Wounding in Hawaiian monk seals (*Monachus schauinslandi*)

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Injuries observed on endangered Hawaiian monk seals (*Monachus schauinslandi*) at Laysan Island and French Frigate Shoals in the northwestern Hawaiian Islands in 1988 and 1989 were classified into six major types, based on the source of the wounds: mating attempts by adult male monk seals; nonmating aggressive interactions with other seals; attacks by large sharks; attacks by cookiecutter sharks (*Isistius brasiliensis*); contact with coral reef or debris; and entanglement in netting or marine debris. At both locations, injuries inflicted by adult male seals during mobbing incidents, in which many males attempt to mate with one seal, were seen more frequently than other types of injuries in 1988 and 1989. Injury data from 1982–1987 at Laysan Island and from 1985–1989 at French Frigate Shoals were used to compare the distribution of mating injuries inflicted by adult males and injuries inflicted by large sharks over size and sex classes of seals. Mating injuries caused by adult male seals were seen primarily on adult females but were also seen on seals in other size classes. Mating injuries inflicted by adult males occurred earlier in the year and with greater frequency at Laysan Island than at French Frigate Shoals. Injuries inflicted by large sharks were observed more often on adult male seals than on seals in other size classes at Laysan Island; however, no such difference was seen among size classes at French Frigate Shoals.

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Les blessures observées chez le Phoque-moine d'Hawaii (*Monachus schauinslandi*), une espèce menacée, à l'île Laysan et sur les hauts-fonds French Frigate dans le nord-ouest de l'Archipel hawaïen en 1988 et 1989 ont pu être classifiées, d'après leur origine, en six catégories principales : aggressions des mâles adultes durant les tentatives d'accouplement, interactions aggressives non reliées à l'accouplement chez les autres phoques, attaques de grands requins, attaques du requin *Isistius brasiliensis*, contacts avec le récif ou les débris coralliens et empêtrements dans les filets de pêche ou autres agrès. Aux deux sites, c'étaient les blessures produites par les mâles adultes durant les cohues, lorsque plusieurs mâles cherchaient à s'accoupler avec une même femelle, qui étaient les plus fréquentes en 1988 et 1989. Des données récoltées en 1982–1987 à l'île Laysan et en 1985–1989 aux hauts-fonds French Frigate ont permis de comparer la répartition d'après la taille et le sexe des blessures infligées par les mâles durant l'accouplement et celles dues aux requins. Les blessures causées par les mâles durant l'accouplement se retrouvaient surtout chez les femelles adultes, mais aussi chez des phoques d'autres classes de taille; à l'île Laysan, ces blessures pouvaient s'observer plus fréquemment et plus tôt dans l'année qu'aux hauts-fonds French Frigate. Les blessures dues aux grands requins apparaissaient plus couramment sur les adultes mâles que sur les autres phoques à l'île Laysan, mais non aux hauts-fonds French Frigate.

[Traduit par la rédaction]

Introduction

Injuries are generally considered detrimental to animals, for they can reduce the probability of survival (Congdon *et al.* 1974; Willis *et al.* 1982) or delay maturation (Maiorana 1977). Various types of scars and fresh injuries are seen on Hawaiian monk seals (*Monachus schauinslandi*) (Kenyon and Rice 1959; Wirtz 1968; Alcorn 1984; Johanos *et al.* 1987), but the different types have not been consistently described. Injuries to monk seals have received increased interest recently because they apparently have a detrimental effect on the reproduction and survival of individual seals, which in turn may negatively affect overall population growth and recovery of this endangered species (Gilmartin 1983). Consequently, it is important to describe and quantify the types of wounds to facilitate monitoring of their origin and frequency and to assess their significance to injured individuals as well as to the monk seal population as a whole.

Most injuries noted in the past have been attributed to attacks by sharks (e.g., Kenyon 1973) and to what has been termed "mobbing" behaviour of adult male monk seals (e.g., Alcorn 1984). Shark attack has been thought to be an important cause of mortality (Kenyon 1973). Although sharks have been observed to attack and feed upon monk seals (Balazs and Whittow 1979; Alcorn and Kam 1986), the extent to which shark predation affects the population is unknown. Mobbing behaviour involves many males trying to mate simultaneously with one female or subadult (male or female) seal (Johnson

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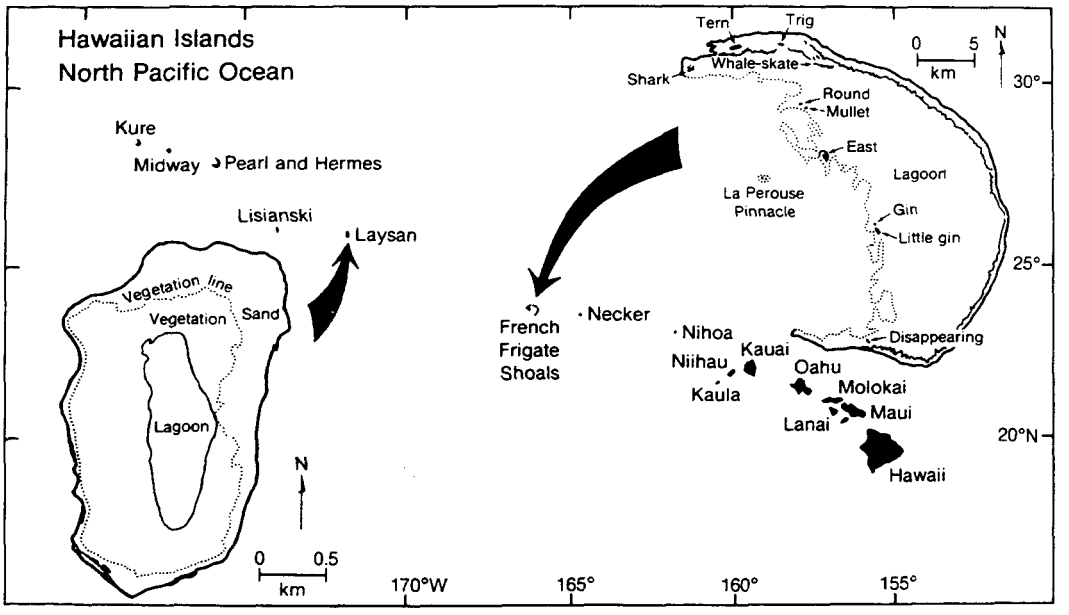

