DATA ON LIFE HISTORY AND CHARACTERS OF *GALEUS PIPERATUS*, A DWARF SHARK OF GOLFO DE CALIFORNIA [1]

By

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INTRODUCTION

The purpose of this paper is to amplify information on the life history and characters of *Galeus piperatus* Springer and Wagner, a dwarf cat shark that has just recently been described from an oceanographically distinctive area in the northern part of Golfo de California, on the Pacific side of northern Mexico. In a way, this contribution supplements the recent account (Hubbs, Iwai and Matsubara 1967) of an even smaller, pelagic, squaloid shark, *Euprotomicrus bispinatus* (Quoy and Gaimard).

Galeus piperatus was described by Springer and Wagner (1966) from two adult females only 296 and 302 mm in total length and one immature female 256 mm long, all from a series of five specimens trawled in Golfo de California. The capture of the type specimens had been discussed by Lavenberg and Fitch (1966) under the name of *Galeus* sp., and the species has been briefly diagnosed with a copy of the original figure by Kato, Springer and Wagner (1967, p. 23, fig. 4), who have assigned it the vernacular name, "peppered shark". For this supplementary account of the species we have had available, in addition to the two mature female types and one additional adult female, three adult and two early juvenile males, and one egg case that, we believe, pertains to this species (Table 1). The types were taken in 1964 by the R/V Alaska of the California Department of Fish and Game; all other specimens, in 1967–1969, by the R/V Velero IV of the University of Southern California, and the research vessels Thomas Washington and Ellen B. Scripps of the Scripps Institution of Oceanography.

HABITAT

All known specimens of *Galeus piperatus* have been taken in the northern part of Golfo de California, in the Salsipuedes basin —in a region that is well known for a rather high incidence of endemism and for extreme fluctuations in physical parameters: the annual temperature range of surface waters is extreme (warm like tropical waters in summer, as cool as southern California waters in winter); tidal currents are strong; and vertical and horizontal turbulence are exceptional (RODEN 1958 and 1964, RODEN and GROVES 1959, HUBBS and RODEN 1964). The species has not been taken by recent trawling in other parts of the Gulf, nor along the open coast of the Baja California peninsula, nor along the coast south of the Gulf. However, it should be looked for in those areas.

The region where this shark occurs is not only one of considerable endemism, but is also one where a number of northern (warm-temperate) fishes and other organisms occur, apparently as Pleistocene relicts, sympatrically with a reduced assemblage of tropical forms (WALKER 1960). Thus, although the fauna of the whole Gulf is largely to be characterized as depleted-tropical, the occurrence of this scyliorhinid in the upper part of the Gulf is not wholly inconsistent with SPRINGER's indication (1966, pp. 583–584) that the "cat sharks appear very rarely in warm waters and inhabit shore waters only in the higher latitudes or in comparatively cool-water areas". The group appears to be mildly anti-tropical, using this term, as originally proposed (HUBBS 1952), to include subtropical and warm-temperate species.

The specimens have been taken through a wide range of bottom depths, from barely over 400 m to hauls at 732–1215 m and 1097–1326 m (Table 1). Similarly, a new hagfish (*Eptatretus* sp.) has been trawled in the same area repeatedly, but nowhere else, at depths from 198 to 1180 m, over a far greater bathymetric range than that inhabited by any of the six other myxinoids we have been collecting in large quantity in Baja California and the Gulf.

Some of the ship records have indicated that this shark at times may enter the midwater zone, in this area of great vertical turbulence. The three type specimens and two others that were misplaced were taken in a large midwater trawl that reportedly was fishing at a depth of approximately 275 m (SPRINGER and WAGNER 1966), but LAVENBERG and FITCH (1966, pp. 92–95) have stated that the trawling depth for the station was determined as 275 m by measuring the cable angle and ship speed [a dubious determination, especially in an area of notoriously fast currents]. They added that the Precision Depth Recorder during the trawling "showed a constant bottom depth of 220 fathoms (400 m)" — close to the

Table 1. Collection data on known specimens of *Galeus piperatus*.

Specimen no.[1]	Ship	Station	Method of capture	Depth of water (m)	Lat. (N)	Long. (W)	Date
SIO 68–89	*Thomas Washington*	MV68–I–59	40′ balloon otter trawl	556–635	29°40.2′– 29°43.9′	113°55.4′– 113°58.0′	1968–I:18
SIO 68–90	*Thomas Washington*	MV68–I–60	40′ balloon otter trawl	545–630	29°39.5′– 29°43.5′	113°55.5′– 113°59.0′	1968–I:18
SIO 69–203	*Ellen B. Scripps*	MV69–II-6	Free-vehicle trap	746	28°40′	113°53′	1969–III:2
LACM 30063–1	*Velero IV*	11821	Beam trawl	731–1215[4]	28°33.0′– 28°46.75′	112°49.5′– 113°06.0′	1967–XI:30
LACM 30303–1[2]	*Velero IV*	11837	Beam trawl	1097–1326	28°37.0′– 28°40.5′	112°56.0′– 113°01.5′	1967–XII:2
LACM 7552 Holotype							
LACM 8818–9 (Paratype)	*Alaska*	64A2–16	Large mid-water trawl	402–412	28°55′	112°50.5′	1964–IV:6
USNM 200413[3] (Paratype)							

[1] LACM = Los Angeles County Museum; SIO = Scripps Institution of Oceanography; USNM = United States National Museum.

[2] The egg case was taken at this station.

[3] This paratype is the only specimen that was not examined or measured by us.

