

DEVELOPMENT AND STRUCTURE OF FINS AND FIN SUPPORTS IN DOLPHIN FISHES *CORYPHAENA HIPPURUS* AND *CORYPHAENA EUISELIS* (CORYPHAENIDAE)¹

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ABSTRACT

The development and structure of the fins and fin supports were studied from a cleared and stained size series of about 400 *Coryphaena hippurus* and about 400 *C. equiselis*. *Coryphaena hippurus* and *C. equiselis* differ in all aspects of fin ray and fin support development; *C. equiselis* is always more advanced than equal-sized *C. hippurus* during development. The species differ in number of fin rays in the single dorsal fin. The pterygiophores of the single dorsal fin each develop from a single cartilage in both species. The cartilage then ossifies to proximal and distal radials. Each fin ray is serially associated with a distal and proximal radial, and each ray is secondarily associated with the following (posterior) proximal radial. Exceptions were found at the anteriormost and posteriormost parts of the dorsal fin. The two species differ only slightly in anal fin ray counts. The pterygiophores of the anal fin are similar in development and structure to those of the dorsal fin. The species do not differ in caudal fin ray counts. The caudal fin rays are supported by some of the bones of the caudal complex, which contains one neural spine, one specialized neural arch, two autogenous haemal spines, one autogenous parhypural bone, five autogenous hypural bones, two paired uroneural bones, and two epural bones. During development, hypurals one and two and hypurals three and four fuse, forming the dorsal and ventral hypural plates. The two epurals fuse into one and the two pairs of uroneurals form one pair. Both species have the same number of pectoral fin rays. In both species, pectoral fin rays are directly supported by the scapula and four radials, and indirectly by the cleithrum and the coracoid. The pectoral suspensorium, which consists of seven bones, connects the pectoral bones to the skull. The posterior process of the coracoid develops as a prominent larval structure that disappears during development. The pelvic fins of both species have one spinous and five soft rays. These fin rays are supported on each side by the pelvic basipterygium. The basipterygium develops in similar fashion to a pterygiophore.

The development and anatomy of the fins and fin supports for *Coryphaena hippurus* and *C. equiselis* have not been described. The purpose of this study was to document the development and anatomy of the fins and fin supports for the family Coryphaenidae and to point up differences in meristic counts and arrangement of fin rays and supporting bones between the two species of *Coryphaena* using cleared and stained material.

No complete study of the fins and fin supports for the two *Coryphaena* species has been done. Studies on the osteology and meristic counts exist without use of cleared and stained material. Jordan and Evermann (1896), Nichols (1909), Gibbs and Collette (1959), Rothschild (1964), Miller and Jorgenson (1973), and Shcherbachev (1973) have published meristic counts for the two

species. Clothier (1950) gave the meristic counts and an illustration of the head and the vertebral column for *C. hippurus*. Potthoff (1971), using cleared and stained material, studied meristic counts of *C. equiselis*. Collette et al. (1969) reported the vertebral numbers of the two species, and Gregory (1933) depicted the skull of *C. hippurus* and commented on the phylogenetic relationship of *C. hippurus*. Starks' (1930) description of the pectoral girdle of *C. hippurus* was presented without illustrations.

Many publications deal with the biology (age, growth, reproduction, food) of *Coryphaena* spp., usually *C. hippurus* (Schuck 1951; Williams and Newell 1957; Gibbs and Collette 1959; Kojima 1961, 1963a, b, 1964; Beardsley 1967; Rose and Hassler 1968, 1974; Shcherbachev 1973; Takahashi and Mori 1973). Others document the distribution of *Coryphaena* spp., most often that of *C. hippurus* (Williams 1953; Morrow 1954; Pew 1957; Gibbs and Collette 1959; Kojima 1960, 1964; Tibbo 1962; Shcherbachev 1973; Takahashi and Mori

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1973). Mito (1960) described the eggs and hatched larvae of *C. hippurus*, and Gibbs and Collette (1959) described large larvae and juveniles of both *Coryphaena* species. Hassler and Rainville³ described the rearing techniques for *C. hippurus* from planktonic eggs and the subsequent growth to juveniles. Burnett-Herkes (1974) worked on *C. hippurus* parasites of the gills and mouth.

METHODS

Size series of 400 specimens of each species were cleared and stained by the enzyme method of Taylor (1967). The bones of four adult specimens (two *C. hippurus* and two *C. equiselis*) were prepared by boiling in water and removing the boiled flesh. Almost all specimens had been caught in the west Atlantic, Gulf of Mexico, and the Caribbean. A few specimens were from the mid-Atlantic, the east Atlantic, and the east Pacific.

For each fin and fin support system, a representative size series was chosen for each species from the cleared and stained material (Table 1). Thus, the same specimen did not necessarily contribute to each of the series.

The terms preflexion, flexion, and postflexion refer to the flexion state of the notochord in the caudal region during larval development. They are used to describe and highlight larval stages based on Ahlstrom et al. (1976).

Only cleared and stained specimens were measured. Preserved larvae were usually too distorted for accurate measurements, but were easily straightened and measured after clearing and staining. Measurements were to the nearest 0.1 of a millimeter using a calibrated ocular micrometer

³Hassler, W. W., and R. P. Rainville. 1975. Techniques for hatching and rearing dolphin, *Coryphaena hippurus*, through larvae and juvenile stages. Univ. N.C., Sea Grant Program UNC-SG-75-31, 17 p.

TABLE 1.—Number and length range (in millimeters NL or SL) of cleared and stained specimens of *Coryphaena* spp. used for study of individual fins and their support structures.

Item	<i>C. hippurus</i>		<i>C. equiselis</i>	
	No.	Length	No.	Length
Dorsal fin	211	5.0-172	161	6.5-230
Pterygiophores	216	5.0-176	197	6.5-230, 314
Anal fin	212	5.0-172	157	6.5-230
Pterygiophores	216	5.0-176	197	6.5-230, 314
Caudal fin	201	5.0-172	138	6.5-230
Caudal complex	47	5.0-172, 690	45	6.5-230, 330
Pectoral fin and supports	123	5.0-172	164	6.5-230
Pelvic fin and supports	105	6.0-176, 449, 920	76	7.0-172, 315, 330

for the smaller specimens (< 20 mm SL) and dial calipers for the larger ones. Each measurement was either notochord length (NL, from the anterior tip of the upper jaw to the posteriormost tip of the notochord) for preflexion and early flexion larvae, or standard length (SL, from the anterior tip of the upper jaw to the posteriormost edge of the hypural bones) for late flexion and postflexion larvae, juveniles, and adults.

All specimens were examined in 100% glycerin under a binocular microscope, and illustrations were drawn with the help of a camera lucida. Ossification was determined from the uptake of alizarin. Very light uptake (pink) of alizarin in a structure was considered as onset of ossification. Cartilage was determined by the presence of structure but absence of red stain, and viewed by carefully manipulating the illumination with the substage mirror. Specimens from which organic calcium had leached due to acid Formalin⁴ did not stain and were not used.

The caudal complex terminologies follow Gosline (1961a, b), Nybelin (1963), and Monod (1968).

Counts of pterygiophores and fin rays include very small and vestigial structures such as fin rays that consisted only of a left or right half, or of two pieces not joined at the center.

RESULTS

Vertebral Column

The development and structure of the vertebral column was not examined in this study. However, it was noted that development is similar in all respects for the two *Coryphaena* species as it was reported for *Thunnus atlanticus* (Potthoff 1975).

Neural and haemal spines developed from cartilage before pterygiophores, but were difficult to count accurately. In small specimens (5.9-6.3 mm NL) interneural and interhaemal space numbers were estimated from myomere counts.

Dorsal Fin

The fully developed dorsal fin of *C. hippurus* has 58-66 rays ($N = 99$, $\bar{x} = 61.3$, $SE = 0.17$, 24-172 mm SL) and that of *C. equiselis* 52-59 rays ($N = 113$, $\bar{x} = 55.0$, $SE = 0.15$, 18-230 mm SL). Adult counts for *C. hippurus* are obtained be-

⁴Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

tween 18 and 24 mm SL and for *C. equiselis* between 13 and 18 mm SL (Figure 1). Gibbs and Collette (1959) reported 46-65 ($\bar{x} = 58.4$) dorsal fin rays for *C. hippurus* and 48-60 ($\bar{x} = 52.6$) for *C. equiselis*. My counts and those of Gibbs and Collette (1959) differ because Gibbs and Collette included counts of small specimens (from about 12 mm SL) of both species in their sample and because *C. equiselis* develops a full complement of dorsal fin rays at a smaller size than *C. hippurus* (13-17 mm SL vs. 18-23 mm SL); therefore, more *C. hippurus* than *C. equiselis* with incomplete dorsal fins were counted by Gibbs and Collette, and inclusion of incomplete dorsal fin ray counts widened the range of counts and lowered the mean number of dorsal fin rays. Dorsal fin ray counts reported by Shcherbachev (1973) (46-67 for *C. hippurus* and 48-60 for *C. equiselis*) are from his own data and those of Gibbs and Collette. Rothschild (1964) reported 54-58 ($\bar{x} = 57.9$) for adult

C. equiselis, all from the Pacific Ocean. Here, count differences probably resulted from the method of counting (cleared and stained vs. preserved material) but may also have been due to population differences.

Dorsal fin rays were first seen in *C. hippurus* at 6 mm SL and were present in all specimens at 8 mm SL (Figure 1). The smallest specimen of *C. equiselis* (6.5 mm SL) already had 12 dorsal fin rays. Development of the dorsal fin rays for both species started in the dorsal finfold at the posterior third of the body (Figure 2). This was above the 22d-24th myomere for three *C. hippurus* with only 3 or 4 dorsal fin rays. With growth, addition of dorsal fin rays was in an anterior and posterior direction for both species, but more fin rays were added anteriorly (Figure 2). The dorsal fin, despite the more rapid addition of rays anteriorly, reached completion posteriorly at a smaller size of the larvae than anteriorly. This is because more

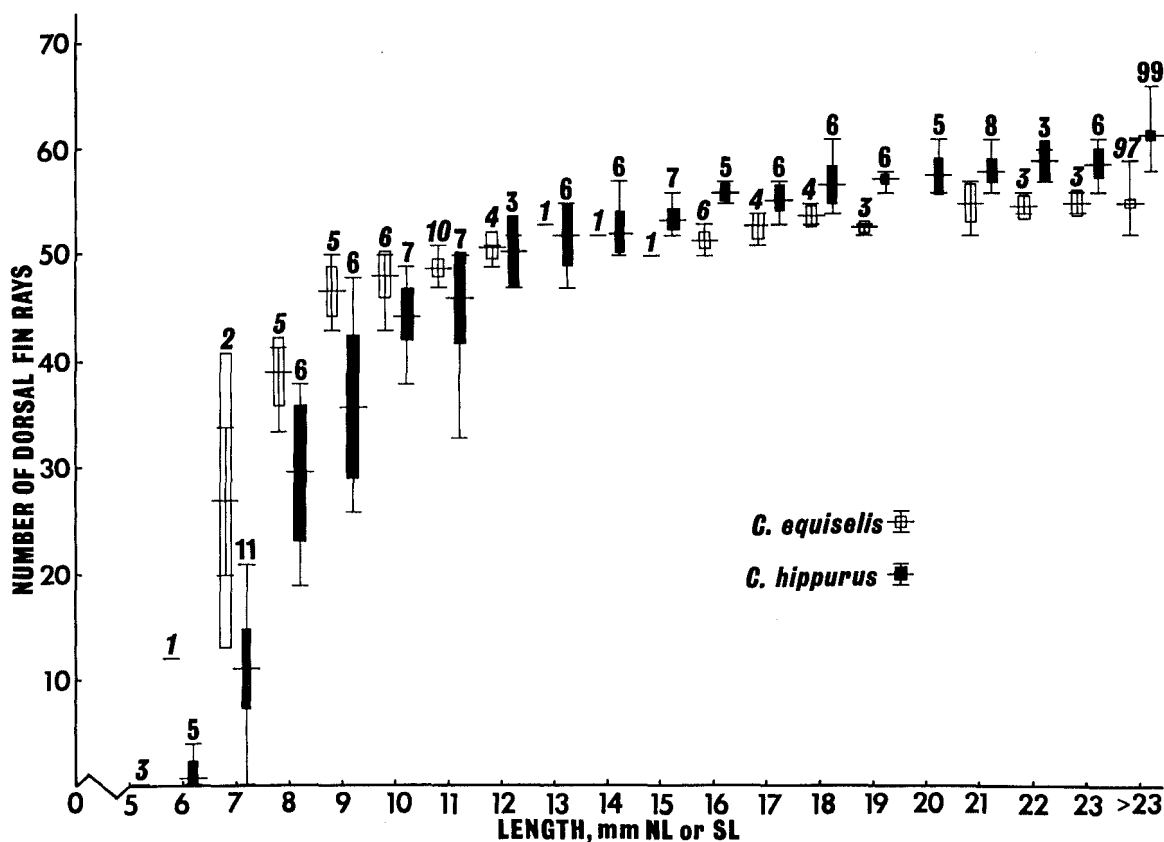
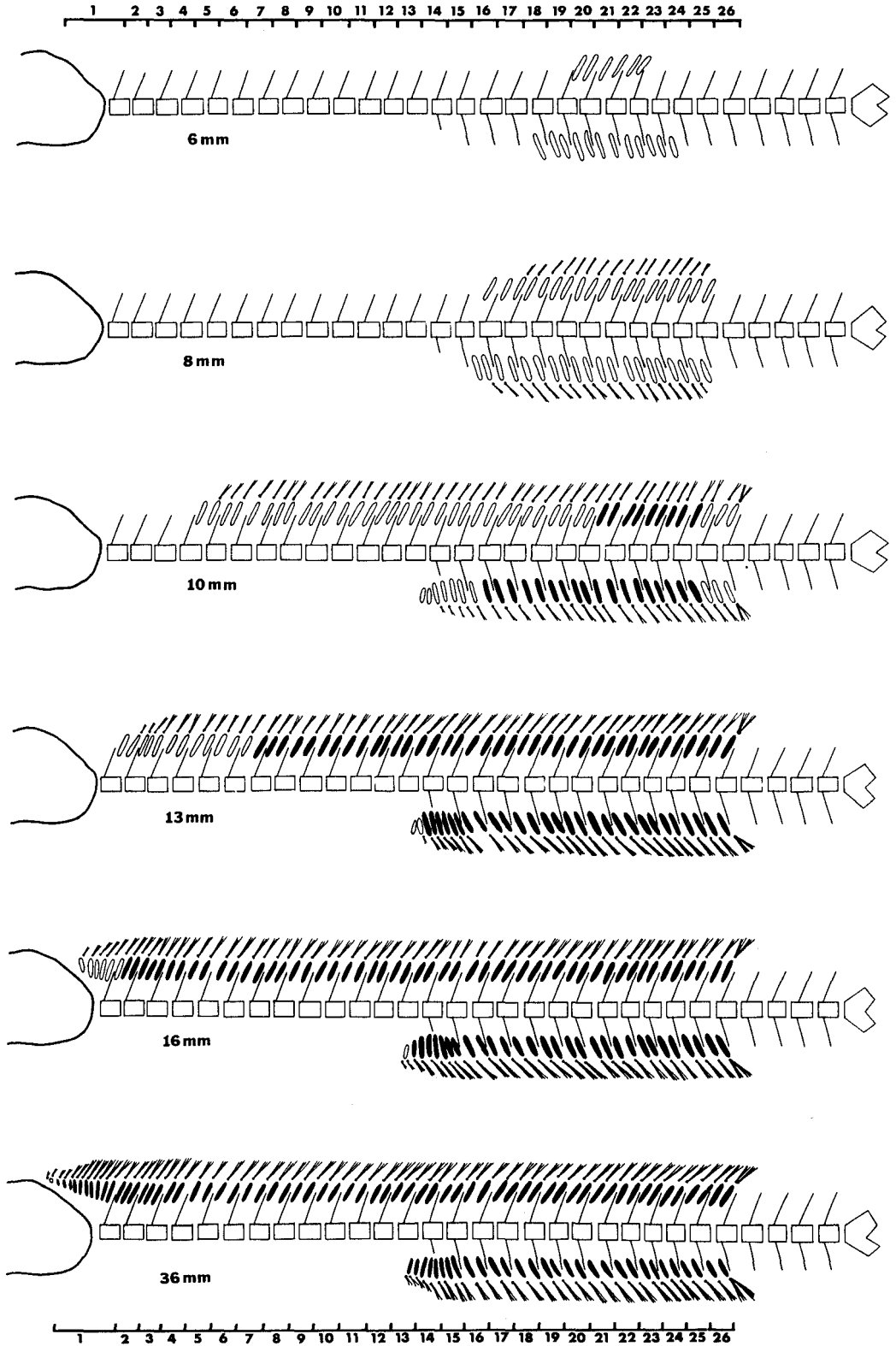


FIGURE 1.—Number of dorsal fin rays in relation to length in 161 *Coryphaena equiselis* (6.5-230 mm NL or SL) and 211 *C. hippurus* (5.0-172 mm NL or SL). Range (vertical line), mean (horizontal line), and 2 standard errors about the mean (white and black bars) are indicated. Number of specimens for each length interval is given above the range and is in italics for *C. equiselis*.



pterygiophores had to be added from place of origin anteriorly than posteriorly. Small *C. hippurus* (5 mm NL-11 mm SL) usually had fewer fin rays compared to equal-sized *C. equiselis* (Figure 1). Between 12 and 14 mm SL both species had about equal dorsal fin ray numbers. Specimens of *C. hippurus* 15 mm SL and longer usually had more dorsal fin rays than equal-sized *C. equiselis*.

The developmental sequence of dorsal fin rays in *Coryphaena* spp. is similar to that observed in *Trachurus symmetricus* (Ahlstrom and Ball 1954), *Haemulon plumieri* (Saksena and Richards 1975), and *Archosargus rhomboidalis* (Houde and Potthoff 1976). It is as though *Coryphaena* spp. is developing two dorsal fins in the same pattern of the above examples, e.g., first the second dorsal fin followed by the first dorsal. It is of interest to note that most scombroids do not follow this pattern and develop the first dorsal fin first (Voss 1954; Potthoff 1975).

Dorsal Fin Pterygiophores

Counts

There was a supporting pterygiophore in both species of *Coryphaena* in a jointed series for each dorsal fin ray, except for the first two or three anteriormost rays. Each pterygiophore had a proximal and a distal radial. The distal radial was located between the bifurcate base of the fin ray. Proximal and distal radial and fin ray formed a series, hence, a serial association. Each fin ray also closely approximated the following posterior pterygiophore in a secondary association. Thus, each pterygiophore supported a ray in a serial association and an immediately anterior ray in a secondary association. The exceptions were found at the beginning and the end of the fin. The anteriormost pterygiophore supported from one to three rays, but most often two rays (Table 2). Also, in 2 out of 70 specimens of both species, no rays were associated with the anteriormost pterygiophore, and the pterygiophore was very small and almost a vestige. The posteriormost ray in the dorsal fin was a double ray which was serially

FIGURE 2.—Schematic representation of dorsal and anal fin and pterygiophore development in *Coryphaena hippurus* in relation to the vertebral column and head. Oval-shaped representation of pterygiophores are cartilaginous when white and ossifying when black. Scale represents interneural and interhaemal spaces and points align with midpoint of vertebral centra.

TABLE 2.—Number (adult count) of anteriormost dorsal fin rays without distal radials and number of dorsal fin rays associated with the anteriormost dorsal fin pterygiophore for 28 *Coryphaena hippurus* (78.8-176 mm SL) and 35 *C. equiselis* (74.1-172, 314 mm SL).

Item	Species	Number of anterior-most dorsal fin rays			
		0	1	2	3
Without distal radials	<i>C. hippurus</i>		12	12	4
	<i>C. equiselis</i>	1	6	25	4
Associated with the anteriormost pterygiophore	<i>C. hippurus</i>		3	24	1
	<i>C. equiselis</i>		1	17	19

associated with the posteriormost pterygiophore. This was the only ray in the dorsal fin which lacked a secondary association. Total dorsal fin ray count in both species was either one less than the pterygiophore count, equal to the pterygiophore count, or one or two greater than the pterygiophore count. Thus, the two species differed in their pterygiophore number as they differed in their fin ray counts.

In larvae, juveniles and small-sized adults of *Coryphaena* spp. the proximal radials of the dorsal fin were inserted in interneural spaces. The first interneural space was bounded anteriorly by the head and posteriorly by the first neural spine, followed posteriorly by the remaining interneural spaces which were bounded by all other neural spines (Figure 3).

Fully developed specimens of the two species of *Coryphaena* differed by the number of pterygiophores that occupied the interneural spaces. The number of pterygiophores found in the first interneural space separated the species most of the time, with 10-14 ($\bar{x} = 11.0$) for *C. hippurus* and 7-11 ($\bar{x} = 8.0$) for *C. equiselis* (Figures 3, 4). The species also differed in the number of pterygiophores associated with the remainder of the interneural spaces. Although individual variability within each interneural space was too great to allow this character to be used to separate the species, the mean number of pterygiophores in each interneural space was always greater for *C. hippurus*.