FIG. 1. Northwestern Hawaiian Islands, showing Laysan Island and French Frigate Shoals in detail. Note the difference in scale between Laysan Island and French Frigate Shoals.

and Johnson 1981; Johanos and Kam 1986; Johanos *et al.* 1987). During mating, the male mounts the female and bites her to hold his position on her back (Johanos *et al.* 1990). Puncture wounds and abrasions may be inflicted on the back of the female during mating. When more than one male tries to mate simultaneously with one seal, the biting becomes intense and harassment of the seal may continue over several hours, resulting in the formation and subsequent enlargement of open dorsal wounds (Johnson and Johnson 1981). In extreme cases the resulting wound may expose up to two-thirds of the dorsum (Alcorn 1984). Because of the apparent severity of such wounds, and of those inflicted by large sharks, the survival rate of wounded seals may be significantly lowered (Wirtz 1968; Johnson and Johnson 1981; Gilmartin 1983; Alcorn 1984).

In this paper we describe six major categories of injuries observed in two Hawaiian monk seal populations in the northwestern Hawaiian Islands during 1988 and 1989. Because wounds inflicted by adult male seals and by large sharks appear severe enough to affect the survival and reproduction of individuals, we examine the frequency of occurrence of these injuries in 1982–1989, and their possible effect on the monk seal population.

Study sites and methods

Laysan Island (latitude 25°42′N, longitude 171°44′W; Fig. 1) is a low coral sand island about 2.8 km long and 1.7 km wide, with a hypersaline lake in its center. The island is surrounded by a fringing coral reef varying from 90 to 460 m in width (Ely and Clapp 1973). In 1989, when the entire monk seal population was identified, it consisted of 258 seals (excluding pups). The ratio of adult males to adult females was about 1.6:1 (Honolulu Laboratory, unpublished data).

French Frigate Shoals (FFS, latitude 23°45′N, longitude 166°10′W; Fig. 1) is a coral atoll with a crescent-shaped fringing reef, approximately 32 km long and 9.6 km wide, covering about 363 km^2 and containing 12 permanent sand islets, several sandspits that vary in size and location through the year, and one island of volcanic rock (Amerson 1971). The estimated monk seal population at FFS in 1988 was 623 animals (excluding pups). From beach counts, the ratio of adult males to adult females was estimated at 0.6:1 (Gilmartin *et al.* 1993).

We collected injury and census data on Hawaiian monk seals at Laysan Island during 28 February – 21 June 1988 and 28 March – 17 July 1989. At FFS, data were collected during 13 April – 30 August 1988 and 28 March – 3 September 1989. We also analyzed census and injury data collected in 1982–1987 at Laysan Island, and in 1985–1987 at FFS by Honolulu Laboratory personnel as part of an ongoing study of the population dynamics of Hawaiian monk seals.

At Laysan Island, adult and subadult seals were identified by means of numbers applied with commercial bleach (Stone 1984; all years except 1982, 1986, and 1987), distinctive scars, and natural markings. In addition, weaned pups were tagged with plastic Temple Tags (Gilmartin *et al.* 1986) each year beginning in 1983, and adult males were tagged from 1983 through 1988 (Johanos *et al.* 1987; Johanos and Austin 1988; Alcorn and Buelna 1989; Johanos *et al.* 1990). Seals with distinctive marks (e.g., large scars, flipper tags, or natural markings) were easily identified between years, but seals known only by marks applied with bleach were not consistently identified between years. At FFS, individuals were identified, when possible, by means of distinctive scars and natural markings. Temple Tags were applied to weaned pups beginning in 1984. No animals were marked with bleach and adult animals were not tagged during the study period.

Each seal was assigned to a size class on the basis of known age (e.g., nursing pup, weaned pup), reproductive state (adult female with nursing pup), or estimated size (juveniles, subadults, and adults), using criteria described in Stone (1984). The sex of a seal was recorded if seen, or if the seal had been previously identified and its

