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Abundance of the Hawaiian monk seal in the main Hawaiian Islands

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Abstract

Most of the extant circa 1400 Hawaiian monk seals *Monachus schauinslandi* live in the Northwestern Hawaiian Islands (NWHI). However, an increasing number of sightings and births have recently occurred in the main Hawaiian Islands (MHI), where no systematic surveys of monk seals were conducted prior to 2000. We estimate that there were at least 45 seals in the MHI in 2000 and at least 52 in 2001, based on aerial surveys of all MHI coastlines, supplemented by sightings of seals from the ground. Moreover, annual births in the MHI have evidently increased since the mid-1990s. Weaned pups in the MHI are longer and have greater girth than those in the NWHI, perhaps reflecting greater per-capita abundance of prey resources. We think that Hawaiian monk seals have recently re-colonized the MHI, which were a very likely part of their historic range. Regardless, the MHI habitat appears to be favorable for continued increases of this endangered species.
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Keywords: Hawaiian monk seal; *Monachus schauinslandi*; Abundance; Body condition

1. Introduction

Channell and Lomolino (2000) examined patterns in range contraction among 245 species and found that remnant populations had a significantly greater than expected tendency to occur in the periphery of their historic range. Moreover, 37% of species examined occurred exclusively in the periphery of their historic range, whereas only 2% remained solely in the core of their original range. This suggests that approaches to conserving endangered species should evaluate the potential for restoration in vacated areas of the historic range, in addition to preserving remnant populations in situ. This requires an assessment of whether unoccupied habitat remains suitable or has been altered to the extent that it may no longer sustain viable populations. The Hawaiian monk seal provides a valuable case study in the practical application of these considerations.

Virtually all of the extant circa 1400 Hawaiian monk seals inhabit the remote Northwestern Hawaiian Islands (NWHI) in six main subpopulations (Fig. 1; Ragen and Lavigne, 1999; Carretta et al., 2002). Owing to substantial declines in abundance after the late 1950s, the species was listed as "endangered" under the US Endangered Species Act in 1976, and subsequent efforts by the US National Marine Fisheries Service (NMFS) to monitor and foster the species' recovery have been focused in the NWHI. These efforts often involve discovering and, when possible, responding to natural and anthropogenic crises and threats to the species, such as human disturbance, fisheries interactions, entanglement in marine debris, intraspecific aggression, shark predation, starvation, and clustered mortality events (Gerrodette and Gilmartin, 1990; Hiruki et al., 1993a,b; Starfield et al., 1995; Craig and Ragen, 1999; Lavigne, 1999; Ragen, 1999; Donohue et al., 2001; Henderson, 2001; Bertilsson-Friedman, 2002; Carretta et al., 2002). Nevertheless, substantial challenges remain to ensure long-term persistence of this species.

The historic and current abundance of monk seals in the main Hawaiian Islands (MHI, Fig. 1) is not well known. Rare sightings of monk seals in the MHI in the

