SPATIAL AND TEMPORAL HAUL OUT PATTERNS OF THE HAWAIIAN MONK SEAL (*MONACHUS SCHAUISLANDI*) AT MIDWAY ATOLL, 1997-2000

By

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Masters project submitted in partial fulfillment of the requirements for the Masters of Environmental Management degree in the Nicholas School of the Environmental and Earth Sciences of Duke University

2003

ABSTRACT

The Hawaiian monk seal is an endangered species with a current population of approximately 1400 animals. Seals are distributed primarily at six sites in the Northwest Hawaiian Islands. The most depleted of these subpopulations occurs at Midway Atoll. Seal numbers declined at Midway by over 90% from the 1950s to 1990s and currently stand at approximately 70 animals. A cooperative agreement between the National Marine Fisheries Service and Hawaii Wildlife Fund in 1997 led to the establishment of a year-round monk seal monitoring program at Midway Atoll from 1997 – 2000. This project reports results from this year-round study.

Data for the study were based primarily on beach censuses that monitored monk seal haul outs at Midway Atoll. Analyses examined (1) changes in haul out patterns by island over time, (2) seasonal patterns in haul outs, (3) the influence of the barrier reef on monk seal beach counts, (4) preferred pupping habitat, and (5) differences between year-round and seasonal data. Results indicate that there was a shift in haul outs between islands over the course of the study. A strong seasonal pattern in beach counts for immature animals was also identified. The barrier reef was identified as an important haul out area, particularly for immature animals. Preferred pupping sites were identified. Finally, year-round studies were shown to be valuable in the identification of mother/pup pairs and in the development of female reproductive histories. Seasonal and year-round studies performed equally well in determining average annual beach counts.

This study may prove important in identifying potential causes of the slow increase in the Midway monk seal subpopulation. It may also suggest possible remedies or management actions to promote or accelerate the recovery of monk seals at Midway Atoll. Recommendations for future research are also discussed.

ACKNOWLEDGEMENTS

Warmest thanks to my two advisors on this project, Dr. Larry Crowder of Duke University and Bill Gilmartin of Hawaii Wildlife Fund. Thanks also to Suzanne Canja and Cynthia Vanderlip for their years of field work and assistance on this project. Special thanks also to Jon Cohen for his assistance and to my fellow classmates through our two years together. Finally, all my love and thanks to my family and wife Joanna for all their support. We will be together again soon!

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CHAPTER 1: INTRODUCTION

The Hawaiian monk seal is listed as an endangered species in the United States and is one of the most endangered of the world's marine mammals. Only about 1400 seals remain in Hawaii, a 60% decline in the population since the late 1950s (Ragen & Lavigne 1999). This population decline resulted from the direct take of seals in the 1800s, destruction of haul out and rookery habitat, abandonment of habitat due to human presence, interactions with fisheries and climatic changes in the North Pacific ecosystem (Ragen & Lavigne 1999).

The most depleted monk seal subpopulation occurs at Midway Atoll in the Northwest Hawaiian Islands. The Midway seal population declined by approximately 90% since the 1950s and is now experiencing a slow recovery (Gilmartin 1983). A large presence of U.S. military personnel at the atoll from the early 1900s to early 1990s was in large part responsible for the population decline. Removal of that military presence in the early 1990s can also be viewed as contributing to the recovery of the Midway monk seal population.

The unique history of Midway Atoll also makes it a continued source of interest for tourists. Midway's key role in World War 2 as well as the unparalleled access to the flora and fauna of the Northwest Hawaiian Islands makes it a prime destination for eco- and history based tourists. The demands of maintaining an infrastructure at Midway to cater to tourist's needs and the needs of the approximately 250 resident staff have to be weighed against the habitat requirements of monk seals and the other plants and animals of the atoll.

In part to address these concerns a recovery plan for the Midway monk seal population was published by the National Marine Fisheries Service in 1998 (Gilmartin & Antonelis 1998). This plan, among other things, called for monitoring of monk seals at Midway to determine spatial and temporal trends in habitat use, to identify preferred pupping habitat, and to look for possible changes in monk seal behavior related to human disturbance. In 1997 a cooperative field research program was initiated by the non-profit group Hawaii Wildlife Fund and the National Marine Fisheries Service to begin year-round monitoring of monk seals at Midway.

This project takes advantage of this unique year-round data set and begins those analyses requested in the 1998 recovery plan. These analyses are conducted with the goal of providing the information necessary to promote and possibly hasten monk seal recovery at Midway Atoll and to ensure that human presence does not negatively impact species recovery. The final report will be presented to Hawaii Wildlife Fund.

CHAPTER 2: LITERATURE REVIEW

2.1 Monk Seal Life History

The Hawaiian monk seal (*Monachus schauislandi*) is one of two extant species in the family Phocinae and subfamily Monachinae. The Phocidae, or "true seals", are characterized by the lack of external ears, internal testes, normal upper canines and lack of mobility of the hind flippers. Subfamily Monachinae has three members – the Hawaiian, Mediterranean and Caribbean monk seals. The Caribbean monk seal is thought to have become extinct by the 1950s (Kenyon 1977).

Monk seals are subtropical in distribution. They are thought to have arrived in the Hawaiian archipelago approximately 14 million years ago (Kenyon 1972). The Hawaiian monk seal is distributed primarily in the Northwest Hawaiian Islands (NWHI). This is an 1840km. stretch of islands and coral atolls (Figure 2.1). The most westward atoll, Kure Atoll, is approximately 2180 km. from Honolulu. The primary monk seal haul out and pupping locations in the NWHI include Kure Atoll, Midway Atoll, Pearl and Hermes Reef, Lisianski Island, Laysan Island, French Frigate Shoals, Necker Island and Nihoa Island. Each atoll comprises a somewhat discrete subpopulation of seals that act relatively independently of other atolls (Gerrodette & Gilmartin 1990). Resightings of known animals indicates that there is a 10% movement of animals between atolls (Kretzmann et al. 1997).

Hawaiian monk seals are generalist, opportunistic feeders. They typically feed in shallow water, around reefs, and on benthic animals. Foraging studies indicate that they feed both nocturnally and diurnally on octopus, squid, and reef and benthic fishes (Parrish et al. 2000, Goodman-Lowe 1998, Goodman-Lowe et al. 1999b). One study of adult males indicated that they spend the majority of their time feeding in 50-100 meters of water in areas of low relief (Parrish et al. 2000). Animals may also make foraging trips that last from several days to several weeks (Gilmartin 1983). Research also indicates that there may be temporal, geographic, and ontogenetic differences in the diet between animals and atolls (Goodman-Lowe 1998, Goodman-

Love et al. 1999, Ragen & Lavigne 1999). No studies of juvenile foraging behavior have yet been conducted.

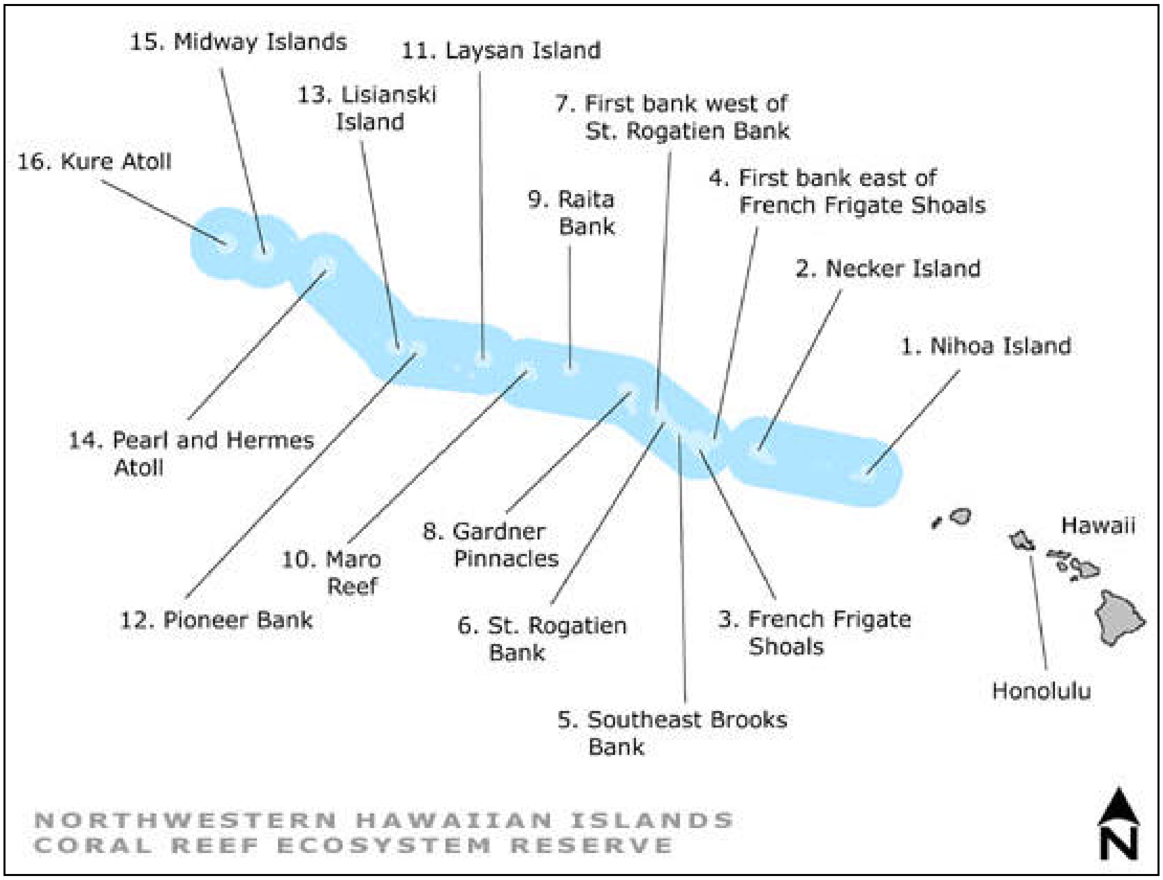


Figure 2.1. Map of the Northwest and Main Hawaiian Islands.

Age at maturity in monk seals is dependent upon reaching a certain percentage of final body size. As a result, age at maturity varies and does so from atoll to atoll. For example, data on known age animals indicate that the age of maturity at FFS is approximately 10 to 12 years while at Pearl and Hermes Reef it is about half that value (Gilmartin 2003 pers. comm.). Monk seals can live in excess of 25 years (Kenyon 1981).

Age at first reproduction is also variable and ranges from 5 to 9 years depending upon subpopulation (Ragen & Lavigne 1999). On average, females give birth every second year but are capable of annual breeding. Pupping season also varies by island but peaks in March and April within a broader season of February to August (Ragen & Lavigne 1999, Johanos et al.

1994). A female will nurse a single pup for 5 to 6 weeks (Johanos et al. 1994). Females may show evidence of mating several weeks after weaning (Johanos et al. 1994).

Hawaiian monk seals spend a proportion of their time "hauled out" on the beaches or emergent reef. Animals haul out to rest, molt, pup, nurse, and escape predators. The number of individuals hauled out typically peaks in the afternoon before declining again toward sunset (Kenyon & Rice 1959). This haul out behavior provides valuable insight into the lives of monk seals by allowing researchers to identify and track individuals, monitor pupping and mother-pup associations, monitor molting, study behavior, as well as examine animals for scars or wounds, and to collect samples.

Research suggests that female Hawaiian monk seals select preferred pupping sites that often differ from their typical haul out locations (Westlake & Gilmartin 1990). These pupping sites may possess different characteristics than normal rest sites (Westlake & Gilmartin 1990, Gerrodette & Gilmartin 1990). The primary feature of these sites is very shallow water adjacent to the shoreline which allows pups to develop their swimming abilities and to do so free from predators (Westlake & Gilmartin 1990, Gerrodette & Gilmartin 1990).

Hawaiian monk seals must also haul out annually to molt. Like elephant seals, immature and adult monk seals molt their fur and epidermis skin layer (Kenyon 1981). The molting process takes 10 to 14 days during which time animals spend a large proportion of their time on the beach. On Laysan Island, non-parturient (not pregnant) females molted between mid-May and mid-July with a peak in late May to early June (Johanos et al. 1994). Parturient females molted between mid-June and early august with a peak in July (Johanos et al. 1994). Adult males are thought to molt more in the fall and immatures are thought to molt throughout the year with a peak from early spring to late summer (Gilmartin 2003 pers. comm.).

Kenyon (1972) noted a distinct seasonal cycle in the number of seals hauled out. Haul outs peaked from late December to March and were lowest during the summer months. Kenyon proposed that this seasonal cycle could be due to increased use of the barrier reef during the summer or to seals avoiding high summer beach temperatures. Seasonality may also suggest certain times of the year in which food is less available and for which greater foraging efforts are required (Gilmartin 2003 pers. comm.). Such activity would take seals away from the atoll and reduce beach counts.