The species also differed in the number of interneural spaces that were occupied by the dorsal fin pterygiophores (Figure 3; Tables 3, 4). In *C. hippurus* the dorsal fin pterygiophores extended to the 26th interneural space and seldom to the 27th, whereas in *C. equiselis* they extended to the 28th and seldom to the 27th or 29th space. There was some overlap for the two species in this character, but if the termination of the anal fin pterygiophores was taken into account, together

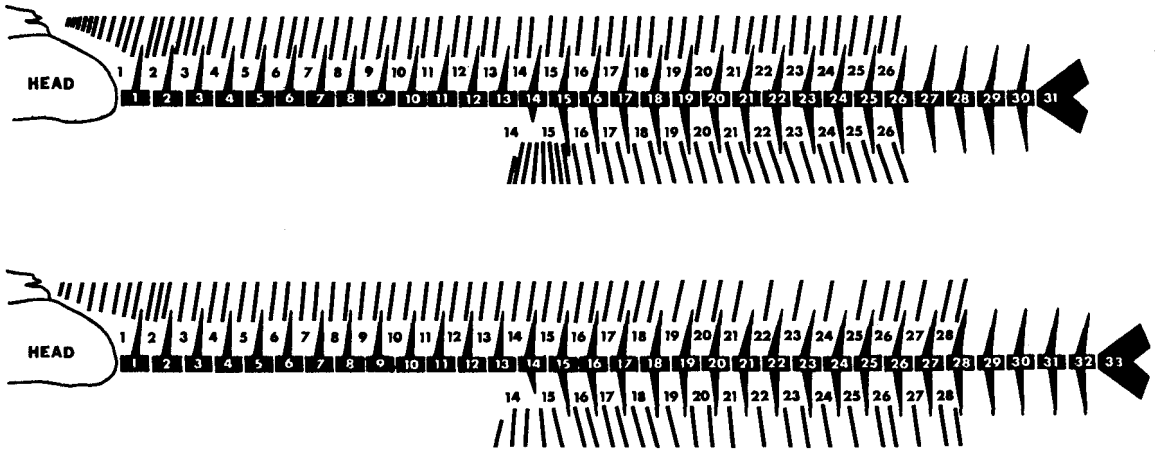


FIGURE 3.—Schematic representation of the relationship of dorsal and anal fin pterygiophores to the vertebral column in adult *Coryphaena hippurus* (upper) and *C. equiselis* (lower). Black numbers, interneural and interhaemal spaces; white numbers, centra.

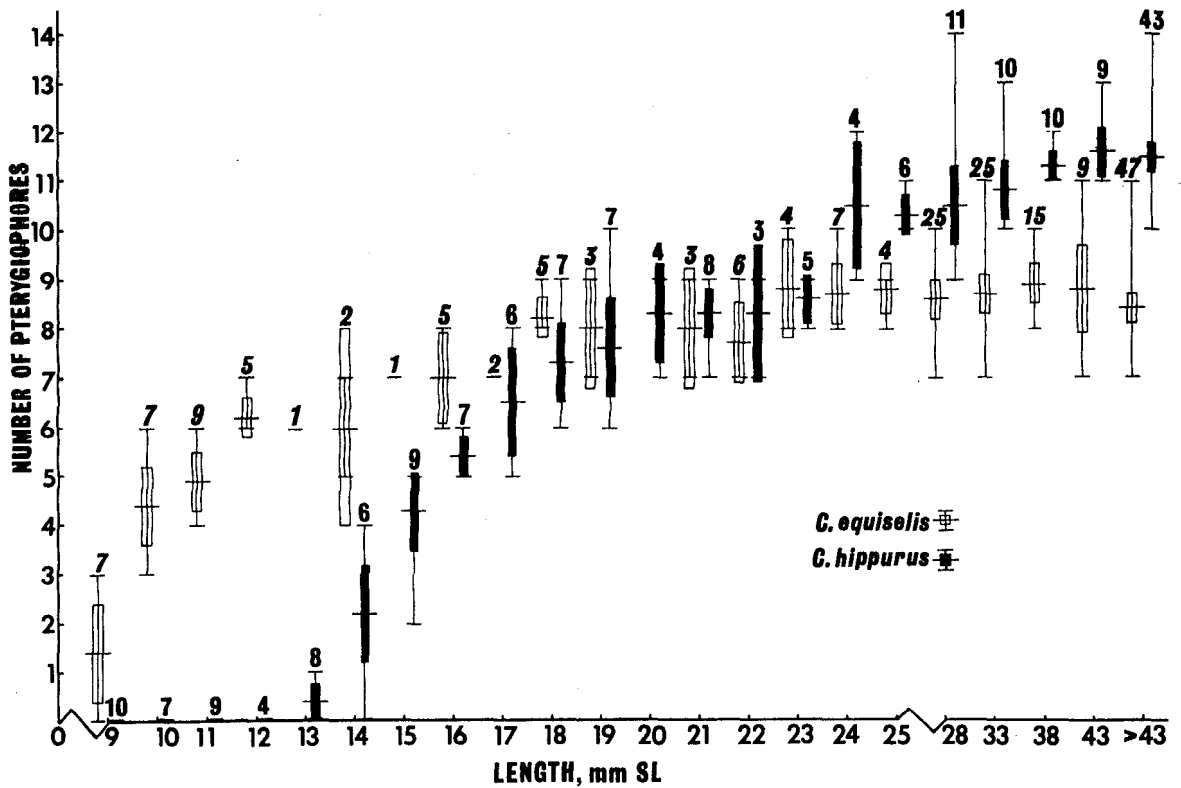


FIGURE 4.—Number of pterygiophores in the first interneural space in relation to length in 192 *Coryphaena equiselis* (8.6-173, 314 mm SL) and 193 *C. hippurus* (8.6-176 mm SL). For explanation of symbols, see Figure 1.

with the termination of the dorsal fin pterygiophores, complete separation for the two species resulted (Figure 3, Table 3).

Dorsal fin pterygiophores had the same pattern of appearance in both species of *Coryphaena* as the dorsal fin rays. Cartilaginous pterygiophores

TABLE 3.—Adult and juvenile position of posteriormost dorsal and anal fin pterygiophores in their interneural and interhaemal spaces for 193 *Coryphaena hippurus* (9.0-176 mm SL) and 186 *C. equiselis* (8.9-172, 314 mm SL). For numbering of vertebrae and spaces, see Figure 3.

Species	Interneural space numbers											
	Interhaemal space numbers					Interneural space numbers						
	26	26	26	27	27	27	27	28	28	28	29	29
<i>C. hippurus</i>	2	172	3	11	5							
<i>C. equiselis</i>						2	2	172	1	4	5	

without rays were first seen in the 22d-24th myomeres at 5.9 mm NL in *C. hippurus* (Figure 2) and with some rays in the 18th-27th myomeres at 6.5 mm NL in the smallest available but more advanced *C. equiselis*. In both species of *Coryphaena* the pterygiophores appeared shortly before the fin rays developed. As pterygiophores were added, anteriorly and posteriorly rays were lacking for one or two anteriormost and posteriormost additions (Figure 2).

In both species, the posteriormost interneural spaces (numbers 26-28) were occupied with pterygiophores between 7 and 8.5 mm SL (Table 4). The anteriormost interneural space started to fill with pterygiophores at 9.3 mm SL in *C. equiselis* and at 13.1 mm SL in *C. hippurus* (Figure 4, Table 4). Adult counts in the anteriormost interneural space of 7-11 pterygiophores were obtained for *C. equiselis* between 12.3 and 23.2 mm SL and for *C. hippurus* of 10-14 pterygiophores between 18.7 and 30.8 mm SL (Figure 4, Table 4).

Ossification of the pterygiophores started in the same area and proceeded in the same directions as the cartilaginous development (Figure 2). Ossification of pterygiophores occurred first at 8.8 mm SL in *C. equiselis* and at 9.7 mm SL in *C. hippurus* (Table 4). The posteriormost interneural space number 28 of *C. equiselis* had ossifying pterygiophores at 8.9 mm SL, and posteriormost interneural space number 26 of *C. hippurus* had ossifying pterygiophores at 10.2 mm SL (Table 4). Specimens 10.3-11.6 mm SL of *C. equiselis*, and 16.2-19.2 mm SL specimens of *C. hippurus* had one or more ossifying pterygiophores in the first interneural space (Figure 4, Table 5). All dorsal fin pterygiophores were ossifying in both species at about 45 mm SL when the count of ossifying pterygiophores was in the adult range and the first interneural space did not have anterior cartilaginous pterygiophores (Figures 4, 5).

TABLE 4.—Development of dorsal fin pterygiophores in the interneural spaces for 105 *Coryphaena hippurus* and 53 *C. equiselis*. For numbering interneural spaces, see Figure 3.

Length mm/NL or SL	Interneural space numbers with pterygiophores				Interneural space numbers with ossifying pterygiophores				Number of specimens	
	Anteriormost space no. (x̄)		Posteriormost space no. (x̄)		Anteriormost space no. (x̄)		Posteriormost space no. (x̄)		<i>C. hippurus</i>	<i>C. equiselis</i>
	<i>C. hippurus</i>	<i>C. equiselis</i>	<i>C. hippurus</i>	<i>C. equiselis</i>	<i>C. hippurus</i>	<i>C. equiselis</i>	<i>C. hippurus</i>	<i>C. equiselis</i>		
4.5-5.5									1	
5.6-6.5	19-22(20.3)	18	(1)	22-25(23.3)					3	1
6.6-7.5	11-22(17.7)	15		23-27(25.2)					9	1
7.6-8.5	8-18(12.6)	5-10(7.0)		25-26(25.6)					3	4
8.6-9.5	5-13(11.5)	1-3(1.6)		26					10	7
9.6-10.5	2-6(3.7)	1		26					7	7
10.6-11.5	2-7(3.2)	1		26					9	9
11.6-12.5	2	1		26					4	5
12.6-13.5	1-2(1.6)	1		26-27(26.1)					8	1
13.6-14.5	1-2(1.1)	1		26-27(26.1)					9	1
14.6-15.5	1	1		26-27(26.4)					10	1
15.6-16.5	1	1		26-27(26.1)					7	5
16.6-17.5	1	1		26					7	3
17.6-18.5	1	1		26-27(26.1)					7	5
18.6-19.5	1	1		26-27(26.1)					7	3
19.6-20.5	1	1		26					7	4

¹No pterygiophores developed.
²No pterygiophores ossified.

TABLE 5.—Sum (adult count) of anal fin pterygiophores in the two anteriormost interhaemal spaces, numbers 14 and 15, in 35 *Coryphaena hippurus* (49.9-176 mm SL) and 32 *C. equiselis* (74.1-172, 314 mm SL). For numbering interhaemal spaces, see Figure 3.

Species	Number of pterygiophores						
	4	5	6	7	8	9	10
<i>C. hippurus</i>				14	18	2	1
<i>C. equiselis</i>	5	20	6	1			

Morphology and Development

The pterygiophores in the center area of the dorsal fin developed first in both species. A pterygiophore (proximal and distal radial) appeared as one elongate piece of cartilage (Figure 6). Ossification was first observed at the middle part of the pterygiophore cartilage (Figure 6) and proceeded distally and proximally along the cartilage until only cartilage tips were present at the extremities. At this point, the sagittal and lateral keels began to develop (Figure 4). Further development of the pterygiophore consisted of growth of the keels, growth of bone around the locus of secondary fin

ray association, and segregation and ossification of the distal radial. The distal radial developed from the distal tip of the pterygiophore cartilage late during ontogeny (Figure 6), and ossified into two pieces of bone (Figure 7).

The pterygiophores in the posteriormost area of the dorsal fin developed similarly to those of the center area. The posteriormost pterygiophore supported one ray in series. This ray developed from two rays but was counted as one according to Hubbs and Lagler (1958). In adults, the base of the anterior ray fitted closely over the base of the posterior ray and the base of the posterior ray articulated with the distal radial of the posteriormost pterygiophore (Figures 8, 9).

The supports of the anterior portion of the dorsal fin developed last. In *C. equiselis* the first interneural space was almost filled with cartilaginous pterygiophores, but in equal-sized *C. hippurus* the first interneural space was empty and the second interneural space had only one cartilaginous pterygiophore (Figures 10, 11). The anteriormost cartilaginous pterygiophores always had

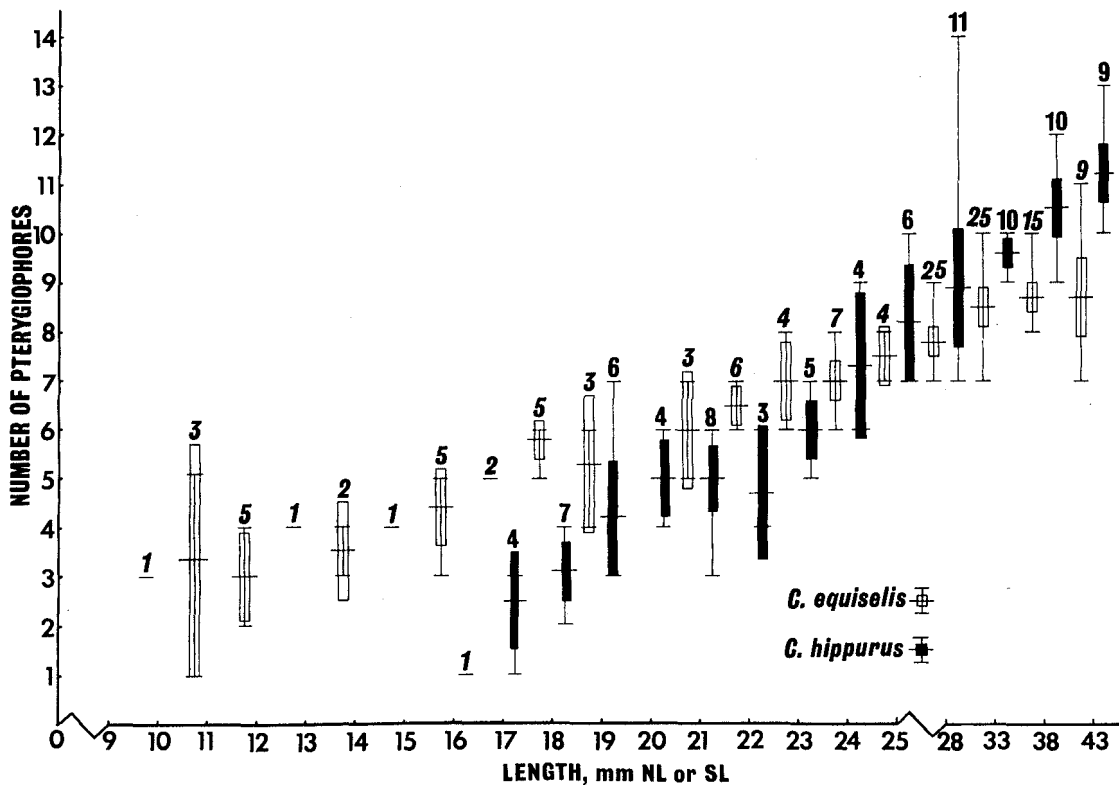


FIGURE 5.—Number of ossifying pterygiophores in the first interneural space in relation to length in 126 *Coryphaena equiselis* and 88 *C. hippurus*. For explanation of symbols see Figure 1.

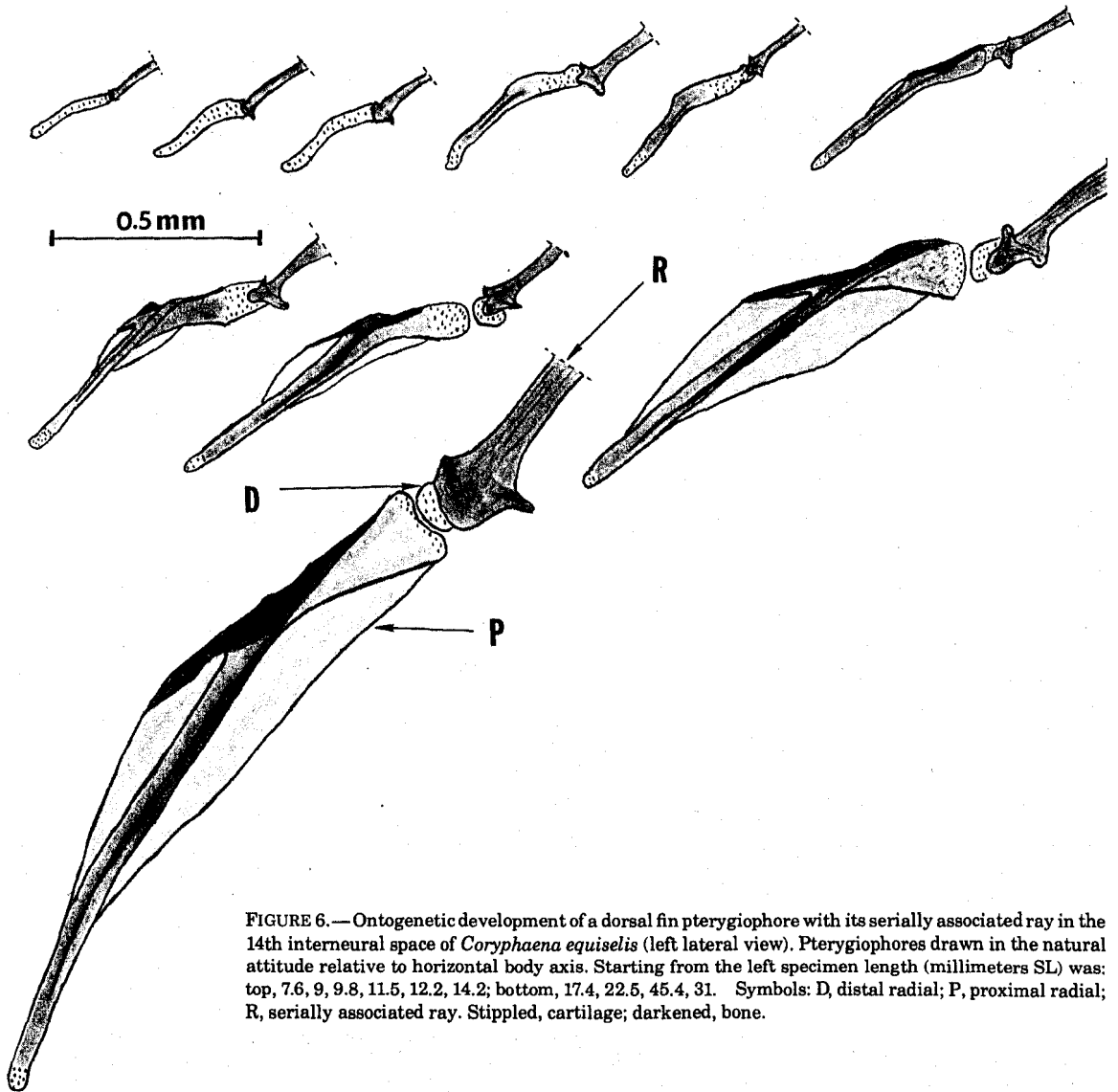


FIGURE 6.—Ontogenetic development of a dorsal fin pterygiophore with its serially associated ray in the 14th interneural space of *Coryphaena equiselis* (left lateral view). Pterygiophores drawn in the natural attitude relative to horizontal body axis. Starting from the left specimen length (millimeters SL) was: top, 7.6, 9, 9.8, 11.5, 12.2, 14.2; bottom, 17.4, 22.5, 45.4, 31. Symbols: D, distal radial; P, proximal radial; R, serially associated ray. Stippled, cartilage; darkened, bone.

a ray developing concurrently (Figures 2, 10, 11). In specimens of both species, which had the full count of pterygiophores in the first interneural space, it was common to have a ray develop in front of the cartilaginous pterygiophore (Figure 2). The pterygiophores of the first interneural space in large juveniles and adults of both species were vertical to the body axis near the first neural spine and slightly anteriorly inclined dorsad near the head (Figure 12). The anteriormost pterygiophore in the adults was either of normal size (not figured), very small (Figures 12, 13), or just a vestige (not figured). In a few instances, in both species, the anteriormost pterygiophore was com-

pletely or partially fused to the second pterygiophore. The anteriormost pterygiophore of both species had either one, two, or three associated rays (Table 2). For the two species the anteriormost dorsal fin ray was either normal in size or a vestige (Figures 12, 13). In both species three types of first fin ray vestiges were observed: a paired vestige (Figure 13), a single right vestige, and a single left vestige.

Distal radials were present between the bases of each fin ray for almost the entire dorsal fin. Distal radials were last to ossify from the distal portion of the pterygiophore cartilage. Only the anteriormost three fin rays of both species sometimes

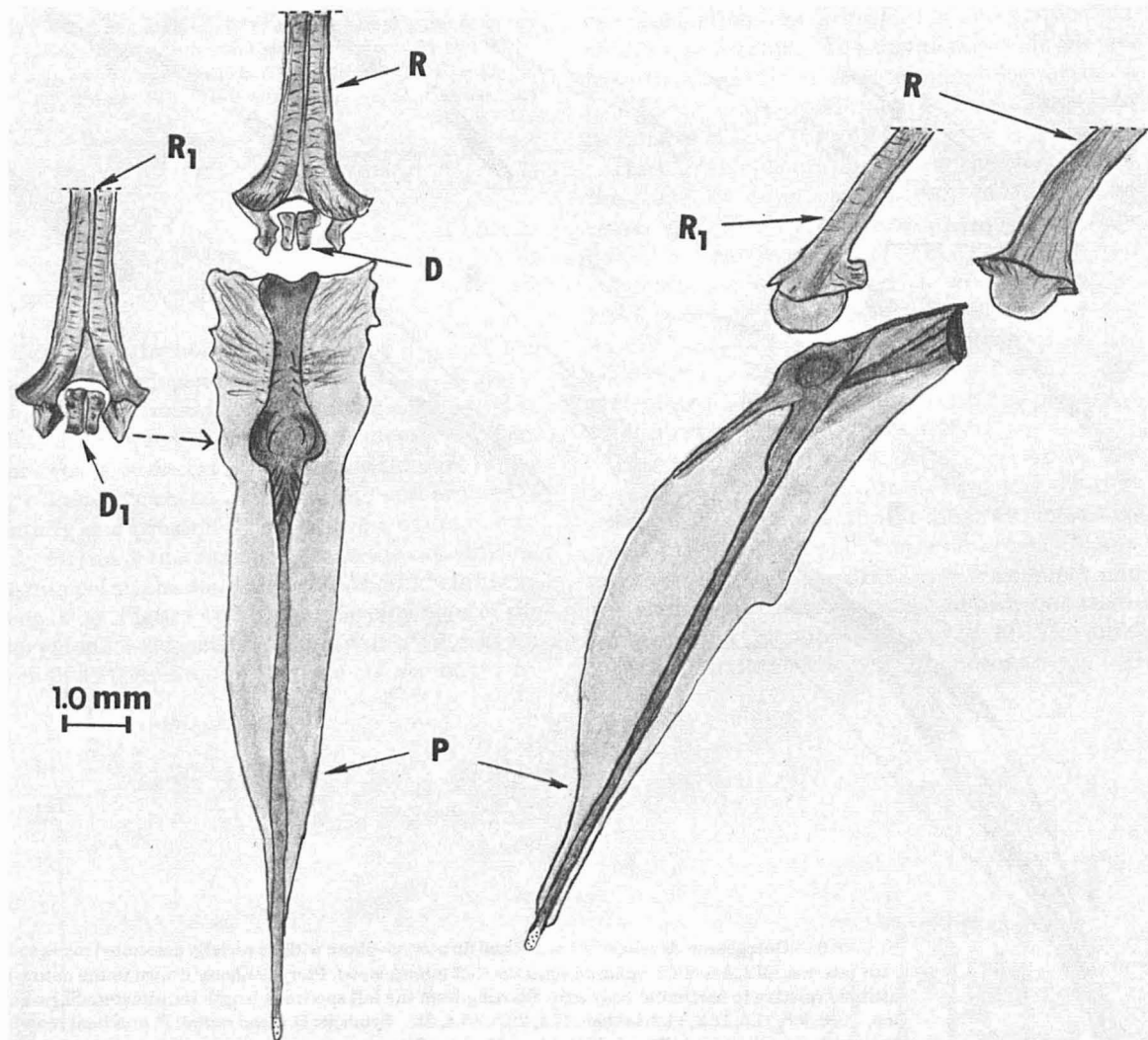


FIGURE 7.—Pterygiophore from 14th interneural space with its secondarily and serially associated rays from a 230 mm SL *Coryphaena equiselis*. Left: anterodorsal view, secondarily associated ray moved to the right of the proximal radial; right: left lateral view. Symbols: D₁, distal radial of secondarily associated ray; D, distal radial of serially associated ray; P, proximal radial; R₁, secondarily associated ray; R, serially associated ray. Stippled, cartilage; darkened, bone.

lacked distal radials. The absence or presence of distal radials was not related to the number of fin rays associated with the anteriormost pterygiophore (Table 2). The first three or four (anteriormost) distal radials of both species differed in structure from the remainder. These radials consisted of one piece of bone (Figure 14) whereas all other radials were of two pieces (Figures 7, 8).

