

AN ABSTRACT OF THE THESIS OF

Jonathan Scordino for the degree of Master of Science in Wildlife Science presented on November 30, 2006.

Title: Steller Sea Lions (*Eumetopias jubatus*) of Oregon and Northern California: Seasonal Haulout Abundance Patterns, Movements of Marked Juveniles, and Effects of Hot-Iron Branding on Apparent Survival of Pups at Rogue Reef.

Abstract approved:

Selina S. Heppell

The Steller Sea Lion Research Initiative was passed in 2001 to provide funding to help scientists determine causes and solutions for the population crash of Steller sea lions (*Eumetopias jubatus*). In response to need to understand population dynamics of Steller sea lions, NOAA Fisheries has spearheaded a large-scale, range-wide research program. The study involved capturing and hot-iron branding sea lions at rookeries from northern California around the Pacific Rim to Russia to provide individually recognizable animals for studies of behavior and vital rates. I report the results of monitoring pups branded and tagged at Rogue Reef, Oregon and St. George Reef, California to determine movement patterns and the affects of branding on apparent survival of Steller sea lion pups immediately after branding.

Counts of Steller sea lion adult female, adult male, juveniles, and pups were collected at haulouts and rookeries of Oregon and northern California from 2002 through 2005. Movement patterns of Steller sea lions were inferred from count data. Adult males were seasonal inhabitants of Oregon and California during the breeding season from May through September before dispersing to northern feeding grounds. Females, juveniles, and pups were dispersed throughout haulouts in Oregon and northern California during all seasons but have seasonally high concentrations at Sea

Lion Caves, Oregon in the winter and at the breeding rookeries during the summer breeding season. The high wintertime abundance of females and pups at Sea Lion Caves suggests that it should be considered as critical habitat for Steller sea lions of the eastern stock.

Resights of marked sea lions collected between northern California and Alaska between 2001 and 2005 were analyzed to determine juvenile and pup dispersal patterns. Most pups stay close to their natal rookery, although 9 - 22% of individuals each year were observed to disperse further than 500 km. As 1-year olds, the mean maximum dispersal range expanded, which may have been a sign of weaning. Sexually dimorphic patterns in sea lion movements were apparent at 3 years of age as males were observed to disperse farther north than females. The percentage of females observed at their natal rookery increased each year to a maximum of 87% as 4-year-olds. This suggested that sexual maturity occurs at, or close to, 4 years of age for females.

Branding provided a useful tool for analyzing movements of Steller sea lions, yet it may have impacts on survival of individuals. Concerns raised by NOAA Fisheries over branding impacts on pup survival were addressed with a study at Rogue Reef in 2005. One-hundred-and-sixty pups captured on 18 July, 2005 were randomly assigned to a treatment of flipper tag only (unbranded pups) or flipper tag and hot-iron branding (branded pups). Aside from the treatment of branding, all pups were handled and treated identically. Over the 73-day course of this study, I found lower apparent survival for branded pups than unbranded pups, with a final apparent survivorships of 0.23 (95% CI 0.01 – 0.48) for branded pups and 0.46 (95% CI 0.15 – 0.77) for unbranded pups. Apparent survivorship includes both mortality and emigration, so differences may be due to differences in emigration rates of the two groups, mortality rates, or both. The scope of inference for this study is only to Rogue Reef in 2005. However, it should provide a good model for future brand evaluation studies at other rookeries and for other pinniped species. Branding is currently the best and only available tool for long-term studies of survival, reproduction rates, and age at sexual maturity which are all critical for demographic models. Nonetheless, researchers should assess the impacts of branding at each

rookery, and will need to consider whether knowledge from branding Steller sea lions is worth the potential reduction in pup survival or change in pup emigration behavior observed in this study.

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Haulout Abundance Patterns, Movements of Marked Juveniles, and Effects of Hot-
Iron Branding on Apparent Survival of Pups at Rogue Reef.

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APPROVED:

Major Professor, representing Wildlife Science

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection.....

Jonathan Scordino, Author

ACKNOWLEDGEMENTS

The scope of this project was way beyond my individual capacity to undertake and complete. I truly learned the meaning of cooperative and collaborative research. I hope through this short acknowledgments section to give thanks to those that have helped and influenced the course of my research and thesis preparation.

I would first like to thank those that funded this research project. Funding for tuition, travel, supplies, and salary was provided through the North Pacific Universities Marine Mammal Research Consortium by the National Oceanographic and Atmospheric Administration and the North Pacific Marine Science Foundation. Funding for remotely operated cameras supplied by SeeMore Wildlife, travel, radio tags, salary for personnel assisting in tagging, contracts for research in Canada, and vessel operations were provided by NOAA Fisheries' National Marine Mammal Lab's California Current Ecosystem Division. Oregon Department of Fish and Wildlife provided funding for research accommodations in Gold Beach and salaries for supporting personnel. Management and staff of the Sea Lion Caves in Oregon provided free admittance to their facilities for the duration of this study.

I could never have surveyed the entire range of juvenile sea lion dispersal without considerable help and cooperation from other agency and university researchers. Resights in Alaska were provided by Alaska Department of Fish and Game and the Alaska SeaLife Center. Special thanks to Lauri Jemison for supplying resight data. University of British Columbia, Department of Fish and Oceans Canada, and Parks Canada provided resights in Canada. Special thanks to Dave Gummeson and Andrew Trites from UBC, Peter Olesiuk from DFO Canada, Wendy Szazilo Parks Canada, and Brian Gisbourne (contracted by OSU and NMML). Pat Gearin was the principal investigator and collector of resights in Washington. He was assisted by Nate Pamplin from the Makah Indian Tribe, Merrill Gosho, and Ryan Jenkinson. To the Washington crews, thank you. In Oregon resights were collected by Oregon Department of Fish and Wildlife employees and researchers from Oregon State University. Kim Raum-Suryan and Emily Hamblen provided resights they collected while performing nursing behavior studies. Lou Taylor assisted me with

surveys of Cascade Head. Matt Tennis and Dan Heiner collected resights at Columbia River's South Jetty and did periodic surveys along the Oregon coast. From 2001 through 2004 Rogue Reef and St. George Reef cameras were monitored by Susan Reimer and Justin Jenniges. They provided the count data and resights of Steller sea lions from those sites. From 2001 to 2004 Justin Jenniges and I were the principal investigators for resight efforts of Steller sea lions in Oregon and northern California. Ken Stump, Dale Paulson, and Elva Paulson volunteered their time to help collect resights along the Oregon Coast. For everyone that helped in Oregon and northern California, thank you. Fortunately, all of these researchers shared their data into a common database maintained by Bryan Wright (ODFW) that I was allowed to use for my thesis.

Planning sea lion captures and marking requires attention and planning to the minutest of details to ensure safety of crew and sea lions, efficiency of work, and the ability to adapt to potential challenges. Fortunately for work at Rogue Reef and St. George Reef, Robert DeLong and Robin Brown coordinated field efforts. In 2005, plans for sea lion captures and tagging to evaluate branding effects were improved by discussions with Susan Reimer, Bryan Wright, Jeff Laake, Justin Jenniges, Pat Gearin, and Sharon Melin. In five years of captures and handling no injuries have occurred to our capture crews and only one pup was died due directly to capture efforts. Special thanks are in order for those that helped in 2005. This crew had to endure added time of gluing transmitters and identification patches to sea lions as well as being routed to assigned randomized tagging stations. Furthermore, they had to endure a very sick graduate student coughing on them. To Justin Jenniges, Matt Tennis, Julie Tennis, Dan Heiner, Susan Reimer, Bryan Wright, Robin Brown, Merrill Gosho, Pat Gearin, Sharon Melin, Tony Orr, Michelle Lander, Sharon Melin, Bryan DeLong, Robert DeLong, Ryan Jenkinson, Beth Jenkinson, Dacey Mercer, Frances Gulland, Pete Dewartz, Jeff Laake, Jack Mortenson, Sophie Dennison, Liz Wheeler, Jeanie Ross, Debbie Wickam, Collin Gillan, Peri Wolf, Mike Pattison, and David Ledig, thank you for your help in sea lion captures and tagging. To Beth Jenkinson, Ryan Jenkinson, Pat Gearin, Merrill Gosho, and Nancy Scordino, thank

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As they say, "All work and no play make Jon a crazy boy." Luckily I had a great support network of family and friends to keep (and sometimes take away) my sanity. On days when my mental gears were jammed, friends were always there for me to provide an ice cold beer and good times to lube my gears back into working order. Thank you all for being there for me. My family, Katrina, Mike, Steve, my parents and my in-laws Julie and Gary were always there for me to call when I felt stressed. They were there to provide stories about Sierra, Grace, Madeline, and Big Joe to keep me laughing and focusing on what is important in life. To Britney, I have called you a distraction during graduate school and I know you took offense, but you were. But a distraction is not always a bad thing. You made me think outside of my

research and become a fuller, more complete person. I thank my friends, family, and Britney for enriching my life these past two years.

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CONTRIBUTION OF AUTHORS

Analyzing the movement patterns of Steller sea lions required a large working team to monitor the entire Steller sea lions range. Robert Delong and Robin Brown coordinated resighting efforts in Washington, Oregon, California, and contracted resight effort in southern Canada. Pat Gearin provided resights of sea lions in Washington and provided direction for research. Justin Jenniges provided resight and count data. Selina Heppell helped focus research goals and provided direction on analyzing a large database. Bryan Wright maintained the brand resight database and assisted in GIS map design, analysis of data, and editing of manuscripts. I hope to submit this manuscript to Marine Mammal Science during 2007.

The evaluation of branding effects on Steller sea lion pups was a collaborative effort of NOAA Fisheries' National Marine Mammal Lab, Oregon Department of Fish and Wildlife, and Oregon State University. Jeff Laake provided the initial idea of evaluating branding effects, sample design, and assisted with data analysis. Bryan Wright reviewed and edited manuscripts, assisted with sampling design, and assisted with data analysis. Pat Gearin designed tags and assisted in coordinating tagging operations. Robert Delong and Robin Brown coordinated the branding effort. Robin Brown also provided review and editing of manuscripts. Robert Anthony discussed issues of modeling survival and reviewed work on data analysis. Selina Heppell provided substantial effort to editing and focusing the manuscript included in this thesis. I hope to submit a manuscript on evaluation of branding effects to the Journal of Wildlife Management during 2007.

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DEDICATION

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Steller Sea Lions (*Eumetopias jubatus*) of Oregon and Northern California: Seasonal Haulout Abundance Patterns, Movements of Marked Juveniles, and Effects of Hot-Iron Branding on Apparent Survival of Pups at Rogue Reef.

CHAPTER 1: GENERAL INTRODUCTION

Sea lions belong to the Order Carnivora, Suborder Pinnipedia, Family Otariidae, and Subfamily Otariinae. Steller sea lions (*Eumetopias jubatus*) are the largest member of the family otariidae and show marked sexual dimorphism of size. The average length of adult males is 282 cm and 228 cm for adult females (maximum of about 325 cm and 290 cm, respectively); weight of males averages 566 kg and females 263 kg (maximum of about 1,120 kg and 350 kg) (Calkins and Pitcher 1982; Loughlin and Nelson 1986). Females sexually mature between 3 – 6 years of age, and males sexually mature at 3 – 7 years of age but cannot hold a breeding territory until 8 – 12 years of age (Pitcher and Calkins 1981). Steller sea lions congregate at breeding rookeries from late April through August where females have one pup. Pups are born between late May and early July and have a thick chocolate brown coat at birth which molts to a lighter brown at six-months of age (Daniel 2003). Juveniles have a similar light brown coat that appears to lighten with age. Adult females have a tawny to silver colored pelt (Mate 1973). Males are characterized by dark, dense fur around the neck that appears like a mane and light tawny coloring to the rest of their body. Steller sea lions prey on a variety of fish and invertebrate species. Many of the fish species Steller sea lion consume are also targeted by human fisheries.

During the past 30 years, Steller sea lions have endured a large population decline and contraction of their range (NMFS 2006). The breeding range of Steller sea lions once extended from California's Channel Islands around the Pacific Rim to Japan (NMFS 1992). In the last century the species range has contracted northward in both the western and eastern Pacific (NMFS 2006). In the 1950s, the worldwide population of Steller sea lions was estimated as 240,000 to 300,000. Between the 1970s and 1998 there was an estimated 80% decline of Steller sea lion abundance in the United States (Angliss and Outlaw 2005). The observed decline led to the listing of Steller sea lions as threatened under the endangered species act in 1990 (NMFS 2006). Interestingly, the decline was not uniform across the range of Steller sea lions.

Rookeries in Oregon, British Columbia, and southeast Alaska have increased by 3% a year since the passage of the Marine Mammal Protection Act in 1972 (NMFS 2006). Meanwhile, populations in the central Gulf of Alaska and west have declined by 5% to 15% annually during the same period (NMFS 2006). Genetic studies by Bickham *et al.* (1996) concluded from mitochondrial DNA evidence that the Steller sea lion population should be divided into a western and eastern stock at the 144° W meridian. Using evidence presented by Bickham *et al.* (1996), the population of Steller sea lions was divided into two distinct population segments for listing under the Endangered Species Act. It was determined that the western stock of Steller sea lions was endangered while the eastern stock remained listed as threatened in 1997 (NMFS 2006).

This large decline in Steller sea lions led to the passing of the Steller Sea Lion Research Initiative in 2001 (Dalton 2005). This initiative led to expanded fiscal resources for research to determine the causes of the decline. Between 2001 and 2005, over 120 million dollars were invested in trying to determine the causes of Steller sea lion population decline (Dalton 2005). There are multiple theories for the observed decline. The most commonly reported theories involve a change in prey resources causing nutritional stress (either due to competition with fisheries or a change in environmental conditions), direct take by fisheries or shootings, and increased predation by killer whales (Laughlin and Nelson 1986; Alverson 1992; Rosen and Trites 2000; Springer *et al.* 2003; Rosen and Trites 2005; Hennen 2006). However, lack of baseline data on the population prevented verification of the possible theories. York (1994) determined through a population model that the observed decline of Steller sea lions could have been caused by a 20 - 30% decline of juvenile survival. Winship and Trites (2006) suggested the decline was also caused by lower survival and fecundity of adult females. To determine what is driving the decline of Steller sea lions, NOAA Fisheries' National Marine Mammal Lab (NMML) has coordinated a large-scale, range-wide study of Steller sea lion vital rates (NMFS 2006).

In order to determine vital rates, researchers require permanently marked, uniquely identifiable individuals that they can monitor over time. Furthermore, due

to low resight rates of marked sea lions, researchers need large sample sizes to determine vital rates with accuracy and precision. It was determined through professional experience and years of trial and error of previous researchers that the best available marker for research goals was hot-iron branding (Merrick *et al.* 1996). Sea lions were branded on rookeries in Russia, the Aleutians, the Gulf of Alaska, southeast Alaska, southern Oregon, and northern California from 2000 to 2005. Researchers from agencies and universities in Russia, Canada, and the United States have monitored sea lion haulouts and rookeries throughout the sea lion range to resight branded sea lions. Resight effort has been concentrated to summer months during more predictable weather and ocean conditions for observer safety; haulouts were monitored year round in areas of easier access. These resights of branded sea lions are stored in databases kept by each agency in each region and in a master database managed by NMML. Researchers recorded brand identification, sex, age, location, and date for each resight collected. Vital rates of interest are, but are not limited to: natality, age at first reproduction, age-specific fecundity and survival rates, and immigration and emigration among haulouts and rookeries (NMFS 2006).

The branding program has also provided large sample sizes of individually recognizable sea lions that have facilitated behavioral studies. Researchers have looked at topics including nursing behavior, pup attendance patterns, effects of disturbance, as well as dispersal and movement patterns (Trites and Porter 2002; Raum-Suryan *et al.* 2002; Kucey 2005). Knowledge of which haulouts are used helps managers identify critical feeding areas because sea lions act as central-place or multiple central-place foragers around rookeries and haulouts (Raum-Suryan *et al.* 2002). Chapter 2 of this thesis examines resights of branded sea lions from Rogue Reef, Oregon and St. George Reef, California to document important sites and dispersal patterns of pup and juvenile age classes. Monthly count data were collected and analyzed to document seasonal abundance patterns of Steller sea lions at haulouts and rookeries in Oregon and northern California from 2002 through 2005.

Hot-iron branding provides a powerful tool for researchers to monitor sea lions. Unfortunately, the impacts of hot-iron branding on Steller sea lions, or any other pinnipeds, are not well understood (Rand 1950; Scheffer 1950; Erickson *et al.*

1993, van den Hoff *et al.* 2004, Daoust *et al.* 2006). Some researchers have questioned the ability of hot-iron branding to leave a discernable, lifelong mark (Scheffer 1950; Roppel 1979; Calkins 1979; Merrick *et al.* 1996; van den Hoff *et al.* 2004), while others have raised concern over its impacts on individual animals. Scheffer (1950), for example, suggested that branding may retard the growth of fur seals making the method biased for age-growth studies. Other researchers have noted that some brand wounds heal very slowly and are either at high risk of infection or show signs of infection post-marking (Rand 1950; Summers and Witthames 1978; Erickson *et al.* 1992; van den Hoff *et al.* 2004; Daoust *et al.* 2006). With the increased risk of infection, concern has also been raised on whether branding increases mortality of marked animals (Roppel 1979; Auriolles *et al.* 1988; Merrick *et al.* 1996; McMahon *et al.* 2006).