2.2 History of Human interaction and Conservation

The Hawaiian monk seal was first identified by the Russian explorer Lisianski in 1814 at the island that would later take his name (Ragen & Lavigne 1999). The story of human-monk seal interactions throughout the 1800s was one of exploitation. Monk seals were hunted throughout the century for their pelts and oil and as food for shipwrecked sailors and feather collectors. By the late 1800s there was evidence that the monk seal population was already depleted. At Midway Atoll in 1888-1889, for example, no monk seals were seen during a 14 month period (Ragen & Lavigne 1999).

Beach counts in the 1950s indicate that populations may have recovered somewhat from the exploitation in the 1800s. Counts at all atolls except French Frigate Shoals were higher in the 1950s than at any time until the present. The greatest declines occurred at Midway Atoll and Pearl and Hermes Reef where populations declined by over 90% from the 1950s to the 1980s (Gilmartin 1983). From the 1950s to the early-1980s the seal population of the whole NWHI declined by approximately 50% (Kenyon 1972). This decline would have been much greater had it not been for the increasing population at French Frigate Shoals (FFS). From the 1950s to the 1970s beach counts at FFS increased six fold (Gilmartin 1983).

The decline of the monk seal population led to their listing in 1976 as depleted under the Marine Mammal Protection Act and as endangered under the Endangered Species Act. The Hawaiian monk seal is also listed as endangered by the IUCN (World Conservation Union).

With listing as an endangered species came increased systematic monitoring and management of monk seal populations. Beginning in 1981, field camps with seasons lasting from several days to several months were established to monitor monk seals at their main pupping sites in the NWHI.

Monitoring and management has not resulted in recovery, however, and since 1985 the monk seal population has continued to decline by about 3% a year (NMFS 2001).

The source of the recent decline has been changes in the population at French Frigate Shoals. In 1983 this subpopulation constituted approximately 50% of the entire population of monk seals. But beginning in the mid-1980s the population at FFS began a steep decline. The source of this decline remains unclear. It may be the result of reduced prey availability caused by a combination of factors including cyclic climatic changes in the North Pacific (Polovina et al. 1994, Schmelzer 2000), the population surpassing its carrying capacity (Craig & Ragen 1999), or from interactions with commercial fisheries (MMC 2001, Demartini et al. 1996).

Polovina et al. (1994) provide evidence for a decrease in oceanic productivity in the NWHI associated with the retreat northward of an Aleutian low pressure system. Given the position of FFS in the southern portion of the NWHI it would be expected to be most vulnerable to these changes in ocean productivity. This climatic change and the resulting change in productivity could in effect have lowered the seal carrying capacity of FFS. It has also been suggested that a collapse in lobster stocks in the NWHI was associated with the rise of a commercial lobster fishery during the 1980s (MMC 2001). This fishery may have resulted in declines in monk seals populations through competition for one of the seals' main food resources.

Pups and immature seals are particularly vulnerable to the change (Gilmartin & Eberhardt 1995). Only 8-25% of weaned pups survived to age 2 from 1989-1991 compared with over 80% in the 3 previous years (Craig & Ragen 1999). Similar rates of decline were also noted at Laysan Island (Craig & Ragen 1999).

Changes in subpopulations at many NWHI locations have been related to human-seal interactions. Kenyon (1972) and Gerrodette and Gilmartin (1990) noted that monk seals are very sensitive to human disturbance. While disturbance included direct harassment by humans and introduced animals like dogs, even seemingly innocuous activities such as walking on beaches are thought to cause seals to abandon preferred pupping and haul out habitat for less suitable locations. The steep population declines at Midway and Kure Atolls have been directly attributed to their intense human development (Gerrodette & Gilmartin 1990). At Midway, for example, during the 1950s to 1980s, the majority of seals hauled out on Spit Island which, although very small, was rarely visited by people. At Kure Atoll, females abandoned their preferred pupping sites when a Coast Guard station was established (Gerrodette & Gilmartin 1990).

These habitat changes can lead to lower survival and reproductive success. At locations other than preferred pupping sites, pups may be more vulnerable to predators or to being swept out to sea by waves and strong currents (Gerrodette & Gilmartin 1990). Human disturbance may also reduce the amount of milk a pup receives through nursing (Gerrodette & Gilmartin 1990). This may result in a lower probability of survival for that pup.

While human disturbance may cause seal populations to decline, the removal of human presence can also lead to recovery. Most notably, removal of a Coast Guard station at FFS led to re-colonization by seals and the dramatic population increase (Ragen & Lavigne 1999). Likewise, at Kure Atoll, reductions in human disturbance have assisted in population recovery (Toorenburg et al. 1993). At Midway Atoll, reductions in personnel and access restrictions to Eastern and Spit Islands have also led to increases in seal numbers and re-colonization of previously unused beaches (Gilmartin & Antonelis 1998).

Even with effective management of human disturbance, however, the monk seal population continues to decline. The mean number of non-pup animals counted during beach surveys has declined by 60% from 1958 to 1999 (NMFS 2001). For 2001 the estimated monk seal population was 1464 (NMFS 2001). Various management and research programs have been initiated in an attempt to better understand these changes and to promote recovery. Eberhardt et al. (1999) noted, "understanding the dynamics of an endangered species sufficiently well to design a management program requires knowledge of reproductive and survival rates." Gerrodette and Gilmartin (1990) expanded on this sentiment and noted:

> Monitoring should include more than estimates of population size. Estimating population size over time is a necessary but insufficient condition for monitoring. Factors that indicate the condition of a population can alert wildlife managers to

incipient problems at an earlier stage. Such factors include individual physiological condition, behavioral observations, and demographic characteristics of the population.

This type of information is gathered through the network of seasonal field camps in the NWHI. Research is also underway to better understand monk seal foraging behavior and prey preferences (Goodman-Lowe 1998, Goodman-Lowe et al. 1999a, Goodman-Lowe et al. 1999b, Parrish et al. 2000, Parrish et al. 2002). "Head starting" and relocation of seals to under-populated atolls has also been proposed and initiated as a means of re-establishing viable subpopulations (Gerrodette & Gilmartin 1990, Gilmartin & Eberhardt 1995, Gilmartin & Antonelis 1998). Rehabilitation and release of underweight female pups at Kure Atoll has resulted in high survival and reproductive success (Gilmartin & Antonelis 1998). Release of rehabilitated seals at Midway Atoll in 1992 and 1993 was less successful. Only 2 of 18 seals released survived beyond their first year (Gilmartin & Antonelis 1998). Finally, efforts continue to reduce human impacts on seals and their habitat (Gerrodette & Gilmartin 1990, Gilmartin & Antonelis 1998).

2.3 Monk Seals and Midway Atoll

Midway Atoll contains the most depleted of the monk seal subpopulations (Gilmartin & Antonelis 1998). The atoll consists of two main islands (Sand Island and Eastern Island) and a sand spit (Spit Island) lying at the southern border of the surrounding barrier reef (Figure 2.2). The 28 million year old atoll is 6 miles wide and contains approximately 1535 acres of land area. The atoll is 1250 km. northwest of Honolulu.

Since its discovery in 1859 Midway Atoll has seen a wide variety of human uses. Throughout the remainder of the 1800s Midway Atoll saw a variety of human inhabitants in the form of shipwrecked sailors and feather and shark hunters. The year 1902 marked the beginning of permanent settlement at the atoll with the establishment of a telegraph cable station. The establishment of a US Military base at Midway would later increase human presence dramatically. After World War 2 this human presence briefly declined but would increase again in the 1950s. The human population at Midway would peak during the 1950s to 1970s at approximately 3000 inhabitants.

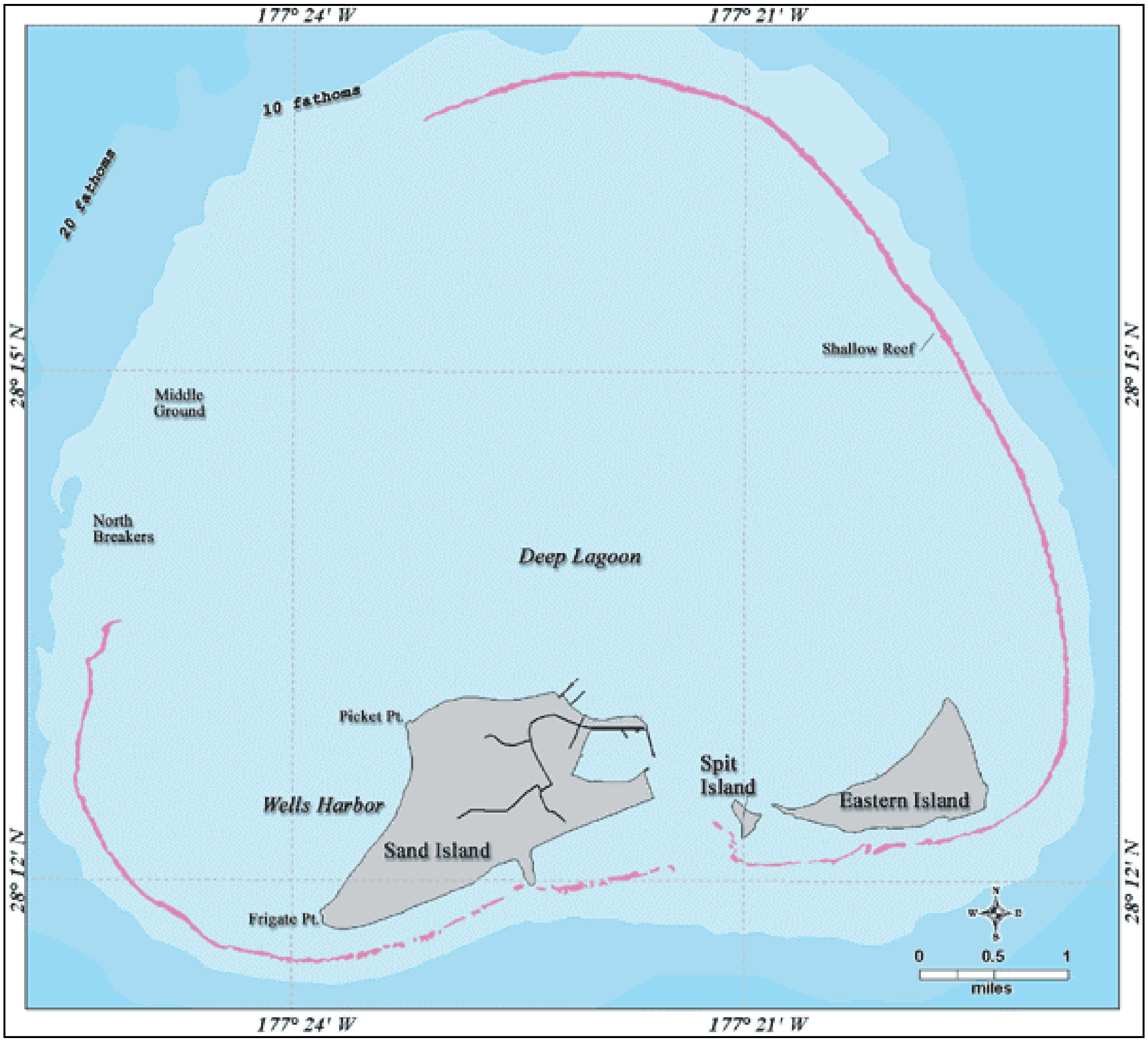


Figure 2.2. Map of Midway Atoll.

By 1978 Midway's human population was reduced to approximately 250 personnel (Ragen & Lavigne 1999). Also, beginning in the late 1980s access to Eastern Island and Spit Island was restricted (Gilmartin & Antonelis 1998). In 1988 Midway Atoll was designated as an overlay National Wildlife Refuge. The Navy air station was closed in 1993. In 1996 an executive order was signed that transferred Midway Atoll from the U.S. Navy to the U.S. Fish and Wildlife Service (FWS) and led to the establishment of the Midway Atoll National Wildlife Refuge. Also in 1996, the FWS entered an agreement with the Midway Phoenix Corporation (MPC). MPC was tasked with maintaining the infrastructure of Midway and providing air service and support for the approximately 250 civilian staff. As part of this agreement MPC also coordinated tourist access to Midway Atoll. From 1997 to 2001 as many as 100 tourists a day would visit Midway to view wildlife and its historic structures and airfields. The potential impacts of tourists on the wildlife, including disturbance of monk seals, are a concern (Gilmartin & Antonelis 1998). In an attempt to limit this impact, access to beach areas is strictly controlled. Spit Island is only accessible to monk seal biologists. Eastern Island is restricted to monk seal biologists, FWS personnel and one weekly tour group that remains in the island center. All inhabitants at Midway live on Sand Island. Beach access on Sand Island is restricted. Only a short section of beach (Sectors 1 – 4) is open for public use.