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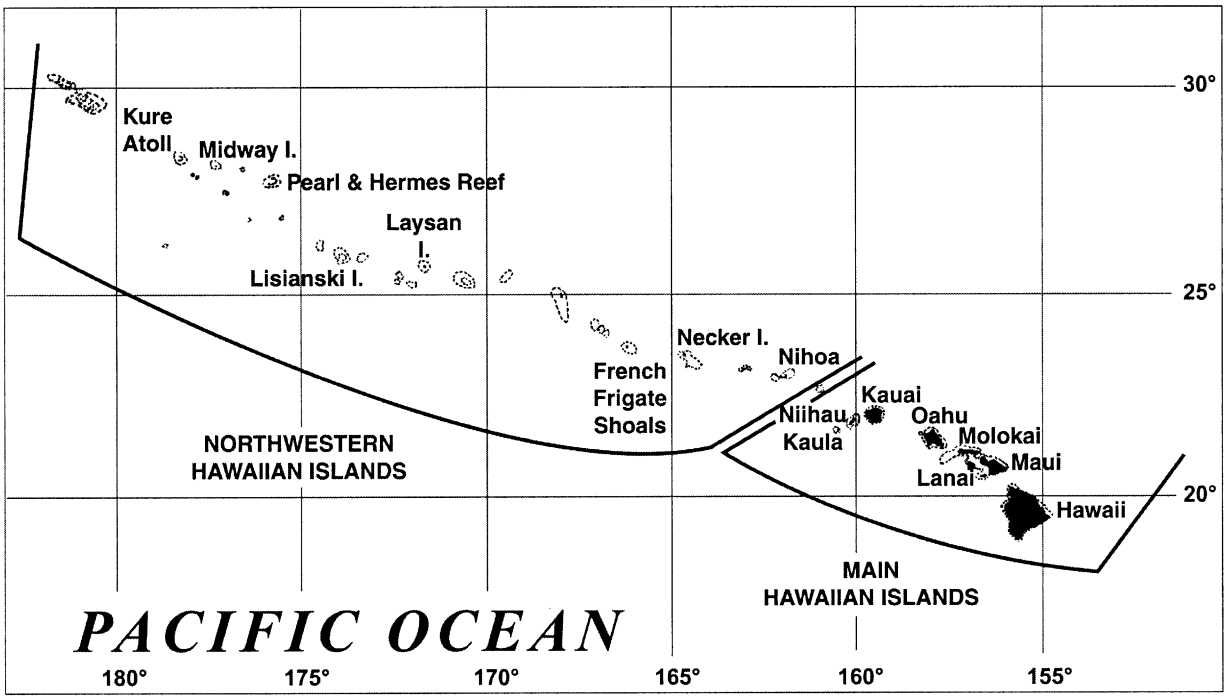

Fig. 1. The Hawaiian Archipelago. The six main subpopulations where monk seals reside in the Northwestern Hawaiian Islands are Kure Atoll, Midway Atoll, Pearl and Hermes Reef, Lisianski Island, Laysan Island, and French Frigate Shoals. Some seals also occur at Necker and Nihoa Islands.

early 20th century were documented by Kenyon and Rice (1959). Beginning in the 1990s, an increasing number of monk seal births and sightings have been recorded in the MHI, but because these reports are not based on systematic surveys, evaluation of trends is equivocal. Similarly, little is known about the physical condition and reproductive success of individuals which breed in the MHI, information which would provide insight regarding habitat quality and the potential for recovery. Here we report the results of studies conducted to document the abundance and physical condition of Hawaiian monk seals in the MHI.

2. Methods

2.1. Study site

The main Hawaiian Islands (Fig. 2) are a subset of the Hawaiian Archipelago. They include eight islands spanning 600 km: Niihau, Kauai, Oahu, Molokai, Lanai, Maui, Kahoolawe, and Hawaii. There are also three small uninhabited crescent-shaped volcanic islets: Kaula Rock, Lehua, and Molokini Crater, and several islets offshore of the various primary islands. The human population on the main eight islands ranges from none (Kahoolawe, a former US military bombing range now under restoration), to 876,000 on the island of Oahu (US Census Bureau, 2001). The total coastline of the MHI is 1506 km (Juvik and Juvik, 1998).

2.2. Survey methods

We conducted surveys of the MHI in 2000 from a Partenavia Observer (twin-engine, high-wing aircraft) with a plexiglass "bubble" nose to facilitate visibility. We searched all coastlines at altitudes ranging from 30 to 150 m and at an average speed of 145 km h^{-1}. To improve detection of seals, we conducted surveys from slower-moving (60–110 km h^{-1}) helicopters (Hughes 500) in 2001. All surveys were made in summer and autumn, after most births should have occurred (Johanos et al., 1994) and when weather was most favorable.

Each individual island survey was completed within 1 day, and to the degree possible, islands located near each other were surveyed the same day to minimize the potential for double counting seals that might have moved within or between islands. When possible, surveys were begun approximately mid-day following the protocol for ground census' of seals in the NWHI (Johanos and Baker, 2001). When a seal was seen, we recorded time and location using a Global Positioning System (GPS) receiver, and took photographs when possible. We classified seals as nursing pups, weaned pups, juveniles (roughly 1–2 years old), sub-adults (roughly 3–4 years old) or adults (minimum of 5 years old), according to size and morphology (cf. Johanos and Baker, 2001). In some cases, sex could also be determined if seals were lying with their ventral surface exposed, or by association with a nursing pup. Photographs were later examined to confirm field assessments of size and sex.

