NOTES

PREDATION BY SHARKS ON PINNIPEDS AT THE FARALLON ISLANDS[1]

What we know about mortality in pinnipeds has largely been derived indirectly. For example, pinnipeds or parts thereof have occasionally been found in shark stomachs. Sharks have thus become known as pinniped predators (e.g., Gogan[2]), but, since few direct observations of shark/pinniped interactions exist, we do not know the extent of such predation. The present paper summarizes observations of shark/pinniped encounters at the Farallon Islands between 1970 and 1979. We relate the frequency of observed encounters to annual and seasonal changes in pinniped population, and the marine climate, and assess the effect of shark-bite injury on the reproductive performance of seals.

Methods

The South Farallon Islands, San Francisco County, Calif. (lat. 37.4° N, long. 123.0° W), lie at the inward edge of the California Current, 30 km west of the California coast. Southeast Farallon, West End, and accompanying rocks compose the South Farallones and in all are about 44 ha (Figure 1). Over 250,000 seabirds of 12 species breed there (Ainley and Lewis 1974). Pinnipeds reach a peak of 2,500 animals—three species breed and occur there year-round: harbor seal, *Phoca vitulina*, northern elephant seal, *Mirounga angustirostris*, and northern sea lion, *Eumetopias jubatus*; a fourth, California sea lion, *Zalophus californianus*, the most numerous of Farallon pinnipeds, occurs most abundantly in spring, but few breed there; and a fifth, northern fur seal, *Callorhinus ursinus*, occasionally hauls out (Pierotti et al. 1977; Ainley et al.[3]).

Since 1968, the Point Reyes Bird Observatory has maintained a year-round research station on Southeast Farallon. On a rotating but continual schedule at least two biologists, plus several volunteer workers, have operated the station. Every day, weather permitting, a census of birds and a general visual survey of inshore waters was made. Beginning in 1970 elephant seals were

[1]Contribution 169 of the Point Reyes Bird Observatory.
[2]Gogan, P. J. P. 1977. A review of the population ecology of the northern elephant seal, *Mirounga angustirostris*. Unpub. manuscr., 68 p. Natl. Mar. Mammal Lab., NMFS, NOAA, 7600 Sandpoint Way, NE., Seattle, WA 98115.

[3]Ainley, D. G., H. R. Huber, R. P. Henderson, T. J. Lewis, and S. H. Morrell. 1976. Studies of marine mammals at the Farallon Islands, California, 1975-76. Final report, Marine Mammal Commission (Contract No. MM5AC027), Wash., D.C., available Natl. Tech. Inf. Serv., Springfield, VA 22151 as PB 2-266249, 32 p.

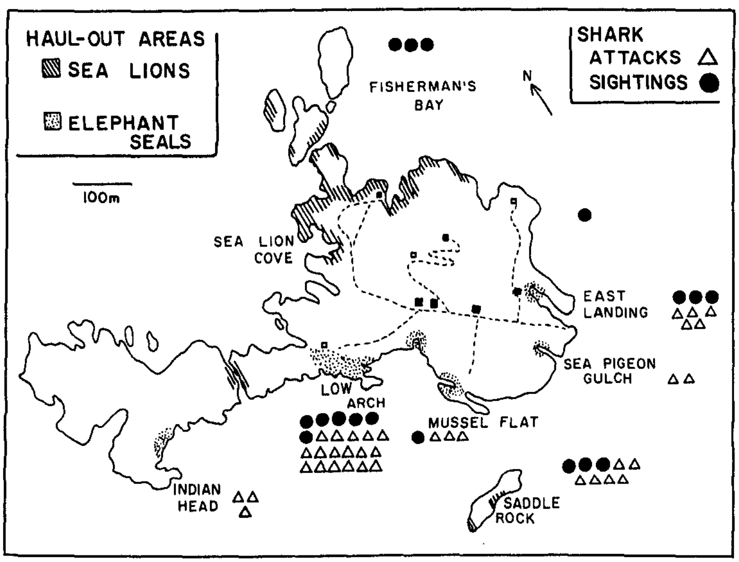

FIGURE 1.—South Farallon Islands, central California, and location of observed shark/pinniped encounters and major haul-out areas of sea lions and elephant seals.

censused weekly during most of the year and daily during the breeding season. Regular weekly censuses of other pinnipeds have been conducted since 1972, and as far back as 1970 irregular counts were made. Since we found shark activity to be seasonal (see below), we included comments on the seasonal changes in sea-surface temperature and salinity. Such information was derived from daily readings made at noon (P.s.t.).