Coincident with human development at Midway were changes in the monk seal population. After the exploitation of monk seals in the mid 19th century it has been suggested that populations experienced a degree of recovery in the early 1900s (Ragen & Lavigne 1999). The first reliable estimates of monk seal abundance at Midway occurred in 1956-57. Beach counts at this time averaged 55.7+/-9.1 animals (Kenyon 1972). However, during the 1960s and 1970s the monk seal population declined sharply. An aerial survey in 1968 identified only one animal (Kenyon 1972). These declines have been attributed to the large human population and resulting disturbance to monk seals (Gilmartin & Antonelis 1998, Gerrodette & Gilmartin 1990).

In the early 1980s monk seal births at Midway averaged less than one per year (Gilmartin & Antonelis 1998). Since that time, however, beach counts and births have increased. Twenty-seven pups were born from 1995-1997 and an average of 15 animals were seen during beach patrols (Gilmartin & Antonelis 1998). While these increases are encouraging they do not compare with the rates of increase seen at Kure Atoll since the mid-1980s or at FFS from the 1950s to mid-1980s. Low survival rates to ages 1 and 2 at Midway may be a factor in slowing recovery of this subpopulation (Gilmartin & Antonelis 1998). Due to its close proximity to Kure Atoll and Pearl and Hermes Reef, Midway also hosts a high number of transient and immigrant seals. It is estimated that 30% of animals at Midway at any given time are either transients or immigrants from the neighboring reefs and atolls. This population of transients and immigrants is thought to have formed the vast majority of animals that used Midway during the 1960s to 1980s (Gilmartin pers. comm. 2003).

Given its special status as a Naval air station, monk seal research and management activities at Midway were limited and did not keep pace with efforts throughout the remainder of the NWHI. Midway Atoll was not included in the critical habitat designation for monk seals and a recovery plan for the population was not developed until 1998. However, management activities did begin to focus on Midway Atoll in the early 1990s. Given rates of decline at Kure Atoll as well as Pearl and Hermes Reef, and the Midway beach counts in the 1950s, it was estimated that Midway could at one time have had beach counts of 250 to 300 animals (Gilmartin & Eberhardt 1995). Similarly, Kenyon (1972) estimated that the pre-disturbance seal population at Midway was approximately 270 animals. These estimates suggest that there may be a large potential for recovery of the Midway subpopulation and the rebuilding of this subpopulation is considered essential (Gilmartin & Eberhardt 1995).

In 1997 the National Marine Fisheries Service (NMFS) released the report Recommended Recovery Actions for the Hawaiian Seal Population at Midway Island. Among the recommended recovery actions of the report were the following:

1. Assess monk seal population and habitat use characteristics,
2. Conduct research to guide recovery efforts,
3. Mitigate threats to seals and initiate recovery actions,
4. Develop an educational program to prevent interactions between humans and monk seals.

In 1997, the nonprofit group Hawaii Wildlife Fund began a year-round monk seal population monitoring program at Midway in cooperation with the National Marine Fisheries Service.

Year-round monitoring was considered essential in satisfying two program goals. First, monitoring would allow for the determination of the timing of post-weaning mortality. Second, monitoring would allow for the determination of whether haul out patterns changed as a result of human activity. Furthermore, the presence of biologists was thought to serve as a deterrent to further human disturbance of monk seals by island residents and tourists.

The cooperative research agreement between HWF and NMFS ended in January of 2000. Since that time NMFS has directly coordinated monk seal research activities at Midway. Year-round surveys were halted and replaced with seasonal research. In January of 2002 Midway Phoenix Corporation withdrew from its agreement with the FWS to maintain the infrastructure of Midway Atoll and provide air service. The departure of MPC also ended tourist access to the islands. Midway now houses a small staff of FWS biologists and support staff.

CHAPTER 3: PROJECT BACKGROUND AND OBJECTIVES

3.1 Project Background

This project entails analysis of monk seal haul out data collected at Midway Atoll from June 1997 to January 2000. This data was gathered by Hawaii Wildlife Fund biologists working in cooperation with the National Marine Fisheries Service and the U.S. Fish and Wildlife Service. Data were analyzed under the supervision of Bill Gilmartin, Director of Research for Hawaii Wildlife Fund.

This project draws directly from the research and management recommendations stated in the 1998 Recommended Recovery Actions for the Hawaiian Seal Population at Midway Island. Among these recommendations were the following high priority recovery actions:

1. Determine spatial and temporal, and age-, seasonal-, and sex-specific hauling patterns.
2. Analyze beach census data for hauling changes related to human activities (tour aircraft, clean-up, research, etc.)
3. Identify preferred pupping and nursery beaches.

Recommended action 1 suggests the value of identifying spatial and temporal patterns and changes in abundance. Such analyses could identify particular times of year or particular size classes of animals in which those animals are present or absent from the atoll for longer periods. This could suggest a time of year in which those animals must spend more time foraging (Gilmartin 2003 pers. comm.). This research is of particular importance for immatures and adult females given their relatively high degree of importance for the recovery of the population. These patterns may suggest possible management strategies to ensure recovery of the Midway subpopulation.

Recommendation 2 addresses the concern over the sensitivity of monk seals to human disturbance. Particularly at Midway Atoll, which until recently had 250 residents and a potential of 100 tourists, human presence could slow recovery of the population. Identification of changes related to human activities could suggest possible management actions to address potential problems.

Recommended action 3 recognizes the importance to monk seal recovery at Midway of identifying preferred pupping habitat and protecting that habitat from human disturbance.

This research draws directly upon these recommended actions in identifying the questions asked and the types of analyses conducted. Given the large amount of information contained within the dataset, other more exploratory analyses were also planned. These analyses include:

1. Assessing the change to beach counts when the barrier reef is included in the analysis.
2. Assessing the differences in information obtained from seasonal vs. year-round studies at Midway with particular emphasis on mean beach counts and number of pups identified.

Beach counts play a key role in assessing monk seal abundance in the NWHI. Yet these counts do not include in their estimates the number of seals hauled out at the same time on the barrier reef. By analyzing data from the barrier reef one can develop a corrected beach count total and have a more accurate estimate of animals hauled out over the entire atoll.

This data set is the only year-round study of Hawaiian monk seals. One can use this data to identify the types of information that would have been lost had the Midway research been conducted seasonally. Such information could prove important in effectively managing monk seals and promoting their recovery.

3.2 Project Objectives

From these broad research questions and recommended actions listed above we developed the following specific research questions and objectives.

1. Determine spatial and temporal, and age-, seasonal-, and sex-specific hauling patterns.
2. Identify preferred pupping and nursery beaches.

3. Analyze beach census data for hauling changes among islands.
4. Assess changes to beach counts when the barrier reef is included in the analysis with particular emphasis on immature and weaned animals.
5. Assess the differences in information obtained from seasonal vs. year-round studies at Midway with particular emphasis on mean beach counts and number of pups identified.

CHAPTER 4: METHODOLOGY

This study is based on field research conducted at Midway Atoll from June 1997 through January 2000. The research consisted primarily of beach monitoring for hauled out monk seals through censuses and patrols.

A census is a "timed standardized beach count in which an entire island or atoll is surveyed for seals on foot (Johanos & Baker 2002)." Censuses occurred approximately weekly and began at 13:00 to coincide with the peak occurrence of seals on the beach (Kenyon 1959). A census was considered complete if Sand, Eastern and Spit Islands were each surveyed within a 2 day period. The primary goal of a census is to quantify the number of animals hauled out at the Atoll on a given day. Patrols refer to "untimed surveys of an entire island perimeter on foot (Johanos & Baker 2002)." Patrols also count individual seals but also spend time collecting additional information regarding seal condition, behavior and sample collection. While censuses and patrols do not provide a direct estimate of population size they do provide an abundance index that can be compared across years and locations (Johanos & Baker 2002).

Information collected on seals during beach surveys includes the following:

- Size class: adult, subadult, juvenile, weaned, pup
- Sex: male or female
- Location: by island and sector
- Beach position: on the beach or in the water
- Identification information: permanent or temporary identification and tag numbers
- Molt status: percentage of molt completed

An adult seal is defined as reproductively active or of breeding size. A mature or probably mature seal (NMFS 1996). A subadult seal is perceptibly larger than juveniles up to breeding size, is less robust than adults and generally has a lighter pelage. Subadults are likely 3 to 6 years of age (NMFS 1996). A juvenile is a short, slight seal from the length of a weaned pup to 20 to 30cm. longer and includes yearlings and perhaps younger seals up to an age of approximately 3 years (NMFS 1996). A weaned seal is one born within a calendar year but no longer nursing. A pup refers to a recently born seal that is nursing.

Identification of individuals is made using a combination of temporary and permanent tags or markings. These include distinctive scar patterns, temporary numbers bleached into an animal's pelt and permanent plastic tags applied to an animal's rear flippers.

To assist in identifying haul out locations each of the three islands is divided into sectors (Figure 4.1). Sand Island, Eastern Island and Spit Island contain 29, 9 and 4 sectors, respectively. These sectors are not of standard size and some sectors contain structures such as seawalls that make haul outs impossible. The barrier reef surrounding the main islands was also monitored regularly and divided into sectors. The barrier reef was not included in censuses.

Particular emphasis was paid to the identification of parturient females. When possible, birth, nursing and weaning information were recorded (Johanos & Baker 2002).

Data was collected and entered by Hawaii Wildlife Fund biologists and managed by the National Marine Fisheries Service in Honolulu, Hawaii.

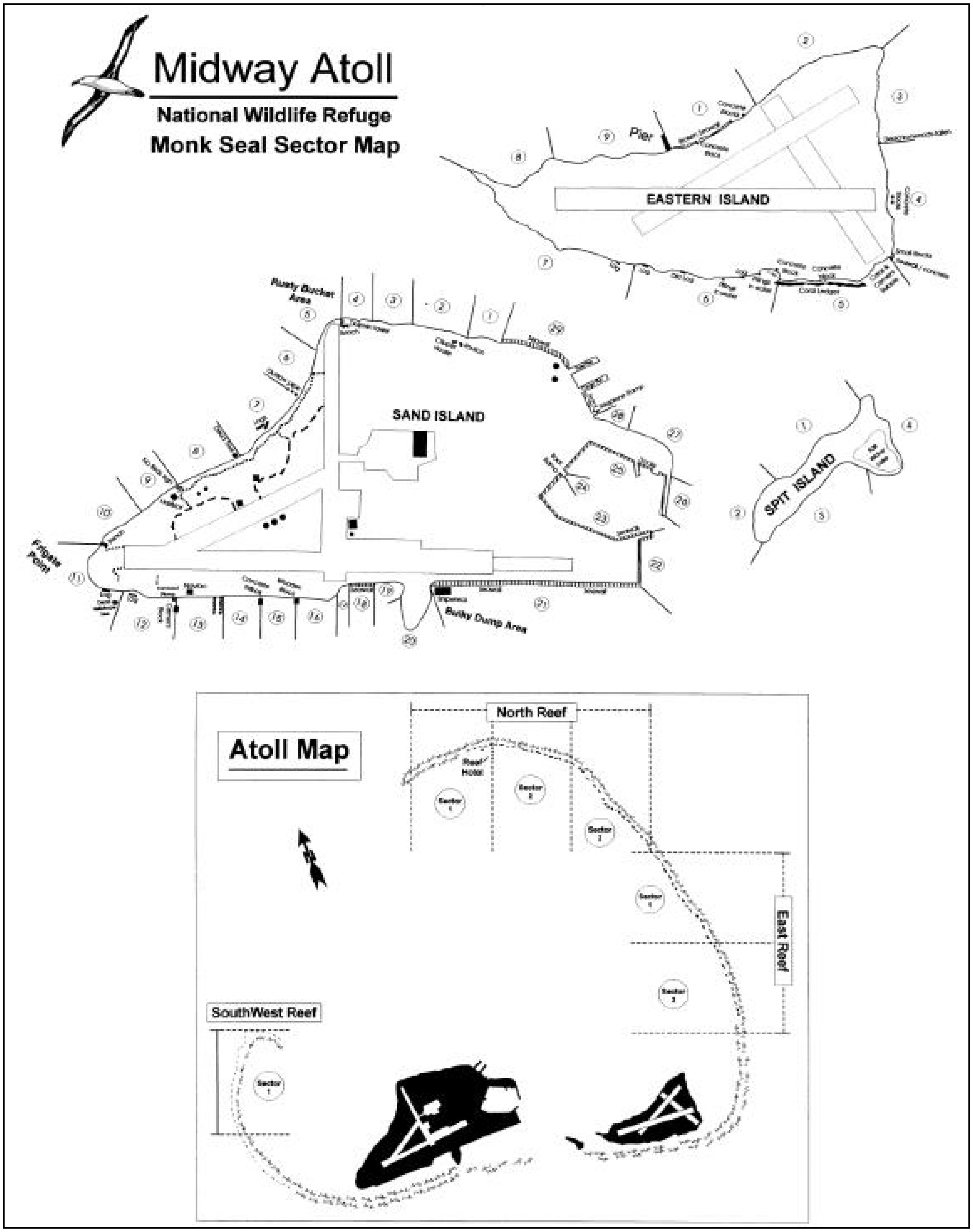


Figure 4.1. Monk seal sector map of Midway Atoll.