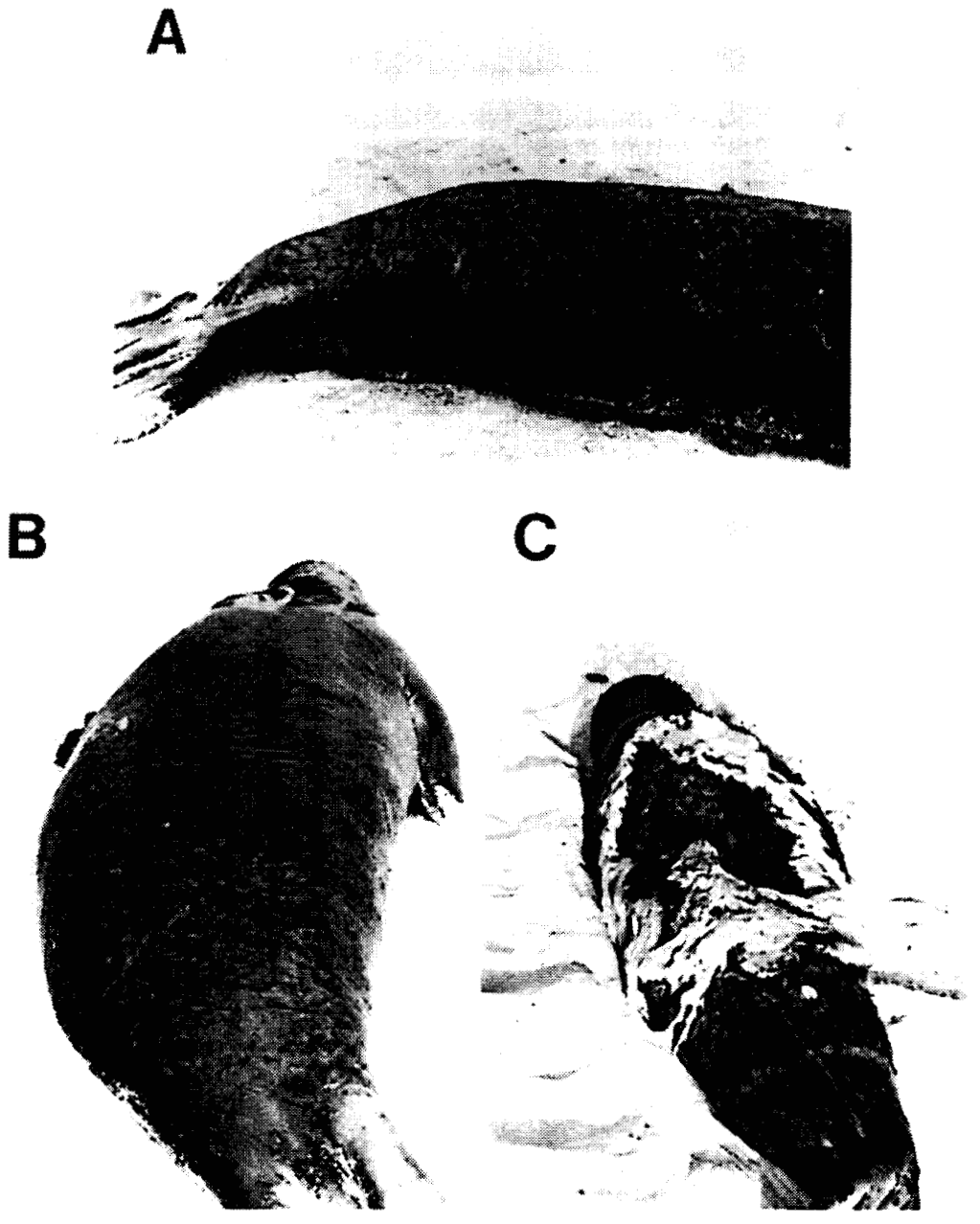

FIG. 2. Typical dorsal abrasions and lacerations (A and B) and gaping open dorsal injury (C) inflicted by adult male seals during mobbing incidents.

sex was known. An adult seal with a nursing pup was always classed as female.

The population composition was determined from daily census data. During censuses, all seals on land (with >50% of the body out of water) were counted as the observer walked around the perimeter of the island. On non-census days, less standardized observations were taken. Slightly different procedures were used at Laysan Island and FFS. At Laysan Island, censuses were conducted every 2–4 d, and took about 2.5 h to complete. Censuses at FFS were conducted every 1–2 weeks over a 2-d period. At islets too small for an