[4] According to the collection records, the beam trawl was calculated from wire angle and ship speed to have fished at the midwater depth of 530–630 fathoms, at least about 100 m off the bottom (see text).

depth of 402–412 m furnished us—and they further stated: "During retrieval, the net actually travelled to the bottom where it rode for sufficient time to pick up several thousand heart urchins . . . mollusks . . . and several kinds of bottom living fishes" (including, in addition to *Galeus*: *Hydrolagus colliei* (LAY and BENNETT), *Coelorhynchus scaphopsis* GILBERT, *Sebastes* spp., *Xeneretmus ritteri* GILBERT, *Symphurus* sp., and others that probably came from the bottom). It therefore seems certain that the trawl did fish on the bottom. Consequently, there is no reason to think that the cat sharks must have been taken above the bottom. One of several large hake, *Merluccius angustimanus* GARMAN, taken at this station spewed up a partly digested *Galeus*.

The collection records for Velero IV Station 11821, where specimen LACM 30063-1 was taken, indicate, again through measurements of cable angle and ship speed, that the beam trawl was fishing at 530–630 m, or about 100 m or more above the minimum water depth of 731 m. The chief technician therefore thought that there is no reason to believe that the trawl ever hit the bottom. However, such calculation of trawl depth proved erroneous in the station just discussed and we regard it as unreliable, especially where currents and turbulence are so strong. A macrourid recorded as having been caught in the trawl further suggests the probability that the trawl reached the bottom.

We think it highly probable that all the specimens of *Galeus piperatus* have been taken on or very near the bottom.

DESCRIPTION OF EGG-CASE

It has generally been assumed that all scyliorhinid sharks are egg layers, but the discovery that one species, *Galeus polli* CADENAT, gives birth to free-living young (CADENAT 1959) calls for an examination of the mode of reproduction in all the species. (We avoid the terms oviparous, ovoviviparous, and viviparous, since among fishes there is a complete spectrum from the fertilization of eggs some time after deposition to the bearing of virtually mature offspring).

Fortunately we have an egg-case (Fig. 1) that we think almost certainly is that of *G. piperatus*, for the following reasons:

(1) The egg-case was trawled along with an adult of *G. piperatus* in the limited area where this species has been taken.

(2) The minute size of the elongate egg-case is consistent with the dwarf size of the species. Young only 71 and 80 mm long (in preservation) are well formed, and the 80-mm juvenile on being trawled uninjured swam long and very vigorously in a tray of water. The egg-case seems to be of a size adequate to hold a coiled embryo about as long as the smaller free-living juvenile. The three adult males although only 280 to 293 mm in total length have fully elaborated claspers and, therefore, had attained their final size.
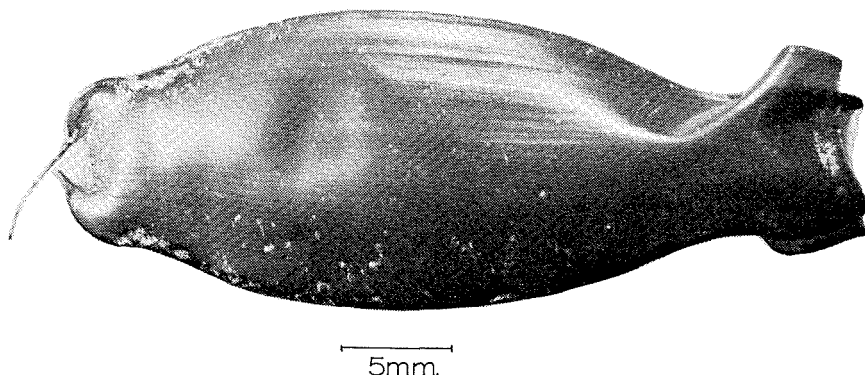
5mm.

Fig. 1. Scyliorhinid egg-case 35 mm long, thought to represent *Galeus piperatus*, taken in trawl with adult male at R/V Velero IV Sta. 11837.

The two largest known females, only 296 and 302 mm in total length, each has "a few large eggs about 7 mm in diameter in the functional right ovary, and are considered sexually mature" (SPRINGER and WAGNER, 1966, p. 8). The proportion of the size of the egg-case (35 mm long) to the estimated total length of the mature female is about the same as in other scyliorhinids. The ratio in this species is 118; in *Cephaloscyllium uter* JORDAN and EVERMANN, regarded by KATO, SPRINGER and WAGNER (1967) as synonymous with *C. ventriosum* (GARMAN), 124, on basis of averaging measurements of nine eggs; in *Apristurus brunneus*, 100 (five measurements); in *Schroederichthys maculatus* SPRINGER (data from SPRINGER 1966), 129; in *Galeus melastomus* (data from TORTONESE 1956), 112.

(3) The egg-case closely resembles that of *Galeus melastomus* (RAFINESQUE) as figured by TORTONESE (1956) and shows points of resemblance as well as difference when compared with figures of egg-cases referred by SPRINGER (1966) provisionally to *Scyliorhinus meadi* SPRINGER, *S. retifer* (GARMAN), and *Schroederichthys maculatus* SPRINGER.

(4) The egg-case is surely that of a scyliorhinid and it seems improbable that it pertains to any of the three other species of the family that occur in Golfo de California. Of these, the *Cephaloscyllium* reaches the length of about 1 m and is known to have much larger egg-cases (nine in the Scripps collection average 100 mm in midline length). *Parmaturus xaniurus* attains a length of about 0.5 m, and almost surely has larger egg-cases. *Cephalurus cephalus* (GILBERT) is incompletely known from a few immature specimens (BIGELOW and SCHROEDER 1941) and its egg-case has not been identified.

The tiny, empty egg-case is translucent-brown. It is rather evenly elliptical, and moderately expanded at the truncate anterior end (now slit open), without evident tendrils. The posterior end becomes somewhat thickened as the two closely approximated sides, each ending in the base of a tendril, are arched very closely together. Very fine longitudinal striations parallel the margin.

