

# HAWAIIAN MONK SEAL (*Monachus schauinslandi*): STATUS AND CONSERVATION ISSUES

BY

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## ABSTRACT

The authors detail pertinent information on the history, current status, and conservation of the endangered Hawaiian monk seal (*Monachus schauinslandi*). The present population is estimated at about 1,200 to 1,300 seals, a decrease of 60% since the 1950s. Counts declined about 5%/yr from 1985 to 1993, remained relatively stable through the year 2000, and then declined again from 2001 to 2003. Population trends have been variable at the six main reproductive subpopulations in the Northwestern Hawaiian Islands (NWHI). Over the last few decades, pup production has averaged about 200, but overall juvenile survival has declined at most sites. The largest subpopulation is at French Frigate Shoals, where counts have dropped by 60% since 1989 and the age distribution has become severely inverted as a result of high juvenile mortality over the last decade. Overall demographic trends and parameters suggest that the total population will likely continue to decline, at least in the short term. Monk seals appear throughout the Hawaiian Archipelago, and although most are found in the NWHI, a small but increasing number haul out and pup in the Main Hawaiian Islands (MHI). Monk seals typically use isolated beaches for resting, molting, parturition, and nursing offspring; and forage on demersal and epibenthic prey. Past and present sources of anthropogenic impacts to monk seals include hunting (during 1800s and early 1900s), disturbance (e.g., prior military activities beginning in WWII), entanglement in marine debris, and fishery interactions. Primary natural factors affecting monk seal recovery include predation by sharks, aggression by adult male monk seals, and reduction of habitat and prey associated with environmental change. Identification and mitigation of these and other possible factors (e.g., disease) limiting population growth represent ongoing challenges and are the primary objectives of the Hawaiian monk seal conservation and recovery effort.

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## OVERVIEW

### Early History

Although it is not clear when monk seals first reached the Hawaiian Archipelago (Repenning and Ray, 1977), archeological research indicates that Hawaiian monk seals were present in the Main Hawaiian Islands (MHI) prior to European contact at about 1400-1760 AD (Rosendahl, 1994). Several primitive monk-seal skeletal characteristics (Ray, 1976; Barnes et al., 1985) indicate that their early ancestors may have been present 14-15 million years ago (mya) (Repenning et al., 1979), and mitochondrial and nuclear DNA studies show the species first split from its *Monachinae* ancestors between 11.8-13.8 mya (Fyler et al., in press).

The natural history of the monk seal is inextricably linked to the biogeographic setting of the Northwestern Hawaiian Islands (NWHI). The monk seal population may be characterized as a classic metapopulation (Hanski and Gilpin, 1991), with semi-isolated subpopulations distributed along the chain. The historic distribution and abundance of the species are unknown, but we can surmise that early monk seals resided in an environment quite different from today's Archipelago, and it may have been capable of supporting many more monk seals than exist today. The extant islands and atolls that comprise the Archipelago range in age from 7.5 to 30 million years old (MacDonald et al., 1983), and many have undergone major changes during the time of monk seal habitation. Some islands have subsided to form seamounts, some have become remnants of their former mass, and some new landmasses have emerged. As these geologic changes have occurred, the monk seal population has undoubtedly also fluctuated in numbers and distribution.

### Range

Monk seals are found throughout the NWHI including the population's six main reproductive sites: Kure Atoll (KUR); Midway Atoll (MID); Pearl and Hermes Reef (PHR); Lisianski Island (LIS); Laysan Island (LAY); and French Frigate Shoals (FFS). Small numbers also occur on Necker and Nihoa Islands, where a few pups are born each year, and monk seals have been observed at Gardner Pinnacles and Maro Reef. Although most monk seals can be found in the NWHI, monk seals are also found throughout the Main Hawaiian Islands (MHI), where documented births and sightings suggest that numbers are increasing (Baker and Johanos, 2004). Monk seals are observed occasionally at Johnston Atoll, and one birth was reported there in 1969.

## LIFE HISTORY AND HABITAT USE

### Terrestrial Habitat

Haul-out areas for parturition, nursing, molting, and resting are primarily sandy beaches, but virtually all substrates, including emergent reefs, are used. If available, monk seals also use the vegetation behind the beaches as a shelter from solar radiation, high surf, wind, or rain; for resting at night; and possibly to avoid disturbance from other seals.

Parturition has been observed in diverse settings and substrates; but on each atoll, certain beaches are preferred for pupping. These areas, typically sandy beaches with protective reef that limit shark access and provide shelter from large surf (Westlake and Gilmartin, 1990), are often shared by multiple females, with some individuals pupping in the same locale each year. Other females seem to favor more isolated beaches where disturbance from other mother-pup pairs is less likely. Births can occur year round but are most common from February through August, with peak parturition in March and April (Johnson and Johnson, 1980; Johanos et al., 1994). Females give birth to a single offspring and remain on shore with their pup for about 6 weeks. Weaning occurs when the mother abandons her pup and returns to the sea to feed. She will mate about 3-4 weeks after weaning her pup, and will haul out again for 10-14 days or more to molt about 5-6 weeks later. Nonparturient adult females usually molt about a month earlier than parturient females (Johanos et al., 1994).

### Marine Habitat

Monk seals' primary habitat is the marine environment, where they spend approximately two-thirds of their time (National Marine Fisheries Service (NMFS), unpublished data). In general, monk seal aquatic behaviors include thermoregulatory cooling, resting, playing, mating, and foraging. Mating behavior is aquatic and rarely witnessed, occurring 5 m to 1 km or more from shore when observed (Johnson and Johnson, 1981; Shallenberger, personal communication). Video camera deployments on adult male monk seals have indicated that while in the water seals spend 34% of their time resting, 9% interacting socially, and 57% of their time foraging and traveling (Parrish et al., 2000).

Most foraging occurs near the sea floor (Goodman-Lowe et al., 1998), where they search for food on substrate composed of talus and sand on marine terraces of atolls (Parrish et al., 2000, 2002, 2005). Monk seal feeding has been observed in reef caves that also appear to be used for resting and refuge from predators (Taylor and Naftel, 1978). Parrish et al. (2002) reported that monk seals forage in or near precious coral beds at subphotic zones at depths below 300 m.

Monk seals forage on a wide variety of prey species that are usually found in benthic and demersal habitats (Rice, 1964; MacDonald, 1982; Goodman-Lowe, 1998; Parrish et al., 2000). Through the analysis of identifiable hard parts found in regurgitate and fecal material, Goodman-Lowe (1998) reported that fishes appeared most frequently

(78.6%), followed by cephalopods (15.7%), and crustaceans (5.7%). Out of 31 different families, Labridae, Holocentridae, Balistidae, and Scaridae were the most commonly identified. Cephalopod prey included 7 species of octopus and 19 species of squid. Some prey species are not represented accurately from scat analysis (e.g., lobster) because of differential digestion and passages of identifiable hard parts (Goodman-Lowe et al., 1999), and other methods (including fatty acid analysis) are currently being evaluated to investigate monk seal diet.

