Original Article

# Pectoral girdle bones in eurypterygian fishes

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**Abstract:** Bones of the pectoral girdle skeleton in representatives of 48 genera in 41 families of eurypterygian fishes were studied. The structure and position of the pectoral girdle is relatively stable in eurypterygians. It consists of the extrascapula, posttemporal, supracleithrum, cleithrum, postcleithrum, scapula, coracoid, actinosts, and fin rays. An ectocoracoid is present in some Gasterosteiformes. Most eurypterygians have a posttemporal with distinct dorsal and ventromedial processes. The dorsal process ligamentously articulates with the epioccipital and the ventromedial process with the intercalary when present, and when absent, with the posteroventral margins of the pterotic and exoccipital. In most taxa, the supracleithrum bears a sensory canal and articulates with the posttemporal anteriorly and with the cleithrum posteriorly. The cleithrum is Y-shaped consisting of the anterodorsal, posterodorsal, and ventral rami. Dorsal and ventral postcleithra are present in some Eurypterygii. The scapula articulates with the cleithrum and bears a foramen which is complete or open anteriorly and bordered by the cleithral ventral ramus. Most taxa have four autogenous actinosts that increase in size gradually from the first to the fourth, but in some, the first actinost is fused. The dorsalmost ray is rudimentary in some taxa.

## Introduction

At least 22 orders comprises the Eurypterygii, including Aulopiformes, Myctophiformes Lampridiformes, Polymixiiformes, Percopsiformes, Atheriniformes, Beloniformes, Cyprinodontiformes, Stephanoberyciformes, Beryciformes, Zeiformes, Gasterosteiformes, Syngnathiformes, Synbranchiformes, Scorpaeniformes, Perciformes, Pleuronectiformes and Tetraodontiformes (Nelson, 2006). The pectoral girdle shows a high diversity in the relative size and shape of its skeletal elements (Cope, 1890; Nelson, 1971; Vorkhvardt, 1987; Stiassny and Moore, 1992). Because of such a diversity, this study was aimed to provide the osteological features of pectoral girdle in representatives of eurypterygian families by describing and illustrating their significant features in selected genera or species. Recently, osteology of the other organs of the euryptrygian fishes have also

been studied (e.g., Keivany, 2014a, b, c). The systematics of the taxa follows Eschmeyer (2014) to reflect the new findings in their systematics.

## Materials and methods

In total 100 specimens of euryptrygian representatives were cleared and stained using alizarin red and alcian blue for osteological examination based on Taylor and Van Dyke (1985) method. A Camera Lucida attached to a Wild M5 dissecting microscope was used for drawings. The skeletal elements of first figure of each anatomical section is arbitrarily shaded and labeled and in the others are shaded in a consistent manner (dark, medium, and clear) to facilitate comparison among the studied taxa. Forty nine genera representing 41 families were studied. The number of genera studied in each order includes Aulopiformes (1), Myctophiformes (1), Lampridiformes (1),

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Cetomimiformes (1), Polymixiiformes (1), Percopsiformes (1), Atheriniformes (2), Cyprinodontiformes (2), Beloniformes (2), Stephanoberyciformes (2), Beryciformes (2), Zeiformes (2), Gasterosteiformes (8), Syngnathiformes (10), Synbranchiformes (2), Scorpaeniformes (5), and Perciformes (5).

The specimens were obtained from the University of Alberta Museum of Zoology (UAMZ), the Smithsonian Institution (United States National Museum) (USNM), California Academy of Sciences (CAS), and Australian Museum at Sydney (AMS). The museum numbers and standard length of the specimens used for figuring osteological features of the taxa are provided in the figure captions and as described in Keivany (2014a, b, c).

## Results and Discussion

The structure and position of the pectoral girdle is relatively stable in eurypterygian fishes, but it shows a high diversity in the relative size and shape of the bones. It consists of the extrascapula, posttemporal, supracleithrum, cleithrum, postcleithrum, scapula, coracoid, actinosts, and fin rays (Fig. 1). Extrascapula is absent in many taxa (e.g., Syngnathiformes) (Figs. 24-29). An ectocoracoid is present in Gasterosteidae, Aulorhynchidae, Aulostomidae, Fistulariidae (Figs. 20, 21, 24 and 25). The extrascapula, posttemporal, supracleithrum, cleithrum, postcleithra, and ectocoracoid are dermal bones, but the scapula, coracoid, and actinosts are endochondral (Rojo, 1991). Most eurypterygians have a posttemporal with distinct dorsal and ventromedial processes (Figs. 1-11). The dorsal process ligamentously articulates with the epioccipital and the ventromedial process with the intercalary when present, and when absent, with the posteroventral margins of the pterotic and exoccipital. In most taxa, the supracleithrum bears a sensory canal and articulates with the posttemporal anteriorly and with the cleithrum posteriorly. The supracleithrum is absent in some taxa (e.g., Aulostomidae) (Fig. 25). The cleithrum is Y-shaped consisting of the anterodorsal, posterodorsal, and

ventral rami. A lamina fills the space between the two dorsal rami. The ventral ramus may bear lateral, medial, posteromedial, and anterolateral flanges. The posteromedial flange provides an articulation surface for the scapula and coracoid. Dorsal and ventral postcleithra are present in some Eurypterygii taxa (e.g., Synodontidae, Myctophidae, Veliferidae, Trachipteridae, Polymixiidae, Percopsidae) (Figs. 1-6). The scapula articulates with the cleithrum and bears a foramen which is complete or open anteriorly and bordered by the cleithral ventral ramus. The coracoid is a broad plate consisting of a shaft and dorsal and ventral flanges and articulates with the cleithrum anteriorly and with the scapula dorsally by scapulocoracoid cartilage (Figs. 1-41). Most taxa have four autogenous actinosts that increase in size gradually from the first to the fourth (Figs. 1-4), but in some, the first actinost is fused to the scapula (e.g., Indostomidae, Pegasidae, Scorpaenidae, Agonidae) (Figs. 23, 24, 33, 36). The dorsalmost ray is rudimentary in some taxa. Nelson (1971) studied the anatomy of the pectoral girdle in sticklebacks, Vorkhvardt (1987) reviewed the origin of the paired fins, Borkhvardt (1992) studied the development of the paired fins in fishes, and Parenti and Song (1996) studied the pectoral-pelvic fin association in acanthomorphs. The general terminology of Johnson et al. (1996) for the pectoral girdle is followed.

### Aulopiformes

**Synodontidae:** *Synodus synodus* (Fig. 1). A relatively large extrascapular is present. The dorsal and ventromedial processes of posttemporal are distinct. The dorsal process is loosely attached to the epioccipital by a relatively long ligament. The supracleithrum is large and overlaps the cleithrum and postcleithrum posteriorly. The cleithrum is tapered and its anterodorsal ramus is short and blunt. The posterodorsal ramus extends beyond the scapula. The ventral ramus of the cleithrum bears perpendicular lateral and posteromedial flanges. The dorsal postcleithrum is flat and bears an anteroventral extension. The ventral postcleithrum is flat and narrow. The two postcleithra are situated behind the cleithral dorsal portion and actinost. The

scapula bears a short dorsal shaft that is tipped with cartilage anteriorly and articulates with the cleithral angle. The scapula also articulates with the cleithrum dorsally and anteriorly bears a complete small foramen. The coracoid is a broad plate consisting of a shaft tipped with cartilage and dorsal and ventral flanges that anteriorly articulates with the cleithrum cartilagenously. Actinosts are autogenous and the fourth one is highly enlarged. Also see Hartel and Stiassny (1986), Baldwin and Johnson (1996) and Johnson et al. (1996).
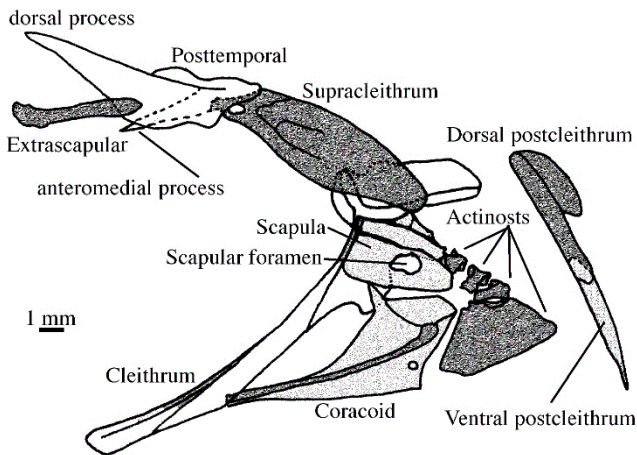


Figure 1. Lateral view of the left pectoral girdle in *Synodus synodus* (UAMZ 1806, 147 mm).