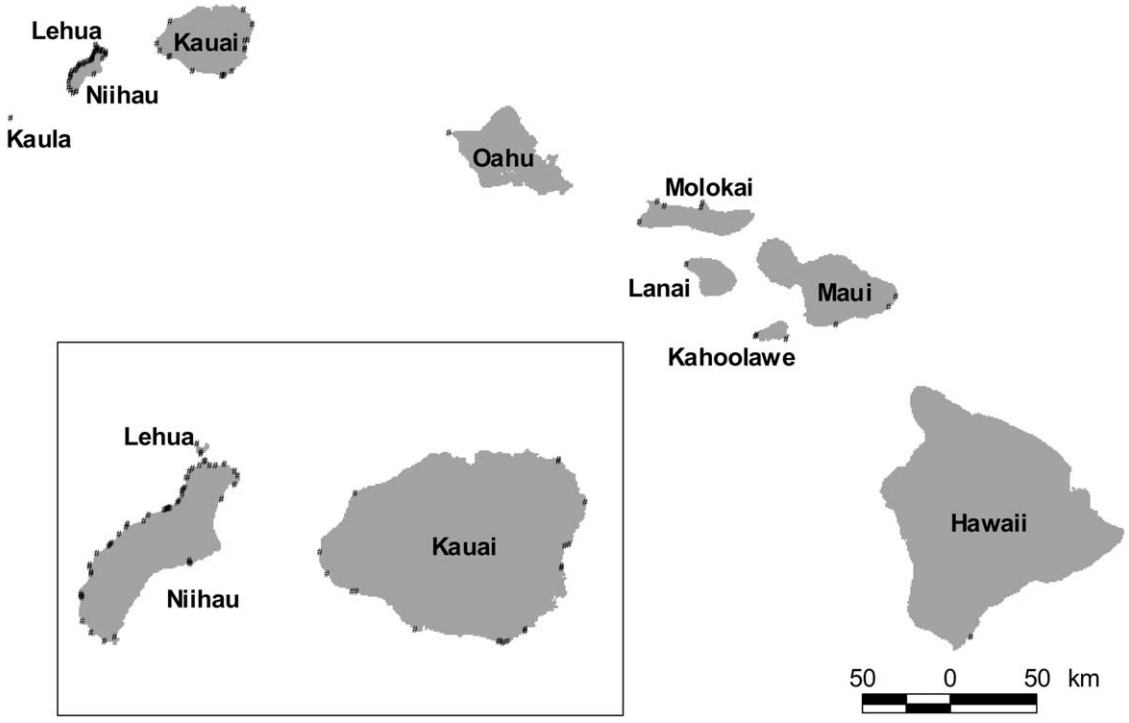

Fig. 2. Location of Hawaiian monk seals observed during aerial surveys (and additional ground sightings) in the main Hawaiian Islands during 2000–2001. Insets of Kauai and Niihau (not to scale) are provided. Sightings of multiple seals near one another often appear as one dot.

2.3. MHI births and weaning condition

Records of monk seal births in the MHI are typically reported by the public and cooperating agencies. NMFS biologists attempt to confirm all records of births, and weaned pups are double-tagged in the rear flippers with Temple Tags™. At the time of tagging, axillary girth and standard dorsal length are measured (Craig and Ragen, 1999). Because pups lose mass while they fast after weaning, statistical analysis of girth and length of pups born at the six main NWHI subpopulations was limited to measurements taken within 2 weeks of weaning. All MHI, Necker, and Nihoa Islands pup measurements were analyzed, even when weaning dates were imprecisely known, in order to use the few samples available. Girths of pups with unknown weaning dates are likely more negatively biased than those measured within 2 weeks' post-weaning. Girths and lengths were analyzed using ANOVA with Student–Newman–Keuls tests for multiple comparisons among locations.