Monk seal movement and diving patterns were characterized by deploying satellite-linked radio transmitters on 147 seals (42 adult males, 35 adult females, 29 juvenile males, 14 juvenile females, 12 weaned male pups, 15 weaned female pups) at the six breeding colonies in the NWHI (Abernathy and Siniff, 1998; Stewart 2004a,b; Stewart and Yochem, 2004a,b,c). Data from these deployments indicated that monk seals foraged extensively around the fringing atoll lagoons and outer slopes at FFS, PHR, MID, and KUR, and seaward of LAY and LIS. Locations obtained along the submarine ridges between those atolls and islands, and at virtually all nearby seamounts, suggested that those areas were also used for foraging. Dives of 150 m or less were most common, but secondary diving modes were registered at various depths (though rarely exceeding 500 m.). Individual seals displayed unique patterns in dive depths, distance traveled, and apparent foraging locations, with some of the variability perhaps owing to sex and age of seals. Foraging ranges of instrumented seals varied from less than 1 km up to 322 km (Abernathy, 1999; Stewart, 2004a,b; Stewart and Yochem, 2004a,b,c).

Another technology that has provided valuable insights into monk seal foraging ecology is the CRITTERCAM. Parrish et al. (2000) attached these devices to 24 adult and subadult male monk seals at FFS to learn more about the habitat depth and substrate at locations where monk seals captured prey items. They found that most diurnal foraging of adult males occurred at the 60-m isobath.

More recently, CRITTERCAMs were used to characterize juvenile monk seal habitat use and foraging behavior at FFS. Footage from that research indicated juvenile seals foraged in the same habitats commonly used by adults, but they may have lacked the size and strength to forage as successfully as their adult counterparts (Parrish et al., 2005). The dive patterns of 13 weaned pups, instrumented with time-depth recorders (TDRs) at FFS in 1999 and 2000, indicated that most dives occurred at depths less than 200 m, but occasionally exceeded 200 m. As with other size classes of seals, there was substantial variability among the pups in depth, duration, and temporal patterns of dives (NMFS, unpublished data).

## **ABUNDANCE AND POPULATION TRENDS**

Most of the data used to estimate population size and composition, demographic rates, migration rates, and other key aspects of the monk seal's life history are derived from annual resightings of permanently identified seals. Individual seals may be permanently identified either by natural markings (primarily scars and distinctive pelage patterns) or by tags (Harting et al., 2004). In the NWHI, flipper tags have been routinely applied to weaned pups since the early 1980s. These "cohort-tagged"

seals are particularly important for estimating vital rates because their age is known. Survival rates are estimated for all six NWHI subpopulations using standard Jolly-Seber methodology (Seber, 1982, as described in Craig and Ragen, 1999 and Harting, 2002). Reproductive rates are estimated for those sites where field effort is of sufficient duration to observe most births or nursing pairs.

### Population Size and Trend

Table 1 shows minimum estimates of abundance at the six main reproductive sites in the NWHI. In some cases, these likely represent total enumeration, although at those sites with shorter field seasons, estimated probabilities that known-aged seals are identified during a given field season suggest that certain age groups could be underestimated by as much as 10-20% (Harting, 2002). Efforts are underway to more precisely determine abundance of NWHI monk seals (e.g., Baker, 2004). The best estimate of the population size in the year 2003 is 1,244 seals (Carretta et al., 2004), but their total numbers likely range between 1,200 and 1,300 individuals. These data can also be used to determine a minimum population estimate ( $N_{\min}$ ) for the total population that accounts for the statistical uncertainty in the abundance estimates, as is done for Stock Assessment Reports required by the Marine Mammal Protection Act (Wade and Angliss, 1997). Using that procedure, the minimum population size for the main reproductive islands is equal to the best estimate of the minimum population size at those sites. The minimum population size for the total population is the sum of these estimates (Table 1).

Direct enumeration provides the most reliable estimate of population size for recent years but cannot be used for characterizing long-term historical trends because the current level of field effort in the NWHI was initiated only within the last two decades (varying by site). Instead, long-term population trends can be inferred from the results of range-wide beach count<sup>1</sup> surveys that began in the 1950s. Although the methods for the earliest counts were not standardized, complete beach counts are approximately comparable.

The historic timeline of range-wide beach count surveys begins in the late 1950s (Kenyon and Rice, 1959; Rice, 1960), with additional counts conducted at MID in 1956-1958 (Rice, 1960), at KUR in 1963-1965 (Wirtz, 1968), and elsewhere throughout the 1960s and 1970s. Data from these surveys suggest that the species declined by about 50 percent between the late 1950s and the mid-1970s (Kenyon, 1973; Johnson et al., 1982). If only non-pups are included (juveniles, subadults and adults), the population declined by approximately 60% from 1958 to 2001 (Fig. 1).

In more recent years, standardized beach counts suggest that the nonpup population declined rapidly from 1985 to 1993, prior to becoming relatively stable (Fig. 2). A broken-line regression (two regression lines joined at a break point optimized to minimize the sum-of-squares error) fitted to the 1985-2003 data (Carretta et al., 2004)

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<sup>1</sup>A beach count consists of a complete enumeration of all the seals present on all accessible beaches. Beginning in 1983, standardized protocols were established for conducting these counts, which typically number eight or more per season and include all islets within an atoll. The mean number of seals observed on all beach counts in a season is used to assess long-term trends.

estimates that the total counts declined 4.2% per year until 1993, and then declined by 1.9% per year thereafter (95% CI = - 3.0% to - 0.9% per year).

Combining the count data for all of the main NWHI sites (Figs. 1 and 2) conceals the diversity of trends in the individual subpopulations (Fig. 3). There has been considerable variability in the population dynamics at the different locations, with the current demographics of each site probably reflecting a combination of different histories of human disturbance and management (Gerrodette and Gilmartin, 1990; Ragen and Lavigne, 1999), and varying environmental conditions (Polovina et al., 1994; Craig and Ragen, 1999). Although the population decline since 1958 was common to most subpopulations, the degree and duration of that long-term decline, as well as the trend in more recent years, has differed among the sites. The pattern at FFS was unlike that of the other atolls: this subpopulation grew rapidly from the early 1960s to the late 1980s, and then collapsed, with nonpup beach counts declining by 70% during 1989-2001. While LAY and LIS have remained relatively stable since approximately 1990, LAY has tended to increase slightly while LIS has decreased slowly. The three westernmost atolls (KUR, PHR, and MID) all experienced a period of recent growth. The subpopulation at KUR grew at an average rate of 5% per year after 1983, largely as a result of decreased human disturbance, increased survival of young seals, and the introduction of rehabilitated female juveniles. Similarly, the subpopulation at PHR increased at approximately 7% per year during 1983-1999, an annual growth rate that is regarded as the best indicator of the maximum net productivity rate ( $R_{max}$ ) for this species (Carretta et al., 2004). The intensive military presence at MID rendered this atoll largely unavailable to monk seals until relatively recently. Aided by protective management policies and immigration from PHR and KUR, the small MID seal population has increased since 1990. Population growth at these three sites has declined in recent years primarily because of decreased juvenile survival (see Juvenile Survival Rates section).

Because of inaccessibility, systematic enumeration and regular population monitoring has not been possible for Necker and Nihoa Islands. Data from a limited number of brief monitoring efforts indicate that seal counts at those islands tended to increase from approximately the year 1970 to 1990. The observed increase may have been a result of an influx of seals from FFS, which was growing during that same period. In 1993, 14 tagged seals marked as pups at FFS were sighted at Necker Island during a 7-day period (Finn and Rice, 1994). Twelve tagged seals were also sighted at Nihoa Island during the same period, including 10 tagged at FFS (Ragen and Finn, 1996).

