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Report of the Alaska Region and Alaska Fisheries Science Center Northern Fur Seal Tagging and Census Workshop

6-9 September 2005,
Seattle, Washington

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Report of the Alaska Region and Alaska Fisheries Science Center Northern Fur Seal Tagging and Census Workshop

6-9 September 2005,
Seattle, Washington

by

S. R. Melin, R. R. Ream, and T. K. Zeppelin

Northern fur seals at San Miguel Island, California.
Photo by NMFS Staff

EXECUTIVE SUMMARY

The northern fur seal is listed as ‘depleted’ in U.S. waters under The Marine Mammal Protection Act of 1972. Under the Marine Mammal Protection Act, a conservation plan is required for all depleted species to assist management and research agencies in recovering the population. In 1993, the Northern Fur Seal Conservation Plan was adopted and has guided northern fur seal research over the past decade. In 2005, the conservation plan was reviewed and updated to reflect the current trends in the population and new biological information. One recommendation of the revised conservation plan was to gather current demographic information on northern fur seal populations. This workshop was convened to outline an approach for a robust marking program that can provide the demographic data necessary to build population models that are needed to assist management in the recovery process for the northern fur seal population. The working group evaluated permanent marking methods including various tagging options, tattoos, hot branding, freeze branding, radio frequency identification tags (RFIDs), natural markings, and new technologies to uniquely identify northern fur seals. The workshop participants also discussed study designs and statistical methods to obtain and analyze demographic data. In addition, the working group examined the current methods of estimating abundance based on direct counts and shear-sampling mark-recapture of pups and discussed alternative methods of population assessment.

The working group agreed that a combination of longitudinal and cross-sectional permanent marking of live animals would provide a complete dataset of population parameters for demographic models. The working group determined that in the near-term, external flipper tags are the most feasible method for marking large numbers of northern fur seals. However, tag loss remains a significant problem with the current tags available and a new tag needs to be developed. The working group acknowledged that the future of unique identification of fur seals lies in the development of electronic tags and remote data recorders. This technology is not yet applicable to the unique habitat, life history, distribution, and environmental conditions of pinniped species. The working group discussed the need to encourage manufacturers to develop an electronic tagging system that would be applicable to the needs of the fur seal and sea lion research community.

The working group concluded that the current census methods of shear-sampling and direct counts of pups were sufficient but alternative methods for estimating abundance (e.g., medium format photography or infra-red imaging) may be useful in combination with the current methods to refine estimates.

WORKSHOP AGENDA

6-9 September 2005
NOAA Fisheries/Alaska Fisheries Science Center
7600 Sand Point Way N.E., Bldg. 4
Seattle, WA 98115
Traynor Seminar Room

Goals of the workshop are to develop a marking and census programs that will provide reliable estimates of:

- Survival to age at first reproduction
- Age and sex specific survival of individuals
- Age-specific reproductive rates for females and males
- Age-specific foraging ecology, distribution and movements
- Total population

Tuesday, 6 September

08:30	Introductions and goals of workshop Dr. John Bengtson, Director, National Marine Mammal Laboratory Dr. Rolf Ream, NMML, Alaska Ecosystem Program Dr. Sharon Melin, NMML, California Current Ecosystem Program
09:00	Overview of Northern Fur Seal Conservation Plan and Management Needs – Mike Williams, Pribilof Islands Program, Alaska Region, Juneau, Alaska
09:30	History of northern fur seal marking and population assessment in Alaska Anne York, A.E. York Consulting, Seattle, Washington
10:30	Overview of current status of northern fur seals in Alaska Dr. Rolf Ream, NMML, Alaska Ecosystem Program
10:50	Break
11:00	Overview of northern fur seal marking and population assessment in California Dr. Robert DeLong, NMML, California Current Ecosystem Program
11:30	Discussion: History of marking and assessment programs
12:00	Lunch

13:30	Some marking and census methods used in seal population in Australian waters Dr. Simon Goldsworthy, SARDI Aquatic Sciences Centre, South Australia, Australia
13:50	Estimating relative survival of northern fur seals from tagging studies in California Dr. Jeff Laake, NMML, California Current Ecosystem Program
14:10	Estimating the effects of tag loss on demographic estimates of Weddell Seals Dr. Michael Cameron, NMML, Polar Ecosystems Program
14:30	Long-term demographic study of Hawaiian monk seals: Successes, limitations and potential for bias Jason Baker, Pacific Islands Fisheries Science Center, Honolulu, Hawaii
14:50	Break
15:00	Re-Inventing the Pinniped Tag or…In Search of the Perfect Pinniped Tag Dr. Bud Antonelis, Pacific Islands Fisheries Science Center, Honolulu, Hawaii (Presented by Sharon Melin)
15:20	Discussion: Benefits and disadvantages of current methods used for long term marking of pinnipeds and their importance in developing a marking program for northern fur seals
17:00	Adjourn

Wednesday, September 7

08:30	Reconvene, updates to agenda
08:40	Health Implications associated with tagging pinnipeds Dr. Frances Gulland, The Marine Mammal Center, Sausalito, California
09:00	Developments in telemetry technology and analysis Dr. Bernie McConnell, Sea Mammal Research Unit, University of St. Andrews, Scotland
09:20	Tagging, Laser Coded Tags, RFID tags Kevin Haas, National Band and Tag Company
10:00	Break

10:15	PIT Tags and Technology Audrey Hopkins, BioMark
11:00	Vendor/Researcher Discussion
12:00	Lunch
13:30	Discussion: Benefits and disadvantages of new or revised methods for long term marking
15:00	Break
15:15	Discussion: Evaluate best methods to use with northern fur seals
17:00	Adjourn

Thursday, 8 September

08:30	Reconvene, updates to agenda
08:40	Discussion: Marking study design and implementation based on new marking methods. Discussion will focus on tailoring design and method for different habitat considerations and population characteristics, developing a time line for testing new methods in trials and field, and duration of field studies to acquire biological information.
10:30	Break
10:45	Discussion: Final considerations and conclusions: marking methods, study design and implementation.
	(Remainder of workshop to focus on census activities/methods)
11:20	Counting seals in Tasmania Dr. David Pemberton, Tasmanian Museum and Art Gallery, Hobart, Australia
11:40	Mark-recapture abundance estimates of fur seals & sea lions in South Australia: problems & positives Dr. Peter Shaughnessy, CSIRO Sustainable Ecosystems, Adelaide, Australia
12:00	Lunch

13:30	Discussion: Benefits and disadvantages of various census methods for northern fur seals: can we improve the way we assess northern fur seal populations?
15:15	Break
15:30	Discussion: Implementation of new or revised census methods. Discussion will focus on testing new methods and consideration of different methods based on habitat and population characteristics.
17:00	Adjourn

Friday, 9 September

08:30	Reconvene, updates to agenda
08:40	Discussion: Final considerations and conclusions: census study design and implementation
10:30	Break
10:45	Workshop Summary/Conclusions
12:00	Adjourn

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CONTENTS

INTRODUCTION

The Northern Fur Seal Conservation Plan identifies current demographic data as a primary need for the effective conservation of northern fur seals (*Callorhinus ursinus*). To accomplish this goal, large numbers of individual animals must be marked and followed through their life to obtain survival and reproductive rates required for demographic models. Northern fur seals have been marked since the early 1900s for various reasons (Scheffer et al. 1984), but the studies were often not designed as long-term demographic studies. In addition, tag loss and low marking or sighting effort resulted in the failure of some marking studies to meet their objectives (York 2006). Consequently, after more than 90 years of marking studies of northern fur seals, there is a paucity of data for estimating survival and reproductive rates of the populations.

This workshop provided the opportunity to gather the best available information from the scientific community on temporary and permanent marking methods that provide life history data such as survival, reproductive rates, age of first reproduction, and site fidelity for fur seals. The working group evaluated permanent marking methods including various tagging options, tattoos, hot branding, freeze branding, radio frequency identification tags (RFIDs), natural markings, and new technologies to uniquely identify northern fur seals. The workshop participants also discussed study designs and statistical methods to obtain and analyze demographic data. In addition, the working group examined the current methods of estimating abundance based on direct counts and shear-sampling mark-recapture of pups and discussed alternative methods of population assessment.

Northern Fur Seal Conservation Plan

The northern fur seal is listed as ‘depleted’ in U.S. waters under The Marine Mammal Protection Act of 1972. Under the Marine Mammal Protection Act, a conservation plan is required for all depleted species to assist management and research agencies in recovering the population. In 1993, the Northern Fur Seal Conservation Plan was adopted and has guided northern fur seal research over the past decade (National Marine Fisheries Service 1993). In 2005, the conservation plan was reviewed and updated to reflect the current trends in the population and new biological information. One of the recommendations of the new plan is to obtain demographic rates for the populations; however, there is currently no long-term marking program in place to provide demographic information for the northern fur seal population in Alaska. The most recent demographic rates were estimated from harvested animals collected between 1958 and 1974 (Lander 1981). A tagging program for the California population of northern fur seals has been underway since 1975 to estimate demographic parameters of the small northern fur seal population at San Miguel Island, California. However, limited access to breeding animals and tag loss have compromised the data and precise estimates of survival and reproduction have not been obtained. This workshop was convened to outline an approach to develop a robust marking program that can provide the demographic data necessary to build population models, a critical step for management and the recovery process of the northern fur seal population.

Geographic Distribution of Northern Fur Seals

The northern fur seal is distributed across the North Pacific Ocean from the Sea of Okhotsk to the northern Bering Sea and as far south as 34° N (Kenyon and Wilke 1953, Gentry 1998). Breeding, however, occurs on only a small number of islands within this range: Robben Island, the Kuril Islands (Lovushki and Srednev), and the Commander Islands (Bering and Medny) in Russia; Bogoslof Island and the Pribilof Islands (St. George and St. Paul) in Alaska; and San Miguel Island and the Farallon Islands in California. The northern fur seal population at the Pribilof Islands is the largest breeding colony, currently accounting for approximately 53% of the total population worldwide (National Marine Mammal Laboratory, unpublished data).

The National Marine Fisheries Service divides populations into management units or stocks. Stocks are subpopulations that have unique population dynamics or genetic differentiation and are managed independently even though they are part of a larger population. Currently, northern fur seals in U.S. waters are classified into two stocks: the Eastern Pacific Stock, which includes the Pribilof Islands and Bogoslof Island or the San Miguel Island Stock which includes the single population at San Miguel Island. Until 1994, the Eastern Pacific Stock was identified as the Pribilof Island Stock.

Status of Northern Fur Seal Populations

The overall abundance of northern fur seals in the North Pacific declined substantially between 1956 and 1980 due in large part to an experimental harvest of females on the Pribilof Islands and scientific pelagic collections (York and Hartley 1981). In 1988, the Pribilof Island Stock of northern fur seals, which in 1994 became the Eastern Pacific Stock, was listed as 'depleted' under the Marine Mammal Protection Act of 1972.

The largest concentration of breeding fur seals occurs at the Pribilof Islands of St. Paul and St. George. After a period of apparent stabilization of trends in abundance, the fur seal breeding colonies on these islands have undergone renewed and substantial declines during the past decade. The reasons for the declines are unknown. Between 1998 and 2004, the annual rate of decline in pup production on the Pribilof Islands was 5.83% (SE = 0.53%, P = 0.01) (Towell et al. 2006). The estimates of the total number of pups born on St. Paul and St. George Islands in 2004 were 122,825 (SE = 1,290) and 16,876 (SE = 239), respectively (Towell et al. 2006). These numbers are less than half of the estimated numbers of pups born in the mid-1970s. Levels this low were last observed during the early 1900s when the population was recovering from unregulated pelagic harvests.

Population trends vary among the breeding islands; during the past decade some of the smaller northern fur seal colonies across the North Pacific have experienced an increase in abundance. Pup production at Bogoslof Island in the eastern Aleutian Islands was estimated at 5,096 during 1997, and the annual rate of growth was 59% (SE = 2.29% and P < 0.001) between 1980 when the first count was conducted and 1997 (Ream et al. 1999). Between 1997 and 2005, annual pup production increased at 15%. The population growth at Bogoslof Island is still due primarily to immigration. It is not clear where the immigrants to Bogoslof Island are coming from. Some may be from the Pribilof Islands, but the increase at Bogoslof Island is not large enough to account for the recent decline at the Pribilof Islands.

The San Miguel Island northern fur seal population represents the southern extent of the species breeding range. The colony was discovered in 1968 and was comprised of immigrants from the Alaska and Russian populations (DeLong 1982). With the exception of severe declines during El Niño Southern Oscillation events (ENSO), the San Miguel population has displayed positive growth since its discovery. The most recent decline occurred in 1998 when an 80% decrease in pup births was recorded in response to the 1997-98 ENSO (Melin et al. 2005). Since then, the number of northern fur seal births has generally increased, but observed births in 2005 were still 22.7% below 1997 (National Marine Mammal Laboratory, unpublished data). The slow recovery of the population from the 1998 decline suggests that adult, juvenile, and pup mortality was significant during the 1997-98 ENSO. A similar decline in 1983 (60%) following the 1982-83 ENSO resulted in recovery 7 years later, also indicating that adult, juvenile, and pup mortality occurred (Delong and Antonelis 1991). Thus, the dynamics of the San Miguel population are strongly influenced by periodic environmental disturbances.

Recently, a small population of northern fur seals has colonized the South Farallon Islands off San Francisco, California. Fur seals were harvested from the South Farallon Islands by American, British, and Russian sealers and the colony was extirpated by the mid-19th century (Pyle et al. 2001). Remains from middens on the islands provide evidence that the islands previously had a northern fur seal colony rather than a Guadalupe fur seal (*Arctocephalus townsendii*) colony as previously thought (Pyle et al. 2001). Northern fur seals were observed at the South Farallon Island again beginning in 1964. Frequent surveys of the island since 1968 indicate that Northern fur seals are present on the island throughout the year. In 1996, the first pups were observed on the Southeast Farallon Islands and the colony has slowly increased since that time. In 2005, 90 individuals and 24 pups were recorded there (W. Sydeman, personal communication). Several animals in this new colony were tagged at San Miguel Island, indicating that at least some of the founders are from that population (Pyle et al. 2001). The number of animals present at the South Farallon colony has increased preceding major ENSO events and has declined, but persisted, afterward. Thus, the colonization and growth of this population may also be affected by ENSO events.

