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Biological Aspects of the Sixgill Shark, *Hexanchus griseus*

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Life history information on 28 sixgill sharks, collected off California, was obtained from May 1982 through Sept. 1984. Only one mature sixgill shark, a 421 cm TL female with term embryos, was examined. Size at maturity was estimated for females by comparing gonad development with length-weight measurements. Gut analysis revealed that the sixgill shark's diet consists mainly of bony and cartilaginous fishes. Since sixgill sharks do not appear to be abundant anywhere, their distribution and movement patterns along the deep coastal waters off California are, for the most part, unknown.

THE sixgill shark, *Hexanchus griseus* (Bonnaterre 1788), is a little-known deep-water shark that is occasionally taken by commercial trawlers along the eastern North Pacific. Although no specific fishery for the sixgill shark exists, when taken they are often marketed for human consumption under the name cowshark. Information concerning the biology of sixgill sharks is scant, due to their apparent lack of abundance and deep water habitat.

Members of this family (Hexanchidae) are ovoviviparous (Gilbert, 1981), but further information on their reproductive biology is limited. Springer and Waller (1969), based on the examination of a few large specimens, estimated that females reached maturity at 450 cm TL. Fecundity has been variously reported between 22 and 108.

Information on the sixgill shark's feeding habits is rather incomplete. Hart (1973) reported that sixgill sharks ingest a wide variety of fishes and crustaceans.

The objective of this research was to gather additional life history information on the sixgill shark. Study aspects include reproductive biology, feeding habits, parasites, examination of possible age determination techniques, movement and distributional patterns.

MATERIALS AND METHODS

Sixgill shark data were collected either from field samples in the Monterey Bay (36°50′N, 121°50′W) area or from reference collections at the California Academy of Sciences, Los Angeles County Museum of Natural History and Moss Landing Marine Laboratories. Field samples were collected by commercial trawlers. Table 1 lists the location data of the material examined. Measurements of shark alternate length (AL, distance between dorsal-fin origin and end of caudal peduncle), girth (G), precaudal length (PCL) and total length (TL) in millimeters and weight (kilograms) were recorded. Weights were not always taken because scales of sufficient capacity were not always available.

The reproductive tracts of individuals of both sexes were examined to determine maturity. Male sharks were categorized according to their maturation status as either juvenile or adult (Holden and Raitt, 1974). Maturity in male sharks was determined by clasper and clasper sac development. As the male shark approaches maturity, the claspers lengthen and stiffen (Holden and Raitt, 1974). Development of the clasper sac mechanism along the claspers also indicates maturity in hexanchid sharks (Ebert, 1984). Internally, the presence of a straight vs coiled wolffian duct indicates maturity. With the onset of maturation the wolffian ducts enlarge and coil (Cailliet et al., 1981; Wischnitzer, 1972).

Sexual maturity of female sharks could be determined only by internal examination. Females were categorized as juvenile, adolescent, or adult. The developmental stage was determined by the condition of the ovaries (Holden and Raitt, 1974). The number and size of eggs or embryos per female were recorded to determine fecundity and size at parturition. A graph depicting the length-weight relationship of females was plotted and combined with the above information to indicate approximate size at maturity. A polynomial regression (Zar, 1974) was fitted to these data.

Stomachs were dissected and the contents identified. Food items not identified in the field were preserved in 10% formalin and returned to the laboratory. Empty stomachs were noted

TABLE 1. LOCATION DATA FOR 28 SIXGILL SHARKS, *Hexanchus griseus*, THAT WERE EXAMINED DURING THE STUDY. CAS: California Academy of Sciences. MLML: Moss Landing Marine Laboratories. LACM: Los Angeles County Museum of Natural History.