The dorsal pterygiophores of *Coryphaena* spp. differed in several ways from other perciform fishes. Predorsal bones reported in Apogonidae (Fraser 1972), Serranidae and Grammistidae (Kendall 1976), Sparidae (Houde and Potthoff

1976), and for all the stromateoid families (Ahlstrom et al. 1976) were lacking. Also lacking was the terminal bone in the dorsal fin support series called a "stay" by Weitzman (1962). Stays have been reported for such families as Characidae (Weitzman 1962), Scombridae (Kramer 1960; Potthoff 1975), Sparidae (Houde and Potthoff 1976), Nomeidae and Centrolophidae (Ahlstrom et al. 1976), and Centropomidae, Kyphosidae, Lutjanidae, Percichthyidae, and Scorpidae (Johnson 1978). A stay was observed in the Scombridae and a double stay in the Gempylidae (Potthoff et al. 1980).

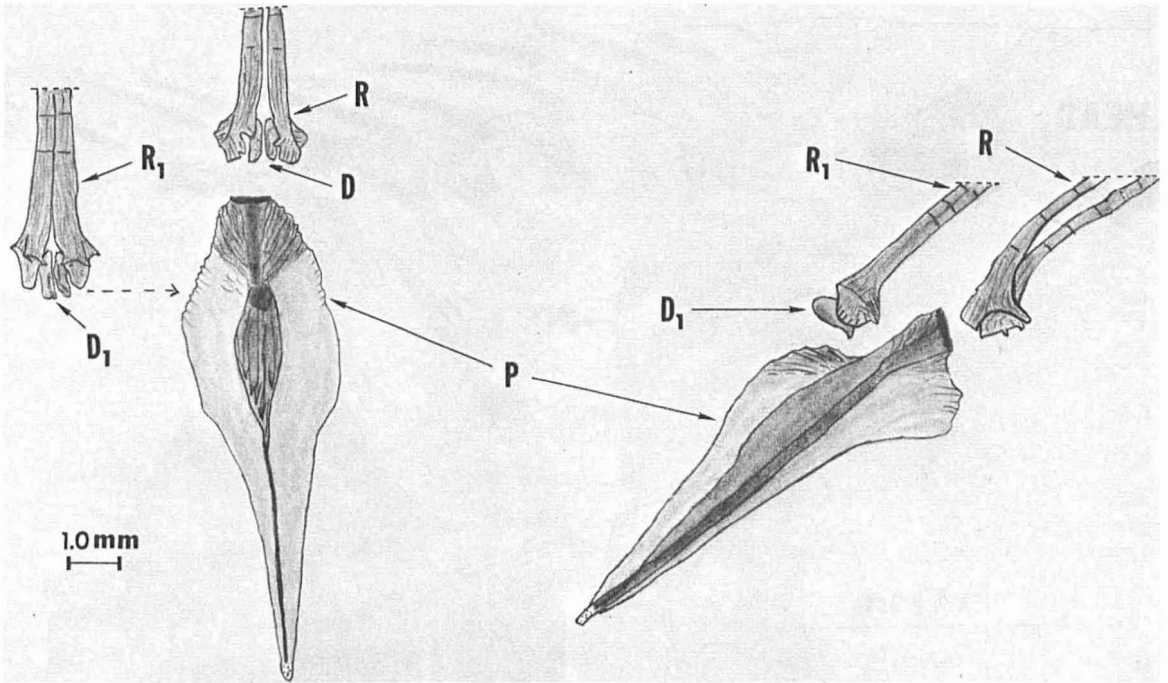


FIGURE 8.—Posteriormost dorsal fin pterygiophore with its secondarily and serially associated rays from a 230 mm SL *Coryphaena equiselis*. Left: anterodorsal view, secondarily associated ray has been moved to the right of the proximal radial; right: left lateral view, pterygiophore has been tilted 30° from the horizontal toward the vertical. Symbols: D₁, distal radial of secondarily associated ray; D, distal radial of serially associated double ray; P, proximal radial; R₁, secondarily associated ray; R, serially associated double ray. Stippled, cartilage; darkened, bone.

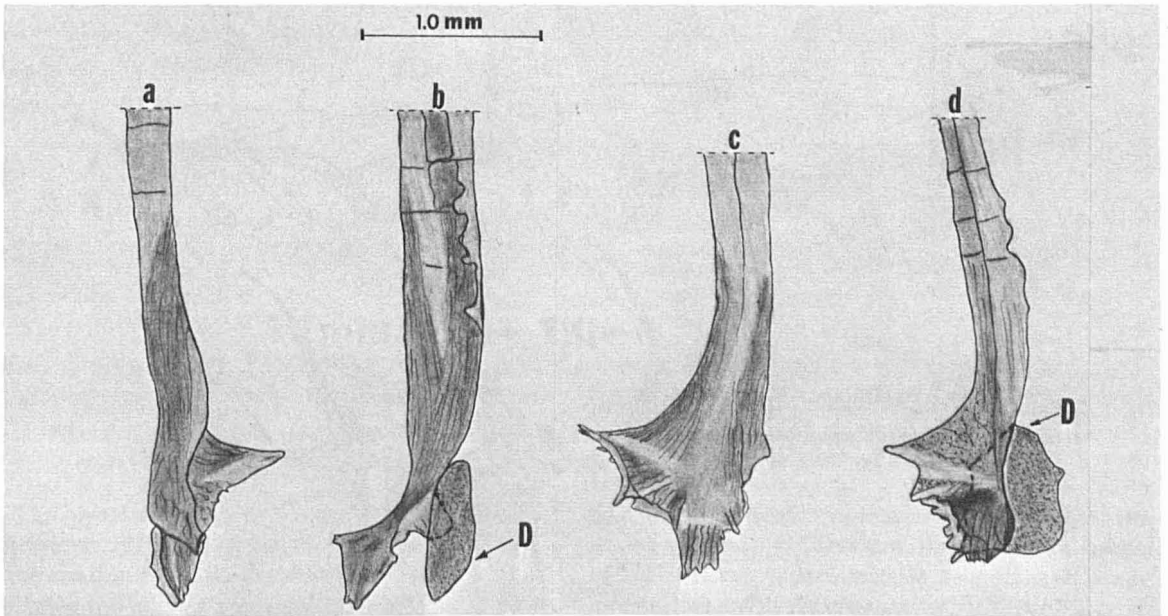


FIGURE 9.—Anterior and right lateral views of right side of a disarticulated posteriormost double dorsal fin ray with its distal radial from a 230 mm SL *Coryphaena equiselis*. a, right half of anterior ray, anterior view; b, right half of posterior ray and right half of its distal radial, anterior view; c, right half of anterior ray, lateral view; d, right half of posterior ray and right half of its distal radial, lateral view. Symbol: D, distal radial.

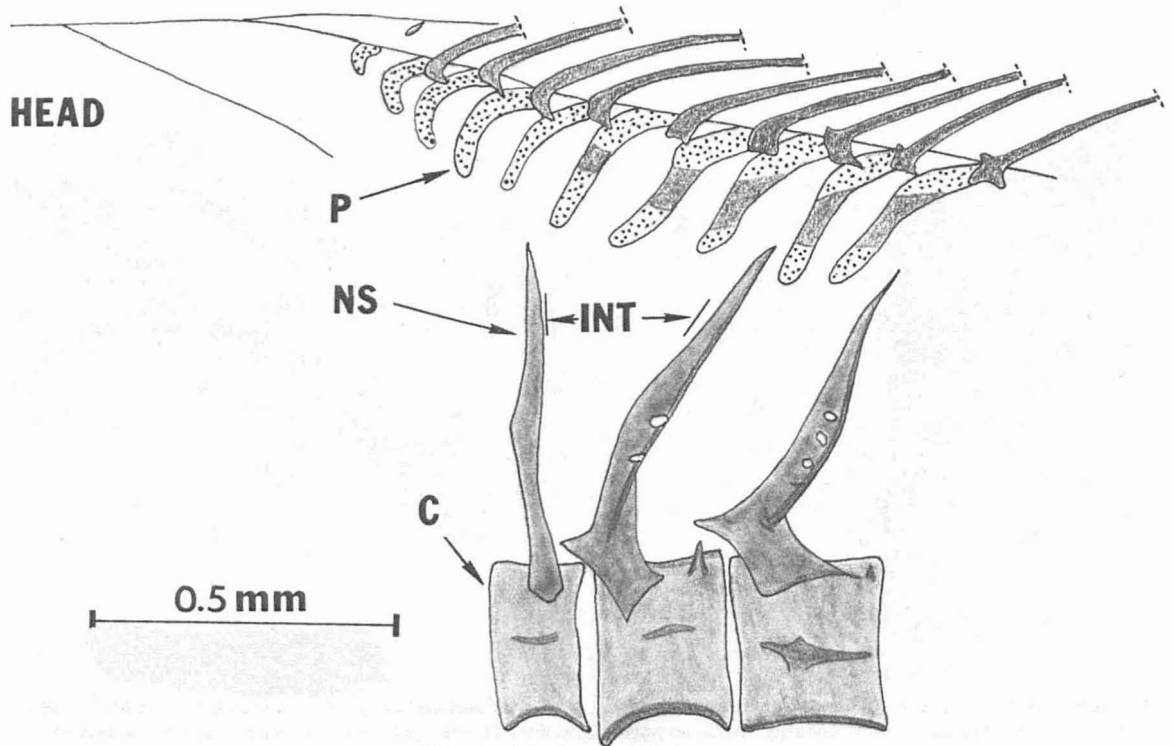


FIGURE 10.—Left lateral view of anteriormost part of the dorsal fin and pterygiophores for a 11 mm SL *Coryphaena equiselis*, showing relationship of pterygiophores to head, interneural spaces, and centra. Symbols: C, first centrum; INT, second interneural space; NS, first neural spine; P, proximal radial. Stippled, cartilage; darkened, bone.

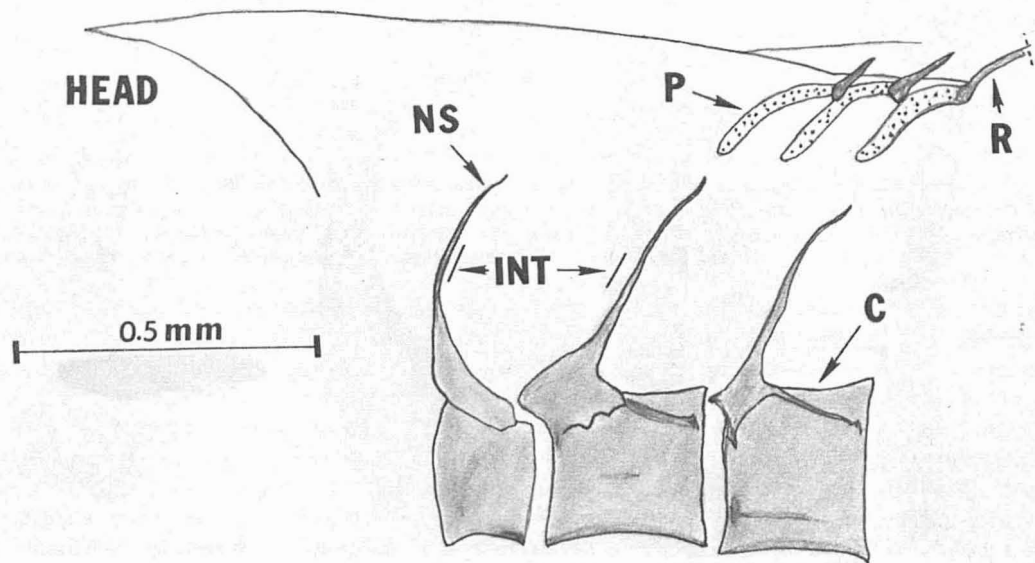


FIGURE 11.—Left lateral view of anteriormost part of the dorsal fin and pterygiophores for a 11 mm SL *Coryphaena hippurus*, showing the relationship of pterygiophores to head, interneural spaces, and centra. Symbols: C, third centrum; R, dorsal fin ray. For explanation of other symbols, see Figure 10. Stippled, cartilage; darkened, bone.

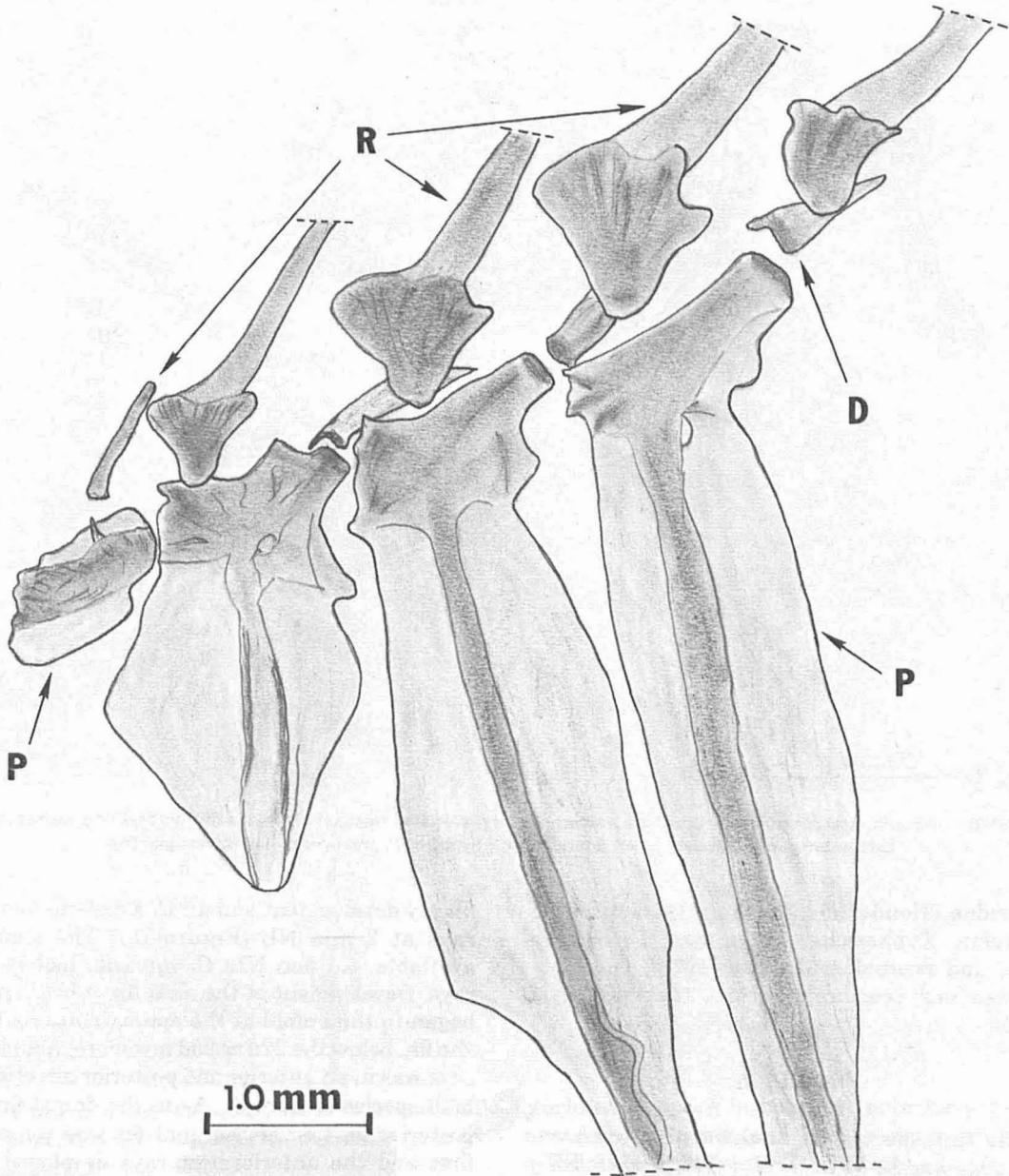


FIGURE 12.—Left lateral view of four anteriormost dorsal fin pterygiophores with secondarily and serially associated rays from a 230 mm SL *Coryphaena equiselis*. Symbols: R, dorsal fin ray; P, proximal radial; D, distal radial.

The proximal and distal radials (except the anteriormost three or four) of *Coryphaena* spp. were similar along the entire fin and were located between the bifurcate bases of the fin rays. Middle radials were absent in the posterior portion of the fin. In most other perciform fishes, distal radials differ between the first and second dorsal fins. The first dorsal fin distal radials are anterior to the

bases of the fin spines, and the second dorsal fin distal radials are between the bifurcate bases of the fin rays, and middle radials are present posteriorly. Anatomically different distal radials for the first and second dorsal fins and the presence of middle radials posteriorly have been reported in the Carangidae (Berry 1969), Scombridae (Kramer 1960; Potthoff 1974, 1975),

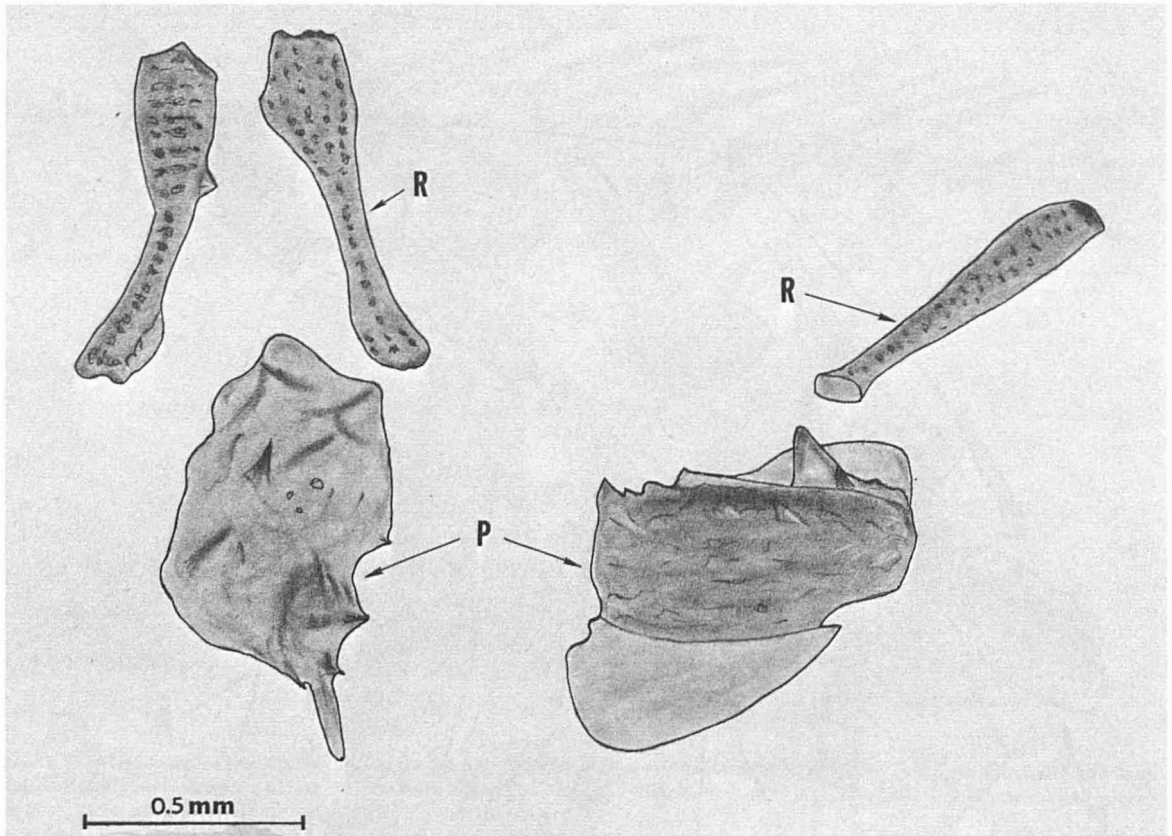


FIGURE 13.—Antermost dorsal fin pterygiophore with secondarily associated vestigial ray from a 230 mm SL *Coryphaena equiselis*. Left: anterodorsal view, right: left lateral view. Symbols: P, proximal radial; R, vestigial ray.

Sparidae (Houde and Potthoff 1976), Centropomidae, Kyphosidae, Lutjanidae, Percichthyidae, and Scorpidae (Johnson 1978), and Gemylidae and Scombrobracidae (Potthoff et al. 1980).

