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SCHOOLING OF THE SCALLOPED HAMMERHEAD SHARK, *SPHYRNA LEWINI*, IN THE GULF OF CALIFORNIA

Groups of sharks have been witnessed occasionally by airborne or shipboard observers (Bass et al. 1975; Clark 1963; Springer 1967; Kenney 1968). Such remote observations, augmented with inferences from fishery records (Ford 1921; Olsen 1954; Jensen 1965), have provided fragmentary descriptions of these groups and speculations on their function. We have studied polarized schools of the scalloped hammerhead shark, *Sphyrna lewini*, by free diving among them at several offshore sites in the Gulf of California. Here we report preliminary observations on the sizes, depths, movements, and compositional dynamics of these schools, and the sizes, sexes, and behavior of the school members. Based upon these observations, we discuss the possible function of such schools.

Previous sightings by others indicated that schools of *S. lewini* might be encountered during the summer at three locations near La Paz, Baja California Sur, Mexico: Las Arenitas Rocks (Isla Cerralvo), El Bajo Espiritu Santo, and Isla Las Animas (Figure 1). These locations were visited between 26 July and 6 August 1979 aboard either our 7 m fiber glass skiff or the 23 m ferrocement research vessel, the *Juan de Dios Batiz*. At these locations and others, four search techniques were employed: 1) Free diving and surface swimming; 2) scuba; 3) baiting with ground Pacific mackerel, *Scomber japonicus*; and 4) playback of pulsed, low-frequency sounds (for description, see Myrberg 1978). Scalloped hammerheads were most easily discovered and approached by free diving, and data were recorded on small plastic slates. Relatively few scalloped hammerheads were observed by divers with scuba, even in areas where this species was abundant. This was probably due to their avoidance of the divers' sounds

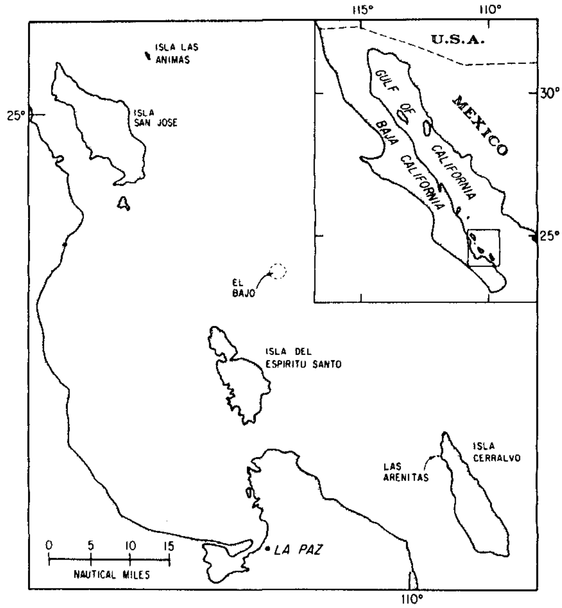

FIGURE 1.—The La Paz study area in the Gulf of California. Grouped scalloped hammerhead sharks were encountered at three sites: 1) Las Arenitas, a cluster of rocks 100 m from Isla Cerralvo; 2) El Bajo Espiritu Santo, a seamount rising to within 14 m of the sea surface; and 3) Isla Las Animas.

and visually conspicuous bubbles. Only three scalloped hammerheads were attracted in 11.5 h of baiting and none during 40 min of sound playback, indicating a lack of interest in these feeding stimuli.

Both individuals and schools of *Sphyrna lewini* were seen. Generally the sharks within schools swam in a polarized manner, remaining relatively equidistant from each other and swimming forward and changing direction together (Figure 2A, B). For the purposes of data sampling, sharks were counted during discrete "observation dives," which usually consisted of free dives, but included some observations from the surface. Scalloped hammerheads were encountered on 91% of the free dives at El Bajo, 58% at Isla Las Animas, and 34% at Las Arenitas Rocks. These percentages are a rough index of relative abundance because they are probably affected by differences in search success and water clarity. School sizes at El Bajo were larger than those at Las Arenitas Rocks and Isla Las Animas, but no large difference existed between group sizes at Las Arenitas Rocks and Isla Las Animas.