Systematic surveys of monk seals were not conducted prior to 2000, so historical abundance data for the MHI are limited. However, the monk seal population in the MHI appears to have increased during the 1990s. One indication of a growing population is the increased number of observed births in the MHI. Prior to and during the 1990s, the number of births observed annually in the MHI was usually zero and never exceeded four. In contrast, beginning in 2000, monk seal births observed in the MHI became more frequent, with 7, 12, 4, and 10 births recorded in 2000, 2001, 2002, and 2003, respectively (Baker and Johanos, 2004; NMFS, unpublished data).

## Reproductive Rates

Pup production varies by island and year, but over the last two decades, approximately 200 Hawaiian monk seal pups have been born annually system-wide. Reproductive data are most complete at LAY and LIS where field observations typically encompass the entire birthing season. At these sites, an average 68% of known reproductively mature females pup each year (Johanos et al., 1994).

Monk seal females usually give birth for the first time between the ages of 5 and 10. Fitted reproductive parameters indicate substantial variability among the three subpopulations having sufficient data to estimate age-specific fecundity (FFS, LAY, and LIS). Maturation occurs approximately 1-4 years earlier at LAY than at the other two sites. In pinnipeds, the onset of sexual maturity usually coincides with the attainment of some percentage of final body size (Laws, 1956), suggesting that the observed delay at both FFS and LIS may be indicative of poorer nutritional conditions for immature seals at these sites. The smaller weaning sizes observed at both of those sites (Craig and Ragen, 1999; NMFS, unpublished data) is consistent with that theory. The maximum fecundity attained by mature females at LAY is also higher than at the other sites (Fig. 4). Sample sizes for older females (ages 15 and older) are very small, but the data indicate a senescent decline in fecundity beginning somewhere between 10 and 15 years at both LAY and FFS (Fig. 4). That pattern is not yet evident at LIS. Data are not sufficient to fit age-specific reproductive schedules for the other three subpopulations (PHR, MID, and KUR); however, based on the number and age of females at those sites and the total number of pups produced, it appears that fecundity is somewhat lower than at LAY but probably not as low as at FFS.

Less is known about sexual development in males, but their size and behavior suggest that they reach maturity at approximately the same age as females. Copulation is rarely observed, and hence the reproductive success of individual males is difficult to evaluate without detailed genetic analysis of the population. Limited observations indicate that males mount the female by biting her back and grasping her sides with their foreflippers. Females are often observed with bite marks and other wounds on the dorsum, providing evidence of possible mating. These injuries are observed most frequently around 26 days after the female has weaned a pup (Johanos et al., 1994).

## Juvenile Survival Rates

Juvenile survival is a key component of monk seal demography, because of its vital role in determining the trajectory for each subpopulation. Like many other pinnipeds, the ability to make the transition successfully from weaning to nutritional self-sufficiency represents a critical stage in their early survival (e.g., Bowen, 1991). Although there is considerable annual variability in survival rates, all six major breeding subpopulations have experienced conspicuous declines in juvenile survival and recruitment in the last 10 years (Fig. 5). The factors underlying this variability are not known with certainty, but there is some evidence that El Niño events or other oceanographic phenomena may influence juvenile survival (Polovina et al., 1994,

Antonelis et al., 2003). With an intrinsic growth rate of less than 1.0 at all sites except LAY in recent years (NMFS, unpublished data), the demographic rates must improve, or most subpopulations are likely to continue declining.

An imbalance in the age/sex structure of some subpopulations is another aspect of monk seal demography that is a cause of concern. A succession of poor cohort survival at some sites (especially at FFS, and, more recently, in the three westernmost sites) has led to a pronounced age structure imbalance in which young adult seals are severely under-represented (Fig. 6). At FFS, the paucity of young seals means that there will be few new females reaching reproductive maturity in coming years, so that annual pup production is expected to drop, and the subpopulation will continue its downward trend.

## **PROTECTIVE LEGISLATION**

In 1909, President Theodore Roosevelt created the Hawaiian Islands Reservation that included all islands of the NWHI except Midway. The Reservation was later renamed the Hawaiian Islands National Wildlife Refuge (HINWR), and as a Federal Refuge, was placed within the jurisdiction of the U.S. Fish and Wildlife Service (USFWS). In 1952, KUR was given to the State of Hawaii and was designated a State Wildlife Refuge. A rapid decline in beach counts of monk seals from the late 1950s to the mid-1970s led to the Hawaiian monk seal's designation as "depleted" under the Marine Mammal Protection Act (MMPA), and as "endangered" under the Endangered Species Act (ESA) in 1976. In 1980, the NMFS initiated efforts to define critical habitat for monk seals through an environmental impact statement (EIS), and by 1986, critical habitat designation was assigned from haul-out beaches out to the 20-fathom isobath around KUR, MID (except Sand Island), PHR, LIS, LAY, Maro Reef, Gardner Pinnacles, FFS, Necker Island and Nihoa Islands. In 2000, the waters from 3 to 50 nm around the NWHI were designated the NWHI Coral Reef Ecosystem Reserve by Presidential Executive Order 13178, which provides specific restrictions on human activities permitted within the Reserve.

## **CONSERVATION AND EFFORTS TO ENHANCE POPULATION GROWTH**

### **Food Limitation**

Recent survival trends (observed to varying degrees at several of the NWHI monk seal subpopulations) indicate that food limitation may be playing a primary role in regulating population growth. Food limitation was first associated with poor juvenile survival at FFS during the early 1990s (Craig and Ragen, 1999). Subsequently, range-wide decreases in juvenile survival have occurred in early 2000 along with relatively low age-specific reproductive rates (including delayed maturity) at FFS and LIS. The conclusion that food limitation is having a significant influence on population decline is reinforced by indications of relatively poor body condition in various juvenile age

classes. Further, although the cause of a die-off of about 11 seals throughout the NWHI in 2001 was not determined, necropsies of six carcasses indicated emaciation with no evidence of disease (Antonelis et al., 2001). Subsequent juvenile survival has remained low at most sites (see survival section), and oceanographic changes resulting in low productivity have been postulated as a potential overriding factor.

NMFS initiated two capture-and-release programs in the 1980s, that were designed to increase female recruitment in the then-depleted KUR monk seal population. The Head Start Project (1981-1991) involved the capture and protection of weaned female pups from KUR during the transition phase from weaning to independent feeding. Recognizing that food limitation was most likely limiting juvenile survival at FFS, NMFS also initiated the Rehabilitation Project in 1984. From 1984 to 1995, undersized, weaned female pups from FFS were brought into captivity for 8-10 months on Oahu to increase weight and released back into the wild at either KUR (all years except 1992) or MID (1992), where they had a higher probability of survival. In some years, undersized juvenile females were also collected at FFS, brought into captivity on Oahu for varying amounts of time, and released at either KUR or MID. Of the 104 immature monk seal pups that were handled for the head-start or rehabilitation programs, 68 were released into the wild and another 22 died in captivity (NMFS, unpublished data). The survival prospects of 14 of the handled seals were deemed insufficient for release, and they were therefore transferred into public aquaria and oceanaria for research.