CHAPTER 5: RESULTS

Results in this chapter are divided into sections based upon the project objectives listed in section 3.2. These include analyses of spatial and temporal haul out patterns, haul out patterns between islands, seasonal changes in haul out patterns, influence on beach counts from inclusion of the north reef data and differences in results of year-round versus seasonal studies.

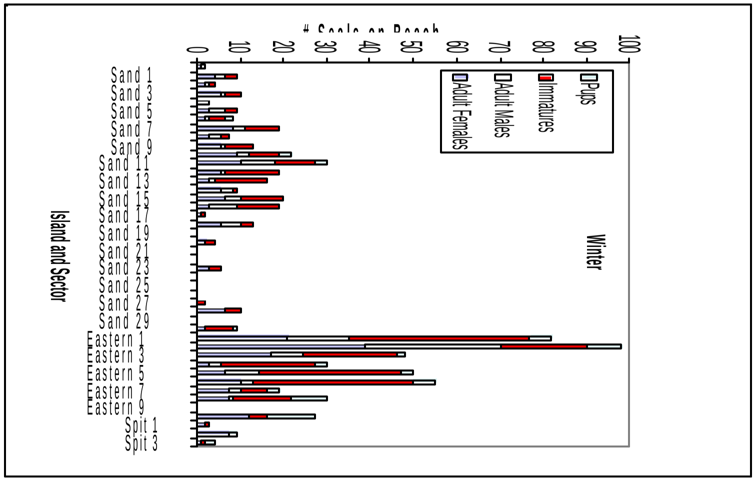
5.1 Spatial and temporal haul out patterns by sex and size class

Haul out patterns may differ by island or by size or sex of animal. To examine these possible differences the data were grouped spatially and temporally and by size class and sex of animal. Spatial groupings refer to organizing the data by island sector. Temporal groupings refer to organizing the data seasonally. The seasons were defined as follows: winter (12/21 to 3/20), spring (3/21 to 6/20), summer (6/21 to 9/22) and fall (9/23 to 12/20). Seals were also organized by size class. Size classes include adult, immature (juveniles + subadults) and pups (nursing and weaned animals in their first calendar year). Animals were also grouped by sex. This analysis included data for all of 1998 and 1999. Data from June to December 1997 and January of 2000 were ignored so as to avoid biasing the seasonal totals.

The results of these analyses are presented in figures 5.1, 5.2, 5.3 and 5.4.

The results in figure 5.1 indicate that the distribution of seals varied seasonally and by size class and sex. Total beach counts were highest in the fall and winter and lowest in the spring and summer. Some island sectors had more than double the number of animals hauled out in the winter than in the summer. For example, sector 3 on Eastern Island had 98 animals hauled out during the winter and 49 during the spring.

Figures 5.1 – 5.4 indicate that the number of animals hauled out was highest on Eastern Island regardless of season. Given its small size, Spit Island also had a high concentration of seals. This is particularly true with respect to adult females which used Spit Island to nurse and molt.



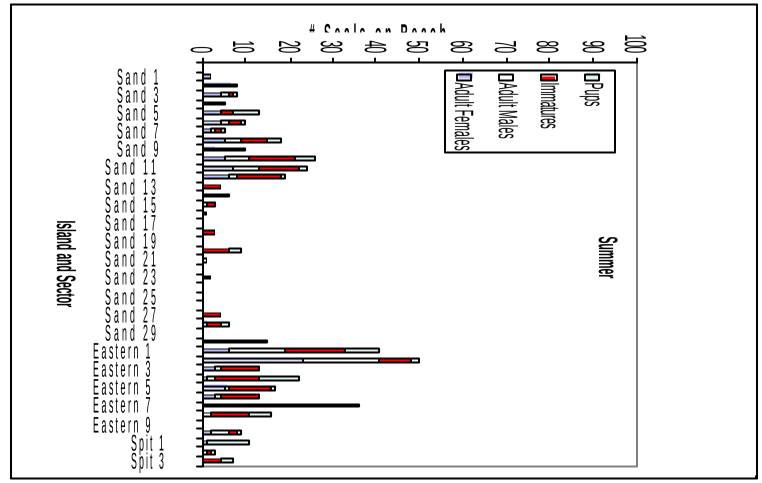
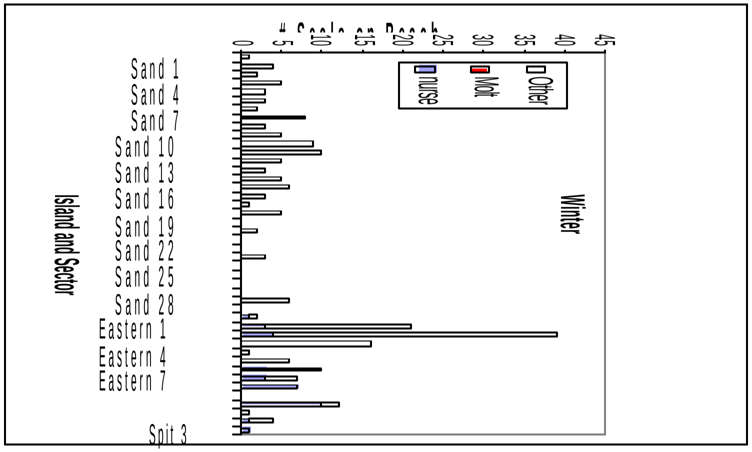


Figure 5.1. Seasonal distribution of monk seals (all size/sex groups) based on beach censuses at Midway Atoll, 1998-1999.



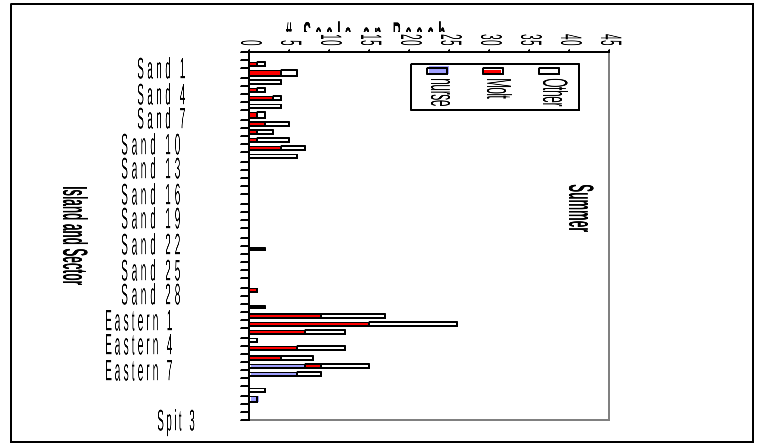
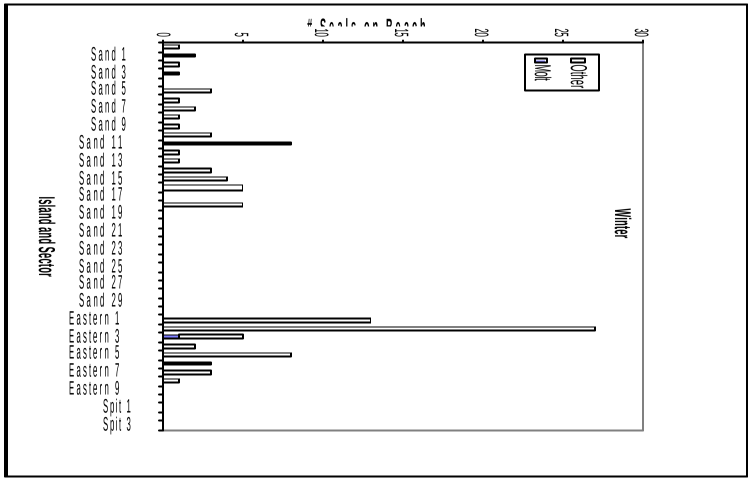


Figure 5.2. Seasonal distribution of adult female monk seals based on beach censuses at Midway Atoll, 1998-1999.



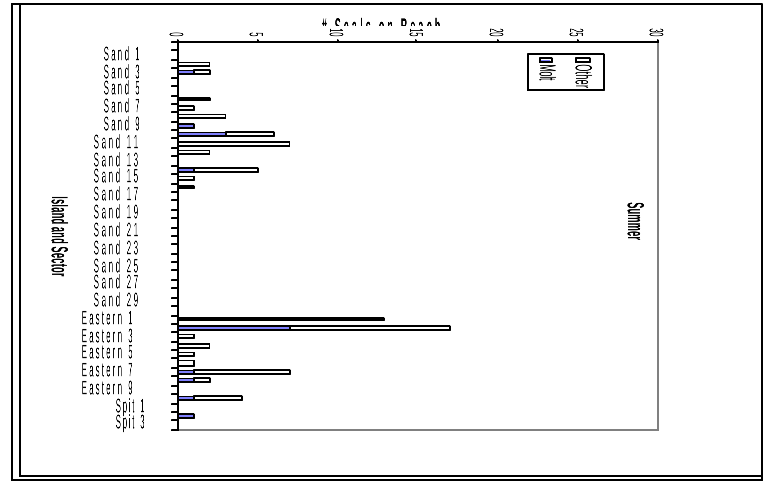


Figure 5.3. Seasonal distribution of adult male monk seals based on beach censuses at Midway Atoll, 1998-1999.

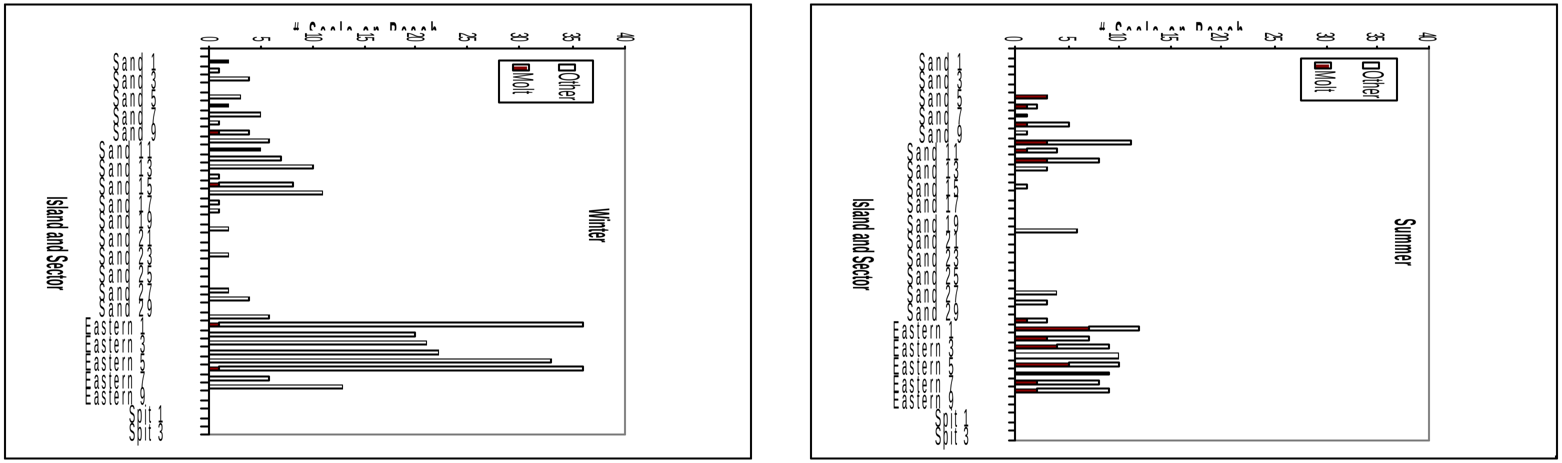


Figure 5.4. Seasonal distribution of immature monk seals based on beach censuses at Midway Atoll, 1998-1999.

The results in figures 5.2 - 5.4 show that the majority of molting occurred on Eastern Island for all size classes and both sexes.

Figure 5.2 indicates that adult females pupped and nursed almost exclusively on Eastern and Spit Islands. Sectors 7 to 9 on Eastern Island as well as all of Spit Island could be considered preferred pupping habitat.

5.2 Analysis of haul out patterns among islands

As was stated in chapter 2, monk seals are very sensitive to human disturbance. Results in section 5.1 indicated that Eastern and Spit Islands had higher concentrations of hauled out seals than Sand Island. This result was expected given that Eastern and Spit Islands have seen little human disturbance since the 1980s while Sand Island maintains a human population of 250. But with establishment of Midway as a national wildlife refuge came greater restrictions on beach access on Sand Island. During the 1990s, beach counts at Midway Atoll also began to increase.