## Myctophiformes
**Myctophidae:** *Myctophum* sp. (Fig. 2). Two round extrascapulars are present. The dorsal and ventromedial processes of posttemporal are distinct. The dorsal process is loosely attached to the epioccipital by a relatively long ligament. The supracleithrum is large and bears a sensory canal. The anterodorsal ramus of cleithrum is short and pointed. The posterodorsal ramus is not distinct. The ventral ramus of cliethrum bears a lateral flange that overlies the scapula and coracoid. The dorsal postcleithrum is flat and ovoid and the ventral postcleithrum is flat and narrow. The scapula bears a complete small foramen. The coracoid consists of a shaft and dorsal and ventral flanges. Actinosts are autogenous and their size increases gradually from the first to the fourth. Also see Stiassny (1996).
## Lampridiformes
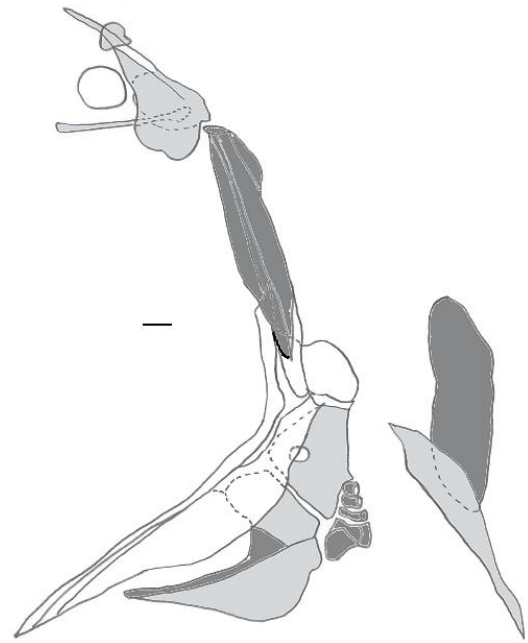**Veliferidae:** *Velifer hypselopterus* (Fig. 3). A



Figure 2. Lateral view of the left pectoral girdle in *Myctophum* sp. (UAMZ 2689, 60 mm).

relatively large extrascapular is present. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is large. The cleithrum is tapered and its anterodorsal ramus is long and pointed. The posterodorsal ramus is not distinct. The ventral ramus of the cliethrum bears perpendicular lateral and posteromedial flanges. The dorsal postcleithrum is broad and bears an anterior strut and the ventral postcleithrum is elongated. The scapula articulates with the posterodorsal shaft of the cleithrum dorsally, but it is free anteriorly and bears a complete foramen. The coracoid consists of a shaft and a dorsal flange. Actinosts are autogenous, hourglass shaped, and their size increases gradually from the first to the fourth. The dorsalmost ray is rudimentary and spiny.

**Trachipteridae:** *Trachipterus altivelis* (Fig. 4). The extrascapulars are absent. The posttemporal bears a long dorsal and a very short ventromedial process. The supracleithrum is long and bears a sensory canal and overlaps the cleithrum posteriorly. The cleithrum is long and roughly sinusoid. The ventral ramus of the cliethrum bears very narrow lateral and posteromedial flanges. The postcleithrum is elongated, originated on the cleithrum, and oriented posteriorly passing behind the fourth actinost. The
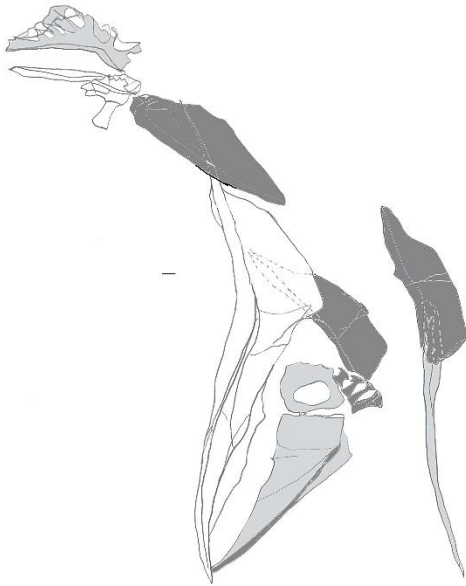
Figure 3. Lateral view of the left pectoral girdle in *Velifer hypselopterus* (AMS 21839005, 101 mm).

small, rectangular scapula articulates with the ventral shaft of the cleithrum, but it is free anteriorly and bears no foramen. The coracoid consists of a shaft and a dorsal flange. Actinosts are autogenous, hourglass shaped, and their size increases gradually from the first to the fourth. The dorsalmost ray is rudimentary and spiny.
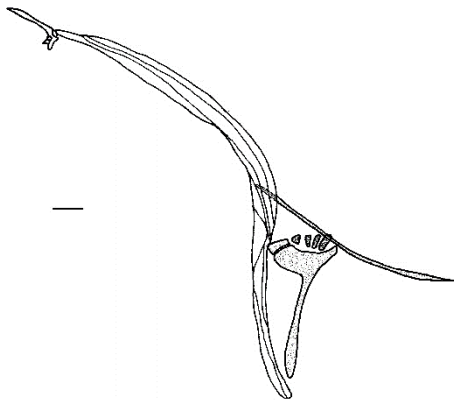


Figure 4. Lateral view of the left pectoral girdle in *Trachipterus altivelis* (CAS 24297, 85 mm).

## Polymixiiformes
**Polymixiidae:** *Polymixia lowei* (Fig. 5). A relatively large extrascapular is present. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is large. The anterodorsal ramus of the cleithrum is short and pointed, but the posterodorsal ramus is not distinct. The ventral ramus of the cliethrum bears medial,

lateral, and posteromedial flanges. The dorsal postcleithrum is broad and bears an anterior strut and ventral postcleithrum is elongated. The scapula articulates with cleithrum dorsally and anteriorly and bears a complete foramen. The coracoid is a broad plate consisting of a shaft tipped with cartilage and a dorsal flange, and cartilagenously articulates with the cleithrum anteroventrally. Actinosts are autogenous, hourglass shaped, and their size increases gradually from the first to the fourth. The dorsalmost ray is rudimentary and spiny.



Figure 5. Lateral view of the left pectoral girdle in *Polymixia lowei* (USNM 159300, 115 mm).

## Percopsiformes
**Percopsidae:** *Percopsis omiscomaycus* (Fig. 6). A small extrascapular is present. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is large. The anterodorsal ramus of the cleithrum is long and pointed, but the posterodorsal ramus is not distinct. The ventral ramus of the cliethrum bears median, lateral, and posteromedial flanges. The postcleithrum is very broad and bears an anteroventral extension. The scapula articulates with the cleithrum dorsally and bears a complete foramen. The coracoid consists of a shaft tipped with cartilage

and a dorsal flange, and cartilaginously articulates with the cleithrum anteroventrally. Actinosts are autogenous, hourglass shaped, and their size increases gradually from the first to the fourth. The dorsalmost ray is rudimentary. Also see Rosen and Patterson (1969).
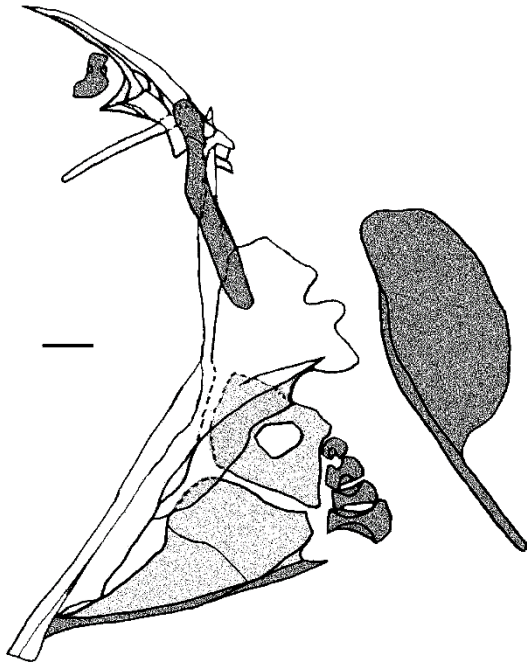


Figure 6. Lateral view of the left pectoral girdle in *Percopsis omiscomaycus* (UAMZ 2048, 55 mm).

### Atheriniformes
*Atherinidae: Allanetta harringotonensis* (Fig. 7). The extrascapulars are absent. The dorsal and ventromedial processes of posttemporal are distinct. The supracleithrum is small and lacks a sensory canal. The anterodorsal ramus of the cleithrum is short and blunt, but the posterodorsal shaft is not distinct. The ventral ramus of the cliethrum consists of posterolateral, lateral, medial, and posteromedial flanges. The dorsal postcleithrum is elongated and the ventral postcleithrum is relatively broad. The scapula bears an incomplete foramen. The coracoid consists of a shaft and dorsal and ventral flanges and articulates with the cleithrum anteriorly. The coracoid is much larger than the scapula and receives the third and fourth actinosts. Actinosts are autogenous, with hourglass shaped cores and dorsal and ventral lamina, and their size increases from the first to the fourth. The dorsalmost ray is rudimentary.

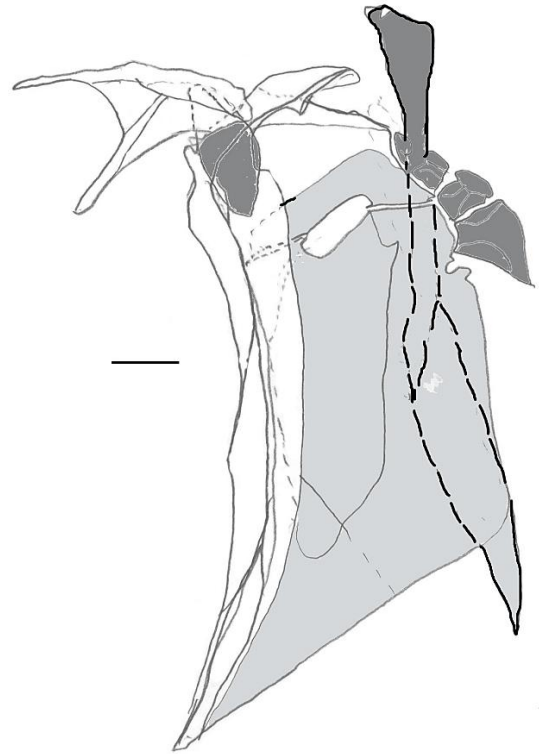The extrascapulars are present in *Atherinops* and *Melanorhinus*, but absent in Bedotiidae (Stiassny, 1990).