DESCRIPTION OF JUVENILE

Two juveniles of *Galeus piperatus*, both males, have been collected. The larger (Fig. 2), SIO 68–89, 85 mm in total length in life, 80 mm on pre-servation, is the one that was noted to swim long and vigorously. The smaller one, SIO 68–90, measures only 71 mm in alcohol, though the yolk-sac is completely absorbed. The larger one was taken with an adult male (SIO 68–89), and both came within the limited area from which adults and the egg-case have been collected.
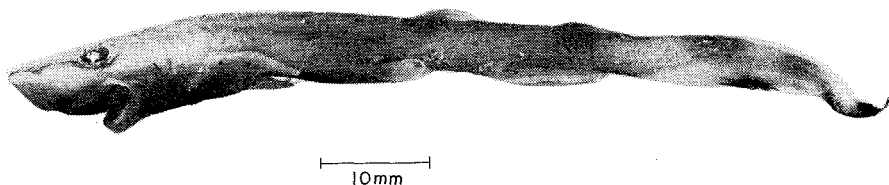

├──────────┤
10mm

Fig. 2. Juvenile male of *Galeus piperatus*, 80 mm in total length (SIO 68–89).

In coloration the juveniles differ strikingly from the adults. In addition to the large melanophores—the "fine pepper-like spots" (Fig. 3, upper, and Fig. 7) that prompted SPRINGER and WAGNER to name the species *piperatus*—the juveniles bear a series of blackish areas (Fig. 2) formed by the concentration of melanophores. A dark area extends from midsides well onto each dorsal fin. Five distinct dark areas mark the caudal fin. Three are on the upper lobe: one at and below the upper caudal origin, another midway along the dorsal lobe, and an intense black area on the upper part of the caudal tip, leaving the extreme end of the caudal axis unpigmented. The ventral lobe bears two dark blotches, one at the ex-treme end and one below the pale area between the first two upper spots. This color pattern is similar to that figured for juveniles of *Galeus polli* CADENAT (1959, Fig. 17), and seems to homologize with the dark saddles and caudal blotches described and figured by SPRINGER (1966) for the adults of several species referred to *Scyliorhinus*, *Galeus* and *Halaelurus*.

In life, the larger juvenile was pale purplish-brown on the upper and posterior parts and silvery on the belly. The dusky to black markings were very conspicuous, and the extreme tip of the caudal lobe was milky white.

The inside of the mouth is not as intensely dark as in adults. The melanophores are limited to the posterior half of the roof of the buccal cavity and the anterior half is quite pale. No denticles are borne in this region in juveniles, but the anterior section bears numerous fleshy tubercles about as large as the teeth. These appear to be sensory papillae, which in the adult are retained, though obscured by the denticles that largely cover this region (as noted below).
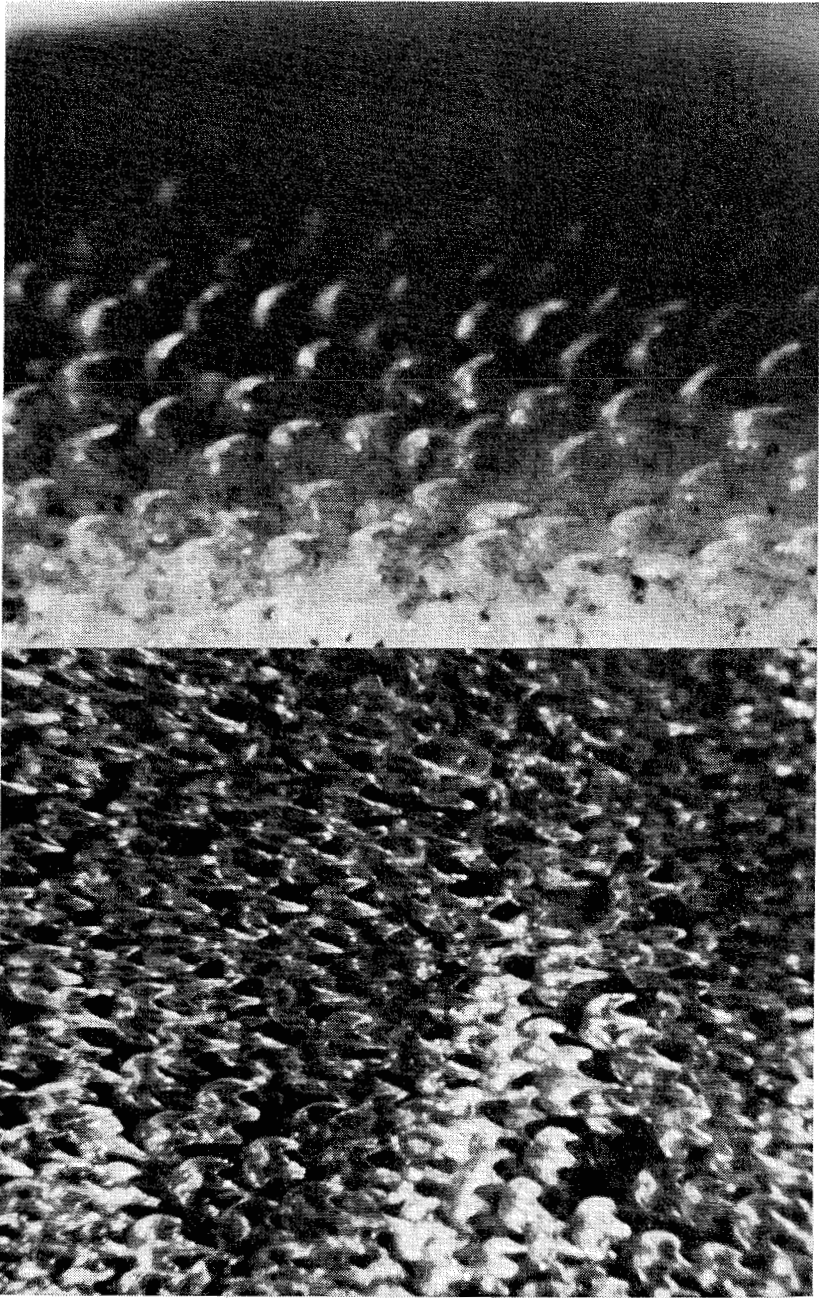
Fig. 3. Denticles of *Galeus piperatus*. Above: denticles of SIO 68–89, an 80-mm juvenile male. Below: denticles of SIO 68–89, a 284-mm adult male. Both views are of areas below the first dorsal fin and are magnified about $70\times$ (anterior to the left).