Anal Fin

The fully developed anal fin of *Coryphaena hippurus* has 25-31 rays ($N = 147$, $\bar{x} = 28$, $SE = 0.01$, 16-172 mm SL) and that of *C. equiselis* 23-29 ($N = 118$, $\bar{x} = 26$, $SE = 0.01$, 16-230 mm SL). The anal fin ray counts, in contrast to the dorsal fin ray counts, differ only slightly from those reported by Gibbs and Collette (1959), Rothschild (1964), and Shcherbachev (1973). Both species have adult anal fin ray counts at smaller sizes than dorsal fin ray counts (*C. hippurus* at 8-11 mm SL, *C. equiselis* at 8-9 mm SL).

Anal fin rays were first seen in some *C. hippurus* at 6 mm NL, just before the onset of dorsal

fin ray development and all *C. hippurus* had anal rays at 7 mm NL (Figure 15). The smallest available (6.5 mm NL) *C. equiselis* had 14 anal rays. Development of the anal fin of both species began in the finfold at the approximate center of the fin, below the 22d or 23d myomere. Addition of rays was in an anterior and posterior direction for both species (Figure 2). As in the dorsal fin, the posterior portion of the anal fin was completed first and the anteriormost rays developed last. From 6 mm NL to 9 mm SL, *C. hippurus* had fewer anal fin rays than *C. equiselis*; at 10 and 11 mm SL, both species had about equal numbers of rays; at 12 mm SL and longer, *C. hippurus* tended to have more anal rays than *C. equiselis* (Figure 15).

Appearance and additional sequence of anal fin rays in *Coryphaena* spp. are similar to *Scomber japonicus* (*Pneumatophorus diego*) (Kramer 1960), *Thunnus atlanticus* (Potthoff 1975), *Haemulon plumieri* (Saksena and Richards 1975), and *Archosargus rhomboidalis* (Houde and Potthoff 1976).

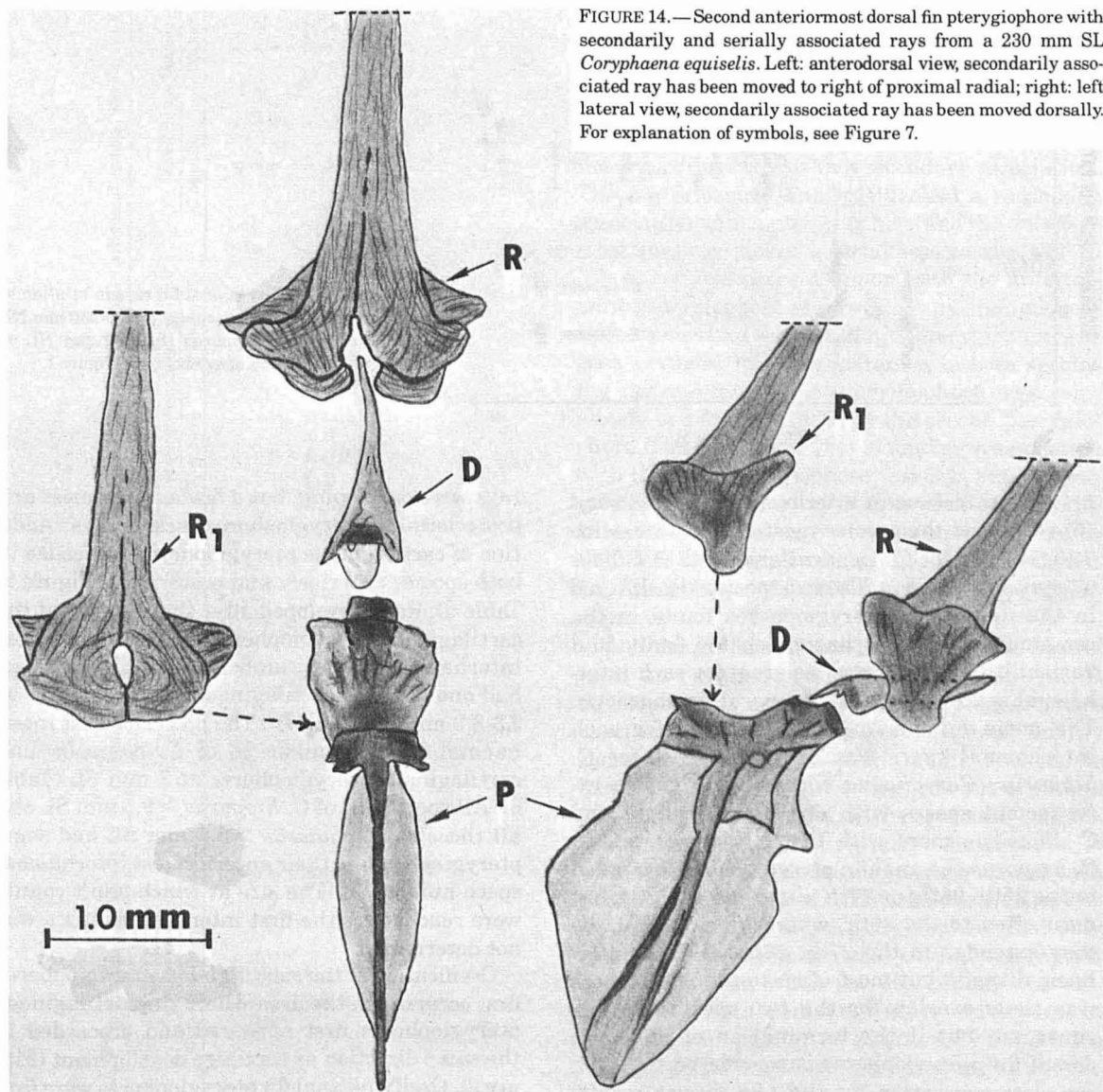


FIGURE 14.—Second anteriormost dorsal fin pterygiophore with secondarily and serially associated rays from a 230 mm SL *Coryphaena equiselis*. Left: anterodorsal view, secondarily associated ray has been moved to right of proximal radial; right: left lateral view, secondarily associated ray has been moved dorsally. For explanation of symbols, see Figure 7.

For *Trachurus symmetricus*, Ahlstrom and Ball (1954) reported an anterior to posterior anal fin development.

Anal Fin Pterygiophores

Counts

The description for dorsal fin pterygiophores in the foregoing section may be applied to anal fin pterygiophores because of the similarities between the two fins and their supports. Pterygiophores of the anal fin are inserted in the interhaemal spaces. The anteriormost (first) in-

terhaemal space is bounded anteriorly by the stomach, intestine, and anus and posteriorly by the first haemal spine. The first haemal spine was of variable length, and in many cases did not reach the anal fin pterygiophores. The anal fin pterygiophores in the two anteriormost interhaemal spaces were therefore summed (Table 5, Figure 3).

Fully developed specimens of *Coryphaena* spp. differed in their numbers and arrangement of anal fin pterygiophores. The total number of pterygiophores closely approximated the anal fin ray count. For both species the pterygiophore count was equal to or one to two less than the anal fin ray count. The sum of the pterygiophores found in the

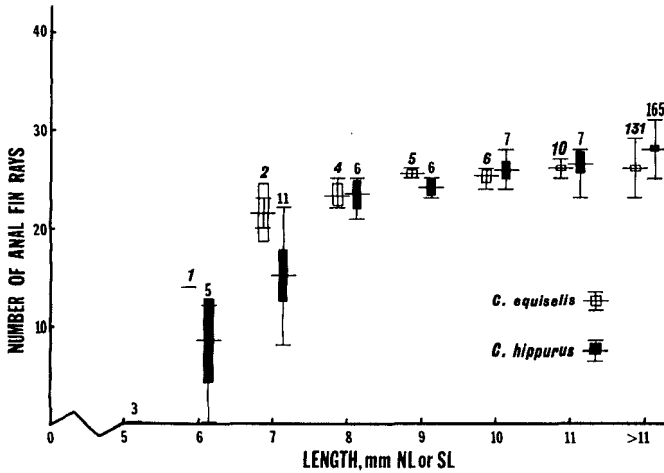


FIGURE 15.—Number of anal fin rays in relation to length in 159 *Coryphaena equiselis* (6.5-230 mm NL or SL) and 210 *C. hippurus* (5.0-230 mm NL or SL). For explanation of symbols, see Figure 1.

first two anteriormost interhaemal spaces (14 and 15) separated the species most of the time, with 7-10 ($\bar{x} = 8.0$) for *C. hippurus* and 4-7 ($\bar{x} = 5.0$) for *C. equiselis* (Table 5). The two species also differed in the number of pterygiophores found in the remainder of the interhaemal spaces. Individual variability, however, was too great for each interhaemal space to serve as a separating character. The mean number of pterygiophores for each interhaemal space was always greater for *C. hippurus*. *Coryphaena equiselis* had more interhaemal spaces with one pterygiophore and *C. hippurus* more with two pterygiophores. In *C. hippurus* the anal fin pterygiophores extended to the 25th, 26th, or 27th interhaemal space, but most often to the 26th, whereas in *C. equiselis* they extended to the 27th, 28th, or 29th interhaemal space, but most often to the 28th. There was some overlap for the two species in this character, but if the termination of anal and dorsal fin pterygiophores is considered together, complete separation for the two species results (Table 3). The dorsal and anal fin pterygiophores most often terminated in opposing interneural and interhaemal spaces (Table 3).

Morphology and Development

Cartilaginous anal fin pterygiophores without fin rays were first observed in the 18th-24th myomeres (which approximately correspond to the 18th-24th interhaemal spaces) in a 5.9 mm NL *C. hippurus* (Figure 2, Table 6), but rays were developing in a 6 mm NL specimen. The smallest available *C. equiselis* of 6.5 mm NL had cartilaginous pterygiophores in myomeres 18-27. Fin

rays were developing, but a few anteriormost and posteriormost pterygiophores lacked rays. Addition of cartilaginous pterygiophores proceeded in both species anteriorly and posteriorly (Figure 2, Table 6). Rays developed after the addition of the cartilaginous pterygiophores. The posteriormost interhaemal space number 26 of *C. hippurus* had one to three cartilaginous pterygiophores at 7.3-8.3 mm SL (Table 6). The posteriormost interhaemal space number 28 of *C. equiselis* had cartilaginous pterygiophores at 7 mm SL (Table 6). All specimens of *C. hippurus* > 9.5 mm SL and all those of *C. equiselis* > 8.5 mm SL had some pterygiophores in their anteriormost interhaemal space number 14. The size at which adult counts were reached for the first interhaemal space was not determined.

Ossification of the cartilaginous pterygiophores first occurred in the area where the cartilaginous pterygiophores first appeared and proceeded in the same direction as cartilage development (Figure 2). Ossifying anal fin pterygiophores were first seen at 8.8 mm SL in *C. equiselis* and at 9.7 mm SL in *C. hippurus* in the 16th-19th and 16th-25th interhaemal spaces (Table 6), and concurrently with ossifying dorsal fin pterygiophores. The posteriormost interhaemal space number 28 of *C. equiselis* had ossifying pterygiophores at 8.9 mm SL and space number 26 of *C. hippurus* had them at 10.2 mm SL (Table 6). All specimens of *C. equiselis* > 9.4 mm SL and all specimens of *C. hippurus* > 11 mm SL had some ossifying pterygiophores in the anteriormost interhaemal space number 14, or rarely space number 15 (Table 6). The anteriormost anal fin pterygiophore was ossifying in *C. equiselis* at 14.9-22 mm SL and in

TABLE 6.—Development of anal fin pterygiophores in the interhaemal spaces for 46 *Coryphaena hippurus* and 34 *C. equiselis*. For numbering interhaemal spaces, see Figure 3.

Length mm NL or SL	Interhaemal spaces with cartilaginous pterygiophores				Interhaemal spaces with ossifying pterygiophores				Number of specimens	
	Anteriormost space no. (\bar{x})		Posteriormost space no. (\bar{x})		Anteriormost space no. (\bar{x})		Posteriormost space no. (\bar{x})		<i>C. hippurus</i>	<i>C. equiselis</i>
	<i>C. hippurus</i>	<i>C. equiselis</i>	<i>C. hippurus</i>	<i>C. equiselis</i>	<i>C. hippurus</i>	<i>C. equiselis</i>	<i>C. hippurus</i>	<i>C. equiselis</i>		
4.6-5.5	(¹)	—	(¹)	—	(¹)	(¹)	(¹)	(¹)	1	1
5.6-6.5	18-22(19.7)	18	23-24(23.7)	27	(²)	(²)	(²)	(²)	3	3
6.6-7.5	14-20(17.3)	15	23-26(25.1)	28	(²)	(²)	(²)	(²)	9	1
7.6-8.5	14-16(14.6)	15-16(15.5)	25-28(25.7)	28	(²)	(²)	(²)	(²)	3	4
8.6-9.5	14-15(14.4)	14	26	28	(²)	21-14-16(14.8)	(²)	21-19-28(26.0)	10	7
9.6-10.5	14	14-15(14.1)	26	28	(²)	14-15(14.1)	(²)	28	7	7
10.6-11.5	14	14-15(14.1)	26	28	21-14-16(15.4)	14-15(14.1)	25-26(25.8)	28	9	9
11.6-12.5	14	14	26	28-29(28.2)	21-14-18(14.7)	14-15(14.1)	25-26(25.9)	28-29	4	5

¹No pterygiophores developed.
²No pterygiophores ossified.

C. hippurus at 17.2-30 mm SL. The development of individual anal fin pterygiophores was similar to that of the dorsal fin pterygiophores.

Each anal fin pterygiophore of both species had two rays; one ray was in a serial association and the preceding ray was in a secondary association. The posteriormost anal ray lacked a secondary association with a pterygiophore and the anteriormost anal ray lacked a serial association (Figure 16). Exceptions were common with the anteriormost pterygiophore and rays. Many specimens of both species had very small first pterygiophores or even vestiges. In a few instances in both species the anteriormost first pterygiophore was completely or partially fused to the second pterygiophore. The normal number of anal rays associated with the first pterygiophore was two, but for both species one or three rays also were found. The anteriormost anal ray was either normal as in Figure 16, very small, or a vestige. As in the dorsal fin, the vestige was either single left or right, or paired.

A distal radial was present between the base of each fin ray almost for the entire anal fin. It developed and ossified from the pterygiophore cartilage. Only the anteriormost anal fin ray sometimes did not have a distal radial between its base (Table 7). Only 1 *C. hippurus* out of 49 had two anteriormost rays without distal radials. When the anteriormost ray had a distal radial, it was either serially or secondarily associated with the first pterygiophore. When the association was serial, the anteriormost pterygiophore had only one ray; when it was secondary, it had two rays. It is possible that, when the association was secondary, the distal radial of the first fin ray was in actuality a vestigial pterygiophore. The specimen in Figure 16 did not have a distal radial for the anteriormost ray. The absence or presence of distal radials for the anteriormost anal fin ray was not related to the number of fin rays that were

TABLE 7.—Number (adult count) of anteriormost anal fin rays without distal radials and number of anal fin rays associated secondarily and serially with the anteriormost anal fin pterygiophore in 49 *Coryphaena hippurus* (41.0-176 mm SL) and 33 *C. equiselis* (74.1-172, 314 mm SL).

Item	Species	Number of anteriormost anal fin rays		
		0	1	2 3
Without distal radials	<i>C. hippurus</i>	24	24	1
	<i>C. equiselis</i>	10	23	
Associated with the anteriormost anal pterygiophore	<i>C. hippurus</i>		3	40 6
	<i>C. equiselis</i>		3	29 1

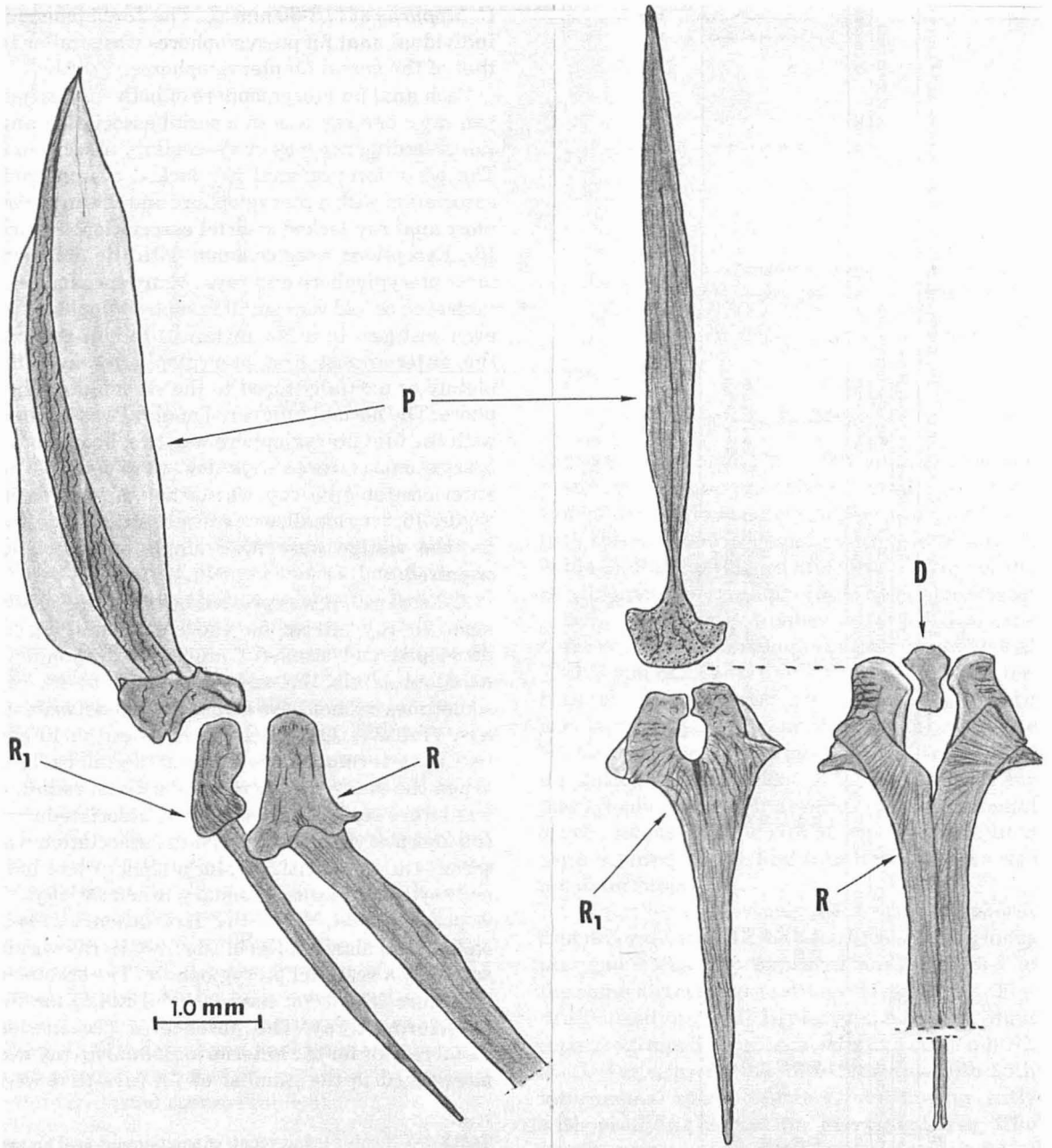


FIGURE 16.—Anteriormost anal fin pterygiophore with secondarily and serially associated rays from a 230 mm SL *Coryphaena equiselis*. Left: left lateral view; right: anterior view, serially associated ray has been moved to the left of the proximal radial. • Symbols: D, distal radial of serially associated ray; P, proximal radial; R₁, secondarily associated ray; R, serially associated ray.

associated with the anteriormost anal pterygiophore (Table 7). In both species either one, two, or three rays were associated with the first pterygiophore. In both species the anteriormost distal radial (which was either between the base of the

first or second anal fin ray) was a single piece of bone (Figure 16). The second distal radial (which was either between the base of the second or third anal fin ray) consisted of two pieces of bone, as shown for the dorsal pterygiophores in Figures 7

and 8. The two pieces of the second distal radial were sometimes partially fused; and in a few rare cases, the second distal radial was one piece of

bone. All following distal radials of the anal fin were two pieces of bone in both species. The posteriormost anal fin ray consisted of two closely approximated rays with one distal radial.

TABLE 8.—Adult caudal fin ray counts for 117 *Coryphaena hippurus* (19.6-172 mm SL) and 97 *C. equiselis* (19.6-230 mm SL). Symbols: USCR, upper secondary caudal rays; LSCR, lower secondary caudal rays; PCR, principal caudal rays.

Total fin ray count	USCR+PCR+LSCR	Number of specimens	
		<i>C. hippurus</i>	<i>C. equiselis</i>
37	10+17+10	0	1
38	10+17+11	2	1
39	10+17+12	0	2
39	11+17+11	10	0
40	11+17+12	12	28
40	12+17+11	3	0
41	11+17+13	0	6
41	12+17+12	36	17
42	12+17+13	23	32
43	13+17+13	26	8
44	13+17+14	2	2
45	14+17+14	3	0

Caudal Fin

The two species differed little in ray counts on fully developed caudal fins. *Coryphaena hippurus* had 38-45 (\bar{x} = 41.4) caudal rays and *C. equiselis* had 37-44 (\bar{x} = 41.1) (Table 8). *Coryphaena hippurus* tended to have an equal number of upper and lower secondary caudal rays whereas *C. equiselis* tended to have one or two more lower than upper secondary caudal rays. Adult caudal ray counts for *C. hippurus* were obtained between 15.6 and 19.6 mm SL and for *C. equiselis* between 11.6 and 12.5 mm SL (Tables 9, 10). A procur-

TABLE 9.—Caudal fin ray development in 201 *Coryphaena hippurus* (5.0 mm NL-172 mm SL) and 138 *C. equiselis* (6.5 mm NL-230 mm SL). Symbols: SCR, secondary caudal rays; PCR, principal caudal rays.