Figure 7. Lateral view of the left pectoral girdle in *Allanetta harringotonensis* (UAMZ 2673, 58 mm).

*Melanotaeniidae: Melanotaenia* sp. (Fig. 8). The extrascapulars are absent. The dorsal and ventromedial processes of posttemporal are distinct. The supracleithrum is small and lacks a sensory canal. The anterodorsal ramus of cleithrum is short and pointed, but the posterodorsal ramus is not distinct. The ventral ramus of cliethrum consists of anterolateral, lateral, medial, and posteromedial flanges. The medial flange bends laterally and articulates with the coracoid. The dorsal postcleithrum is small and round, but ventral postcleithrum is elongated. The scapula articulates with the cleithrum dorsally and anteriorly and bears a complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges and articulates with the cleithrum anteriorly. The coracoid is much larger than the scapula and highly notched to receive the third and fourth actinosts. The first actinost is fused to the scapula, but the other three are autogenous, with hourglass shaped cores and dorsal and ventral

lamina, and their size slightly increases from the first to the fourth. The dorsalmost ray is rudimentary. For other families of the order see Parenti (1984, 1993) and Dyer (1996, 1997).
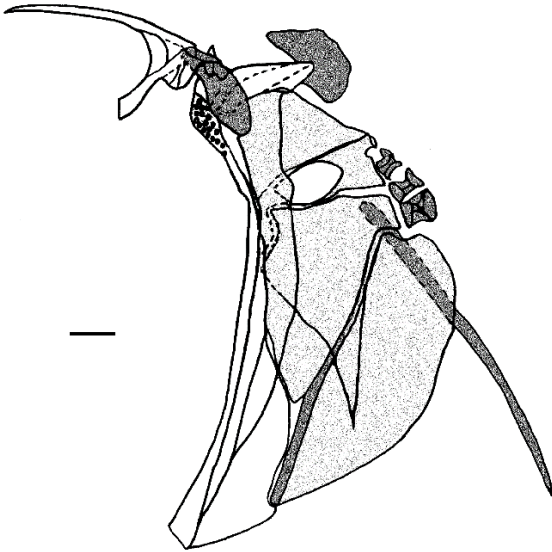


Figure 8. Lateral view of the left pectoral girdle in *Melanotaenia* sp. (UAMZ 3526, 51 mm).

### Cyprinodontiformes

**Aplocheilidae:** *Rivulus hartii* (Fig. 9). The extrascapulars are absent. The dorsal and ventromedial processes of posttemporal are distinct. The supracleithrum is small. The posterodorsal ramus of the cleithrum is not distinct. The ventral ramus of the cleithrum consists of lateral, medial, anterolateral, and posteromedial flanges. The postcleithrum is elongated. The scapula articulates with the cleithrum dorsally and anteriorly and bears a complete, small foramen. The coracoid consists of a shaft and dorsal and ventral flanges, and articulates with the cleithrum anterodorsally and anteroventrally. The coracoid is the same size as the scapula and highly notched posteriorly. Actinost are autogenous, with hourglass shaped cores and dorsal and ventral lamina, and their size increases from the first to the fourth. In *Aplocheilus panchax* the ventromedial process of posttemporal is just a bud and a small round dorsal postcleithrum is present (Parenti 1981).

**Cyprinodontidae:** *Cyprinodon nevadensis* (Fig. 10). The extrascapulars are absent. The dorsal and ventromedial processes of posttemporal are distinct.
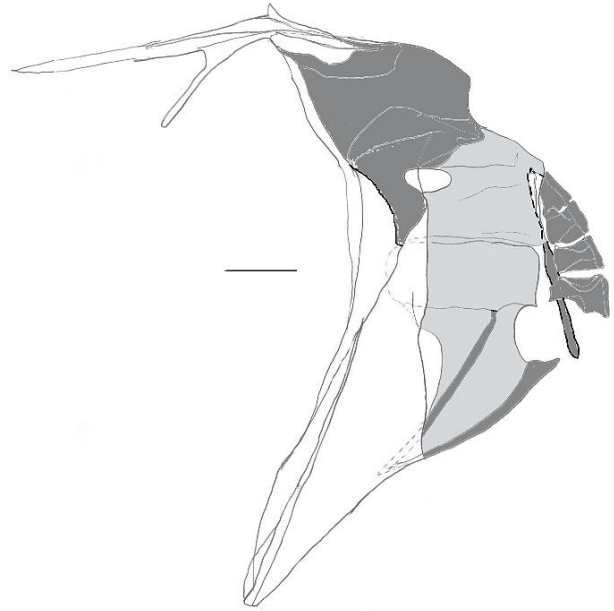


Figure 9. Lateral view of the left pectoral girdle in *Rivulus hartii* (UAMZ 6660, 47 mm).

The supracleithrum is small. The posterodorsal ramus of the cleithrum is not distinct. The ventral ramus of the cleithrum consists of lateral, medial, anterolateral, and posteromedial flanges. The dorsal postcleithrum is broad and the ventral postcleithrum is elongated. The scapula is twisted anteriorly and articulated with the cleithrum dorsally and anteriorly and bears a complete small foramen. The coracoid consists of a shaft and dorsal and ventral flanges and articulates with the cleithrum anterodorsally and anteroventrally. The coracoid is the same size as the scapula and both are highly notched posteriorly. Actinosts are autogenous, with hourglass shaped cores and dorsal and ventral lamina, and their size increases from the first to the fourth. The first actinost is sutured to the scapula. In representatives of *Fundulus* and *Cubanichthys*, the posttemporal anteromedial process is not distinct (Costa, 1998). Also see Ghedotti (1998).

### Beloniformes

**Belonidae:** *Pseudotylosurus* sp. (Fig. 11). The extrascapulars are absent. The dorsal and ventromedial processes of posttemporal are distinct. The supracleithrum is small. The dorsal rami of cleithrum are not distinct. The ventral ramus of the cliethrum consists of lateral and posteromedial
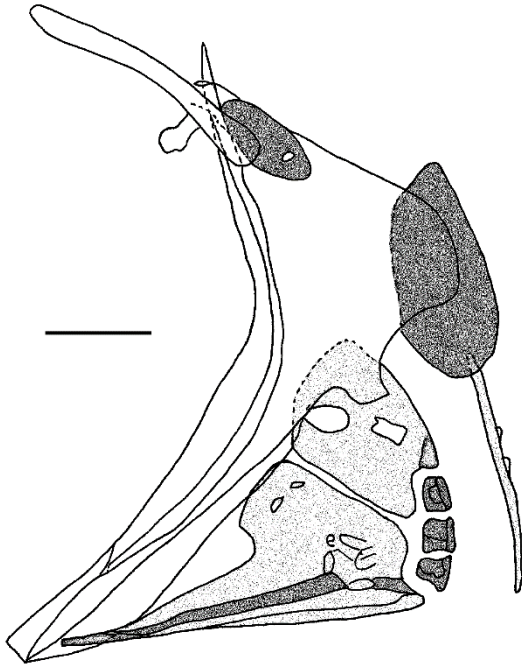
Figure 10. Lateral view of the left pectoral girdle in *Cyprinodon nevadensis* (UAMZ 3114, 34 mm).

flanges. The postcleithrum is elongated. The scapula bears a complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges and articulates with the cleithrum anterodorsally and anteroventrally. The coracoid is much larger than the scapula and highly notched to receive the fourth actinost. The actinosts are autogenous, with hourglass shaped cores and dorsal and ventral lamina, and their size increases from the first to the fourth. The dorsalmost ray is rudimentary. Also see Collette (1966).

**Hemiramphidae:** *Arrahamphus sclerolepis* (Fig. 12). The extrascapulars are absent. The ventromedial process of the posttemporal is not distinct. The supracleithrum is small. The dorsal rami of the cleithrum are not distinct. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. The postcleithrum is elongated and positioned vertically. The scapula articulates with the cleithrum dorsally and anteriorly and bears a complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges, and articulates with the cleithrum anterodorsally and anteroventrally. The coracoid is much larger than the scapula and highly notched to receive the fourth
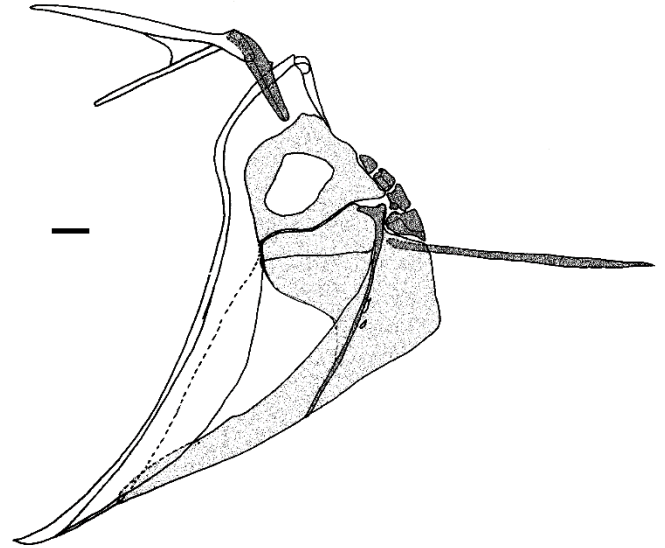


Figure 11. Lateral view of the left pectoral girdle in *Pseudotylosurus* sp. (UAMZ 8165, 173 mm).

actinost. The first and second actinosts strongly articulate with the scapula and the third and fourth ones with the coracoid. The dorsalmost ray is rudimentary. Also see Rosen (1964).



Figure 12. Lateral view of the left pectoral girdle in *Arrahamphus sclerolepis* (UAMZ 3523, 103 mm).