The results in this section assess whether there were any shifts in beach counts between islands from 1997 to 2000. That is, have beach counts begun to shift from Eastern and Spit Islands to Sand Island as management and controls on human disturbance have been improved?

Figure 5.5 illustrates the variations in beach counts by island from 1997 to 2000. Similar to the results displayed in figures 5.1 – 5.4 this figure indicates that there is a seasonal cycle in beach counts. Beach counts were highest on all islands during the winter months and lowest during the summer. One can test this statistically using autocorrelation analysis (Levine et al. 2002, Chatfield 1975). Autocorrelation analysis of the data for Sand, Eastern and Spit Islands indicated that all three time series were serially correlated.

To accurately assess a serially correlated time series it is necessary to remove the cyclic pattern from the data. Serial correlation coefficients were derived to remove the serial correlations from the time series (Ramsey & Schafer 1997). These coefficients were then applied to the slope

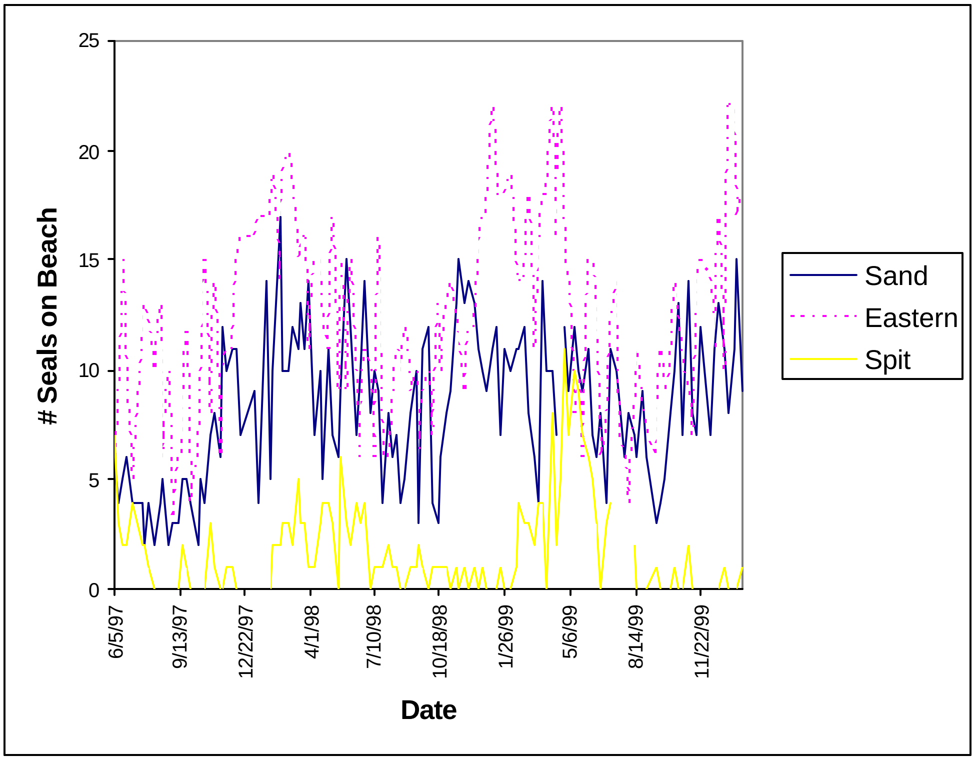


Figure 5.5. Monk seal beach censuses for Sand, Eastern and Spit Islands, 1997 - 2000.

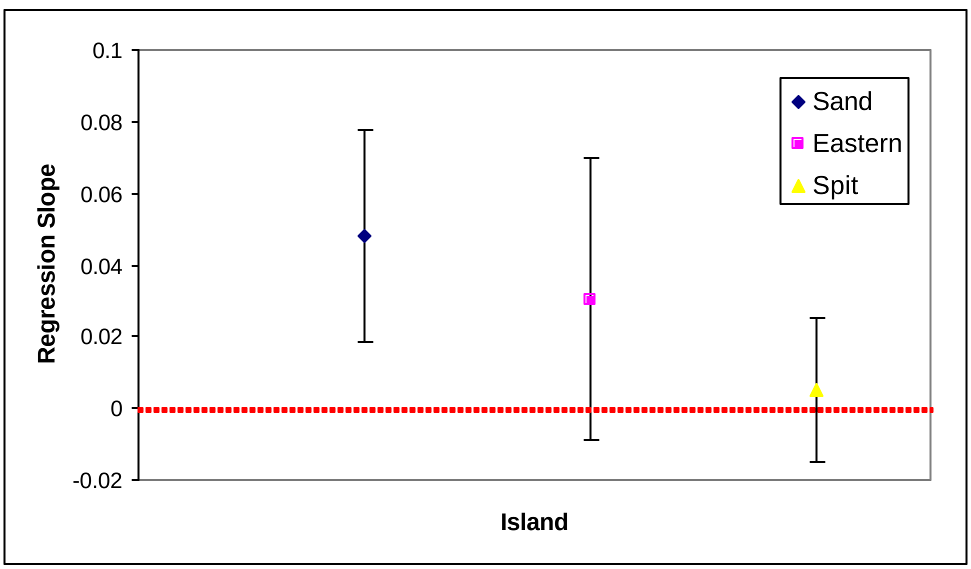


Figure 5.6. Regression slope values with confidence intervals for beach counts on Sand, Eastern and Spit Islands after correcting for serial correlations.

values of the regression lines for each data set to yield a corrected slope value. This corrected value is the slope of the regression line for each time series with the seasonal cycle removed.

Figure 5.6 plots the corrected slopes and confidence intervals for each island. The results indicate that that there is a statistically significant increase in beach counts on Sand Island. Beach counts on Eastern and Spit Islands could not be shown with statistical significance to be either increasing or decreasing. However, the slope values for both Eastern and Spit were positive.

5.3 Analysis of seasonal changes in haul outs

Sections 5.1 and 5.2 have described the presence of a season cycle in haul out data by island, sex and size class. This section extends the analysis of seasonality in beach counts. Figure 5.7 plots beach count totals for total non-pup animals, adult females and immatures. These plots suggest varying strengths of seasonal signals in the time series.

Adult females and immatures were selected due to their particular significance in leading to the recovery of the Midway seal subpopulation. Adult males were excluded from the analysis because of differences in their behavior. Adult males spend considerable amounts of time cruising the waters of the atoll in search of females. It is therefore difficult to differentiate between the time adult males spend foraging and the time spent searching for potential mates.

Levine et al. (2002) describe a method for assessing the relative strength of a rhythmic pattern in a time series. This method entails calculating a ‘Rhythmicity Index (RI)’ based upon the results of autocorrelation analysis. In this method the strength of a rhythm is based upon the height of the second peak in the correlogram (figure 5.8). Peak heights can be compared between time series because they are based on normally distributed and dimensionless correlation coefficients (figure 5.9).

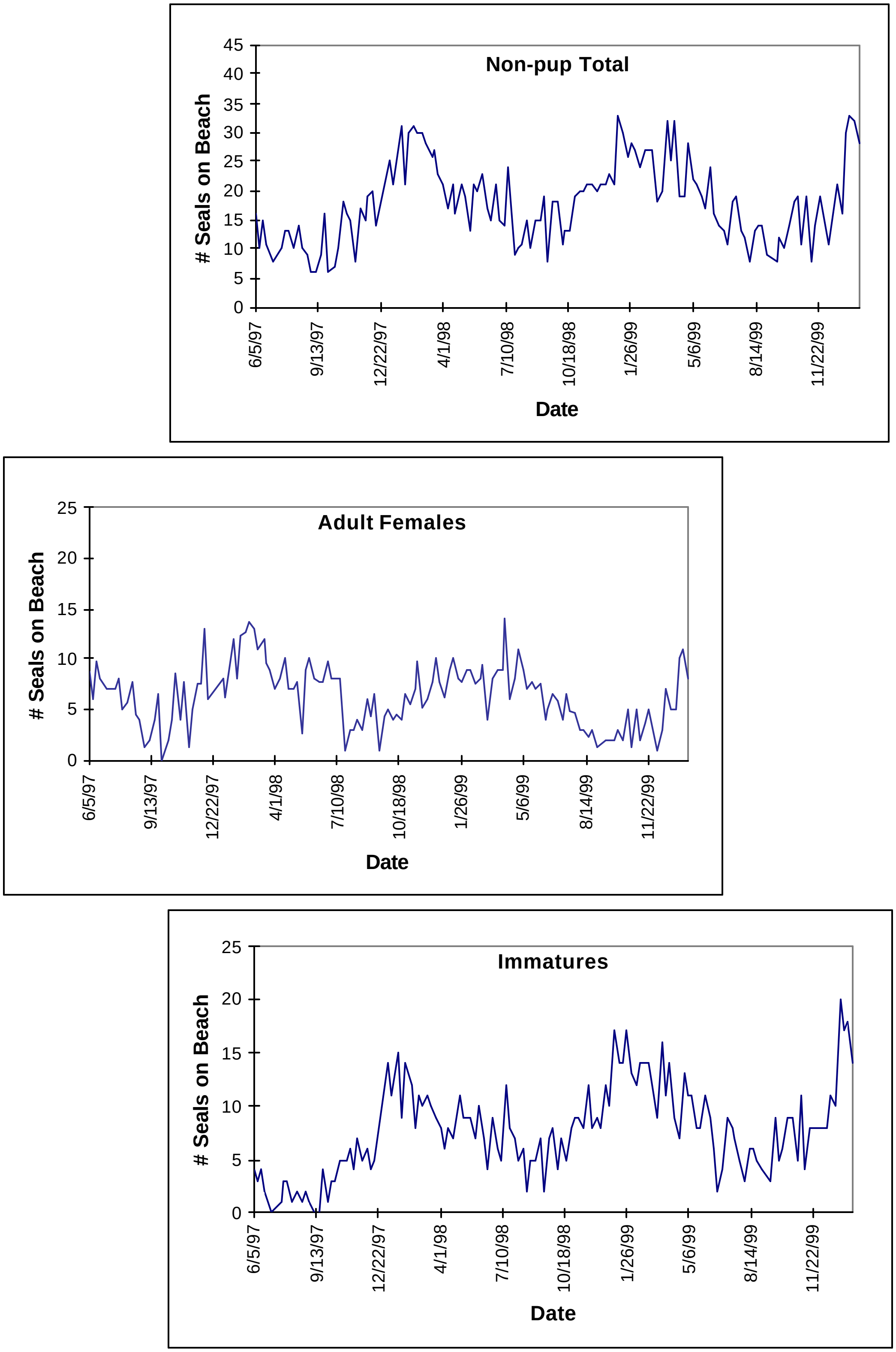


Figure 5.7. Numbers of seals counted during beach censuses at Midway Atoll, 1997-2000.

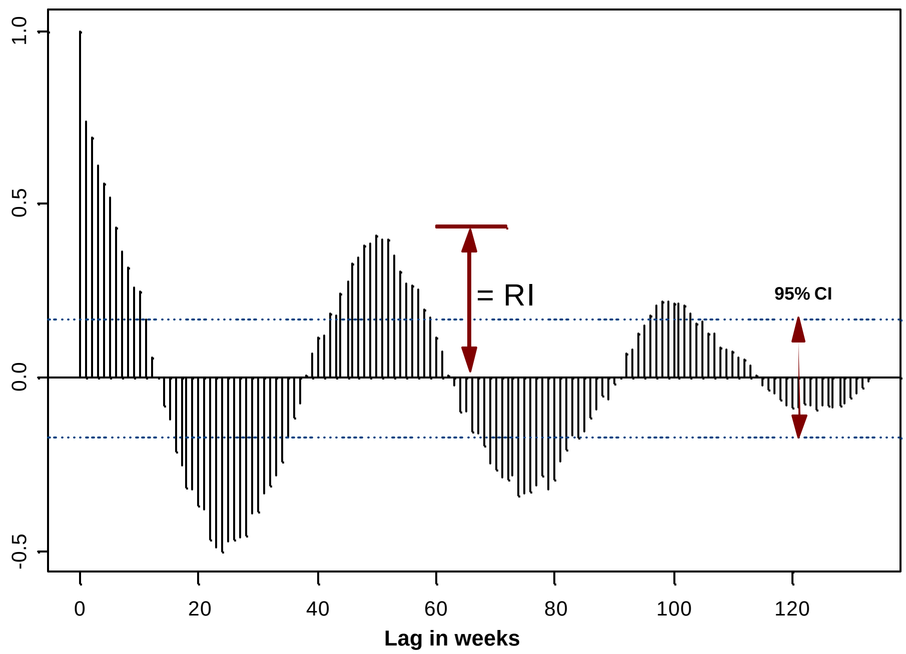


Figure 5.8. Sample data set showing how a Rhythmicity Index value is calculated from a correlogram. Note, a rhythmic cycle exists when the second upper peak to the left crosses the 95% confidence interval.