Researchers have tried to assess whether the concerns about branding were valid and, if they were, how to alleviate their effects. The concern of branding producing illegible marks has been greatly minimized through changes of method and equipment (Hoek 1979), training workshops (Hobbs and Russell 1979), and the use of experienced personnel (Erickson *et al.* 1993). Presently, studies using hot-iron branding report that brand marks have 87 - 98% readability 2 years post marking depending on species (Merrick *et al.* 1996; van den Hoff *et al.* 2004; Pendleton *et al.* 2006). Scheffer's (1950) concern that the stress and injury of branding would retard the growth of fur seals was tested on California sea lions (*Zalophus californianus*) in an unpublished study in the late 1980s by Delong and Melin (NOAA 1993). Randomly selected branded and unbranded pups of the same age were weighed and measured and no significant differences in growth were detected (NOAA 1993). The risks of infection have not been addressed and a search of literature reveals that only one branding study has used antibiotics to combat infection (Erickson *et al.* 1993). A recent study showed that 75.8% of hot-iron brands on harbor seals show little to no healing 9 – 10 weeks post branding (Daoust *et al.* 2006). Given the results of the Daoust *et al.* (2006) study there is a need for detailed assessment of the effects of branding on the survival and behavior of pups, particularly due to the high risk of infection of open and unhealed wounds.

Pinniped branding has been evaluated in the past but studies have suffered from shortcomings of experimental design (Murray and Fuller 2000). Evaluation studies have been affected by lack of appropriate controls (see Auriolles *et al.* 1988; Merrick *et al.* 1996; McMahon *et al.* 2006) or have been completely qualitative (see Chittleborough and Ealey 1951; Ingham 1966; Hoek 1979). Due to shortcomings of past studies it is unclear what effect, if any, branding has on pup survival. If branding does increase mortality it would bias survival estimations and could lead to inappropriate management decisions based on poor information (Murray and Fuller 2000).

Biologists from NMML and Oregon Department of Fish and Wildlife (ODFW) expressed interest in evaluating whether branding affects pup survival. With the guidance of NMML and ODFW biologist and statisticians, a rigorous study design was developed and used to compare survival of branded sea lions to a reference group of unbranded sea lions. One-hundred-sixty pups were captured on 18 July 2005. All pups were handled, marked, and anesthetized identically except for the treatment of hot-iron branding. Eighty pups were branded and tagged and 80 were only tagged. Pups were monitored for 11 weeks post branding to estimate survival. Survival rates were assessed using a Cormack-Jolly-Seber model in the Program MARK (Nichols 2005). Results of this study are presented in Chapter 3.

The final chapter of this thesis includes a discussion on knowledge gained from Chapters 2 and 3. From this gained knowledge and past experiences, I present research recommendations for future studies of Steller sea lions.

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CHAPTER 2: SEASONAL HAULOUT ABUNDANCE PATTERNS OF STELLER
SEA LIONS (*EUMETOPIAS JUBATUS*) IN THE PACIFIC NORTHWEST AND
MOVEMENTS OF MARKED JUVENILE STELLER SEA LIONS

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Abstract:

We investigated the seasonal abundance patterns of Steller sea lions (*Eumetopias jubatus*) at haulouts and rookeries along the Oregon and northern California coastline and the dispersal patterns of pups and juveniles marked at Rogue Reef, Oregon and St. George Reef, California rookeries. Counts of sea lions at haulouts in Oregon and northern California were monitored monthly from Nov. 2002 – Dec. 2005. We found that adult males inhabit Oregon and northern California only during the breeding season (May to August) before they disperse north for the non-breeding season. Females, juveniles, and pups were dispersed throughout the coast for most of the year. However, the majority of females, juveniles, and pups observed in Oregon and northern California reside at Sea Lion Caves on the central Oregon coast during the winter. Between 2001 and 2005, over 6,500 resights of 841 marked sea lions were collected for analysis. Analysis of these data showed that pups stayed close to their natal rookery during their first year, although 9 - 22% per year dispersed beyond 500 km. Sea lions expanded their mean maximum dispersal distance as 1-year-olds which may have been a sign of weaning. Sexually dimorphic patterns in dispersal are evident starting at 2 years of age as males dispersed further on average than females. We predict that females reach maturity at approximately 4 years of age, based on observed movement patterns and resights at natal rookeries. Eighty-seven percent of observed 4-year-old females were seen at their natal rookery during the breeding season. Furthermore, 4-year-old females were observed to have movement patterns very similar to pups. This suggests 4-year-old females are utilizing the same resources as females with dependent pups, which may increase “local knowledge” of feeding resources which enhances a female’s ability to raise a pup.

Key words: *Eumetopias jubatus*; movement patterns; Steller sea lion; dispersal; Oregon; California

Introduction:

Seals and sea lions utilize both water and land habitat (Berta *et al.* 2006). All seals and sea lions must come to shore to pup and nurse their young; some are fully pelagic between breeding seasons while others use terrestrial haul out sites year-round (Boyd *et al.* 1999). Seals and sea lions that use terrestrial haulouts outside of the breeding season often forage in proximity to where they haul out, acting as either central-place foragers (using just one terrestrial site) or as multiple central place foragers (using multiple terrestrial haulout sites closer to feeding resources) (Raum-Suryan *et al.* 2004). An important consideration in pinniped studies is change in how resource allocation and site use with time as males and females are often observed to have different dispersal ranges and feeding areas following the breeding season (*e.g.* males generally disperse further from the rookery than females) (Boyd *et al.* 1998; van den Hoff *et al.* 2001; Maniscalco *et al.* 2004). Knowledge of movement patterns of different age and sex classes helps managers determine critical habitat for the protection of the species.

Prior to research advances such as satellite transmitters, movement patterns and haulout use were monitored by visual sightings (often referred to as ‘resights’) of tagged or branded animals (Scheffer 1950; Nicholls 1970) and population counts (Bartholomew 1951; Pearson and Verts 1970; Mate 1973). In recent years, researchers of southern elephant seals (van den Hoff *et al.* 2001) and Steller sea lions (Raum-Suryan *et al.* 2002) have taken advantage of large brand-resight databases (collected for vital parameter studies) for analysis of animal movements. Analysis of resights to determine a movement of branded sea lions and seals has important benefits. First, the large sample sizes of each study allows for documentation of a distribution of movement behaviors of study animals. Second, branding marks an animal for its lifetime (Rand 1950; Scheffer 1950; Merrick *et al.* 1996), allowing researchers to analyze how movement patterns change throughout the life of the study animal. But there are disadvantages. Branded seals and sea lions can be monitored effectively only at terrestrial haulout sites; resights of branded individuals in the water do occur, but are relatively rare. Some sites are easily accessed and monitored while others are not, so brand resights do not perfectly document coastal distributions and

provide no information on behavior at sea. Furthermore, analysis of terrestrial haulout use may be biased by areas of high resight probabilities compared to areas of low resight probability. Despite these disadvantages, resighting branded seals and sea lions provides the best available tool for long-term monitoring of animal movements with large sample sizes.

Steller sea lions are a case study of a long-lived species in which dramatic declines are thought to have resulted from low juvenile survival (York 1994). Studies of dispersal, distribution, and movements can play a critical role in understanding sea lion behavior (Raum-Suryan *et al.* 2004). Understanding movements may allow researchers to document ages at which sea lions are at the greatest risk of mortality to promote management to mitigate for those risks. Furthermore, studies of movements of individuals through time may allow documentation of timing important biological changes (*e.g.* weaning, age at maturity).

The primary goal of this study was to document seasonal fluctuations of demographic groups of Steller sea lions along the Oregon and northern California coast and to determine dispersal patterns of Steller sea lions branded at Rogue Reef, Oregon (ROR) and St. George Reef, California (SGR). We tested for differences in mean maximum dispersal distance by age, sex, and rookery. Of particular interest was documenting at what age sexual dimorphic patterns of movement and migration, as seen in adults (Mate 1973), are apparent in juvenile Steller sea lions.

Methods:

Seasonal fluctuations in demographic counts of Steller sea lions in Oregon and northern California

Between November 2002 and December 2005, ODFW, NMML, and OSU biologists performed monthly scan counts of Steller sea lions at accessible haulouts and rookeries in Oregon and northern California (Figure 1). The counts were broken down into demographic groups of adult female, adult male, juvenile (defined as 11-months-old until development of sexually dimorphic characters, usually around 4 years of age for females and 5 years of age for males), pups (birth to 11-months), and unknown for animals that could not be determined. Counting was not standardized to

tide cycle, time of day, or any other variable; therefore, all analyses of these data were purely descriptive. Many counts were affected by disturbances caused by weather or environmental variables; using average counts would likely have biased interpretation of haulout use low. Therefore, inferences to general movement patterns of the four demographic groups were described for the maximum monthly count collected between 2002 and 2005. Monthly average, median, maximum, and minimum counts are provided in Appendix A for California sea lions, harbor seals, elephant seals, and Steller sea lion demographic groups for the duration of this study. ArcGIS 8 was used to make maps of maximum seasonal site use for each of the demographic groups. Seasons were defined as: summer (June – August), fall (September – November), winter (December – February), and spring (March – May).

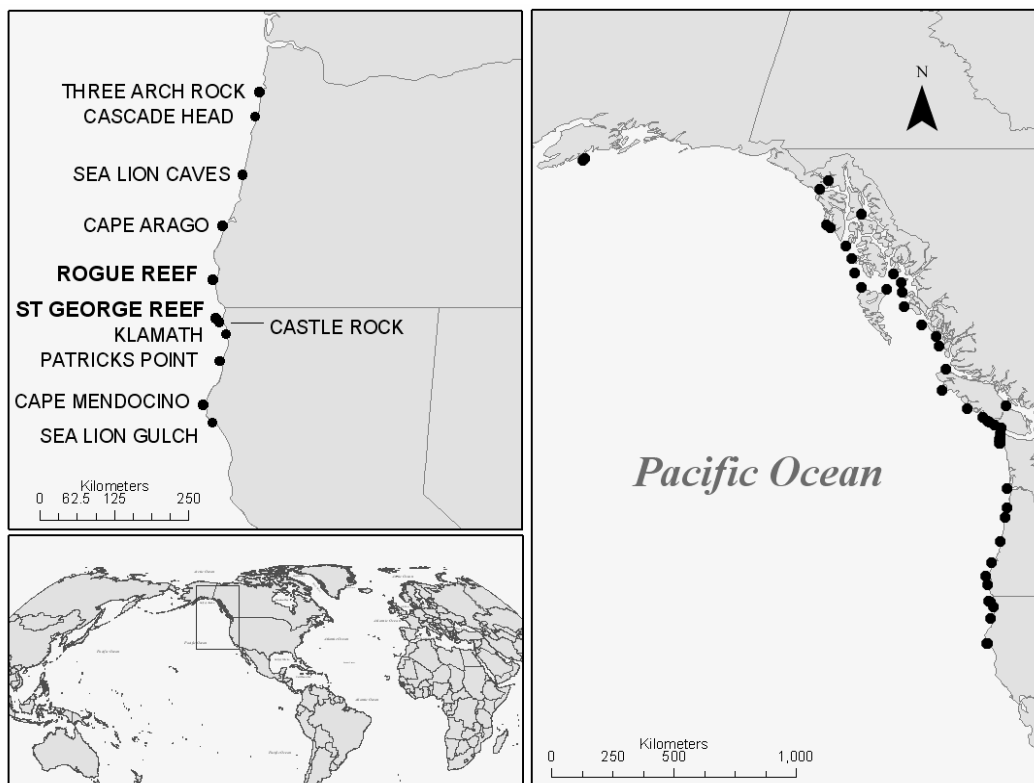


Figure 1: Study area for analyzing movements of Steller sea lions. The focalized study area for this study was Oregon and northern California (upper left) where demographic counts were performed. The breeding rookeries where branding occurred (**Rogue Reef** and **St. George Reef**) are listed in bold. The map on right shows the resulting study area for juvenile dispersal patterns from shared resight data of collaborating agencies and universities.

Resights of marked sea lions

Records of observed branded and tagged Steller sea lions from St. George Reef, California (SGR) and Rogue Reef, Oregon (ROR) were part of a long-term collaborative life-history study by NOAA Fisheries' National Marine Mammal Lab (NMML) and Oregon Department of Fish and Wildlife (ODFW). From 2001 – 2005, 761 Steller sea lions were marked with hot-iron brands on their left side and with Allflex TM white, goat ear-tags on the trailing edge of their foreflippers (Erickson *et al.* 1993; Merrick *et al.* 1996). During odd numbered years, captures were at Rogue Reef; in even numbered years captures were at St. George Reef (table 1). In 2005 an additional 80 pups were marked with flipper tags only and not branded to assess the acute effects of hot-iron branding on pup survival (Chapter 2).

Table 1: Capture results of Steller sea lion pups marked at Oregon and northern California rookeries from 2001-2005. Captures are listed by site, year, number marked, and type of markers used.

Year	Site	Number Marked	Brands	Tags
2001	Rogue Reef	180	1R - 90R; 901R; 92R – 180R	-
2002	St. George Reef	140	1Y - 140Y	-
2003	Rogue Reef	190	181R - 370R	-
2004	St. George Reef	151	141Y - 291Y	-
2005	Rogue Reef	180	371R -470R	001 – 080

Resights of marked sea lions were reported from a variety of sources. NMML monitors California, Oregon, Washington, and Alaska west of the Gulf of Alaska, and contracts for surveys in southern British Columbia, Canada. ODFW monitors northern California and Oregon with emphasis on monitoring the Rogue Reef and St. George Reef rookeries during the breeding season. Oregon State University has complimented and aided resight efforts of ODFW and NMML in northern California and Oregon from 2004 through present. Department of Fish and Oceans, Canada, monitors southeast Vancouver Island and teamed up with the University of British Columbia for summer research cruises of all Canadian sea lion haulouts from 2002-2005. Alaska Department of Fish and Game monitors southeast Alaska and assists on

Canadian research cruises. Alaska Sea Life Center monitors the Kenai Peninsula of Alaska. Other sources of resights are from volunteers in the public and interested naturalists from other agencies. These collaborated efforts resulted in a study area extending from northern California to the western side of the Gulf of Alaska (Figure 1).

Details collected for each resight of a marked sea lion were: identification number, clarity of brand (if branded), tag presence/numbers, sex, age, date, location (latitude and longitude of rookery or haulout), and whether or not a photo was taken. Each reported resight was entered in a database maintained collectively by NMML and ODFW. Photos were compared to reference photos when possible to reduce the chance of brand misreads.

From 2001 – 2005, over 6,500 resights were reported. Many of these resights were collected at the natal rookery immediately following marking. Resights at the natal rookery within 6 months of capture were not used in the analysis because the focus of this study was dispersal patterns of Steller sea lions. This resulted in 3,817 resights of individuals available for movement analysis. For each resight, we calculated the great circle distance (i.e., shortest distance between two points on the surface of a sphere) from the sea lion's natal rookery to where it was resighted. Resights of each individual were grouped by the age of the sea lion. To assign sea lion age, 1 June was used as the arbitrary birth date for all sea lions in the study. Distribution of resights by age, sex, and rookery were mapped using ArcMap™.

We used maximum distance each individual was resighted away from its natal rookery for each year of age for analyzing differences in maximum dispersal distance by age, sex, and rookery. Effort to collect resights was variable and discontinuous in both time and space. Due to inconsistencies in effort through time we could not make comparisons of dispersal by cohort year-class. Therefore, to examine effects of age and sex on movement patterns a cross-sectional analysis of resights collected in 2005 was performed. An information criteria approach was used to rank the resulting models to find which variables are most important to defining juvenile Steller sea lion maximum dispersal distance (Burnham and Anderson 2002). Pair wise comparisons

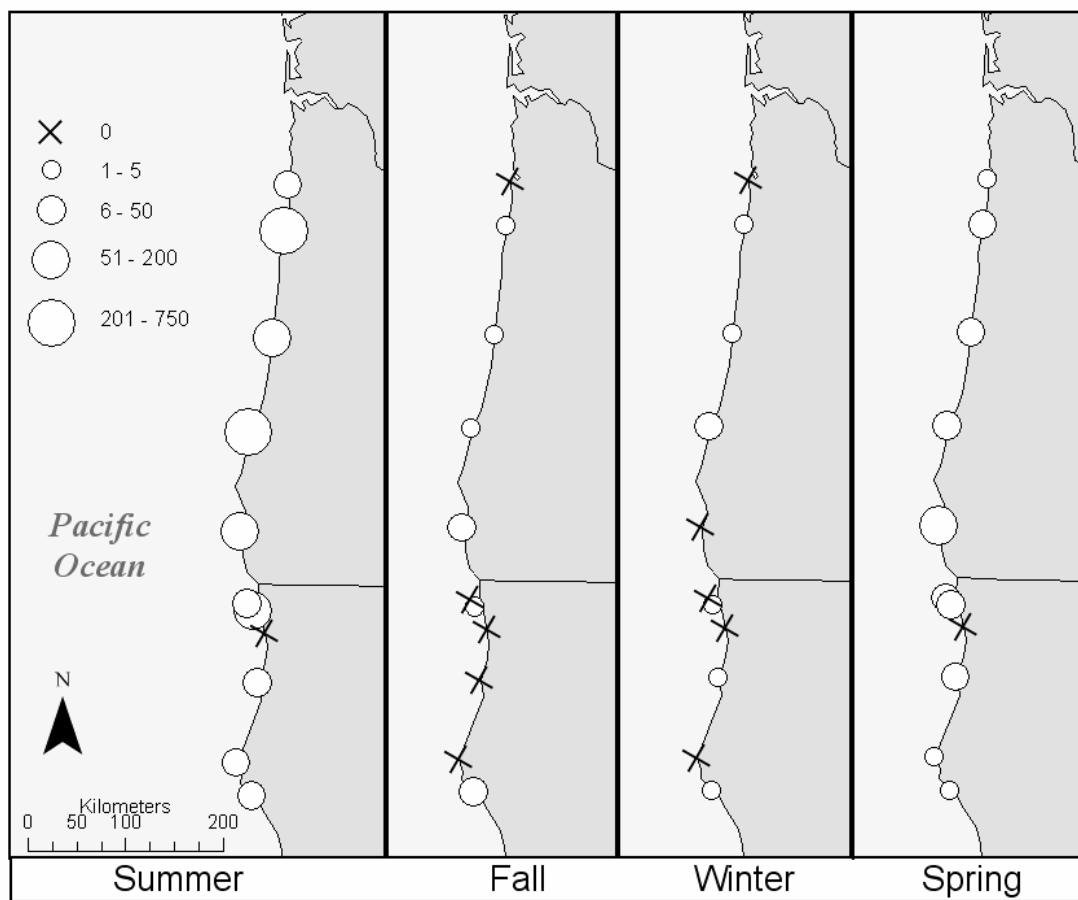
to test for differences in maximum dispersal distance between ages and between sexes within ages were made with a Wilcoxon rank-sum test.