## Stephanoberyciformes
**Stephanoberycidae:** *Stephanoberyx monae* (Fig. 13). The extrascapular is large and tightly connected to the cranium. The ventromedial process of the posttemporal is distinct. The supracleithrum is large. The posterodorsal ramus of the cleithrum is long and

pointed. The ventral ramus of the cleithrum consists of lateral and medial flanges. The dorsal postcleithrum is broad and bears an anterior strut, but the ventral postcleithrum is elongated. The scapula articulates with the cleithral posterodorsal ramus and bears a complete small foramen. The coracoid consists of a shaft and dorsal and ventral flanges and articulates with the cleithrum anteriorly. Actinosts are autogenous, with hourglass shaped cores and dorsal and ventral lamina, and their size increases gradually from the first to the fourth.
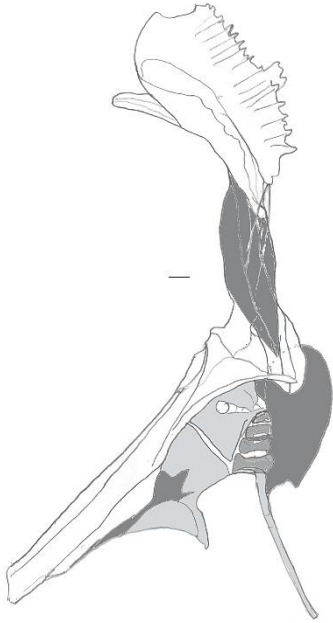


Figure 13.    Lateral view of the left pectoral girdle in *Stephanoberyx monae* (USNM 304353, 92 mm).

## Cetomimiformes

**Rondeletiidae:** *Rondeletia loricata* (Fig. 14). The extrascapulars are absent. The posttemporal is large and roughly pyramidal and its dorsal and ventromedial processes are not distinct. The supracleithrum is relatively small. The posterodorsal ramus of the cleithrum is not distinct. The ventral ramus of the cleithrum is highly expanded and bears a huge posteroventral extension and consists of a broad lateral and small medial and posteromedial flanges. The postcleithrum is elongated. The scapula is highly reduced and does not bear a foramen. The coracoid is also highly reduced and consists of a shaft and a dorsal flange. Actinost are tiny and autogenous, with hourglass shaped cores and dorsal

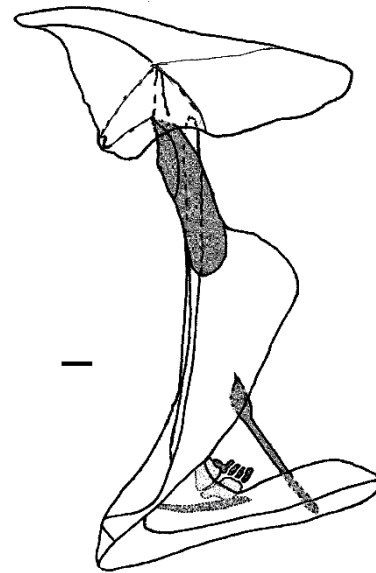and ventral laminae. Also see Kotlyar (1991a, b).



Figure 14.   Lateral view of the left pectoral girdle in *Rondeletia loricata* (AMS 20523001, 37 mm).

## Zeiformes

**Grammicolepididae:** *Xenolepidichthys dalgleishi* (Fig. 15). The extrascapulars are absent. The dorsal and ventromedial processes of posttemporal are not distinct. The supracleithrum is elongated. The anterodorsal ramus of the cleithrum is long and pointed, but the posterodorsal ramus is not distinct. The ventral ramus of cleithrum consists of lateral, medial, and posteromedial flanges. The postcleithrum is elongated and articulated with the cleithrum. The scapula articulates with the cleithrum anteriorly and bears a complete small foramen. The coracoid consists of a shaft and a dorsal flange and articulates with the cleithrum anterodorsally and anteroventrally and bears a posterior process. Actinost are autogenous, with hourglass shaped cores and dorsal and ventral laminae, and their size increases from the first to the fourth.

**Caproidae:** *Antigonia* sp. (Fig. 16). The extrascapulars are absent. The dorsal and ventromedial processes of the posttemporal are not distinct. The supracleithrum is elongated. The posterodorsal ramus of the cleithrum is pointed. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. The postcleithrum is relatively broad dorsally, but
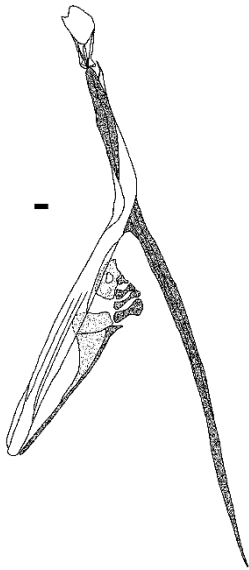
Figure 15.    Lateral view of the left pectoral girdle in *Xenolepidichthys dalgleishi* (USNM 322673, 68 mm).

elongated ventrally. The scapula articulates with the cleithrum anteriorly and bears a complete foramen. The coracoid consists of a shaft and a dorsal flange and weakly articulates with the cleithrum anterodorsally and bears a posterior process. Actinost are autogenous, with hourglass shaped cores and dorsal and ventral lamina, and their size increases from the first to the fourth. In Diretmidae, the ventral flange of coracoid is very large and all the actinosts are fused (Olney et al., 1993), although, in representatives of *Diretmoides* only the first actinost is fused (Moore, 1993). Also see Rosen (1964).
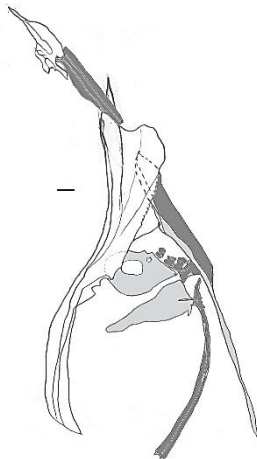


Figure 16.  Lateral view of the left pectoral girdle in *Antigonia* sp. (USNM 266901, 37 mm).

## Beryciformes
**Monocentridae:** *Monocentris* sp. (Fig. 17). A large

extrascapular is tightly attached to the cranium. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is relatively small. The posterodorsal ramus of the cleithrum is long and pointed. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. The postcleithrum is relatively broad and with an anterior strut. The scapula bears a complete small foramen. The coracoid consists of a shaft and dorsal and ventral flanges and articulates with the cleithrum anterodorsally and anteroventrally. The coracoid is larger than the scapula and bears a posterior process. Actinost are autogenous, with hourglass shaped cores and dorsal and ventral lamina, and their size increases from the first to the fourth. The dorsalmost ray is rudimentary.
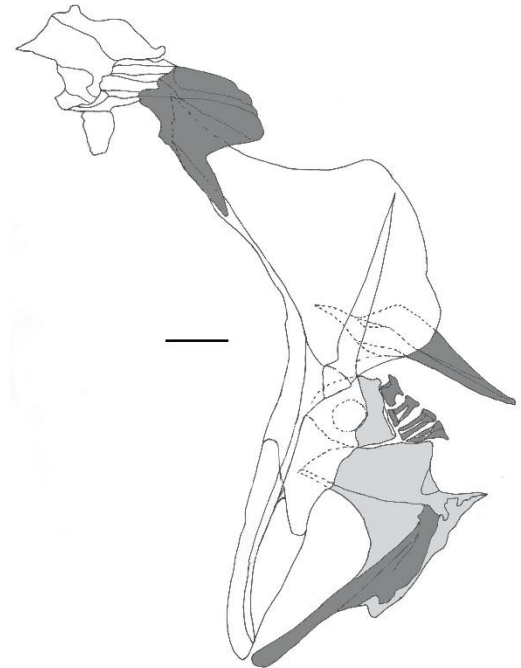


Figure 17.  Lateral view of the left pectoral girdle in *Monocentris* sp. (UAMZ 7854, 92 mm).

**Holocentridae:** *Sargocentron vexillarium* (Fig. 18). A large extrascapular is tightly attached to the cranium. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is broad. The posterodorsal ramus of the cleithrum is pointed. The ventral ramus of the cleithrum is divided into three struts ventrally and consists of lateral, medial, and posteromedial flanges. The

postcleithrum is relatively broad and bears an anterior strut. The scapula articulates with the cleithrum anteriorly and bears a complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges, and articulates with the cleithrum anterodorsally and anteroventrally. Actinosts are autogenous, with hourglass shaped cores and dorsal and ventral lamina, and their size increases from the first to the fourth. The dorsalmost ray is rudimentary. In *Ostichthys* the extrascapular is large, the dorsal postcleithrum is broad, and the ventral postcleithrum is long. In Anomalopidae, postcleithrum is broad and with a long anteroventral extension. In Diretmidae, the actinosts are located on the dorsal margins of the scapula and coracoid (Zehren, 1979). In Trachichthyidae, the extrascapular is large (Kotlyar, 1992; Zehren, 1979).
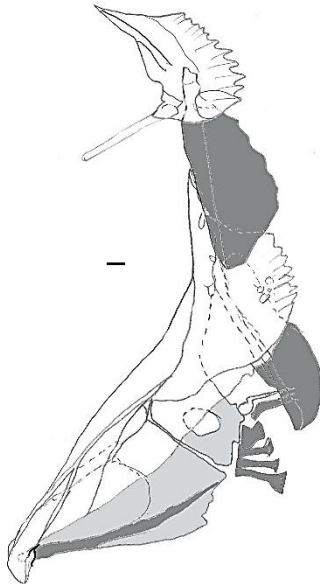


Figure 18. Lateral view of the left pectoral girdle in *Sargocentron vexillarium* (UAMZ 5075, 44 mm).

