a more valuable sign of vocal ability than disturbance context observations. In younger individuals of the families Clariidae and Mochokidae, the absence of ridges was shown in the present results.

In conclusion, the shape and structure of the spine of the pectoral fins of the five catfishes examined were variable and showed the following set of characteristics, (1) the shape of the spine-shaft tip varies from finely to broadly and rounded pointed, (2) the curvature of the spine-shaft is either straight or curved partially or complete, (3) the shape, number and spacing of the anterior serrae varies between is either broad or irregular, varies between 4 and 5, with either slight or no spacing between them, (4) the anterior ridge groove is well developed, deep, and curved, with some pores in some species, (5) the shape, number, size and distribution of the anterior dentations varies between short and sometimes are merged together or curved and their number decreased towards the tip, (6) the shape, number, size and distribution of the posterior dentations can vary between absent or long and numerous and sometimes increased in their number towards the tip of the spine, they usually having irregular shape and some of them merged together, (7) the dorsal, anterior and ventral processes are well developed structures, with rounded, flange-like. Ridges and honeycomb structure on the dorsomedial margins may present and could be supplemented with pores, and (8) the shape of the basal fossa varies in having narrow, elongated, boat-shape, with high walls at sides, very wide fossa and lunate in shape. It is usually deep with high walls.

On the bases of a set of distinguishing characters that separate the five catfish species examined in the present study (Table 1), it was possible to distinguish two groups of characters of the pectoral fins spines features: (1) exclusive characters that clearly define a taxonomic group (genus or species); (2) characters that are shared by several genera, but that may be useful to define certain species within a genus. Therefore, these features are useful for taxonomic identification of the catfish species investigated, but they need to be check for showing phylogenetic signals.

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