Northern fur seals breeding on islands in Russia account for less than half of the total number of northern fur seals in the North Pacific. The Commander Islands form the largest concentration of breeding fur seals in Russia and the population has been declining slightly over the past decade (V. Burkanov, personal communication). The breeding colonies at the Kuril Islands and at Robben Island have, on the other hand, exhibited substantial increases in abundance during the past decade (V. Burkanov, personal communication).

Life History of Northern Fur Seals

The northern fur seal has a polygynous, synchronized breeding system (Gentry and Holt 1986, Gentry 1998). Adult males arrive on beaches throughout the range in May and June and establish territories. The territories are “stacked” along the beach from the water’s edge inland to cliffs and vegetation. Adult females arrive in June and July and settle into a territory to give birth. Females give birth to a single pup shortly after arriving ashore. Females remain in constant attendance with the pup for 7.7 to 8.8 days (Gentry and Holt 1986). Females come into estrous and breed at the end of the perinatal period and then a day later, begin a cycle of feeding and nursing trips. The pup remains ashore and fasts while the female is at sea feeding. The first feeding trip is between 4 and 6 days. The feeding trips increase in duration to 7 to 10 days throughout lactation. Nursing visits are between 1 and 2 days. Adult males disperse from the breeding areas in August, followed by juveniles and adult females and pups in October and November. Pups are weaned between 4 and 5 months of age and disperse from the breeding colonies. Some pups will not return to land until 3 or 4 years of age. Adult females from the Alaskan populations move through the Bering Sea and into the North Pacific Ocean during the winter (Ream et al. 2005). Some females forage in the subarctic-subtropical transition region in the North Pacific while others move down into the California Current along the coasts of Washington, Oregon, and California (Ream et al. 2005). Adult males from the Alaskan populations are found throughout the Bering Sea, Gulf of Alaska, and North Pacific during the fall and winter (Loughlin et al. 1999). Information on the winter distribution of the Russian populations comes largely from pelagic collections of tagged animals as part of the North Pacific Fur Seal Commission Scientific Program between 1958 and 1984 (see North Pacific Fur Seal Commission Reports). Ichihara (1974) and Boltnev (1987) summarize these data. Animals from the Commander Islands were mostly found in the seas off Japan near Hokkaido and northeastern Honshu coasts with some moving into the Sea of Japan and the eastern Pacific Ocean. The Robben Island animals were widespread in the same areas but a large number of them were collected in the Sea of Japan. Little is known of the Kurile Islands population but they are thought to also disperse to the Japanese coastal waters. More recently, satellite telemetry studies of females from the Commander Islands indicate that they migrate to areas in the western, central, and eastern North Pacific, overlapping in their distribution with animals from the Pribilof Islands population (Baba et al. 2000). The distribution of adult females and pups from San Miguel Island is currently being studied.

Vital parameters of the Pribilof Islands population have been estimated from data collected during the commercial harvest and scientific pelagic collection periods that occurred mostly before the implementation of the MMPA in 1972. Vital parameters have also been estimated from behavior studies at the Pribilof Islands and San Miguel Island since the 1970s (Gentry and Kooyman 1986, Gentry 1998, DeLong 1982). Northern fur seal females can become sexually mature at 3 years of age, giving birth for the first time at 4 years of age, but most give birth when they are 5 years or older. About 57% of the females give birth each year. Males are sexually mature at 4 or 5 years of age but most are not able to defend territories until they are socially mature at 8 or 9 years of age. Pup mortality is estimated at 50% in the first year (Lander 1981), annual juvenile mortality is between 10% and 20% (Lander 1981), annual adult male mortality is between 33% and 38% (Chapman 1964, Peterson 1965, Johnson 1968) and adult female mortality is between 5% and 10% (Chapman 1964, Lander 1981).

The expansive range and the life history of the northern fur seal present challenges for marking and census studies. Although all the animals concentrate in predictable locations every summer, at no time are all individuals present on land. Thus, trends in the population are monitored using census techniques that rely on indices to estimate the total population. Traditionally these techniques have used numbers of territorial bulls and pups as indices because the two groups remain ashore for much of the breeding season and are therefore available for census. Multipliers have been used to estimate the total abundance from these indices (Angliss and Lodge 2003).

The most difficult aspect of estimating age-specific survival rates of this species is obtaining information on juvenile survival. Once pups go to sea after weaning, the majority of the cohort does not return to land until they are 3 years of age. Only small proportions of 2 and 3 year old juveniles come ashore each year. Thus, few animals that are marked as pups are sighted before they are adults. In addition, the breeding structure of the colony presents challenges for sighting marked individuals. The dense aggregations of animals along the beaches and the “stacked” nature of territories makes access to individuals difficult during much of the breeding season. The territories provide a structure that protects females and pups from socially immature males that may steal and kill pups or attack females in an effort to mate with them. Thus, observations of marked animals must be made from blinds, cliff tops, or catwalks to avoid disturbance to the breeding structure.

Marking programs for northern fur seals began in the 1870s but large-scale efforts were undertaken between 1940 and 1975 (Roppel 1984). Of 863,584 tags deployed on pups during the 36-year period, about 80% were deployed at St. Paul Island and 20% were deployed at St. George Island (Roppel 1984). Tagged animals were given check marks by the removal of a digit on the rear flippers, a V-notch on the leading edge of the foreflipper or the removal of the tip of the foreflipper, as an additional mark in case they lost their tags. Sightings of the tagged animals were obtained during the commercial harvest or pelagic collections each year. The focus of these studies was on growth and migration and as a census method using ratios of marked to unmarked pups to estimate production (Roppel 1984). Information was also obtained on natal site fidelity. Data were garnered from these studies but it was determined that tag loss, missed tags, and tag-caused mortality were substantial and thus, the mortality estimates were inflated. Double-tagging studies were undertaken to estimate tag loss and these studies confirmed that tag loss was significant with 67% of the pups losing one tag and 3% losing both tags by 3 years of age (Scheffer et al. 1984). Even so, without a better alternative, metal tags were accepted as the best method of marking and tagging studies continued until 1969. Because of the problems associated with tag loss, tag-caused mortality, and overlooked marks, tagging was replaced with physical marking techniques until the marking program was abandoned in its entirety in 1975 (Roppel 1984). Since the cessation of the large-scale tagging program, two other marking studies have provided some information on survival, reproduction, and philopatry. The St. George Island Program was initiated in 1972 and continued until 1985 (Gentry 1998). Large numbers of animals were tagged and life history and behavioral data were collected. However, precise estimates of survival were not possible because of tag wear, breakage, and loss. Between 1987 and 1990, a tagging effort was undertaken to test the reliability of a new tag, estimate juvenile survival rates, and natality rates of adult females. Tagged animals were sighted during the subsistence harvest or during round-ups at St. Paul Island between 1990 and 1992. The program was terminated due to lack of funding in 1992, but it provided estimates of juvenile male survival based on weight at tagging and natal site fidelity of animals (Baker et al. 1994, 1995). Since 1992, there have been no large-scale marking programs in the Pribilof Islands. It is important to note that, to date, no marking program on the Pribilof Islands has been specifically designed to estimate age-specific survival, natality, and age at first birth for the purpose of developing a population demographic model.

A tagging program at San Miguel Island, California, has been underway since 1975 to estimate immigration rates and age-specific survival, natality, and age at first birth. Summaries of the percentages of tagged individuals that returned to San Miguel have been reported (Delong et al. 1981, Antonelis et al. 1989, Melin and DeLong 1997, Melin et al. 2005) but an age-specific demographic model has not been developed because tag loss has not been precisely quantified. Consequently, there are no estimates of current vital parameters for northern fur seals anywhere in their range. This information is critical to identifying the components of the population that are driving the decline in the Pribilof Islands and increases in the San Miguel Island and Russian populations. The only way to obtain such information from live animals is through long-term longitudinal studies of uniquely marked individuals.

Workshop Objectives

A priority of the Northern Fur Seal Conservation Plan is to estimate vital parameters of the northern fur seal population. The workshop was convened to:

1) Evaluate current marking techniques.
2) Develop a marking technique and program to estimate survival and reproduction.
3) Evaluate current census techniques.
4) Develop a census program that will provide reliable estimates of population size.

The workshop participants had varied experience in marking and census of fur seals to estimate vital parameters and population size. The workshop consisted of a review of the NMFS tagging and census program for northern fur seals, the new Northern Fur Seal Conservation Plan, methods used to mark and census fur seals and sea lions around the world, and a discussion of new technologies that might improve the quality of the data obtained from marking and census programs. Here, we summarize the workshop findings based on presentations and discussions of the workshop participants.

MARKING TECHNIQUES

Hot Branding

Hot-iron branding has been used as a permanent marking method of California sea lions (*Zalophus californianus*) (Aurioles and Sinsel 1988, Laake et al. 2000, Melin 2002), Steller sea lions (*Eumetopias jubatus*) (Calkins and Pitcher 1982, Calkins and Pitcher 1996, Merrick et al. 1996, Chumbley et al. 1997, 2001), New Zealand sea lions (*Neophoca cineria*) (I. S. Wilkinson, personal communication), grey seals (*Halichoerus grypus*) (Schwartz and Stobo 2000), harbor seals (*Phoca vitulina*) (Huber et al. 2004), southern elephant seals (*Mirounga leonina*) (Chittleborough and Ealey 1949, Carrick and Ingham 1962, D. Pemberton, personal communication), northern elephant seals (*Mirounga angustirostris*) (National Marine Mammal Laboratory, unpublished data), northern fur seals (Scheffer 1950a), and South African fur seals (*Arctocephalus pusillus*) (Rand 1950). Hot brands destroy the hair follicles leaving a dark, bald permanent mark that grows proportionally with the animal. Hot branding techniques for pinnipeds are described in Merrick et al. (1996). Animals must be physically restrained or chemically immobilized while the brand is applied. This marking method has been successful on most species and has resulted in estimates of survival and reproductive rates for pinnipeds. It is particularly useful as a method to mark species that cannot be approached easily or repeatedly and for species that do not require their fur for thermoregulation.

The advantages of hot branding are that it provides a reliable, permanent mark when applied correctly, can be applied easily to a large number of animals, is inexpensive, and marks can be read from afar reducing disturbance to colonies during sighting. The disadvantages are that fur is permanently removed, poor application can lead to severe scarring and illegible marks, and it is labor-intensive to mark and resight large numbers of animals.

The working group agreed that hot branding is not viable for northern fur seals because the removal of the guard hair and underfur to create a visible mark would compromise the thermoregulatory capabilities of the animal and could pose health risks due to heat loss. Hot branding was used as a method to batch-mark northern fur seals in the 1970s and as a pelage-marring method in the 1920s (York 2006). However, sighting rates of branded animals were lower than non-branded animals suggesting that even small marks may affect survival. With further study, hot branding may have some utility as a batch marking method to identify animals that are marked with other, less apparent external marks such as tags, or internal marks such as a RFID tag. The batch mark would be a small bald brand somewhere on the body where heat loss would be minimized. The area to be branded would be determined based on the outcome of experiments investigating the impact of hair removal from different parts of the body on thermoregulation of fur seals in rehabilitation facilities.

Freeze Branding

Freeze branding involves using super-cooled brands to apply a permanent mark (Cornell et al. 1979, White et al. 1981). Freeze branding has been used to mark harbor seals (Härkönen et al. 1999), Australian fur seals (*Arctocephalus pusillus*) (Warneke 1979), northern fur seals (Keyes and Farrell 1979), and New Zealand fur seals (*Arctocephalus forsteri*) (S. Goldsworthy, personal communication). Freeze brands may be applied as a bald brand, or may produce a hair brand by permanently altering the pelage color. Bald brands require a longer exposure time than hair brands and destroy both the pigment producing follicle and hair growth follicle producing a black bald mark similar to the mark produced by hot brands. Thus, bald freeze brands have the same disadvantages as hot brands and involve longer handling times for animals (hot brands require about 3 seconds per mark). Therefore bald freeze brands are not a viable marking method for northern fur seals.

Hair freeze brands require a short exposure time relative to bald freeze brands. Brands of this type destroy the pigment producing hair follicle resulting in non-pigmented white hair during re-growth. Experiments with hair freeze branding Australian fur seals on the flank produced permanent, readable marks but the process was too slow to be useful for marking large numbers of fur seals (Warneke 1979). In contrast, freeze branding northern fur seals during the breeding seasons between 1966 and 1978 did not produce permanent marks on the flipper skin or on furred areas of the flipper (Keyes and Farrell 1979). The hair re-pigmented after a few months and the skin marks were difficult to read. The researchers suggested that the pigment cells and hair follicles may be more responsive in the fall with the onset of molt and new hair growth, however this was not tested.

Recent experiments with hair freeze branding New Zealand fur seal pups have resulted in some success (S. Goldsworthy, personal communication). Solid copper, lead, brass, or stainless steel branding irons were immersed in a liquid coolant, either 95% alcohol and dry ice or liquid nitrogen bath (S. Goldsworthy and D. Pemberton, personal communication). The fur was shaved and the area was soaked with alcohol to provide a good medium for temperature transfer. The iron was applied for 2 to 10 seconds, but 7 to 10 seconds was the recommended time. The animal must remain still while being branded or the quality of the brand is compromised, thus anesthesia is required. As in the studies with northern fur seals, the researchers suggested that marking adults would provide a shorter time frame in which to evaluate the method (12 to 18 months) and that the different stages of the molt may affect the quality and retention of the brand (S. Goldsworthy, personal communication).