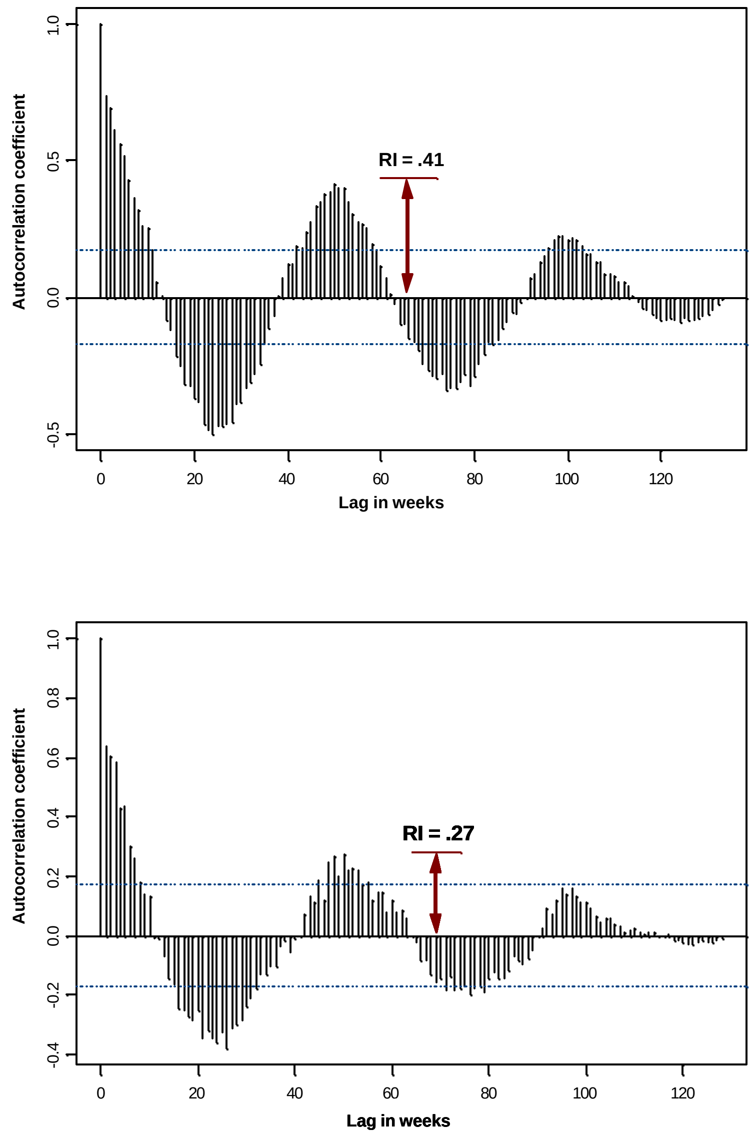


Figure 5.9. Demonstration of how the relative strength of Rhythmicity Indices can be compared between two time series.

The goal of this analysis is to identify seasonality associated with the presence/absence of seals on the beach. Absence of seals from the beach indicates times when those animals are foraging. A stronger seasonal signal could indicate a tighter connection between seals and a seasonally abundant food source. It is also known that animals that are molting or nursing are much more likely to be counted during beach patrols. Yet the presence of these animals on the beach is not indicative of behavior associated with foraging. To get an accurate seasonal signal for the presence/absence of seals on the beach independent of molting and nursing behavior it was necessary to remove molting and nursing animals from the analysis.

Each of the time series – non-pup total, adult females, and immatures – was first tested using autocorrelation analysis. Results indicated that a rhythmic pattern was present in each time series (Figure 5.10). The second positive peak in each correlogram indicates the completion of one complete cycle. The lags in these data sets occurred at the 50^{th} time step. Since each time step is equal to approximately one week this indicates that the cycle described repeats itself approximately annually (50 time steps = 50 weeks). The rhythmicity indices for each time series are listed in table 5.1.

The strongest seasonal signal was for total non-pup animals. Immature animals also have a strong seasonal signal. Adult females have the weakest of seasonal signals although there is still rhythmicity present in this time series.

Table 5.1. Rhythmicity Index values for selected time series.

Time Series	Rhythmicity Index (RI)
Total Non-pup Animals	0.4115
Adult Females	0.2874
Immatures	0.3454

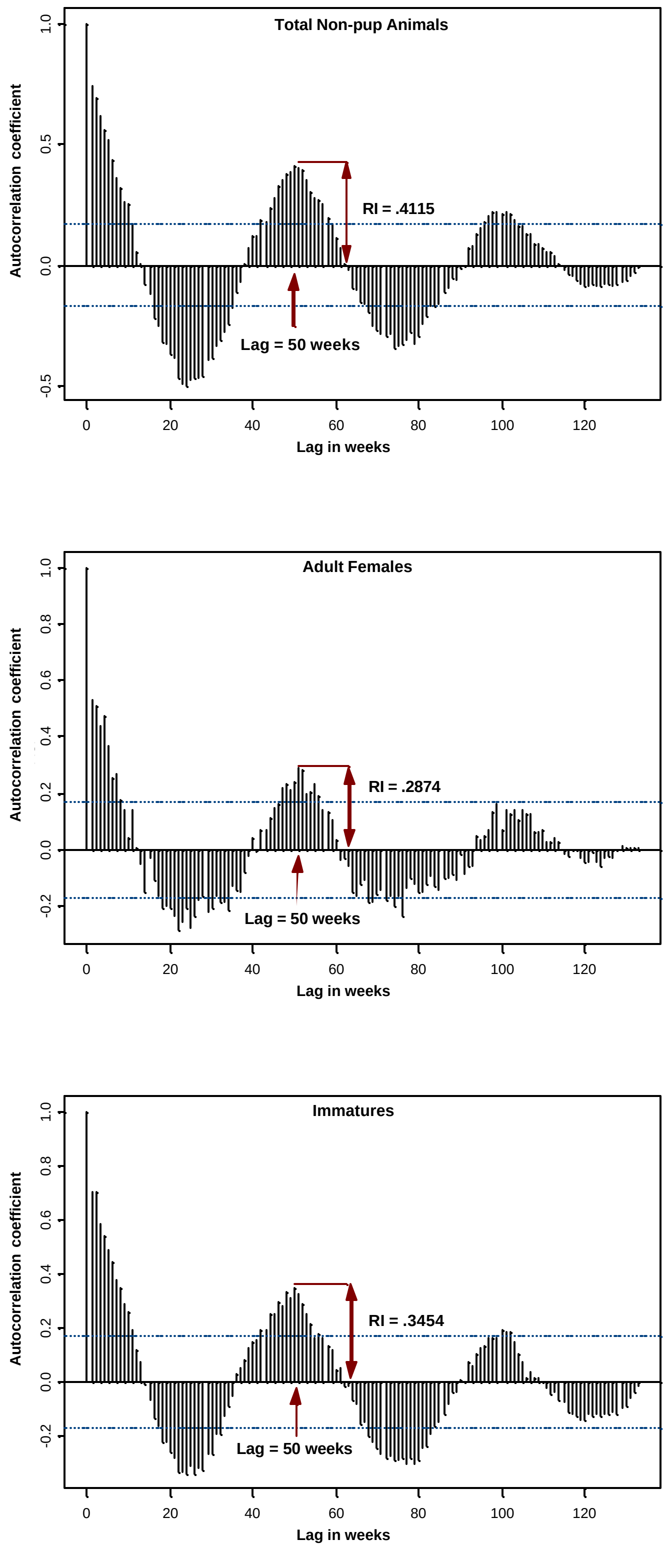


Figure 5.10. Results of autocorrelation analysis on total non-pup animals, adult females and immatures.

5.4 Influence of the North Reef on beach counts

Beach censuses do not include the barrier reef surrounding atoll islands. Yet it is known that monk seals haul out on the barrier reef. The year-round nature of the Midway study along with a suitable island infrastructure and access to equipment (boats, kayaks, radios, etc.) allowed biologists to make frequent seal patrols along the barrier reef. Patrols of the reef began in January of 1998 and continued throughout the remainder of the study. This section uses this data to assess the influence that inclusion of barrier reef data has on beach counts by season and size class.

Data for the barrier reef were grouped according to reef sectors: North Reef, East Reef and Southwest Reef (Figure 4.1). Usage of the East and Southwest Reefs was negligible and will be excluded from further analysis. The North Reef, however, showed consistent use. A daily average of 4.6 ± 2.5 and a maximum of 11 animals used the North Reef (Table 5.2).

Use of the North Reef also varied seasonally and by size class. Figure 5.11 presents the seasonal distribution of animals on the north reef by size class and sex. Daily average reef counts were highest for pups followed by immatures and adults (Table 5.2). Figure 5.11 and Table 5.3 indicate that use of the North Reef also varied by season. Usage peaked in the summer and was lowest for all size classes in the spring and fall. Much of the seasonal variation was due to fluctuations in the number of pups (first year animals) using the reef (Figure 5.11). Pup beach counts must be viewed with some caution. The zero value for winter beach counts is due to the fact that all first year animals are automatically converted to juveniles on January 1. As a result, pups only enter the population as they are born, nursed and weaned. This is represented in the data as the increase in pups throughout the spring and summer. This may also partially explain the high winter value seen for immatures (as pups are reclassified as juveniles).

After determining that seals regularly used the North Reef the next step was to determine how this might affect the haul out patterns seen in the census data. The particular question of interest was whether, by adding the North Reef data in with the census data, the strength of the seasonal signal would be diminished. To combine the North Reef data with the census data it was

Table 5.2. Average haul outs at the North Reef by animal size class.

Size Class	Mean ± Standard Deviation
Total Animals	4.64 ± 2.49
Adults	1.00 ± 1.13
Immatures	2.14 ± 1.26
Pups	1.51 ± 1.67

Table 5.3. Haul outs at the North Reef by season and animal size class. Values are averages ± standard deviation.

Size Class	Winter	Spring	Summer	Fall
Total Animals	4.33 ± 2.31	3.43 ± 1.89	5.55 ± 2.77	4.61 ± 2.26
Adults	1.54 ± 1.53	1.07 ± 1.33	0.93 ± 1.02	0.77 ± 0.80
Immatures	2.75 ± 1.06	2.25 ± 1.11	2.20 ± 1.30	1.71 ± 1.35
Pups	0.00 ± 0.00	0.18 ± 0.39	2.43 ± 1.65	2.13 ± 1.57

Table 5.4. Comparison of average beach counts for beach censuses with and without data for the North Reef. Values are averages ± standard deviation.

	Beach Census Only	Beach Census + North Reef
Total Animals	22.04 ± 7.04	26.02 ± 6.25
Total Adults	8.95 ± 3.48	9.24 ± 3.65
Total Immatures	7.43 ± 3.56	9.52 ± 3.94
Total Pups	4.33 ± 2.52	6.02 ± 2.53

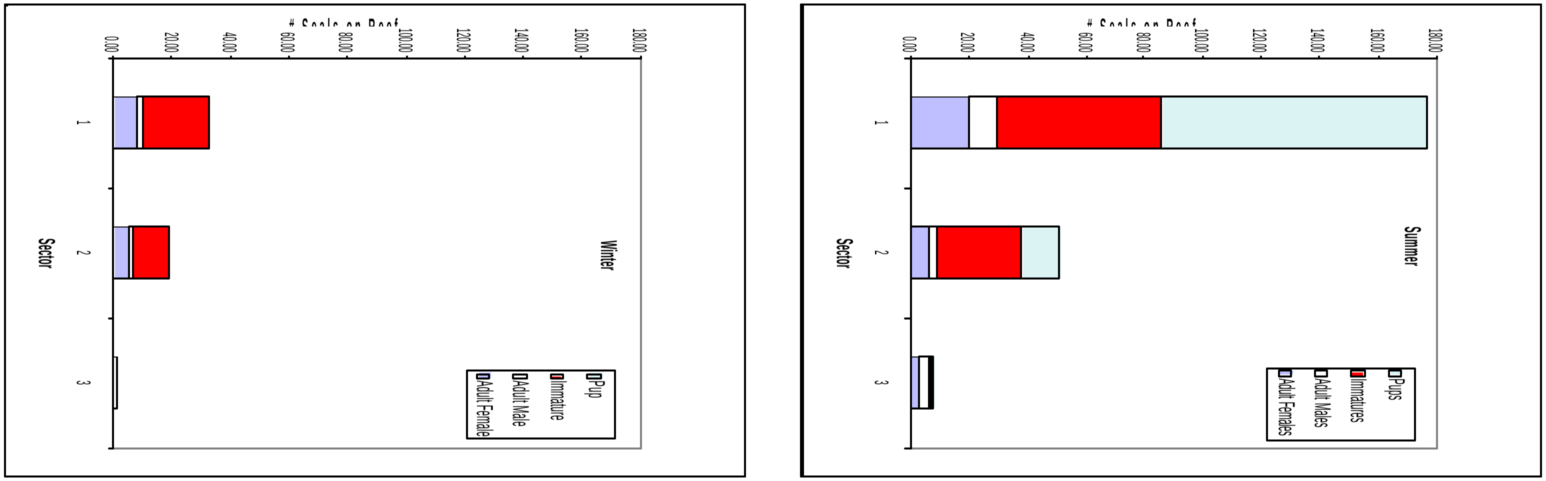


Figure 5.11. Results from reef patrols showing the seasonal distribution of animals hauled out on the North Reef at Midway Atoll, 1997-2000.

necessary to identify those dates on which a North Reef patrol was conducted within one day of a beach census. Forty-two of the 133 possible dates satisfied this requirement. These 42 dates can be considered “whole atoll” censuses as opposed to censuses of just the 3 atoll islands.