Results

We recorded events involving sharks 58 times between 9 September 1970 and 9 February 1979. Of these, 37 were definite observations of sharks eating pinnipeds (i.e., "shark attacks") and the remainder (21) were mostly of sharks seen within 1 km of the island. In definite shark attacks, we were first (36 of 37 times) alerted to the incident by a flock of gulls (mostly the western gull, *Larus occidentalis*), hovering above a large bloody area (5 m^2) in the water. Usually we saw the shark's head and dorsal and caudal fins which offered clues to species identification and estimation of size and number. We often saw the pinniped prey as well. On five occasions only an area of bloody water and the hovering gulls were observed. These, too, were likely shark attacks on pinnipeds, but we did not include them in the 37 known attacks. Observations, from discovery of the gull flock to dissipation of blood and gulls, lasted from 3 to 15 min. If the carcass was not consumed in that time, then its disappearance was probably due to sinking. In the areas of most shark/pinniped interactions the water was 4-12 m deep.

In 20 interactions we saw the pinniped prey sufficiently well for a positive identification. Two involved sea lions, one or perhaps two involved harbor seals, and the remainder involved elephant seals. Based on size, we could tell that seven elephant seals were young individuals, about 3 yr old or less, and an eighth was an adult female. On rare occasions, we have observed sea lions with obvious, fresh shark-bite wounds. However, the location of most shark attacks in the vicinity of the elephant seal hauling out areas (Figure 1) further supports what other data indicate, that at Southeast Farallon, sharks more frequently ate elephant seals than other pinnipeds.

In 30 instances, the white shark, *Carcharodon carcharias*, was identified as the species seen preying on seals. All were at least 3 m long and most about 3.5-5 m long. In 16 of 21 nonattack observations within 1 km of the island, the shark was also identified: 14 involved white sharks and two involved the blue shark, *Prionace glauca*. How many sharks were present at any one time is not known. On at least three occasions two sharks, and once three sharks, simultaneously fed on one pinniped. On 8 January 1976, a 3 m long white shark was caught in Fisherman's Bay and 7 d later two larger white sharks were seen on the opposite side of the islands.

Sharks were more abundant or more active during the late fall and winter over the 9 yr (Figure 2). The number of attacks in December and January was perhaps artifically low (see below) because on many days during those months few if any gulls were present to alert observers. The possibility that attacks were missed was particularly likely in December 1976 and January 1977. Sharks were known to be present then because several seals hauled out with fresh shark-bite wounds and part of another was seen floating in the water. Yet no attacks were seen. The timing of greatest shark activity corresponded closely with the Davidson Current period (October-February) which, as described by Bolin and Abbott (1963), is characterized by slowly declining sea-surface temperatures and salinities and the appearance of a northward flowing countercurrent (shoreward of the south-flowing California Current). White sharks were thus present (or at least active, see below) when waters were warm but not necessarily the warmest (Figure 2). Blue sharks, on the other hand, were definitely most abundant during the warm oceanic period (July-September), when the California Current slackens, allowing warm saline oceanic waters to flow shoreward. They were observed commonly but only at 3 km or more away from the island. Few were involved in the observations reported here.

The timing of most shark attacks also corresponded closely with the late autumn peak in elephant seal numbers (Figure 2). Each year the elephant seals reached maximum numbers twice, during midspring and again during late fall (Le Boeuf et al. 1974). A third, smaller peak occurred during the winter breeding season. Only two shark attacks, both involving elephant seals, were observed during the upwelling period (March-July), when the California Current flows most strongly and temperatures reach their lowest. One of these attacks occurred during the spring peak in elephant seal numbers. During the fall, when most shark attacks were observed, the populations of other pinniped species at the Farallones were usually near their annual low (Ainley et al. footnote 3), which indicates even further that elephant seals were the usual prey of sharks. Rather exceptional were the high numbers of California sea lions present in the fall 1978 (Huber et al.[4]). Sharks and shark incidents were seen often then but we could identify few of the pinniped prey. One incident definitely involved a sea lion but most others occurred in areas frequented by elephant seals and not by sea lions.