### Insertae sedis

**Elassomatidae:** *Elassoma zonatum* (Fig. 19). A triradiated extrascapular is present. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is broad and overlaps the cleithrum posteriorly. The anterodorsal ramus of the cleithrum is long and pointed. The ventral ramus of the cleithrum consists of narrow lateral, medial, and posteromedial flanges. The dorsal postcleithrum is broad and bears an anterior strut. The ventral

postcleithrum is broad but smaller and bears an elongated ventral extension. The scapula articulates with the cleithrum anteriorly and bears a small complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges, bears a small posterior process, and articulates with the cleithrum anterodorsally and anteroventrally. Actinosts are autogenous, consists of hourglass shaped cores and dorsal and ventral laminae, and their size increases from the first to the fourth. Also see Johnson and Springer (1997) and Jones and Quatrro (1999).
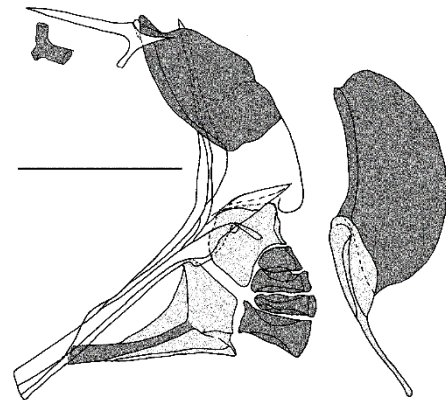


Figure 19. Lateral view of the left pectoral girdle in *Elassoma zonatum* (UAMZ 6920, 30 mm).

### Gasterosteiformes

**Hypoptychidae:** *Hypoptychus dybowskii* (Fig. 20). Two small extrascapulars are present. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is relatively small. The posterodorsal ramus of the cleithrum is pointed. The ventral ramus of the cleithrum is broad ventrally and consists of narrow lateral, medial, and posteromedial flanges. Postcleithra are absent. The scapula bears a complete foramen. The coracoid is broad and bears an incomplete foramen. Actinost are autogenous and rectangular. Also see Ida (1976).

**Gasterosteidae:** *Spinachia spinachia* (Fig. 21). The extrascapulars are absent. In *Spinachia*, dorsal and ventromedial processes of the posttemporal are absent. In *Apeltes*, the ventromedial process is absent. In *Gasterosteus*, *Culaea*, and *Pungitius*, the dorsal and ventromedial processes are distinct. The supracleithrum is relatively small. The anterodorsal ramus of the cleithrum is strongly pointed. The
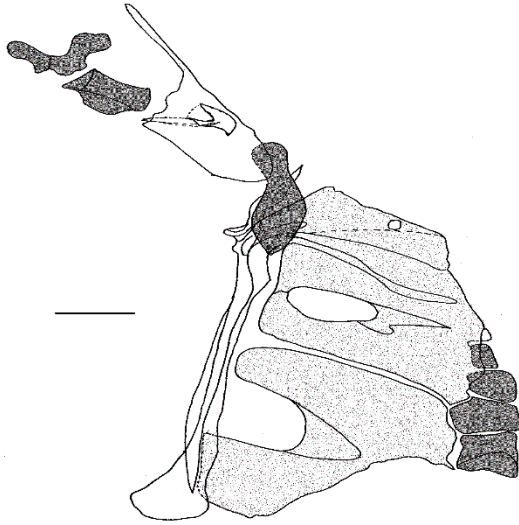
Figure 20. Lateral view of the left pectoral girdle in *Hypoptychus dybowskii* (UAMZ 5550, 80 mm).

ventral ramus of the cleithrum bears lateral, medial, and posteromedial flanges. The scapula articulates with the cleithrum dorsally and bears an incomplete foramen and posteriorly notched to receive the actinosts. The coracoid is broad and bears a foramen and an anteroventral shaft that articulates with the cleithrum anteriorly and with the ectocoracoid ventrolaterally. The ectocoracoid reaches the posterior end of the actinosts. Actinosts are autogenous, cuboidal, almost the same size, and are cartilage filled. The fourth actinost bears an anteroventral strut that articulates with the coracoid. The posttemporal and supracleithrum are absent in *Gasterosteus wheatlandi* (Nelson 1971). Also see Bown (1985, 1994), Orr (1995), Keivany (1996, 2000) and Keivany and Nelson (2004, 2006).

*Aulorhynchidae: Aulichthys japonicas* (Fig. 22). The extrascapulars are absent in *Aulorhynchus*, but a small triradiate extrascapular is present in *Aulichthys*. The posttemporal is elongated, bifurcated anteriorly, and its dorsal and ventral processes are not distinct. In *Aulichthys*, the posttemporal is broad and bears distinct dorsal and ventral processes. The supracleithrum is absent in *Aulorhynchus*, but a small supracleithrm is present in *Aulichthys*. The anterodorsal ramus of the cleithrum is short and pointed and the ventral ramus is divided into two parts ventrally and consists of
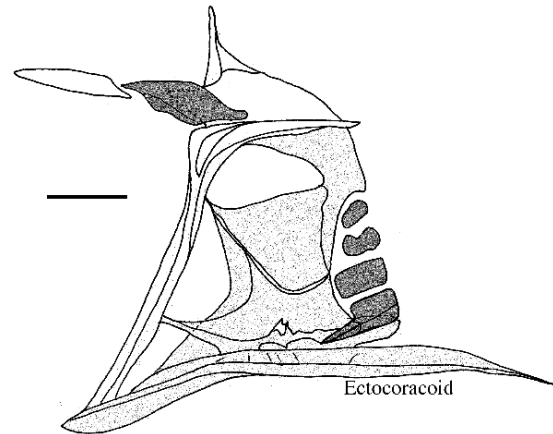


Figure 21. Lateral view of the left pectoral girdle in *Spinachia spinachia* (UAMZ 6582, 53 mm).

narrow lateral, medial, and posteromedial flanges. The scapula articulates with the cleithrum dorsally and bears an incomplete foramen. The coracoid is broad and bears an anteroventral extension that articulates with the cleithrum anteriorly and with the ectocoracoid ventrolaterally. The ectocoracoid which is known only in Aulorhynchidae, Gasterosteidae, and Aulostomoidea, is a superficially ornamented bone which extends along the coracoid and reaches posterior end of the actinosts. Actinosts are autogenous and with almost the same size, cuboidal in *Aulorhynchus*, but hourglass shaped with foramina in between in *Aulichthys*, and are cartilage filled. The fourth actinost bears an anteroventral strut that articulates with the coracoid.
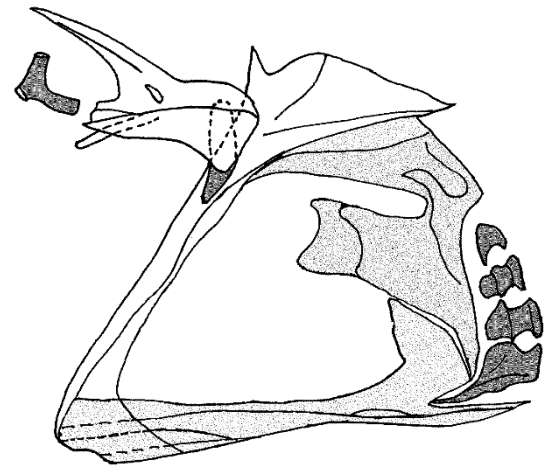


Figure 22. Lateral view of the left pectoral girdle in *Aulichthys japonicus* (UAMZ 5542, 47 mm).

**Indostomidae:** *Indostomus paradoxus* (Fig. 23). The extrascapulars are absent. The posttemporal is scute-like and with a distinct anteromedial process. The supracleithrum is small. The cleithrum is fused to body scutes. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. The postcleithra are absent. The scapula is rectangular and similar to the actinosts. The coracoid is funnel shaped and articulated with the cleithrum anteriorly and with the actinosts posteriorly. Actinosts are large, rectangular, and cartilaginously articulated together and to the coracoid, and except the first one which is smaller and fused to the scapula, are the same size. The fourth actinost sends a posteroventral extension to the coracoid. I agree with Banister (1970) and Bowne (1994) that the ectocoracoid-like scutes are not homologous with the ectocoracoid in sticklebacks, but disagree with them in the number of actinosts.
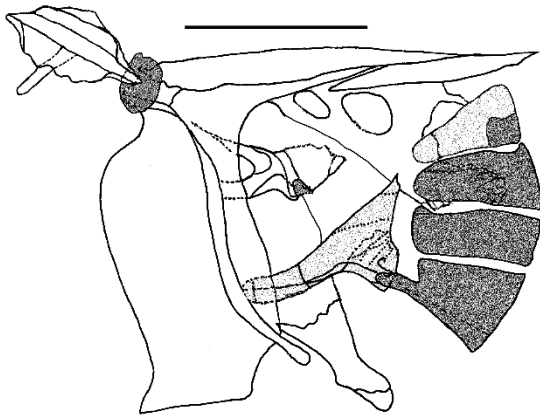


Figure 23. Lateral view of the left pectoral girdle in *Indostomus paradoxus* (CAS 64017, 25 mm).