Unfortunately because of this limited number of dates and because these dates were not evenly distributed throughout the study period (reef patrols occur primarily in the summer) it was not possible to use autocorrelation analysis to assess the rhythmicity of the data. However, a comparison of average beach counts with and without North Reef data was possible (Table 5.4). Total beach counts rose by approximately 4 animals when the North Reef was included. Daily totals for immatures and pups each increased by approximately 2 animals.

Further analysis of the North Reef data revealed that several immature seals hauled out at the North Reef for extended periods, typically during the summer. In the most extreme case seal RY00, a female born in 1997, was not identified hauled out on Sand, Eastern or Spit Islands for two periods of over 100 days. RYOO was not seen on the islands from 4 April 1999 to 9 August 1999 (127 days) and from 11 August 1999 to 6 December 1999 (117 days). The average number of days between sightings of RYOO with and without inclusion of the North Reef data was 3.9 and 7.4 days, respectively. If Midway operated as a seasonal field camp with no reef patrols than it is possible that this animal would not have been seen for the entire year 1999

5.5 Differences between year-round and seasonal research

A final goal of this project was to begin to describe the types of information that can be derived from a year-round study of monk seals that could not be obtained from a seasonal study.

To do this it was necessary to subset the Midway data based on the dates of the seasonal research camps on the other islands in the NWHI. Season lengths for each of the main field camps were obtained for the years 1993 to 2000. An average field season was then calculated based upon the average start and end dates. The resulting sample field season began on May 5 and ended on July 17. Any census data for Midway that did not fall within this sample field season was discarded (Figure 5.12).

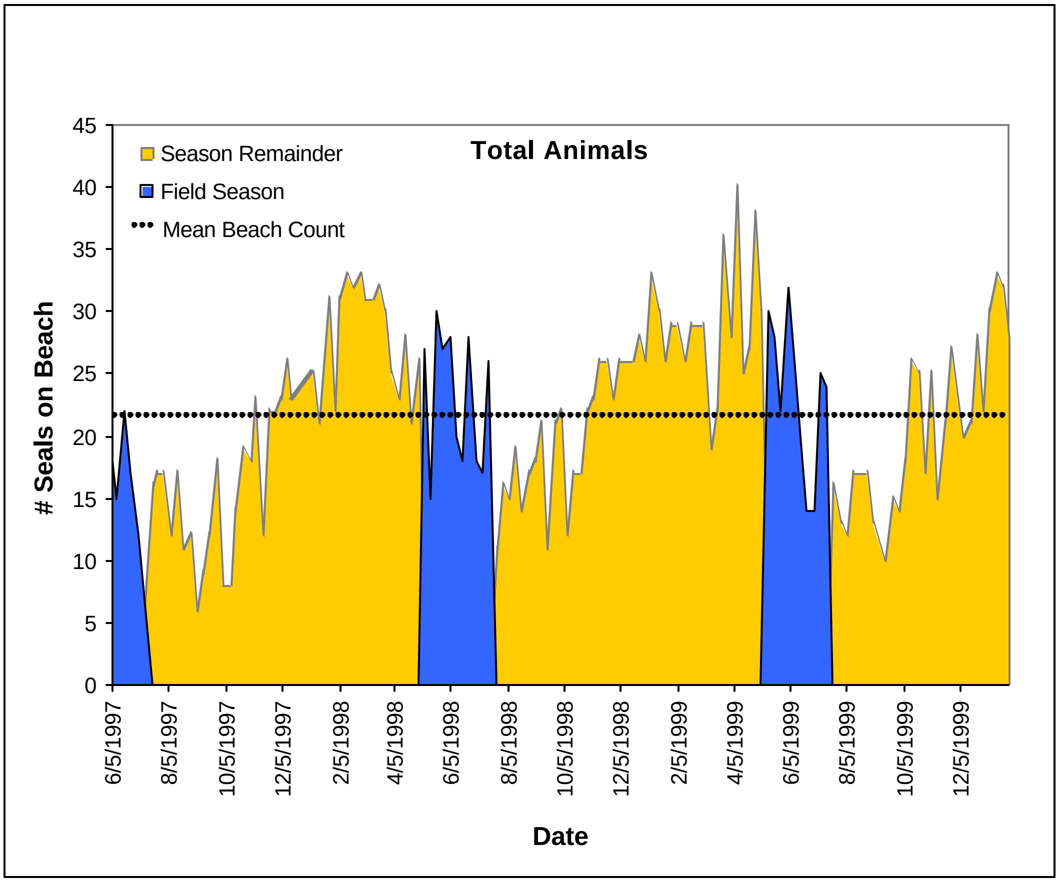


Figure 5.12. Beach census totals for Midway Atoll, 1997-2000. The blue region represents census data that would have been collected during a field season lasting from May 5 to July 17. The yellow region represent those censuses that would have fallen outside the seasonal field camp. The dotted line is the mean beach count for both the total data set and the blue region only.

Two questions were of interest with this shortened data set:

1. How does the shortened data set impact the ability to develop reproductive histories for adult females (how often does she pup, which animals are her offspring, what is the survival rate of her offspring, etc.)?
2. How does the shortened data set affect the mean beach count?

To answer the first question it was necessary to identify (1) the first day a newborn pup and mother were identified and (2) the last day the mother/pup pair were seen together before weaning. If both these dates fell outside the shortened field season then the reproductive information for that female was lost as well as all associated information for the pup. This analysis revealed that of the 34 mother/pup pairs at Midway from June 1997 to January 2000, 19 (56%) would not have been identified with a seasonal field camp.

The second question required comparing mean beach counts from the shortened field season with that of the entire data set. Somewhat surprisingly, the mean beach counts for the shortened season and whole data set were exactly equal, 22.04 seals/day. What is clear, however, is that the shortened data set fails to capture the seasonal cycle in beach counts (Figure 5.12).

CHAPTER 6: DISCUSSION

The discussion of results will proceed in the same order in which the results were presented. This discussion will be followed by recommendations for future research.

6.1 Spatial and temporal haul out patterns by sex and size class

Section 5.1 presented the first exploratory analysis of the Midway monk seal data. This analysis revealed several patterns in the data. First, the distribution of monk seals at Midway Atoll differed by season, animal size and sex. Second, beach counts were highest during the winter and lowest during the summer. Third, haul outs were concentrated on the two uninhabited islands, Eastern Island and Spit Island. Fourth, the majority of molting occurred on Eastern Island. Fifth, pupping occurred almost exclusively on Eastern Island and Spit Island with sectors 7 to 9 on Eastern Island being considered as preferred pupping habitat.

These findings guided some of the other analyses discussed in this project and will be discussed with reference to those sections. However some conclusions can be drawn here. It is clear that the history of human presence at Midway has altered the haul out behavior of monk seals. The majority of haul outs are concentrated on the two uninhabited islands. Pupping and molting in particular were heavily concentrated on Eastern and Spit. This is not surprising given the fact that these are two time periods when seals are most sensitive to disturbance. This finding further bolsters the argument presented by other researchers regarding the sensitivity of monk seals to human disturbance and the need to manage human presence at haul out sites (Gerrodette & Gilmartin 1990). Haul outs at Sand Island could increase, even to include molting animals, if effective management of human presence continues.

This research also identified the main pupping sites at Midway to be on Eastern and Spit Islands. The areas identified, particularly sectors 7 to 9 on Eastern, are wide beach zones with shallow and somewhat protected nearshore waters. These sites will likely remain preferred pupping sites and should be considered as areas worthy of increased protection from human disturbance. The lack of sites with similar physical characteristics on Sand Island suggests that even with better management of the human population, Sand Island will not see a large increase in pupping (Gilmartin pers. comm. 2003).

6.2 Analysis of haul out patterns between islands

Changes in monk seal management practices at Midway since the 1980s along with the transition of the atoll to national wildlife refuge status have resulted in a population increase. The purpose of this section was to assess whether that recovery has occurred at different rates on the three islands that make up the atoll. Of particular interest was the trend in beach counts on Sand Island. Sand Island was the residence for the atoll's human population and saw often intense use by tourists interested in viewing wildlife and accessing beaches and coastal trails. It also saw the implementation of beach closures and other measures designed to minimize disturbance of monk seals.

The results presented here indicate that these measures may have been successful in helping to control disturbance and to facilitate the re-colonization of Sand Island by monk seals. The trend in beach counts for Sand Island was distinctly positive. This differed somewhat from Eastern Island, which, while it had a positive slope to its beach count trend, could not be concluded statistically to have an increase in beach counts. Beach counts at Spit Island also could not be determined statistically to be either increasing or declining.

With an increasing seal population at Midway and with the majority of haul outs occurring on Eastern and Spit it may be unclear why these two islands do not show an increase in beach counts. Several explanations are possible. It may be that, given the low number of seals using Sand Island, an increasing trend in beach counts would be more easily identified. Results for Eastern Island also had a large 95% confidence interval. This is due in part to the large temporary increases in beach counts on Eastern Island due to molting, pupping and nursing. This results in some beach counts being particularly high while others are at more expected levels. By removing nursing and molting animals from the analysis the confidence interval for Eastern Island may tighten and result in a clear positive trend in beach counts. Due to its small size, Spit Island may simply be reaching a carrying capacity in terms of the number of seals willing to haul out on its beaches. The presence of nursing females on Spit Island also discourages adult males from approaching the beach (Gilmartin pers. comm. 2003).

Gerrodette and Gilmartin (1990) stated, "monk seals and humans can coexist on these islands if humans do not disrupt the seals' vital activities of hauling out, pupping and feeding." The increase in beach counts at Sand Island is encouraging and suggests that just such a coexistence has begun. However, further management measures may be required if pupping or molting at Sand Island increase.

6.3 Analysis of seasonal changes in haul outs

As early as 1959 seasonality in monk seal haul outs was noted (Kenyon 1959). This seasonality, it was suggested, could be due to increased use of the barrier reef during summer months or from avoidance of high summer beach temperatures. The fact that the monk seal field camps throughout the NWHI have relatively short summer seasons does not allow for assessing seasonality in beach counts. The results of the year-round Midway study do, however, allow for this type of analysis.

Section 5.1 discussed the shift from high winter beach counts to low summer counts. Section 5.3 took that analysis further by looking for varying strengths in the beach count cycle by size class of animals.

The autocorrelation analysis results indicate that there is an annual cycle in beach counts with a peak in counts in the winter months and a decline in counts during the summer. This cycle could be seen for the non-pup total and the adult female and immature totals. The rhythmicity index values indicated that the strength of these seasonal signals differed. The strongest signal was for the non-pup total (RI = 0.4115), followed by the immature total (RI = 0.3454) and the adult female total (RI = 0.2874).

After removing molting and nursing animals from the dataset the primary reason animals come to shore is to rest. Nursing and molting animals spend extended periods of time on shore and nursing animals do not forage. By removing the nursing and molting animals from the data one is left with a dataset of animals that are either on shore resting or off shore foraging.

These results therefore indicate that there is an increase in time spent foraging in the summer and a decrease during the winter. This is opposite to the effect one would expect if the pattern in haul outs was determined by seasonal changes in weather conditions. If weather determined prey capture efficiency then calm summer weather should result in high beach counts. However it is during the summer that beach counts are lowest.

The strength of the non-pup total cycle indicates that this increased foraging time affects all size classes of animals. This suggests changes in the abundance or ease of capture of prey species with animals becoming more abundant or easier to catch during the winter months. The results also indicate that immature animals may be more closely tied than adult females to this seasonally abundant or catchable food source.