Results:

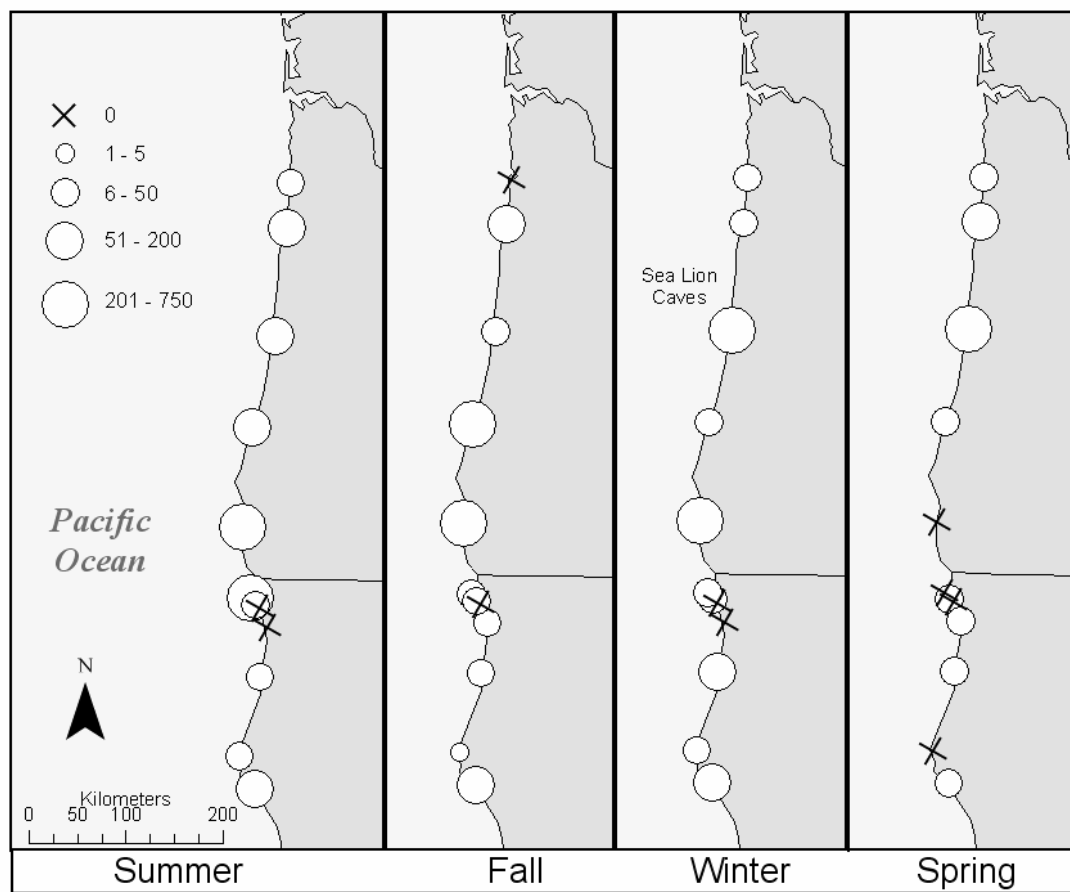
Seasonal fluctuations in demographic counts of Steller sea lions in Oregon and northern California

Adult males:

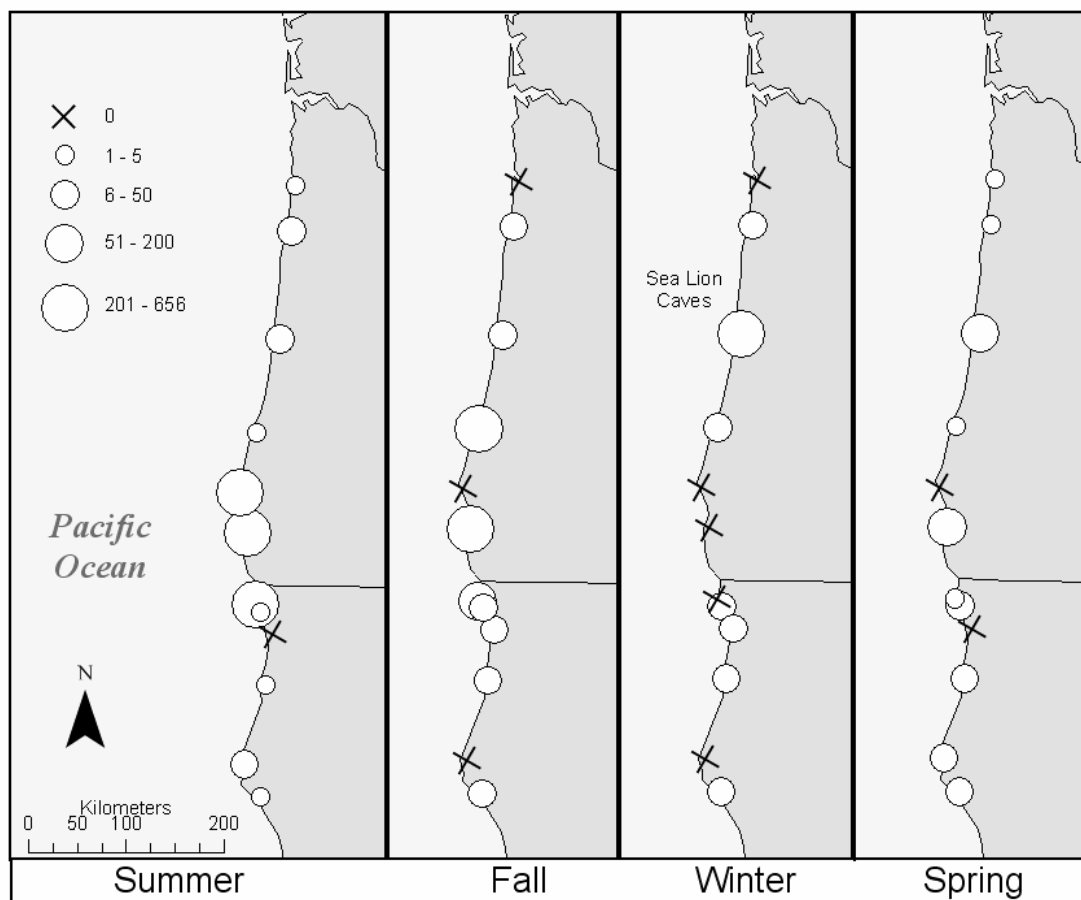
There was a marked seasonal pattern of adult male Steller sea lion abundance in Oregon and northern California with peak counts in summer and few to no males in the winter (Figure 2a). Males were observed migrating back into Oregon and California from winter feeding areas in Washington, British Columbia, and Alaska in mid April. The first males to establish territories were small adult males. They established territories at the 3 main rookeries in Oregon and Northern California (Orford Reef, ROR, and SGR) and at 4 haulouts: Three Arch Rock, OR; Sea Lion Caves, OR; Patrick's Point, CA; and Sea Lion Gulch, CA (Figure 2a). Larger males that are more capable of defending a territory arrived in May and displaced less-dominant males. Some displaced males hauled out on peripheral sites to the main rookeries or haulouts from which they were displaced. Many of the displaced males also congregated at a non-breeding site, Cape Arago, OR, during the breeding season (Figure 3). Males dispersed back north to feeding areas in the late summer and fall. Before dispersing north many of the males staged at Cape Arago and Cascade Head (Figure 3). By late October, and through the winter, sightings of male Steller sea lions in Oregon or northern California were rare occurrences.



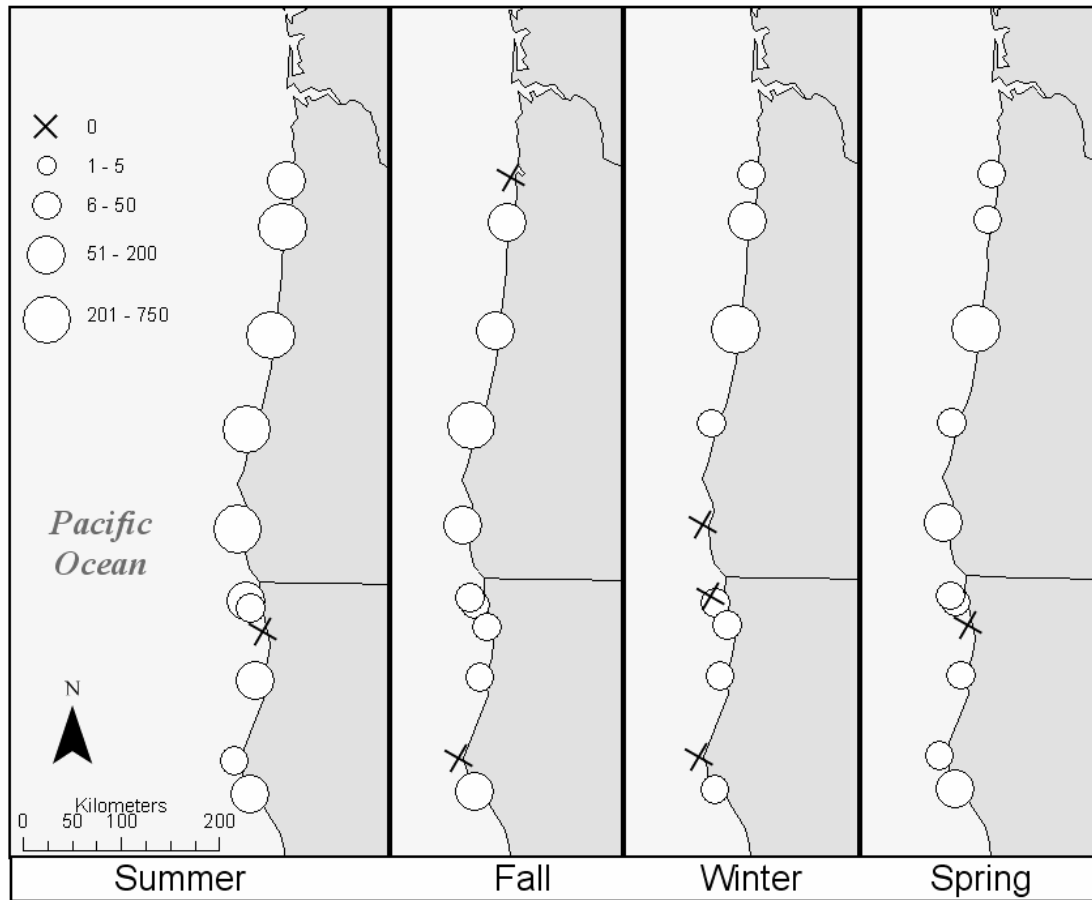
(a)



(b)



(c)



(d)

Figure 2: Map showing seasonal fluctuations in maximum counts of (a) male, (b) female, (c) pup, and (d) juvenile Steller sea lions at Oregon and northern California haulouts and rookeries between 2002 and 2005. Males are defined as adult males which show sexually dimorphic size or facial characters, females are adult females, pups are defined as animals between birth and 11-months of age, and juveniles are 11-months of age until secondary sexual characteristics are observable (usually 4-years of age for females and 5-years of age for males). The seasons are defined as summer (June – August), fall (September – November), winter (December – February), and spring (March – May).

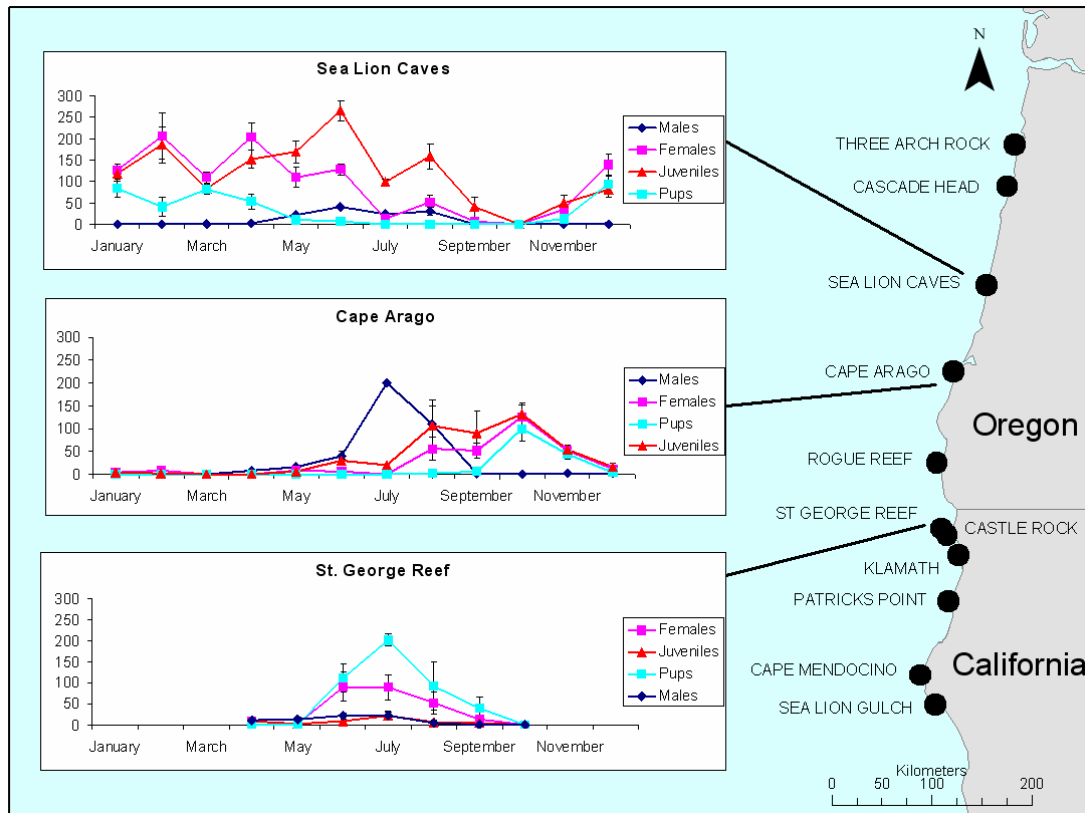


Figure 3: Mean monthly counts of demographic groups of Steller sea lions from three principle sites in Oregon and Northern California, 2002-2005. Sea Lion Caves represents year-round haulout patterns, Cape Arago is a summer bachelor bull site and fall staging area pattern, and St. George Reef is a breeding rookery.

Females and pups:

Females also showed a marked pattern in seasonal abundance and distribution (Figure 2b). During the breeding season females dispersed throughout the Oregon and northern California coastline with greatest concentrations at the breeding rookeries of ROR, SGR, and Orford Reef. Most females arrived at ROR and SGR in early June. Peak pup counts were observed around 1 July at both rookeries. Few pups were born off the main rookeries suggesting that most females at non-rookery haulouts were not pregnant. Females that did not return to the main rookeries still had opportunities for mating; two haulouts in Oregon and two in northern California had territorial bulls and copulations were commonly observed. Starting in August, females showed up in abundance at Cape Arago and Cascade Head in Oregon and to a smaller degree at Patrick's Point in California (Figure 2b, 3). Pups were not seen at

coastal haulouts until October, suggesting that females with dependent pups dispersed from the breeding rookeries later than other females (Figure 3). Through the fall the number of females and pups in Oregon and northern California declined as many individuals traveled north beyond the Oregon border. In November, when the ocean conditions worsened, most females and pups on the Oregon coast congregated at Sea Lion Caves. During the winter months from 60-78% of females counted on the Oregon and northern California coast were seen at Sea Lion Caves. In January of each year, over 90% of the pups counted were present at Sea Lion Caves (Figure 2c). As spring approached pups were seen at more sites throughout the coast. Some pups returned to ROR or SGR with their mothers where they were either weaned or continued to nurse as one-year-olds.

Juveniles:

Movements of juveniles (defined as 11-mo-old till development of sexually dimorphic characters) were very similar to adult females in this study area (Figure 2d). During the summer juveniles were dispersed throughout the coast with peak counts at the breeding rookeries. Between August and October, most juveniles congregated at Cascade Head or Cape Arago where they staged before traveling either north out of this study area or to Sea Lion Caves for the winter and spring months. Unlike adult females, juveniles were present at Sea Lion Caves during the late summer and into the fall (Figure 3).