Location	Latitude	Longitude	Date (month-year)	Depth (m)	Museum cat. #
Northern California					
Russian River mouth	38°49′N	123°08′W	1959	120	CAS 1959—VII:27
Central California					
Diablo Point	37°49′N	122°30′W	6-81	—	CAS 1982—I:14
Hunter's Point	37°40′N	122°21′W	7/62	17	CAS 1962—XII:9
Coyote Point	37°36′N	122°19′W	9/50	8	CAS 1950—IV:19
Monterey Bay	36°50′N	121°55′W	12/78	—	—
Monterey Bay	36°50′N	121°55′W	12/78	—	—
Monterey Bay	36°50′N	121°55′W	1/80	41	MLML 1
Monterey Bay	36°50′N	121°55′W	1/80	41	MLML 2
Monterey Bay	36°50′N	121°55′W	1/80	41	MLML 3
Monterey Bay	36°50′N	121°55′W	2/80	—	MLML 4
Monterey Bay	36°50′N	121°55′W	5/82	—	—
Monterey Bay	36°50′N	121°55′W	5/82	—	—
Monterey Bay	36°50′N	121°55′W	6/82	—	—
Monterey Bay	36°50′N	121°55′W	6/82	160	—
Monterey Bay	36°50′N	121°55′W	6/82	160	—
Monterey Bay	36°50′N	121°55′W	7/82	300	—
Monterey Bay	36°50′N	121°55′W	3/84	—	—
Monterey Bay	36°50′N	121°55′W	7/84	50	—
Monterey Bay	36°50′N	121°55′W	7/84	100	—
Monterey Bay	36°50′N	121°55′W	9/84	76	—
Lopez Point	36°00′N	121°38′W	1/83	160	—
Church Rock	35°09′N	120°41′W	5/75	160	LACM 34365-1
Church Rock	35°09′N	120°41′W	5/75	160	LACM 34365-23
Church Rock	35°09′N	120°41′W	5/75	160	LACM 34365-25
Southern California					
Bird Rock	32°50′N	117°25′W	1/47	—	CAS: H47-13
Bird Rock	32°50′N	117°25′W	2/47	—	CAS: H47-13A
Baja California					
Todos Santos Bay	31°46′N	116°45′W	10/70	—	LACM 31679-1
Unknown	?	?	?	—	LACM 38369-1

and discarded. Food items were identified to the lowest possible taxa.

Vertebral sections were collected from some specimens and returned to the laboratory for use in age determination. Vertebrae were removed from an area just posterior to the head region. Ageing techniques used for elasmobranch studies at Moss Landing Marine Laboratories (Cailliet et al., 1981, 1983a, b) were tested. These techniques enhance calcified rings that are present on the centra (Cailliet et al., 1981, 1983a). However, since the centra in hexanchids can be recognized only by the presence of a transverse septum of fibro-cartilage (Ridewood, 1921), the vertebrae were cross-sectioned and examined for calcified rings.

Sixgill sharks were grossly examined for parasites. Parasite samples were collected and preserved in 10% formalin for later identification.

RESULTS

Data on 28 sixgill sharks were obtained from May 1982 through Sept. 1984. Eleven sixgill sharks were taken in field collections. Ten of these came from Monterey Bay and one from off Lopez Point (36°00′N, 121°38′W). Information on the remaining 17 sixgill sharks was obtained from museum specimens.

Only five male sixgill sharks, ranging from 110–170 cm TL, were examined and none were mature. The wolffian ducts of all these specimens were small and straight. All females recorded were immature, with the exception of one 421 cm TL adult specimen caught 30 May 1975 off Church Rock, San Luis Obispo County, California at a depth of 160 m (L.A.C.M. 34365-1). This specimen contained 51 near-term embryos that ranged from 68–73.6 cm TL.

Using a combination of lengths and weights from field caught and museum specimens and literature (Castro, 1983) data, the weight of female sixgill sharks rapidly increases as they reach maturity at approximately 421 cm TL (Fig. 1).

Prey items were found in eight of the 15 sixgill shark stomachs examined. All prey items observed occurred only once, except for the spiny dogfish (*Squalus acanthias*) which was found in the stomachs of two sixgills. Other prey items observed were whale blubber, pinniped remains, the prickly shark (*Echinorhinus cookei*), the ratfish (*Hydrolagus colliei*), the hake (*Merluccius productus*), the Pacific lamprey (*Lampetra tridentata*), the Pacific hagfish (*Eptatretus stoutii*) and five unidentified bony fish. The hagfish was of further interest since its stomach contained the remains of a relatively shallow water (10 m) brown alga, *Cystoseira osmundacea*. The sixgill shark that contained the hagfish was caught at 100 m depth.