**Pegasidae:** *Pegasus volans* (Fig. 24). The pectoral girdle is rotated laterally so that the original lateral surface becomes ventral. The extrascapulars are absent. The posttemporal is firmly sutured to the cranium and bears the dorsal and anteromedial processes. The supracleithrum is small. The posterodorsal ramus of the cleithrum is blunt. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges and it is divided ventrally. Postcleithra are absent. The scapula bears an incomplete foramen. The coracoid consists of a shaft and dorsal, ventral, and lateral flanges, sutured

to the scapula, and bears a posterior process. Actinosts are square and the same size. The first actinost is fused to the scapula and others are autogenous, but firmly connected to each other and to the coracoid. Also see Jungerson (1915) and Pietsch (1978).
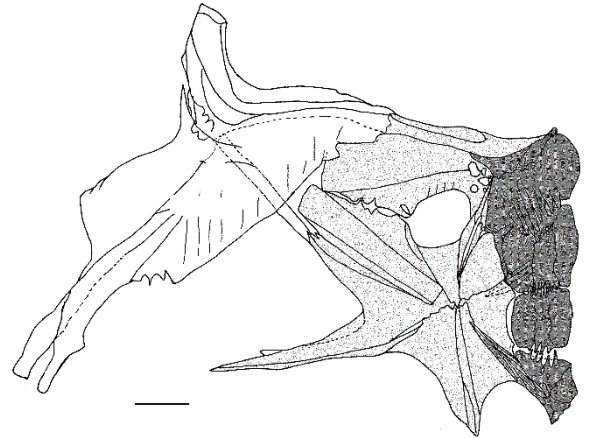


Figure 24. Lateral view of the left pectoral girdle in *Pegasus volans* (UAMZ 4616, 99 mm).

## *Syngnathiformes*

**Aulostomidae:** *Aulostomus valentini* (Fig. 25). The extrascapulars are absent. The posttemporal is laterally broad. The supracleithrum is absent. The posterodorsal ramus of the cleithrum is horizontal and articulated with the postcleithrum. The ventral ramus of the cleithrum bears lateral and posteromedial flanges which send a strut to the coracoid. The large sinusoidal postcleithrum originates on the posterodorsal end of the cleithrum and touches the ectocoracoid and extends posteriorly beyond it. The scapula articulates with the cleithrum dorsally and bears a complete foramen. The coracoid is broad and bears an anteroventral shaft that articulates with the cleithrum anteriorly and with the ectocoracoid laterally. The ectocoracoid is very long. The first actinost is smaller and tightly connected to the scapula, but others are autogenous, hourglass shaped, the same size, and cartilage filled.

**Fistulariidae:** *Fistularia petimba* (Fig. 26). The extrascapulars are absent. The posttemporal is fused to the cranium and bears distinct dorsal and anteroventral processes. A dorsolateral extension connects the posttemporal to the cranium. The
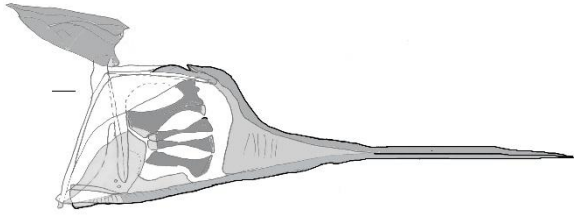
Figure 25. Lateral view of the left pectoral girdle in *Aulostomus valentini* (CAS 11979, 139 mm).

supracleithrum is very small. The anterodorsal ramus of the cleithrum is short and blunt. The posterodorsal ramus is horizontal and articulated with the postcleithrum. The ventral ramus of the cleithrum bears the lateral and posteromedial flanges which send a strut to the coracoid. A large postcleithrum originates on the posterodorsal end of the cleithrum and touches the ectocoracoid posteriorly. The scapula is indistinguishable from the actinosts and articulates with the cleithral posterodorsal ramus dorsally and with the posteromedial flange anteroventrally, making a foramen in between. The coracoid is broad and bears an anteroventral shaft that articulates with the cleithrum anteriorly and with the ectocoracoid ventrolaterally. The ectocoracoid is long and expanded posteriorly. The first actinost is small and articulated with the scapula, but others are autogenous, hourglass shaped, the same size, and cartilage filled.
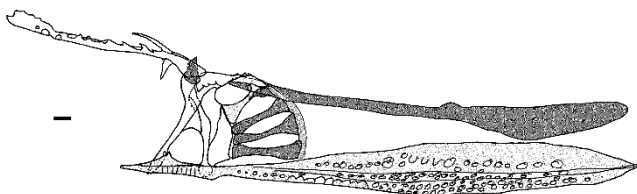


Figure 26. Lateral view of the left pectoral girdle in *Fistularia petimba* (UAMZ 6348, 158 mm).

**Centriscidae:** *Aeoliscus strigatus* (Fig. 27). The extrascapulars are absent. The posttemporal is sutured to the cranium. The supracleithrum is sutured to the body plates and lies entirely on the cleithrum. The anterodorsal ramus of the cleithrum is short and blunt and the posterodorsal ramus is horizontal. The ventral ramus of cleithrum is divided into anterolateral and posteromedial struts and bears lateral and posteromedial flanges. The sinusoidal

postcleithrum originates on the posterodorsal end of the cleithrum and is oriented posteriorly. The scapula articulates with the cleithrum anteriorly and bears a tiny foramen. The coracoid is broad and bears an anteroventral extension that articulates with the cleithrum anteriorly and bears a posterior process. The ectocoracoid is absent. Actinosts tightly articulate with the scapula and consist of hourglass shaped cores and dorsal and ventral laminae. Distally, actinosts are bend 90° laterally. The fourth actinost is larger and sends an anteroventral strut to the coracoid. The dorsalmost ray is rudimentary. Also see Mohr (1937).
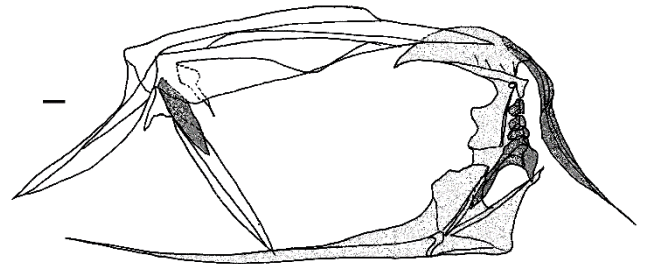


Figure 27. Lateral view of the left pectoral girdle in *Aeoliscus strigatus* (UAMZ 4048, 89 mm).

*Macroramphosus scolopax* (Fig. 28). The extrascapulars are absent. The posttemporal is fused to the cranium. The supracleithrum is relatively small and entirely lies on the cleithrum. The anterodorsal ramus of the cleithrum is short and blunt and the posterodorsal ramus is horizontal and articulates with the postcleithrum. The ventral ramus of the cleithrum bears lateral and posteromedial flanges. The broad postcleithrum originates on the posterodorsal end of the cleithrum and is oriented posteriorly. The scapula articulates with the cleithrum anteriorly and bears a complete foramen. The coracoid is broad and bears an anteroventral extension that articulates the cleithrum anteriorly and for its entire length with its counterpart ventrally. The ectocoracoid is absent. Actinosts are small and tightly articulated with the scapula, with hourglass shaped cores and dorsal and ventral laminae, and all the same size. The fourth actinost sends an anteroventral strut to the coracoid. The dorsalmost ray is rudimentary.

Figure 28.    Lateral view of the left pectoral girdle in *Macroramphosus scolopax* (USNM 344398, 99 mm).

**Solenostomidae:** *Solenostomus paradoxus* (Fig. 29). The extrascapulars are absent. The posttemporal is pyramidal and its dorsal and ventromedial processes are distinct. The supracleithrum is flat and relatively small. The posterodorsal ramus of the cleithrum is horizontal and sends a flange over the scapula. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. A spike borders the posteromedial flange which articulates with the coracoid. Postcleithra are absent. The scapula is indistinguishable from the actinosts and articulates with the cleithrum anterodorsally and anteroventrally. The coracoid consists of a shaft and a dorsal flange and weakly articulates with the cleithrum anterodorsally and anteroventrally and bears a long posterior process. Actinosts are autogenous, hourglass shaped, cartilage filled, and almost the same size.

**Syngnathidae:** *Syngnathus griseolineatus* (Fig. 30). The extrascapulars are absent. The posttemporal is convex and its dorsal and ventromedial processes are not distinct. The supracleithrum is absent. The dorsal rami of the cleithrum are horizontal. The ventral ramus of the cleithrum is bifurcated ventrally and consists of lateral, medial, and posteromedial flanges. The postcleithra are absent. The scapula is indistinguishable from the actinosts and articulates with the cleithrum. The coracoid consists of a shaft
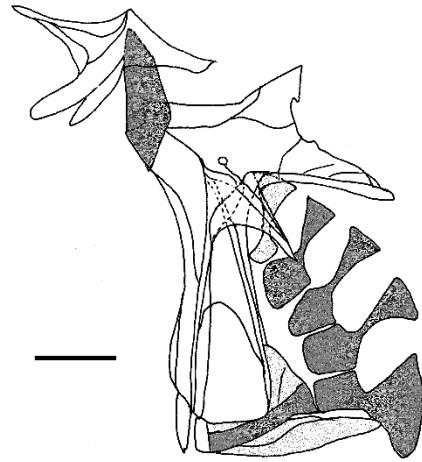


Figure 29.  Lateral view of the left pectoral girdle in *Solenostomus paradoxus* (AMS 17111002, 51 mm).

and dorsal and ventral flanges and weakly articulates with the cleithrum. Actinosts are autogenous, hourglass shaped, and relatively the same size. For the order also see Bowne (1985, 1994).
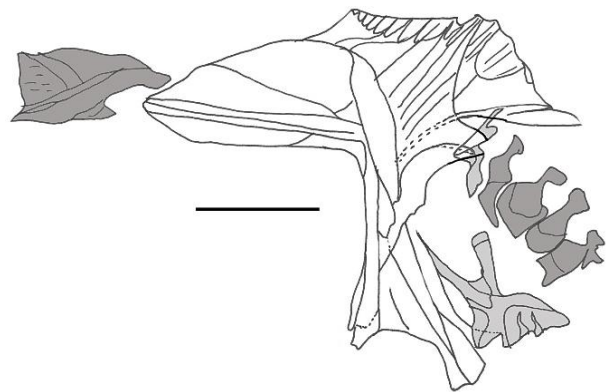


Figure 30.  Lateral view of the left pectoral girdle in *Syngnathus griseolineatus* (UAMZ 3469, 272 mm).