Dispersal of marked sea lions:

During the course of this study 6,504 resights of 571 individual sea lions were collected. Resights of sea lions observed at their natal rookery within 6 months of capture were removed from analysis. This resulted in 3,817 resights of 405 individual sea lions for movement analysis. Resight rates were greater for SGR sea lions (59% of marked sea lions resighted) than for ROR sea lions (42% of marked sea lions resighted). Branded juvenile sea lions were observed to disperse to 58 haulout and rookery sites spanning from Sea Lion Gulch, California (40° 9' N, 124° 11' W) to Chiswell Island, Alaska (59° 36' N, 149° 34' W) (Figure 1). Resight effort in terms of time was not recorded by all participants in this study. Assuming the number of

resights of marked sea lions per number of marked individuals observed was a surrogate for reporting effort, we had greatest effort in Oregon throughout this study, and effort on Vancouver Island drastically increased in 2005 (Table 2).

Table 2: Effort to resight marked Steller sea lions from Rogue Reef and St. George Reef rookeries by region and year. Reported are the number of resights (Res.) and individuals sighted (Ind.) by region and year. The total marked were the number of animals available to be resighted in each given year. Regions with greater resights per individual were assumed to have greater effort.

	2001		2002		2003		2004		2005	
	Res.	Ind.	Res.	Ind.	Res.	Ind.	Res.	Ind.	Res.	Ind.
Gulf of Alaska							2	1	4	1
SE Alaska					5	3	7	3	9	5
British Columbia							9	4	17	15
Vancouver Island					8	8	18	18	240	75
Washington			11	6	14	11	57	35	99	61
Oregon	1	1	129	17	748	103	960	146	1398	210
California					41	10	24	14	49	35
Total Marked		180		320		510		661		841

Dispersal by rookery:

Sea lions of the SGR and ROR rookeries were observed to have very similar dispersal patterns and range (Figure 4), as most dispersal appeared to be to the north. On average, the maximum dispersal distance of observed SGR sea lions was 483 km (SE = 29.2 km) with a maximum of 2040 km to South Marble Island, Alaska by 82Y. ROR sea lions had an average maximum dispersal distance of 437 km (SE = 23.6 km) and a maximum of 2560 km to Chiswell Island, Alaska by 228R. Although SGR sea lions were observed on average 45.9 km further away from their natal rookery than ROR sea lions, the difference was not statistically significant (Wilcoxon sum rank test $n = 403$, $p = 0.29$). The observed difference was likely caused by SGR being 71.7 km south of ROR with the main direction of dispersal for both rookeries being to the north. Dispersal to the south was much less likely for both SGR and ROR sea lions (17% and 7% of branded sea lion resights, respectively). SGR is the more southern of the two rookeries and this may have influenced habitat utilization. Sea

lions from SGR were 2.27 times more likely to use haulouts south of their natal rookery than sea lions from ROR (Fisher's Exact Test, $n = 405$, $p = 0.019$).

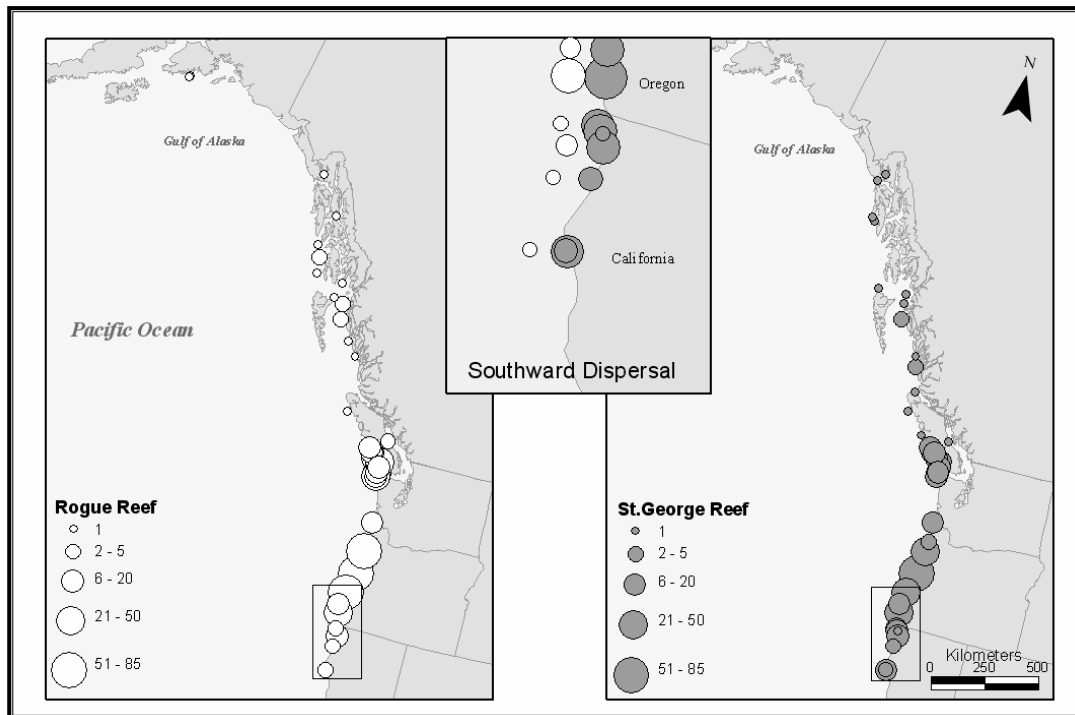


Figure 4: Map of dispersal distributions of individual sea lions marked at Rogue Reef, Oregon and St. George Reef, California from resights collected between 2001 and 2005. Sea lions marked at Rogue Reef, Oregon are marked with open circles and at St. George Reef, California with filled circles. The inset shows counts of sea lions south of their natal rookery.

Observed changes in dispersal range by age and sex:

Using an information criteria approach (Burnham and Anderson 2002), 8 models were tested to find what variables, or combination of variables, had the greatest evidence for modeling maximum dispersal distance of sea lions observed in 2005 (Table 3). Evidence in the data suggests that the distance a sea lion was observed away from its natal rookery increases with age until a peak and then decreases. The inclusion of an interaction of age and sex in the best model suggests that males and females have different trends in the maximum observed distance from their natal rookery (Figure 5).

Table 3: Selection table used to select the best model to describe maximum observed dispersal distance in 2005.

Model	AIC	Δ AIC	K
Age + Sex + Age:Sex + Age ²	4163.54	0.00	6
Age + Sex + Age:Sex + Age ² + Age ² :Sex	4165.50	1.96	7
Age + Sex + Age ²	4167.31	3.77	5
Age + Sex + Age:Sex	4169.76	6.22	5
Age + Sex	4172.96	9.42	4
Age + Age ²	4174.11	10.57	4
Age	4179.76	16.22	3
Sex	4181.81	18.27	3

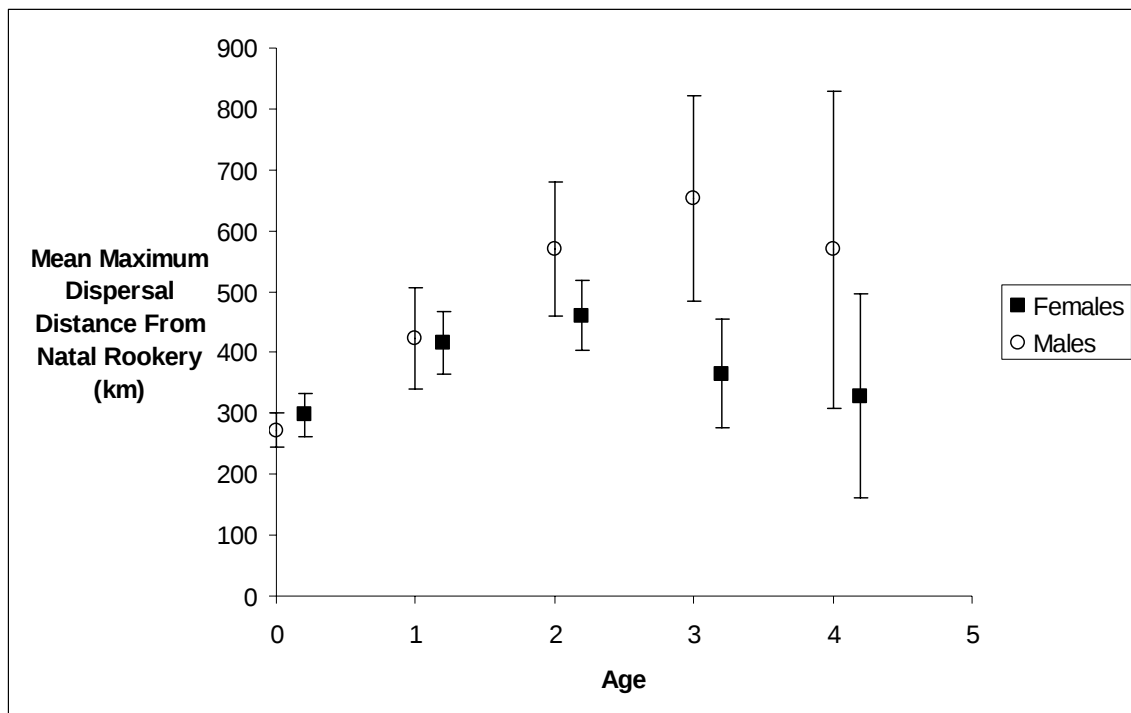


Figure 5: Mean maximum dispersal distances (from natal rookery) by sex and age for individual branded Steller sea lions. Open circles show mean maximum distance sighted away from natal rookery for males; closed squares show maximum for females. Error bars expressed as one 95% confidence intervals of mean estimates.

Most pups stayed within Oregon and California, although 9% to 22% of observed individuals were seen >500 km from their natal rookery in Washington and

southern British Columbia each year. The mean maximum dispersal as yearlings was 133.7 km greater than pups (Wilcoxon rank-sum test, $p < 0.001$) (Figure 6). Sexual dimorphism in movement patterns was evident starting at 3 years of age as female range contracted and male range continued to expand (Wilcoxon rank-sum test, $p = 0.017$). Female range continued to contract until at 4-years-old their mean maximum dispersal distance was similar to pups (Wilcoxon rank-sum test, $p = 0.804$).

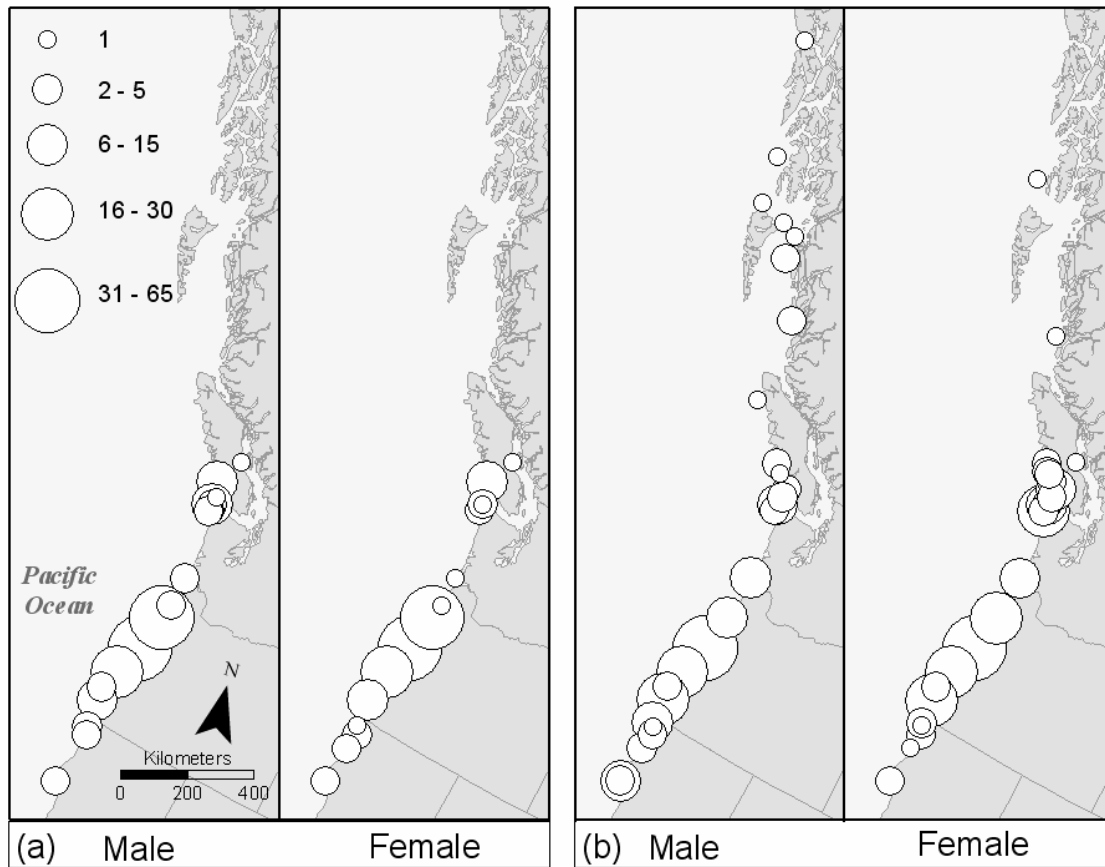


Figure 6: Map of distributions of the maximum distance individual pups (a) and yearlings (b) were observed from their natal rookery by sex. One outlier was not included in the maps; a yearling male (228R) was seen at Chiswell Island, Alaska (2,500 km from Rogue Reef).

The proportion of sea lions returning to their natal rookery was also dependent on age and sex (Table 4). Some pups and yearlings return to their natal rookery with their mothers. Through 3 years of age similar proportions of observed marked male and female sea lions were seen at their natal rookery. During their fourth year, the majority of females were observed at their natal rookery, suggesting an age of

maturity of four years. However, only one of four year old female was observed with a dependent pup.

Table 4: Observed proportion of female and male Steller sea lions by age that returned to their natal rookery.

Age	Female	Male
Pup	9%	11%
1-year-old	20%	22%
2-year-old	15%	12%
3-year-old	33%	31%
4-year-old	85%	23%

Discussion:

Seasonal fluctuations in demographic counts of Steller sea lions in Oregon and northern California:

Movement patterns of adult males have changed little since the population was last monitored by Bruce Mate in the late 1960s (Mate 1973). One change we observed was during the late 1960s Cape Arago was a small rookery (Mate 1973), whereas today the site appears to act as a bachelor bull site. Females were not commonly observed at Cape Arago during the breeding season and pups were rarely seen during this study. Furthermore, males were not arranged in territorial breeding structures suggesting that the site no longer acts as a rookery. The marked population spike of male Steller sea lions utilizing Cape Arago in the summer suggested the site now acts largely as a bachelor bull site for males staging to travel to the breeding rookeries, leaving the rookeries, or males that are just unable to access breeding rookeries. Mate (1973) hypothesized that that increasing California sea lion population would increase interspecies competition leading to earlier dispersal by Steller sea lion males. Instead, despite an increase in California sea lions of 5-6.2% a year since 1972 (Carretta *et al.* 2005), timing of male Steller sea lion dispersal looked similar, if not later, than Mate observed in the late 1960s.

Female Steller sea lions in Oregon and northern California can be divided into two groups, those with dependent pups and those without. Movements of pups and adult females do not perfectly mirror each other throughout the year as would be

expected since pups depend on adult females for sustenance (Pitcher and Calkins 1981). For example, there is a spike in abundance of female and juvenile Steller sea lions in August at Cape Arago and Cascade Head. Interestingly, pups do not arrive until late September, which suggests that pup swimming ontogeny determines when females disperse from the rookery.

An interesting finding of this study was the importance of Sea Lion Caves, Oregon, as a wintertime haulout site. Sea Lion Caves appears to act as a nursery; most of the juveniles and pups observed at Sea Lion Caves appear to be nursing during the winter and spring. It is unknown why Sea Lion Caves was such an important site for females with dependent offspring in the winter. Sea Lion Caves may be an important site due to protection from weather and ocean conditions, availability of prey at nearby Heceta Bank, and/or protection from human disturbance by the staff and ownership of Sea Lion Caves.

In general, haulout use patterns of juvenile Steller sea lions are very similar to adult females without dependent pups. The spike in haulout use of Cape Arago and Cascade Head in August and September is mirrored by females and juveniles, but not in pups. These juveniles are either freely moving and using the best resources of haulouts and feeding areas like adult females do; or, they may be dependent on these adult females as many Steller sea lions do not wean during their first year and are seen suckling into their third year (Pitcher and Calkins 1981). An interesting difference in movements of juveniles and adult females is the use of Sea Lion Caves in the late summer and fall. Females abandon Sea Lion Caves and only juveniles and some males inhabit the site in the late summer. The juveniles left at the site may have recently weaned and have not yet dispersed.

Dispersal of marked sea lions:

Movements by rookery were very similar in total range and mean maximum dispersal distance. This finding is not surprising given the two rookeries are only 71.5 km apart. What is surprising is that given the similarities of range between sea lions of both rookeries, that SGR sea lions were more likely to utilize haulouts south of their natal rookery than ROR sea lions. A possible reason for this is proximity to

haulouts and rookeries to the south of each rookery. To utilize haulouts to the south, ROR sea lions have to travel at least 71.5 km to SGR; SGR sea lions only have to travel 9 km to the south to the closest haulout to their natal rookery.

Branded pups were not seen beyond 500 km of their natal rookery in a study of Steller sea lions in Alaska (Raum-Suryan *et al.* 2002). We did not observe the same pattern. Between 2003 and 2005, 9 – 22% of observed branded pups were seen in northern Washington and southern British Columbia (600 – 700 km north of SGR and ROR) by 9 months of age. The observed difference in pup dispersal beyond 500 km is likely due to geography of haulouts. In Alaska, haulouts are spread out to the north and south and to the east and west of breeding rookeries giving females a wide range of haulouts, and therefore ocean conditions, to choose within a 500 km post-breeding dispersal range. In Oregon and northern California, haulouts are all arranged to north and south of breeding rookeries, which may cause females with a dependent pup to travel further to find ideal feeding and haulout conditions than their Alaskan counterparts.