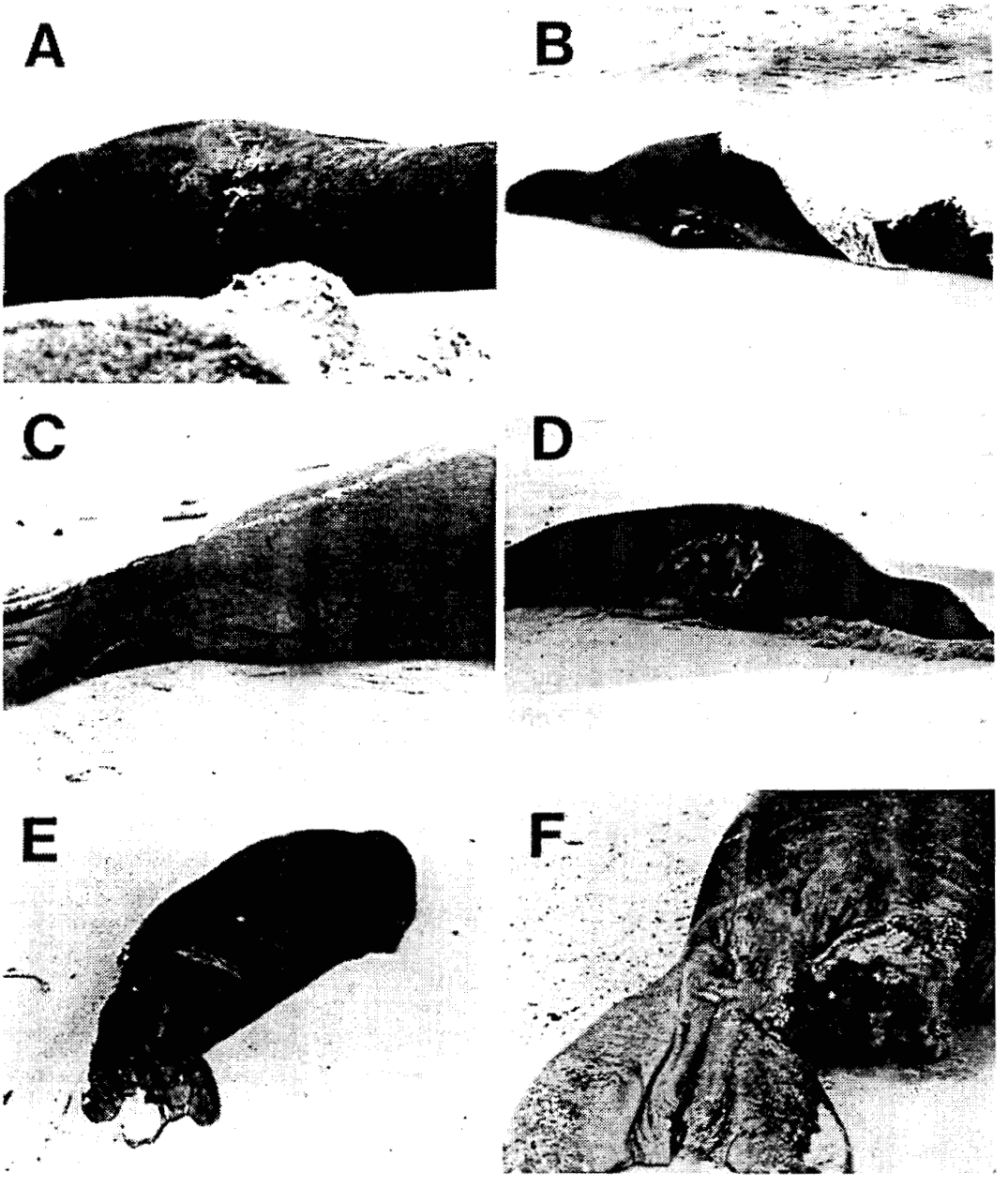

FIG. 3. Seal with a small open dorsal injury (A) and, about 10 days later, with a gaping open dorsal injury (B), both inflicted by adult male monk seals. (C) Seals with lacerations showing the shape of a shark's jaw. (D) A gaping injury showing the shape of a shark's jaw. (E) Fresh lacerations. (F) Seal with a hind flipper amputated.

observer to land without disturbing the seals, animals were counted from the boat.

Injuries were recorded both on census and non-census days. We standardized injury descriptions by grouping injuries into six types, based on physical characteristics: (1) *puncture*: small-diameter (<2 cm) hole, such as that created by a sharp pointed object piercing the skin; (2) *abcess*: a swollen, blister-like area under the skin; (3) *abrasions and lacerations*: scratches or tears in the skin ranging in depth from surface scratches (not breaking the skin) to deep tears in the muscle tissue; (4) *gaping wound*: an open, irregular- or oval-shaped wound

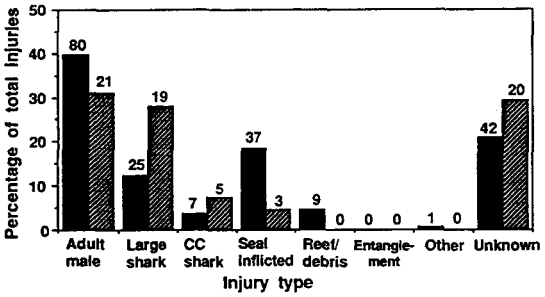

FIG. 4. Relative frequencies of different types of wounds observed on Hawaiian monk seals from April to June of 1988 and 1989 at Laysan Island (solid bars) and French Frigate Shoals (FFS) (hatched bars) in the northwestern Hawaiian Islands. See text for a description of wound types. The number of injuries of each type is indicated above each bar. "CC shark" indicates the cookiecutter shark (*Isistius brasiliensis*).

where flesh was removed; (5) *circular wound*: a wound ranging from a semicircular cut through the skin to a circular wound with flesh removed; (6) *amputation of a limb*: all or part of a limb removed from the body. Injuries recorded in 1988 and 1989 were classified by the observer. We classified injuries recorded by Honolulu Laboratory personnel from 1982 to 1987 by examining drawings and photographs taken at the time of observation. Each injury was used once in the analysis. If an animal was injured more than once during a season and the injuries were from a different source, the two injuries were counted separately.

Data analyses

Only data from 1988 and 1989 were used to examine the frequency of occurrence of injuries from different sources because wounds were recorded more often and more systematically during those years. Data from all years (1982–1989) were used when examining injuries inflicted by adult male seals or by large sharks, as emphasis in data collection from 1982–1987 was placed on monitoring aggressive male behaviour and interactions between sharks and seals (e.g., Alcorn and Buelna 1989).

To minimize seasonal variation in censuses (Gerrodette 1985), we used the average number of seals counted in May and June of 1988 and 1989 as an index of the relative size of the population. To compare the monthly frequencies of occurrence of injuries inflicted by adult male seals and by large sharks between Laysan Island and FFS, we divided the monthly numbers of the two injury types by this index of population size.

To determine if data collected in 1988 and 1989 were similar to those collected in 1982–1987, we compared the two data sets (*G*-test; Sokal and Rohlf 1981). We pooled the data sets where no statistically significant differences were detected. All tests were evaluated at the 0.05 significance level.

Results

Causes of injuries

The shape of an injury and its location on the seal's body were often indicative of its origin. Six characteristic types of injuries, based on the cause of the wound, were observed.

Injuries inflicted by adult male monk seals during mating attempts

Wounds inflicted by adult males during mating attempts consisted of abrasions on the dorsum of the injured seal, occasionally extending to its sides. The scratches were caused by

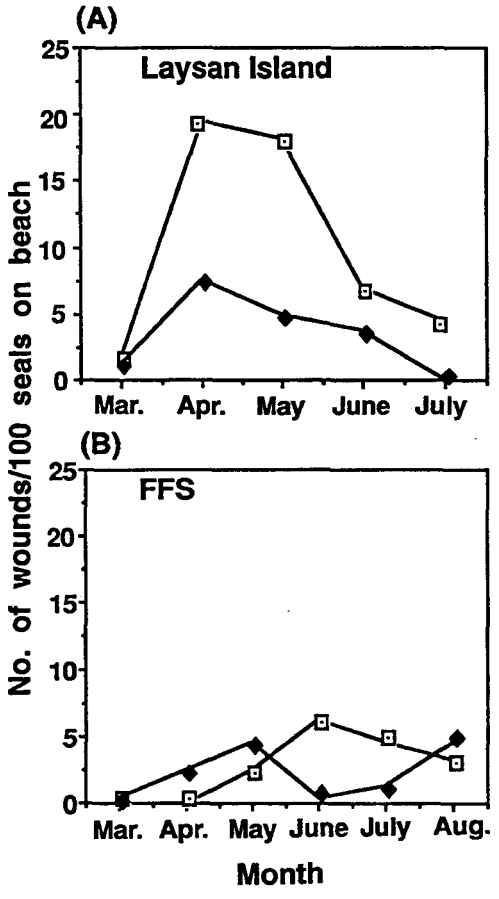

FIG. 5. Rate of wounding of Hawaiian monk seals by other adult male monk seals (▫) and large sharks (♦) at Laysan Island (A) and French Frigate Shoals (B) in the northwestern Hawaiian Islands, 1988 and 1989. Seals of all size and sex classes are included.