The denticles on the body (Fig. 3) of the juveniles differ notably from those of the adult. Instead of being trident-shaped and bearing a high central ridge and a less elevated marginal ridge above and below, the denticles on the juveniles are long, hooked spines with only the median element apparent. Instead of being borne on a pedicel, they are sessile. The specialized denticles that form the crest on the caudal fin —a feature of the genus *Galeus*—resemble those of the adult.

The teeth of the juveniles, both males, resemble those of the adult males (as described below). The lower jaw bears a total of only ten to thirty irregularly arranged teeth. At the lip line there is a definite transition between the teeth and the denticles.

The vertebrae are apparently completely formed in this species by the time a length of 70–80 mm has been attained, for the numbers in young and adult are approximately equal (Table 3), even in the caudal region, with the possible exception of one or a very few terminal rudiments, because they are not all completely calcified. Thus, the early development of adult characters in this dwarf species is highlighted. The contrast in relative lengths of monospondylous and diplospondylous vertebrae seems greater in the juveniles than the adults, but the penultimate monospondylous vertebra is much less elongate in form in the juvenile than in the adult, yielding a lower "B" ratio (Table 3). However, as noted below, this ratio is of somewhat dubious significance.

Although essentially adult form is attained at an exceptionally small size, the juveniles differ from adults in various morphometric features (Table 2). As is usual in elasmobranch development the urosome is markedly elongated in juveniles, as is shown by measurements 5, 6, 10, and 56, most notably for the caudal-fin dimensions (44, 45). In compensation, the predorsal lengths (1, 2) are shorter. The relative shortening of the anterior regions involves primarily the anterior trunk (the measurement from insertion of pectoral fin to origin of first dorsal, 7, constitutes 16 or 17 instead of 19 to 25 per cent of the total length). Measurements involving the head do not change markedly. Oddly, the orbit-length proportion (30) remains essentially constant. The caudal peduncle (14, 16) is proportionately deeper and wider in the juveniles. The vertical fins have longer bases (39, 42, 45, 55), and, correlatively, interdorsal space (4) is shorter. The paired fins (46–52) are much smaller. The gill-slits (18) are more closely approximated ventrally, but the interorbital width and interspiracular distance (31, 32) seem to be somewhat greater. In certain changes with age, especially the elongation in the dimensions of the snout (19–22, 34), the shortening of the mouth-projection measurement (28), and the broadening of the mouth (29), the abrupt transformation apparently occurs over the size range of our two young specimens (71 to 80 mm in total length).

MORPHOMETRY

All known specimens of the species, with the exception of the two mislaid individuals that were trawled with the types and of one paratype (USNM 200413), have been measured for fifty-seven dimensions (Table 3). This has been done to illustrate morphometric differences between juveniles and adults, as just indicated and to determine what differences, if any, distinguish the sexes. These measurements, furthermore, provide data for future comparisons of *G. piperatus* with other species, particularly with the western North Atlantic cognates, *G. arae* (NICHOLS) and *G. cadenati* SPRINGER (1966), and with the three species described from eastern Asia: *G. eastmani* (JORDAN and SNYDER) from Japan, *G. sauteri* (JORDAN and RICHARDSON) from Taiwan, and *G. hertwigi* (ENGELHARDT) from Japan (references in SPRINGER and WAGNER 1966).

For greater accuracy measurements were taken from point to point. The only projection measurement was "mouth length" (Number 28 in Table 2). Precision dial calipers were used on the larger specimens, under magnification as needed. The two juveniles were measured with an optical micrometer. Origins of vertical fins and insertions of paired fins were located by gently pushing one point of the calipers against the anterior base of the fin until slight resistance was felt. Depending on obvious context, either the minimal or the maximal measurement was employed. In general, the methods follow the recommendations of HUBBS and LAGLER (1964), and, with some exceptions and additions, are those used in HUBBS, IWAI and MATSUBARA (1967) in describing another dwarf shark. The method of measurement was somewhat modified for several parts, numbered as in Table 2:

2, "Length to D2", and all other dimensions, were measured linearly and none were computed by addition.

10, "D2 origin to upper C origin", and all other measurements involving the upper lobe of the caudal fin, were made considering the upper caudal origin to occur at the extreme front of the row of modified denticles cresting the caudal fin (Fig. 5).

13, "Body depth (greatest)" and 15, "Body width (greatest)", and other dimensions were measured as the specimen, if distorted by preservation, was manipulated to approximate its normal form in life.

20, "Snout length (preoral)", was taken by us from tip of snout to the margin of the lip on the midline.

21, "Prenarial length, outer" represents distance from tip of snout to nearest point of margin of outer opening of nostril.

22, "Prenarial length, inner" represents distance from tip of snout to extreme inner-posterior angle of nostril.

28, "Mouth length (projection)" was measured from margin of upper lip along a mid-sagittal line to a straightedge laid between extreme ends of gape.

29, "Mouth width" is the distance between extreme corners of the gape.

44, "Upper lobe C (extreme)" and 45, "Lower lobe C (extreme)" are measured between the appropriate origin and the extreme tip of the caudal fin.

All measurements are expressed as thousandths of the standard length. The abbreviations used for fins are: P1 = pectoral, P2 = pelvic, D1 = first dorsal, D2 = second dorsal, and C = caudal.