During 2005, 22% of observed branded pups were seen in northern Washington or British Columbia. This result coincided with the first year of concentrated effort in southern British Columbia during the fall. Therefore, it is currently unclear if 2005 was an anomalous year of pup dispersal behavior or if our increased effort allowed documentation of a normal, yet previously undocumented, dispersal pattern. During 2005, delayed upwelling and decreased primary production resulted in significant changes in prey abundance and distribution (Brodeur *et al.* in Review IN Weis 2006). This may have caused increased dispersal range of adult females with dependent pups following the 2005 breeding season. However, our lack of resight data for southern British Columbia during the fall in 2001 to 2004 prevents examining correlations of northward dispersal range by year to ocean conditions. Consequentially, we cannot determine if anomalous sea conditions in 2005 caused a change in dispersal trends. If effort were standardized it would allow future research to document plasticity in movement behaviors in the face of anomalous ocean conditions (*e.g.* El Niño).

Weaning in Steller sea lions is most commonly reported as occurring between 1-3 years of age (Gentry 1970; Sandegren 1970; Calkins and Pitcher 1982). The large change in maximum dispersal distance observed between pups and yearlings suggests that many, if not most, sea lions may wean around 1 year of age. Yet, the observed increased dispersal range may represent the increased ability females have to expand their dispersal range as dependent juveniles have greater swimming capabilities than pups. In other mammals post-weaning dispersal is greater for males than females (Greenwood 1980; Wolff 1993; Soderquist and Lill 1995; Warren *et al.* 2005). We did not see a sexual difference in dispersal until age 2. From 2 years of age through the end of our study males dispersed significantly further from their natal rookery than females; therefore, weaning may occur at around 2 years of age for ROR and SGR sea lions.

The change in movement patterns of females by age may be an indication of timing of sexual maturity. Sexual maturity for female Steller sea lions is reported as between 3 and 7 years of age (Pitcher and Calkins 1981). During each progressive year, we observed increased rates of females returning to their natal rookery during the breeding season to a maximum of 87% of 4-year-olds. Furthermore, we observed a contraction in range of movements in 4-year-old females that resulted in a range very similar to pups (and hence reproductive adult females). These changes in behavior may provide females with “local-knowledge” of breeding and haulout sites which would give them the potential benefits of knowledge of often patchy local food resources, predator refugia, predator movements and habits, and ideal pupping sites (Robertson and Cooke 1999). These benefits possibly confer to increased ability to rear pups due to increased foraging efficiency (Irons 1998) and knowledge of the breeding site.

Management Implications:

Results of this study on the movement patterns of Steller sea lions should assist managers to determine critical habitat in Oregon and northern California. Results from this study suggest that Sea Lion Caves is a very important haulout for Steller sea lion conservation due to the large abundance of pups and dependent

juvenile Steller sea lions that utilize the site during the winter. Currently only Rogue Reef and Orford Reef are listed as critical habitat for Steller sea lions of Oregon and northern California (NMFS 2006). Both of these sites are important rookeries, yet the recovery plan fails to recognize four other rookery sites in Oregon and northern California (St. George Reef, Sugarloaf/Cape Mendocino, Ano Nuevo, and the Farallon Islands) or important winter haulouts like Sea Lion Caves (NMFS 2006). Currently Steller sea lion populations in Oregon and northern California are increasing and do not need additional protection (NMFS 2006). However, if the eastern stock of Steller sea lions experiences the drastic population declines as observed in the western stock, then all rookeries and Sea Lion Caves should be documented and considered for critical habitat listing for Steller sea lions in Oregon and northern California.

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CHAPTER 3: EVALUATION OF HOT-IRON BRANDING OF STELLER SEA LIONS PUPS AT ROGUE REEF, 2005

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Abstract:

Marking of animals is an integral part of wildlife research. Selecting an appropriate marker is challenging and requires evaluation to ensure the marker does not affect the ability of the study animal to survive and reproduce. We evaluated effects of hot-iron branding on survival of 80 branded as compared to 80 “reference” Steller sea lion (*Eumetopias jubatus*) pups at Rogue Reef, Oregon during the summer of 2005. Our reference group consisted of pups that were treated identically to the branded animals, with the exception of the hot-iron brand itself. Resight data were analyzed using Cormack-Jolly-Seber models in the Program MARK, which allowed for different resight probabilities for branded and unbranded pups. Over the 73 day course of this study, apparent survival was lower for branded pups than our unbranded pups, with a final apparent survivorship for branded pups of 0.23 (95% CI 0.01 – 0.48) and apparent survivorship for unbranded pups of 0.46 (95% CI 0.15 – 0.77). Apparent survival includes both mortality and emigration, so differences may be due to differences in emigration rates of the two groups, mortality rates, or both. Half of handled pups received radio tags to test for differences in emigration rates. However, the rapid loss of radio transmitters due to molting restricted analysis of emigration to the first week of study; we found no evidence of a difference in emigration rates during that short time period. Our results show that controlled study of the effects of branding on pinnipeds is possible and can yield important results for evaluation of the costs and benefits of this permanent marking method. Additional research is needed to determine if the difference in apparent survival is due to effects of emigration or health of the animals, and if our results from Rogue Reef in 2005 were typical of branding studies for this species.

Key words: *Eumetopias jubatus*; hot-iron branding; marking evaluation; marking techniques; mark-recapture; pinnipeds

Introduction:

Marking individuals or groups of animals is an integral part of wildlife research and management (Nietfeld *et al.* 1996). Marked animals provide the basis for a variety of studies including social and reproductive behavior, population dynamics, and life history (Nietfeld *et al.* 1996; Murray and Fuller 2000; Beausoleil *et al.* 2004). Selection of an appropriate marking method requires consideration of study objectives, duration of the study, level of recognition required, life history, and physical attributes of the species involved, and potential impacts of the marker on the welfare of the animals involved (Beausoleil *et al.* 2004).

Marking can affect animals by altering their behavior and their capacity to survive and reproduce (Beausoleil *et al.* 2004). In recent years, advancements in research methods and analysis tools have improved the evaluation of marking procedures (Murray and Fuller 2000) to detect more subtle changes to survival rates, physiology, and energetics. For example, Dugger *et al.* (2006) used pit tags, a weigh bridge, and the Program MARK to evaluate the effects of flipper bands on Adelie penguins (*Pygoscelis adeliae*). They found that bands caused penguins to increase foraging time and that flipper bands reduced apparent survival. Researchers need to evaluate all marking procedures for potential negative impacts, including accepted techniques that have been used for some time. This paper focuses on the evaluation of hot-iron branding as a permanent marker of Steller sea lions (*Eumetopias jubatus*).

Hot-iron branding has been used for many years as a tool in pinniped research and conservation. Branding was first used in the 19th century as a conservation strategy to protect the breeding stock of female northern fur seals (*Callorhinus ursinus*) from pelagic sealers by marring their pelts (Scheffer 1950). Following those efforts, biologists realized that branding left a visible mark for the lifetime of a study animal. Early fur seal researchers took advantage of these lifetime marks for growth-curve studies (Perkins 1945), studies of site fidelity, and studies of survival rates (Scheffer 1950). The efficiency of using brands on fur seals was noted by other pinniped researchers who have branded a wide variety of species through the years to achieve many research objectives (Appendix C). Presently, branding is the research

tool of choice for researchers interested in long-term monitoring and study of pinnipeds.

Due to precipitous population declines of Steller sea lions in latter half of 20th century NOAA Fisheries has undertaken a range-wide branding program to document vital rates of Steller sea lions (Dalton 2005). Concern has been raised by program biologists that hot-iron branding has the potential for negative effects on Steller sea lion pup survival (NOAA 2002). Logistically the best site for a brand evaluation study was Rogue Reef, Oregon. Rogue Reef has been monitored efficiently since 2001 with remotely operated cameras and vessel surveys. Furthermore, the large breeding aggregation assured access to a large sample size of pups for a statistically rigorous study. Pups were captured and monitored during the summer of 2005. Our primary goal was to determine if branded and unbranded pups had comparable survival rates.

Study area:

Rogue Reef is located in southern Oregon, 60 km north of California border, and 3 km offshore from Gold Beach, Oregon (Figure 7). Rogue Reef is the largest Steller sea lion rookery in the contiguous United States and supports production of 800-1000 pups per year (ODFW unpub. data). The reef is a complex of islands that are used by Steller sea lions, California sea lions, and harbor seals; Pyramid Rock is the primary rookery and was used as our study site. Pyramid Rock has a surface area of roughly 0.8 hectares (Merrick 1987) of impermeable meta-sedimentary rock that is devoid of plant life. The west end of Pyramid Rock reaches roughly 14 meters above sea level and was used as the primary vantage point for observing with spotting scopes and remotely operated cameras. The reef receives very little rainfall through the summer breeding season and has average daily high temperatures of around 18 C.

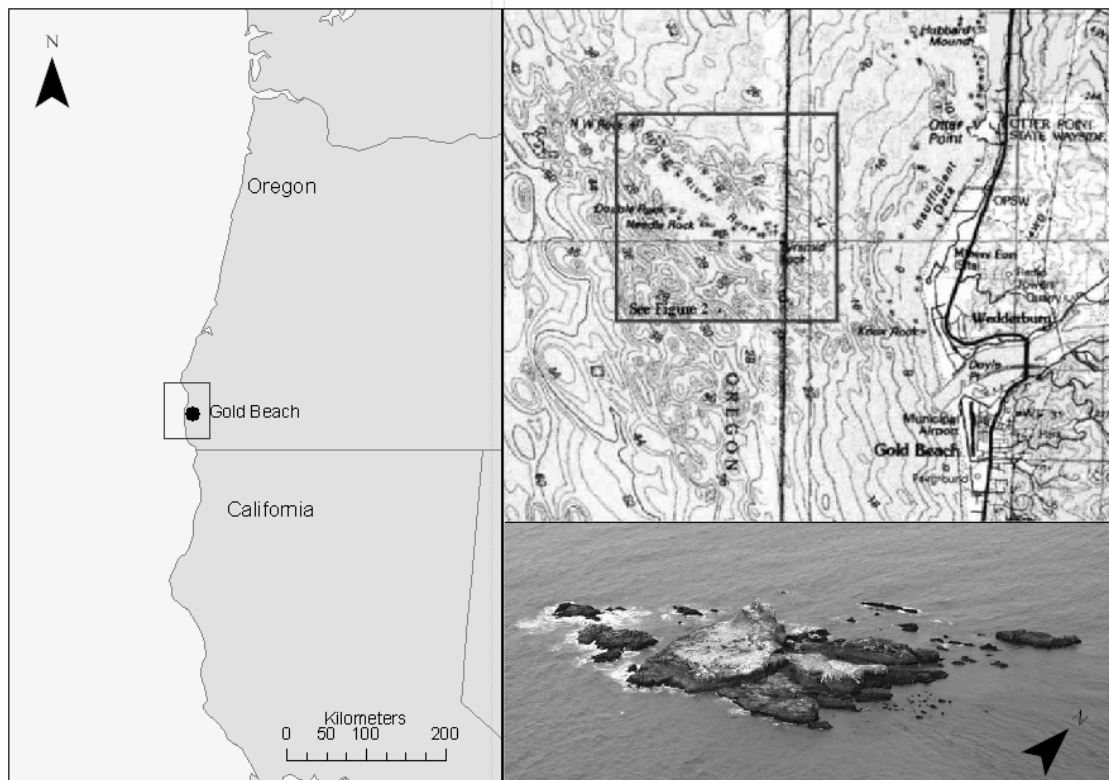


Figure 7: Study area for the brand evaluation study. All resight work was conducted on Pyramid Rock with remotely operated cameras and with 15 – 45x spotting scopes.

Methods:

Pup capture and marking

All pups were treated in the same manner other than marking treatment. Pups were anesthetized with isoflurane gas (see Heath *et al.* 1996; Heath *et al.* 1997) with the goal of keeping anesthesia time constant between groups. Anesthesiologists were rotated among the treatments to prevent an anesthesiologist effect that could skew a marking treatment effect. All pups were tagged with All-flex tags TM on the trailing edge of their fore-flippers (see Rand 1950 or Merrick *et al.* 1996) and had a neoprene patch (2.5 x 2 in) painted bright yellow with Tool Dip TM and glued between their shoulder blades using Locktight Glue TM. On unbranded pups the neoprene patch had a bright yellow background with black lettering painted on with black Tool Dip to signify the pup's tag number. Branded pups also received a patch, but without a letter code. Radio tags (Advanced Telemetry Systems, Inc. model # MM160; 164.001 to

164.850 kHz) were glued and tied to neoprene patches of the same dimension as identity patches. When both a patch and a radio were to be applied, the radio was placed between the shoulder blades to prevent the pup from chewing on it and the identity patch was placed 3 to 7 cm more posterior.

As a rough guide for sample size, we conducted a power analysis for a test of differences between 2 binomial proportions. Marking 160 pups, 80 branded and tagged and 80 tagged only, would allow us to detect with 90% power a difference in survival of 15 percentage points. To ensure we had equal sample sizes for the treatment groups, we used a complete randomized block design, which assigned each group of four pups to one of four marking treatments: brand with a radio, brand with no radio, unbranded with radio, and unbranded with no radio. This design resulted in 40 pups receiving each of the four marking treatments. Prior to capture, a random number generator was used to determine which treatment a pup would receive. Animal handlers were blind to which treatment their pup would receive to prevent selection of healthier looking pups for either treatment.

Pups were captured on 18 July 2005. Members of a large capture team from Oregon State University (OSU), Oregon Department of Fisheries and Wildlife (ODFW), NOAA Fisheries National Marine Mammal Lab, United States Fisheries and Wildlife Service, the Marine Mammal Center, and volunteers herded the pups into a holding area in the center of Pyramid Rock. Smaller groups of pups were herded from this holding area to a corral close to the marking site. From there, pup handlers captured the pups in hoop nets and carried the pups to a weighing station. At that time, the data recorder told the handlers which random treatment station the pup was assigned. Once at the station, pups were anesthetized by trained veterinarians and veterinary technicians using isoflurane gas (Heath *et al.* 1997). The anesthesiologists made efforts to standardize anesthetic time, defined as time from gas anesthesia cone on till cone off (Troy *et al.* 1997) and depth of anesthesia for all pups. Once anesthetized, pups were measured for both total length (tip of nose to tip of tail) and axillary girth. Other factors such as animal condition, sex, and visible signs of illness or injuries were also recorded. Flipper tags were applied to the trailing edge of the fore-flippers of the pups. The left flanks of pups were then

washed with seawater and dried using a sequence of terry cloth wiping followed by blow drying with compressed air from a scuba tank. We then wiped down the area between the shoulder blades of reference pups with acetone to remove the oils from the pup's fur that could prevent a solid seal of glue from the radio patch or identity patch to the hair. Pups were branded before receiving acetone treatment to prevent the risk of fire. Pups were branded following the protocols outlined by Merrick *et al.* (1996). The capture team, anesthesiologists and branders rotated positions after each group of 20 pups.

Resights

Pups were "resighted" using both radio telemetry and visual surveys. Two radio receivers and digital data loggers were placed on Rogue Reef with enough memory to monitor the pups for 6-weeks. The gain was set to monitor pups on Pyramid Rock and not the surrounding reef. A radio receiver and data logger were also placed on shore to monitor pups on the whole reef and to provide a back-up if the two systems on Pyramid Rock should fail. An observer manually monitored the shore system two to three times daily to ensure good data collection. Vessel and aerial radio surveys were conducted on the reef surrounding Pyramid Rock and nearby haul-outs to monitor for pup emigration from Rogue Reef. On vessel surveys, the pups were also monitored visually. Shore-based visual surveys were performed daily at Pyramid Rock for the first six weeks post marking using four remotely operated cameras installed on Pyramid Rock by SeeMore Wildlife. After the initial six weeks, the effort continued for two more weeks but on a more sporadic basis. On five occasions observers landed on Pyramid Rock to visually monitor pups with 15-45x spotting scopes. The five occasions were spread out from the beginning of the seventh week through the end of the study at irregular intervals.

All work was conducted under authorization of Oregon State University's Animal Care and Use Committee (permit no. 3196). All handling, branding, and subsequent resight work on Steller sea lions was conducted under a research permit to the Oregon Department of Fish Wildlife (permit no. 434-1669-03) issued by NOAA Fisheries Protected Resources Division.

Data Analysis

An *a priori* list of models was developed for Steller sea lion pup survival and resight probability (Appendix D). Our main interest was to test if branding reduced *apparent* survival of Steller sea lion pups, which is a result of both mortality and emigration. However, other variables in this study could have affected pup survival. Past studies have found that females have greater survival than male pinniped pups (Hall *et al.* 2001; Beauplet *et al.* 2005). Furthermore, each brander responds to different cues on when a brand is complete (Erickson *et al.* 1993). This results in some brander's marks being of greater risk to infection due to different degrees of tissue damage. For these reasons treatment, sex, and brander were all included as main effects for analysis in addition to time. Mark-recapture data was coded into an input file with 10 groups (i.e. brander 1 female, brander 1 male, brander 2 female, brander 2 male, brander 3 female, brander 3 male, brander 4 female, brander 4 male, unbranded male, unbranded female) allowing for investigation of main effects of brander, sex, treatment, and time (Appendix E). Individual covariates of mass and anesthetic time were also included in the input file for analysis.