3. Results

3.1. Minimum abundance

In 2000, we surveyed the islands of Hawaii, Maui, Kahoolawe, Molikini Crater, Lanai, Molokai and Oahu once during 10–12 July 2000. Surveys of the remaining islands were delayed owing to military operations. Consequently, we surveyed Kauai, Niihau, Lehua, and Kaula Rock on 8 August. Because of the relatively large number of seals seen then, we conducted a second survey of those islands on 26 September 2000.

We counted a total of 45 seals in 2000. This was the sum of the maximum counts from each aerial survey, plus four additional seals counted from the ground, but not seen from the air (Table 1).

In 2001, we made one survey of Hawaii, Maui, Kahoolawe, Molikini Crater, Lanai, Molokai and Oahu

Table 1
Number of Hawaiian monk seals counted during aerial surveys of the main Hawaiian Islands in 2000 and 2001[a]

Island	2000 (1st survey)	2000 (2nd survey)	2001
Kaula Rock	3	0	–
Niihau	5	29	29
Lehua	2	0	3
Kauai	7	7(2)	5(2)
Oahu	0	–	1
Molokai	3(2)	–	3(2)
Lanai	0	–	1
Maui	1	–	3
Kahoolawe	1	–	2
Hawaii	0	–	0(1)
Minimum Abundance	24	45[b]	52

[a] Numbers in parentheses indicate seals which were seen by observers on the ground that were not seen from the air.

[b] Total of second survey tally at Kaula, Niihau, Lehua, and Kauai plus the tally of single survey of all other islands.

from helicopters during 27–30 August. We surveyed Kauai, Niihau and Lehua Rock on 1 October 2001. Kaula Rock was not surveyed in 2001 because it was too far from fueling facilities. We counted 47 seals during the aerial surveys and five others were reported by ground observers, for a total of 52 seals (Table 1). Immature animals (pups, juveniles, and subadults) accounted for 49% of the seals seen in 2000 and 56% of those seen in 2001.

3.2. Births

The first recorded birth in the MHI occurred on Kauai in 1962 (Table 2), when a pup was found abandoned on the beach. The pup was turned over to the State Fish and Game Department, and presumably died soon thereafter. The next MHI birth was reported in 1988. Since 1996, births have been recorded every year and with increasing frequency on various islands, including seven pups we observed while surveying Niihau in 2000 and 2001.

3.3. Weaning condition

The axillary girth of weaned pups in the MHI averaged 121.7 cm (S.D. = 9.6, $N = 23$) compared to 104.7 cm (S.D. = 10.6, $N = 2003$) in the NWHI. Standard length of pups in the MHI averaged 140.3 cm (S.D. = 5.9, $N = 23$) compared to 126.0 cm (S.D. = 7.7, $N = 1910$) in the NWHI. At Necker, Nihoa, and the MHI we could not confirm if the measurements of nine pups were taken within 2 weeks of weaning. These size differences of MHI versus NWHI pups were highly statistically significant. Both girths and lengths of MHI pups were significantly greater when compared to those at French Frigate Shoals, Laysan Island, Lisianski Island, Pearl and Hermes Reef, Midway Atoll, and Kure Atoll ($P < 0.001$) and the few pups measured at Necker and Nihoa Islands ($P < 0.025$). Nearly all (20 of 23) pups measured in the MHI were born during 1996–2001. When data from NWHI pups were constrained to those same years, the means changed little and MHI girths and lengths remained significantly greater.

Table 2
Known number of monk seal births in the main Hawaiian Islands

Year	Niihau	Kauai	Oahu	Molokai	Maui	Kahoolawe	Hawaii	Total
1962	0	1	0	0	0	0	0	1
1988	0	1	0	0	0	0	0	1
1991	1	1	1	0	0	0	0	3
1992	0	1	0	0	0	0	0	1
1996	0	0	1	1	0	0	0	2
1997	0	0	1	1	1	0	0	3
1998	0	0	2	1	1	0	0	4
1999	0	1	0	1	1	0	0	3
2000	2	4	0	1	0	0	0	7
2001	5	3	0	2	0	1	1	12