an adult male attempting to hold the seal with its teeth and foreflippers while mounting it (Figs. 2A, 2B). Often the dorsum of the injured seal was dark because of subcutaneous hemorrhage (Alcorn 1984) and fluids leaching from the abrasions. Some seals also sustained more severe gaping wounds, usually in the midbody to posterior dorsal area. These gaping wounds ranged from small (ca. 2 cm diameter; Fig. 3A) to large open areas covering up to two-thirds of the injured animal's back (Figs. 2C, 3B; Alcorn 1984). In many cases the injured seal was observed with one or more adult males.

Mating injuries inflicted by adult males were the most frequently observed of all injuries at both Laysan Island and FFS (Fig. 4). These injuries were observed earlier in the year (April and May; Fig. 5), and the number of injuries (per 100 seals counted) inflicted was much higher at Laysan Island than at FFS. In June and July the rates from both areas were similar. At both Laysan Island and FFS the distribution of injuries inflicted by adult male seals over the size and sex classes of

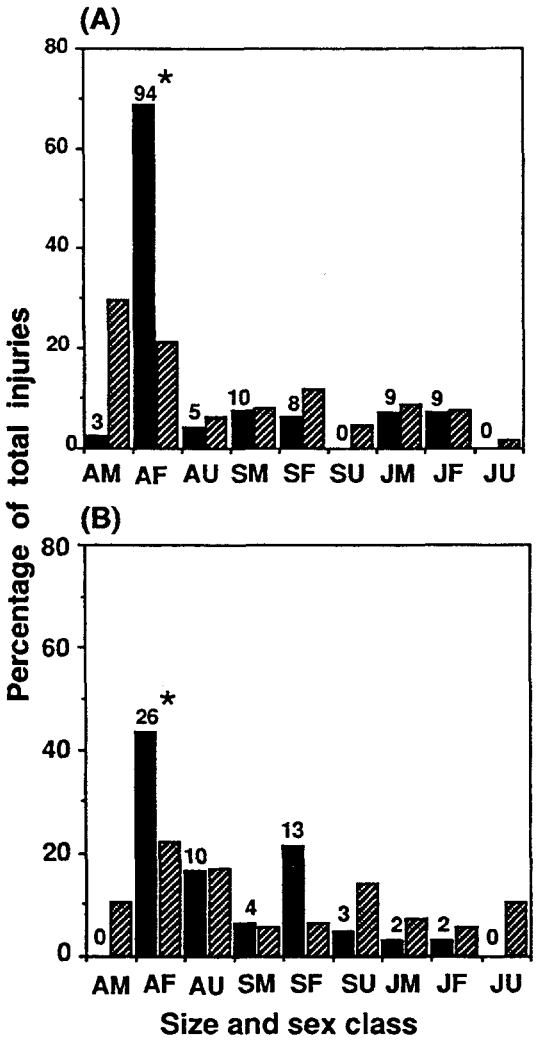

FIG. 6. Observed (solid bars) and expected (hatched bars) proportions of injuries inflicted by adult male Hawaiian monk seals on seals of different size and sex classes at Laysan Island (A) and French Frigate Shoals (B) in the northwestern Hawaiian Islands, 1982–1989. Expected frequencies are based on mean censuses in May and June of 1982–1989. The number of injuries in each class is indicated above each bar. AM, adult male; AF, adult female; AU, adult of unknown sex; SM, subadult male; SF, subadult female; SU, subadult of unknown sex; JM, juvenile male; JF, juvenile female; JU, juvenile of unknown sex. An asterisk indicates a significant difference between expected and observed proportions in a class.

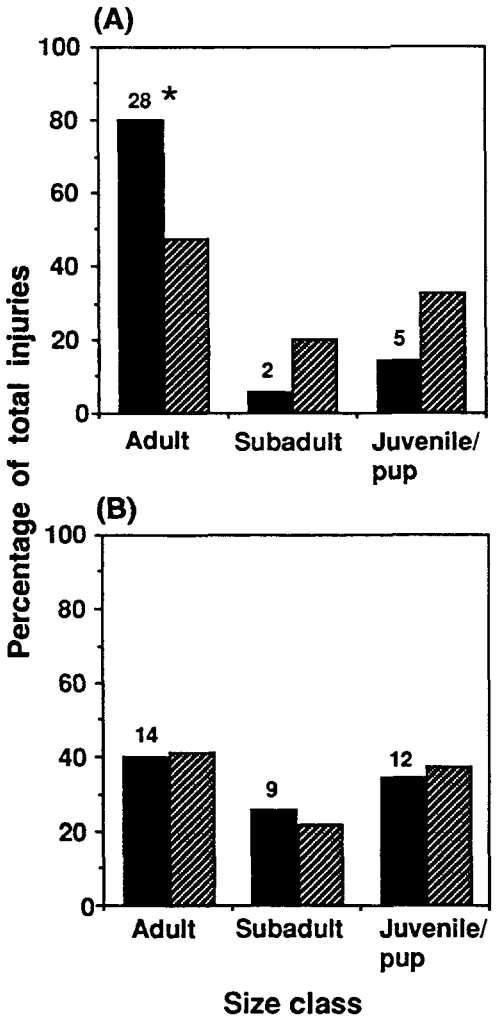

FIG. 7. Observed (solid bars) and expected (hatched bars) injuries inflicted by large sharks on Hawaiian monk seals of different size-classes at Laysan Island (A) and French Frigate Shoals (B) in the northwestern Hawaiian Islands, 1982–1989. Expected frequencies are based on mean censuses in May and June of 1982–1989. The number of injuries in each class is indicated above each bar. An asterisk indicates a significant difference between expected and observed proportions in a class.