The success of hair freeze brand marking of fur seals has been difficult to assess because the brands do not appear until after the animals have molted. In the case of fur seal pups, branded pups are generally not seen for several years after they have been branded, so without an additional mark, it is impossible to determine how many brands disappear or become illegible over time. Researchers have found that standardizing the application of freeze brands is difficult and long-term data suggest that fur may re-pigment. It is unclear if these problems could be reduced by modification of the techniques currently used or by marking animals after the molt or at older ages. Hair freeze branding appears to have promise as a marking method for fur seals. Further research into freeze branding should be first tested on fur seals in rehabilitation so that the effects can be monitored over time. If these trials prove successful, additional marking techniques should be used in addition to freeze branding to evaluate the method on free-ranging animals.

Tattooing

Tattooing is a common marking method in livestock and pets. An applicator is used to inject ink under the skin in a unique pattern to identify an individual. There are applicators available that allow unique tattoos to be applied in the field on a large number of animals. Currently, reliable, long-term tattoos are applied to livestock and pets using dark green and black ink which probably would not be visible on the dark skin of the flippers of fur seals. This technique has not been used on fur seals. This technique could be useful but would require a substantive amount of research and development into new inks and applicators.

Radio Frequency Identification Tags

Radio frequency identification tags (RFID tags), also called passive integrated tags (PIT tags) or implantable transponders, are low frequency (LF) computer chips that have an identification number programmed into them and are encapsulated within a biocompatible material. The tags can be injected under the skin, embedded in external tags, or implanted into the body cavity. The size of the tags depends on the application but subcutaneous tags are as small as 1 cm. Tags that are placed internally provide no external indication that the animal has the internal tag. So, an external visual mark may also be required to identify animals with internal tags when it is not possible to check all animals in the colony for internal tags. RFID tags have been used in livestock, pets, and wild animals for many years and the technology continues to broaden in its application. The computer memory in the microchip contains a number that uniquely identifies an individual animal. A scanner sends radio waves that excite the microchip, and the microchip then sends back the unique identification code it contains. The scanner displays the identification code or writes it to a computer file that can be downloaded at a later time.

RFID tags are small, easy to apply, inexpensive, and will last the life of the animal. RFID tags injected under the skin have been successfully used in small populations of New Zealand fur seals and Australian sea lions (S. Goldsworthy and I.S. Wilkinson, personal communication). However, close access to the animals is required to read the tags, and there have been problems with migration of the tag once placed in the animal. Scanners currently on the market are limited by a maximum distance of 1.0 m to read tags and the distance is reduced if the reader is in the wrong orientation to the tag. Sleeves have been developed to prevent the migration of the tags within the tissue, so migration may not be an issue in the future. Further research into antenna and reader arrays and remote reading devices is needed to determine if this technology can be adapted to a large, densely aggregated population such as fur seals in the Pribilof Islands.

High frequency RFID tags are also available but there are restrictions to their use because of interference with radio communications. High-frequency (850 MHz to 950 MHz and 2.4 GHz to 2.5 GHz) systems offer long read ranges (greater than 90 feet) and high reading speeds and are used for such applications as railroad car tracking and automated toll collection. These tags are larger than low frequency tags (7 cm × 5 cm × 2 cm) because they require an internal power source such as a battery. Thus, they can only be applied externally or surgically implanted. Such tags have been successfully implanted in the body cavities of sea otters (Garshelis and Siniff 1983, Williams and Siniff 1983, Ralls et al. 1989) and harbor seals (Lander et al. 2005). Deployment of the tags in this way requires surgical procedures, and this is not a feasible tagging method for large numbers of northern fur seals.

Although most RFID tags are passive, external active RFID tags that use body movement or solar power to recharge batteries or to power the transmitter, and tags that can act as data transmitters and receivers are on the horizon. Such tags could provide a new direction in long-term marking of fur seals but they are not yet available.

Flipper Tags

Livestock tags placed in the rear or foreflippers of seals have been the standard marking method for pinnipeds (Scheffer 1950a, Hobbs and Russell 1979). A variety of tag types have been used depending on the species, habitat, and duration of study. Tags made of monel steel, nylon, and polyurethane have been used in a variety of configurations, colors, sizes, and attachments. VHF transmitters have also been attached to external flipper tags to obtain behavior data through the molt (S. Goldsworthy, personal communication). The primary problems with all external flipper tags currently available are tag loss and tag readability. The life of a flipper tag generally does not exceed 5 years on most fur seal and sea lion species. By this time either the tag is lost or the numbers become illegible. Re-tagging animals that are observed with only one tag may extend the life of the study (Cameron et al. 2004) but requires repeated handling and access to the animal throughout its life and is only reasonable for small populations. This is often not possible with fur seals or sea lions. It is also possible that external flipper tags may have an energetic cost to survival by interfering with swimming efficiency. Historical data from the commercial harvest of northern fur seals found a lower recovery rate of tagged animals than un-tagged animals (Scheffer et al. 1984).

Until another method is developed, flipper tags will remain the standard marking method for fur seals. Depending on the species, flipper tags may be suitable for studies that are designed to address questions that can be answered in less than 5 years or in which tag loss can be quantified. However, most demographic studies of fur seals require a longer time horizon than 5 years, and tag loss is difficult to quantify without another mark that lasts longer than the tag. The working group discussed tags that have been most successful which included one-piece metal tags with etched numbers and two-piece plastic roto tags (northern fur seals) and super-flexi plastic tags (New Zealand fur seals). New developments in the tag industry include laser imprinting, larger numbers, more durable plastics and colors, and configurations that improve tag attachment and visibility. These improvements may increase the retention and readability of tags and should be pursued. In addition, the working group discussed techniques for improving sighting probabilities including the use of mobile blinds that allow observers to walk through the colony, remote-controlled devices such as cameras or unmanned miniature automated aircraft, photographic techniques including high power zoom scopes and camera combinations, and gathering large groups of animals after the breeding season structure has disbanded to process them through a chute where tags can be read.

Natural Markings

Identification of individuals using scar or pelage patterns has been used on some species of pinnipeds that have distinctive markings or scarring that last the life of the animal (e.g., harbor seals and monk seals). Northern fur seals are fairly uniform in their pelage color patterns and are not prone to scarring. However, vibrissae color and length, and pelage color patterns on the muzzle, chest and belly can be used as an age class indicator (Scheffer 1962, Nikulin 1997). As animals age, the white chest and belly markings become less apparent until they disappear and the animal is a uniform brown. Vibrissae change color with age from black, to mixed black and white, to white when the animal reaches maturity. These methods require the ability to approach animals and clearly distinguish color patterns and associate them with standards determined from pelagic collections and from observation studies of known-aged tagged animals for which markings were recorded. This method may be useful to establish age categories of animals in small colonies or animals that are handled, but would be difficult to implement in large, densely aggregated colonies.

Tooth Extraction As An Ageing Technique

Pinnipeds may be aged by determining the number of growth layer groups of a sectioned tooth (Scheffer 1950b). While not a marking technique in itself, tooth extraction can supply age-specific and historical information on juvenile and adult animals. When combined with marking techniques on the same animals, the method could provide survival and natality data for juveniles and adults while avoiding or reducing the limitations and biases associated with survival and natality estimates obtained from the tagging of pups (e.g., reduced survival and progressive tag loss). Dead animals are usually aged by sectioning an upper canine tooth because it is the largest tooth and has the straightest root which makes sectioning and identifying the growth layers easier than for smaller teeth. Canines cannot be extracted from live animals because they are important in the capture of food. Incisors and post-canine teeth have been extracted from live, anesthetized Antarctic fur seals (*Arctocephalus gazella*) (Arnbom et al. 1992), New Zealand fur seals (S. Goldsworthy, personal communication) and California sea lions (National Marine Mammal Laboratory, unpublished data) for ageing. Anesthesia methods are well established for sea lions and fur seals and pose little risk to the animals. Tooth extractors are used to remove the tooth and the animal is marked with a tag before release for future identification. Adult female California sea lions from which a single post-canine tooth was extracted have been observed 12 years after the procedure (National Marine Mammal Laboratory, unpublished data). This method can be used to age juveniles and adults that have not been marked as pups. Once aged, sighting records of tagged adults or juveniles can provide age-specific information on survival and reproduction of individuals.

The National Marine Mammal Laboratory (NMML) is currently evaluating the efficacy of ageing northern fur seals using the post-canines from known-age animals in the NMML osteological collection. If successful, the advantage to this method of ageing fur seals is that it provides age-specific data quickly compared to a long-term, longitudinal marking program of pups. Because mortality is greatest during the first few years of life, a high resight probability would also be expected for animals tagged as juveniles or adults. The disadvantages are that it is invasive compared to other marking options and is labor intensive and expensive for a small sample because animals need to be anesthetized for the tooth extraction. In addition, because different age and reproductive classes are ashore at different times of the season, to get a representative sample of all reproductive and age groups, individuals should be sampled throughout the season which may require a longer field season and more field personnel. Thus, this method may be feasible for small populations in California or at Bogoslof Island but sample sizes would need to be determined to evaluate whether this method is practical for a large population such as that on the Pribilof Islands.

Emergent Technologies

The discussion on emergent technologies was limited to remote-controlled sighting devices, nearest neighbor and neural network frameworks, and wireless technologies. Remote-controlled devices may have onboard cameras to photograph marked animals as it passes above them or a receiving device that could record an electronic identification of a marked animal. With some investigation, this has potential to be useful at many sites where the density of animals or other factors reduces the ability of researchers to approach the animals for visually or electronically reading tags. The nearest neighbor and neural network technologies are expansions of the RFID marking system. Animals would be marked with an internal tag that would emit a signal and also receive signals from other marked animals in close proximity. When any marked animal passed by a receiving station, the information would be downloaded for that individual and all the other individuals that had been within the receiving range of that individual. These tags could eventually include physiological monitors such as heart rate, physical activity sensors, or body temperature sensors. This technology has not been developed for this application at this time but has potential. Wireless technology is currently being used to transmit foraging locations of animals at sea to satellites and land based cellular phone towers and then to cellular phones. RFID tags could be designed to transmit signals using this technology but it requires further development to be used as a sighting tool. This technique could be employed in any area where wireless services were available or where cellular towers could be placed specifically for the research (e.g., at a particular rookery or haul-out site).

MARKING PROGRAM

Survival and reproductive rates currently available for northern fur seals are predominately from the commercial harvest and pelagic scientific collections that occurred from the 1950s through the 1970s. The harvests selected specific age and sex classes based on management goals and so do not represent an unbiased sample of the population. The marking of large numbers of pups on the Pribilof Islands was terminated in 1969. Consequently, there has been no data to estimate vital parameters of the populations for the past 35 years. Marking programs require that a large number of animals are marked over several years to account for annual variability in survival and to obtain large enough sample sizes to estimate age-specific natality over the average lifetime of females. Such studies also require extensive resighting effort for many years to obtain precise estimates and the resighting effort must continue for several years after the last cohort is marked. Thus, large field crews and substantial field time are required and such programs can be logistically difficult and expensive. To some degree, marking adult animals, ageing them, and following them provides an abbreviated time frame in which to obtain the data (perhaps 10 years rather than 15 to 25 years). But, if juvenile survival or age of recruitment is driving the population trend, as they often do in long-lived species, an adult marking program will not identify problems for these age classes. Thus, the goals of the study must be clearly determined and the marking program must be designed to meet specific goals. Ideally a marking program would continue until the population has recovered and birth and survival rates for a healthy fur seal population are known; however, there may be short-term goals, such as age-specific foraging distribution, that can be reached while pursuing the long-term goals.

The working group discussed the components of a marking program to estimate survival and reproductive rates of the northern fur seal populations in Alaska and California. They discussed focusing the marking effort on females because they are the driving force in the population trend in a polygynous species. However, the survival of juvenile males has been historically monitored and therefore, it is the parameter that would logically be used to compare current and historical rates. The working group agreed that any marking program should include juvenile males. The working group also recognized that an extension of the marking program is the ability to use known-age animals to describe age-specific or reproductive-class specific foraging ecology and distribution and movements by attaching instruments to them and tracking them while they are at sea. Because behavior, survival, and successful reproduction are linked, examining the behavior of individuals can help identify factors that influence the survival and birth rates (e.g., foraging areas and migratory range).

The primary questions regarding reproduction and survival are whether the rates have declined since the 1950s thereby contributing to the decline of the population in the Pribilof Islands, and if San Miguel Island, Bogoslof Island, and some of the Russian islands where populations are increasing, have different reproduction and survival rates than the Pribilof Islands. The working group outlined two approaches to estimating vital rates: 1) an age-specific study design where pups, juveniles and/or adults are marked and followed throughout their lives; and 2) a reproductive class study design where animals are marked, assigned to a reproductive class (e.g., juvenile, adult reproductive, adult non-reproductive), and followed for some period of time to determine the proportion of each reproductive class that is surviving and reproducing annually. Before any new studies are initiated, the working group agreed that thorough reviews are needed of historical information including: 1) tagging and sighting data from a study conducted in the Pribilof Islands in the late 1980s and early 1990s on juvenile males, 2) results of behavior studies between 1974 and 1990 at St. George Island, Alaska, on reproductive behavior of adult females, 3) survival and birth rates of adult females collected in the commercial harvest and pelagic scientific collections in the 1950s and 1960s, and 4) data from the commercial harvest and pelagic scientific collections for juvenile males (3 and 4 year-olds) during the 1980s and 1990s. These data will provide baselines from which new data can be evaluated relative to historical trends and will help in designing the new studies so that the results can be compared to historical data (e.g., target same rookeries and same age classes).