4. Discussion

Our counts of 45 seals in 2000 and 52 seals in 2001 (Table 1) are minimum estimates of the number of Hawaiian monk seals in the MHI, as some seals were undoubtedly at sea and thus not counted (cf. Ries et al., 1990; Thompson and Harwood, 1990; Huber et al., 2001). In the NWHI, it has been estimated that 2–3 seals exist for every one counted during beach censuses (NMFS unpublished data). However, such multipliers are likely a function of terrestrial habitat characteristics, proportion of time spent foraging (which likely is determined in part by proximity and abundance of prey), and time spent in social activities and sleeping in the water (Parrish et al., 2000). These factors, especially habitat characteristics, may differ greatly between the NWHI and MHI, such that to assume NWHI correction factors apply in the MHI would be imprudent. In addition to seals missed in the water, the probability of detecting seals on land during aerial surveys is less than 100%. The altitude, speed and turbulence of the aircraft, and regulations limiting flight distances from people and structures, all conspire to reduce sighting probability.

The location of MHI monk seals (Fig. 2) suggests that two interacting factors may influence their distribution. The number of seals tends to decrease moving along the archipelago from the northwest to the southeast, and fewer seals occur where human presence is greater. Consequently, most seals were seen at Niihau at the northwestern end of the MHI, where only 230 people live (Juvik and Juvik, 1998). The second highest counts were on Kauai (human population 58,000) just east of Niihau. Moving to the southeast, just one seal was seen on densely populated Oahu (population 876,000). However, seals were more regularly sighted on the next island to the southeast, Molokai (population 6700), the remote areas of Maui (population 91,000), uninhabited Kahoolawe, and sparsely populated Lanai (population 3200). Notably, the island furthest to the southeast, Hawaii (population 149,000), comprises 30% of the tidal shoreline of the MHI (Juvik and Juvik, 1998), yet only one seal was found there during this study.

The documented number of births in the MHI is a minimum estimate, especially for Niihau. Most mothers selected remote areas for parturition, reducing the probability they are discovered. While most monk seals were seen on Niihau during aerial surveys, births on that island have not been reported by local residents. They have been documented only by research biologists on three occasions over 11 years.

The size of phocid pups at weaning is the result of both pre- and post-partum maternal investment, which in part reflects prey availability (Kovacs and Lavigne, 1986; Fowler and Siniff, 1992; Burton et al., 1997; Vergani et al., 2001). We think that the difference in body

condition of monk seal pups weaned in the MHI compared to the NWHI (Fig. 3) may reflect better foraging conditions in the MHI. This contrasts with general findings of better conditions in the central portion of a species' range compared to the periphery (e.g. Brown, 1984). Moreover, substantial evidence indicates that some components of marine ecosystems around the MHI have been impoverished by sport and commercial fishing. For example, Friedlander and DeMartini (2002) estimated that the biomass of shallow water reef fishes was 260% greater in the NWHI than in the MHI, owing to fishing pressure.

We suggest three factors that may explain the differences in body condition of pups in the MHI compared to the NWHI. First, because the monk seal population in the MHI appears to be small, the per capita availability of prey may be relatively high, even if absolute prey abundance is lower than in the NWHI, where up to several hundred seals reside and forage at single atolls. Second, absolute densities of preferred monk seal prey