Comparison of the measurements of three adults of each sex (Table 2) disclosed hardly a trace of sexual dimorphism. The length of the abdomen, as measured between the insertions of the paired fins (dimension No. 12) averages slightly higher in females (189) than in males (178), but the difference is much less notable than was indicated for the pelagic dwarf shark *Euprotomicrus bispinatus* by HUBBS, IWAI and MATSUBARA (1967, pp. 13–14, Fig. 1). In that form the greater length of the abdomen in females was suggested "as an adaptation to fecundity in a dwarfed shark". The difference may be related to the simultaneous development of the whole brood by *Euprotomicrus bispinatus* and the presumable development of mature eggs one by one in *Galeus piperatus*.

COLOR

In the original description of *Galeus piperatus* stress was placed on the uniformity of the coloration, with the exception of the sprinkling of large melanophores (such as shown in Figs. 3, upper, and 7) in the largest known specimen, the holotype (LACM 7552, 302 mm in total length). The somewhat smaller paratypes were described as having "irregular and indistinct blotches that contrast little with the background color". Our subsequently collected specimens show moderately conspicuous dark markings set off by a narrow, light, subhexagonal reticulum, approaching that figured by SPRINGER (1966, Fig. 20) for a specimen of *G. arae* (NICHOLS) of comparable size. The figure of the holotype and the specimen itself show almost no trace of a blackish margin along the anal and caudal fins and little blackening on the dorsal fins, but our specimens show these markings strongly. We suspect that the lack of contrast in the types is attributable at least in part to the method of preservation.

Life colors were recorded on a 280-mm fully adult male (SIO 68–89–5A1). Dorsally the color is rather rich brown. The ventral region of the trunk is gray, with bright-blue reflections. A wide dorsolateral stripe, extending to between the dorsal fins, is marked by a pale subhexagonal network colored like the belly. In contradistinction to the original description, there is a sharp contrast between the dorsal and ventral color. A mid-dorsal stripe is slightly lighter and yellower than the reticulum. There is an irregular trace of the reticulations on the tail.

Table 2. Measurements of *Galeus piperatus* in thousandths of total length.

Specimen no.	Male					Female		
	SIO 68–90	SIO 68–89	SIO 69–203	SIO 68–89	LACM 30303–1	LACM 8818–9[2]	LACM 30063–1	LACM 7552[1]
Total length (mm)	71	80	280	284	293	256	295	302
1. Length to D1	427	417	464	451	451	430	468	440
2. Length to D2	592	569	621	623	608	598	624	613
3. Between dorsal origins	159	152	161	165	163	157	158	171
4. Interdorsal space	75	62	88	89	87	81	85	88
5. D2 origin to end C	408	435	379	380	403	406	369	383
6. Tip D2 to end C	335	352	305	301	318	329	302	308
7. P1 insertion to D1 origin	170	160	208	194	226	209	251	200
8. Prepectoral length	211	227	238	224	223	219	234	195
9. Prepelvic length	390	373	386	391	375	363	393	358
10. D2 origin to upper C origin	111	130	98	89	92	107	96	99
11. P2 insertion to lower C origin	255	227	225	244	232	238	214	262
12. Between P1 and P2 insertions	182	176	186	177	171	200	192	176
13. Body depth (greatest)	82	77	99	103	100	73	94	115
14. C peduncle depth (least)	44	40	39	39	38	36	38	36
15. Body width (greatest)	89	95	93	89	89	100	87	86
16. C peduncle width at front C	23	22	20	18	19	16	21	16
17. Length to first gill-slit	177	181	188	175	183	174	201	163
18. Width between first gill-slits (ventrally)	80	97	111	97	110	101	104	108
19. Snout length (preocular)	82	91	85	83	83	88	86	77
20. Snout length (preoral)	58	79	80	72	76	80	86	70
21. Prenarial length, outer	49	53	55	55	52	55	57	51
22. Prenarial length, inner	51	68	64	61	61	59	63	56
23. Nostril width (maximum)	26	30	25	25	26	25	29	26

Specimen uo.	Male					Female		
	SIO 68–90	SIO 68–89	SIO 69–203	SIO 68–89	LACM 30303–1	LACM 8818–9[2]	LACM 30063–1	LACM 7552[1]
24. Internarial width (least)	29	31	27	28	27	27	28	27
25. Between tips of narial flaps	57	55	56	54	62	62	58	61
26. Nostril to orbit (least)	29	34	34	29	30	24	35	27
27. Nostril to mouth (least)	16	17	18	19	18	21	25	20
28. Mouth length (projection)	64	58	49	43	43	36	41	37
29. Mouth width	85	90	108	100	103	132	104	95
30. Orbit length	41	42	39	43	41	41	42	40
31. Interorbital width (fleshy)	89	110	86	85	84	82	87	86
32. Interspiracular distance (dorsally)	107	109	105	95	100	101	106	96
33. Spiracle length (maximum)	9	10	6	5	9	10	4	7
34. Spiracle to snout tip	134	148	137	132	131	128	138	127
35. Spiracle to P1 insertion	138	146	159	150	151	153	159	141
36. Between fronts of gill-slits 1 and 5	60	70	49	55	60	67	49	61
37. Height, first gill-slit	28	21	21	26	26	19	20	20
38. Height, fifth gill-slit	19	13	13	19	17	11	13	15
39. D1 base	54	57	45	45	43	50	50	49
40. D1, origin to extreme tip	89	97	75	76	76	88	84	78
41. D1 height (insertion to extreme tip)	36	39	38	39	45	49	42	32
42. D2 base	58	57	49	43	47	48	47	49
43. D2, origin to extreme tip	87	95	74	68	74	75	72	71
44. Upper lobe C (extreme)	314	322	281	286	307	292	278	284
45. Lower lobe C (extreme)	325	362	289	290	319	311	287	303
46. P1 base (fin appressed)	41	49	70	69	67	67	77	67
47. P1, lower-anterior edge	85	110	121	128	120	127	119	117
48. P1, lower-distal edge	44	47	103	86	90	95	91	101

Specimen no.	Male					Female		
	SIO 68–90	SIO 68–89	SIO 69–203	SIO 68–89	LACM 30303–1	LACM 8818–9[2]	LACM 30063–1	LACM 7552[1]
49. P2 base	60	70	84	77	74	76	100	79
50. P2 origin to tip of rays	74	99	118	101	99	116	116	113
51. P2 origin to tip clasper	64	78	162	159	157	—	—	—
52. Cloaca to tip clasper	31	35	107	105	102	—	—	—
53. Cloaca to tip P2 rays	42	69	70	52	52	74	71	65
54. Snout to anal-fin origin	514	492	561	553	533	504	536	540
55. Length anal base	132	125	112	108	122	128	134	123
56. End of anal fin to lower C origin	35	16	14	20	9	14	11	12
57. Length anal fin	141	151	127	129	140	146	146	146

[1] Holotype.