### Fishery Interactions

Fisheries can potentially interact with monk seals in multiple ways that may be broadly classified into two categories: direct and indirect interactions. Under direct interactions, seals become hooked or entangled in active fishing gear, feed on fishing refuse, remove bait or catch from fishing lines, or become entangled in derelict fishing gear. Indirect interactions are those which operate through fishery impacts on monk seal prey or habitat. No indirect interactions have yet been documented; however, some prey species (e.g., lobster) have been commercially fished. The diet and foraging habits of monk seals are being carefully evaluated and monitored to determine the importance of such species to monk seals and better assess the nature and magnitude of indirect interactions. In contrast, some examples of direct interactions are known. Direct interactions were documented between the Hawaii-based longline fishery and monk seals in the late 1980s and early 1990s (Lavigne, 1999), and in most cases the interactions involved serious injuries to seals. Direct but rare interactions have also been reported for the bottomfish fishery and the lobster fishery (presently closed) operating in the NWHI. Based on data collected by observers in 1990-1992 from bottomfish vessels fishing around Nihoa Island and Kaula Island, Nitta and Henderson (1993) estimated that monk seals removed bottomfish from fishing lines at a rate of one interaction event per 34.4 hours of fishing. The observers did not record any interactions involving hooking or entanglement. More recently, from October 2003 through the end of June 2004, fishery observers were placed on bottomfish vessels and, having completed 10 bottomfish cruises to date, no monk seal interactions have been observed (NMFS Pacific Islands Regional

Office, Bottomfish Quarterly Status Reports). The recent lack of interaction in this fishery is probably a result of modification in fishing techniques voluntarily initiated by the fishers.

During the last few years, an increasing number of monk seal hookings have occurred in the MHI, apparently associated with state-regulated, shore-based recreational fisheries. These MHI incidents probably represent less of a threat to monk seals than had they occurred in the NWHI, because of the greater opportunity for detection and successful intervention (dehookings) in the MHI. The nearshore gillnet recreational and commercial fisheries in the MHI are also known to interact with monk seals. Since 1982, only one monk seal was found dead in a gillnet associated with these fisheries (NMFS, unpublished data).

In 1991, NMFS and the Western Pacific Regional Fishery Management Council established a permanent Protected Species Zone (PSZ) to reduce the probability of direct interaction between the Hawaii-based longline fishery and monk seals. The PSZ extends 50 nm around the NWHI and the corridors between the islands, and all longline fishing was prohibited in the Zone. No interactions with the longline fishery have been documented since establishment of the PSZ.

Several studies have shown overlap between the foraging habitat of some monk seals and certain types of deep-water precious corals (Abernathy and Siniff, 1998, Parrish et al., 2002). Thus, removal of corals from these habitats could affect monk seals indirectly if the abundance of coral-associated seal prey was reduced. President Clinton's Executive Order 13178 established the NWHI Coral Reef Ecosystem Reserve which precludes precious coral harvest within 50 nmi of the NWHI.

### Male Aggression

Single- and multiple-male aggressions that severely injure or kill adult females and immature seals have been recorded since the 1970s (e.g., Johnson and Johnson, 1981; Alcorn and Henderson, 1984; Johanos and Austin, 1988; Hiruki et al., 1993). Although evidence of male aggression has been observed at all major breeding sites, the intensity of the problem varies by location and year.

From 1984-1994, a total of 37 adult males were captured on Laysan and either transported to Johnston Atoll or the MHI, or brought into permanent captivity in an effort to balance the sex ratio and reduce multiple-male aggression. At French Frigate Shoals, three individual adult males were observed repeatedly attacking and killing pups; one male was euthanized in 1991 (Craig et al., 1994), and two males were captured and relocated to Johnston Atoll in 1998 (Craig et al., 2000). None of the relocated males have returned to their site of capture. Such actions have successfully reduced deaths as a result of male aggression and will be continued in the future, as necessary.

## Entanglement in Marine Debris

Monk-seal entanglement in marine debris continues to affect monk seals despite international law prohibiting the intentional discard of debris from ships at sea (MARPOL<sup>1</sup>, Henderson, 2001). Monk seals have one of the highest documented rates of entanglement of any pinniped species (Henderson, 1984, 1985, 1990, 2001). The number of annual entanglements has varied over the last 21 years, but, to date, a peak in the number of entanglements occurred in 1999, when 25 incidents were reported (Henderson, 2001). The sources of debris come from fisheries and other maritime activities around the Pacific Rim (Donohue et al., 2001), and current studies indicate there is no sign of this problem abating in the future (Boland and Donohue, 2003).

Since the inception of the NMFS Marine Mammal Research Program (MMRP) beach debris removal program in 1982, the incidence of entangled monk seals at breeding sites of the NWHI has been well documented, and the field staff has actively worked to disentangle seals and remove potential entangling debris from haul-out beaches. From 1982 to 2003, a total of 238 monk seals were disentangled from marine debris.

In 1996, the severity of the problem was quickly discovered, and a large-scale, multi-agency cleanup effort was initiated in 1998. In 1999, the Coral Reef Ecosystem Division of the NMFS Pacific Islands Fisheries Science Center (PIFSC) was designated to lead the cleanup effort. Currently, approximately 440 metric tons of potentially entangling marine debris have been removed from the coral reefs and beaches of the NWHI (Boland et al., 2006). In addition to the cleanup efforts, national and international agreements are needed to stop the generation of debris in the marine environment.

## Shark Predation

Most mature monk seals are scarred from earlier encounters with sharks, and shark predation has been directly witnessed on several occasions (Bertilsson-Friedman, 2002; Wirtz, 1968; Taylor and Naftel, 1978; Balazs and Whittow, 1979; Johanos and Kam, 1986; Alcorn and Kam, 1986). Prior to the late 1990s, shark predation was thought to be a relatively minor component of the overall mortality, with most predation incidents assumed to be from tiger sharks.

Beginning in the late 1990s, there was a significant increase in shark predation on monk seal pups prior to or near the time of weaning at FFS. Initially, the problem was detected only at the Trig/Whaleskate Island complex, where from 1997 to 1999, 18-28 pups were apparently killed each year by Galapagos sharks patrolling the shoreline<sup>2</sup>. Since that time, the number of apparent mortalities at Trig has declined to three to nine pups each year, but the incidence of shark attacks and mortalities of pups prior to or near

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<sup>1</sup>The MARPOL Convention is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. It is a combination of two treaties adopted in 1973 and 1978, respectively, and updated by amendments through the years.

<sup>2</sup>Many of the mortalities attributed to shark predation are not directly observed but are inferred based on the disappearance of a pup, plus the presence of patrolling sharks and/or the absence of any other compromising survival factor.

the time of weaning at other sites in the atoll has increased. From 2000-2003, the proportion of pups born at FFS believed to be attacked by sharks (including confirmed attacks and mortalities and inferred disappearances) has ranged from 18 to 30% of the annual cohort. It is suspected that the high predation rate is an unusual behavior involving a limited (possibly small) number of Galapagos sharks at FFS. The conspicuous lack of Galapagos shark predation on monk seal pups at the other five breeding sites is consistent with this view.

Although nonlethal shark deterrents were preferable to lethal removal, attempts to haze sharks away from pupping beaches in 2000-2001 proved unsuccessful and made sharks wary and more difficult to catch. During those same years, six Galapagos sharks were removed using hook and line and harpoon, and another four sharks were removed in 2002-2003. These efforts have greatly enhanced pup survival at Trig Island (within FFS), by reducing the number taken by sharks (including both confirmed and inferred losses) from 28 to 3 in 1997 and 2003, respectively. To further enhance post-weaning survival, pups were relocated from Trig Island to other sites in the atoll (e.g., Gin Island) where little or no shark predatory behavior had been previously observed. Beginning in 2003, Galapagos shark predation on preweaned pups was detected at several other islets in the atoll, indicating that mitigation efforts should be expanded to include those sites. The objective of the subsequent expanded program was to reduce the likelihood of this shark behavior spreading to other sites at FFS and possibly throughout the Archipelago. To date, mitigation efforts to reduce Galapagos shark predation on pups prior to and near the time of weaning have reduced the total estimated shark predation at FFS from 31 in 1997 to 11 in 2003.