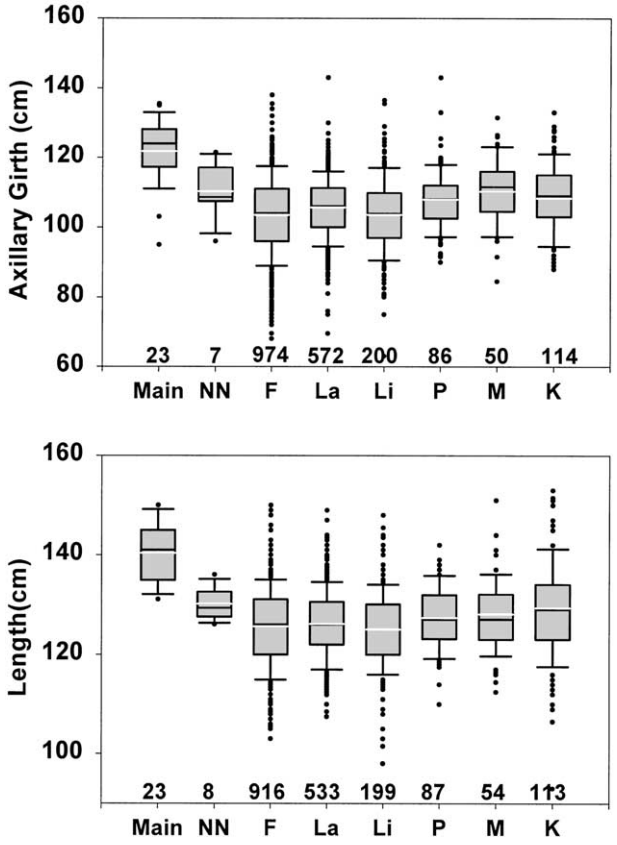

Fig. 3. Box plots of weaned monk seal girth and length distributions by birth location. White bars indicate mean; black bars show medians. Boxes encompass 25th–75th percentiles; extended bars are 10th and 90th percentiles. Points indicate remaining outlying measurements. Numbers of pups measured in all years are shown below each plot. Main = main Hawaiian Islands, NN = Necker and Nihoa Islands combined, F = French Frigate Shoals, La = Laysan Island, Li = Lisianski Island, P = Pearl and Hermes Reef, M = Midway Atoll, K = Kure Atoll.

may not differ between the MHI and the NWHI as much as the comparison of total shallow water reef fish biomass in Friedlander and DeMartini (2002) would indicate. When apex predators (i.e. sharks and jacks upon which monk seals do not prey) are excluded, the difference in the remaining components of shallow water reef fish biomass drop from 260 to 70% greater in the NWHI compared to the MHI (calculated from Friedlander and DeMartini, 2002, Table 1). Available information on the foraging habitat preferences of Hawaiian monk seals in the NWHI indicates that seals forage on the sea floor on the outer slopes of atolls and on terraces and submerged sea mounts with modal depths of 50–80 m and deeper (Abernathy, 1999; Parrish et al., 2000; 2002, B. Stewart, pers. comm.). No comparisons of prey abundance at those depths in the NWHI and MHI are available. Common prey items of NWHI seals include eels, wrasses, and many other benthic species which are not prized by sport and commercial fishermen (Goodman-Lowe, 1998; Parrish et al., 2000). Thus, the potential for competition between foraging monk seals and fisherman may be lower than it might seem at first glance. However, hookings of monk seals on recreational and perhaps commercial fishing hooks in the MHI indicate that some degree of overlap occurs. There have been 16 such hookings recorded, 11 since 1996 (NMFS unpublished data).

A third factor that may influence prey availability for monk seals in the MHI is a difference in the structure of the marine community relative to the NWHI. In the NWHI, apex predators such as large sharks and jacks are abundant (Friedlander and DeMartini, 2002). The diets of these predators overlap with that of monk seals (Kenyon Rice, 1959; De Crosta et al., 1984; Sudekum et al., 1991; Wetherbee et al., 1996; 1997; Goodman-Lowe, 1998; Meyer et al., 2001) and direct competition for prey items has been observed on video collected with seal-mounted cameras in the NHWI (F. Parrish, pers. comm.). These interactions involve sharks and jacks associating with foraging seals, including kleptoparasitism. In contrast, large predators are rare in the MHI as large sharks and jacks have been heavily fished, the latter being a very popular trophy and food fish (Friedlander and DeMartini, 2002). Thus, low interspecific competition with other top predators may enhance the foraging success of monk seals in the MHI. Further, Parrish and Boland (submitted for publication) suggest that high densities of apex fish predators can constrain the movements of reef fishes to habitat with predator refugia, thus effectively reducing reef fish productivity and density.