monk seals was not directly proportional to the number of seals in each size and sex class counted on the beach (G-test with Williams' correction; Sokal and Rohlf 1981; Laysan: $G = 172.65$, df = 8, $p < 0.005$, Fig. 6A; FFS: $G = 53.38$, df = 8, $p < 0.005$, Fig. 6B; injured animals of unknown sex were excluded from the analysis). Significantly more adult females were injured at both Laysan Island and FFS than expected from their relative numbers in the population (Laysan: $G = 52.76$, df = 1, $p < 0.005$; FFS: $G = 7.48$, df = 1, $p < 0.01$). At FFS, the distribution of injuries inflicted by adult males over size and sex classes should be interpreted conservatively because adult females were more likely to be identified than adult males, therefore the expected numbers of adult males and females may have been biased in favour of females. Even so, the proportion of mating injuries inflicted

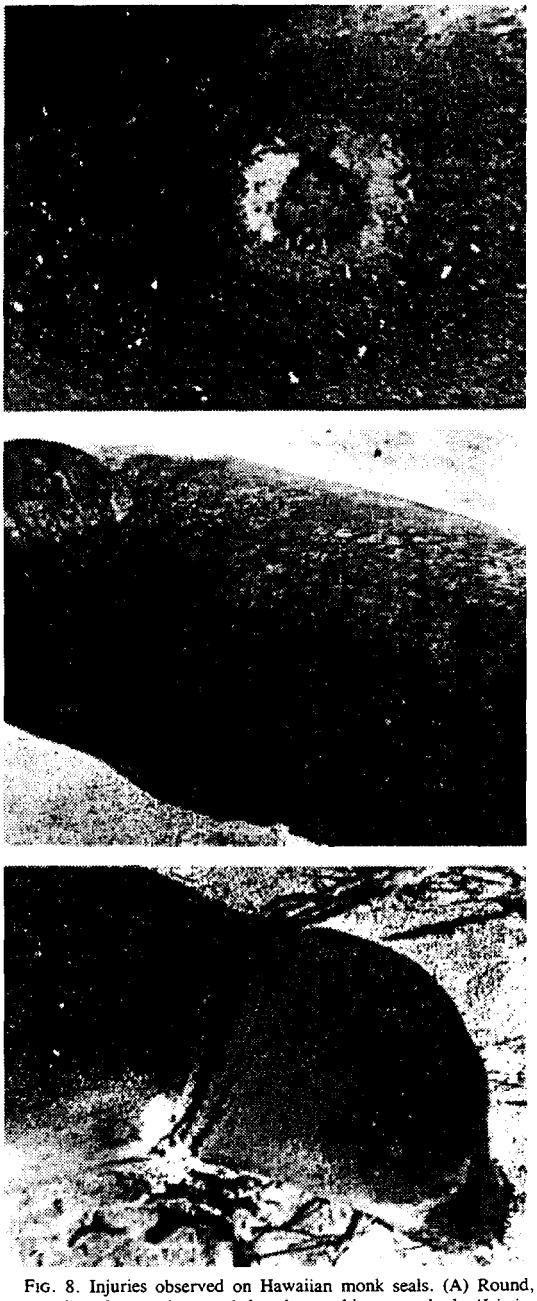

FIG. 8. Injuries observed on Hawaiian monk seals. (A) Round, crater-shaped wound caused by the cookiecutter shark (*Isistius brasiliensis*). (B) Parallel abrasions, close together, caused by contact with coral reef or debris. (C) Deep linear injury around neck of seal caused by a fishing net.

by adult males on adult and subadult females was much higher than on any of the other size classes (Fig. 6B).

Injuries inflicted by other seals during aggressive interactions

Seals inflicted abrasions and bite wounds on each other during jousting interactions, where two seals lunge at one another with open mouths and occasionally bite each other (Kenyon and Rice 1959) around the head, neck, and hind flippers. Injuries due to aggressive interactions accounted for 18.4% of injuries seen at Laysan Island but only 4.4% of injuries at FFS. Of 37 injuries of this type at Laysan Island, adult male seals were injured significantly more often than seals of other size and sex classes ($n = 27$; $G = 23.52$, df = 1, $p < 0.005$). At FFS, two of the three seal-inflicted injuries were sustained by adult males.

Injuries inflicted by large sharks

Injuries inflicted by large sharks included shallow punctures in the skin, deep lacerations, gaping wounds, and amputated limbs (Figs. 3C–3F). The characteristic crescent shape of these wounds reflected the shape of a shark's jaw (Figs. 3C, 3D). Large sharks inflicted 12.4% of injuries observed at Laysan Island and 27.9% of those seen at FFS (Fig. 4).

The number of injuries inflicted by large sharks observed (per 100 seals) at Laysan Island was highest from April through June (Fig. 5). At FFS over the same period, the rate of shark-inflicted injuries observed per 100 seals varied, but was lower than at Laysan Island in most years.

At Laysan Island, injuries inflicted by large sharks were observed significantly more often on adult seals than on subadults and juveniles ($G = 15.83$, df = 2, $p < 0.005$, Fig. 7A), and were observed significantly more frequently on adult males than on seals of other size classes ($G = 15.95$, df = 1, $p < 0.005$). At FFS, the distribution of large shark inflicted injuries was independent of size class ($G = 0.369$, df = 2, $p > 0.9$; Fig. 7B). Adult males did not sustain a significantly greater proportion of injuries than expected ($G = 1.67$, df = 1, $0.5 < p < 0.1$).