The number of scalloped hammerhead sharks in the vicinity of El Bajo was estimated by using the

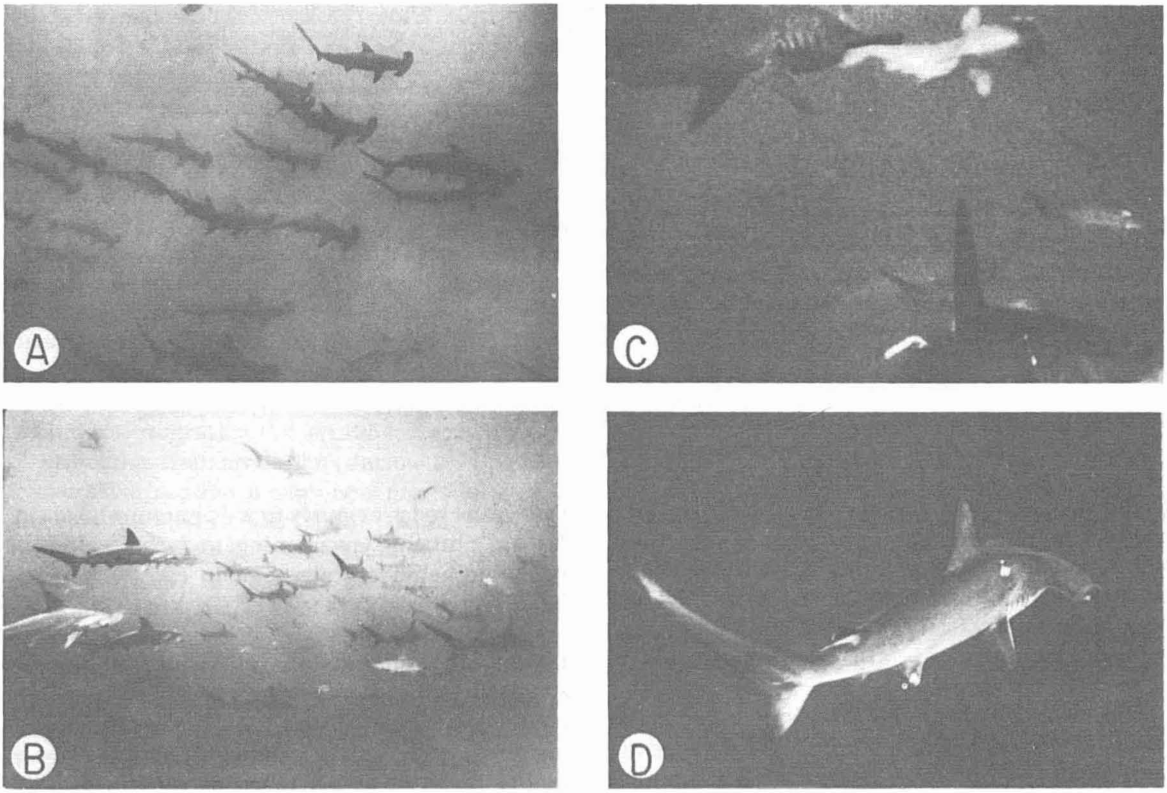

FIGURE 2.—Scalloped hammerhead sharks photographed in the Gulf of California: A. Hammerhead school as viewed obliquely from below. Note leading edge of school, orientation of sharks in same direction, and similar spacing between sharks. B. Side view of school. C. Shark in upper right-hand corner performing headshaking behavior. Note shark with color-coded streamer tag beneath headshaking shark. D. Female hammerhead possessing ellipsoid scar (above last gill slit), possibly inflicted during courtship.

Lincoln Index capture-recapture analysis, modified for observational data. On the morning of 3 August, 21 sharks were tagged with color-coded, plastic-streamer dart tags. Upon spear application of the tags, the sharks often accelerated momentarily, but usually remained within their groups. That afternoon, 9 tagged sharks were observed again within a group of 225, yielding an estimate of 525 sharks in the seamount vicinity (2-4 ha). We feel that this estimate was unbiased because all 21 of the tagged sharks dispersed among various groups after tagging.

We observed groups of 3 to 225 scalloped hammerhead sharks per dive with a mean of 19 (Table 1). Groups of sharks were encountered on 83% of the dives, two sharks on 7%, and single shark on 20% of the dives. Group size varied greatly; this in part reflected the dynamic composition of the groups as sharks left and returned. This was tested by noting the number of sharks associated with a tagged shark when it was reobserved. Tagged sharks (39 were tagged at El Bajo over the study period) were reobserved with varying numbers of accompanying sharks. For example, shark no. 19 was reobserved on four occasions during 135 min on the morning of 6 August with successive groups of 50, 15, 100, and 10 sharks. Such dynamics also were evident to an observer who remained for 120 min above one large group, which varied over that time from 50 to 225 sharks. Subgroups of up to 50 sharks departed and returned to this main group. Groups either appeared to remain at one certain spot (e.g., just upcurrent of the seamount at El Bajo) or repeatedly to follow a path within a relatively small area (ca. 2 ha). At Las Arenitas Rocks a group of ca. 50 scalloped hammerheads repeatedly traveled a particular oblong circuit once each 15 min.