Length mm NL or SL	<i>Coryphaena hippurus</i>							<i>Coryphaena equiselis</i>								
	Upper		Lower		Total fin ray count			Upper		Lower		Total fin ray count				
	SCR	PCR	PCR	SCR	Range	\bar{x}	$S_{\bar{x}}$	N	SCR	PCR	PCR	SCR	Range	\bar{x}	$S_{\bar{x}}$	N
4.6-5.5	0	2-4	2-5	0	4-9	7.0	1.5	3	—	—	—	—	—	—	—	—
5.6-6.5	0	4-8	5-8	0	9-16	11.3	1.6	4	0	6	6	0	12	—	—	1
6.6-7.5	0	1-8	2-8	0-1	3-17	12.9	1.3	10	0	9	8	1-2	18-19	18.5	0.5	2
7.6-8.5	0	9	8	1-2	18-19	18.8	0.2	6	0-3	9	8	2-4	19-24	21.2	1.2	5
8.6-9.5	0-3	9	8	2-4	19-24	19.8	1.1	5	3-8	9	8	4-8	24-33	29.0	1.9	4
9.6-10.5	1-4	9	8	2-5	21-26	23.3	0.7	7	5-9	9	8	6-9	28-35	31.0	1.3	5
10.6-11.5	0-4	9	8	2-5	19-26	24.7	1.0	7	7-9	9	8	8-9	32-35	33.6	0.4	7
11.6-12.5	4-5	9	8	5-7	26-29	27.7	0.9	3	10-11	9	8	11-12	38-40	38.5	0.5	4
12.6-13.5	5-6	9	8	6	28-29	28.6	0.2	5	11	9	8	12	40	—	—	1
13.6-14.5	7-8	9	8	8-9	32-34	33.3	0.3	6	11	9	8	12	40	—	—	1
14.6-15.5	7-9	9	8	8-10	32-36	34.7	0.6	6	12	9	8	12	41	—	—	1
15.6-16.5	9-11	9	8	10-12	36-40	37.5	0.7	6	11	9	8	11-13	39-41	40.0	1.0	2
16.6-17.5	9-11	9	8	9-11	35-39	36.6	0.7	5	11	9	8	11-13	39-41	40.0	0.6	3
17.6-18.5	9-11	9	8	9-11	35-39	38.2	0.8	5	11-12	9	8	12-13	40-42	40.5	0.5	4
18.6-19.5	8-12	9	8	12	37-41	39.5	0.6	6	11	9	8	12	40	—	—	1
>19.5	10-14	9	8	11-14	38-45	41.4	0.1	117	10-13	9	8	10-14	37-44	41.1	0.1	97

TABLE 10.—Length (in millimeters NL or SL) at which parts of the caudal complex first appear in cartilage and then ossify in 41 *Coryphaena hippurus* (5.0 mm NL-110 mm SL) and 39 *C. equiselis* (6.5-85 mm SL). "First appearance in cartilage" does not pertain to all specimens of that size but only indicates a first appearance. Symbol: Pu, preural centrum.

Part	<i>Coryphaena hippurus</i>				<i>Coryphaena equiselis</i>			
	First appearance in cartilage	First evidence of ossification	Ossifying in all specimens	Completely fused	First appearance in cartilage	First evidence of ossification	Ossifying in all specimens	Completely fused
Neural spine, Pu ₂	7.4	9.5	11.9	—	>6.5 but <7.6	7.6	8.1	—
Specialized neural arch, Pu ₂	7.4	11.9	11.9	—	>6.5 but <7.6	9.5	9.5	—
Large uroneural	—	8.0-10.6	11.9	75.0-85.0	—	>6.5 but <7.6	7.6	75.0-80.0
Small uroneural	—	11.9	11.9		—	(9.5?)	10.8	
Epurals	7.4-8.0	14.6	14.6	40.0-47.0	>6.5 but <7.6	10.8	10.8	34.0-39.0
Urostyle	—	8.0	11.9	—	—	7.6	7.6	—
Pu ₂ centrum	—	9.5	11.9	—	—	7.6	9.5	—
Pu ₃ centrum	—	9.5	11.9	—	—	7.6	9.5	—
Haemal spine, Pu ₃	6.0	9.5	11.9	—	<6.5	7.6	9.5	—
Haemal spine, Pu ₂	5.0	9.5	11.9	—	<6.5	7.6	9.5	—
Parhypural	<5.0	9.5	11.9	—	<6.5	7.6	7.6	—
Hypural 1	<5.0	9.5	11.9	106.0	<6.5	7.6	7.6	69.0
Hypural 2	<5.0	9.5	11.9		<6.5	7.6	7.6	
Hypural 3	<5.0	9.5	11.9		<6.5	7.6	7.6	
Hypural 4	6.0	9.5	11.9	106.0	6.5	7.6	7.6	69.0
Hypural 5	8.1-9.5	11.9	11.9		—	7.6	9.5	

rent spur (Johnson 1975) was not observed in either species.

The caudal rays first developed in both species from the midline between hypurals 2 and 3 in preflexion larvae (Figure 17). Rays were added in a posterior and anterior direction (Figure 18). After complete notochord flexure the secondary caudal rays were added in an anterior direction. For equal-sized specimens from 6.5 mm NL to 19.5 mm SL, *C. hippurus* had fewer caudal fin rays than *C. equiselis* (Table 9).

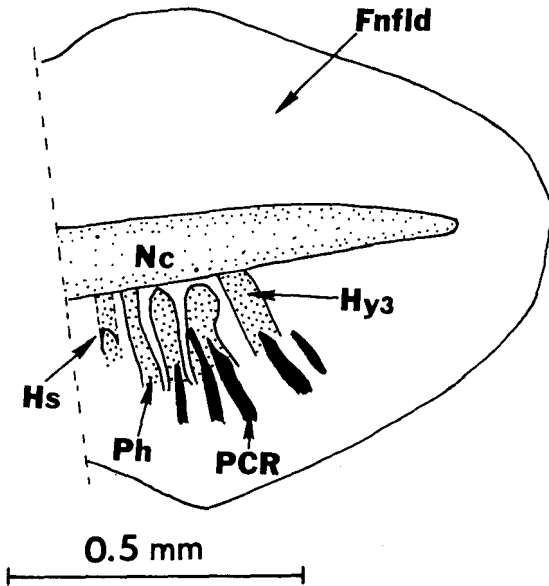


FIGURE 17.—Caudal complex of *Coryphaena hippurus*, 5.0 mm NL. Symbols: Fnfld, finfold; Hs, haemal spine; Hy, hypural; Nc, notochord; PCR, principal caudal ray; Ph, parhypural. Stippled, cartilage; darkened, ossifying bones or rays.

Caudal Fin Supports

The caudal fin rays of *Coryphaena* spp. were supported by some of the bones of the caudal complex. Three posteriormost centra were involved in this support. In 2 out of 97 *C. equiselis* the caudal fin rays were also supported by a fourth centrum. This variation was not observed in *C. hippurus*.

Supporting bones of the caudal complex consisted of three centra (urostyle and preural centra numbers 2 and 3), one neural spine, one specialized neural arch, two autogenous haemal spines, one autogenous parhypural bone, five autogenous hypural bones, two paired uroneural bones, and two epural bones. These parts were seen during

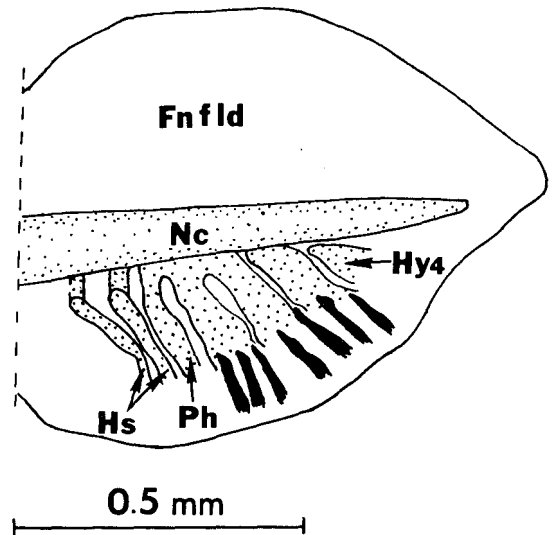


FIGURE 18.—Caudal complex of *Coryphaena hippurus*, 6.0 mm NL. For explanation of symbols, see Figure 17. Stippled, cartilage; darkened, ossifying bones or rays.

development, but not all the parts are readily discerned in the adults due to ontogenetic fusion.

The species did not differ in the anatomy of the caudal complex, but they differed in the size at which parts appeared and ossified. The 6.5 mm NL *C. equiselis* was at the same stage of caudal development as a 6.5 mm NL *C. hippurus*. From 7.6 to 16 mm SL, *C. equiselis* was more advanced. Specimens >16 mm SL of both species had the caudal complex equally ossified for the same lengths, but epural, uroneural, and hypural fusions occurred at shorter lengths in *C. equiselis*.

Development of the caudal complex of *C. hippurus* is described here rather than *C. equiselis* because small specimens were not available for *C. equiselis*. Most of the illustrations of the caudal complex are of *C. equiselis* because they were drawn before it was apparent that *C. equiselis* <7.6 mm were not available. Because both species had identical caudal complex anatomy, no drawings of *C. hippurus*' caudal complex were made for specimens >7.6 mm SL.

At 5 mm NL, *C. hippurus* had a straight notochord. Hypurals 1 to 3, the parhypural, and the haemal spine of the future preural centrum 2 were present in cartilage and 2 + 3 principal caudal rays were counted (Figure 17). At 6 mm NL, hypural 4 and an additional cartilaginous haemal spine of the future preural centrum 3 were present (Figure 18). Notochord flexion in *C. hip-*

purus was between 7 mm NL and 7.5 mm SL, and in *C. equiselis* between 6.5 mm NL and 7.6 mm SL (Figure 19). During the flexion stage of some *C. hippurus* the neural spine of preural centrum 3, the specialized neural arch of preural centrum 2, and the two epurals began to develop from cartilage (Figure 19). Hypural 5 was first seen in cartilage at 8.1 mm SL. The two paired uroneurals did not develop from cartilage—in *C. hippurus* the larger, more ventrally and ante-

ognized only one epural for adult *C. hippurus*. In *Coryphaena* spp., hypurals 1 and 2 and hypurals 3 and 4 fused to a dorsal and ventral hypural plate (Figures 20-23, Table 10). During fusion paired bony ventrolateral and dorsolateral articular projections formed on the ventral edge of hypural 3 and on the dorsal edge of hypural 2. These projections became the articular surfaces between the dorsal and ventral hypural plates (Figures 20-23). The two hypural plates of *Cory-*

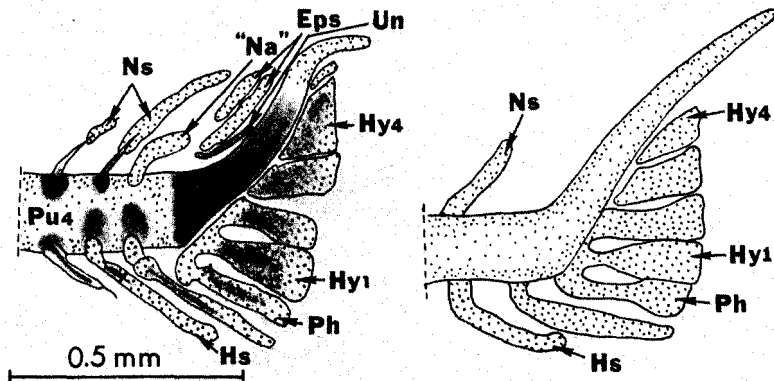


FIGURE 19.—Supporting bones of the caudal complex of *Coryphaena hippurus* (right) 7.6 mm SL and *C. equiselis* (left) 7.6 mm SL. Symbols: Eps, epurals; Hs, haemal spine; Hy, hypural; "Na", specialized neural arch; Ns, neural spine; Ph, parhypural; Pu, preural centrum; Un, uroneural; Ur, urostyle. Stippled, cartilage; darkened, ossifying bones; stippled darkened areas are cartilage just beginning to ossify.

riorly located pair was seen at 8-10.6 mm SL, and the smaller, more dorsally and posteriorly located pair was seen at 11.9 mm SL. Development of the two paired uroneurals occurred at a smaller size in *C. equiselis* (Figure 19 left, Table 10). The smaller uroneural pair gradually fused to the outside of the larger uroneural pair in both species. This fusion was completed between 75 and 85 mm SL for *C. hippurus* and between 75 and 80 mm SL for *C. equiselis* (Table 10). Monod (1968) recognized only one uroneural (stegural) pair in adult *C. hippurus*.

Ossification of the cartilage bones in the caudal complex of *C. hippurus* began with the urostyle at 8 mm SL. Last to ossify at 14.6 mm SL were the two epurals. The ossification sequence of all hypural bones is shown in Table 10. The epurals of *C. hippurus* developed and fused in the same manner as those of *C. equiselis*, although development and fusion were always at a smaller size for *C. equiselis* (Figures 19-23, Table 10). Monod (1968) rec-

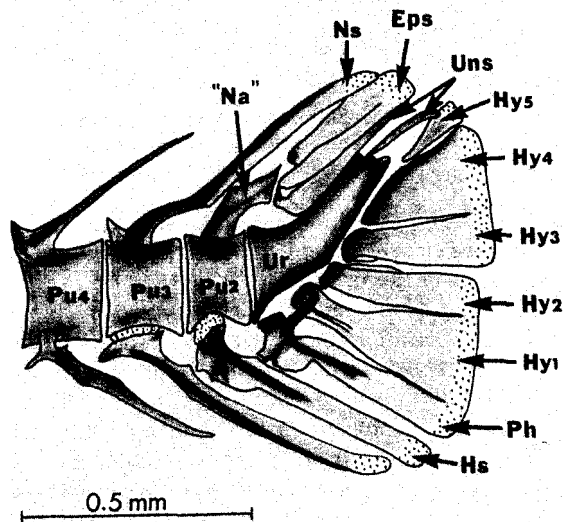


FIGURE 20.—Supporting bones of the caudal complex of *Coryphaena equiselis*, 11.0 mm SL. Symbols: Uns, uroneurals. For explanation of other symbols, see Figure 19. Stippled, articular cartilage; darkened, bone.

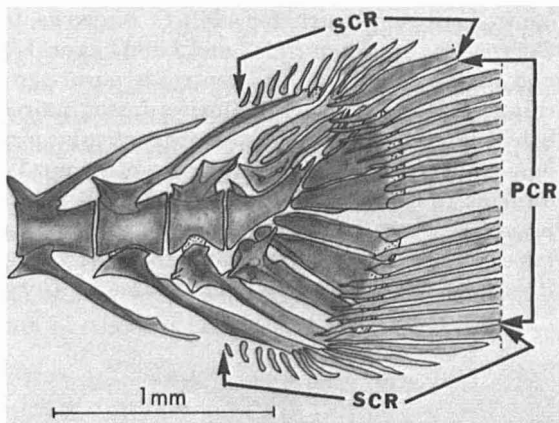


FIGURE 21.—Caudal complex of *Coryphaena equiselis*, 15.9 mm SL. Symbols: PCR, principal caudal rays; SCR, secondary caudal rays. Stippled, articular cartilage; darkened, bone.

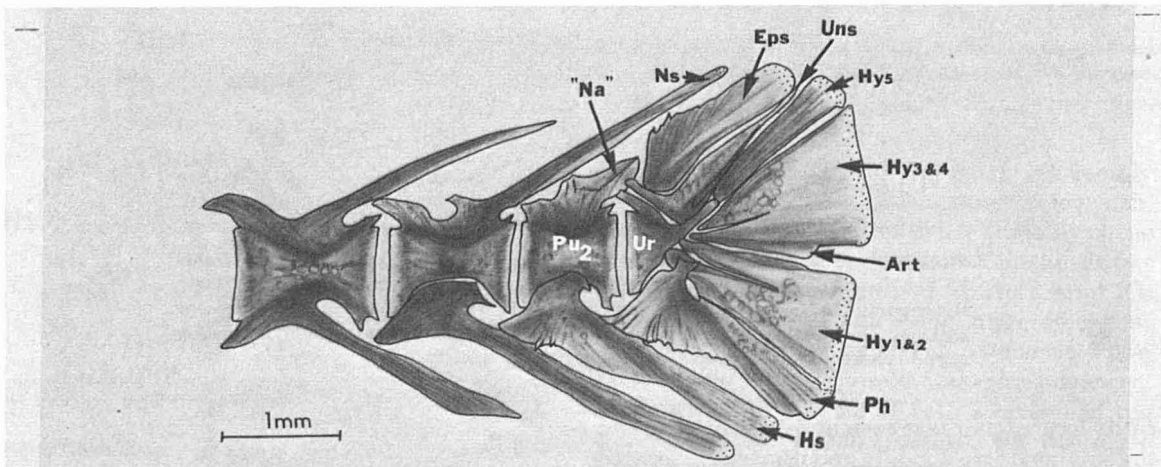


FIGURE 22.—Supporting bones of the caudal complex of *Coryphaena equiselis*, 55.5 mm SL. Symbols: Art, articular projection. For explanation of other symbols, see Figures 19, 20. Stippled, articular cartilage; darkened, bone.

phaena spp. remained autogenous in the adults, but were closely articulated with the ventroposterior edge of the urostyle.

During development of the hypural complex bones a small hypurapophysis (Lundberg and Baskin 1969) was observed on hypural 1 in both species. It appeared before hypural fusion, but could not be illustrated in the lateral view. Disarticulation of adult caudal skeletons of both species of *Coryphaena* revealed the presence of the hypurapophysis. The hypurapophysis articulated with the urostyle just dorsad of the parhypurapophysis (Nursall 1963).

In the adults of *Coryphaena* spp., most bones of the hypural complex were closely articulated, but

autogenous (Figures 23, 24). These were two haemal spines, a parhypural, a ventral and dorsal hypural plate, hypural 5, a uroneural pair (fused from two pairs), and an epural (fused from two). Nonautogenous bones were the specialized neural arch and one neural spine. The relationship of the urostyle with the uroneural pair and hypural 5 is shown in Figure 24. Articular cartilage was present on all distal parts of the hypural complex posterior to preural centrum 4 (Figure 22).

The parhypural and hypurals 1-5 supported the principal caudal rays. The distribution of principal caudal rays on the various hypural bones can only be seen in larvae and smaller juveniles of both species before hypural fusion (Table 11). There was no difference in distribution of principal caudal rays between the two species.

The anatomy and development of the caudal complex of *Coryphaena* spp. had similarities and dissimilarities with other fish. The hypurapophysis observed in *Coryphaena* spp. was noted in such fish as siluriform catfish (Lundberg and Baskin 1969) and adult sea bream, *Archosargus rhomboidalis* (Houde and Potthoff 1976). The hypurapophysis was not observed in the blackfin tuna, *Thunnus atlanticus* (Potthoff 1975).

In the *Coryphaenidae* and other percoid fishes such as Apogonidae (Fraser 1972), *A. rhomboidalis* (Houde and Potthoff 1976), Carangidae (Ahlstrom and Ball 1954; Berry 1969), *Haemulon plumieri* (Saksena and Richards 1975), and some Scombridae (Conrad 1938; Mago Leccia 1958), the

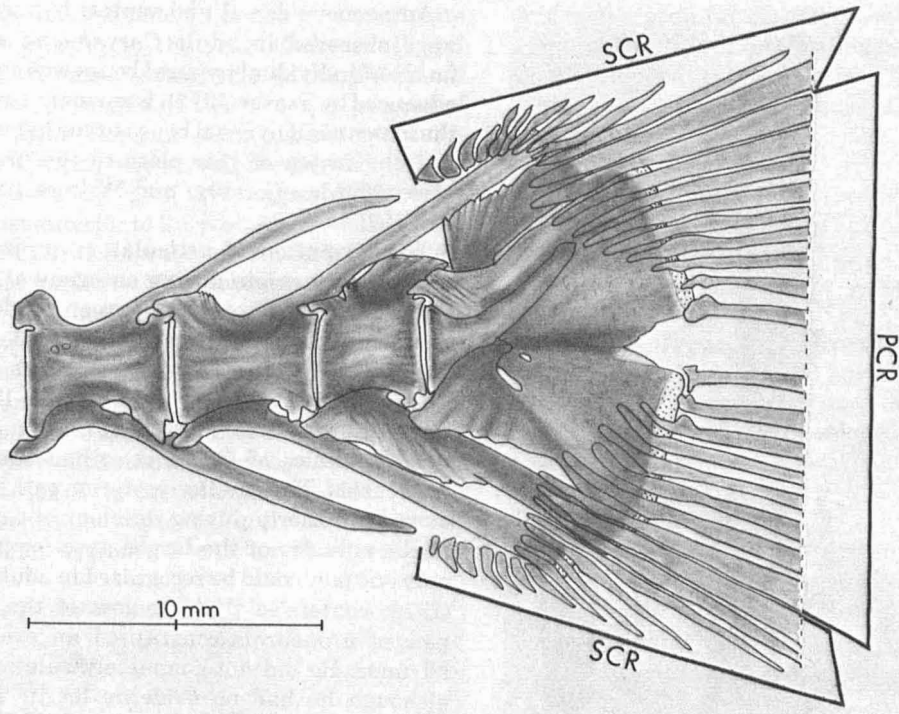


FIGURE 23.—Caudal complex of a *Coryphaena equiselis*, 230 mm SL. For explanation of symbols, see Figure 21. Stippled, articular cartilage; darkened, bone.

TABLE 11.—Distribution of principal caudal rays on the hypurals in 136 *Coryphaena hippurus* (8.0-53 mm SL) (*C. h.*) and 75 *C. equiselis* (7.0-52 mm SL) (*C. e.*).

Part	Number of principal caudal rays									
	1		2		3		4		5	
	<i>C. h.</i>	<i>C. e.</i>	<i>C. h.</i>	<i>C. e.</i>	<i>C. h.</i>	<i>C. e.</i>	<i>C. h.</i>	<i>C. e.</i>	<i>C. h.</i>	<i>C. e.</i>
Parhypural			51	24	85	51				
Hypural 1					52	22	80	51	4	2
Hypural 2	39	32	97	43						
Hypural 3			28	27	97	45	11	3		
Hypural 4					6		72	36	58	39
Hypural 5	37	16	98	58	1	1				

epurals were autogenous. In part of the Scombridae (Fierstine and Walters 1968; Monod 1968; Patterson 1968; Collette and Chao 1975; Potthoff 1975) the anteriormost epural is secondarily fused to the specialized neural arch of preural centrum 2. Based on the epurals, *Coryphaena* spp. is advanced because epural numbers are reduced from 3 to 2 and fused to 1 (Patterson 1968; Fraser 1972).