Several elephant seals arrived at the Farallones for the breeding season bearing shark-bite wounds, some fresh and some healed. The histories of these animals are noteworthy, particularly since their being severely wounded may have affected their reproductive performance. Twenty-four breeding attempts by females identifiable as individuals were available for analysis. In 10 attempts, females arrived with fresh wounds. In only one (10%) did she successfully rear a pup by herself, three lost their pups, three received help from other cows (i.e., they shared suckling), and three apparently did not pup. In 1977 three newly wounded cows disappeared (not even present during spring molt) after leaving the island with healed wounds. In 14 pupping attempts by known females with no wounds (but wounded in a later year) or with old, healed wounds, all but two (86%) successfully raised a pup without help. The difference is significantly different from the 10 attempts mentioned above (t = 3.3, $P<0.001$). Since many of the freshly wounded females were probably pupping for their first time, it could have been lack of experience that resulted in their poor record rather than being wounded. Two females, however, without wounds raised their first pups successfully but the next season, each with a fresh wound, they either allowed another cow to help in suckling or failed to pup successfully. In addition, of 11 females pupping for their first time in 1977 and not having shark-bite wounds, 7 (64%) were successful, and only 1 allowed its pup to be nursed by another female. Thus females with fresh, severe shark-bite wounds were less successful in pupping than others. Perhaps the energy and tissue-building resources needed to heal a severe wound were taken from those required in the rearing of a pup. None of the 6 females with fresh shark wounds in the 1977 breeding season was observed to copulate; among other females 99 (77%) were observed in copulation.

Two male elephant seals have also hauled out at the Farallones, bearing shark-bite wounds. One first visited in December 1972 as a subadult bull (probably about 5 yr old) and had an old shark-bite wound. He returned each season through the 1976 breeding season. Another was first seen in 1972 as a young adult (Le Boeuf et al. 1974) and was the alpha bull in the breeding hierarchy during 1972, 1973, and 1974. In 1975 he arrived for the fourth year, was initially the alpha bull, but was dethroned before the end of the breeding season. In 1976 he appeared on the island with two fresh shark wounds. Thereafter he visited the breeding colony intermittently, but was not part of the hierarchy of breeding bulls.

[4]Huber, H. R., D. G. Ainley, S. H. Morrell, R. R. LeValley and C. S. Strong. 1978. Studies of marine mammals at the Farallon Islands, California, 1977-78. Final report, Marine Mammal Commission (Contract No. MM7AC025), Wash., D.C., available Natl. Tech. Inf. Serv., Springfield, VA 22151 as PB 80-111602, 50 p.

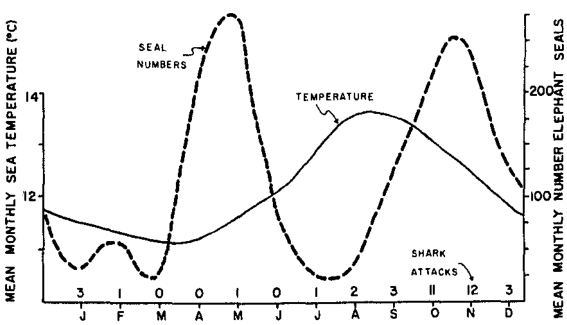

FIGURE 2.—Annual cycles in monthly mean sea-surface temperature, elephant seal numbers and number of shark/pinniped interactions in the Farallon Islands, central California, vicinity, 1970-78. Seal numbers are from Ainley et al. (text footnote 3) and Huber et al. (text footnote 4).

Discussion

It is obvious that the frequency of shark attacks on pinnipeds and other shark observations have been increasing at the South Farallon Islands (Table 1). We are convinced this is not an artifact of increasing observer awareness for a number of reasons, because a flock of 50+ gulls hovering for 10-15 min above a large, blood-red patch of water within 50 m of shore is not easy to miss, particularly from such a small island; and daily censuses have been conducted consistently since 1970.

Since the seasonal occurrence of some sharks is related to water temperatures (e.g., O'Gower

TABLE 1.—Annual data on elephant seal numbers, shark attacks, water temperatures, and frequency of attacks relative to seal numbers at the Farallon Islands, central California.