Adult monk seals are more experienced foragers than immature animals. As a result, one would expect that immature animals must spend more time foraging. Immature animals are also not as strong swimmers as adults and do not have the stores of energy that adults have (Gilmartin pers. comm. 2003). Immature animals are therefore more limited in the prey species for which they forage (Parrish et al. 2000, Goodman-Lowe 1998). If these prey species were seasonally abundant then immature beach counts would fluctuate in response. A similar signal would be expected to be weaker for adult seals because they are not as dependent on any one prey species and they are also able to satisfy their energy requirements more quickly than immatures.

Unfortunately, research into the foraging behavior of monk seals, particularly immature animals, is limited (Goodman-Lowe 1998). Research on reef fish abundance in the NWHI has shown an approximate 30% decline in densities at Midway and FFS (DeMartini et al. 1996). If this decline also impacted immature monk seal prey species then this could help explain the greater foraging times required.

Such studies are more than just scientific curiosities. Recovery of the monk seal population at Midway has been slow primarily due to low immature survival rates. The results presented here suggest that seasonal changes in foraging efficiency could contribute to this situation. Management actions could be taken to assist immature animals in periods of low prey abundance. For example, immatures could be placed in holding pens and fed during the summer months and released when prey abundance increases (Gilmartin pers. comm. 2003).

This issue is not specific to Midway Atoll. Declines in the population at FFS are also primarily due to low immature survival (Craig & Ragen 1999). Immatures in this population show signs of emaciation and slow growth rates. Possible causes of the decline at FFS include (1) the seal population surpassing its carrying capacity, (2) the carrying capacity itself was reduced due to environmental changes, and (3) interactions with fisheries leading to direct or indirect competition for prey (Craig & Ragen 1999).

Several indices can be used to assess whether monk seals are approaching an atolls carrying capacity. These are (1) a decrease in pup and immature survival, (2) a decrease in pup girth at time of weaning and (3) an increase in age at maturity (Gilmartin pers. comm. 2003, Craig & Ragen 1999). These conditions apply at FFS and suggest that the population is at or beyond carrying capacity for the current environmental conditions.

That Midway’s immatures also have low immature survival is somewhat puzzling for several reasons. First, the seal population at Midway is considered to be well below its historic carrying capacity. Second, there is limited commercial fishing in the waters around Midway. This information suggests that monk seal prey should be relatively abundant at Midway.

This situation lends support to the scenario first described by Polovia et al. (1994) in which they provide evidence for a decrease in ocean productivity in the North Pacific beginning in the mid-1980s. This change, which is thought to have most directly impacted FFS, may also be impacting monk seal survival at Midway (Craig & Ragen 1999). The 30% declines in reef fish densities at FFS and Midway have been attributed to this decrease in ocean productivity and support this scenario (DeMartini et al. 1996). If ocean productivity and fish abundance in the NWHI have declined then there may have been a decrease in the carrying capacity at Midway. A decline in pup girth at time of weaning at Midway also suggests that carrying capacity may have been reached (Gilmartin pers. comm. 2003). Taken together these factors help explain the slow recovery of the Midway subpopulation.

6.4 Influence of the north reef on beach counts

Section 5.4 presented the results of the analysis of the barrier reef data for Midway Atoll. The results indicate that the barrier reef is consistently used as a haul out site. Haul outs were primarily confined to the North Reef zone. Haul outs are likely concentrated on the north because, due to weather and current patterns, this area is typically the most productive reef zone in the NWHI (Gilmartin pers. comm. 2003).

An average of 4.6 animals/day used the North Reef. This represents 21% of the total average beach count for the Sand, Eastern and Spit Islands. The majority of these animals were either immatures or weaned pups. Reef counts also showed some evidence of seasonal variation. The seasonal cycle was strongest for weaned pups. With the end of pupping season it appears that some weaned animals began hauling out at the North Reef. These animals may be taking advantage of the calm summer weather to haul out on the exposed reef and thus remain close to their foraging areas. Weaned and immature seals have little reason to return to the main islands to haul out. By using the reef as a haul out site these animals avoid a longer swim back to the islands and also avoid harassment by adult male seals (Gilmartin pers. comm. 2003). Immatures and weaned pups also benefit from remaining at the North Reef because they have to forage more frequently to meet their energy demands. While an adult animal may be able to forage for several hours and satisfy its energy needs for several days, an immature may have to make repetitive foraging trips throughout the day (Gilmartin pers. comm. 2003).

After determining that seals were present at the barrier reef the next step in the analysis was to include these animals with the standard census data into a new “whole atoll” census. Due to data limitations it was not possible to assess the influence of the North Reef on the strength of the seasonal cycle. Surveys of reef areas are weather dependent and were more frequent during the calm summer months. Intervals between reef surveys were therefore inconsistent and could not be assessed using autocorrelation techniques.

The "whole atoll" census did however give a more accurate picture of the number of animals hauled out at all islands and reef areas on a given day. These results showed that total daily average beach counts increased from 22 to 26 animals. Immature and pup counts increased from 7 to 9 and from 4 to 6, respectively.

Evidence that the barrier reef is used as a consistent haul out site is important for several reasons. First, beach censuses are used as a population index for seal populations throughout the NWHI. This research suggests that this value could be increased by an average of 21% with the inclusion of haul out data for the barrier reef. The importance of this difference lies in the interpretation of beach counts. As a population index it may be appropriate to continue using only the islands in beach censuses. But absence of an animal from the islands should not be taken to mean that the animal is definitely foraging. Rather, the animal may simply be hauled out on the barrier reef. It is therefore important that the interpretation of island censuses remain clear – as island censuses, not censuses of the entire possible haul out area of the atoll.

Second, surveys of the barrier reefs are particularly important when attempting to understand the behavior and foraging ecology of weaned and immature animals. The report Recommended Recovery Actions for the Hawaiian Seal Population at Midway Island listed as one of its priorities to, "assess the timing and potential cause(s) of pup and juvenile mortality (Gilmartin & Antonelis 1998)." Reef surveys may assist in this work given the relatively large numbers of weaned pups and juveniles seen on the reef. This research is particularly important given the low survival rates of immature animals at Midway. Continued monitoring of the reef areas could allow for an earlier assessment of potential problems in the population, particularly for the newly weaned pups which spend a large amount of time at the reef.

It is also clear that particular monk seals are seen more regularly on the barrier reef. The constant presence of these animals at the reef tends to exaggerate somewhat the use of reef zones. However it is also clear that without patrolling the reef these animals could go for months or even years without being seen. The importance of gaining information on these individual animals must be weighed against the cost and effort of surveying the reef.

6.5 Differences between year-round and seasonal research

It is obvious that no data on monk seals is being collected in the NWHI when the seasonal research camps are not operating. Having access to the year-round dataset from Midway allows one to ask more precise questions regarding the trade off between seasonal and year-round research.

Section 5.5 listed the results from the analysis of creating a shortened data set for Midway to match the average field season at the other field stations. Several conclusions were drawn. First, the simulated field season did an excellent job of estimating the average monk seal beach count at Midway. Average beach counts for the year-round and short data sets were in fact identical. Second, the shortened data set failed to capture the seasonality present in beach counts. Third, 56% of monk seal births would have occurred outside the field season. As a result, all information associated with the birth and the identification of the mother would have been lost.

The fact that the shortened season data accurately estimated the mean beach count is encouraging. This suggests that the general trend in population size can be monitored effectively with a modest research effort. But as Gerrodette and Gilmartin (1990) state, "monitoring should include more than estimates of population size." To anticipate changes in the monk seal population at Midway requires a greater level of effort than counting animals on the beach. Furthermore, negative impacts on the population may not occur during the summer months. As the results of this project make clear, there is a distinct rise and fall in beach counts at Midway. This suggests the existence of complex interactions between seals and their environment. An understanding of these interactions is more likely with year-round data than with one season of data.

Gerrodette and Gilmartin (1990) go on to note that declines in the monk seal population at Kure Atoll would have been detected earlier if data collection methods had been more extensive. A similar situation may now be developing at Midway Atoll. Year-round data allowed for determining the timing of juvenile mortalities, weekly monitoring of the health status of individuals, monitoring of pupping activity, etc. Having access to these types of data for only one season of the year would make detection of changes in the population more difficult. Also made more difficult would be the interpretation of these data toward the recommendation of new management strategies.

Data on reproductive histories would also be lost with a shortened field season. This is particularly important when assessing the success of management measures such as rehabilitation and release of animals. In 1992 and 1993 18 rehabilitated female seals were released at Midway. Of these only two survived beyond their first year. This relocation project was considered a failure. However, the success of this project could also be measured in terms of the ability of the two surviving females to reach maturity and successfully reproduce at a rate similar to other adult females (Gilmartin pers. comm. 2003). The ability to monitor the reproductive history and success rates of adult females was possible with year-round monitoring. It would not be possible from seasonal research.

What the year-round data set at Midway makes clear is that there are specific types of information that can be identified that will be missing from seasonal research seasons. These include information on seasonal patterns in beach counts and reproductive histories. It is the task of managers to assess whether this information is important enough to the recovery of monk seals at Midway Atoll to warrant extending the research season.

6.6 Recommendations for future research

Three areas of research can be identified that would improve the understanding of monk seal population and foraging dynamics at Midway and also improve the ability to assess the potential for recovery.

6.6.1 Influence of transients and immigrants on beach counts

The influence of immigrant and transient animals on beach counts and monk seal recovery at Midway remains unclear. Approximately 30% of animals using Midway at any time are either transients or have immigrated to Midway from one of the nearby atolls. As a result, it is unclear whether the increase in beach counts and the general increase in the population at Midway is due to (1) increased use by transient or immigrant seals or (2) births and recruitment from within the resident seal population.

Monk seal identification tags are coded to identify the atoll at which the animal was born. The dataset for Midway therefore provides the potential to assess the number of transient and immigrant animals sited at Midway throughout the year.

This question can also be approached statistically. In section 5.2 a slope value was calculated for the rate of increase in beach counts at each of the three islands. This same technique can be used to calculate a rate of increase in beach counts for Midway Atoll as a whole. This trend line can then be used to calculate an expected value for the number of seals sighted at Midway. This value can then be compared to the known population value for Midway. Any discrepancy between these two values must be due to the presence of immigrants and transients in the population.

6.6.2 Seasonality in monk seal prey species

Previous research has shown that reef fish populations in the NWHI, and Midway in particular, have decreased by approximately 30% from the 1980s to the 1990s (DeMartini et al. 1996). This line of research could be extended to examine intra-annual patterns in reef fish populations. This information could help explain the timing of and reasons for seasonal variations in monk seal beach counts at Midway. This research could also be used to make forecasts of pup and immature survival rates based upon the abundance of prey species know to be occurring on the reefs in a given year. This research could also help in the development of timely management strategies to promote pup and immature survival.

6.6.3 Immature monk seal foraging behavior

Based on declines in juvenile survival at FFS, Craig and Ragen (1999) recommended further research into the foraging ecology of monk seals, particularly juveniles. Based on low rates of immature survival this same recommendation could be made for Midway Atoll. Previous research using "crittercams" (Parrish et al. 2002, Parrish et al. 2000) and scat and spew sampling (Goodman-Lowe 1998) have contained little information on immature animals. If focused on immature monk seals, these types of research at Midway could assist in identifying foraging areas, foraging behaviors and prey species. Access to this information better prepare managers to respond to continued or future declines in immature monk seal survival.

CHAPTER 7: CONCLUSION

This project used a unique dataset to examine aspects of monk seal behavior and haul out patterns at Midway Atoll from 1997 to 2000. Analyses examined spatial and temporal trends in haul outs, changes in haul out patterns between islands, the influence of including the barrier reef in beach count data, and the differences between seasonal and year-round research.

This project identified variations in haul out patterns by season, size class and animal sex. Preferred molting and pupping sites were identified. A distinct seasonal cycle in beach counts was documented. This cycle was also shown to vary in strength by monk seal size class. Immature animals were shown to have a stronger seasonal signal which may indicate a tighter linkage with prey species. The North Reef at Midway was identified as an important haul out site, particularly for weaned pups and immature animals. Seasonal data was shown to adequately estimate mean beach counts but did a poor job at identifying seasonal changes in beach counts and in establishing reproductive histories for females and their pups.

These results and continued year-round research could help to better define monk seal management priorities both at Midway Atoll and throughout the NWHI. Identification of seasonal patterns in beach counts could improve the understanding of monk seal foraging behavior. Monitoring changes in haul out patterns between islands may help in the evaluation of management strategies designed to minimize human disturbance at sensitive monk seal haul out sites. Continued monitoring of the barrier reef may improve the interpretation of beach counts and our understanding of pup and immature foraging behavior. This type of research could also improve the ability of managers to anticipate changes to the seal population and respond to those changes.

Wildlife managers are thus left with the task of weighing the benefits of this increased monitoring effort and the data it provides against the increased costs associated with a continuous monitoring program. It is not an enviable task. And, in the case of the Hawaiian monk seal, a misstep or missed opportunity could propel the population down the road to extinction.

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