The haemal spines of preural centrum 2 and 3 were autogenous in *Coryphaena* spp. This state is considered basic because advanced percoids have these spines secondarily fused to the centra (Fraser 1972). Fusion of these haemal spines occurs in *T. atlanticus* (Potthoff 1975), and some apogonids (Fraser 1972).

The two prezygapophyses of the urostyle (Figure 24) of *Coryphaena* spp. are true prezygapophyses; whereas in *T. atlanticus* and other Thunnini and Sardini (Collette and Chao 1975; Potthoff 1975) the prezygapophyses of the urostyle represent the pair of uroneurals which have fused to the urostyle during development.

Articular cartilage was present in *Coryphaena* spp. on the caudal complex on all parts distally inclusive of preural centrum 3. No articular cartilage was observed anterior to this centrum. Articular cartilage was observed in scombrids by Fierstine and Walters (1968), in *T. atlanticus* by Potthoff (1975), and in *A. rhomboidalis* by Houde and Potthoff (1975). The absence of articular cartilage in the caudal complex drawings of

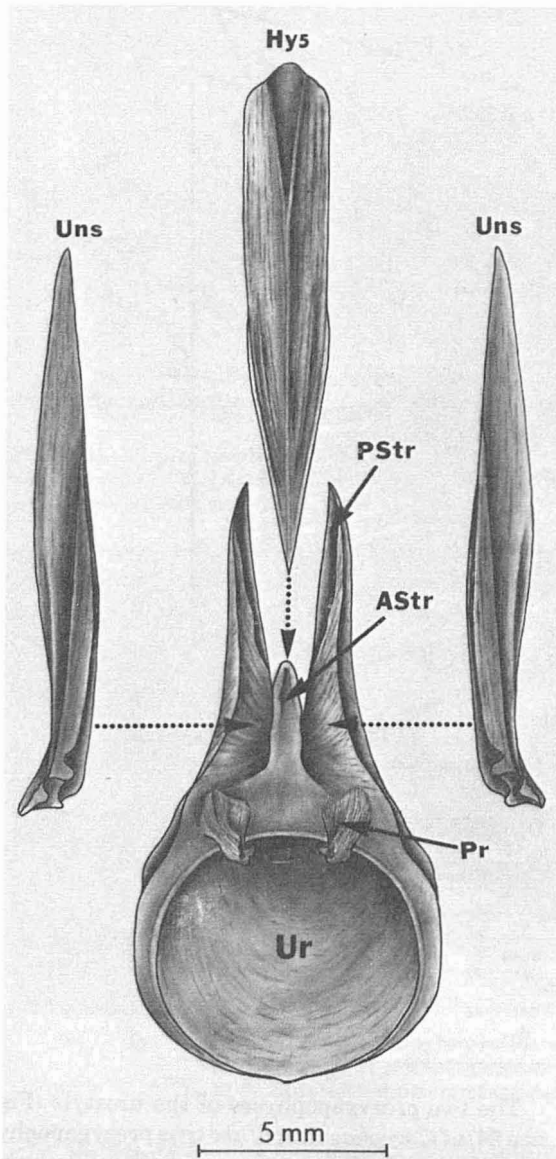


FIGURE 24.—Urostyle of a *Coryphaena equiselis*, 330 mm SL, with disarticulated uroneurals and hypural 5. Dashed lines with arrows point towards place of articulation. Symbols: AStr, anterior strut of urostyle; Hy, hypural; Pr, prezygapophysis; PStr, posterior strut of urostyle; Uns, uroneurals; Ur, urostyle. The articular cartilage is not shown on hypural 5 because of the boiling and drying method of preparation.

apogonids (Fraser 1972) is probably an oversight by the author since he used cleared and stained material. The lack of articular cartilage in most of the drawings of caudal complexes by Monod (1968) can probably be attributed to the method of skeletal preparation, e.g., boiling and subsequent drying.

Autogenous dorsal and ventral hypural plates were observed in adult *Coryphaena* spp. The fusion of individual hypural bones was considered advanced by Fraser (1972). Even more advanced is the fusion of all hypural bones to one hypural plate and the fusion of this plate to the urostyle as in scombrids (Fierstine and Walters 1968; Potthoff 1975).

The formation of articulatory projections of membranous origin during ontogeny at the midline of the caudal complex between the dorsal and ventral hypural plates was observed in *Coryphaena* spp. (Figures 20-22) as well as in *Scombrolabrax heterolepis* (Potthoff et al. 1980), but not in *T. atlanticus* (Potthoff 1975).

Both species of *Coryphaena* had two pairs of uroneurals. The smaller posterior pair gradually moved anteriorly during development and fused to the outsides of the larger anterior pair, until only one pair could be recognized in adults. Fraser (1972) contended that the loss of the posterior pair of uroneurals constituted an evolutionary advance. He did not completely rule out fusion, although he had no evidence for it. There are fishes such as the scombrids which only develop one pair of uroneurals (Potthoff 1975). Loss or fusion of uroneurals can be ascertained through the examination of developmental series.

Pectoral Fin and Supports

The following description is based upon juveniles > 13 mm SL of both *Coryphaena* species with adult counts of 19-21 rays. These counts were obtained between 19 and 13 mm SL in *C. equiselis* and between 11 and 13 mm SL in *C. hippurus*. Individual differences in counts between the left and right pectoral fins were lower in both species of *Coryphaena* than in four species of *Thunnus* (Potthoff 1974). Only 1% of 171 *Coryphaena* spp. examined with adult counts > 13 mm SL differed by 2 rays between each side, 18% differed by 1 ray, and 81% had the same count on both sides. The pectoral fin rays were directly and indirectly supported on each side by a number of bones which composed the pectoral girdle and its suspensorium. On each side the pectoral girdle consisted of a scapula (which supported the first fin ray directly), four radials (which supported the remainder of the rays directly), a coracoid, and a cleithrum. The scapula and coracoid were connected by cartilage. The suspensorium consisted of seven bones. The supracleithrum and posttemporal were attached

in a row from the outside of the posterior plate of the cleithrum to the rear of the skull and postcleithra 1 and 2 extended over the abdominal area from the inside of the posterior process of the cleithrum. The supratemporal and two intertemporals, which belong with the posttemporal to the laterosensory canal (Harrington 1955), originated just anterior to the posttemporal and ended just short of the supraoccipital crest. Except for individual variation there was no specific difference in the shape of bones of the girdle and suspensorium between the two species. The relationship of bones of the pectoral girdle, suspensorium, and pelvic basiptyrgium to each other is shown in Figure 25.

Formation of the pectoral fin rays started in the dorsal border of the larval pectoral blade (Figure 26) and continued ventrad (Figure 27). For equal-sized specimens from 6.5 to 13 mm SL, *C. equiselis*

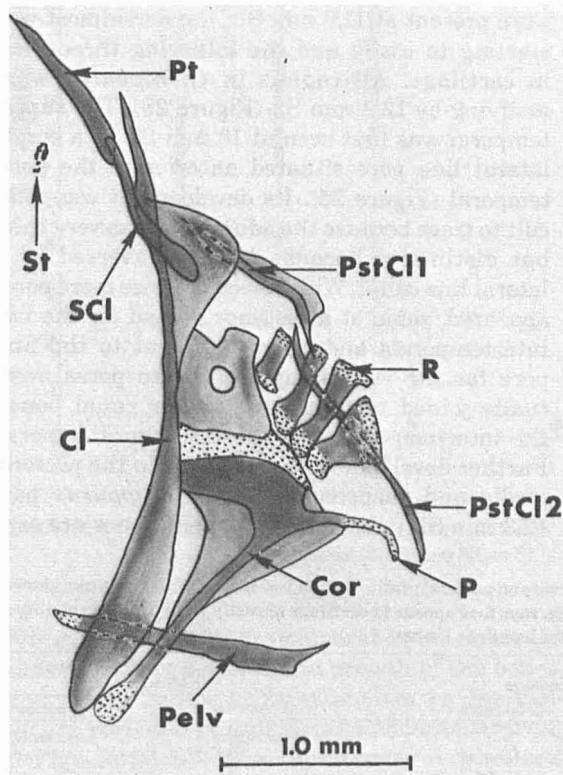


FIGURE 25.—Lateral external view of left sides of pectoral girdle and suspensorium from a 20.8 mm SL *Coryphaena hippurus*. Symbols: Cl, cleithrum; Cor, coracoid; P, posterior process of the coraco-scapular cartilage; Pelv, pelvic basiptyrgium; PstCl 1, postcleithrum 1; PstCl 2, postcleithrum 2; Pt, posttemporal; R, radial; SCl, supracleithrum; St, supra-temporal (beginning to develop). Stippled, cartilage; darkened, bone.

had more pectoral fin rays than *C. hippurus* (Figure 28). Of 86 individuals of both species with developing fins <13 mm SL, 5% differed by 2 rays between the left and right sides, 43% differed by 1 ray between the sides, and 52% had the same count on both sides.

The two species differed in length at which development of the pectoral girdle occurred but not in its structure (Table 12). The 6.5 mm NL *C. equiselis* had the same pectoral girdle development as a 6.5 mm NL *C. hippurus*. For individuals of equal length between 7.6 and 18 mm SL, *C. equiselis* was more advanced. At lengths >18 mm SL specimens of both species had the pectoral girdle equally developed except for the supratemporal-intertemporal bones which were first seen at 13 mm SL in *C. equiselis* and at 18 mm SL in *C. hippurus*.

Regarding development of the pectoral girdle in *C. hippurus*, the smallest (5 mm NL) specimen had a simple rod-shaped, bony cleithrum, and a coraco-scapular cartilage (Figure 26). The car-

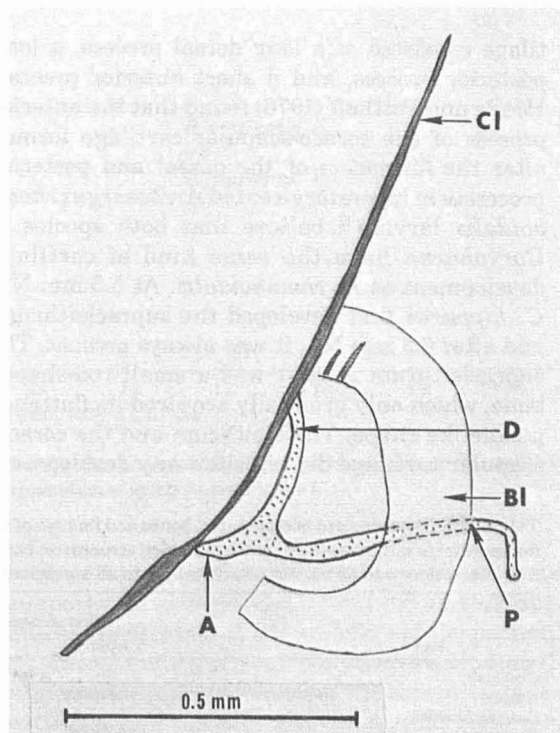


FIGURE 26.—Lateral external view of left side of pectoral girdle from a 5.0 mm NL *Coryphaena hippurus*. Symbols: A, anterior process of the coraco-scapular cartilage; Bl, blade of the larval pectoral fin with two fin rays developing dorsally; Cl, cleithrum; D, dorsal process of the coraco-scapular cartilage; P, posterior process of the coraco-scapular cartilage. Stippled, cartilage; darkened, bone.

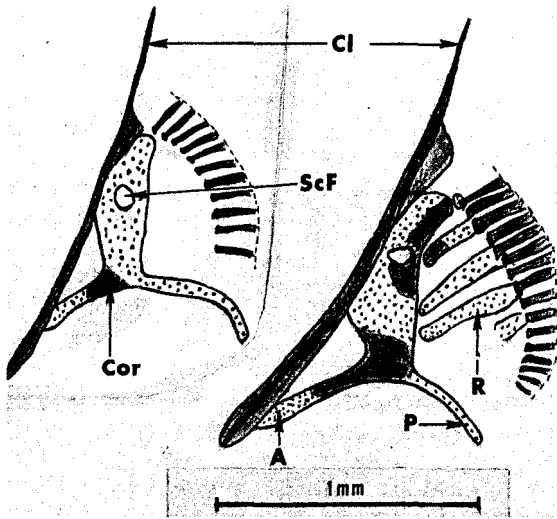


FIGURE 27.—Lateral external view of left side of pectoral girdle from a 8.1 mm SL *Coryphaena hippurus* (left) and a 7.9 mm SL *C. equiselis* (right). Symbols: ScF, scapular foramen. For explanation of other symbols, see Figures 25, 26. Stippled, cartilage; darkened, bone.

tilage consisted of a long dorsal process, a long posterior process, and a short anterior process. Houde and Potthoff (1976) found that the anterior process of the coraco-scapular cartilage formed after the formation of the dorsal and posterior processes in laboratory-reared *Archosargus rhomboidalis* larvae. I believe that both species of *Coryphaena* have the same kind of cartilage development as *A. rhomboidalis*. At 5.5 mm NL, *C. hippurus* first developed the supracleithrum, and after 6.3 mm NL, it was always present. The supracleithrum at first was a small rod-shaped bone, which only gradually acquired its flattened paddlelike shape. The cleithrum and the coraco-scapular cartilage did not show any development

between 5 and 7.3 mm NL. The posttemporal first developed as a small, rod-shaped bone at 6.3 mm NL. In larvae of 7.4 mm SL the scapular foramen was first seen in the dorsal process of the coraco-scapular cartilage, and at 7.6 mm SL the posterior process of the cleithrum first appeared (Figure 27). Between 7.6 and 8.4 mm SL many developmental changes occurred. In an 8 mm SL specimen the first dorsalmost radial was seen in cartilage; the radial was absent in an 8.1 mm SL specimen (Figure 27), but present again at 8.3 mm SL. The bony rod-shaped postcleithrum 2 was first seen at 8.3 mm SL. Ossification of the coraco-scapular cartilage started at 8.1 mm SL in the region of the future coracoid at the juncture of the dorsal and anterior processes. The scapula started to ossify first around the scapular foramen at 9.5 mm SL. Also at 9.5 mm SL the postcleithrum 1 was first seen as a tiny speck of bone, but not until 11.9 mm SL was this structure easy to see. All four radials were present at 11.9 mm SL; the dorsalmost was starting to ossify and the following three were in cartilage. All radials in *C. hippurus* were ossifying by 12.3 mm SL (Figure 29). The suprtemporal was first seen at 18 mm SL as a single lateral line pore situated anterior to the posttemporal (Figure 25). Its development was difficult to trace because the adult bone was very thin, but distinctive because it was traversed by a lateral line canal. With increasing size more pores appeared, some at a distance dorsad for the two intertemporals and others adjacent to the first pore for the suprtemporal. These pores eventually joined to form two tubular canal bones, the intertemporals and the thin suprtemporal. Further development of the bones in the pectoral girdle and suspensorium of *C. hippurus* past 12.3 mm SL (when all component bones are ossi-

TABLE 12.—Development of structures, bones and fin rays of the pelvic and pectoral girdles for the two species of *Coryphaena*, shown for lengths (in millimeters NL or SL) at which structures, bones or fin rays first appear in cartilage or ossify. Lengths given signify a first observance and do not necessarily apply to all specimens of that length or longer.

Part	First appearance in cartilage		First evidence of ossification (Stain uptake)	
	<i>C. hippurus</i>	<i>C. equiselis</i>	<i>C. hippurus</i>	<i>C. equiselis</i>
Cleithrum	—	—	not known	not known
Scapula	not known	not known	9.5	7.0
Scapular foramen	7.4	7.0	—	—
Coracoid	not known	not known	8.1	7.0
Radials 1-4	8.0-11.9	8.0-8.9	11.9-12.3	8.8- 9.8
Posttemporal	—	—	6.3	not known
Supracleithrum	—	—	5.5	not known
Postcleithrum 1	—	—	9.5	8.9
Postcleithrum 2	—	—	8.3	7.4
Supratemporal-intertemporals	—	—	18.0	13.0
Pectoral fin rays	—	—	5.0	not known
Pelvic basipterygium	7.0	(6.0?) 7.0	8.7	8.7
Pelvic fin rays	—	—	7.0	7.3

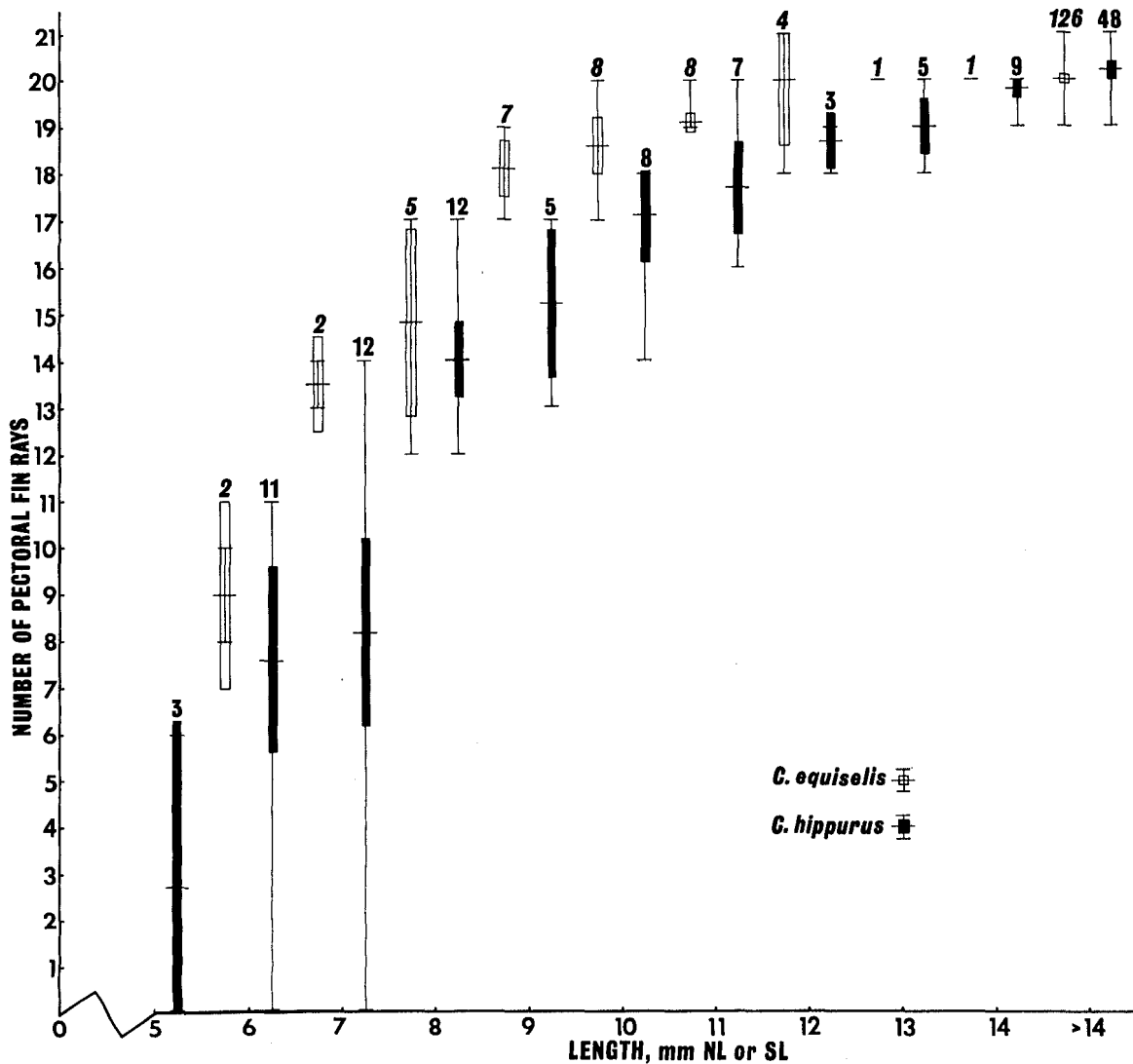


FIGURE 28.—Number of left pectoral fin rays in relation to length in 164 *Coryphaena equiselis* (6.5-230 mm NL or SL) and 123 *C. hippurus* (5-172 mm NL or SL). For explanation of symbols, see Figure 1.

fyng, except the supratemporal-intertemporals) consisted of ossification and growth of the bones, and the formation of bony shelves on the cleithrum, coracoid, posttemporal, and postcleithrum 1 (Figures 29, 30). The supratemporal developed thin membranous bones around the lateral line canal tubes. Development also involved loss of cartilage. The cartilage separating the scapula and coracoid became narrower with increasing length (Figures 29, 30). The cartilage from the prominent larval posterior process of the coracoid completely disappeared by 40 mm SL (Figure 30).