#### Human Disturbance

Monk seals avoid beaches where they are often disturbed, and the consequence of disturbance ultimately equates to a reduction of available habitat and population size (Kenyon, 1972; Gerrodette and Gilmartin, 1990). Chronic disturbance may cause seals to abandon haul-out sites and preferred sites for parturition. Such behavior may lead to increased vulnerability to shark predation, especially for recently weaned or preweaned pups (Ragen, 1999). Although the closure of all military base and navigation aid stations in the NWHI eliminated one of the primary threats of human disturbance, the relatively low level of ongoing human activities in the NWHI must still be carefully regulated, monitored, and assessed to ensure there are no deleterious effects (e.g., Baker and Johanos, 2002; Littnan et al., 2004). Additionally, monk seals in the MHI have probably grown in numbers (Baker and Johanos, 2004), resulting in an increased likelihood of human interactions in that expanding population.

Public outreach and education remain the single most powerful tools for reinforcing a stewardship ethic that promotes the conservation of the Hawaiian monk seal and the habitat in which it occurs. As monk seal numbers increase in the MHI, so does the importance of increasing educational efforts to systematically include all potential stakeholders.

## Habitat Loss

Critical habitat loss from erosion is a serious concern for monk seals in the NWHI. At FFS, the attrition of terrestrial habitat over the last two decades has reduced the availability of beaches for parturition by more than 50% at most sites (Table 2). The disappearance of Whaleskate Island in 1998-99 is particularly noteworthy because it led to a dramatic increase in the density of mother-pup pairs at Trig Island in 1999. Concurrently, high levels of shark predation on preweaned pups at Trig Island were documented, suggesting that the high density of seals and frequent female/female interactions led to the separation of mothers and pups and facilitated the high predation level by Galapagos sharks. Additional loss of island habitat at FFS and possibly at other sites in the NWHI, as a result of a combination of potential environmental factors and changes in oceanographic conditions (e.g., frequency of storms, rate of coral-reef growth, sea-level rise, and prevailing currents), could exacerbate this problem.

In 2004, a conspicuous decrease in the size of all islands in FFS is apparent when compared to previous information collected in 1923, 1942, and 1963 (Table 2). In a few instances, there was a slight increase from 1923 to 1963 (e.g., East Island), and, in one instance, there was a large increase in the size of Tern Island because of the construction of a runway for the Navy in 1942. However, in most cases, the islands sizes at FFS were at least 50% smaller in 2004 than in 1963. Future studies are needed to assess the rate of loss and the capacity of monk seals and other protected species to spatially adapt to the disappearance of habitat critical for their reproductive success.

One mitigation option is to evaluate the efficacy of habitat restoration to increase available haul-out sites for monk seals. Such an endeavor could also increase nesting habitat for Hawaiian green sea turtle (*Chelonia mydas*) and numerous seabirds. The benefits of such mitigation can be inferred from observing the increase in available habitat for breeding monk seals, turtles, and seabirds associated with the enlargement of Tern Island by the Navy.

## Infectious Diseases

Exposure to known pathogens has been serologically observed in all subpopulations. The impacts of these pathogens in causing disease or inhibiting recovery are unknown. To date, no epidemics of infectious disease have been positively identified in monk seal populations, but the immunologically naive population is very vulnerable to many exotic diseases. Although the probability of any particular disease being introduced into the population is unknown, disease in seal populations can be and has been devastating (e.g., Osterhaus et al., 1997).

Reducing the risk of disease introduction is an ongoing effort, with support of quarantine, vector control, and comprehensive stranding response. Further, baseline serological surveys and continual surveillance will enhance response and control of observed pathogens. Vaccination and translocation are being explored to reduce potential impacts of pathogens.

## Biotoxins

The role of biotoxins in the morbidity and mortality of monk seals is unclear because of the lack of specific and sensitive assays to test seal tissues for these compounds and their metabolites, the lack of data on the distribution of biotoxins in monk seal prey, and knowledge about temporal variation in background levels of biotoxins in the monk seals' environment. Scientific advancement in detection of sodium channel-blocking biotoxins and potentially harmful algal blooms will improve our understanding of the effects of intoxication and improve our response toward the conservation of seals. Vessel groundings that result in damage to coral reefs and trauma to reefs associated with such events have been implicated in biotoxin outbreaks that may have a secondary effect on monk seals.

## Contaminants

Historic human use of the NWHI has resulted in the deposition of a number of contaminants in monk seal habitat (e.g., polychlorinated hydrocarbons). Many of the contaminants found in the NWHI result from the past use of this area by the military and/or for navigational aid stations. Extensive remedial cleanup has been undertaken at FFS, MID, and KUR, but some contaminant sources (both known and suspected) remain in those environments. The effects of these compounds on monk seal health, reproduction, and survival are unknown, but are presently not believed to represent a significant risk to recovery.

## **FUTURE CONSERVATION EFFORTS**

Previously, an assortment of science-based recovery efforts were implemented to address specific mortality sources, stabilize declining populations, or catalyze the recovery of severely depleted monk seal subpopulations. The conspicuous slowing of the overall rate of the population decline in the mid-1990s (Fig. 2) should be viewed as a success by providing more time to refine our enhancement techniques and identify new recovery strategies based on ongoing scientific investigations.

While the status of the species would undoubtedly be far worse had none of these interventions been applied, the population is now at its lowest level in approximately five decades. Further, multiple indicators (beach counts, population estimates, age/sex structures, and demographic rates) suggest that, at most sites, the prognosis for imminent improvement is poor.

It is apparent that the ultimate goal of reversing overall population decline will hinge on a comprehensive, scientifically sound characterization and mitigation of natural and anthropogenic factors limiting population growth. We must also anticipate and plan for those factors not currently constraining population growth, but likely to become threats at some future time (e.g., morbilliviruses). Certainly, some of these limiting factors (such as a declining forage base associated with oceanographic phenomenon) cannot be directly mitigated through management intervention. The task is, then, to

identify a suite of mitigations that are achievable, cost-effective, and likely to maximize the biological return (in terms of growth potential) until such time as natural conditions allow us to scale back the level of direct intervention. There is much to learn before our understanding of monk seal ecology is complete enough to know precisely all of the possible interventions and how they should be implemented. But with the aid of rapidly evolving technologies (e.g., satellite transmitters, CRITTERCAM, fatty acid analysis) we are gaining new insight into aspects of the monk seal's world that could not have been anticipated a decade ago. We are optimistic that these advances will motivate creative solutions to mitigate the primary factors now limiting monk seal recovery.