*Injuries inflicted by cookiecutter sharks (*Isistius brasiliensis*)*

Injuries inflicted by cookiecutter sharks included circular or semicircular cuts through the skin or round, open wounds 3–7 cm in diameter and 1–2 cm in depth, sometimes with a circular plug of skin and tissue attached to the edge of the wound (Fig. 8A). These injuries were seen with greater frequency at Laysan Island than at FFS (Fig. 4).

Injuries due to contact with coral reef or debris

A seal sustained abrasions, close together and parallel to each other (Fig. 8B), and single scratches when it scraped past a coral reef or sharp pieces of metal or glass debris. These injuries were minor and not observed frequently at FFS (Fig. 4).

Injuries due to entanglement in netting

Injuries caused by entanglement in netting or marine debris were deep, linear wounds, usually around the neck of the animal (Fig. 8C).

Other injuries and unknown causes

Injuries due to known but infrequently seen causes were classed as "other." Any injuries for which the cause was uncertain were classed as "unknown." At both Laysan Island

and FFS the proportion of injuries of unknown origin was high (20.9% at Laysan Island; 29.4% at FFS).

Discussion

Injuries inflicted by adult males during mating incidents

Mating injuries inflicted by adult males are likely to have a negative impact on the monk seal population because of their frequency (Fig. 4), severity (e.g., Figs. 2C, 3B), and occurrence mostly on female seals (Fig. 6; Hiruki *et al.*[2]). Although comparisons between Laysan Island and FFS should be interpreted cautiously, given the differences in frequency and methodology of seal counts at the two locations, the disparity in timing and rate of occurrence of adult male inflicted injuries is striking. Adult male inflicted injuries were observed earlier in the year and with 3–4 times greater incidence per 100 seals at Laysan Island than at FFS (Fig. 5). The higher frequency of such wounds at Laysan Island, combined with a small adult female population and increased female mortality due to injuries (Hiruki *et al.* 1993; Hiruki *et al.*[2]), suggest that wounding is likely to have a greater impact on the monk seal population at Laysan Island than on the population at FFS (Hiruki *et al.*[2]).

In other species, males also inflict injuries on females during courtship and mating, though the wounds may not be fatal. Male crabeater seals (*Lobodon carcinophagus*) usually bite the female on the neck while attempting to mount her (Siniff *et al.* 1979), resulting in considerable light wounding and superficial bleeding. Male southern elephant seals (*Mirounga leonina*) commonly inflict wounds on the female's neck during mating (McCann 1982). Male sea otters (*Enhydra lutris*) apparently infict wounds on the female during mating when the male takes a hold on the female's nose with his teeth (Foott 1970). Hatler (1972) found more serious wounds in a wild population of mink (*Mustela vison*) on Vancouver Island, where nearly every female mink observed during the mating season had extensive neck wounds.

Simultaneous pursuit of, and mating attempts with, a single female by many males, sometimes leading to injury or death of the female, is known in species other than the Hawaiian monk seal. Harassment of individual females by a group of males has been recorded for Australian sea lions (*Neophoca cinerea*; Marlow 1975) and southern sea lions (*Otario byronia*; Campagna and Le Boeuf 1988), where groups of subordinate males harass females as they arrive at or leave the breeding colony. Female northern elephant seals (*Mirounga angustirostris*), when harassed by groups of subordinate males, may sustain injuries serious enough to be fatal during mating (Le Boeuf and Mesnick 1990; Mesnick and Le Boeuf 1991). Groups of male manatees (*Trichechus manatus*) often pursue a single estrous female and attempt to copulate with her (Hartman 1979). Female dugongs (*Dugong dugon*) are frequently scarred by males attempting to mate with them (Anderson and Birtles 1978) and are sometimes mounted by several males until the female "appears very tired" (Preen 1989). A female mink can die from neck injuries that become enlarged when several males mate with her over a short period of time (Hatler 1972). In many species of waterfowl, forced extra-pair copulatory behaviour, in which one or several males pursue and attempt to mate with one female, has been widely documented (e.g., Titman and Lowther 1975; Bailey *et al.* 1978), and the female is occasionally killed during these incidents (McKinney *et al.* 1983). Female white-fronted bee-eaters (*Merops bullockoides*) are often chased by as many as 12 males during forced copulation attempts (Emlen and Wrege 1986). Female toads (*Bufo bufo*) and wood frogs (*Rana sylvatica*) involved in mating struggles in areas of high density may be drowned at the center of a ball of struggling males (Howard 1980; Arak 1983). Thus, the phenomenon of severe injuries inflicted on females by many males during the mating season is not unique to Hawaiian monk seals but is nevertheless important if the number of female seals is reduced as a result of mortality caused by these wounds, such as in the monk seal population at Laysan Island (Hiruki *et al.* 1993; Hiruki *et al.*, see footnote 2).

Injuries inflicted by seals during aggressive interactions

The higher rate of injuries inflicted by seals during jousts or aggressive interactions at Laysan Island during 1988 and 1989 (Fig. 4) may indicate a higher level of intrasexual competition and aggressive behaviour between males at Laysan Island than at FFS. Males of many species often wound each other when competing for females (e.g., Weddell seals, *Leptonychotes weddelli*: Smith 1966; northern elephant seals: Le Boeuf 1974; Cox 1981; crabeater seals: Siniff *et al.* 1979; red deer, *Cervus elaphus*: Clutton-Brock *et al.* 1979; mule deer, *Odocoileus hemionus*, and white-tailed deer, *O. virginianus*: Geist 1986). In the context of males competing for females, other factors that may promote a higher level of aggressive behaviour at Laysan Island include its smaller size in comparison with FFS (Fig. 1), and the adult sex ratio at Laysan Island, which is skewed towards males. Deutsch (1985) found that Hawaiian monk seal males compete in two ways, as defined by Barash (1978): scramble competition, where a male searches for receptive females, and contest competition, where a male defends a female against intruding males. At Laysan Island, the distance a male must travel to find a receptive female is less than at FFS, suggesting that males at Laysan Island encounter receptive females, or males defending females, more frequently than at FFS. In addition, the greater number of males per female in the adult population at Laysan Island than at FFS implies that there are more contests between males for each female at Laysan Island. Thus, male monk seals at Laysan Island appear more likely than males at FFS to be involved in contests and aggressive interactions.