Mark-resight models of a single age cohort are characterized by the following assumptions: 1) each pup was randomly sampled from the same population; 2) resight and survival probabilities are adequately modeled; 3) marks are not lost and marks are reported correctly; and 4) sampling time is negligible relative to the survival interval (Cameron and Siniff 2004; Cooch and White 2006). Our monitoring efforts resulted in 53 capture occasions for mark-resight analysis over a period of 73 days. However, due to an unanticipated high rate of loss of identification patches from unbranded pups we added constraints to our analysis to reduce heterogeneity and model complexity. Resights were limited to the first week of remote camera effort (19-25 July) and 5 days of effort on Pyramid Rock with spotting scopes: 20 August, 2 September, 6 September, 13 September, and 29 September.

Program MARK (White and Burnham 1999) was used for fitting models to the data, model selection, and estimates of apparent survival and recapture probabilities using Cormack-Jolly-Seber (CJS) models (Lebreton *et al.* 1992). Akaike's Information Criteria corrected for small sample sizes (AICc) was used to

rank the appropriateness of survival and resight probability models to assist in model selection (Burnham and Anderson 2002). However, the AIC_c was modified to account for heterogeneity, observed as extra-binomial variation in the count of capture histories, which is common in mark-recapture data (Lebreton *et al.* 1992; Cameron and Siniff 2004). We used median c-hat, a subroutine within Program MARK, to test for goodness-of-fit of our global model to the general CJS model to test for extra-binomial variation in our resighting data (Cooch and White 2006). We estimated a c-hat of 1.71; consequently, we used quasi-likelihood AIC ($QAIC_c$) for each model and chose the best approximating model based on minimum $QAIC_c$.

Each of our main effects (treatment, brander, sex, and time) was added together in single-, double- and triple- factor additive models for capture and survival calculations. Interactions of effects were also hypothesized to affect survival. We modeled time as a linear trend (T), a quadratic trend (TT), a logarithmic trend (lnT), and as time varying (t) effect. Risk of mortality due to branding may change with time as susceptibility to infection increases or decreases; therefore, we considered interactions of brander*time and treatment*time for survival models in our analysis. For capture probability models, we also included time interaction with sex to allow for effects of changing behaviors of the sexes with time to influence resight rates. We also modeled survival with anesthetic time and pup mass as individual covariates. These two covariates were important because heavier pups have been shown to have greater survival (Harding *et al.* 2005), and pups can be overdosed or overheated when sedated. In the end, we modeled 37 capture probability models and 74 apparent survival models to test biologically meaningful hypotheses (Appendix D).

Due to our large model set we took a multiple step approach to find the best overall model. We first compared all possible resight probability (p) models to a parameter rich apparent survival (Φ) model ($\Phi_{\text{brander*sex*time}}$) and for completeness also to a reduced model (Φ_{constant}). We selected the best p models, those with the lowest $QAIC_c$, to compare to all Φ models. We then modeled all main effect Φ models. Then we included individual covariates to survival models within 4 $QAIC_c$ of the best model. The most parsimonious (lowest $QAIC_c$ values) Φ models were then examined to find what variables most affected apparent survival. The importance of a variable

in a model was tested by examining slope coefficients (β_i), following Dugger *et al.* (2006). Those variables which had 95% confidence intervals around the β_i that did not include zero were considered to have strong evidence of effect. The best model including a treatment or brander effect was compared to the best model without a treatment or brander effect to determine the strength of evidence of a branding effect on apparent survival. All Φ models were included in a model averaged estimate of apparent survival rates (Burnham and Anderson 2002). The cumulative product of apparent survival estimates for each occasion was used to compute apparent survivorship for the full 73 day study period for branded and unbranded pups. We then used the Delta Method (Cooch and White 2006) to compute 73-day apparent survivorship variances for computing confidence intervals.

Results:

Analysis of radio transmitter data

We used radio transmitters to determine if branded and unbranded pups had equal emigration rates. Unfortunately, gluing identification patches and radio transmitters to the fur of Steller sea lion pups did not work reliably for this study. The data were only reliable for the first week because the radios were lost rapidly due to early molt and pup play behavior. On 19 July (one day post branding), radio receivers on Pyramid Rock detected the presence of 75% of 40 branded and 90% of 40 unbranded pups with radio transmitters; a Fisher's exact test showed no evidence for differences in presence of branded versus unbranded pups (Fisher's exact test, $p=0.14$). On 24 July (six days post branding) 72.5 % of branded and 67.5% of unbranded pups were detected; there was again no statistical difference in the number of pups with radio transmitters from each treatment group detected on Pyramid Rock (Fisher's exact test, $p=0.81$). Aerial surveys revealed that 2 branded and 1 unbranded pup had emigrated to Orford Reef; this difference in known emigration was insignificant. Therefore, we had no evidence from radio transmitter data to show a difference in emigration rates of the two treatment groups during the first week post branding.

Known Mortalities

Searching for dead pups was not within our study design. However, on one occasion, 20 August, we were able to perform an incomplete search of Pyramid Rock for dead pups and collect flipper tags. All dead pups reported by the public were investigated by a project biologist; no systematic beach scans for dead pups were performed. From these opportunistic efforts 4 dead pups were observed, all of which were branded. Three dead pups were found on Pyramid Rock and one washed ashore on Nesika Beach, Oregon. A fisherman reported another branded pup dead floating around Rogue Reef but this sighting was never confirmed. We cannot account for differences in detection rates of dead branded and unbranded pups and no statistical comparisons were performed.

Mark Resight Data Analysis

All biologically important resight probability models from our *a priori* factor list (Appendix D) were fitted with a full apparent survival model $\Phi(\text{brander}*\text{sex}*\text{time})$ and a constant apparent survival model $\Phi(.)$. The resight model (p) with the lowest QAIC_c for both Φ models included a treatment effect with an additive time effect. Selection of $p(\text{treatment} + \text{time})$ indicated that branded pups consistently had a higher resight probability than unbranded pups and that resight rates changed for each capture occasion (Figure 8). The resight model of $p(\text{time})$ was strongly competing, suggesting that treatment effects were negligible. An examination of the coefficient for the treatment effect indicated that it was a weak effect ($\beta = 0.5213$, 95% CI -0.0797 to 1.122). For completeness, $p(\text{time})$ and $p(\text{treatment} + \text{time})$ were compared to all Φ models; $p(\text{time})$ always resulted in poorer fit to the data and was omitted from the results.

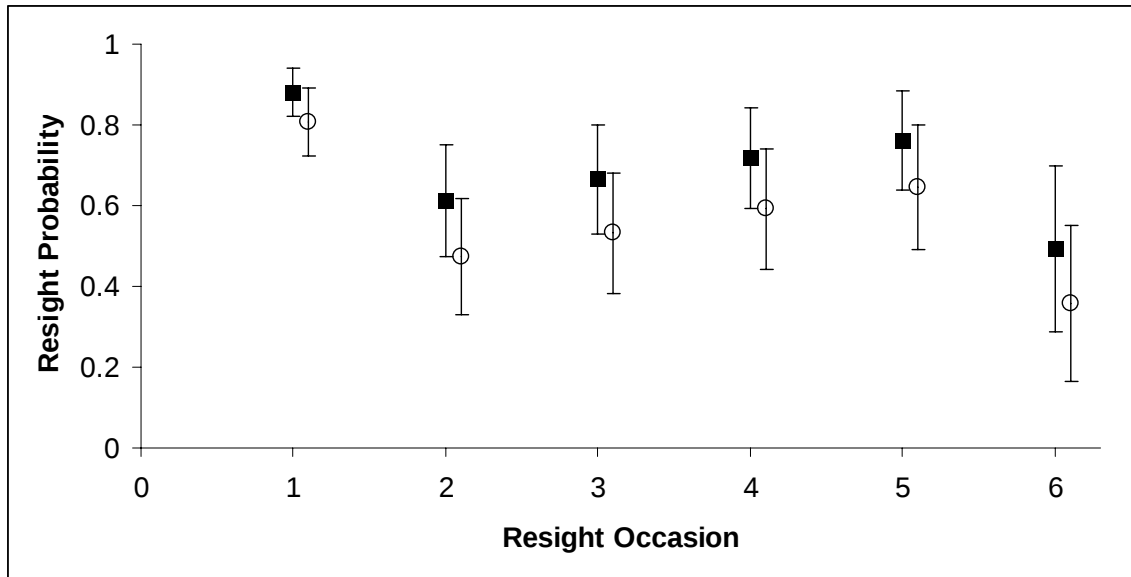


Figure 8: Probability of resighting branded and unbranded pups during each resight occasion based on Cormack-Jolly-Seber models in the program MARK. Branded pups are reported with a closed square and unbranded pup with an open circle. Resight occasions were 19-25 July, 20 August, 2 September, 6 September, 13 September, and 29 September. Error bars express 95% confidence intervals.

We fit our *a priori* Φ models and found that the best Φ model, among a few highly competitive models, was $\Phi(\text{treatment})$ (Table 5). This provides evidence that the best predictor of apparent survival was whether or not the pup was branded ($\beta = -0.7516$, 95% CI -1.3935 to -0.1097). Using Akaike's weights to compute an evidence ratio (Burnham and Anderson 2002), we found there was six times more evidence that $\Phi(\text{treatment})$ was a better model than the best model excluding a branding effect ($\Phi(.)$). The model $\Phi(\text{treatment})$ shows that through the course of this study the difference in apparent survivorship of the two treatments gradually increased (Figure 9). We had 6 strongly competing models (those within 1 QAIC_c) to the best model. Five of the models were additive models to $\Phi(\text{treatment})$; they included the effects of mass, anesthetic time, sex, and linear and logarithmic time effects. Estimates of coefficient values and 95% confidence intervals revealed little support for competing models with an additive effect to treatment as each broadly overlapped zero (Table 6). Of our *a priori* model list, the only competing model without 95% confidence intervals of coefficients including zero was $\Phi(\text{brander})$. This model shows an association of branders and apparent survival of branded pups suggesting that

individual branders may affect the survival of pups. Branderers were not randomized throughout the day. Interestingly, the earliest brander had the lowest projected apparent survival and the last brander had the highest (Figure 10). Therefore, the observed effect of individual branders was confounded with time of marking effect and the observed effect may have been time of day, brander, or both.

Table 5: Model selection results for a priori investigations of treatment, brander, sex, mass, anesthetic time (AnTime), linear time trends (T), log-linear time trends (lnT), quadratic time trends (TT), and daily varying models (t). Small sample-size adjusted quasi-likelihood Akaike's Information Criteria (QAIC_c c-hat = 1.709), the difference in QAIC_c between each candidate model and the model with the lowest QAIC_c value (Δ QAIC_c), number of model parameters (k), and model deviance (Deviance) are included for each model. The Global model [$\Phi(\text{brander}*\text{sex}*\text{time})$ p($\text{brander}*\text{sex}*\text{time}$)] used for testing of c hat and a model with no effects on survival [$\Phi(.)$] are also included.

Model	QAIC _c	Δ QAIC _c	W _i	k	Deviance
Φ (treatment) p(treatment+time)	590.36	0.00	0.10	9	571.99
Φ (treatment+mass) p(treatment+time)	590.65	0.29	0.09	10	570.19
Φ (brander) p(treatment+time)	590.74	0.38	0.08	12	566.09
Φ (treatment+T) p(treatment+time)	591.23	0.88	0.06	10	570.78
Φ (treatment+lnT) p(treatment+time)	591.26	0.90	0.06	10	570.81
Φ (treatment+antime) p(treatment+time)	591.48	1.12	0.06	10	571.03
Φ (brander+T) p(treatment+time)	591.97	1.61	0.04	13	565.21
Φ (brander+mass) p(treatment+time)	592.02	1.66	0.04	13	565.26
Φ (brander+lnT) p(treatment+time)	592.19	1.83	0.04	13	565.44
Φ (brander+sex) p(treatment+time)	592.31	1.95	0.04	13	565.55
Φ (treatment*sex) p(treatment+time)	592.44	2.08	0.04	11	569.89
Φ (treatment*T) p(treatment+time)	592.47	2.11	0.03	11	569.93
Φ (treatment*lnT) p(treatment+time)	592.57	2.21	0.03	11	570.02
Φ (brander+AnTime) p(treatment+time)	592.57	2.21	0.03	13	565.81
Φ (treatment+sex+mass) p(treatment+time)	592.63	2.27	0.03	11	570.08
Φ (treatment*mass) p(treatment+time)	592.70	2.34	0.03	11	570.15
Φ (treatment+lnT+sex) p(treatment+time)	592.81	2.45	0.03	11	570.27
Φ (treatment+T+sex) p(treatment+time)	592.82	2.46	0.03	11	570.27
Φ (treatment+TT) p(treatment+time)	593.30	2.94	0.02	11	570.75
Φ (brander+lnT+mass) p(treatment+time)	593.47	3.11	0.02	14	564.59
Φ (brander+T+sex) p(treatment+time)	593.63	3.27	0.02	14	564.75
Φ (brander+lnT+sex) p(treatment+time)	593.79	3.43	0.02	14	564.92
Φ (.) p(treatment+time)	594.03	3.67	0.02	8	577.73
Φ (brander*sex*time) p(brander*sex*time)	780.25	189.89	0.00	104	516.25

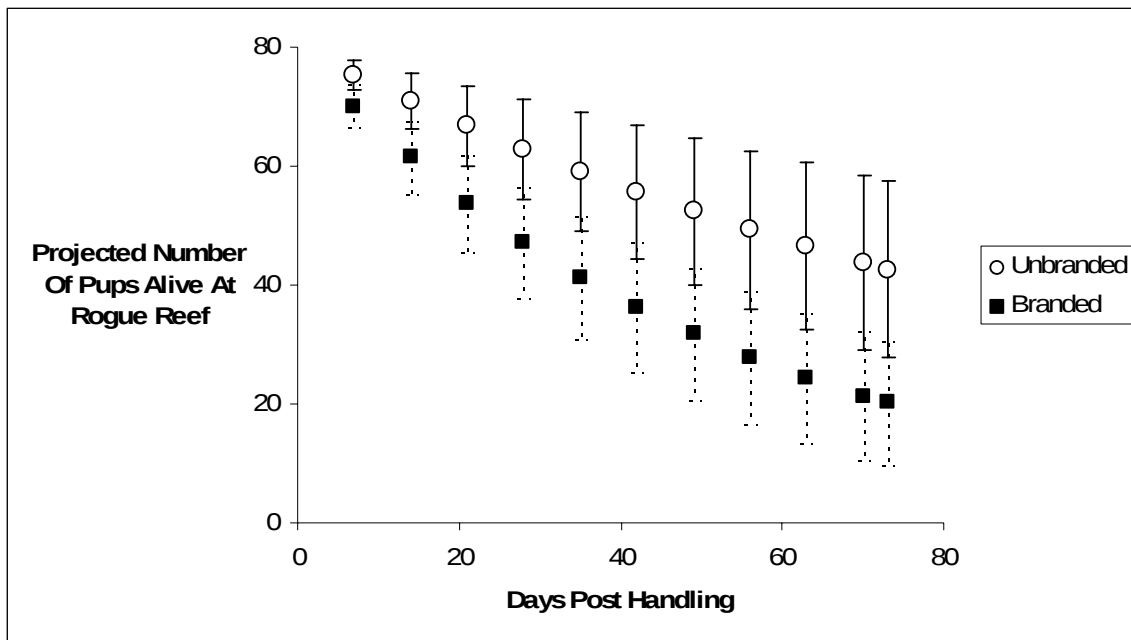


Figure 9: Daily change in projected “apparent” survivorship (apparent survivorship equals 1 minus mortality and emigration) of branded and unbranded pups from the best a priori mark-resight model [$\Phi(\text{treatment}) p(\text{treatment} + \text{time})$]. Solid squares represent branded pups and open circles represent reference unbranded pups. Error bars expressed as 95% confidence intervals.

Table 6: 95% confidence intervals for additive model slope coefficients (β) of competing models to best *a priori* model $\Phi(\text{treatment})$.

Parameter	β	LCL	UCL
Mass	0.14	-0.16	0.45
Sex	-0.23	-0.82	0.37
T	-0.12	-0.50	0.26
lnT	-0.28	-1.31	0.74
AnTime	-0.04	-0.30	0.23

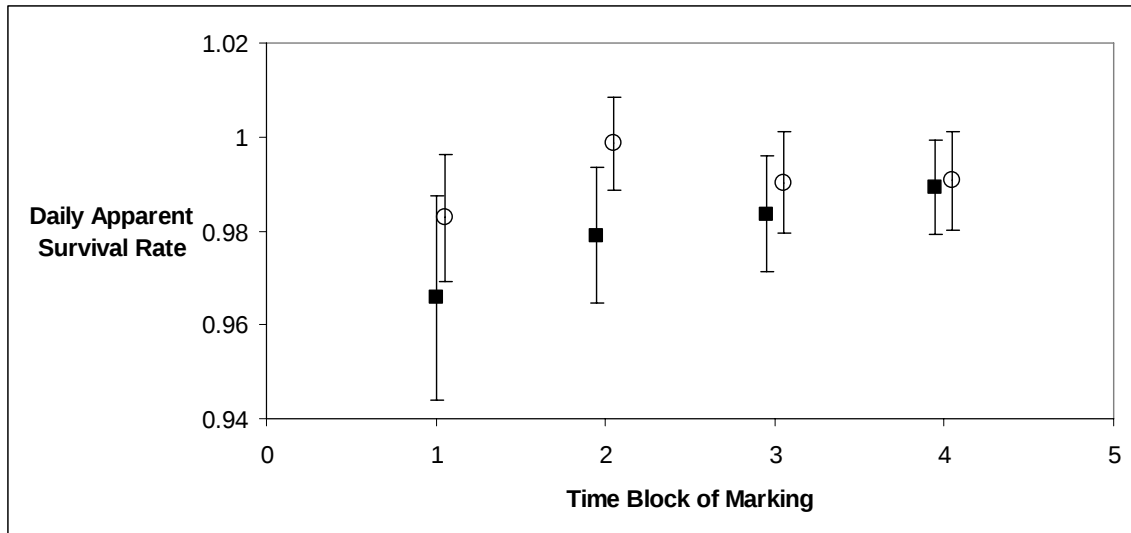


Figure 10: Daily apparent survival rates of pups marked by each time block of 40 pups from the beginning to the end of the day. The time blocks are separated by brander. Closed squares are projected mean daily apparent survival rates of branded pups. Open circles represent the mean for unbranded pups handled during the same time block.