There appeared to be some departures of sharks from El Bajo. Although 16 of the 21 sharks tagged the morning of 4 August were reobserved later

TABLE 1.—School size, depth, shark length, and sex composition of schools of scalloped hammerhead sharks at Las Arenitas Rocks, El Bajo Espiritu Santo, Isla Las Animas, and all locations in the Gulf of California. Numbers in parentheses refer to numbers of observations.

Descriptive categories	Las Arenitas Rocks	El Bajo	Isla Las Animas	All locations pooled
[1]School size, no.:				
Mean (*n*)	12(128)	44(54)	11(43)	19(225)
Maximum	100	225	50	225
[2]Individuals depth, m:				
Minimum	.6	.6	.6	.6
Mean (n)	10.1 (114)	10.7 (43)	11.7 (43)	10.4 (200)
Maximum	22.7	22.7	22.7	22.7
Variation around mean	4.3 (6)	8.5 (11)	3.1 (4)	6.7 (21)
Total length, m:				
Minimum	.9	.9	.9	.9
Mean (*n*)	1.6 (39)	1.8 (28)	1.7 (7)	1.7 (74)
Maximum	2.3	3.4	2.4	3.4
Sex ratios:				
Male:female (*n*)	1:1.6 (63)	1:3.8 (84)	1:3.1 (65)	1:2.7 (212)

[1]School defined as three or more sharks.
[2]Individuals' mean and maximum depths based only on observable sharks, since at times (particularly at El Bajo) schooling sharks extended to depths beyond our vision.

that day, only 5 were reobserved 2 d later, despite the fact that an equivalent amount of searching was conducted. The possibility of such migratory or dispersal movements was supported by the occasional observation of single scalloped hammerhead moving slowly at the surface over deep water between islands.

The mean depth of the schooling individuals was 10.4 m with sharks as shallow as 0.6 m and as deep as 22.7 m (Table 1). Depths were estimated with the aid of wrist-worn depth gages. Small groups of sharks were seen swimming close to the sandy or rocky substrate and at times appeared to explore rocky crevices.

The scalloped hammerhead schools were composed of sharks of variable size; both sexes were present in a school, but females were more common (Table 1). The largest individuals, which appeared to be females, often remained at the top of the schools. The sharks at El Bajo were larger than those at Las Arenitas Rocks, but no difference existed between those at El Bajo and Isla Las Animas and at Las Arenitas Rocks and Isla Las Animas. Females were more prevalent at all three sites with male:female ratios ranging from 1:3.8 at El Bajo to 1:1.6 at Las Arenitas Rocks (Table 1).

Within the groups, sharks performed a number of behavior patterns, including the following (in order of decreasing frequency): 1) tilting the body laterally; 2) accelerated swimming with headshaking (Figure 2C); 3) accelerated swimming, dorsal or ventral surface upward, while thrusting the midsection; 4) accelerated corkscrew swimming, rotating 360° around the longitudinal axis; 5) hitting of conspecific with the snout; 6) jaw opening; and 7) clasper flexion. Headshaking has been observed previously in wild hammerheads by Herald[1]; hitting, jaw opening, and clasper flexion resemble behaviors observed in captive bonnethead, *S. tiburo* (Myrberg and Gruber 1974).

Sharks of all sizes and both sexes performed tilting. This generally occurred when a diver was swimming above or behind the shark, perhaps enabling the shark to see the diver better. In one instance, while tilting, a shark flexed his clasper in the direction of an adjacent conspecific. Six males and three females varying from 1.5 to 1.8 m long were observed headshaking. Medium-sized sharks also performed corkscrewing; the sex of the single shark identified was male. Although jaw opening, apparently directed at divers, occurred in sharks outside of groups, headshaking, midsection thrusting, and corkscrewing usually occurred within the group, often at long distances from the diver. On two occasions sharks followed headshaking and corkscrewing by hitting their snouts against adjacent individuals, lateral or anterior to the first dorsal fin.

Many sharks bore abrasions (Figure 2D). These were small, recently inflicted, whitish patches (estimated diameter 4-8 cm), or partially healed black patches. In 21 out of 27 sharks, these were located lateral or anterior to the first dorsal fin, and if two patches were present, at times appeared bilaterally symmetrical. Possessors were predominately female (23 out of 27) and ranged from 1.2 to 2.1 m long ($\bar{x}$ = 1.7 m). These scars may be inflicted by males during mating. Captive, small

[1]Herald, E. The shimmy behavior of the hammerhead shark. Unpubl. manuscr., 4 p. Steinhart Aquarium, San Francisco, Calif., available from authors.

male bonnetheads accelerated from a position just above and behind a large female and scraped her dorsum between the first and second dorsal fins with their heads, often leaving similar scrapes (Myrberg and Gruber 1974). Bite scars, often consisting of a row of teeth marks, are inflicted during courtship in some sharks (Stevens 1974; Klimley 1980). The presence of these scarred females raises the possibility that the scalloped hammerhead schools may have a reproductive function. Grouping for reproduction has been speculated for *Galeorhinus australis* (Olsen 1954) and *Squalus acanthias* (Jensen 1965).