### ACKNOWLEDGEMENTS

Much of the text used in this paper was summarized from material originally prepared by the co-authors for use in the draft Monk Seal Recovery Plan in collaboration with the Hawaiian Monk Seal Recovery Team<sup>1</sup>. We are grateful to the Team for its many insights and diligent effort in preparing the Plan, and thereby helping to bring this manuscript to fruition. In addition to the Team members, we wish to extend a special thanks to Jessica Rogers whose work has been invaluable both in reviewing the draft Plan and in coordinating the Plan revisions. Lloyd Lowry (Scientific Advisor for the Marine Mammal Commission) was also instrumental in drafting the Plan. We also thank the U.S. Fish and Wildlife Service for their many years of cooperation and logistic support, all of the staff affiliated with the monk seal program at the Pacific Island Fisheries Science Center, as well as the many seasonal field team members who were instrumental in collecting the demographic and life history data reviewed in this manuscript.

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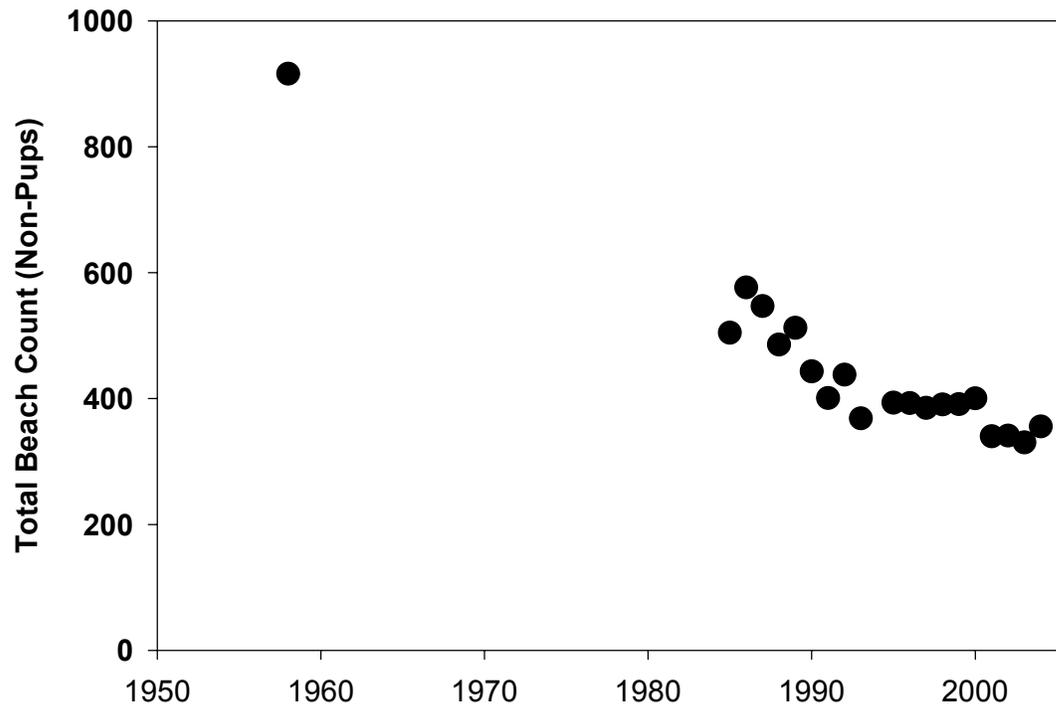
Table 1. Estimated 2003 monk seal abundance for each population segment ( $N_{\min}$ ), calculated according to the methods of Wade and Angliss (1997).

Site	Estimation Method	N	Std Dev	$N_{\min}$
FFS	Direct enumeration	311	NA	311
LAY	Direct enumeration	272	NA	272
LIS	Direct enumeration	150	NA	150
PHR	Direct enumeration	209	NA	209
MDY	Direct enumeration	63	NA	63
KUR	Direct enumeration	92	NA	92
Necker	Corrected beach counts	48.3	19.6	35
Nihoa	Corrected beach counts	47.2	21.2	33
Main HI	Aerial survey	52	NA	52
TOTAL		1,244.5		1,217

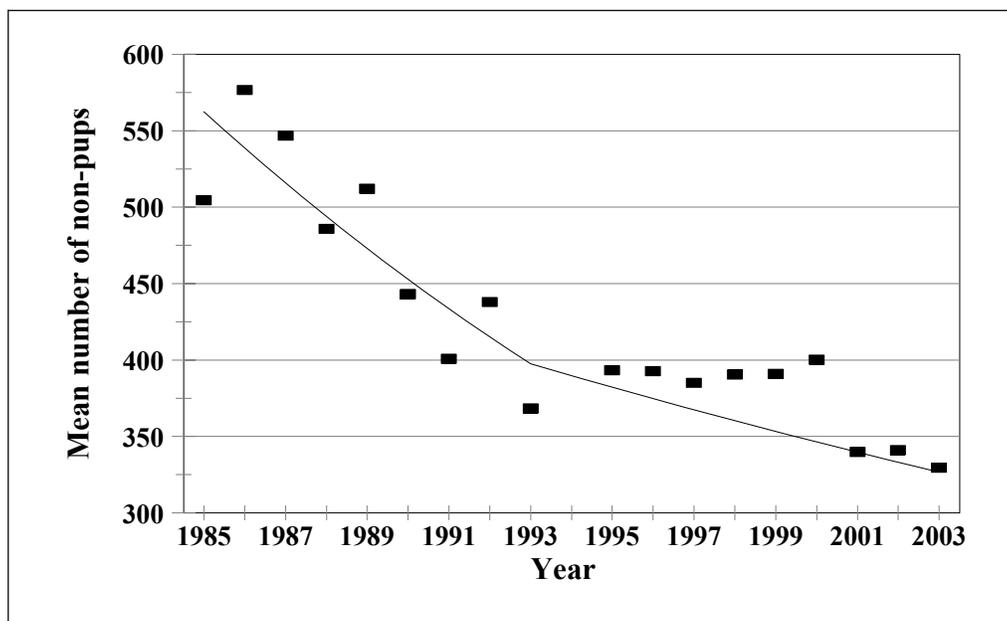
Table 2. Changes in size (acres) of emergent islets at French Frigate Shoals. (1923 to 1966: Amerson, 1971).

LOCATION	YEAR (month)				
	1923(Jun.)	1942(Aug.)	1963(Jun.)	1966(Jan.)	2004(Sept.)*
Bare Island	0.1		0.1		<0.1
Disappearing Island			6.2		0.4
East Island	9.6		11.3		6.2
Gin Island			3.2		2.1
Little Gin			5.1		2.3
Mullet Island	0.4		0.5		<0.1
Near Island			0.1		<0.1
Round Island	1.6		0.5		<0.1
Shark Island	1.1			0.8	0.1
Tern Island	11	11	56.8		25.5
Trig Island	5.3		9.9		1.1
Whale-Skate	8.3		16.8		<0.1