**Synbranchiformes**

**Synbranchidae:** *Monopterus albus* (Fig. 31). The extrascapulars are absent. The posttemporal bears distinct dorsal and anteromedial processes. The supracleithrum is present. The cleithrum is a simple curved bone with a small lateral flange. The postcleithra, scapula, coracoid, actinosts, and rays are absent.

**Mastacembelidae:** *Macrognathus aculeatus* (Fig. 32). The extrascapulars are absent. The posttemporal is small and cylindrical. The supracleithrum is elongated. The cleithrum is broad laterally and its dorsal rami are not distinct. The ventral ramus of the cleithrum consists of lateral and medial flanges. The
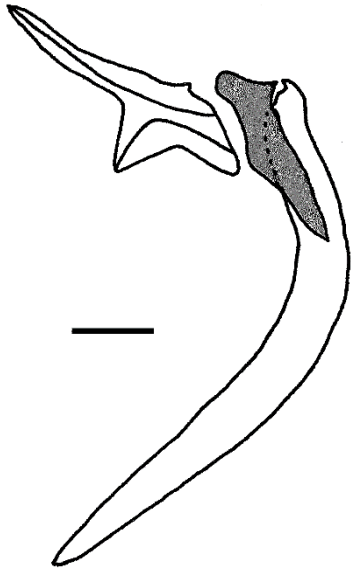
Figure 31.  Lateral view of the left pectoral girdle in *Monopterus albus* (USNM 192939, 193 mm).



Figure 32.  Lateral view of the left pectoral girdle in *Macrognathus aculeatus* (UAMZ 1855, 119 mm).

postcleithra are absent. The scapula articulates with the cleithrum anteriorly and bears a complete foramen. The coracoid consists of a shaft and a dorsal flange, articulates with the cleithrum anteriorly, and bears a posterior process. Actinosts are autogenous, with hourglass shaped cores and dorsal and ventral laminae, and their size increases from the first to the fourth. Similar pectorals are found in specimens of *Mastacembelus*, but some have an extra element before the posttemporal that might be homologous to the extrascapula, however, Travers (1984) called it the posttemporal. For other families of the order also see Rosen and Greenwood (1976), Gosline (1982) and Britz and Kottelat (2003).

## Scorpaeniformes

**Scorpaenidae:** *Sebastes caurinus* (Fig. 33). Two autogenous extrascapulars are present. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is relatively large. The anterodorsal ramus of the cleithrum is short and pointed, but the posterodorsal ramus is not distinct. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. The dorsal postcleithrum is broad and bears an anterior strut, but the ventral postcleithrum is elongated. The scapula articulates with the cleithrum dorsally, and
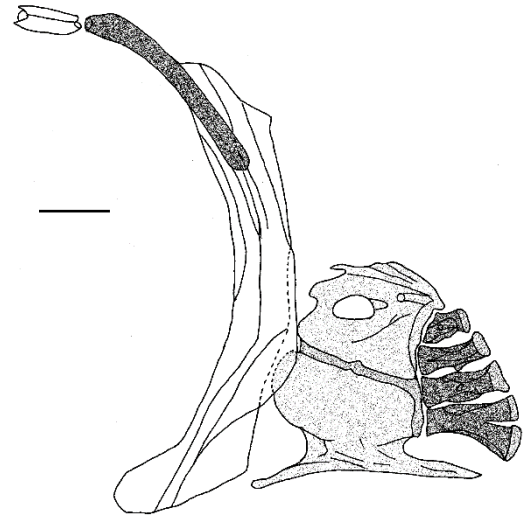
anteriorly, and bears a complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges and articulates the cleithrum anterodorsally and anteroventrally. The first actinost is fused to the scapula and the other three are autogenous, hourglass shaped, and their size increases from the first to the fourth.
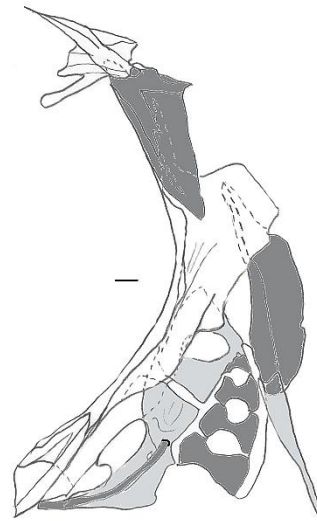


Figure 33.  Lateral view of the left pectoral girdle in *Sebastes caurinus* (UAMZ 3142, 75 mm).

**Dactylopteridae:** *Dactylopterus volitans* (Fig. 34). The pectoral girdle is rotated laterally so that the original lateral surface becomes ventral. The extrascapulars are absent. The posttemporal is firmly sutured to the cranium and bears a distinct anteromedial process. The supracleithrum is small

and does not articulate with the posttemporal. The anterodorsal ramus of the cleithrum is long and pointed and articulates with the posttemporal. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. The postcleithrum is elongated and bears a small triangular head. The scapula articulates with the cleithrum dorsally and anteriorly, and bears a complete foramen and sends spikes to the coracoid posteriorly. The coracoid consists of a shaft and dorsal and ventral flanges and bears a posterior process. Actinosts are tipped with cartilage from both sides, autogenous, hourglass shaped, and their size increases from the first to the fourth. The dorsalmost ray is rudimentary.
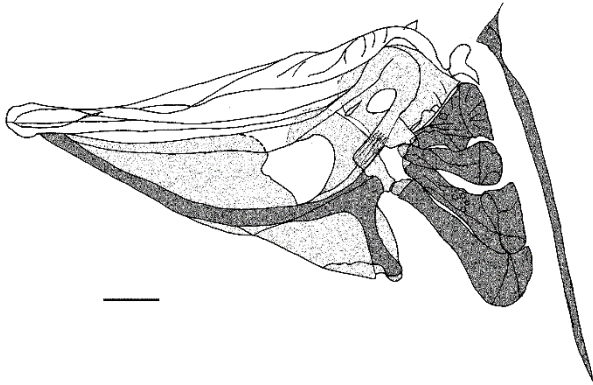


Figure 35. Lateral view of the left pectoral girdle in *Hexagrammos decagrammus* (UAMZ 3190, 50 mm).



Figure 34. Lateral view of the left pectoral girdle in *Dactylopterus volitans* (UAMZ 2633, 74 mm).

**Hexagrammidae:** *Hexagrammos decagrammus* (Fig. 35). Two autogenous extrascapulars are present. The dorsal and ventromedial processes of posttemporal are distinct. The supracleithrum is broad and overlaps the cleithrum and postcleithrum posteriorly. The anterodorsal ramus of the cleithrum is long and pointed, but the posterodorsal ramus is not distinct. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. The dorsal and ventral postcleithra are elongated. The scapula bears an incomplete foramen. The coracoid consists of a shaft and dorsal and ventral flanges and articulates with the cleithrum anteriorly. Actinosts are autogenous, hourglass shaped, and their size increases from the first to the fourth. Also see Shinohara (1994).
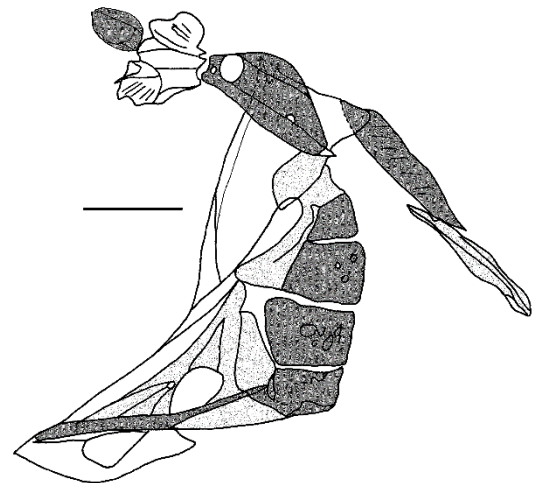
**Agonidae:** *Xeneretmus latifrons* (Fig. 36). An



Figure 36. Lateral view of the left pectoral girdle in *Xeneretmus latifrons* (UAMZ 3196, 95 mm).

extrascapular is present. The posttemporal is firmly sutured to the cranium and does not bear a distinct anteromedial process. The supracleithrum is small. The anterodorsal ramus of the cleithrum is pointed. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. Both postcleithra are relatively broad. The scapula articulates with the cleithrum dorsally and anteriorly and bears an incomplete foramen. The coracoid consists of a shaft and dorsal and ventral flanges and bears a posterior process. The first actinost is smaller and fused to the scapula, but others are autogenous, square, and the same size.
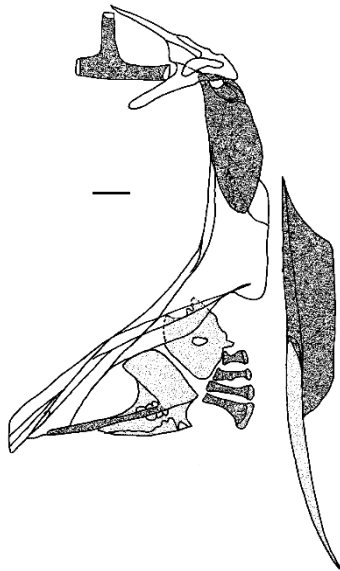
Figure 37. Lateral view of the left pectoral girdle in *Lepomis gibbosus* (UAMZ 7715.4, 40 mm).
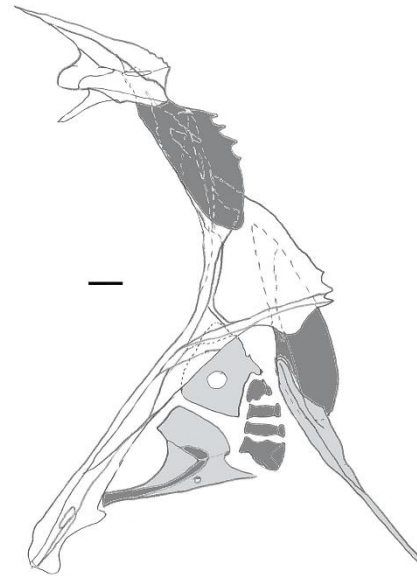


Figure 38. Lateral view of the left pectoral girdle in *Perca flavescens* (UAMZ 1244, 54 mm).