Other functional possibilities for the schooling include: 1) migration (Olsen 1954; Kenney 1968), 2) protection from predation (Barlow 1974), and 3) cooperative location or capture of prey (Coles 1915; Bigelow and Schroeder 1948). Other than the departure of tagged sharks from El Bajo, little evidence for or against the first hypothesis can be marshalled. The second hypothesis seems unlikely due to the absence of known predators. We do, however, have some evidence against the last hypothesis. Feeding was not observed, although scalloped hammerheads were often swimming through large schools of fishes. No feeding responses were directed at baits placed either among or above large numbers of scalloped hammerheads. Although fishing was carried out continuously, only a single male was captured. Feeding readiness was also tested by playing back sounds, attractive to many species of sharks including *Sphryna* sp. (Nelson and Johnson 1972), and baiting immediately after encountering grouped sharks. In 20 min of sound playback and 125 min of baiting, only a single shark was attracted. The phenomenon of grouped hammerhead sharks presents a unique opportunity for the further understanding of shark social behavior, since the sharks are found in sufficiently clear water for observation, shallow enough for free diving, remain in a sufficiently limited area for prolonged observations, and tolerate the approach of divers.

Acknowledgments

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CLEANING SYMBIOSIS BETWEEN TOPSMELT, *ATHERINOPS AFFINIS*, AND GRAY WHALE, *ESCHRICHTIUS ROBUSTUS*, IN LAGUNA SAN IGNACIO, BAJA CALIFORNIA SUR, MEXICO

Many species of marine fishes are known to engage in various forms of cleaning symbiosis (Limbaugh 1961; Hobson 1969, 1971). The cleaners, generally small or juvenile fish, remove ectoparasites and necrotic tissue from larger host fish. This promotes the well-being of the host and provides food for the cleaner. Cleaning symbiosis between topsmelt, *Atherinops affinis*, cleaners and gray whale, *Eschrichtius robustus*, hosts was observed during the author's study of breeding gray whales in Laguna San Ignacio, Baja California Sur, Mexico, supported by the United States Marine Mammal Commission, the National Geographic Society, and the World Wildlife Fund-U.S. (Swartz and Jones[1]). Topsmelt are perennial residents of the lagoon and gray whales occupy the lagoon for 3 to 4 mo each winter. As we photographed gray whales from our skiff, schools of topsmelt were seen accompanying the whales and picking at clusters of parasitic barnacles, *Cryptolepas rhachianecti*, and whale lice, *Cyamus* sp., which incrust these cetaceans (Rice and Wolman 1971).

Topsmelt in association with gray whales were collected during the 1978-79 winter with a "mackerel rig" consisting of 1 m of monofilament line with four No. 6 brass hooks spaced 10 cm apart. The standard length (SL) of each fish was measured and its gut contents examined. A second series of topsmelt were collected during the same winter in the absence of gray whales.

The topsmelt ranged from 17 to 29 cm SL. All 38 specimens collected in association with gray whales contained bits of sloughed gray whale epidermis and whale lice appendages. No barnacle appendages or other material was found in these fish. None of 25 topsmelt collected in the absence of whales contained any gray whale epidermis or whale lice; rather they contained bits of filamentous brown algae, *Ectocarpus* sp., and gammarid amphipods.

Topsmelt are described as opportunistic feeders on marine plants, small crustaceans, bryozoans, and hydroids (Frey 1971). During the breeding season of the gray whale, topsmelt in Laguna San Ignacio supplement their diets by cleaning sloughing epidermal tissue and external parasites from gray whale hosts.

[1]Swartz, S. L., and M. L. Jones. 1978. Gray whales, *Eschrichtius robustus*, during the 1977-1978 and 1978-1979 winter seasons in Laguna San Ignacio, Baja California Sur, Mexico. Available Natl. Tech. Inf. Serv., Springfield, Va., as PB-289 737, 35 p.

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MORPHOLOGICAL FEATURES OF THE OTOLITHS OF THE SAILFISH, *ISTIOPHORUS PLATYPTERUS*, USEFUL IN AGE DETERMINATION[1]

Because of its spectacular runs and leaps, sailfish, *Istiophorus platypterus*, is highly valued by sport fishermen, and the fishery contributes substantially to the economics of coastal regions (de Sylva 1969). However, information on the biology of sail-