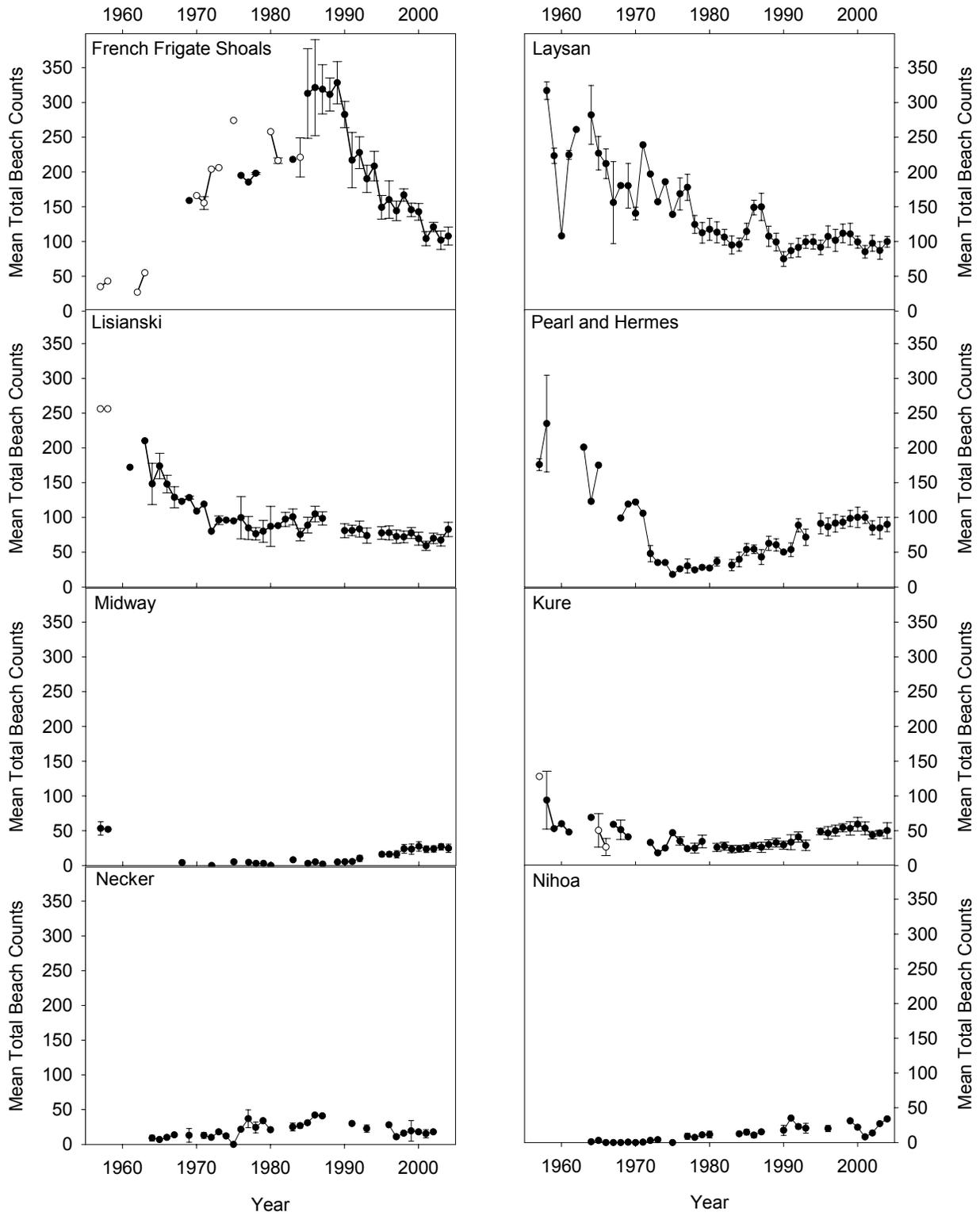
\* 2004 island acreages derived from GPS perimeter measurements.



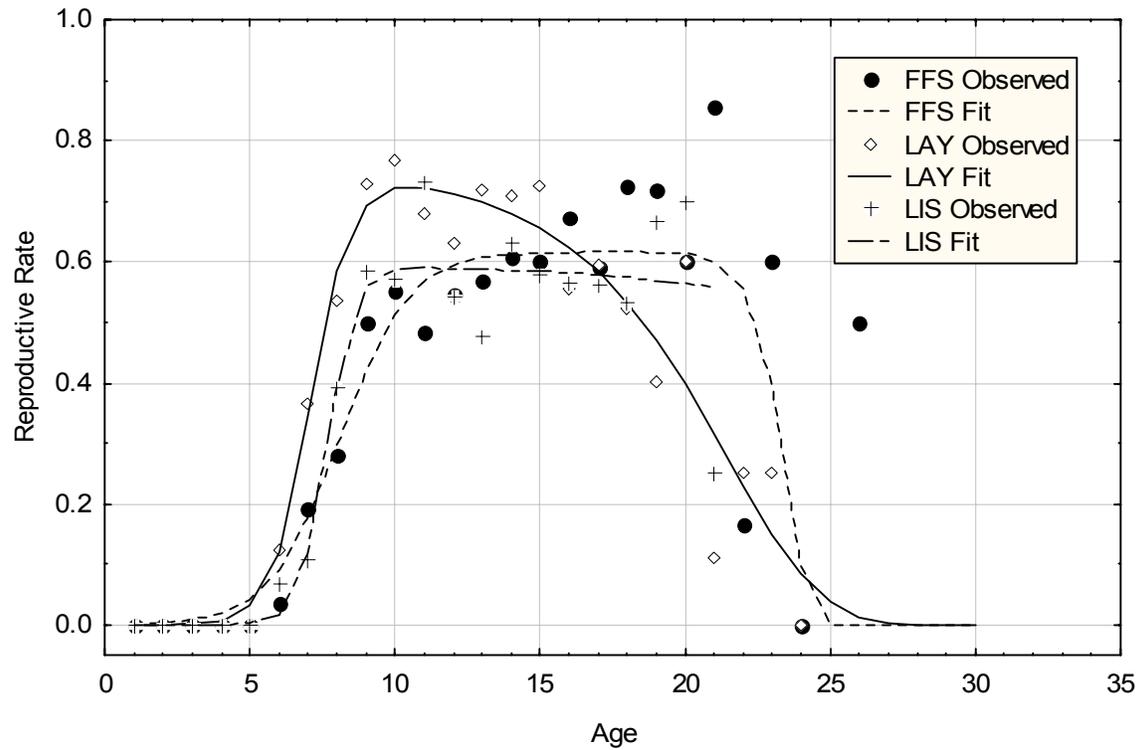
**Figure 1.** Historical trend in mean beach counts (nonpups) of Hawaiian monk seals at the six main subpopulations.