Estimation of Age-Specific Survival and Birth Rates

Age-specific birth and survival rates can be obtained from permanently marked pups or from animals aged and marked as juveniles or adults. The marked animals are followed from the time of marking throughout their lives. This is a standard method for obtaining age-specific birth and survival rates for mammals but has not been very successful for pinnipeds because of the long duration of this type of study for a long-lived animal, and the poor retention of marks once animals reach reproductive age. This design requires:

1) A marking technique that uniquely and permanently identifies individuals throughout their lives. This could be any of the methods previously described or a combination of methods. For example, an animal could be tagged with a color-coded tag and an RFID tag. The color-coded tag is a batch mark to identify the cohort that an animal belongs to and indicates that the animal has an RFID tag.
2) An ageing technique for adults that is feasible for large numbers of animals and can be conducted in the field. A pilot study to evaluate whether post-canine teeth of adult northern fur seals can provide reliable estimates of age should be undertaken. Known-age specimens in the collection at the National Marine Mammal Laboratory could be used to validate the ageing method. This method is currently being employed for Antarctic fur seals (*Arctocephalus gazella*) (Arnbom et al. 1992) and New Zealand fur seals (S. Goldsworthy, personal communication) and has produced age-specific birth rates for New Zealand fur seals. Alternatively, an age class could be assigned to marked individuals based on age-length curves from historical data or morphological characteristics that would allow a general age-class model to be developed without the extraction of teeth (e.g., pelage color patterns of females differ for ages 1-3 years, 4-7 years, 8-11 years, greater than 11 years; vibrissae color changes from black for ages up to 3 years, to mixed black and white for ages 4-6 years, and to white for females older than 7 years). A clear classification of morphological characteristics relative to age class needs to be developed and validated for an age-class program to be successful. Once developed, the classifications could be validated using marked animals currently at San Miguel Island, California.
3) A marking program that 1) annually marks a large number of pups at 3 or 4 months of age for a minimum of 5 years. Pup mortality to this age must be documented to accurately estimate survival rates post-marking, and/or 2) annually mark a large number of adults and/or juveniles of different reproductive classes. The marking effort must consider fidelity to areas for breeding, the feasibility of detecting marked individuals based on habitat and distribution at each colony, and the sample size of pups or adults and juveniles needed to have an adequate sample size when animals reach the ages of interest (i.e., age at first birth, peak reproductive age).
4) A sighting program that addresses potential movements of individuals, the probability of sighting by area, and continues for 15 years to obtain recruitment data for five cohorts and up to 25 years to obtain reproductive life-span and longevity data. Each year sighting effort would be conducted at designated colonies. At a minimum, the

presence and reproductive status of marked animals would be recorded and standard mark-recapture models would be used to estimate survival and birth rates.

Estimation of Survival and Birth Rates by Reproductive Class

Having age-specific data is most useful if the population problem lies in the behavior of a specific age (e.g., pups and yearlings). Another approach to gaining vital parameter information for a population is to assign marked individuals to a reproductive class (e.g., juvenile, adult reproductive, adult non-reproductive) and then use multi-state models to estimate the proportion that survive and the probability that they will reproduce in a given year. Elements 1, 3, and 4 of the age-specific design would apply. In addition, this design requires an assessment of the availability and sample size needed for each reproductive class and the distribution of the reproductive classes among the different colonies in each of the northern fur seal populations to determine the feasibility of such an approach. A review of historical data from commercial harvests and pelagic scientific collections to determine age-length curves and relationships between age and reproductive class may allow for this type of study to also have an age-class component.

CENSUS TECHNIQUES

Northern fur seal abundance is estimated at the breeding islands using the numbers of pups as an index because prior to learning to swim, all or most of the pups are available on land for observation; in contrast, an unknown number of adults and juveniles are at sea during any given time so total numbers of these groups are not possible to obtain. The total population size can be estimated from the pup counts based on formulas that relate the number of pups born to the total population (Angliss and Lodge 2003). Counts of adult males have been collected as a population monitoring tool since the early 1900s on the Pribilof Islands but are not dependable as the sole method for estimating northern fur seal population size. The following discussion of census techniques will be limited, therefore, to pup indices.

Determination of fur seal abundance at the Pribilof Islands, where the overwhelming majority of the world’s breeding population of northern fur seals was found, was originally driven by the economic value of the historical commercial harvest and by international government negotiations related to the harvest. Over the years, a number of techniques were developed and have been used to estimate the number of pups born on the Pribilof Islands: direct counts, mark-recapture, and ratio estimation. Reliable estimates of pup production date to the early 1900s and, in an effort to increase precision, the methods have evolved over the decades. Because some techniques are better suited to the specific traits of different breeding colonies (e.g., terrain or size of population), different census techniques may be used at different colonies.

Direct Count

Direct counting of pups as an index of abundance is most feasible for small populations. Direct counts are difficult when the terrain has boulders or cliff overhangs where pups can be hidden from view, when animals are located close to the water and enter the water when approached or, when the population is very large or densely aggregated. Accurate direct pup counts are, in fact, impossible at most rookeries in Alaska because of the large, dense aggregations and the rocky terrain. Direct counts are currently used to determine pup production at San Miguel Island. Direct counts provide precise estimates of the San Miguel Island colonies because the pups are distributed in small groups and can be easily observed. Direct counts were used at Bogoslof Island until 1997 when the increased density of pups required replacement of the direct count with the shear-sampling technique (see below).

Mark-Recapture

Mark-recapture involves capturing and marking pups with a mark that can be identified during a ‘recapture’ survey at a later date. The proportion of marked pups to unmarked pups is estimated from the recapture surveys, and the pup production is estimated by dividing the number of pups originally marked by the proportion of marked animals among all surveyed. Mark-recapture methods assume that, during marking, each pup has an equal chance of being marked and that, during recapture surveys, marked and unmarked animals have an equal chance of being observed.

From the 1940s until the 1960s, fur seal pups were marked by branding, tagging, or notching of their flippers (Roppel 1984, Scheffer et al. 1984). These permanent or semi-permanent marks were used to estimate the number of pups born in a year by conducting recapture surveys of these animals as juveniles, 2 to 3 years later, during the commercial harvest. As a result, the estimate of pup production for a given year could not be made for a number of years after the pups were marked. The delay between marking and first sighting violated the mark-recapture assumptions that marked and unmarked animals have an equal chance of being observed and that sampling is instantaneous. In addition, tag loss, which was known to occur, violated the assumption that no marks are lost during the study. While there were unknown effects of the marking methods on fur seal pup health and survival which could have negatively affected the estimates by increasing mortality, undetected tag loss likely had a greater affect on the estimates and resulted in an overestimate of the fur seal population size during the time period that flipper tagging was used as the primary marking technique.

Since 1963, the shear-sampling method has been used on the Pribilof Islands to estimate northern fur seal pup production (Chapman and Johnson 1968, York and Kozloff 1987). It is also currently used at Bogoslof Island. The shear-sampling method not only allowed the researchers to conduct the recapture surveys closer to the time of marking (therefore reducing potential loss of the marks), but it also allowed for the use of temporary and less invasive marks. This method of marking involves shearing a small patch of dark hair from the head of a pup to expose the light-colored underfur. Pups are rounded up in early August before they have begun to swim, but after the social structure on the rookeries has begun to break apart. The number of pups sheared is based on a goal of marking approximately 10% of the total born based on the most recent estimate of pup production. A few days after marking, sampling (recapture) surveys are conducted on two occasions to estimate the proportion of marked pups at the rookery. The final calculation of pup production also accounts for dead pups which are counted directly during one of the sampling surveys.

Ratio Estimation

Ratio estimation uses partial counts (or mark-recapture estimates) of pup production in combination with counts of adult males to estimate total population size (Roppel 1984). The assumption is that the ratio of adult breeding males to pups remains stable over time or it needs to be recalculated each year. Some of the early estimates of pup production on the Pribilof Islands relied on direct counts of pups at selected rookeries and breeding males at all rookeries. The total pup production was estimated by multiplying the total number of breeding males with the ratio of pups to breeding males determined from the selected rookeries.

More recently, ratio estimation has been used in combination with shear-sampling estimates. The combination of the two methods results in greatly reduced research effort and disturbance to the animals. Shear-sampling estimates of pup production on the Pribilof Islands have often involved ratio estimation, a process accomplished by sub sampling pup production at specific rookeries and combining these with ratios to adult breeding males (which have been counted at all rookeries). Pup production estimates from ratio estimation generally have a higher variance than shear-sampling estimates alone; the use of ratio estimation with shear-sampling must therefore balance the need for greater precision against the resources available to conduct the research and an acceptable level of disturbance to the animals.

CENSUS PROGRAM

Due to the decline in northern fur seal abundance at the Pribilof Islands, and because these islands represent the majority of the breeding population, there is growing concern and attention (including research effort) into the issues surrounding the northern fur seal. The workshop participants were asked to review the current northern fur seal census program and to provide expert recommendations regarding the current or alternative methods. The primary concerns identified regarding the shear-sampling methods currently used on the Pribilof Islands were the resources required, the level of disturbance to individuals in a declining population, and the unknown biases during marking or sampling that affect the estimates.

The working group discussed the use of aerial medium format photography and infra-red imaging to count pups. While these methods may be appropriate to count adults, they do not have the resolution necessary to conduct pup production estimates at the Pribilof Islands, and are complicated by the same factors that make direct counts difficult at these colonies: animal density and terrain. In addition, weather conditions and associated flight costs could be limiting, and extensive validation would be required. The working group suggested that it might be possible to determine population trends from either total non-pup counts or a combination of pup and non-pup counts; these ideas will be explored further.

Without viable alternative methods for pup production estimates, the working group recommended that the NMML continue annual direct counts at San Miguel Island, and shear-sampling at the Pribilof Islands and at Bogoslof Island. Shear sampling is much more effective than direct counts on the Pribilof Islands because of the density of pups and the rocky terrain.

The working group noted that in areas where direct counts are easily made, relatively small differences have been observed between direct counts and shear-sampling estimates (P. Shaughnessy, personal communication). However, up to 80% more Australian sea lion pups were counted using the shear-sampling method than when using direct counts at colonies with rocky terrain similar to that found on the Pribilof Islands. In order to minimize effort and disturbance associated with the Pribilof Islands shear-sampling procedures while obtaining a high level of precision in the estimates, biennial surveys at all rookeries were determined as the preferred approach rather than annual shear sampling surveys at some rookeries combined with ratio estimation at other rookeries. Due to the remote location of Bogoslof Island, pup production estimates are conducted only on an opportunistic basis. However, efforts should be made to increase the regularity of the estimates at this rapidly growing colony.

The working group presented a number of recommendations with respect to the shear-sampling method that were aimed at assessing and reducing disturbance or bias. A high level of disturbance is caused during the marking of pups and when dead pups are counted, but the impacts of these disturbances on the population are unknown. The working group suggested that the impact of shear-sampling on fur seals should be investigated. The working group also suggested sub-sampling rookeries to count dead pups and using ratio estimation to estimate the total number of dead pups to reduce disturbance to the colonies.

Violations of the assumptions of mark-recapture (each pup has an equal chance of being marked and an equal chance of being observed) could lead to biased pup production estimates. In most cases, the existence and direction of any bias is difficult or impossible to assess. For instance, it has been hypothesized that a greater proportion of small pups may be marked than large pups because they are slower and easier to handle. In this scenario, it would be difficult to determine if, and how, the resulting pup production estimate would be biased. In other situations, however, it may be feasible to examine and quantify bias associated with the recapture surveys, or with the observers themselves. It is often thought that there is a tendency for the observer's eye to be drawn toward shear-marked pups, resulting in 'over-sampling' and causing the pup production to be underestimated. Various types of bias related to observer sampling could be tested, most likely by using video or photography from close distances (e.g., tripods or cliffs) to determine the proportion of shear marks in an area.

The working group recommended improvements in the shear-sampling protocols that may reduce bias in the northern fur seal pup production estimates. First, shear marks should be extended forward on the top of the head of the pup, and placed between the eyes. This minor change in methods would reduce the likelihood of missing a sheared pup because the top of the head was not observed. Second, the current method of recording each marked pup during the marking phase relies on each shearer to record their own data. It is possible that some marks are not recorded properly if the shearer becomes distracted. Thus, to ensure that an accurate count of the number of marks deployed is obtained, only one individual who is not shearing could record data, while other individuals shear pups and call out their totals to the recorder.

SUMMARY

Marking Techniques

The working group determined that in the near-term, external flipper tags are the most feasible method for marking large numbers of northern fur seals. The smaller populations on the

Pribilof Islands now allow greater access to the animals with less disturbance, and the use of mobile blinds allow observers to approach animals more closely in some areas than was possible during previous tagging studies. These changes should improve the probability of sighting tagged animals. Rounding up adults and juveniles after the breeding structure of the colony has disbanded in September through November and recording tags should also increase the number of individuals sighted annually. However, tag loss remains a significant problem with the current tags available. The working group agreed that a new tag needs to be developed that has the following characteristics:

1) The tag must be small to reduce drag but have large numbering or lettering that can be read from a distance of 20 m or more with visual aids.
2) The tag post should be smooth and round to avoid cutting into the flipper tissue as the animal grows. An expandable post would be ideal to allow for flipper expansion with growth.
3) The tag should be composed of metal or UV resistant plastics or a combination of these materials for longevity.
4) Lettering or numbering should be double-stamped or laser etched with imprinted ink to increase longevity of readability.
5) Creating a hole for the tag before applying the tag may reduce trauma to the flipper tissue at the tagging site and may increase tag retention time.

The working group agreed that the future of unique identification of fur seals lies in the development of electronic tags and remote data recorders. The most promising electronic tags are subcutaneous low frequency RFID tags and readers that have long distance readability ranges (between 10 and 20 m). At this time, the readers for low frequency RFID tags are not capable of reading tags at distances greater than 1.0 m and the tags must be oriented in specific way for maximum readability. However, the working group discussed several ways in which the current technology has been and could be used until a new electronic tag system is available. The options include 1) gathering groups of animals and processing them through a chute where a reader could be used to obtain their identification, 2) modification of the colony so that animals have to pass through specific areas where readers are positioned and each time an animal passes through the area, the identification is read and stored in a remote data logger, and 3) placement of an array of antennas along the entrance to the colony such that animals could pass under or over the antenna as they leave and return from sea. Some of these techniques have been successfully used to identify Australian sea lions with subcutaneous RFID tags (S. Goldsworthy, personal communication). The working group agreed that manufacturers need to be engaged and encouraged to develop an RFID system that would be applicable to the needs of the fur seal and sea lion research community. An organized effort among interested researchers may provide the resources to fund research and development of a system that could be adapted for the unique habitat, life history, distribution, and environmental conditions of different species around the world.