The three methods tested to age sixgill sharks by using their vertebrae proved unsuccessful. Calcified rings were not observed on cross-sectioned vertebrae. The vertebrae were very pliable and tended to shrivel up during preparation.

Two parasite species were examined on sixgills. A digene, *Otodistomum veliporum* (Azygiidae), was found in the stomachs of two specimens and the copepod, *Pandarus bicolor* (Pandaridae), was found externally on the paired and unpaired fins and head region of five specimens.

Discussion

Field collections for the sixgill shark are difficult due to their deep water habitat. Their occasional occurrence in San Francisco Bay (37°42′N, 122°20′W) (Herald and Ripley, 1951) is most likely due to its relative great depth (120 m) near the bay's entrance. Sixgill sharks do not

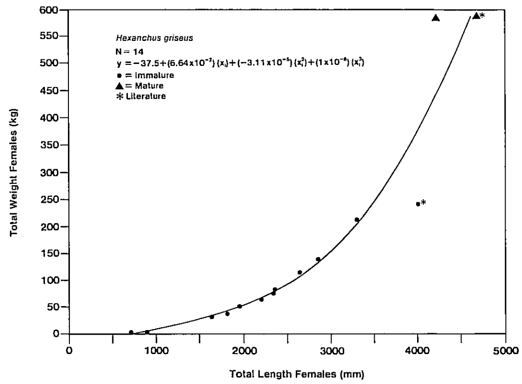

Fig. 1. Total length (mm) vs weight (kg) for 14 female sixgill sharks.

inhabit shallow bays such as Humboldt Bay (40°52′N, 122°15′W), but they do occur outside this bay in deeper water (Ken Bates, commercial fishermen, Eureka, California, pers. comm.). Sixgill sharks along the California coast have been reported to depths of 291 m (Miller and Lea, 1972). This deep water habitat has precluded acquisition of data on the sixgill's movement patterns.

The 421 cm TL Church Rock specimen is apparently the only reported mature sixgill shark from the eastern North Pacific. Springer and Waller (1969) noted that no mature sixgill shark, male or female, had been reported from the eastern North Pacific. The Church Rock specimen also appears to be the smallest mature female world wide based on Springer and Waller's (1969) estimate of maturity at 450 cm TL. Apparently, there are no catch records for mature male sixgill sharks and none were found in the literature. Springer and Waller (1969) reported a male sixgill shark that was immature at 348 cm TL. The 421 cm TL Church Rock specimen was noted to be giving birth while being brought on board ship and it is likely that some new born young spontaneously aborted during capture. Therefore, the actual number of young carried by this specimen was uncertain. The tendency of near-term females to abort their young upon being captured may account for the wide discrepancy reported by Springer and Waller (1969) for sixgill shark fecundity.

The size range of term sixgill shark embryos (68–73.6 cm TL) taken from the 421 cm TL specimen was consistent with that reported by Vaillant (1901). Desbrosses (1938) reported juvenile sixgill sharks smaller than 67 cm TL had been taken in the Mediterranean Sea, but Springer and Waller (1969) thought these specimens may have been *H. vitulus*, a considerably smaller shark. However, the occurrence of *H. vitulus* has not been confirmed in the Mediterranean Sea (Springer and Waller, 1969).

Female sixgill sharks showed a sharp increase in weight at about the onset of sexual maturity (Fig. 1). This growth pattern is similar to that seen for female sevengill sharks (*Notorynchus cepedianus*) (Ebert, 1984). The largest reported sixgill shark is 482 cm TL (Castro, 1983).

Based on my findings and that reported in the literature (Backus, 1957; Bigelow and Schroeder, 1948; Hart, 1973; Springer and Waller, 1969; Wheeler, 1975) the diet of sixgills consists mainly of cartilaginous and bony fishes. The consumption of marine mammals has also been reported by Wheeler (1975). Invertebrates have been reported in the guts of sixgills by several authors (Backus, 1957; Bigelow and Schroeder, 1948; Hart, 1973).

Sixgill sharks do not appear to be abundant anywhere and their occurrence along the deep coastal waters off California is for the most part unknown.

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