	Winter (late December-February)				Summer (late March-early July)				Fall (late August-mid-December)			
Year	A Max no. seals	B No. attacks	C Ratio A:B	Mean sea temp	A Max no. seals	B No. attacks	C Ratio A:B	Mean sea temp	A Max no. seals	B No. attacks	C Ratio A:B	Mean sea temp
1970	0	0	0	11.3	60	0	0	10.0	35	[1]1	0	15.5
1971	0	0	0	11.5	50	0	0	[2]8.8	120	0	0	16.8
1972	3	0	0	11.5	120	0	0	10.0	155	1	.01	17.0
1973	10	0	0	12.1	176	0	0	10.8	170	2	.01	14.5
1974	20	0	0	11.0	290	1	.003	8.8	300	2	.01	15.0
1975	30	[2]0	0	10.9	305	0	0	10.0	330	6	.02	13.5
1976	55	0	0	10.5	460	0	0	9.3	450	4	.01	16.0
1977	110	[2]0	0	12.7	523	0	0	10.0	507	7	.01	13.6
1978	182	4	.02	13.6	717	1	.001	12.4	609	7	.01	12.0
1979	250	[2]1	.004	11.6	776	0	0	11.2				

[1] Thought to be an attack on a sea lion.
[2] Cows arrived with fresh shark-bite wounds; in 1979 the remains of a cow, likely a shark victim, was seen floating in the water.

and Nash 1978), it was worthwhile to consider the relationship between temperature and sharks at the Farallones. As shown in Table 1, water temperature during the fall when most shark attacks and sightings occurred, compared among the years, fluctuated up and down but did not relate clearly to yearly fluctuation in shark attack frequency. The same was true for temperatures during the winter elephant seal breeding season. The year 1978 provides an instructive example of this. In the spring-summer, temperatures were unusually high. In spite of record numbers of elephant seals only one shark attack was observed, and that occurred in July, long after the seal population peak (only 24 were present; 452 sea lions, though, were present). Later in the fall, temperatures were lower than during spring but much shark activity was evident (Table 1). The only major relationship that was evident between shark attacks and water temperature was that all but one observed attack occurred when temperature generally exceeded 12° C (as summarized in Figure 2). Unfortunately, there is no published information of the seasonality of white sharks to explain this. Off Durban, South Africa, where water temperatures are higher than at the Farallones, Bass (1978) found small white sharks more abundant when temperatures dropped to the annual low (equivalent to highest Farallon temperatures), but the number of white sharks the size of those at the Farallones did not change.

The factor that best relates to the general increase in white sharks is an increase in elephant seal numbers. The fall, winter, and spring populations of elephant seals have been increasingly rapidly at the Farallones over the past several years (see Le Boeuf et al. 1974; Ainley et al. footnote 3; Table 1). The seal population during the fall, the period of most shark attacks, has increased about 3.9 fold since 1972, the first year of the period when shark attacks have been seen consistently year after year. In the fall data there is a direct relationship between the number of shark attacks and the number of seals ($r = 0.895$; $P < 0.01$). The ratio of attacks to the number of seals, except during spring and the 1979 seal breeding season, has remained at about 0.01-0.02.

Shark attacks during the elephant seal breeding season (winter) have been observed less often than during the fall but they may be increasing during that period, too, if the 1977-79 seasons are any indication. Interestingly, attacks were first seen during winter in the year when the elephant seal population surpassed 120 animals (1978), the same population level that occurred in conjunction with the first fall sighting of elephant seal/shark interactions (1972). This further indicates a density-dependent relationship between shark predation and elephant seal populations.

Acknowledgments

The Farallon Island field station of the Point Reyes Bird Observatory was supported financially by members and donors and by contracts from various agencies. In addition to our members, we wish especially to thank the Lucius M. Beebe Foundation, Charles E. Merrill Trust, McNaughton Foundation, Dean Witter Foundation, San Francisco Foundation, Packard Foundation, Standard Oil of California, and the U.S. Fish and Wildlife Service. Marine mammal observations from 1975 to 1979 were under contract from the Marine Mammal Commission. We also wish to thank the U.S. Coast Guard and particularly the Oceanic Society for logistic support. William I.

Follett kindly reviewed some photographs that we took of sharks, thus confirming our identifications, and checked an earlier version of this paper.

Literature Cited

AINLEY, D. G., AND T. J. LEWIS.
1974. The history of Farallon Island marine bird populations, 1854-1972. Condor 76:432-446.