Emergent technologies such as neural network and nearest neighbor frameworks, remote controlled or unmanned miniature automated aircraft, and wireless communication technology are in their infancy in applied marine mammal behavior research. However, these technologies may revolutionize the way we gather data on individuals. All of these technologies require substantial research and development to produce a product that will be cost efficient and logistically feasible for the northern fur seal marking programs in Alaska and California.

Marking Program

The working group outlined the components of a long-term marking program for northern fur seals but expressed concerns about embarking on a northern fur seal marking program without a thorough review of the historical data and without a commitment by researchers and policy makers to a long-term program. The program should continue until the population has recovered to obtain vital rates for a healthy fur seal population. The minimum commitment would be 15 years but up to 25 years to obtain data on longevity and vital rate trends. Previous attempts to conduct long-term studies have failed due to a lack of funding and unreliable marking methods. However, other than direct harvest of individuals, mark-recapture studies of live animals provide the only method by which to obtain vital rate information necessary to develop population models. The working group agreed that a combination of longitudinal and cross-sectional studies would provide a complete dataset of population parameters. Such data are needed to identify the components of the population that are driving the decline in the Pribilof Islands and the increases in the other populations. Population models assist managers in identifying natural or anthropogenic factors influencing trends and help identify a course of action to recover the population. In addition, long-term studies have value in that tracking survival and birth rates over time allows analysis of the effects of environmental changes, on short and long time scales, on the population. Longitudinal records of individuals will provide a critical dataset for evaluation of how climate change and oceanographic changes influence northern fur seal population trends in the future.

Census Techniques

Northern fur seal abundance is estimated at the breeding islands using measurements of pup production. Direct counts and shear-sample (mark-recapture) estimation are currently used to estimate pup production in Alaska and California. The efficacy of each method differs depending on the terrain and density of the breeding colonies. Shear sampling is appropriate at the Pribilof Islands and at Bogoslof Island because of the high density of pups and rocky terrain. But direct counts are suitable at San Miguel Island because the population is small and the pups are easily observed. In reviewing census techniques, the working group discussed alternative methods for estimating abundance (e.g., medium format photography or infrared imaging) and concluded that these methods could be used in combination with the current methods to refine estimates, but that the current methods were sufficient.

Census Program

Without a better alternative for pup production estimates, the working group recommended that the NMML continue estimating abundance as currently done. Specifically, direct counts will be conducted at San Miguel Island each year, and shear-sampling will be conducted at the Pribilof Islands biannually and at Bogoslof Island opportunistically. In order to minimize effort and disturbance while obtaining a high level of precision, biennial shear-sampling surveys at all rookeries was the recommended approach rather than annual shear sampling surveys at some rookeries combined with ratio estimation at other rookeries. Due to the remote location of Bogoslof Island, shear-sampling will be conducted on an opportunistic basis. The working group recommended improvements in the shear-sampling protocols that may reduce bias in the northern fur seal pup production estimates. First, shear marks should be extended forward on the top of the head of the pup, and placed between their eyes. Second, only one individual who is not shearing should record data, while other individuals shear pups and call out their totals to the recorder.

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APPENDICES

APPENDIX 1

The Assessment of the Northern Fur Seal Population on the Pribilof Islands – a History

by
Anne E. York

ABSTRACT

This report briefly describes the history of population assessment of the northern fur seal, *Callorhinus ursinus*, on the Pribilof Islands of Alaska. I did not find data from the period of Russian ownership of the Pribilof Islands; the report only covers the period of U.S. ownership from 1867 to present.

INTRODUCTION

From the time of their discovery by Gerasim Pribilof in 1786 until their sale to the United States in 1867, the Pribilof Islands were a possession of Russia. The Russian fur seal harvests were unregulated until 1799 when the Russian-American Company assumed control of the Pribilof Islands because the harvests were declining. The harvests continued to decline and in 1834, the Company outlawed female harvests, and the herd began to recover. When the United States purchased Alaska, the herd was sustaining a yearly harvest of several thousand animals.

From 1868-1869, the harvest on land was unregulated and approximately 250,000 skins were taken. The U.S. government then set aside the Pribilof Islands as a reserve for the protection of fur seals (Lander 1980) and from 1870 until approximately 1910, the Pribilof seal herd was managed under leases from the government. During this time, uncontrolled commercial pelagic sealing began. By 1890, the pelagic harvest exceeded the commercial harvest on land. It is well-known (e.g., Roppel and Davey (1965) and Baker et al. (1970)) that this harvest decimated the fur seal herd on the Pribilof Islands because pelagic sealing killed mostly females in contrast to the harvest on land which killed mainly subadult males. The North Pacific Fur Seal Convention of 1911 was negotiated between the United States, Great Britain (for Canada), Japan, and Russia and prohibited pelagic sealing. The lack of a reliable assessment of the size of the herd was a significant factor in prolonging the signing of the Convention. With the cessation of pelagic sealing under the Convention, the herd and the commercial harvests grew rapidly. The

Convention remained in effect until Japan abrogated the treaty in 1941 on the grounds that the large fur seal herd was damaging its fisheries. In 1956, the Convention was renegotiated among the United States, Canada, Japan, and the Soviet Union and remained in effect until 1985 when its term expired and it was not renegotiated. The international convention was reinforced in the United States by passage of The Fur Seal Act of 1966 (Baker et al. 1970).

The North Pacific Fur Seal Convention of 1956 included priorities for scientific fur seal research. A Standing Scientific Committee was established and this was a convenient vehicle for fur seal scientists to share knowledge and results. The Convention also required the parties to provide statistics on the herd. Especially for Japan, it was important that the herds not get too large, and the mangers of fur seal rookeries were required to provide estimates of the total population size of their herds. To study migration and inter-mixture, large-scale tagging programs were encouraged as part of the assessment programs. In 1973, the commercial harvest on St. George Island was suspended, and the island was declared a research sanctuary. The last commercial harvest on St. Paul Island took place in 1984. Until the St. George research sanctuary was declared, the main purpose of northern fur seal research was driven by concerns for the harvest (e.g., to produce a maximal sustainable yield or to harvest only males of a particular age).

In this report, I attempt to provide a history of assessment of northern fur seals. Since I did not find data from the period of Russian ownership of the Pribilof Islands, the report only covers the period of U.S. ownership from 1867 to the present. Schffer et al. (1984) notes that the papers left by the last Russian manager of the Pribilof Islands were destroyed when they were used to plug holes in a house on St. Paul Island.

Abundance of Adult Males

U.S. Treasury Agent Joseph Murray during the 1890s standardized the methods for counting adult males. On the basis of observations over several years, he noted that the highest count was achieved during 10-20 July (Scheffer et al. 1984).

Adult male seals have been counted annually since 1909 with the exception of a few years when research was redirected or interrupted by war (Lander 1980). Breeding males are a consistent component of the fur seal population to assess because they stay on shore in predictable locations for a definitive period of time. Their physical size and relatively few numbers make them conducive to direct counts. Classifications of adult males have been relatively consistent since 1909 (Lander 1980). However, it was tacitly assumed over the years (e.g., by Osgood et al. 1915, Kenyon et al. 1954) that all adult males were present on land during the breeding season and that the count of adult males actually reflected their number, rather than an index of their abundance. Lander (1979) realized that this assumption was not valid and his biomass estimates reflect use of the counts as an index of the abundance of adult males.

Estimation of Pup Numbers

The determination of the total number of northern fur seals in the Pribilof population is not possible. Pups are the only component of the herd completely accessible on land at one time. Even estimating their number is a daunting task, especially if the number of pups is large. Over the years, biologists, statisticians, biostatisticians, accountants, and others have proposed many ways to estimate the number of pups and to derive estimates of the size of the other components of the herd (and by way of inference, that of the total herd) based on biological models. The following methods have been used to estimate the number of pups:

1. Counts.
2. Models.
3. Counts on sample rookeries combined with a ratio to area or harem bulls.
4. Mark-recapture.
5. Mark-recapture on sample rookeries combined with a ratio to harem bulls.
6. Combinations of the above.

The first attempt at population estimation appears to have been done by C. Bryant on St. Paul Island in 1869. He measured the total rookery shoreline at 18 miles (29 km) and estimated an average width of 15 rods wide (75.4 m). He estimated that there were about 20 breeding adults per square rod (1 rod = 5 m and 1 square rod = 25 m). Converting from rods to meters, Bryant's estimated the density of adult seals was 20/25 = 0.8 seals per square meter. Using this method, Bryant determined that there were over 3 million breeding adults and pups on the island (Scheffer et al. 1984).

During 1872-1874, H. W. Elliot mapped the rookeries and estimated the area of rookeries from the maps. From observations, he estimated that the density of seals (males, females, and pups) was 47 seals per 100 square feet, and concluded that there were 4.7 million seals. Elliot's estimated density is equivalent to about 5 seals per square meter. It is not clear what portion of these are adult females, pups, or breeding males. Assuming roughly half are adult females, Elliot's estimate of the density of adult seals was about 2.5 to 3 times that of Bryant's estimate.

Besides standardizing dates for counting adult males, U.S. Treasury Agent Joseph Murray appears to have originated the idea of using the average harem size to estimate the number of pups born (Scheffer et al. 1984). It is not clear, however, how he determined the average harem size. In 1889, he estimated pup production on St. Paul at 481,350. After his term as Treasury Agent, he visited St. Paul in 1895 and reported that number of pups was no more than half of those seen in 1889 (Scheffer et al.1984).

The first complete count of northern fur seal pups was conducted by G. A. Clark in 1912 (Scheffer et al.1984). In early August, before many pups had gone to the water, pups were herded behind snow fences and counted as they ran the gauntlet back toward where they had been on the rookery. The count was conducted on all rookeries of St. Paul (including Sea Lion Rock) and St. George Islands. The counts were repeated by G. Dallas Hanna between 1913 and 1916 and in 1922 on all rookeries of St. Paul and St. George Islands. Between 1917 and 1921 and in 1924, counts were made on 4 to 8 rookeries of St. Paul Island and 3 to 4 rookeries of St. George Island (Kenyon et al.1954). Dead pups were counted at the same time and the total number of pups born was determined from the sum of dead and live pups. In years when only partial counts were made, estimates of the total number of pups were determined from the product of the ratio of pups to breeding males on the rookeries that were censused, and the total count of breeding males (Table 1).

From 1925 to 1940, there was virtually no scientific research on northern fur seals (Scheffer et al. 1984). The herd managers continued to count breeding males every year, but accountants in Washington DC determined the pup numbers using the average annual observed increase of 8% from counts conducted in 1916 and 1922. If P_i is, the pup count in year i, then the estimated number of pups born in 1925 was estimated by assuming a fixed rate of increase of 8% per year:

$P_{1925} = 1.08 \times P_{1924}$.

Pup numbers were estimated by multiplying the previous year's estimate by a fixed rate of increase from 1925 until 1941. By 1940, the "official" estimate of fur seal pups on St. Paul Island was approximately 580,000. As the herd continued to increase and the expected harvest size fell below expectations (Kenyon et al. 1954), it became clear that the 1920s estimated 8% growth rate was not sustained (Lander 1980). However, the herd managers continued to use the accounting method until 1947, but they reduced the growth rates to 7% for 1942 - 1946, and to 6% in 1947. Reanalysis of the data using the ratio of pups to breeding males on one counted rookery produced an estimate of about 420,000 in 1940 compared to the 580,000 estimated from the fixed rate of increase method (York 1985). A re-examination of fur seal pup numbers from 1916 to 1924, using all available counts on St. Paul Island and weighted by the number of rookeries counted in each census year, indicated that the rate of increase of pup numbers was 8.2% (SE = 0.4%) per year.

When scientific fur seal research was resumed in 1940, marking of fur seals also began anew (Scheffer et al. 1984). In 1940, 1941, and 1945, seals were branded or tagged on St. Paul Island (see York 2005, Table 3). The efforts to determine the sizes of the 1940 and 1941 cohorts deserves special mention. Because of the evacuation of Aleuts from the Pribilof Islands in 1942 (following the invasion of Aleutian Islands by the Japanese), there was no commercial harvest in 1942. However, sealers did return to the Pribilof Islands in 1943 and Palmer (1943) describes measuring and resighting branded and tagged subadult male fur seals in that harvest. Counts were also made on a few rookeries during the 1940s and these were summarized by Kenyon et al. (1954). There is an opportunity to revisit these data and, perhaps, to estimate the size of the 1940 and 1941 cohorts. This would be very useful, as it would provide an estimate of the carrying capacity of the fur seal herd-- an important statistic for management considerations.

Following this period, a large-scale tagging experiment was carried out on the Pribilof Islands between 1947 and 1968 (except in 1950). The main purpose of the tagging experiment was to estimate the number of northern fur seal pups born via mark-recapture in the commercial harvest. This was a very large scale experiment: over 500,000 northern fur seal pups were tagged and another 150,000 marked with check marks over the course of the experiment (York 2005, Table 3). Tagged subadult males were usually harvested like unmarked subadult males if they were judged to be within the length limits then in force. There were some exceptions to this practice. During the 1950 harvest, there was deliberate killing of all tagged animals, and during the 1951 harvest, there was deliberate killing of animals from the 1947 and 1948 cohorts, but animals from the 1945 cohort were spared. The ostensible purpose of the deliberate killing was to avoid bias in population estimates calculated from tagged animals. Because of length restrictions on animals that could be harvested, the smallest and largest animals were spared during the regular harvest. I believe that the purpose of sparing tagged animals in some years was to be able to directly estimate the survival rates of tagged subadult males and to eventually have marked animals in the breeding population. A small number of tag retrievals were made in the course of the pelagic investigations of Canada, Japan, the Soviet Union, and the United States; somewhat larger numbers of retrievals were made during the Soviet harvests of sub-adult males. However, by 1963, it was clear that the estimates of pup production based on tagging greatly overestimated the size of the population (Chapman 1964; Chapman and

Johnson 1968) because of undetected tag loss. However, by that time, mark-recapture estimates had been developed for estimating the numbers of pups born in the current year (Chapman and Johnson 1968), and little attention has been given to the large-scale tagging data. Chapman (1964) produced “cumulative estimates” of pup numbers for 1949–1959 based on a life-table and known removals of adult females.