We conducted an *a posteriori* analysis to see if the sequence of handling was associated with the apparent survival rates of pups. To do this, we added an individual covariate to our model indicating how many hours our marking party was on the reef after marking the pup. This new model, $\Phi(\text{treatment} + \text{post marking time})$, had 3 times more evidence than our best *a priori* model of $\Phi(\text{treatment})$ (Table 7). Furthermore, the negative coefficient of post marking time ($\beta = -0.3218$, 95% CI -0.6359 to -0.0077) indicated apparent survival was negatively associated with time post-marking (Figure 11).

Table 7: Model selection results for *a posteriori* investigations. Models marked with an ^a) were *a posteriori* models used to examine effects of time sequence of pup branding. Factors added to *a posteriori* models were post marking time (postmarkingtime) and a log converted post marking time (Lnpostmarkingtime). Small sample-size adjusted quasi-likelihood Akaike's Information Criteria (QAIC_c c-hat = 1.709), the difference in QAIC_c between each candidate model and the model with the lowest QAIC_c value (Δ QAIC_c), number of model parameters (k), and model deviance (Deviance) are included for each model.

Model	QAIC _c	Δ QAIC _c	W _i	k	Deviance
^a Φ (treatment+postmarkingtime) p(treatment+time)	588.24	0.00	0.16	10	567.79
^a Φ (treatment+Lnpostmarkingtime) p(treatment+time)	589.70	1.45	0.08	10	569.24
^a Φ (treatment*postmarkingtime) p(treatment+time)	589.82	1.57	0.07	11	567.27
Φ (treatment) p(treatment+time)	590.36	2.12	0.06	9	571.99
Φ (.) p(treatment+time)	594.03	5.78	0.01	8	577.73

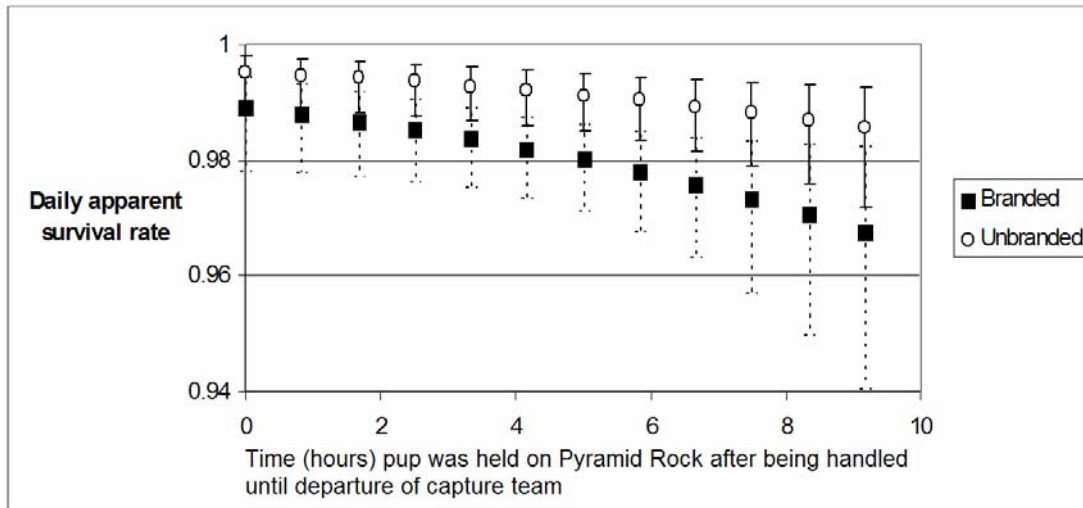


Figure 11: Daily apparent survival rate of branded and unbranded pups compared to time of marking till the research team concluded marking. Unbranded pups are indicated with open circles. Branded pups are indicated with solid squares. Error bars are expressed as 95% confidence intervals.

To determine the magnitude of effect of branding, model averaging was performed on all *a priori* models. The apparent survivorship of unbranded pups to

day 73 was estimated as 0.46 (95% CI 0.15 – 0.77). For branded pups the apparent survivorship was 0.23 (95% CI 0.01 – 0.45).

Discussion:

In our study, branding and tagging Steller sea lion pups from Rogue Reef in 2005 affected apparent survival to a greater extent than tagging alone. The scope of inference of this study is limited by small sample size ($n=160$), 1 sample site, and only 1 year of study. In terms of disease, 2005 was an abnormal year with high prevalence of lesions and lice; the high prevalence of disease may have caused pups to have greater susceptibility to infection than normal. We are unsure if our results were caused by 2005 being an abnormal year or if our findings are consistent for Rogue Reef. Despite these shortcomings and caveats, we believe our results are important for the general evaluation of the effects of hot-iron branding on Steller sea lions.

Apparent survival includes both mortality and emigration, whereas true survival is only affected by mortality. Due to radio transmitter loss, and therefore an inability to determine emigration rates, this study is inconclusive for detecting a difference in true survival. To assess this study as a difference in true survival, we have to assume that branded and unbranded pups emigrated from the reef at equal rates. Analysis of radio transmitter data for one week post marking provided no evidence to suggest that emigration was different for branded versus unbranded pups. Yet, the movement patterns one week post branding cannot be assumed to stay constant throughout an 11-week study. Therefore, what we can conclude is that branding either affected emigration, mortality, or both to a greater degree than tagging alone for Steller sea lion pups at Rogue Reef, Oregon in 2005. This is the first study to conclude that branding causes a negative impact on the apparent survival of pinnipeds as compared to reference unbranded animals. Presently we are unsure if the difference between this study and past studies is due to biological differences in animals marked, or if the difference is an artifact of differences in study design.

This study used a more rigorous study design than past studies to ensure proper statistical evaluation of apparent survival of branded pups and unbranded pups. Merrick *et al.* (1996) reported that even ratios of branded and tagged and tagged only pups were observed post branding. However, they did not report the detection probabilities of the two treatments; if these varied then their results would be biased. Auriolles *et al.* (1988) compared survival of branded and unbranded pup marked in a different years without accounting for natural annual variations in survival. McMahon *et al.* (2006) also lacked selection of an appropriate control in their study of affects of hot-iron branding on southern elephant survival on Macquarie Island. They marked branded and reference pups in the same year, but not in the same area. Spatial differences in pup survival around Macquarie Island may have influenced their conclusion that branded pups had significantly higher first year survival than unbranded pups. On the other hand, weaned pups at middle beach (where reference pups were tagged) were heavier on average [7.8 kg (male) and 6.8 kg (female)] than weaned pups at the isthmus (Engelhard *et al.* 2001) where pups were branded. McMahon *et al.* (2003) found that body mass at weaning was positively correlated with first year pup survival. So, despite deficiencies in study design, conclusions from the McMahon *et al.* (2006) study may be correct; discrepancy with our study may be due to biological reasons.

Susceptibility of pups to infection is one likely biological reason for our results. Past branding evaluation studies have been performed on rookeries made up of sand (Auriolles *et al.* 1988), gravel (Merrick *et al.* 1996), or shingle beaches (McMahon *et al.* 2006). These beach types allow urine and fecal matter to seep into the ground. This contrasts greatly to Pyramid Rock in which the whole surface is impermeable and, due to the high density of animals, is covered in feces. This difference in habitat can cause different rates of disease transmission. Summers and Witthames (1978) suggested seals tagged on ice have lower risks of infection than seals tagged on less sterile land sites. Rogue Reef was likely an even less sterile land site than sites of previous branding studies. Therefore, it is a probable hypothesis that differences in branding effects seen in this study compared to past studies are caused by differences in susceptibility of pups to infections.

Analyzing differences in survival was not our only objective; we were also interested in what factors influenced apparent survival rates of pups. Using an information criteria approach (Burnham and Anderson 2001; Burnham and Anderson 2002) we were able to test many hypotheses concerning what affects apparent survival of pups. Past studies have reported that mass (McMahon *et al.* 2000; Harding *et al.* 2005) and sex (Hall *et al.* 2001; Beauplet *et al.* 2005) are important factors in pup survival. In our analysis neither sex nor mass were important factors for apparent survival. However, the inclusion of mortality and emigration in estimates of apparent survival may have masked effects of mass or sex on survival. Testing for potential effects of anesthesia was important since the technique has been evaluated for immediate effects (Heath *et al.* 1997), but not for longer term effects. We found no evidence that time under anesthesia affected apparent survival of Steller sea lion pups.

During analysis of our *a priori* model set we discovered what appeared to be a time trend affecting apparent survival rates for each bander. In an *a posteriori* analysis we added an individual covariate for the amount of time post-marking a pup was on the reef. This model showed a negative correlation between how long post-marking a pup was on Pyramid Rock before the research team concluded marking and the apparent survival rate of the pup (Figure 11). We examined a couple of hypotheses to explain this finding. One hypothesis for this trend is that pups marked in the beginning of the day were anesthetized into a deeper sleep than pups marked later in the day. To examine this hypothesis we modeled anesthesia effect as administration of anesthesia until full recovery. There was a trend through the day that pups handled earlier in the day had longer recovery times. However, when models were rerun with anesthesia effect instead of anesthetic time, the anesthesia effect was still not a strongly competing model (ΔQAIC_c 4.22 from $\Phi(\text{treatment})$). Our second hypothesis was that pups marked in the beginning of the day were displaced off the rookery by our work and emigrated sooner than their cohorts. We used logistic regression to examine whether pups handled early in the day were more likely to leave the rookery than pups handled later in the day. Specifically, we modeled the probability of radio-marked pups being detected in the first week of the

study as a function of post-handling time (time since first animal released) and treatment (brand, no brand). Two of the 40 branded pups, and 4 of the 40 non-branded pups, were not detected during the first week. While the odds of detection decreased by a factor of 0.825 for each one hour increase in time we spent in the rookery, the 95% confidence interval for the multiplicative odds factor contained one (0.586 to 1.163). Overall, there was no evidence that first week detection probabilities varied with treatment or post-handling time (drop-in-deviance test between additive and null models, Chi-square=2.03, df=2, P=0.36). Although we are uncertain of the mechanism causing reduced survival of pups marked in the beginning of the work day, we recognize that when marking at Rogue Reef we should take into consideration how long we will work on the reef and how it may affect the pups we handle.

Management Implications

Hot-iron branding is currently the best available tool for marking in long-term studies of Steller sea lion vital rates. Yet, this study shows that researchers should not assume that branding does not affect Steller sea lion pup mortality or emigration and must incorporate this knowledge into future study designs and analyses. Studies of vital rates, such as age-specific survival, that require a sample size of animals at a certain age may require more pups to be marked than originally assumed. When analyzing branding data of Steller sea lion at Rogue Reef researchers must make adjustments for potentially increased mortality and/or emigration of branded pups. Furthermore, if adjustments of increased mortality are not made, estimation of survival rates of Steller sea lions from Rogue Reef has a high probability of bias. This bias can lead to a misleading result of lower pup survival that could misguide management decisions (Murray and Fuller 2005). Consequentially, long-term research is needed in the future at Rogue Reef to find the full affect of branding on Steller sea lion pups. Additionally, research is needed for all branding studies to determine if this study was an anomaly or if hot-iron branding reduces apparent survival of pups in other places and species.

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CHAPTER 4: RESEARCH RECOMMENDATIONS

During the last four years I have participated in Steller sea lion studies from northern California through Alaska. During this time I have made some observations that I hope will improve scientific studies of Steller sea lions of the eastern stock. When I began my studies to document vital rates of Steller sea lions from Oregon and northern California rookeries, I was impeded by lack of knowledge of where juvenile Steller sea lions disperse. Consequentially, study designs were not organized as efficiently as possible to maximize band resights. Increased knowledge from this study should help managers design more efficient study designs to estimate juvenile Steller sea lion survival.

Chapter 2 documented dispersal ranges of juvenile Steller sea lions and terrestrial sites use on the coast by sex, age, and season. This chapter increased the knowledge of an endangered species in a poorly studied portion of its distribution, and these data can be used to increase the efficacy of future sea lion studies and to address critical habitat.

Given the broad range of dispersal of juveniles observed in this study, resight probabilities of juveniles would be maximized by visiting all haulout and rookery sites at low intensity instead of visiting a few haulouts and rookeries with high intensity. Concentrating resight effort in summer makes sense both in logistical as well as statistical terms. Summer climatic and ocean conditions allow surveys of haulout sites not accessible during the winter. Furthermore, an important assumption of mark-resight models is that zero mortality of marked animals occurs during the period of resight effort (O'Brien *et al.* 2005). Therefore, reducing the resight effort period to the summer months will reduce the probability of biasing estimates of survival by reducing the chance of violating the assumption of zero mortality compared to year-round surveys.

In the 1993 Steller sea lion recovery plan, Three Arch Rock, Orford Reef, Rogue Reef, St. George Reef, and Sugar Loaf Island (Cape Mendocino) were recognized as major haulouts and rookeries in Oregon and northern California (NMFS 1992). The 2006 draft states that the critical habitat for Steller sea lions in

Oregon and northern California is Rogue Reef and Orford Reef. An interesting omission in both recovery plans was the site of Sea Lion Caves (SLC). As observed in Chapter 2, SLC acts as an important pup and juvenile rearing site on the Oregon coast. During the month of January, 90% of pups observed on the coast were counted at SLC. Given this high figure, the impact of the loss of SLC on Steller sea lion population health in Oregon and northern California could be quite significant. Pups would no longer have the protection from climatic and ocean conditions afforded by SLC. Displaced females and juveniles would no longer have “local knowledge” of forage and shelter resources and may have decreased fitness or survival as a result. SLC deserves listing as critical habitat for the eastern stock of Steller sea lions. St. George Reef and Sugarloaf Island are breeding rookeries that also should be listed as critical habitat. Results from this study suggest that critical habitat designations should be revised for northern California and Oregon.

Without the use of hot-iron branding, the dispersal patterns of juvenile Steller sea lions in Chapter 2 could not have been examined. Branding also has allowed researchers to evaluate the vital rates of sea lion populations that will aid in conservation and protection measures (Pendleton *et al.* 2006). Yet, Chapter 3 shows that the benefits of hot-iron branding come with a risk of reduced survival or premature emigration from the rookery. Attempts have been made in the past to replace hot-iron branding with flipper tags or freeze-branding (Troy *et al.* 1997; Harkonen *et al.* 1999; McMahon *et al.* 2006). These alternative techniques have proved unsatisfactory for studies of pinnipeds (Troy *et al.* 1997; Merrick *et al.* 1996; Daoust *et al.* 2006). Other alternatives to branding need to be developed if branding is deemed inappropriate for sites like Rogue Reef. Horning and Hill (2005) have developed an implant tag called a “life history transmitter” that has the potential to document movements and survival of sea lions for 7 years. These tags have potential but currently have only been applied in sterile environments (Horning and Hill 2005). Researchers must still determine if implant tags would put study animals at risk of infection in very non-sterile study sites such as Rogue Reef.

Many studies over the last century have used hot-iron branding to mark pinnipeds. Some of these studies have never been published and others have a scope

with a narrow goal. Scientists should recognize that once an animal is permanently marked it can provide a study subject for a myriad of studies. Given the potential risks of branding of pup survival, managers should plan to make use of every opportunity to use these uniquely marked animals for other studies besides their main goal.

The goal of this thesis project was to increase knowledge of Steller sea lions to increase the potential of determining and resolving the cause for the drastic population declines in the latter half of the 20th century. Understanding of the increasing eastern stock of Steller sea lions may help scientists determine why the western stock has declined. Findings in Chapter 3 on the impacts of branding should be considered in future pinniped studies. The technique needs to be evaluated for each species and at each site it is used. Hopefully, through results of this project and other projects funded under the Steller sea lion initiative (Dalton 2005) the cause of the Steller sea lion decline will be resolved.

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APPENDICES

Appendix A: Abundance patterns of pinnipeds at Oregon and northern California haulouts and rookeries from 2002 to 2005.