BASS, A. J.
1978. Problems in studies of sharks in the southwest Indian Ocean. *In* E. S. Hodgson and R. F. Mathewson (editors), Sensory biology of sharks, skates, and rays, p. 545-549. Off. Nav. Res., Arlington.

BOLIN, R. L., AND D. P. ABBOTT.
1963. Studies on the marine climate and phytoplankton of the central coastal area of California, 1954-1960. Calif. Coop. Oceanic Fish. Invest. Rep. 9:23-45.

LE BOEUF, B. J., D. G. AINLEY, AND T. J. LEWIS.
1974. Elephant seals on the Farallones: population structure of an incipient breeding colony. J. Mammal. 55: 370-385.

O'GOWER, A. K., AND A. R. NASH.
1978. Dispersion of the Port Jackson shark in Australian waters. *In* E. S. Hodgson and R. F. Mathewson (editors), Sensory biology of sharks, skates, and rays, p. 529-544. Off. Nav. Res., Arlington.

PIEROTTI, R. J., D. G. AINLEY, T. J. LEWIS, AND M. C. COULTER.
1977. Birth of a California sea lion on southeast Farallon Island. Calif. Fish Game 63:64-66.

DAVID G. AINLEY
CRAIG S. STRONG
HARRIET R. HUBER
T. JAMES LEWIS
STEPHEN H. MORRELL

Point Reyes Bird Observatory
Stinson Beach, CA 94970

IN SITU OBSERVATIONS ON REPRODUCTIVE BEHAVIOR OF THE LONG-FINNED SQUID, *LOLIGO PEALEI*

There are several published accounts of reproductive behavior, including copulation and egg laying, of the long-finned squid, *Loligo pealei* Lesueur, in the laboratory (Drew 1911; Arnold 1962); but with the exception of Stevenson's (1934) field observations of *L. pealei*'s behavior around an egg mass, no in situ observations of egg-laying behavior have been documented for this species. Field and laboratory observations of reproductive behavior have been made for the California market squid, *L. opalescens* (McGowan 1954; Fields 1965; Hobson 1965; Hurley 1977), the tropical arrow squid, *L. plei* (Waller and Wicklund 1968), *L. bleekeri* (Hamabe and Shimizu 1957), *L. vulgaris* (Tardent 1962), the broad squid, *Sepioteuthis bilineata* (Larcombe and Russell 1971, and *S. sepioidea* (Arnold 1965). However, each species' in situ egg-laying behavior differed from the behavior we observed in *L. pealei*.

Observations

Each summer *L. pealei* and its egg masses are common in shallow coves along the coast of Rhode Island, such as our study site at Fort Wetherill on Conanicut Island in Narragansett Bay. Scuba divers, including ourselves, have observed squid to be numerous in these areas, particularly at night when they occur singly or in small, loosely formed schools.

On 16 June 1979, at 1230 h on an incoming tide (temperature 14.5°-15.0° C, depth 6 m) using scuba we observed a large squid egg mass (50-60 cm across) attached to one side of a small boulder. The surrounding area was a sandy/mud bottom with unattached fragments of the seaweeds *Ulva lactuca*, *Laminaria* sp., and *Porphyra* sp. Because the egg mass was larger than the 12-15 cm masses we regularly see in this area while diving, we spent some time observing it. Squid began to appear at the limit of the water visibility (about 4.0 m) and moved toward the egg mass in a semicircle. They stopped about 2.5-3.0 m from the mass and remained stationary approximately 1-m off the bottom. The squid were in well-defined pairs with the smaller females (mantle length 16-18 cm) parallel to and on the left of each male (20-22 cm) as we faced them (Figure 1). Eight pairs were visible at that time. The animals had moderate pigmentation over the mantles, but we did not observe the distinctive spots of color at the base of the arms as were reported by Arnold (1962), nor did we observe color changes during the observation period. Contrary to McGowan's (1954) observations on *L. opalescens*, all of the animals appeared to be in good condition; no torn epithelium was obvious and no dead or dying individuals had been seen in the area of the egg mass or anywhere else in the cove during the hour-long dive.

One pair of squid at a time approached the egg mass with their arms held forward and tentacles extended. Because of our position directly facing the squid, it was impossible to observe the beginnings of an egg finger protruding from the funnel as Drew (1911) and Tardent (1962) had observed in