Starting in 1960, the number of pups born was estimated using mark-resighting of the tagged animals (Lander 1980). But, in 1963 the marking method of shearing a small patch of guard hair from the pup’s head to expose the light underfur was begun. This method is currently used to estimate pup production. As described in York and Kozloff (1987), a large number of pups (approximately 10% of the previous pup estimate) is marked in early August, by shearing a small patch of hair from the top the their heads. This exposes the pale underfur and produces an easily identifiable mark. Marking is done as the breeding structure breaks up, but before pups spend much time in the water. Marking is allocated throughout the rookery so that each pup has an approximately equal chance of being marked. This is accomplished by allocating the marking effort according to the relative proportion of breeding males in standardized sections of each rookery. Beginning a few days later, each rookery is sampled twice during different periods to estimate the proportion of marked animals on the rookery. Thus, estimates of the population size is the normal Petersen estimate (the number of sheared animals divided by the proportion of sheared pups among all those resighted) and the variance of the estimate is one-fourth the squared difference of the two estimates.

York and Kozloff (1987) justified the method of subsampling the rookeries. A shearing sampling pup estimate on the sampled rookeries was obtained, and then the total pup abundance was estimated by applying the ratio of pups to breeding males from the sampled rookeries to two non-sampled rookeries. This method took advantage of a very high correlation between the number of pups and breeding males within a given year (most values of r^2 were greater than 0.98) and was therefore considered reasonable. Several subsampling plans were investigated, and a stratified random sampling plan based on three strata (small, medium, and large rookeries), with two small, one medium, and one large rookery sampled was chosen. It was also specified that each rookery be sampled at least once, but no more than twice over a 5-year period, and it was suggested, that every 5 years all rookeries be sampled to verify that the assumptions inherent in the procedure (most importantly, that the ratio of pups per breeding male was approximately uniform across the rookeries) were still valid. Shearing-sampling on all rookeries resumed in 1990 due to a very high variance in the 1989 estimate. All rookeries were sampled after 1992 (except in 1996). The commercial harvest was terminated in 1984 and large numbers of animals spared from the harvest became breeding age in 1989. I hypothesize that, due to topographic complexity, the opportunity to establish territories was easier on some rookeries than on others, and that this factor caused the ratio of pups to breeding males to be less uniform after 1989. However, this hypothese has not yet been tested.

There have been some variations in the resampling procedures and thus, the variance estimation procedures since 1962. From 1962 to 1990, each sampler was responsible for sampling non-overlapping subsections of the rookery. In 1962, the population was much higher and for speed and minimization of disturbance, this was done. Between 1990 and 1992, teams of samplers were responsible for the non-overlapping subsections; the purpose of this change was to be able to estimate the consistency of observers. After 1994, all samplers were responsible for the entire rookery (York and Towell 1996).

Bias of Pup Estimates

York (1989) analyzed sources of bias of the shearing-sampling method. Potential sources are violations of the assumptions required for the mark-recapture method to be unbiased. Most importantly, during the marking phase, each pup must have an approximately equal chance of being marked and seen during the re-sighting phase; the marked pups must have the same probability of being observed as the unmarked pups. The only direct method of assessing the bias of the shearing-sampling method is to compare it to some unbiased method of pup estimation. In York (1989), an analysis of all simultaneous shearing-sampling estimates and total rookery counts was made. In all cases in which the count and the shearing sampling estimate were significantly different, the count was larger. It is important to note that the counts were made by clearing the rookeries of adults and herding the pups between two counters. Thus, the comparison does not apply to counts made on undistrurbed rookeries (e.g., counting from a cliff above a rookery). York (1989) also presented an analysis of photographs of groups of pups and concluded that the ratio of sheared to non-sheared pups in the photographs was not significantly different from the ratio done in the field by the samplers. Fur seal researchers in Uruguay have compared cliff counts with shearing-sampling estimates and have found that the counts were about 35% lower than the shearing-sampling estimates (Mauricio Lima, personal communication). Coincidentally, counts made at South Rookery on St. George Island in 2004, were approximately 35% lower than the shearing-sampling estimate (Bruce Robson, personal communication).

Stock Size Estimate

There are three main sources for determining an estimate of the total stock size of the Pribilof herd. All three methods are based on assumed constant life tables of the fur seal population and other assumptions. Osgood et al. (1915) provided the first estimate of the total stock size of northern fur seals. It was not clear how they determined their survival estimates to age 1, 2, and 3. They assumed that the number of pups equaled the number of adult females (i.e. all females age 3 years and older are pregnant), and that the bull count was an actual count of all adult males. Their estimated stock size was 3.47 times the estimated number of pups. Kenyon et al. (1954) provided a new estimate of stock size (Table 3). Their survival estimates to age 1, 2, and 3 were based on estimates from the large scale tagging experiment described in York (1986) and estimates of mortality from known takes in the commercial harvest. Their estimates of adult female mortality rates were calculated from age distribution of adult females taken in the first international pelagic sampling cruise conducted off North America in 1952 (e.g., Taylor et al. 1955). Like Osgood et al. (1915), they also assumed that all adult males were represented in the July counts of adult males. Their method estimates the total population at 3.37 times the estimated number of pups. Loughlin et al. (1994) (Table 4) provided a new stock size estimate based on the life-table of Lander (1979) adjusted for the cessation of the commercial harvest. Their total estimate was about 4.47 times the estimated number pups. In the application of Kenyon et al. (1954) and Loughlin et al. (1994), to adjust for interannual variability in vital rates and probable lack of stability of the population, they used a running average of three censuses of pup numbers instead of simply the current pup estimate. Kenyon et al. (1954) assumed the pregnancy rate of 3+ females was 60%. Loughlin et al. (1994) corrected the pregnancy rate because, in the Pribilof population, the pregnancy rate of 4+ females was actually 60% (Lander

1979). Table 5 shows how the stock size estimates between the three approaches compared. The largest discrepancy between the estimates was the number of 3+ females due to the differences in assumptions of the pregnancy rates. Another important discrepancy was due to the assumption in the 1914 and 1953 estimates that the adult male count reflected the total counts rather than an index of the total numbers alive.

Other Methods to Estimate Pup Numbers

There are other ways to estimate pup numbers. The shearing-sampling method causes a lot of disturbance to the rookery, but in my opinion, it is the most accurate method (usually giving a CV of less than 10%). Changing to a method that causes less disturbance will require several years of calibration.

Anyone contemplating a change in the procedures to estimate pup numbers must read Kenyon et al. (1954). They compared six methods for determining pup numbers (unfortunately, with no estimates of variability):

1. Tag recoveries in the harvest 530, 000.
2. Sample counts plus area ratio 580, 000.
3. Trend of commercial harvest 590, 000.
4. Trend of harem bull counts 550, 000.
5. Rapid field estimates 440, 000.
6. Sample counts plus harem bull ratios 470, 000.

Although the estimates were of similar magnitude, the rapid field estimates and the sample counts combined with the harem bull counts (methods 5 and 6) were more similar, while methods 2 and 3 were larger, and method 1, in between. It is possible to recalculate most of the estimates in Kenyon et al. (1954) and estimate the variances. If estimates that are as precise as the shearing-sampling estimates are not required for management, other methods could be employed. However, for ground–truthing a new procedure, shearing-sampling would need to be continued for some time, in my opinion.

Each rookery presents a slightly different problem for estimation. For example, Polovina Rookery on St. Paul and South Rookery on St. George are amenable to cliff counts for which a correction factor might be devised. Other rookeries, such as Tolstoi on St. Paul are, in my opinion, extremely difficult to assess without visiting the rookery. The first step, I think, is to decide how much variability in the pup estimate can be tolerated. This exercise was done several times in the past (York, unpublished data), with the desire of being able to detect a specified rate of change in the population over a given time interval, using the method of Gerodette (1987).

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Table 1. -- Numbers of northern fur seal pups on St. Paul and St. George Islands, Alaska, 1911–2004. The methods used for determining the estimate are provided.

Year	St. Paul	Method	St. George	Method
1912	66,727	direct counts	11,949	counts
1913	75,436	direct counts	12,811	counts
1914	74,956	direct counts	13,867	counts
1915	88,137	direct counts	15,390	counts
1916	98,855	direct counts	18,122	counts
1917	108,689	direct counts	19,335	counts
1918	122,617	direct counts	20,298	counts
1919	133,914	direct counts	23,258	counts
1920	143,275	direct counts	24,252	counts
1921	149,865	direct counts	26,790	counts
1922	158,886	direct counts	27,028	counts
1923	169,363	Unknown	28,296	Unknown
1924	172,528	ratio	35,868	ratio
1925	184,451	8% increase	41,639	8% increase
1926	199,146	8% increase	44,968	8% increase
1927	215,001	8% increase	48,565	8% increase
1928	232,274	8% increase	52,451	8% increase
1929	250,844	8% increase	56,647	8% increase
1930	270,905	8% increase	61,179	8% increase
1931	292,569	8% increase	66,073	8% increase
1932	315,961	8% increase	71,359	8% increase
1933	341,232	8% increase	77,067	8% increase
1934	368,519	8% increase	83,232	8% increase
1935	397,993	8% increase	89,890	8% increase
1936	429,767	8% increase	97,081	8% increase
1937	464,134	8% increase	104,848	8% increase
1938	501,264	8% increase	113,235	8% increase
1939	541,339	8% increase	122,295	8% increase
1940	584,641	8% increase	132,078	8% increase
1940	420,000	York 1986		
1941	630,602	8% increase	142644	8% increase
1942	672,152	7% increase	152,629	7% increase
1943	716,612	7% increase	163,313	7% increase
1944	764,183	7% increase	174,745	7% increase
1945	815,086	7% increase	186,978	7% increase
1946	869,552	7% increase	200,066	7% increase
1947	919,499	6% increase	212,068	6% increase
1949	421,000	Kenyon et al. 1954	105,300	25% of St. Paul
1950	451,000	Chapman 1964	112,750	25% of St. Paul
1951	447,000	Chapman 1964	111,750	25% of St. Paul
1952	438,000	Chapman 1964	109,500	25% of St. Paul
1953	445,000	Chapman 1964	111,250	25% of St. Paul
1954	450,000	Chapman 1964	112,500	25% of St. Paul
1955	461,000	Chapman 1964	115,250	25% of St. Paul
1956	453,000	Chapman 1964	113,250	25% of St. Paul

Table 1 (Cont.).-- Numbers of fur seal pups on St. Paul and St. George Islands, Alaska, 1911–2004. The methods used for determining the estimate are provided.

Year	St..Paul Island	Method	St..George Island	Method
1957	420,000	Chapman 1964	105,000	25% of St. Paul
1958	387,000	Chapman 1964	96,750	25% of St. Paul
1959	335,000	Chapman 1964	83,750	25% of St. Paul
1960	320,000	Chapman 1964	80,000	25% of St. Paul
1961	342,335	shear all rookeries	85,584	25% of St. Paul
1962	300,828	shear all rookeries	75,207	25% of St. Paul
1963	262,498	shear all rookeries	65,624	25% of St. Paul
1964	283,922	shear all rookeries	70,980	25% of St. Paul
1965	253,768	shear all rookeries	63,442	25% of St. Paul
1966	319,045	shear all rookeries	69,406	shear all rookeries
1967	291,000	ratio-shear	72,750	25% of St. Paul
1968	235,000	ratio-shear	58,750	25% of St. Paul
1969	232,870	shear all rookeries	58,217	25% of St. Paul
1970	230,485	shear all rookeries	54,366	shear all rookeries
1972	269,000	ratio-shear	67,250	25% of St. Paul
1973	236,500	ratio-shear	60,385	shear all rookeries
1974	269,000	ratio-shear	51,917	25% of St. Paul
1975	278,261	shear all rookeries	53,704	25% of St. Paul
1976	291,000	ratio-shear	56,163	25% of St. Paul
1977	235,200	take ratio	43,407	shear all rookeries
1978	247,100	take ratio	47,248	shear all rookeries
1979	245,932	shear all rookeries	47,465	25% of St. Paul
1980	203,825	shear 4 rookeries	39,338	25% of St. Paul
1981	179,444	shear 4 rookeries	38,152	shear all rookeries
1982	203,581	shear 4 rookeries	39,291	25% of St. Paul
1983	165,941	shear 4 rookeries	31,440	shear all rookeries
1984	173,274	shear 4 rookeries	33,442	25% of St. Paul
1985	182,258	shear 4 rookeries	28,869	shear all rookeries
1986	167,656	shear 4 rookeries	32,358	25% of St. Paul
1987	171,610	shear all rookeries	33,120	25% of St. Paul
1988	202,229	shear 4 rookeries	24,819	shear all rookeries
1989	171,534	shear 4 rookeries	33,106	25% of St. Paul
1990	201,305	shear all rookeries	23,397	shear all rookeries
1992	182,437	shear all rookeries	25,160	shear all rookeries
1994	192,104	shear all rookeries	22,244	shear all rookeries
1996	170,125	6 sample rookeries	27,385	shear all rookeries
1998	179,149	7 sample rookeries	22,090	shear all rookeries
2000	158,763	6 sample rookeries	20,176	shear all rookeries
2002	145,716	shear all rookeries	17,593	shear all rookeries
2004	122,825	shear all rookeries	16,876	shear all rookeries

Table 2.-- Computation of total number of northern fur seals in Pribilof Islands, Alaska stock reported in Osgood et al. 1915. Number is scaled to 100 pups.