No developmental studies of the pectoral fin and supports have been done for *Coryphaena* spp. Starks (1930) studied the anatomy of the pectoral girdle in a variety of adult bony fishes including *C. hippurus*. The development of the coraco-scapular cartilage to a scapula and a coracoid bone and some or total atrophy of the cartilaginous posterior process of the coracoid occurs in most fishes (Swinnerton 1905; Starks 1930). More recently Houde and Potthoff (1976) observed the atrophy of the posterior process in *A. rhomboidalis* and Saksena and Richards (1975) reported the presence

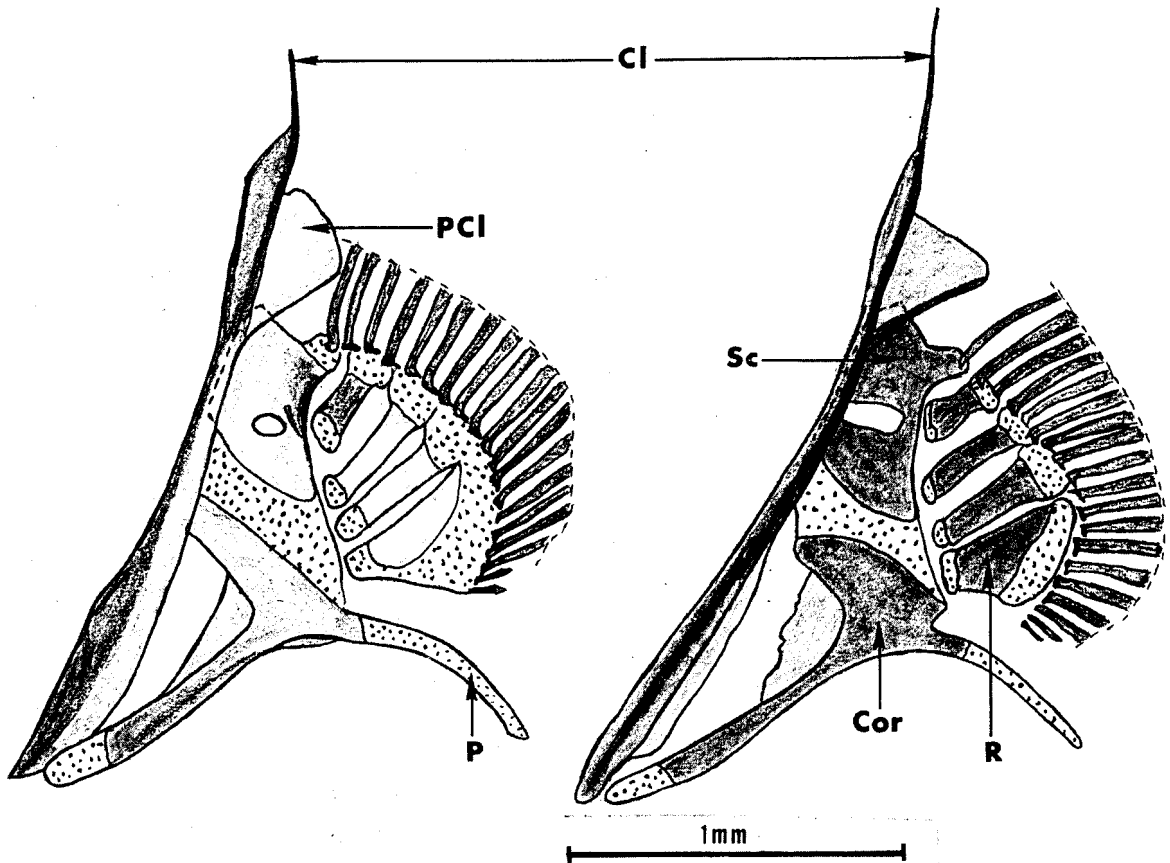


FIGURE 29.—Lateral external view of left side of pectoral girdle from a 12.3 mm SL *Coryphaena hippurus* (left) and a 10.3 mm SL *C. equiselis* (right). Symbols: CI, cleithrum; Cor, coracoid; P, posterior process of the coraco-scapular cartilage; PCI, posterior process of the cleithrum; R, radial; Sc, scapula. Stippled, cartilage; darkened, bone.

of a Y-shaped cartilaginous coracoid (probably coraco-scapular cartilage) in *Haemulon plumieri* larvae. In the Blenniidae, Characidae, and Pholidichthyidae, a small posterior process of the coracoid was observed in adults (Weitzman 1962; Springer 1968; Springer and Freihofner 1976). For the family Gobiiesocidae, however, Springer and Fraser (1976) reported large posterior processes of the coracoid. Thus, it seems that the posterior process of the coracoid is present in most fishes, but that it disappears during development in more advanced forms. It also appears that this process remains as a neotenic structure in small fishes.

In more primitive fishes such as the Osteoglossidae (Greenwood and Thomson 1960), Characidae (Weitzman 1962), most stomiatooid families (Weitzman 1974), and *Lile piquitinga* (Clupeidae) (Gomez Gaspar 1976) a mesocoracoid was present. This bone is absent in the Coryphaenidae.

The presence of intertemporals is considered primitive because these bones are absent in more advanced groups, such as scombrids (Collette and Chao 1975).

Pelvic Fin and Fin Supports

Description is based on large juveniles of both species > 90 mm SL, two adults of *C. equiselis* and two adults of *C. hippurus*. There were 15 rays in each of the pelvic fins which were located on the underside of the body below the pectoral fin. All *C. hippurus* > 10.7 mm SL and all *C. equiselis* > 8.6 mm SL had the full count. Each side of the pelvic fin was supported by a basipterygium; no radials were present. The two basipterygia were closely approximated medially, but not fused (Figure 31). They were located in the abdominal body wall and were lying between the ventral portions

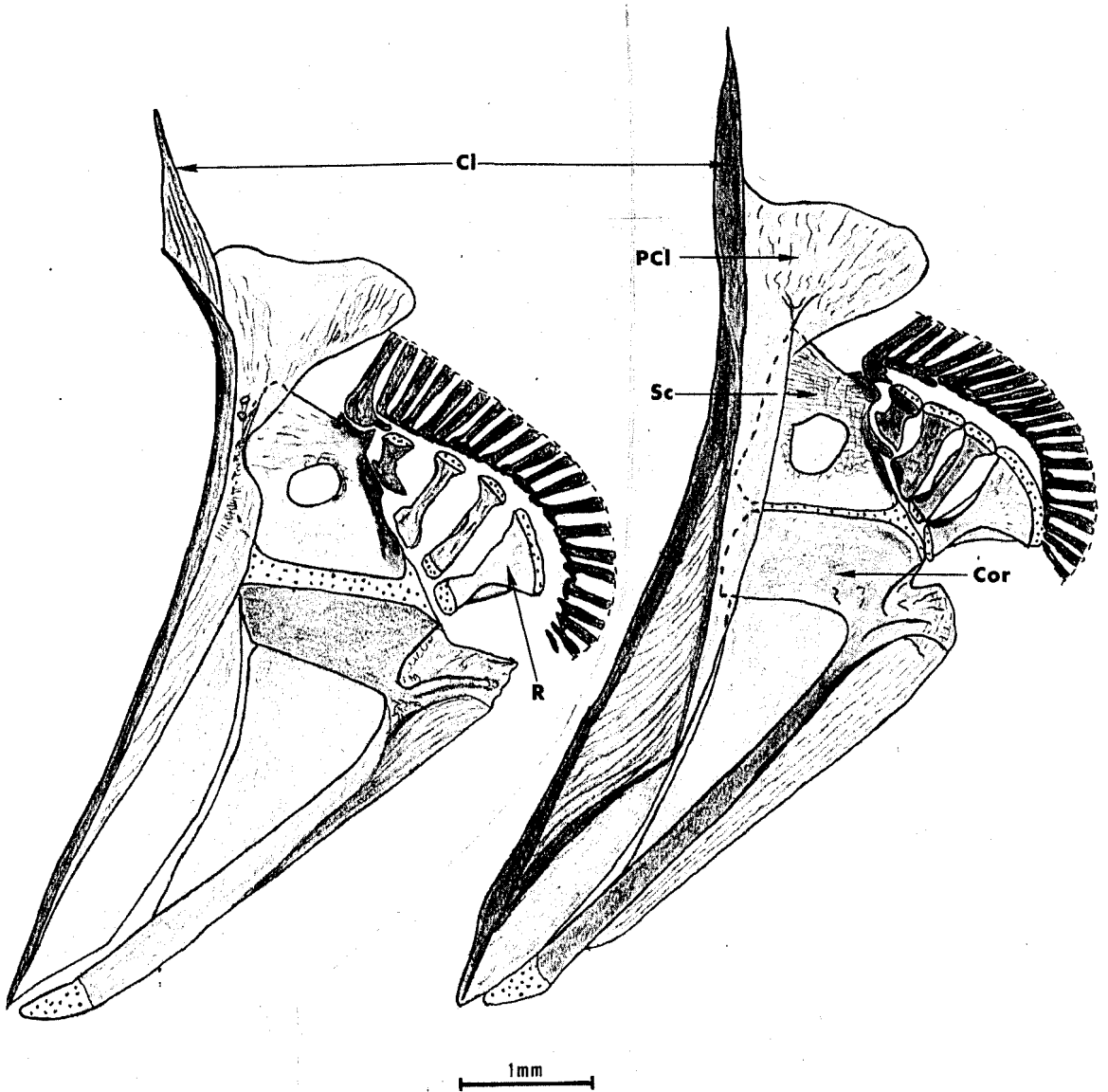


FIGURE 30.—Lateral external view of left side of pectoral girdle from a 47.6 mm SL *Coryphaena hippurus* (left) and a 48 mm SL *C. equiselis* (right). For explanation of symbols, see Figure 29. Stippled, cartilage; darkened, bone.

of the two cleithra and coracoids (Figure 25). No fleshy interpelvic processes were present between the bases of the fins.

The basipterygium is a complex bone. For convenience of description, it was divided into three parts which corresponded to the ontogeny of the bone: the central part, which was the original cartilage, the wings (Kishinouye 1923) of membranous bone origin, and the two xiphoid processes (de Sylva 1955), of which the posterior process was of cartilage origin and the anterior process of bone

origin. The central part of the basipterygium carried the four wings along its length (Figures 31-33). Anteriorly the central part was tipped by a small piece of cartilage. Posteriorly the central part served the articulation of the fin rays. A thin layer of articular cartilage was present in adults on the posteriormost portion of the central part (Figures 31, 32). Each basipterygium had four wings, reminiscent of the two sagittal and two lateral keels of pterygiophores. The wings formed a dorsal and a ventral "V" shaped groove, and a

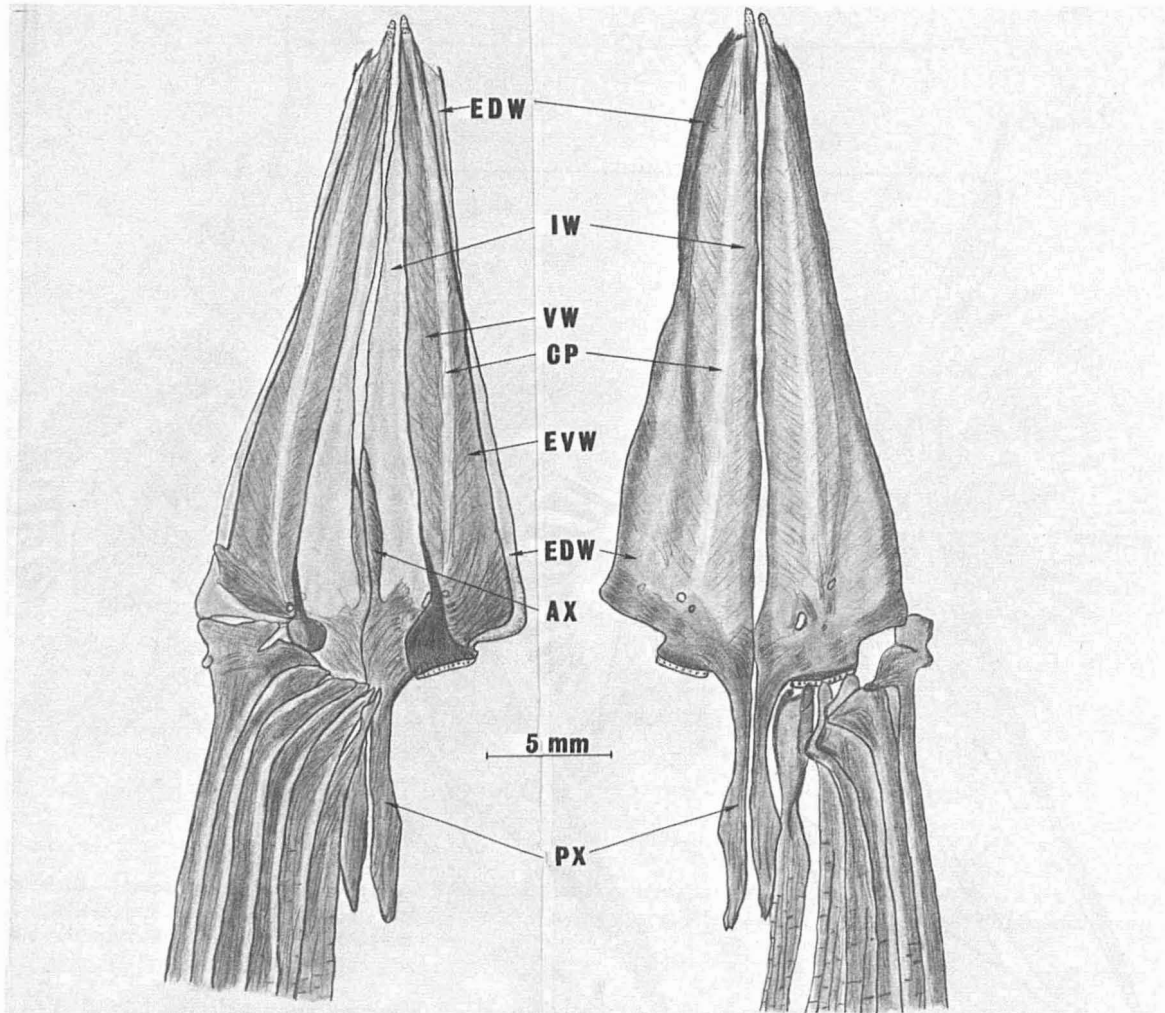


FIGURE 31.—Pelvic fin and basipterygia from a 449 mm SL *Coryphaena hippurus*. Left: ventral external view; right: dorsal internal view. Left pelvic fin has been removed. Symbols: AX, anterior xiphoid process; CP, central part; EDW, external dorsolateral wing; EVW, external ventrolateral wing; IW, internal dorsolateral wing; PX, posterior xiphoid process; VW, ventral wing. Stippled, cartilage; darkened, bone.

lateral “[” shaped channel (Figure 33). The xiphoid processes were located internally at the midline on the basipterygia (Figures 31-33). The anterior xiphoid process was an anteroventral extension of the posterior xiphoid process (Figure 32). The posterior xiphoid process, which pointed in a posterodorsal direction was attached to the posterior part of the basipterygium by a heavy bony strut from the central part and anteriorly by the internal dorsolateral wing (Figures 32, 33). The two basipterygia were closely approximated at the edges of the two internal dorsolateral wings and the internal surfaces of the four xiphoid processes

(Figure 31). The closest approximation was observed on the xiphoid processes at the place where the anterior and posterior processes were joined (Figure 32). Here the bone was rough with minute projections. These projections gave a close fit when the surfaces were brought together and prevented the basipterygia from sliding.

No anatomical differences in the development of the pelvic fin and supports were found between *C. hippurus* and *C. equiselis*. Larval and juvenile specimens of *C. equiselis* were more advanced in pelvic development than equal-sized specimens of *C. hippurus* (Table 13; Figures 34, 35). In both

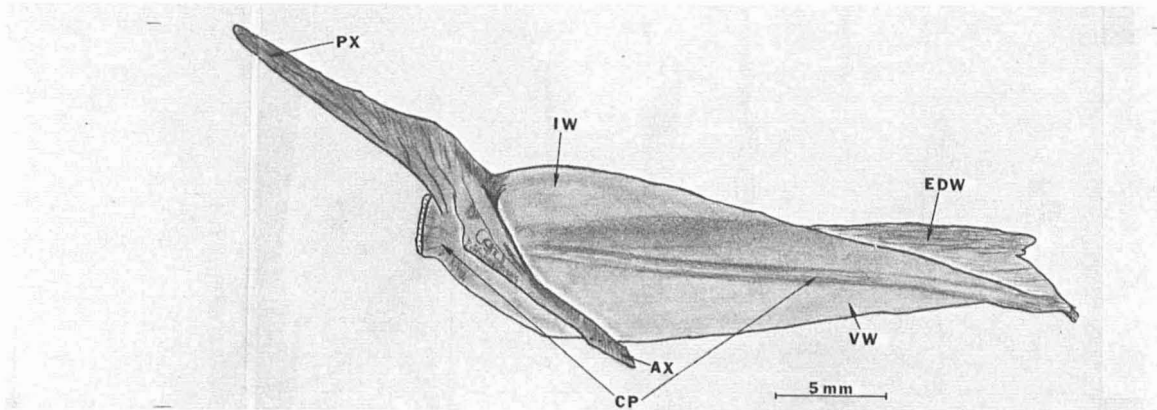


FIGURE 32.—Lateral internal view of left basipterygium from a 449 mm SL *Coryphaena hippurus*. For explanation of symbols, see Figure 31. Stippled, cartilage; darkened, bone.

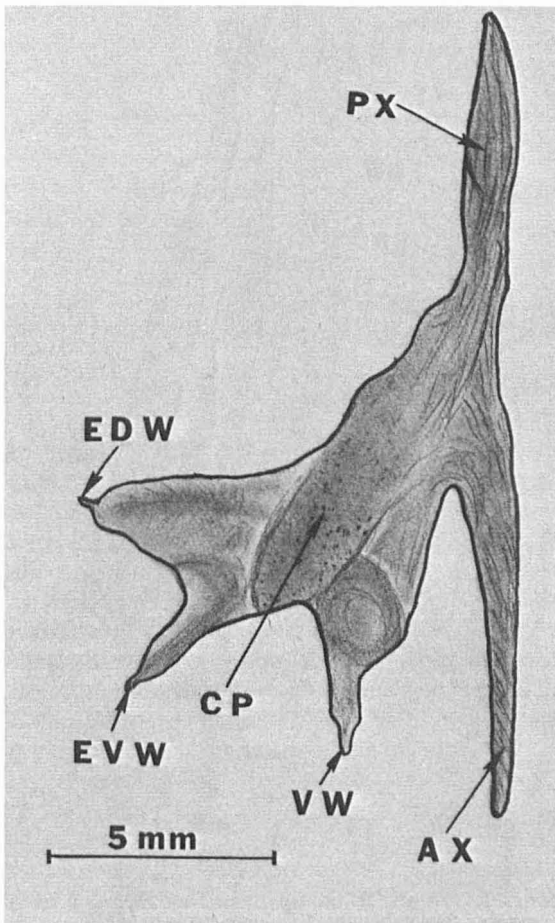


FIGURE 33.—Posterior view of left basipterygium after left pelvic fin had been removed from a 449 mm SL *Coryphaena hippurus*. For explanation of symbols, see Figure 31.

species a fin bud developed first on the abdomen (Table 13). Simultaneously to the fin bud appearance, two cartilaginous basipterygia developed internally at 7 mm SL in flexion larvae of *C. hippurus*. In *C. equiselis* it probably occurred in flexion larvae between 6 and 7 mm SL, but the smallest available specimen measured 7 mm SL (Table 12). The pelvic fin rays developed in the fin bud after basipterygium formation. Fin ray appearance was from the outside of the specimen towards its midline in both species, so that the first ray to appear was the spinous ray. In *C. hippurus* the pelvic fin ray development began at 7-7.5 mm SL and was completed at 10.7 mm SL, and in *C. equiselis* it began at 7.3 mm SL and was completed at 8.6 mm SL.

Each cartilaginous basipterygium in both species was cylindrical with its base expanded posteriorly near the fin bud (Figure 34). The cartilaginous projection of the posterior xiphoid process developed posteriorly at the inner corner of the expanded base (Figure 34). Ossification of the basipterygium cartilage to the central part began in both species at the center and progressed anteriorly and posteriorly as the larvae grew (Figure 34). For *C. hippurus* it began at 8.7-10.8 mm SL, and for *C. equiselis* at 8.7 mm SL (Tables 12, 13). After the cartilaginous central part of the basipterygium had ossified, all structures of membranous origin developed simultaneously; these were the anterior xiphoid process and the four wings (Figure 34). All wings developed from the base in an anterior direction. The posterior xiphoid process was of cartilage origin and started

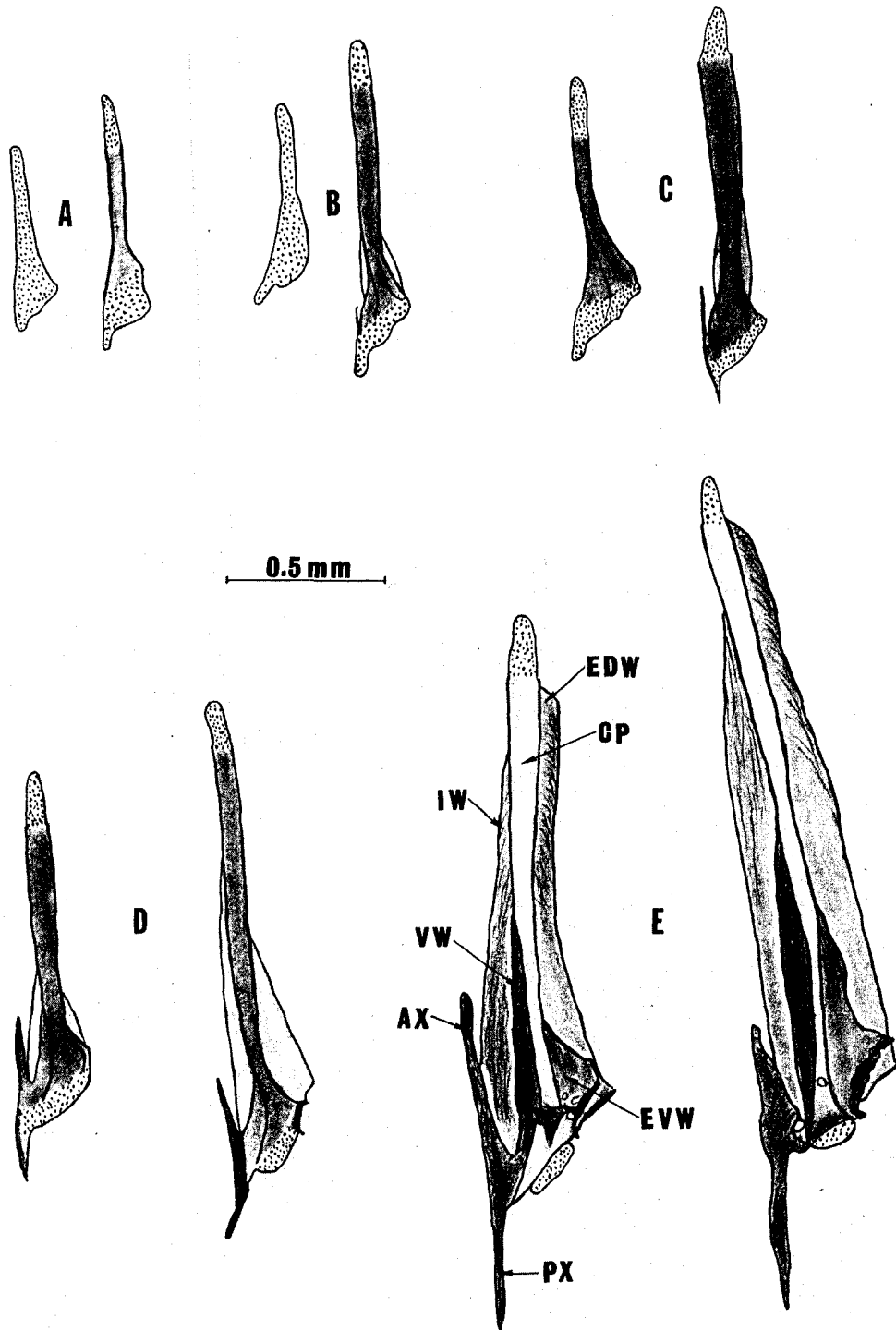


FIGURE 34.—Development of left basipterygium of *Coryphaena* spp. Basipterygium of *C. hippurus* is to left of letters, that of *C. equiselis* is to right. Lengths: A, 8.3 and 8.9 mm SL; B, 10.3 and 10.1 mm SL; C, both 11.3 mm SL; D, 14.1 and 14.2 mm SL; E, 21 and 20.9 mm SL. For explanation of symbols, see Figure 31. Stippled, cartilage; darkened, bone.