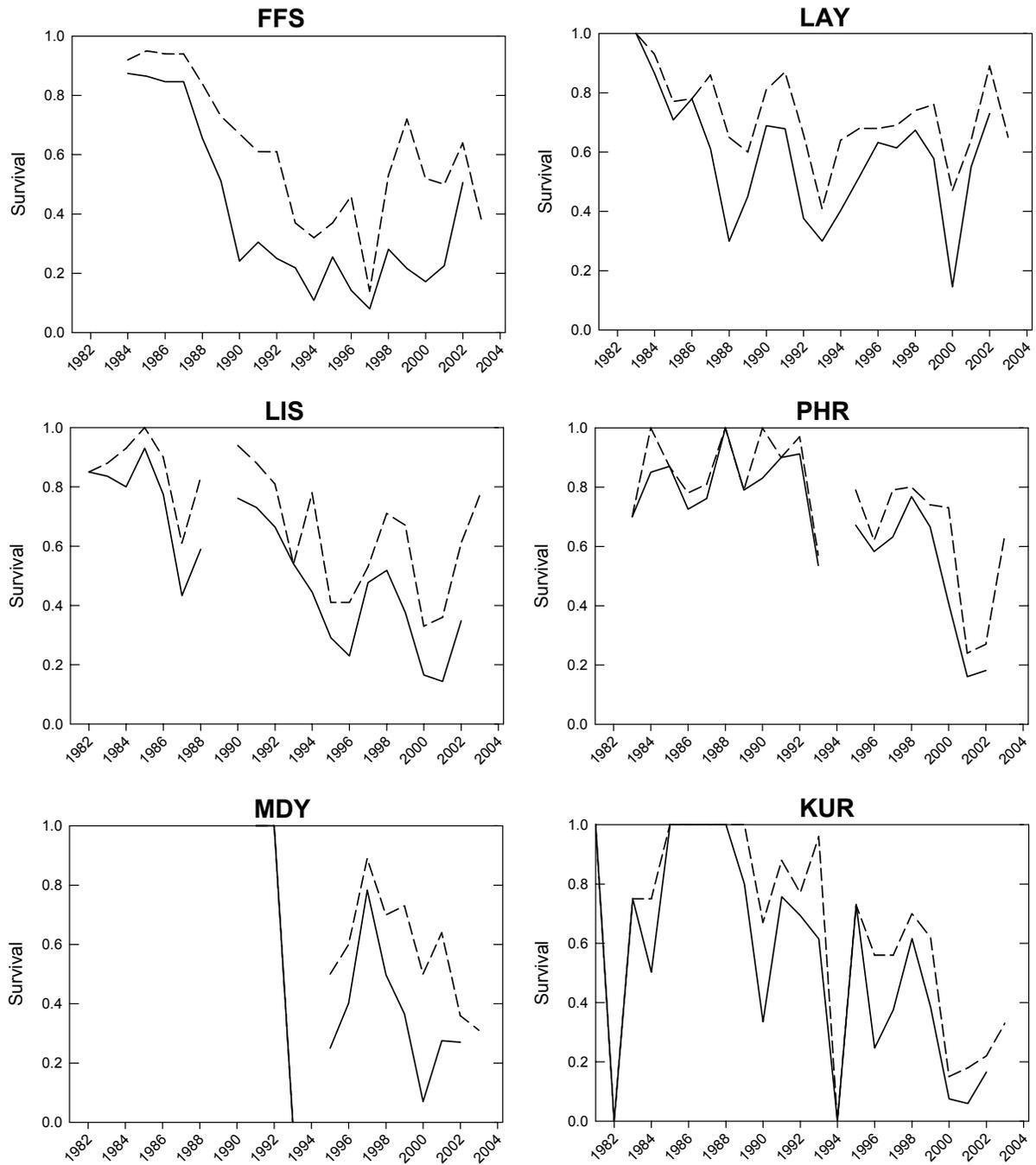
**Figure 2.** Recent (1985-2003) trend in monk seal population abundance in the NWHI. Plotted values are the mean number of nonpups observed during standardized beach counts at all six of the primary breeding subpopulations.



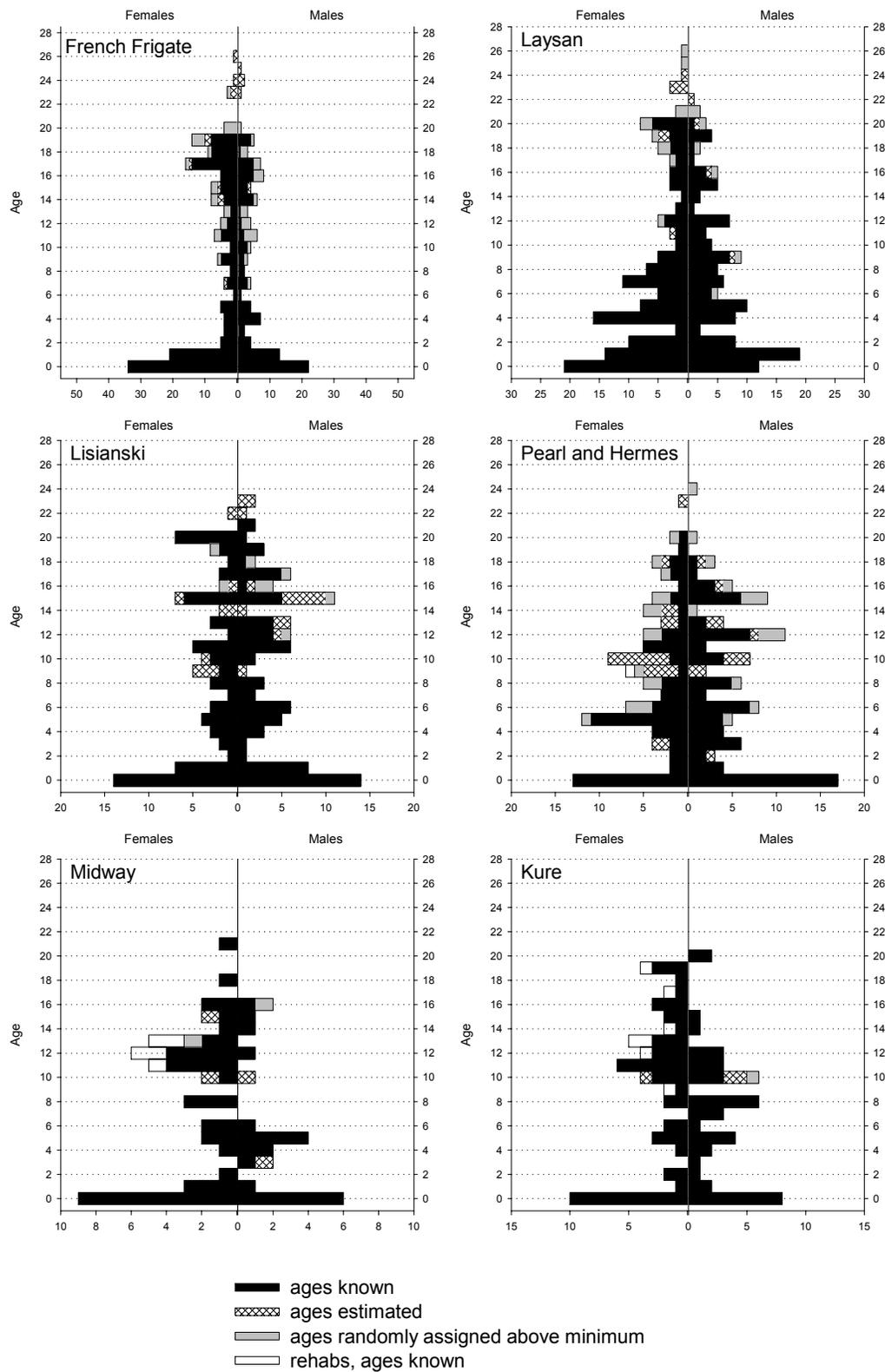
**Figure 3.** Population trend index (mean beach counts) for individual NWHI subpopulations (---o--- indicates less reliable historical counts).



**Figure 4.** Comparison of age-specific reproductive rates for Hawaiian monk seals at FFS, Laysan Island, and Lisianski Island. Curves are fitted reproductive functions to observed reproductive frequencies for known-age seals pooled over all years.



**Figure 5.** Cohort survival (weaning to age 1 and weaning to age 2) for the six primary breeding subpopulations (----- Survival to 1 year of age, — Survival to 2 years of age).



**Figure 6.** Current (2003) monk seal age structure for the six primary breeding subpopulations in the NWHI. Females are shown on the left and males are shown on the right. Patterns indicate different levels of certainty for the true age of each seal (see legend).

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