[2] Paratype.

DENTICLES

To supplement the original account of denticles on the body of adults we include (Fig. 3, lower) the reproduction of a photomicrograph of the pedunculated tridents, which contrast boldly with the simple, hooked, sessile spinelets of the juveniles (Fig. 3, upper), as already noted. The denticles on the body also contrast sharply with the minute lanceolate oral denticles noted and figured by SPRINGER and WAGNER (1966, pp. 3–4, Fig. 2) for *G. piperatus* and found by them in all species of *Galeus* that they examined. The occurrence, distribution, and form of denticles on the surfaces of the buccal cavity provide diagnostic characters in sharks, as the late Swiss paleontologist BERNHARD PEYER found during unpublished research at Scripps Institution several years ago.

The specialized form and pattern of the denticles on the clasper are mentioned below.

TEETH

The collection of males makes it possible to point out sexual dimorphism in the tooth structure of adults, somewhat in the direction of, but far less extreme than, the sexual dimorphism of the teeth in *Apristurus riveri* BIGELOW and SCHROEDER, as described and figured by SPRINGER (1966, pp. 591–593, Fig. 10). The females exhibit a greater degree of heterodonty than the males. The teeth of females vary from tricuspid anteriorly, with a long central cusp near the symphysis, to posterior teeth with cusps, of more uniform length, numbering four or five in the upper jaw and five to seven in the lower jaw (Fig. 4). In males, tricuspid teeth continue to the end of the jaw, with some reduction in relative length of the central cusp. One male (SIO 69–203) bore a few pentacuspid teeth near the end in each jaw. Generally, all teeth of the adult males are similar to the anterior tricuspids of the females. As already noted, small juvenile males have teeth similar to those of adult males.

In adults of each sex the tooth rows range from twenty-nine to thirty-two on each side of the jaw.

VERTEBRAE

As determined by radiography, the vertebrae in eight specimens vary in number as follows (Table 3): monospondylous vertebrae 30 to 33 (mean 32.7), precaudal diplospondylous vertebrae 36 to 39 (37.4), total precaudals 66 to 72 (69.1), caudals 41 to 49 (45.6), total count 112 to 118 (114.7). In all the radiographs the monospondylous vertebrae give way to the diplospondylous condition clearly and abruptly over the insertion
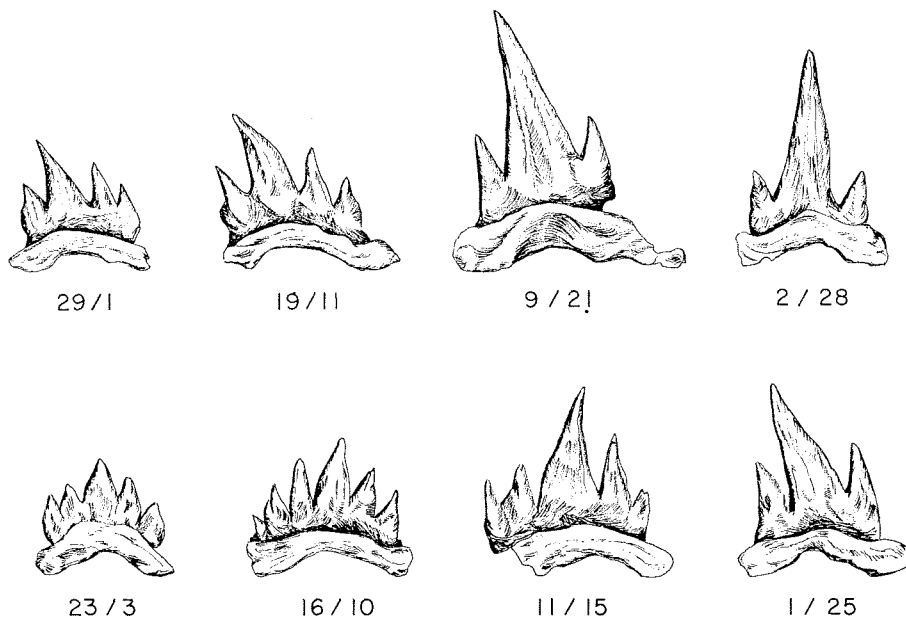
29/1   19/11   9/2!   2/28

23/3   16/10   11/15   1/25

Fig. 4. Teeth from the left jaw of an adult female of *Galeus piperatus* (LACM 8818–9, a paratype, 256 mm long). Upper jaw, above; lower jaw, below. The first figure represents the number of teeth between that tooth and the symphysis; the second figure, the number of teeth between that tooth and the end of the jaw.

of the pelvic fins (Fig. 5), thus rendering precise the counting of monospondylous centra. The diplospondylous vertebrae are designated as precaudal and caudal, by the definition of the first caudal (Fig. 6) as the first vertebra lying wholly or by any part below the beginning of the double row of tubercles that dorsally crest the caudal fin (the same point that is regarded by us, for measurements, as the origin of the caudal fin).

The very early virtual completion of vertebral formation reflects the dwarfed nature of the species, as already noted in discussing the juveniles.