The history of monk seals in the MHI is indefinite. Kenyon and Rice (1959) reviewed seven MHI sightings accumulated from 1928 to 1956, and a long-time Niihau resident has reported that seals became common on Niihau after 1970 (interview with J. Baker). We think it

likely that monk seals came to the MHI from the NWHI before tagging was consistently done, though it is also possible that some seals persisted in the MHI prior to this hypothesized dispersal. The distribution of seals (Fig. 2) and the fact that while most seals in the NWHI have been tagged since the mid-1980s, only two are known to have voluntarily moved to the MHI, suggests that seals may currently be spreading to other parts of the MHI from Niihau.

In addition to seals naturally occurring in the MHI, 21 adult males were translocated from the NWHI to the MHI in 1994 in order to correct a male-biased sex ratio at Laysan Island, where male aggression was reducing female survival (Hiruki et al., 1993a,b; Starfield et al., 1995). The translocated animals were all tagged, and account for only a small portion of sightings in the MHI.

Before Polynesians arrived approximately 1500–1600 years ago (Bellwood, 1978), monk seals likely occurred throughout the MHI. The Hawaiian monk seal is thought to be an evolutionarily primitive species, having originated either elsewhere in the Pacific Basin or made its way to the Hawaiian Islands from the North Atlantic via the Central American Seaway, perhaps 15 million years ago (Repenning and Ray, 1977; Repenning et al., 1979; Berta and Sumich, 1999). The Hawaiian Archipelago is formed of volcanos which emerged from an oceanic hot spot in the central Pacific. The volcanos erode as they move to the northwest on the Pacific Plate at about 9 cm year^{-1}, eventually evolving from large islands (such as the current MHI) to coral atolls and seamounts such as the NWHI (Juvik and Juvik, 1998). The ages of various dated Hawaiian volcanos range from the island of Hawaii, less than one-half million years (mya) old, to Midway Atoll aged 27.7 mya (Juvik and Juvik, 1998). Thus, when monk seals likely arrived in Hawaii, the current MHI and some of the more recent NWHI did not yet exist, while the older NWHI would have been larger and located further to the southeast than they are now. Monk seals would likely have colonized and eventually spread throughout the entire archipelago. In geologic time, they also would have necessarily abandoned atolls that subsided and naturally colonized newly formed islands of the dynamically changing Hawaiian Archipelago.

Extinction of species following human colonization is well documented in the Pacific Islands and elsewhere (Olson and James, 1982; Martin and Klein, 1984; Martin et al., 1985; Anderson, 1989; Stuart, 1991; Caughley and Gunn, 1996; Holdaway and Jacomb, 2000; Burney et al., 2001; Grayson, 2001; Duncan et al., 2002). After Polynesians arrived, monk seals may have been extirpated from the MHI and constrained to the NWHI, where, other than at Necker and Nihoa Islands, there is no evidence of Polynesian presence (Rauzon, 2001). The NWHI, now the species' primary range, may represent formerly peripheral habitat. Caughley and Gunn (1996) note that "remnant populations of an endangered species often end up not in the habitat most favorable to it but in the habitat least favorable to its agent of decline." While there is no archaeological evidence of monk seals in the MHI, the seals occupy ephemeral shoreline habitats, making preservation of hard parts unlikely.

Current abundance of monk seals in the MHI is low, but may be increasing, and the excellent condition of weaned pups indicates potential for further population growth. This poses both opportunities and challenges for the conservation of this species. The addition of another viable component to the monk seal metapopulation may enhance the species' long-term persistence. Public exposure to wild monk seals provides excellent opportunities for education and development of a conservation ethic. However, seals in the MHI are exposed to many threats. Monk seals have proven vulnerable to harassment by humans and their domesticated animals (Ragen, 1999), and the human population in the MHI is approximately 1.2 million (US Census Bureau, 2001) compared to less than 100 in the NWHI. Other threats in the MHI include hooking by fishermen, collision with vessels, and oil spills. Finally, there is potential for disease transfer to MHI monk seals from domesticated animals. If this occurs, and disease is subsequently transmitted to the NWHI population, the results could be devastating (Heide-Joergensen et al., 1992; Thompson et al., 1993; Forcada et al., 1999).

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