The same conditions are found in other agonids, but in members of some genera the first actinost is not fused (Kanayama, 1991). In Cottoidea, scapula and coracoid are reduced, but actinosts enlarged and constitute most of the pectoral girdle (Yabe, 1981; Yabe, 1985; Yabe, 1983; Yabe, 1991; Jackson and Nelson, 1998). Also see Washington et al. (1984), Stein et al. (1991), Balushkin (1996) and Yabe and Uyeno (1996).

### Perciformes

*Centrarchidae: Lepomis gibbosus* (Fig. 37). A triradiated extrascapular is present. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is broad. The anterodorsal ramus of the cleithrum is pointed. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. The dorsal postcleithrum is broad and bears an anterior strut, but the ventral postcleithrum is elongated. The scapula articulates with the cleithrum anteriorly, and bears a small complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges, bears a posterior process, and articulates with the cleithrum anterodorsally and anteroventrally. Actinosts are autogenous, hourglass shaped, and their size increases from the first to the fourth. The dorsalmost ray is shorter than the next ray.

In general, perciforms have extrascapulars, a posttemporal with distinct processes, a medium size supracleithrum, a cleithrum with medial, lateral, and posteromedial flanges, a broad dorsal postcleithrum and an elongated ventral postcleithrum, well developed scapula and coracoid, and four autogenous actinosts (Ida, 1976; Gill and Mooi, 1993; Bellwood, 1994; Matsuoka, 1985; Pietsch, 1989; Sasaki, 1989; Simons, 1991; Simons, 1992). However, there are some variations in the number, shape and size of the extrascapulars and postcleithra and shape and size of the actinosts and supracleithra (Doyle, 1998; Mok, 1983; Springer, 1993).

*Percidae: Perca flavescens* (Fig. 38). A triradiate extrascapular is present. The dorsal and ventromedial processes of posttemporal are distinct. The supracleithrum is broad and overlaps the cleithrum posteriorly. The anterodorsal ramus of the cleithrum is pointed. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. The dorsal postcleithrum is broad and bears an anterior strut, but the ventral postcleithrum is elongated. The scapula articulates with the cleithrum anteriorly, and bears a small, complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges, bears a posterior process, and articulates with the cleithrum

anterodorsally and anteroventrally. Actinosts are autogenous, hourglass shaped, and their size increase from the first to the fourth.

*Cirrhitidae: Amblycirrhitus pinos* (Fig. 39). A triradiated extrascapular is present. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is broad and overlaps the cleithrum posteriorly. The anterodorsal ramus of the cleithrum is pointed. The ventral ramus of the cleithrum is widely divided and consists of lateral, medial, and posteromedial flanges. The dorsal postcleithrum is broad and bears an anterior strut, but the ventral postcleithrum is elongated. The scapula articulates with the cleithrum anteriorly and bears a small complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges, bears a posterior process, and articulates with the cleithrum anterodorsally and anteroventrally. Actinosts are autogenous, hourglass shaped, and their size increases from the first to the fourth.
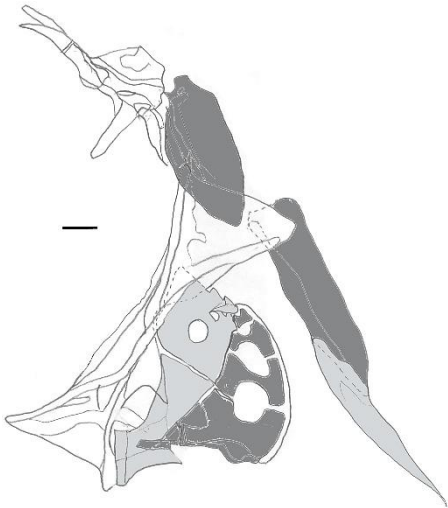


Figure 39.    Lateral view of the left pectoral girdle in *Amblycirrhitus pinos* (UAMZ 3640, 45 mm).

*Mugilidae: Mugil* sp. (Fig. 40). Three extrascapulars are present. The dorsal and ventromedial processes of posttemporal are distinct. The supracleithrum is relatively small. The anterodorsal ramus of the cleithrum is short and pointed, but the posterodorsal ramus is not distinct. The ventral ramus of the cliethrum consists of lateral and posteromedial flanges. The dorsal postcleithrum is broad and bears an anterior strut and the ventral postcleithrum is

elongated. The scapula articulates with the cleithrum dorsally and anteriorly and bears a complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges, and articulates with cleithrum anterodorsally and anteroventrally. The coracoid is highly notched to receive the fourth actinosts. Actinosts are autogenous, with hourglass shaped cores and dorsal and ventral lamina, and their size slightly increases from the first to the fourth. The dorsalmost ray is rudimentary. Also see Stiassny (1993).
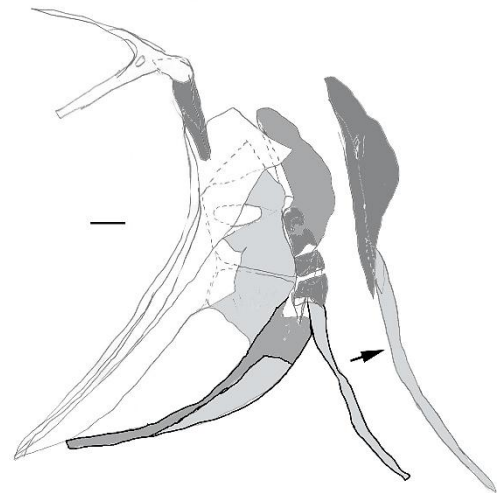


Figure 40.   Lateral view of the left pectoral girdle in *Mugil* sp. (UAMZ 5125, 66 mm).

*Pomacentridae* (Fig. 41). A triradiated extrascapular is present. The dorsal and ventromedial processes of the posttemporal are distinct. The supracleithrum is broad. The anterodorsal ramus of the cleithrum is pointed. The ventral ramus of the cleithrum consists of lateral, medial, and posteromedial flanges. The dorsal postcleithrum is broad and bears an anterior strut, but the ventral postcleithrum is elongated. The scapula articulates with the cleithrum anteriorly and bears a small complete foramen. The coracoid consists of a shaft and dorsal and ventral flanges, bears a posterior process, and articulates with the cleithrum anterodorsally and anteroventrally. Actinosts are autogenous, hourglass shaped, and their size increases from the first to the fourth. The dorsalmost ray is shorter than the next ray. For other members of the order, also see Potthoff (1980), Simons (1991, 1992), Westneat (1993), Gill and
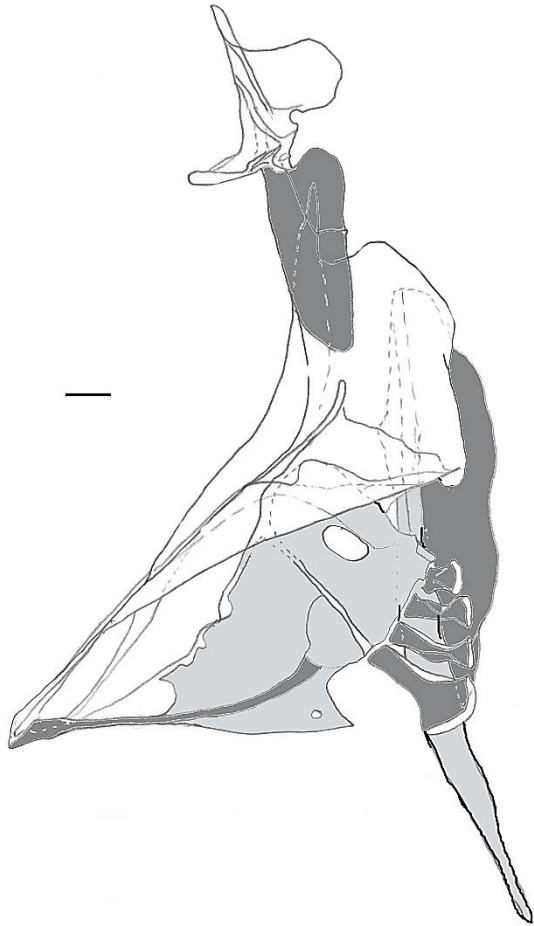
Figure 41. Lateral view of the left pectoral girdle in *Stegastes partitus* (UAMZ 3640, 34 mm).

Mooi (1993), Bellwood (1994), Gomon (1997) and Jackson and Nelson (1998).

## Acknowledgements

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