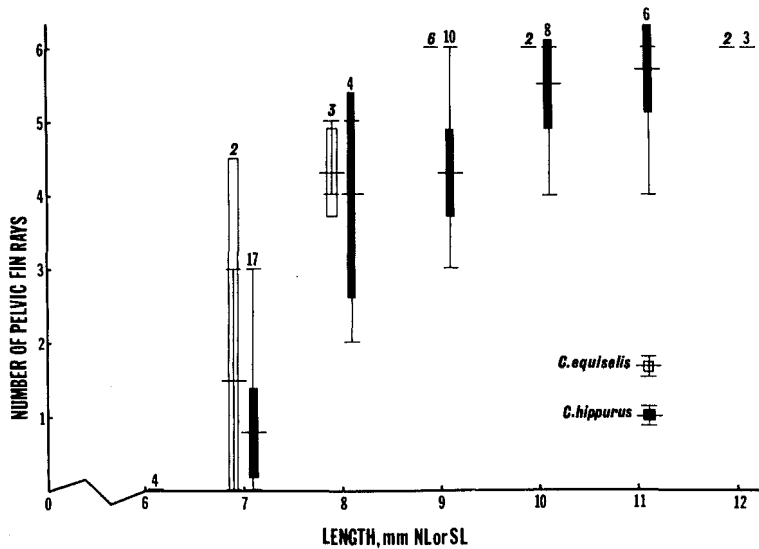


FIGURE 35.—Number of pelvic fin rays in relation to length in 15 *Coryphaena equiselis* (7.0-12.4 mm SL) and 52 *C. hippurus* (6.0-12.5 mm NL or SL). For explanation of symbols, see Figure 1.

TABLE 13.—Development of pelvic fin and supports in 52 *Coryphaena hippurus* (6.0 mm NL-12.5 mm SL) (*C. h.*) and 15 *C. equiselis* (7.0-12.4 mm SL) (*C. e.*). Numbers denote number of specimens, dashes denote specimens not available.

Length mm NL or SL	Fin bud				Fin rays				Basipterygia					
	Absent		Present		Absent		Present		Absent		Cartilaginous		Ossifying	
	<i>C. h.</i>	<i>C. e.</i>	<i>C. h.</i>	<i>C. e.</i>	<i>C. h.</i>	<i>C. e.</i>	<i>C. h.</i>	<i>C. e.</i>	<i>C. h.</i>	<i>C. e.</i>	<i>C. h.</i>	<i>C. e.</i>	<i>C. h.</i>	<i>C. e.</i>
5.6- 6.5	4	—	0	—	4	—	0	—	4	—	0	—	0	—
6.6- 7.5	6	0	11	2	12	1	5	1	10	0	7	2	0	0
7.6- 8.5	0	0	4	3	0	0	4	3	0	0	4	3	0	0
8.6- 9.5	0	0	10	6	0	0	10	6	0	0	9	0	1	6
9.6-10.5	0	0	8	2	0	0	8	2	0	0	1	0	7	2
10.6-11.5	0	—	6	—	0	—	6	—	0	—	1	—	5	—
11.6-12.5	0	0	3	2	0	0	3	2	0	0	0	0	3	2

to ossify shortly after the appearance of the anterior xiphoid process (Figure 34).

A comparison of pelvic bones of *Coryphaena* spp. with those of more primitive fishes revealed the absence of radials in *Coryphaena* spp. It is not known if the radials have been lost, or if they have fused to the central part and the articular cartilage during evolution. In the more primitive stomioid fish families (Weitzman 1974) and in *Lile piquitinga* (Gomez Gaspar 1976), radials are present between the bases of the fin rays.

DISCUSSION

In a tentative classification of the Perciformes, Greenwood et al. (1966) placed the *Coryphaenidae* to follow the family *Carangidae*. This placement was arbitrary because *Coryphaena* spp. is

more advanced than some families that follow in the placement.

The one continuous dorsal fin of *Coryphaena* spp. extends to the head, so that the first interneural space, bounded by the head bones and the first neural spine, is occupied by pterygiophores which support the fin rays. Smith and Bailey (1961) contended that the dorsal fin of *Coryphaena* spp. represents an evolutionary advance and specialization because of its anterior extension and the loss or reoccupation by fin rays of the predorsal bones. In diverse fishes, such as characins, sparids, carangids, scombrids, and lutjanids, the pterygiophores in the posterior parts of the dorsal and anal fins have three parts. This triserial pterygiophore structure is considered basic (Eaton 1945; Lindsey 1955; Johnson 1978). Most pterygiophores in *Coryphaena* spp. are biserial, and one or two anterior-most ones uniserial. Thus, the pterygiophores of

Coryphaena spp. are more advanced or specialized due to either a loss or fusion of the middle radial. The loss of the "stay" for the posteriormost dorsal and anal pterygiophore also represents an advance. Therefore, based on the dorsal and anal fin and supports, placement of *Coryphaena* spp. should be phylogenetically higher than that given by Greenwood et al. (1966).

The vertebral number is higher for *C. equiselis* than for *C. hippurus* (Jordan and Evermann 1896; Collette et al. 1969), yet *C. equiselis* has fewer dorsal fin rays than *C. hippurus*. *Coryphaena equiselis* also tends to have fewer anal fin rays than *C. hippurus*. Therefore, since fin ray number is approximately equal to the pterygiophore number, *C. equiselis* has fewer dorsal pterygiophores arranged in more interneural spaces, and *C. hippurus* has more dorsal pterygiophores arranged in fewer interneural spaces. The situation is similar for the anal fin. It is noteworthy that the same number of vertebrae is found in both species posteriorly to the end of the dorsal and anal fins (Figure 3). The evolutionary significance of the relationship between vertebral numbers and pterygiophore numbers is not understood (Lindsey 1955), but may be phylogenetically important.

During development, except for the presence of two rather than three epurals, *Coryphaena* spp. have the basic (unreduced) perciform caudal skeleton (Gosline 1961a; Monod 1968; Patterson 1968; Fraser 1972). Adults of *Coryphaena* spp., however, have a more advanced caudal skeleton. The presence of a single epural and uroneural, as well as a dorsal and ventral hypural plate, shows advance over the basic type, although the fused parts remain autogenous. In the modified and advanced caudal complex of most Scombridae these parts may be fused to the centra. For example, the epural may be fused to the specialized neural arch, the uroneurals and hypural plates may be fused to the urostyle, the parhypural and the hypural plate may be fused to the urostyle, and two haemal spines may be fused to preural centra 2 and 3.

The pectoral skeletons of *Coryphaena* spp. are of the basic perciform type. The pectoral supports fit the description of Greenwood et al. (1966) for the Acanthopterygii. The presence of supratemporal-intertemporal bones and two postcleithra in *Coryphaena* spp. characterize them as a basic perciform pectoral support system. Some fishes may lose some or all supratemporal-intertemporal bones (Scombridae) and some also may lose

a postcleithrum (*Gymnapogon*, Apogonidae, Fraser 1972; *Xiphias gladius*, author's personal observation).

The pelvic fin and supports are of the acanthopterygian (perciform) type, one bone supporting an unbranched and five branched rays in a thoracic position. The development and structure of the pelvic basipterygium is similar to that of a pterygiophore. The central part and wings of the basipterygium closely resemble proximal radials with sagittal and lateral keels.

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LITERATURE CITED

- AHLSTROM, E. H., AND O. P. BALL.
1954. Description of eggs and larvae of jack mackerel (*Trachurus symmetricus*) and distribution and abundance of larvae in 1950 and 1951. U.S. Fish Wildl. Serv., Fish. Bull. 56:209-245.
- AHLSTROM, E. H., J. L. BUTLER, AND B. Y. SUMIDA.
1976. Pelagic stromateoid fishes (Pisces, Perciformes) of the eastern Pacific: kinds, distributions, and early life histories and observations on five of these from the north-west Atlantic. Bull. Mar. Sci. 26:285-402.
- BEARDSLEY, G. L., JR.
1967. Age, growth, and reproduction of the dolphin, *Coryphaena hippurus*, in the Straits of Florida. Copeia 1967: 441-451.

- BERRY, F. H.
1969. *Elagatis bipinnulata* (Pisces: Carangidae): morphology of the fins and other characters. *Copeia* 1969: 454-463.
- BURNETT-HERKES, J.
1974. Parasites of the gills and buccal cavity of the dolphin, *Coryphaena hippurus*, from the Straits of Florida. *Trans. Am. Fish. Soc.* 103:101-106.
- CLOTHIER, C. R.
1950. A key to some Southern California fishes based on vertebral characters. *Calif. Dep. Fish Game, Fish. Bull.* 79, 83 p.
- COLLETTE, B. B., AND L. N. CHAO.
1975. Systematics and morphology of the bonitos (*Sarda*) and their relatives (Scombridae, Sardini). *Fish. Bull., U.S.* 73:516-625.
- COLLETTE, B. B., R. H. GIBBS, JR., AND G. E. CLIPPER.
1969. Vertebral numbers and identification of the two species of dolphin (*Coryphaena*). *Copeia* 1969:630-631.
- CONRAD, G. M.
1938. The osteology and relationships of the wahoo (*Acanthocybium solandri*), a scombroid fish. *Am. Mus. Novit.* 1000, 32 p.
- DE SYLVA, D. P.
1955. The osteology and phylogentic relationships of the blackfin tuna, *Thunnus atlanticus* (Lesson). *Bull. Mar. Sci. Gulf Caribb.* 5:1-41.
- EATON, T. H., JR.
1945. Skeletal supports of the median fins of fishes. *J. Morphol.* 76:193-212.
- FIERSTINE, H. L., AND V. WALTERS.
1968. Studies in locomotion and anatomy of scombroid fishes. *Mem. South. Calif. Acad. Sci.* 6:1-31.
- FRASER, T. H.
1972. Comparative osteology of the shallow water cardinal fishes (Perciformes: Apogonidae) with reference to the systematics and evolution of the family. *Rhodes Univ. Dep. Ichthyol., Ichthyol. Bull.* 34:1-105.
- GIBBS, R. H., JR., AND B. B. COLLETTE.
1959. On the identification, distribution, and biology of the dolphins, *Coryphaena hippurus* and *C. equiselis*. *Bull. Mar. Sci. Gulf Caribb.* 9:117-152.
- GOMEZ GASPAR, A.
1976. Osteologia de *Lile piquitinga* (Schreiner y Miranda Ribeiro 1903) (Pisces Clupeidae). *Bol. Mus. Mar. Bogotá* 8:1-52.
- GOSLINE, W. A.
1961a. The perciform caudal skeleton. *Copeia* 1961: 265-270.
1961b. Some osteological features of modern lower teleostean fishes. *Smithson. Misc. Collect.* 142(3):1-42.
- GREENWOOD, P. H., AND K. S. THOMPSON.
1960. The pectoral anatomy of *Pantodon buchholzi* Peters (a freshwater flying fish) and the related Osteoglossidae. *Proc. Zool. Soc. Lond.* 135:283-301.
- GREENWOOD, P. H., D. E. ROSEN, S. H. WEITZMAN, AND G. S. MYERS.
1966. Phyletic studies of teleostean fishes, with a provisional classification of living forms. *Bull. Am. Mus. Nat. Hist.* 131:341-455.
- GREGORY, W. K.
1933. Fish skulls: A study of the evolution of natural mechanisms. *Trans. Am. Philos. Soc.* 23:75-481. [Re-issue 1959, Eric Lundberg, Laurel, Fla., seen.]
- HARRINGTON, R. W., JR.
1955. The osteocranium of the American cyprinid fish, *Notropis bifrenatus*, with an annotated synonymy of teleost skull bones. *Copeia* 1955:267-290.
- HOUDE, E. D., AND T. POTTHOFF.
1976. Egg and larval development of the sea bream *Archosargus rhomboidalis* (Linnaeus): Pisces, Sparidae. *Bull. Mar. Sci.* 26:506-529.
- HUBBS, C. L., AND K. F. LAGLER.
1958. Fishes of the Great Lakes Region. Rev. ed. *Cranbrook Inst. Sci. Bull.* 26, 213 p.
- JOHNSON, G. D.
1975. The procurrent spur: an undescribed perciform caudal character and its phylogentic implications. *Occas. Pap. Calif. Acad. Sci.* 121, 23 p.
1978. Limits and relationships of the Lutjanidae and associated families. Ph.D. Thesis, Univ. California, San Diego, 211 p.
- JORDAN, D. S., AND B. W. EVERMANN.
1896. The fishes of North and Middle America. *U.S. Natl. Mus. Bull.* 47:951-953.
- KENDALL, A. W., JR.
1976. Predorsal and associated bones in serranid and grammistid fishes. *Bull. Mar. Sci.* 26:585-592.
- KISHINOUE, K.
1923. Contributions to the comparative study of the so-called scombroid fishes. *J. Coll. Agric., Imp. Univ. Tokyo* 8:293-475.
- KOJIMA, S.
1960. Fishing for dolphins in the western part of the Japan Sea V. Species of fishes attracted to bamboo rafts. *Bull. Jpn. Soc. Sci. Fish.* 26:379-382.
1961. Studies on fishing conditions of dolphin, *Coryphaena hippurus* L., in the western region of the Sea of Japan III. On food contents of the dolphin. *Bull. Jpn. Soc. Sci. Fish.* 27:625-629.
1963a. Studies on fishing conditions of the dolphin, *Coryphaena hippurus* L., in the western region of the Sea of Japan VII. Relationship between the stomach contents and the pelagic fauna of juveniles. *Bull. Jpn. Soc. Sci. Fish.* 29:407-414.
1963b. Studies on fishing conditions of the dolphin, *Coryphaena hippurus* L., in the western region of the Japan Sea—VIII. Comparison of juvenile fish fauna in the sea and in the stomachs of dolphin. *Bull. Jpn. Soc. Sci. Fish.* 29:507-513.
1964. On the distribution of the dolphin, *Coryphaena hippurus* L., in the Pacific Ocean and the Indian Ocean. *Bull. Jpn. Soc. Sci. Fish.* 30:472-477.
- KRAMER, D.
1960. Development of eggs and larvae of Pacific mackerel and distribution and abundance of larvae 1952-56. *U.S. Fish Wildl. Serv., Fish. Bull.* 60:393-438.
- LINDSEY, C. C.
1955. Evolution of meristic relations in the dorsal and anal fins of teleost fishes. *Trans. R. Soc. Can.* 49, Ser. 3, Sect. 5:35-49.
- LUNDBERG, J. G., AND J. N. BASKIN.
1969. The caudal skeleton of the catfishes, order Siluriformes. *Am. Mus. Novit.* 2398, 49 p.
- MAGO LECCIA, F.
1958. The comparative osteology of the scombroid fishes of the genus *Scomberomorus* from Florida. *Bull. Mar. Sci. Gulf Caribb.* 8:299-341.

- MILLER, G. L., AND S. C. JORGENSON.
1973. Meristic characters of some marine fishes of the western Atlantic Ocean. *Fish. Bull.*, U.S. 71:301-313.
- MITO, S.
1960. Egg development and hatched larvae of the common dolphin-fish, *Coryphaena hippurus* Linné. *Bull. Jpn. Soc. Sci. Fish.* 26:223-226.
- MONOD, T.
1968. Le complexe urophore des poissons téléostéens. *Mém. Inst. Fondam. Afr. Noire* 81, 705 p.
- MORROW, J. E.
1954. Data on dolphin, yellowfin tuna and little tuna from East Africa. *Copeia* 1954:14-16.
- NICHOLS, J. T.
1909. A note on the dolphins (*Coryphaena equisetis* and *Coryphaena hippurus*). *Bull. Am. Mus. Nat. Hist.* 26: 131-133.
- NURSALL, J. R.
1963. The hypurapophysis, an important element of the caudal skeleton. *Copeia* 1963:458-459.
- NYBELIN, O.
1963. Zur Morphologie und Terminologie des Schwanzskelettes der Actinopterygier. *Ark. Zool.*, Ser. 2, 15: 485-516.
- PATTERSON, C.
1968. The caudal skeleton in Mesozoic acanthopterygian fishes. *Bull. Br. Mus. (Nat. Hist.) Geol.* 17:49-102.
- PEW, P.
1957. Occurrence of young dolphin, *Coryphaena hippurus*, in a Texas Bay. *Copeia* 1957:300.
- POTTHOFF, T.
1971. Observations on two species of dolphin (*Coryphaena*) from the tropical mid-Atlantic. *Fish. Bull.*, U.S. 69: 877-879.
1974. Osteological development and variation in young tunas, genus *Thunnus* (Pisces, Scombridae), from the Atlantic Ocean. *Fish. Bull.*, U.S. 72:563-588.
1975. Development and structure of the caudal complex, the vertebral column, and the pterygiophores in the blackfin tuna (*Thunnus atlanticus*, Pisces, Scombridae). *Bull. Mar. Sci.* 25:205-231.
- POTTHOFF, T., W. J. RICHARDS, AND S. UEYANAGI.
1980. Development of *Scombrabolax heterolepis* (Pisces, Scombridae) and comments on familial relationships. *Bull. Mar. Sci.* 30:329-357.
- ROSE, C. D., AND W. W. HASSLER.
1968. Age and growth of the dolphin, *Coryphaena hippurus* (Linnaeus), in North Carolina waters. *Trans. Am. Fish. Soc.* 97:271-276.
1974. Food habits and sex ratios of dolphin *Coryphaena hippurus* captured in the western Atlantic Ocean off Hatteras, North Carolina. *Trans. Am. Fish. Soc.* 103: 94-100.
- ROTHSCHILD, B. J.
1964. Observations on dolphins (*Coryphaena* spp.) in the central Pacific Ocean. *Copeia* 1964:445-447.
- SAKSENA, V. P., AND W. J. RICHARDS.
1975. Description of eggs and larvae of laboratory-reared white grunt, *Haemulon plumieri* (Lacépède) (Pisces, Pomadasidae). *Bull. Mar. Sci.* 25:523-536.
- SCHUCK, H. A.
1951. Notes on the dolphin (*Coryphaena hippurus*) in North Carolina waters. *Copeia* 1951:35-39.
- SHCHERBACHEV, YU. N.
1973. The biology and distribution of the dolphins (Pisces, Coryphaenidae). *J. Ichthyol.* 13:182-191.
- SMITH, C. L., AND R. M. BAILEY.
1961. Evolution of the dorsal-fin supports of percoid fishes. *Pap. Mich. Acad. Sci. Arts Lett.* 46:345-363.
- SPRINGER, V. G.
1968. Osteology and classification of the fishes of the family Blenniidae. *U.S. Natl. Mus. Bull.* 284, 85 p.
1976. Synonymy of the fish families Cheilobranchidae (= Alabetidae) and Gobiesocidae, with descriptions of two new species of *Alabes*. *Smithson. Contrib. Zool.* 234, 23 p.
- SPRINGER, V. G., AND W. C. FREIHOFER.
1976. Study of the monotypic fish family Pholidichthyidae (Perciformes). *Smithson. Contrib. Zool.* 216, 43 p.
- STARKS, E. C.
1930. The primary shoulder girdle of the bony fishes. *Stanford Univ. Publ. Biol. Sci.* 6:147-240.
- SWINNERTON, H. H.
1905. A contribution to the morphology and development of the pectoral skeleton of teleosts. *Q. J. Microsc. Sci.*, New Ser., 49:363-382.
- TAKAHASHI, M., AND K. MORI.
1973. Studies on relative growth in body parts compared in *Coryphaena hippurus* and *C. equiselis*, and notes on gonadal maturation in the latter species. [In Jpn., Engl. summ.] *Bull. Far Seas Fish. Res. Lab. (Shimizu)* 8:79-113.
- TAYLOR, W. R.
1967. An enzyme method of clearing and staining small vertebrates. *Proc. U.S. Natl. Mus.* 122 (3596), 17 p.
- TIBBO, S. N.
1962. New records for occurrence of the white-tip shark, *Pterolamiops longimanus* (Poey), and the dolphin, *Coryphaena hippurus* L., in the northwest Atlantic. *J. Fish. Res. Board Can.* 19:517-518.
- VOSS, N. A.
1954. The postlarval development of the fishes of the family Gempylidae from the Florida Current. I. *Nesiarchus* Johnson and *Gempylus* Cuv. and Val. *Bull. Mar. Sci. Gulf Caribb.* 4:120-159.
- WEITZMAN, S. H.
1962. The osteology of *Brycon meeki*, a generalized characid fish, with an osteological definition of the family. *Stanford Ichthyol. Bull.* 8, 77 p.
1974. Osteology and evolutionary relationships of the Sternoptychidae, with a new classification of stomiatooid families. *Bull. Am. Mus. Nat. Hist.* 153:327-478.
- WILLIAMS, F.
1953. Catches of *Coryphaena hippurus* (L) in the western Indian Ocean. *Nature (Lond.)* 171:703-704.
- WILLIAMS, F., AND B. S. NEWELL.
1957. Notes on the biology of the dorade or dolphin-fish (*Coryphaena hippurus*) in east African waters. *East Afr. Agric. For. J. (Kenya)* 23:113-118.