Our counts of the holotype and one paratype show some divergence from those by SPRINGER and WAGNER (1966). The counts of monospondylous vertebrae agree, but the diplospondylous precaudal counts (obtained by subtraction from their Table 3) differ by as much as three and the caudal counts by as much as five. Perhaps those workers chose a different point for the caudal origin, or counted caudal rudiments differently. In his review of western Atlantic scyliorhinids SPRINGER (1966) presented counts of monospondylous vertebrae only, stating that "diplospondylous vertebrae near the tail tips were difficult to count". Whereas monospondylous and precaudal diplospondylous counts are quite precise, the number of caudal vertebrae is subject to some counting error due to

Table 3. Vertebral characters in eight specimens of *Galeus piperatus*, from radiographs.

Specimen no.	Sex	T. L. (mm)	Precaudal vertebrae		Total precaudal vertebrae	Caudal vert.	Total vert.	A[1]	B[2]
			Mono-spondylous	Diplo-spondylous					
SIO 68–89	♂	284	31	39	70	46	116	146	130
SIO 68–89	♂	80	31	38	69	45	114	188	93
SIO 68–90	♂	71	33	39	72	41	113	186	85
SIO 69–203	♂	280	33	36	69	47	116	143	142
LACM 30303–1	♂	293	30	36	66	47	113	149	142
LACM 7552 (Holotype)	♀	302	33	36	69	49	118	136	127
LACM 8818–9 (Paratype)	♀	256	31	39	70	46	116	178	124
LACM 30063–1	♀	295	32	36	68	44	112	156	140
Averages			32.7	37.4	69.1	45.6	114.7	160.3	122.9

[1] $A = \dfrac{\text{length of penultimate monospondylous centrum}}{\text{length of first diplospondylous centrum}} \times 100.$

[2] $B = \dfrac{\text{length of penultimate monospondylous centrum}}{\text{diameter of penultimate monospondylous centrum}} \times 100.$
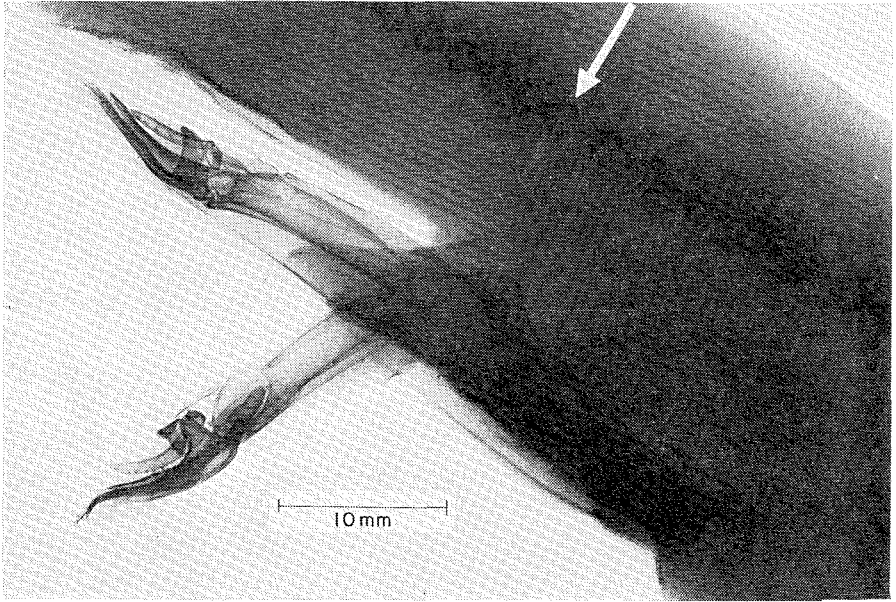
Fig. 5. Radiograph of pelvic claspers and median vertebrae of adult male *Galeus piperatus* in right lateral view (SIO 68–89). Arrow indicates point of change from monospondyly to diplospondyly.
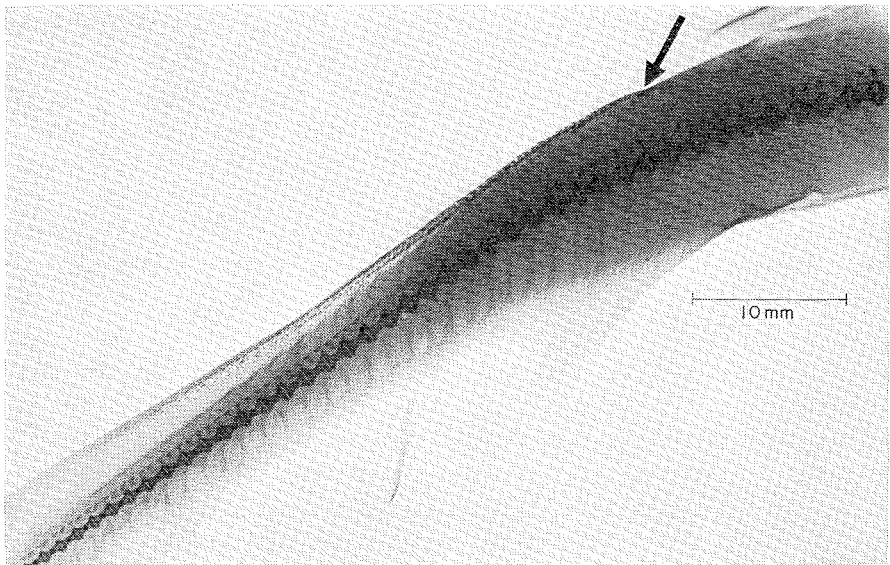

Fig. 6. Radiograph of caudal fin of holotype of *Galeus piperatus*. Arrow indicates beginning of double row of enlarged denticles used as a marker for origin of caudal fin and caudal vertebrae.

the minute and irregular size of the centra and the distorted shape of the last few elements. Nevertheless, we feel that with good X-ray equipment, and with due care in exposures and in counting, that reasonably reliable counts can be obtained for the diplospondylous vertebrae—certainly for the precaudal ones, if a precise point for the start of the precaudal count is established.