Injuries inflicted by large sharks

Of the sharks commonly seen in the northwestern Hawaiian Islands (NWHI), tiger sharks (*Galeocerdo cuvier*) have the most potential to affect the monk seal population, as they are known to attack and eat monk seals (Taylor and Naftel 1978; Balazs and Whittow 1979; Alcorn and Kam 1986; B. L. Becker and L. M. Hiruki, personal observations). Hammerhead sharks (*Sphyrna lewini*) and mako sharks (*Isurus paucus*) have also been observed in the NWHI (Rice 1960), but there is no evidence that they attack monk seals. Although gray reef sharks (*Carcharhinus amblyrhynchos*) have not been observed to attack monk seals, they may be present when tiger sharks attack monk seals (Alcorn and Kam 1986).

[2]L. M. Hiruki, I. Stirling, W. G. Gilmartin, B. L. Becker, and T. C. Johanos. Effects of wounding on monk seal (*Monachus schauinslandi*) population dynamics. Manuscript in preparation.

At Laysan Island, the larger proportion of injuries inflicted by sharks on adult monk seals than on seals of other size classes (Fig. 7A) may indicate either that juveniles are not injured by large sharks or, more likely, that juveniles are less likely to survive attacks by large sharks. Immature seals are generally considered to be more vulnerable to shark attack than adult seals (Le Boeuf *et al.* 1982; Brodie and Beck 1983; Ainley *et al.* 1985), perhaps because their lack of experience or smaller size makes them easier prey for sharks (Ainley *et al.* 1985). Both juvenile gray seals (*Halichoeurus grypus*; Brodie and Beck 1983) and juvenile bottlenose dolphins (*Tursiops truncatus*; Cockcroft *et al.* 1989) are relatively free of the scars typical of shark attacks, suggesting that they rarely escape when attacked by sharks. The predominance of young dolphin remains in shark stomachs also indicates that juveniles may be more vulnerable to shark attack than seals of other size classes (Cockcroft *et al.* 1989). If juvenile monk seals are less likely than adults to survive a shark attack, the effect of shark predation on juvenile seals may be greater than is indicated in Fig. 7.

Among adult seals, injuries inflicted by large sharks were observed more often on males than on females. Most of the injuries inflicted by large sharks were observed in April and May (Fig. 5), coinciding with the peak of the pupping season (Kenyon and Rice 1959; Kenyon 1981); however, as our observations did not extend past August, we have no data on the frequency of shark-inflicted injuries outside the pupping season. Nursing females stay on land or in shallow water until their pups are weaned (Kenyon and Rice 1959). During the same period, adult males spend most of their time in the water patrolling the shore and searching for receptive females. Thus, adult males may be more vulnerable than adult females to injury from sharks during the pupping season.

The decrease in the rate of wounding by sharks at both Laysan Island and FFS in June and July (Fig. 5) may have been due to tiger sharks shifting their focus to albatross chicks (*Diomedia* spp.). Tiger sharks begin to swim near the shore of several islands in the NWHI in mid-June, apparently to prey on albatross fledglings as they land in the water to rest between flights (Rice 1960; Johnson and Johnson 1981; W. R. Strong, personal communication). The seasonal predation on albatross chicks by tiger sharks in the NWHI may thus influence the frequency of shark attacks on monk seals (Rice 1960; Fisher 1975; W. R. Strong, personal communication).

Injuries inflicted by cookiecutter sharks

The cookiecutter shark is a small squaloid shark, 14–50 cm long, that inhabits the deep (85–3500 m) water of tropical and subtropical areas of the Atlantic, Pacific, and Indian oceans (Castro 1983; Compagno 1984). Jones (1971) speculated that the bioluminescent pattern of the cookiecutter shark mimics that of a squid, and in doing so attracts squidophagous predators. Le Boeuf *et al.* (1987) view this as a likely explanation of how the cookiecutter shark attacks northern elephant seals. It is probable that Hawaiian monk seals are attacked in a similar way while feeding.

Interactions between wounding by adult male monk seals and by sharks

At Laysan Island the rates of wounding by both adult male seals and large sharks were relatively high in April and May (Fig. 5). The overlap in peak periods of adult male inflicted mating injuries in shark-inflicted injuries may be related: body fluids leaching from a seal's injuries probably attract sharks, or a wounded seal may be less vigilant and less mobile in the water, both of which could increase its vulnerability to shark attack. Further, activity in the water can attract sharks; tiger sharks have been seen patrolling underneath aquatic mobbing incidents (Johanos and Austin 1988) and have subsequently attacked injured female seals (Alcorn and Kam 1986) as well as males involved in mobbing incidents (Johanos and Austin 1988). The combination of wounding by adult male monk seals and by sharks may thus increase the mortality rate for seals.

At FFS, the peak period of adult male inflicted injuries (June–July) did not overlap with the peak period of shark-inflicted injuries (April–May). This may indicate that sharks have less opportunity at FFS than at Laysan Island to attack seals involved in mobbing incidents. Alternatively, large sharks may be present at FFS later in the year, when fewer mating injuries occur, or their attacks upon injured seals at FFS may be rarely documented.

Of the six types of injuries observed on Hawaiian monk seals, those with the most potential to affect the population are caused by adult male monk seals during mating attempts and by large sharks. Adult male inflicted mating injuries were seen more often than other types of injuries and were inflicted mostly on females; shark-inflicted injuries may increase the mortality rate for such injured females. These two types of injuries are significant to the extent that they could negatively affect female survival and productivity, both of which are critical to population growth (Eberhardt 1985) of this endangered species.

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