Component	Calculation	Number
Pups	Count	100.00
Adult females	Count of Pups	100.00
Yearlings (both sexes)	Pups from previous year x 0.5	50.00
Age 2 (both sexes)	Yearlings from previous year x 0.85	42.50
Males age 3	(Age 2 males -Age 2 harvested) x 0.9	19.12
Males age 4	(Age 3 males -Age 3 harvested) x 0.9	17.21
Males age 5	(Age 4 males -Age 4 harvested) x 0.95	16.35
Idle Bulls	Count	0.14
Harem Bulls	Count	1.67
Total Stock	Sum	346.99

Table 3.-- Computation of total number of northern fur seals in the Pribilof Islands, Alaska stock reported in Kenyon et al. 1954. Number is scaled to 100 pups.

Component	Calculation	Number
Pups	Average number of pups over 3-5 years	100.00
Females 3+	Average number of pups ÷ 0.6	166.67
Female Yearlings	0.4 x 0.5 x average number of pups	20.00
Male Yearlings	0.4 x 0.5 x average Pups	20.00
Age 2 (both sexes)	Yearlings x 0.8	16.00
Males age 3	0.5 x Age 2 x 0.7	5.60
Males age 4	0.4 x Males age 3	2.24
Males age 5	0.2 x Males age 4	0.45
Males age 6	0.75 x Males age 5	0.34
Males 7+	Bull count	3.00
Total Stock	Sum of all components	334.29

Table 4.-- Computation of total northern fur seal Pribilof Islands, Alaska stock reported in Loughlin, 1992. Number is scaled to 100 pups.

Component	Calculation	Number
Pups	Average pups over 3-5 years	100.00
Females 4+	Average pups ÷ 0.6	166.67
Yearlings (both sexes)	0.5 x Average pups	50.00
Age 2 (both sexes)	Yearlings x 0.8	40.00
Females age 3	0.5 Age 2 x 0.86	17.20
Males age 3	0.5 x Age 2 x 0.80	16.00
Males 4+	3.6 x Males age 3	57.60
Total	Sum of Components	447.47

Table 5.-- Comparison of three methods of the total number of northern fur seals in the Pribilof Islands, Alaska stock in 1914, 1956 and 1992.

Component	Year		
	1914	1956	1992
Pups	100.00	100.00	100.00
Females 3+	100.00	166.67	183.87
Yearlings (both sexes)	50.00	50.00	50.00
Age 2 (both sexes)	42.50	40.00	40.00
Males age 3-5	52.69	21.84	43.20
Males 6+	1.80	5.00	30.40
Total	346.99	383.51	447.47

APPENDIX 2

Tagging and Marking of Northern Fur Seals on the Pribilof Islands – a History

by
Anne E. York

ABSTRACT

This report documents the history of marking of northern fur seals on the Pribilof Islands, Alaska. Because of the lack of written evidence of tagging under the Russian rule of the Pribilof Islands, this report will only discusses branding and tagging under United States possession.

INTRODUCTION

Although there is no written evidence that seals were tagged when the Russians were in charge of the herd (from the discovery of the Pribilof Islands in 1786 until their sale to the United States in 1867), one wonders how they learned what they did know without marking animals. For example, they knew the approximate age structure of the harvest, the age at first reproduction of females, and the approximate ages of breeding males. Because of the lack of written evidence of tagging under the Russian rule of the Pribilof Islands, this report will only discuss branding and tagging under United States possession.

Seals have been marked for a variety of reasons. The earliest record of marking was conducted in 1870 to determine homing tendencies of males in the commercial harvest in (Scheffer et al. 1984). Before 1980, the main impetus for marking appears to have been to improve various aspects of the commercial harvest of seals. After the cessation of the commercial harvest, marking was justified as an important tool for understanding the biology of the fur seal so as to better manage the populations under the laws that applied to fur seal management. There is documentation that marks have been applied to northern fur seals for the following purposes:

1. Determine homing tendencies.
2. Scar animals so that they would be unattractive to pelagic sealers.
3. Determine size at age (especially of harvestable age males).
4. Estimate life expectancy.

5. Determine distribution at sea.
6. Determine intermixture rates between Pribilofs and North Western Pacific populations.
7. Estimate abundance.
8. Determine survival and reproductive rates of known individuals.
9. Have access to a sample of known animals for studying behavior.

Before 1911

From 1870 until approximately 1911, the Pribilof fur seal herd was managed under leases to the government. During this time, commercial pelagic sealing began. By 1890, the pelagic harvest exceeded the commercial harvest on land. It is well-known that this harvest decimated the fur seal herd on the Pribilof Islands because pelagic sealing killed mainly females in contrast to the harvest on land which killed mainly subadult males (e.g., Roppel and Davey 1965, Baker et al. 1970).

In 1870, Charles Bryant, the first U.S. Treasury Agent on the Pribilof Islands, clipped the right ear on 50 male pups from one rookery and the left ear on another 50 pups from another rookery, 2 miles from the first. In 1873, four were killed on St. Paul Island and two were killed on St. George Island. In 1885, one of bulls (then age 14 years old) was seen on Reef rookery. Thus, the first known marking experiment eventually verified that some adult males can live to be 14 years old, and that young fur seals may return to rookeries other than their natal site.

In 1896, Joseph Murray, another U.S. Treasury Agent (and a Colorado cattleman) conducted the first hot branding experiments on northern fur seals. Brands were batch brands, with sometimes a different pattern in different years placed on the nape of the neck. The purpose of this branding was to scar females so that their fur would be unattractive to pelagic sealers. Branding continued at least until 1903. Almost 23,000 female fur seal pups were branded, but I found no systematic record of the number of resightings. Table 1 from Hanna (1919b) summarized the brand descriptions and numbers branded on each island. Osgood et al. (1915; Plate XII) show a photograph of a branded adult female which they argue was at least 12 years old. The branding experiment was not successful in deterring pelagic sealers, but in 1914, it did establish that female seals could live at least 12 years. Later, Hanna (1921) reported the sighting of a branded seal on St. George Island that was probably 21 years old. These observations negated the previous belief that the maximum age span of female fur seals was about 12 -13 years (Hanna, 1919b). Sadly, as Scheffer et al. (1984) note, no one appears to have recognized the value of the branded seals as known-aged specimens.

There are references in the fur seal industry reports to the branding of subadult males for the ”breeding reserve” during 1904 -1911. The breeding reserve was a collection of subadult males that were marked and purposefully permitted to escape the harvest so that there would be sufficient numbers of adult males for breeding purposes. Hanna (1921) states that he scoured the record for these data and determined that not all the animals were hot branded; sometimes ”branded” meant that the animals were temporarily marked by shearing some hair off their flanks, but in all cases, with the possible exception of the first year, the marks were probably not permanent.

1911 -1939

In 1912, more than 5,000 fur seal pups were batch branded with a ”T” brand on the top of the head. The purpose of this branding was to demonstrate that the sealing management was following the law by harvesting primarily 3-year-old males (Scheffer et al. 1984; Lembkey 1914). Up to then, the ages of harvested animals was determined mainly by guesswork. Thus, the main purpose of the 1912 branding was to determine an age-length key, primarily so that the harvest would follow the law. Numbers of seals branded on each rookery are presented in Table 2.

The branded cohort of 1912 provided a growth curve for male northern fur seals up to 9 years old (Hanna 1919a, 1923). I could find no similar growth curve for females, nor, unfortunately, a consistent record of the number of branded animals that were rounded up in the harvest. It is probable that those data were recorded, as Bower and Allen (1917) mention that when branded animals were encountered in the round-ups, those not killed were marked by shearing on the flank, so that they would not be doubly counted. Those few records that were found were summarized by Scheffer et al. (1984).

During the l920s and 1930s, there was little scientific research on the northern fur seal (Scheffer et al. 1984); the basic management system had been determined and the herd was producing income for the government. During this period, the Fur Seal Industry Reports note that several thousand subadult male fur seals were marked for the breeding reserve as in 1904-1911. Some were hot branded and others were marked by shearing, so that the clubbers would not kill them in the harvest round-ups. Numbers marked varied over time, but I found no record of them resighted in subsequent round-ups. Such a record would have helped determine annual survival rates of sub-adult and adult males. The hot-branding of males for the breeding reserve appears to have been discontinued in the 1930s. Scheffer (1950) notes that by 1925, Japanese fisheries agents had become aware of marked fur seals from the Pribilof Islands appearing at Robben and the Commander Islands in the North Western Pacific Ocean. In 1927 and 1928, the St. Paul Island manager had 200 subadult males tagged with aluminum tags. Scheffer (1950) notes that these experiments were not published nor were they mentioned in the logs of St. Paul Island. Twenty-eight tags were later recovered in the Pribilofs, 28 in “waters off Japan”, and 1 in the Commander Islands. This was the first evidence that seals from the Pribilofs intermingled with seals in the western North Pacific Ocean and was instrumental in Japan’s later decision to abrogate the Fur Seal Treaty in 1940 (Scheffer 1950); however, the details were not known to U.S. scientists until the U.S. occupation of Japan following World War II.

As an aside, Victor Scheffer proposed cooperative research among Soviet, Japanese, Canadian, and U.S. fur seal scientists in the early 1950s. He received a letter of reprimand from the State Department, essentially accusing him of treason, and was subsequently exiled from northern fur seal research and relocated to Colorado. He was permitted to return to government research a few years later after a change in the Bureau of Fisheries administration in Washington, DC (V. Scheffer, personal communication).

Period of Large-Scale Marking, 1940 -1968

Table 3 shows numbers of northern fur seal pups branded, tagged, and marked and the type of mark given on the Pribilof Islands, Alaska during 1940 – 1975. Pups were generally tagged with a single Monel tag (5,000 were double-tagged in 1958) and, in order to determine the rate of tag loss, most cohorts were also marked with a check mark (usually a slice or notch cut into one flipper). Pups were tagged on both islands during 1956 – 1964 and 1966 – 1968 and on St. Paul only during 1941, 1947 – 1955 (except for 1950) and 1965; pups were branded on St. Paul in 1940 and a few in 1941. In several years, exceptions to this general marking program were employed; tagged animals from 1947 cohort were given check marks but an ”unspecified number” of non-tagged animals were also given the same check mark; the 1948 and 1949 cohorts were not given check marks; and during 1969-75, no animals were tagged and only check marks were placed on pups. Animals of both sexes were marked as pups and the organized tag retrieval or resighting took place in harvests on the U.S. and Soviet breeding islands and in catches taken in the course of pelagic research, conducted by Canada, Japan, the Soviet Union and the United States. The most consistent effort for recovery of tags was from sub-adult males (2-5 years old) in the commercial harvests. A large commercial harvest of females took place on St. Paul and St. George Islands during 1956 – 1968 and tagged females were recovered during this harvest.

The efforts to study the 1940 and 1941 cohorts deserve special mention. Because of the evacuation of Aleuts from the Pribilof Islands in 1942 (following the invasion of Aleutian Islands by the Japanese), there was no commercial harvest in 1942. However, sealers did return to the Pribilof Islands in 1943 and Palmer (1943) describes his work measuring and resighting branded and tagged subadult male fur seals in that harvest. There is an opportunity, perhaps, for more analytical work to put lower bounds on the survival rates of juvenile males and to estimate the size of the 1940 and 1941 cohorts. The measurements of known-aged males in the harvest by Palmer (1943) indicated that the size of 3-year old males in 1943 was smaller than the 3-year old males measured by Hanna (1919b). I independently verified that this difference of about 2.5 cm was statistically significant.

The remainder of this section presents information from the tagging of male northern fur seals marked on the Pribilof Islands during 1947-1968 (except in 1950) and retrieved in the commercial harvest of subadult males; 1968 was the last year of large-scale tagging before 1987.

The main purpose of the tagging experiment was to estimate the number of northern fur seal pups born via mark-recapture in the commercial harvest. This was a very large-scale experiment: over 700,000 northern fur seal pups were marked during the marking program, and to my knowledge, no comprehensive analysis of the data exist. Steve Syrjala worked for the National Marine Fisheries Service served as a NRC post-doc at the Alaska Fisheries Science Center, Seattle, Washington tasked with analysis of these data. He spent over 2 years cleaning the data, but his funding was not renewed and he was not able to complete his analyses. York (1986) analyzed several aspects of these tagging studies to guide the design of yet another tagging experiment that began in 1987 to estimate subadult male survival. The analyses that have been completed for the large-scale marking program are presented in York (1986).

Tagged subadult males were usually harvested like unmarked subadult males if they were judged to be within the length limits then in force. There were some exceptions to this practice. During the 1950 harvest, there was deliberate killing for tags; during the 1951 harvest, there was deliberate killing for animals from the 1947 and 1948 cohorts, but animals from the 1945 cohort were spared. A small number of tag retrievals were made in the course of the pelagic investigations of Canada, Japan, the Soviet Union, and the United States and somewhat larger numbers of retrievals were made during the Soviet harvests of subadult males.

Numbers of animals tagged and numbers retrieved were obtained from combined 4-year reports of the North Pacific Fur Seal Commission and cross-checked in the yearly Fur Seal

Investigations of the United States (Table 2, and York 1986). The estimate of the number of pups born was obtained by tagging a known number of pups and retrieving tags in the commercial harvest. Since the age composition of the harvest was estimated from tooth samples, an estimate of the number of animals alive at the time of tagging was obtained by assuming that the fraction of tagged animals alive at the time of tagging and taken in the commercial harvest population were equal (e.g. if 10% of the harvest of 3 year old males was tagged, the estimate of pups born from that cohort was 10 times the harvested number of 3 year old males). Estimates of survival were completely dependent on the quality of the estimate of numbers of pups born. By 1963, it was clear that the estimates of pup production based on tagging greatly overestimated the size of the population because of undetected tag loss (Chapman 1964). By that time, the shearing-sampling method had been developed for estimating the numbers of pups born directly (Chapman and Johnson 1968). As a consequence of the overestimation of the numbers of pups born, the corresponding estimates of survival to age 3 years based on the tag retrievals were negatively biased.