Other striking differences occur between our values and those of SPRINGER and WAGNER (1966) for the "A" and "B" ratios (defined in Table 3), which were originally proposed and utilized by SPRINGER and GARRICK (1964). Furthermore, the range of variation for each ratio is very large. In small sharks, such as *Galeus piperatus*, a typical vertebra is about 2–3 mm long. Measurement under magnification is essential, but is complicated by the large grain size that appears under such enlargement. The limits of the centra are difficult to ascertain with certainty. In addition, different exposure times can cause measurements for the same specimen to diverge. This results from the circumstance that inadequate X-ray exposures fail to represent the full length of the centra, because the thin fore and aft ends of the amphicoelous vertebrae fail to register, whereas the width of the centrum remains scarcely altered. Until exposure times and methods of measuring can be standardized, we feel that the "A" and "B" ratios will be of little value, especially for small sharks.

CLASPERS

The claspers of *Galeus piperatus* (Fig. 7) are large, robust, and highly complex, particularly as shown by radiography (Fig. 5). They are very mobile and are jointed about midway of their length. The siphons open laterally at about 0.9 of the distance out from the cloaca. The pattern of grooves and of hard and soft flaps, folds, and prominences is complicated but consistent. The detailed structures and homologies are yet to be worked out, and we are pleased to learn that STEWART SPRINGER has undertaken a study of the claspers of the Scyliorhinidae. In gross features, the clasper of *G. piperatus* conforms with SPRINGER's (1966, Fig. 4B) sketch of the claspers and general pelvic region in a western North Atlantic species, *G. arae* (NICHOLS), and definitely contrasts with LEIGH-SHARPE's (1920) non-detailed brief account and figures for the European species *Scyllium catulus* = *Scyliorhinus catulus* (L.) and *Scyllium canicula* = *Scyliorhinus canicula* (L.). We feel that in all probability the finer structure of the diverse elements of the clasper will provide key value in the recognition of genera and species of Scyliorhinidae and in the interpretation of their relationships.

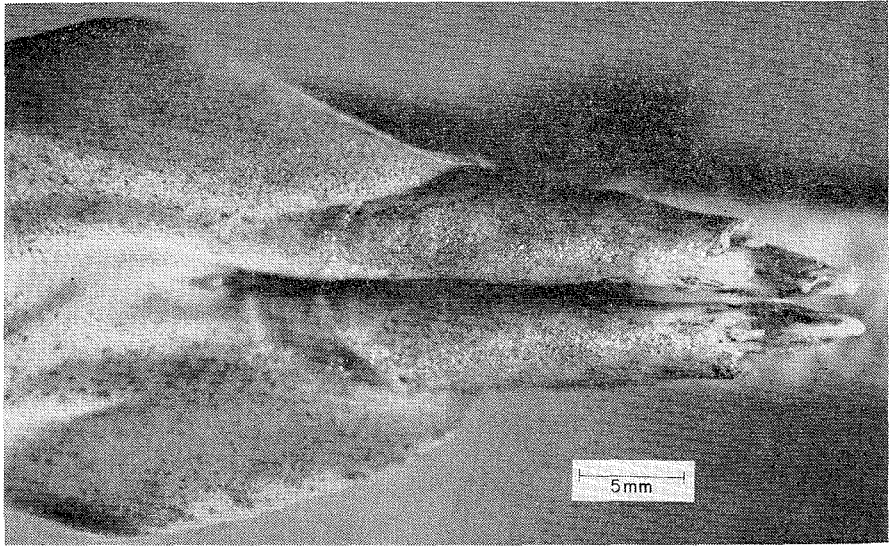The denticles on the clasper are distinctively modified in pattern and

Fig. 7. Pelvic claspers of adult male of *Galeus piperatus* (SIO 68–89).

form. They completely cover a large area over the ventral surface basally. Distally, this area spirals laterally and dorsally. This major patch is continuous with the squamation of the flat lower surface of the pelvic fins, though the intervening denticles are weak. The patch ends abruptly against the smooth denticle-free skin, which is irregularly marked with black (Fig. 7). Beyond the subterminal notch in the clasper as seen in ventral view (Fig. 7), and just proximal to the whitish flesh-covered tip of the clasper, there is a discrete patch of denticles, which are mostly loose and lanceolate, but outward and upward, where concealed by a prepuce-like hood, they become strong and fixed. On the opposite side, opposite the basal part of the terminal patch and extending farther proximally, is a second discrete patch of denticles, which are moderately flattened, slender and sharply pointed.

Most notable among the diverse denticles on the clasper are the very slender, mostly loosely attached hooks that biserially line the edge of the spiralling sperm duct on the outer and upper sides of the organ. A few occur at the outer tip of the subterminal notch as seen in ventral view (Fig. 7), but the main part of the double file is along the firm edge that angles proximad and entad. The hooks arise from a dorsal terminal cartilage (Fig. 6). These hooks closely approach the denticles on the body of the juveniles (Fig. 3, upper).

An example of the finding of profound differences in clasper characters between two species of squaloid sharks that were long thought, probably

erroneously, to be very closely related, has recently been presented (HUBBS, IWAI and MATSUBARA, 1967, pp. 33–36, Fig. 7, pls. 2, 6, 7). Thorough critical, detailed, and comparative studies of myxopterygial structures in all sharks are, indeed, long overdue.

SUMMARY

Information is presented on a recently described dwarf shark, *Galeus piperatus*, which occurs through a wide range of depth in turbulent waters of highly varying physical parameters in Golfo de California, Mexico. It barely exceeds 300 mm in total length and an egg-case presumed to be of this species is only 35 mm long. Young about 80 mm long are well formed and very active. The sexes are remarkably alike in most respects but differ in tooth structure. The denticles of the young bear a single hooked spine, but are pedunculated tridents in the adult. The claspers are large, robust, and of highly complex external and internal structure.

ACKNOWLEDGMENTS

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