Tag Loss

Because undetected tag loss was the main cause of the failure of the experiment to estimate the cohort size, it is important to discuss this issue in some detail. The detected rate of tag-loss was relatively high for the 1947 cohort when pups were tagged and given a check mark (a 1/4" hole in the flipper). However, the results must be viewed with some caution since there were an "unspecified number" of animals given check marks but no tags. If the "unspecified number" of animals was very large, the estimate of the tag loss rate would be very biased. The apparent rate of detection of tag loss increased for the 1952-59 cohorts (from about 5% to about 36%); there was no pattern of increasing tag loss for year classes after 1959 (however three cohorts showed somewhat higher tag loss– 50% for the 1966 cohort and about 43% for the 1965 and 1968 cohorts). Detected tag loss varied with age of the animal at retrieval. The increasing pattern (by cohort) was also seen for ages 2, 3, and 4 but strongest among the 2-year-old animals. The detected tag loss for 5 year old animals was extremely variable over cohorts; probably due to small sample sizes (e.g. small harvest of animals at age 5).

In addition to patterns of tag loss by age and cohort, the pattern of detected tag loss in the tagging study also varied by year due to recovery effort. The observed fraction of lost tags increased sharply beginning in 1962; this was, at least partly, due to increased effort and care in searching for check marked animals in the killing fields and processing plants. (D. Chapman and A. Johnson, pers. commun.) Generally, the fraction of lost tags was greater on St. Paul.

Five thousand pups were double-tagged on St. Paul Island in 1958. An analysis of the recoveries for males ages 3, 4, and 5 years estimated the cumulative rate of single tag loss at 0.216 for age 3 years, 0.374 for age 4 years, and 0.471, age 5 years. These translate to a cumulative double tag loss rate (assuming independence of the tags) of 0.047, 0.140, and 0.222 at ages 3, 4, and 5, respectively. Soviet scientists, reported similar single tag loss rates of approximately 0.3, 0.4, and 0.5 for male fur seals ages 3, 4, and 5 years, respectively (V. Vladimirov, pers. comm.).

I attempted to compare the recovery rates of tagged and non-tagged animals from the tagged cohorts (York 1986). I calculated the recovery rates of tagged males as the total number of recoveries of tagged males on St. Paul Island (including the estimated numbers of those that lost their tags) from the given cohort (sum of recoveries at age 2, 3, 4, and 5 years) divided by the estimated number of tagged males from that same St. Paul cohort (assumed to be one-half of the animals tagged there). I calculated the return rates on non-tagged animals for St. Paul Island from the number of non-tagged males harvested from each cohort on St. Paul Island divided by the estimated number of non-tagged male pups alive at the time of tagging on St. Paul; that number was computed as half the estimate of pups born less the count of dead pups from the cohort.

In York (1986), I estimated that the return rate of non-tagged animals was higher than that of tagged animals for all cohorts. The return rates of tagged and non-tagged animals are significantly correlated ($r^2 = 0.53$) but not so highly correlated to be able to use the recovery rate of tagged animals to accurately predict the return rate of the non-tagged animals. A higher return rate of non-tagged animals is not unexpected since tag loss is probably underestimated, and there was probably some mortality due to tagging. However, the pup estimates used for these calculations, Chapman (1964) cumulative estimates, were not determined from the tagging estimates so the lack of consistency is disconcerting. The greatest discrepancies between the return rates of tagged and non-tagged animals are for the 1958, 1959, and 1968 year classes. The correlation between the return rates of tagged and non-tagged males from the 1962-68 cohorts is even lower ($r^2 = 0.22$); the lower correlation for the later cohorts is even more disconcerting, since the pup estimates after 1961 based on shearing-sampling are considered more reliable than estimates for the 1950-61 cohorts (Chapman and Johnson 1968, York and Kozloff 1986). These issues emphasize the obvious fact that tagging experiments generally have no controls.

Effect of Time of Tagging on Subsequent Return Rates

It was hypothesized for several years that relatively more tags would be recovered from animals tagged in September rather than in August. Results of an experiment conducted in 1963 and 1964 suggest that there is a statistically significant effect of time of tagging but that the effect was not constant across cohorts and can be quite variable.

Tagged Animals for Behavioral Studies

Peterson’s (1968) behavioral studies must also be mentioned here. He used tags to obtain a sample of known animals and measured many important demographic parameters, such as attendance patterns, natality rates, timing of pupping. These studies provided much more detailed information on fur seal behavior than Bartholomew and Hoel (1953), who counted animals, but who did not mark them. I am unaware if any of these studies influenced the conduct of the subadult male harvest.

1969 -Present

<u>Tagged Animals for Behavior Studies</u>

Gentry and Kooyman (1986) and Gentry (1998) summarize long-term studies conducted on St. George Island. Those studies employed plastic tags to obtain a sample of known animals to study behavior of fur seals. In addition, this research was able to obtain estimates of vital rates that were independent of those measured by large-scale tagging experiments and from data from the commercial harvest. I am unaware if any of these studies influenced the conduct of the subadult male harvest.

Tagging Experiment, 1987 -1990 Cohorts

As discussed above, an experimental design for a tagging mark-recapture study was presented in York (1986). The experiment proposed to tag several thousand northern fur seals with modified (rounded post) Monel metal tags. The principle purposes of the tagging experiment were to estimate the reliability of the new tag, the survival rate of juvenile males, and natality of adult females. Both male and female fur seal pups were double-tagged on all the rookeries of St. Paul Island, Alaska. Animals (mostly males) would be resighted in round-ups 2, 3, 4, and/or 5 years later on the hauling grounds of St. Paul Island. An important difference between the proposed tagging study and past tagging studies was that the tagged animals would not be removed from the population after they are resighted; this feature is the key to estimating the rate of survival. Capture histories of individual animals would be available for individual animals throughout the study period. York (1986) estimated the sample sizes thought to be required to obtain survival estimates with a 95% confidence interval width of about 4-5%.

York (1994) showed that the new tag was more reliable than the older Monel tags and provided estimates of the 1987 and 1988 cohorts that were somewhat less than the average survival estimates of Lander (1979). The confidence intervals about the survival estimates were wider than the original design specified because the resighting rates of animals in the round-ups were less than assumed. This was caused by the greater number and size of subadult males on the haulouts (as there was no harvest) (York 1994). The resighting effort was begun in 1989 but, unfortunately, ended in 1992; thus, only the 1987 cohort had the intended complete record of resights. Resights from the 1992 cohort were only available for one year.

The addition of marked animals into the population between 1987 and 1992 also enabled a study of homing behavior (Baker et al. 1995) and a verification of the hypothesis that larger pups had higher survival rates (Baker and Fowler 1992). The intended study of natality did not, to my knowledge, take place.

DISCUSSION

Efforts to mark northern fur seals have provided valuable information. At the same time, there have been many missed opportunities. It is absolutely crucial that before another large-scale marking program is begun, that

1. The studies are well-designed.
2. The goals of the study are reasonable.
3. Funding will be available to complete the project.
4. The minimum time length of the study be specified.

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Table 1.-- Numbers of female pups branded on the Pribilof Islands, 1896-1903.

Year	St. Paul Island	St. George Island	Total
1896	315	62	377
1897	5,371	1,880	7,251
1898	2,363	0	2,363
1899	2,191	0	2,191
1900	1,698	0	1,698
1901	4,173	686	4,859
1902	1,416	1,326	2,742
1903	0	1,352	1,352
Total	17,527	5,306	22,833

Table 2. -- Brands applied in 1912 to northern fur seals on the Pribilof Islands, AK. The brand was a ”T” applied to the top of the head of all seals.

Island	Date	Area	Males	Females	Unknown Sex	Total
St. Paul	29 Aug	Lukanin	28	18	0	46
	3 Sep	Gorbatch	311	254	0	565
	7 Sep	Reef	407	328	0	735
	8 Sep	Reef	202	172	0	374
	8 Sep	Kitovi	10	9	0	19
	29-30 Oct	Kitovi and Lukanin	0	0	1,005	1,005
	29-30 Oct	Reef	0	0	483	483
		Total St. Paul	958	781	1,488	3,227
St. George	16 Sep	North	475	455	0	930
	17 Sep	Starya Artil	350	360	0	710
	9 Oct	North	102	139	0	241
	16 Oct	North	59	61	0	120
		Total St. George	986	1,015	0	2,001
Both		Grand Total	1,944	1,796	1488	5,228

Table 3. -- Record of marks applied in large-scale marking program of northern fur seals, Pribilof Islands, Alaska, 1940-1975.

			Number marked			
Year	Mark Type	Series	St. Paul	St. George	Location of mark or tag	Check marks
1940	Brands		5,000		Bar at the top of the head	None
1941	Flipper tags	USA 1-10000 USA 1-1000 USA 5001-6000	10,000 1000 1000		Males right fore and hind flipper Females left fore and hind flipper	Branded, nape of neck Double tagged, branded nape of neck
1945	Flipper tags	10001-11000 (no letter prefix)	973		Left front flipper	None
1947	Flipper tags	A 1-20000	19,183		Left front flipper and 2nd digit left hind flipper	1/4" hole between 1st and 2nd digits
1948	Flipper tags	B 1-19673	19,532		Left front flipper	None
1949	Flipper tags	C 1-20000	19,963		Left hind flipper	None
1951	Flipper tags	D 1-1000	1,000		Right hind flipper	1/2 left ear removed on 100 pups

Table 3. (Cont.) -- Record of marks applied in large-scale marking program of northern fur seals, Pribilof Islands, Alaska, 1940-1975.

			Number marked			
Year	Mark Type	Series	St. Paul	St. George	Location of mark or tag	Check marks
1952	Flipper tags	E 1-20000	19,979		Right front flipper	Tip of 1st digit right hind flipper removed
1953	Flipper tags	F 1-10000 G 7001-7400	9,990 398		Left front flipper	Tip of left front flipper removed
1954	Flipper tags	G 1-7000 G 7401-10400	7,000 3,000		Right front flipper	”V” notch near tip right front flipper
1955	Flipper tags	H 1-10000 10001-50000 (no letter prefix)	49,870		Left front flipper	Tip of 1st digit on left hind flipper removed
1956	Flipper tags	I 1-10000 I 10001-50000	39,900	9,894	Right front flipper	Tip of right front flipper

Table 3. (Cont.) -- Record of marks applied in large-scale marking program of northern fur seals, Pribilof Islands, Alaska, 1940-1975.

			Number marked			
Year	Mark Type	Series	St. Paul	St. George	Location of mark or tag	Check marks
1957	Flipper tags	J 1-10000		9,972		
			39,890		Left front flipper	“V” notch near tip right front flipper
		J 10001-50000				
1958	Flipper tags	K 1-10000		9,994	Right front flipper	“V” notch near tip right front
		K 10001-50000	39,923			Doubled tagged plus checkmark
		K 10001-50000	5,000		Right and left front flippers	
1959	Flipper tags	L 1-10000		9,980	Left front flipper	Tip of left front flipper removed
		L 10001-50000	39,901			
1960	Flipper tags	M 1-12000		11,992	Right front flipper	Tip of right front flipper removed
		M 12001-60000	47,989			
1961	Flipper tags	N 1-10000		9,988	Left front flipper	“V” notch near tip of left front flipper
		N 10001-50000	39,933			
1962	Flipper tags	O 1-10000		9,980	Right front flipper	”V” notch near tip right front flipper
		O 10001-50000	39,928			
1963	Flipper tags	P 1-5000		4,993	Left front flipper	Tip of left front flipper removed
		P 5001-25000	19,978			

Table 3. (Cont.) -- Record of marks applied in large-scale marking program of northern fur seals, Pribilof Islands, Alaska, 1940-1975.

			Number marked			
Year	Mark Type	Series	St. Paul	St. George	Location of mark or tag	Check marks
1964	Flipper tags	Q 1-5000		4,993	Right front flipper	Tip of right front flipper sliced off
		Q 5001-25000	19,998			
1965	Flipper tags	R 1-10000	10,000		Left front flipper	”V” notch tip left front flipper
	Check mark	Marked	10,007		Not tagged	”V” notch tip right front flipper
		Marked	10,080		Not tagged	Tip of 1st digit on right hind flipper removed
1966	Flipper tags	1-2500		2,499	Left front flipper	Tip of left front flipper removed
		S 2501-12500	10,000		Right front flipper	Tip of 2nd digit on right hind flipper removed
	Check mark	Marked		2,503	Not tagged	Tip of 3rd digit on right hind flipper removed
		Marked	9,578		Not tagged	Tip of 2nd digit on left hind removed
1967	Flipper tags	T 9-2500		2,492	Right front flipper	Tip of right front flipper removed
		T 5001-15000	9,980			
1968	Flipper tags	U 1-2500		2,475	Left front flipper	”V” notch near tip left front flipper
		U 2501-12500	9,200			
1969	Check mark	Marked		5,000	Not tagged	Tip of 1st digit (big toe) on left hind flipper removed
		Marked	20,000			Tip of 1st digit (big toe on right hind flipper removed

Table 3. (Cont.) -- Record of marks applied in large-scale marking program of northern fur seals, Pribilof Islands, Alaska, 1940-1975.

			Number marked			
Year	Mark Type	Series	St. Paul	St. George	Location of mark or tag	Check marks
1970	Check mark	Marked		5,000	Not tagged	Tip of 2nd digit on left hind flipper removed
		Marked	20,030			Tip of 2nd digit on right hind flipper removed
1971	Check mark	Marked		5,000	Not tagged	Tip of 3rd digit on left hind flipper removed
		Marked	19,995			Tip of 3rd digit on right hind flipper removed
1972	Check mark	Marked		5,000	Not tagged	Tip of 1st digit on right hind flipper removed
		Marked	20,019			Tip of 1st digit on left hind flipper removed
1973	Check mark	Marked		5,000	Not tagged	Tip of 2nd digit on right hind flipper sliced off
		Marked	20,000			Tip of 2nd digit on left hind flipper sliced off
1974	Check mark	Marked	20,000		Not tagged	Tip of 3rd digit on right hind flipper sliced off
1975	Check mark	Marked		5,000	Not tagged	Tip of 1st digit (big toe) on left hind flipper sliced off
		Marked	10,000			Tip of 1st digit (big toe) on left hind flipper sliced off