Cascade Head, Oregon

Month	Adult male			Adult female			Juvenile			Pup		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	1	0	0.7	32	9	18.3	16	5	10.3	3	0	1.3
Feb	1	0	0.5	42	2	26.5	24	6	12.8	1	1	1.0
Mar	1	0	0.5	41	16	28.5	9	2	5.5	0	0	0.0
Apr	4	0	2.0	10	3	6.5	4	2	3.0	2	0	1.0
May	10	8	9.0	8	0	4.3	5	0	3.0	2	0	0.7
Jun												
Jul												
Aug	233	8	113.3	105	0	30.0	505	21	155.8	8	0	2.5
Sep	5	5	5.0	111	95	103.0	134	132	133.0	15	6	10.5
Oct	1	0	0.5	106	36	71.0	74	47	60.5	50	24	37.0
Nov	0	0	0.0	6	6	6.0	5	5	5.0	3	3	3.0
Dec	1	0	0.2	99	8	51.0	71	19	38.8	30	8	19.0

Castle Rock, California

Month	Adult male			Adult female			Juvenile			Pup		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	1	0	0.5	37	16	26.5	21	18	19.5	5	5	5.0
Feb	0	0	0.0	13	13	13.0	5	5	5.0	3	3	3.0
Mar	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Apr	3	3	3.0	14	14	14.0	13	13	13.0	8	8	8.0
May	10	1	5.5	9	4	6.5	5	2	3.5	4	0	2.0
Jun	55	28	41.5	15	0	7.5	27	3	15.0	0	0	0.0
Jul												
Aug	1	1	1.0	9	0	4.5	7	0	3.5	1	0	0.5
Sep	3	0	1.5	7	0	3.5	3	0	1.5	1	0	0.5
Oct	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Nov	0	0	0.0	13	11	12.0	23	14	18.5	6	5	5.5
Dec	0	0	0.0	25	17	21.0	50	28	39.0	25	7	16.0

Klamath, California

Month	Adult male			Adult female			Juvenile			Pup		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan												
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep	0	0	0	29	29	29	18	18	18	13	13	13
Oct	0	0	0	1	1	1	1	1	1	8	8	8
Nov	0	0	0	26	26	26	6	6	6	29	29	29
Dec	0	0	0	30	30	30	26	26	26	24	24	24

Patrick's Point, California

Month	Adult male			Adult female			Juvenile			Pup		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	1	0	0.5	14	14	14.0	10	3	6.5	5	5	5.0
Feb	1	1	1.0	1	1	1.0	1	1	1.0	1	1	1.0
Mar												
Apr	2	0	1.0	13	0	6.5	22	1	11.5	5	0	2.5
May	12	5	8.5	51	32	41.5	45	20	32.5	11	0	5.5
Jun	21	17	19.0	44	6	25.0	97	67	82.0	0	0	0.0
Jul	3	2	2.5	10	8	9.0	21	20	20.5	0	0	0.0
Aug	4	1	2.5	11	0	5.5	5	0	2.5	4	0	2.0
Sep	0	0	0.0	23	5	12.0	18	5	13.0	7	1	3.3
Oct	0	0	0.0	5	5	5.0	2	2	2.0	8	8	8.0
Nov	0	0	0.0	26	0	12.3	21	4	11.7	13	0	6.3
Dec	2	0	0.7	44	0	20.0	22	0	10.7	10	0	5.3

Rogue Reef, Oregon

Month	Adult male			Adult female			Juvenile			Pup		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan												
Feb												
Mar	0	0	0.0	72	72	72.0	44	44	44.0	0	0	0.0
Apr	81	3	26.2	138	0	55.2	118	0	34.2	96	0	51.7
May	105	18	69.5	219	21	87.9	157	29	95.0	69	0	24.6
Jun	100	58	84.2	736	0	405.8	174	26	90.8	636	16	305.4
Jul	85	0	61.6	589	0	338.7	212	0	118.7	662	314	494.3
Aug	47	5	20.0	244	90	188.6	174	25	94.4	505	230	371.1
Sep	8	6	7.0	239	135	187.0	89	65	77.0	298	114	206.0
Oct	1	0	0.4	203	6	120.4	125	0	65.8	248	11	131.6
Nov	0	0	0.0	4	4	4.0	0	0	0.0	6	6	6.0
Dec												

Sea Lion Caves, Oregon

Month	Adult male			Adult female			Juvenile			Pup		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	2	0	0.3	249	54	127.1	205	24	116.9	222	0	83.9
Feb	1	0	0.1	457	90	206.5	401	72	185.4	134	0	41.0
Mar	0	0	0.0	204	68	108.7	149	43	83.2	111	0	82.0
Apr	11	0	3.1	368	69	193.7	272	52	152.5	161	0	48.8
May	36	2	20.7	253	1	109.5	291	7	170.1	97	0	11.7
Jun	57	29	40.0	197	76	127.6	356	174	266.0	33	0	6.1
Jul	28	18	23.0	20	6	13.0	106	90	98.0	0	0	0.0
Aug	58	0	29.9	116	3	51.1	262	50	158.6	0	0	0.0
Sep	1	0	0.3	12	0	5.5	100	2	39.8	1	0	0.3
Oct	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Nov	1	0	0.3	49	6	33.5	99	2	49.3	35	4	13.3
Dec	1	0	0.1	312	82	154.3	180	20	89.7	141	62	112.2

Sea Lion Gulch, California

Month	Adult male			Adult female			Juvenile			Pup		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	1	1	1.0	33	33	33.0	33	33	33.0	7	7	7.0
Feb	0	0	0.0	33	33	33.0	37	37	37.0	23	23	23.0
Mar												
Apr	5	0	2.5	137	2	69.5	80	6	43.0	34	3	18.5
May	3	3	3.0	57	57	57.0	55	55	55.0	21	21	21.0
Jun	10	10	10.0	51	25	38.0	103	101	102.0	0	0	0.0
Jul	5	5	5.0	0	0	0.0	3	3	3.0	0	0	0.0
Aug	1	1	1.0	13	5	9.0	47	10	28.5	1	0	0.5
Sep	1	0	0.3	24	0	8.0	23	0	7.7	0	0	0.0
Oct	6	2	4.0	83	40	61.5	59	51	55.0	30	5	17.5
Nov	12	0	7.3	68	33	52.0	83	43	66.3	44	24	30.5
Dec	2	0	0.7	11	0	3.7	13	0	4.3	12	0	4.7

St. George Reef, California

Month	Adult male			Adult female			Juvenile			Pup		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan												
Feb												
Mar												
Apr	11	11	11.0	9	9	9.0	8	8	8.0	0	0	0.0
May	29	0	13.7	8	0	1.1	6	0	1.6	1	0	0.4
Jun	43	0	22.9	215	0	90.7	19	0	9.4	237	12	121.7
Jul	33	0	22.5	143	4	89.3	51	0	22.5	240	176	202.5
Aug	6	0	3.7	89	1	51.7	15	0	6.0	198	4	92.0
Sep	0	0	0.0	21	0	13.7	7	0	3.7	89	0	39.0
Oct	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Nov												
Dec												

Three Arch Rock, Oregon

Month	Adult male			Adult female			Juvenile			Pup		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Feb	0	0	0.0	15	15	15.0	16	16	16.0	0	0	0.0
Mar	0	0	0.0	9	0	4.5	8	0	4.0	0	0	0.0
Apr	2	0	0.7	23	0	10.7	27	0	10.3	5	0	2.5
May	4	0	2.0	8	0	4.0	32	0	16.0	4	0	2.0
Jun	7	2	4.0	24	6	16.0	58	17	35.7	0	0	0.0
Jul	2	2	2.0	14	14	14.0	39	39	39.0	2	2	2.0
Aug	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Sep	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Oct	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Nov	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Dec	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0

Table A2: Total counts of all pinnipeds observed at haulouts and rookeries in Oregon and northern California during coastal surveys from 2002 to 2005.

Cape Arago, Oregon

Month	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	597	8	220.0	185	0	90.0	19	9	13.3	20	0	11.7
Feb	873	41	411.8	164	31	108.8	30	11	21.3	38	0	10.4
Mar	200	7	92.6	175	0	95.2	23	0	8.2	8	0	2.8
Apr	750	30	330.8	600	10	208.7	30	5	13.0	35	0	8.4
May	3073	510	1523.1	970	0	322.4	54	0	21.5	100	18	42.0
Jun	147	127	137.0	550	435	492.5	5	5	5.0	200	73	142.6
Jul	84	84	84.0	550	550	550.0	3	3	3.0	241	241	241.0
Aug	2000	725	1247.3	245	0	134.7	5	0	2.3	462	49	248.6
Sep	2000	790	1365.0	335	105	232.5	6	1	3.8	311	68	152.5
Oct	520	115	355.4	300	2	148.0	7	2	5.0	740	217	404.5
Nov	456	135	256.0	222	0	122.0	20	2	12.6	280	87	175.3
Dec	2024	40	579.4	36	0	19.4	7	1	3.6	76	1	30.2

Cape Mendocino, California

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan												
Feb												
Mar	493	493	493.0	24	24	24.0	1	1	1.0	26	26	26.0
Apr	735	735	735.0	0	0	0.0	9	9	9.0	81	81	81.0
May												
Jun												
Jul										32	32	32.0
Aug	923	923	923.0	19	19	19.0	0	0	0.0	78	78	78.0
Sep										83	17	50.0
Oct	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Nov	2000	2000	2000.0	0	0	0.0	0	0	0.0	1	1	1.0
Dec										12	12	12.0

Cascade Head, Oregon

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	528	40	207.3	6	0	2.0	0	0	0.0	49	15	30.7
Feb	497	63	325.5	0	0	0.0	0	0	0.0	61	9	39.0
Mar	503	186	344.5	0	0	0.0	0	0	0.0	51	18	34.5
Apr	363	165	264.0	0	0	0.0	0	0	0.0	14	11	12.5
May	1700	430	1152.7	0	0	0.0	0	0	0.0	25	10	18.7
Jun												
Jul												
Aug	2432	273	1002.8	29	0	13.0	0	0	0.0	625	111	267.4
Sep	2532	494	1513.0	0	0	0.0	0	0	0.0	261	170	228.0
Oct	167	35	101.0	0	0	0.0	0	0	0.0	455	108	229.3
Nov	0	0	0.0	0	0	0.0	0	0	0.0	364	3	174.2
Dec	605	433	519.0	0	0	0.0	0	0	0.0	192	100	153.9

Castle Rock, California

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	400	231	315.5	79	0	39.5	2	0	1.0	212	57	134.5
Feb	71	71	71.0	0	0	0.0	1	1	1.0	47	47	47.0
Mar	75	75	75.0	180	180	180.0	0	0	0.0	130	45	87.5
Apr	380	135	257.5	35	30	32.5	4	0	2.0	287	46	160.8
May	400	350	375.0	35	34	34.5	11	5	8.0	29	16	22.5
Jun	288	99	193.5	125	40	82.5	4	2	3.0	76	59	67.3
Jul										100	40	70.0
Aug	310	67	188.5	113	76	94.5	2	0	1.0	27	1	14.0
Sep	900	10	455.0	125	35	80.0	0	0	0.0	130	0	38.5
Oct	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Nov	431	45	238.0	0	0	0.0	0	0	0.0	165	27	77.0
Dec	155	110	132.5	12	0	6.0	0	0	0.0	282	58	157.0

Crescent City, California

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	11	11	11.0	56	56	56.0	0	0	0.0	0	0	0.0
Feb	24	24	24.0	40	40	40.0	0	0	0.0	0	0	0.0
Mar	40	34	37.7	57	21	34.7	0	0	0.0	0	0	0.0
Apr	66	23	48.3	19	0	12.0	0	0	0.0	0	0	0.0
May	60	29	44.5	32	11	21.5	0	0	0.0	0	0	0.0
Jun	7	0	2.3	52	42	48.0	0	0	0.0	0	0	0.0
Jul	16	16	16.0	42	42	42.0	0	0	0.0	0	0	0.0
Aug	26	26	26.0	23	23	23.0	0	0	0.0	0	0	0.0
Sep	19	15	17.0	13	0	6.5	0	0	0.0	0	0	0.0
Oct										0	0	0.0
Nov	48	3	31.3	110	13	49.0	0	0	0.0	0	0	0.0
Dec	22	8	15.0	57	0	28.5	0	0	0.0	0	0	0.0

Klamath, California

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan												
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep	156	156	156	0	0	0.0	0	0	0.0	67	67	67.0
Oct	13	13	13	0	0	0.0	0	0	0.0	10	10	10.0
Nov	63	63	63	0	0	0.0	0	0	0.0	65	65	65.0
Dec	112	112	112	0	0	0.0	0	0	0.0	94	94	94.0

Newport, Oregon

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	527	12	166.5	0	0	0.0	0	0	0.0	0	0	0.0
Feb	66	36	55.3	0	0	0.0	0	0	0.0	0	0	0.0
Mar	120	2	34.3	0	0	0.0	0	0	0.0	0	0	0.0
Apr	26	11	20.3	0	0	0.0	0	0	0.0	0	0	0.0
May	23	9	16.0	0	0	0.0	0	0	0.0	0	0	0.0
Jun	18	0	8.5	0	0	0.0	0	0	0.0	0	0	0.0
Jul	1	0	0.5	0	0	0.0	0	0	0.0	0	0	0.0
Aug	204	124	164.0	0	0	0.0	0	0	0.0	0	0	0.0
Sep	189	150	169.5	0	0	0.0	0	0	0.0	0	0	0.0
Oct	186	27	112.1	0	0	0.0	0	0	0.0	0	0	0.0
Nov	166	45	88.3	0	0	0.0	0	0	0.0	0	0	0.0
Dec	174	16	95.0	0	0	0.0	0	0	0.0	0	0	0.0

Patrick's Point, California

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	135	19	77.0	35	0	17.5	0	0	0.0	33	17	25.0
Feb	15	15	15.0	0	0	0.0	0	0	0.0	4	4	4.0
Mar												
Apr	164	72	118.0	0	0	0.0	0	0	0.0	42	4	23.0
May	340	205	272.5	116	94	105.0	0	0	0.0	103	92	97.5
Jun	327	5	166.0	285	60	172.5	0	0	0.0	151	122	136.5
Jul	61	0	30.5	27	27	27.0	0	0	0.0	71	32	51.5
Aug	700	15	357.5	0	0	0.0	0	0	0.0	23	4	13.5
Sep	301	30	126.7	65	0	21.7	0	0	0.0	53	23	36.3
Oct	36	36	36.0	0	0	0.0	0	0	0.0	15	15	15.0
Nov	78	2	33.7	68	0	40.3	0	0	0.0	73	27	42.7
Dec	56	0	22.3	25	0	8.3	0	0	0.0	88	0	42.3

Rogue Reef, Oregon

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan												
Feb										127	1	68.3
Mar	0	0	0.0	0	0	0	0	0	0	323	17	172.1
Apr	72	0	8.9	16	0	1	0	0	0	514	14	293.1
May	106	0	13.0	1	0	0	0	0	0	763	234	410.2
Jun	21	0	2.9	2	0	0	0	0	0	1747	938	1287.9
Jul	1	0	0.2	2	0	0	0	0	0	1786	1021	1392.9
Aug	39	0	13.0	1	0	0	0	0	0	1347	463	880.0
Sep	40	39	39.5	0	0	0	0	0	0	774	13	276.0
Oct	179	2	90.2	0	0	0	0	0	0	724	6	221.7
Nov	5	5	5.0	0	0	0	0	0	0	83	10	54.5
Dec												

Sea Lion Caves, Oregon

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	87	0	20.2	0	0	0	0	0	0	605	190	313.1
Feb	105	1	26.3	0	0	0	0	0	0	841	249	452.4
Mar	4	0	0.8	0	0	0	0	0	0	370	216	276.4
Apr	5	0	0.7	0	0	0	0	0	0	601	215	399.3
May	14	0	4.5	0	0	0	0	0	0	849	270	456.1
Jun	31	0	8.6	0	0	0	0	0	0	615	291	456.1
Jul	1	0	0.5	0	0	0	0	0	0	184	151	167.5
Aug	51	0	14.3	0	0	0	0	0	0	387	53	252.3
Sep	0	0	0.0	0	0	0	0	0	0	110	2	45.5
Oct	2	0	0.8	0	0	0	0	0	0	1	0	0.3
Nov	119	0	30.8	0	0	0	0	0	0	194	12	99.0
Dec	190	0	46.7	0	0	0	0	0	0	492	210	322.0

Sea Lion Gulch, California

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	2	2	2.0	0	0	0.0	0	0	0.0	92	92	92.0
Feb	0	0	0.0	0	0	0.0	0	0	0.0	126	126	126.0
Mar												
Apr	0	0	0.0	0	0	0.0	0	0	0.0	286	26	156.0
May	10	10	10.0	0	0	0.0	0	0	0.0	151	151	151.0
Jun	22	1	11.5	76	0	38.0	0	0	0.0	161	133	147.0
Jul	0	0	0.0	4	4	4.0	0	0	0.0	11	11	11.0
Aug	46	0	23.0	100	13	56.5	0	0	0.0	63	20	41.5
Sep	2	0	0.7	2	0	0.7	0	0	0.0	48	0	16.0
Oct	0	0	0.0	0	0	0.0	0	0	0.0	240	173	206.5
Nov	5	0	1.5	0	0	0.0	0	0	0.0	242	147	172.5
Dec	2	0	0.7	0	0	0.0	0	0	0.0	110	0	41.7

St. George Reef, California

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan												
Feb												
Mar												
Apr	0	0	0.0	0	0	0.0	0	0	0.0	28	28	28.0
May	30	0	6.0	2	0	0.3	0	0	0.0	45	1	18.4
Jun	3	0	0.9	2	0	0.6	0	0	0.0	553	98	271.6
Jul	0	0	0.0	0	0	0.0	0	0	0.0	525	347	416.8
Aug	2	0	0.7	0	0	0.0	0	0	0.0	335	5	166.7
Sep	4	0	1.7	0	0	0.0	0	0	0.0	115	0	58.7
Oct	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Nov												
Dec												

Three Arch Rock, Oregon

	California sea lion			Harbor seal			Elephant seal			Steller sea lion		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Jan	0	0	0.0	0	0	0.0	0	0	0.0	38	38	38.0
Feb	0	0	0.0	0	0	0.0	0	0	0.0	31	31	31.0
Mar	0	0	0.0	0	0	0.0	0	0	0.0	17	0	8.5
Apr	11	0	3.7	0	0	0.0	0	0	0.0	50	0	23.3
May	8	0	4.0	0	0	0.0	0	0	0.0	48	8	28.0
Jun	0	0	0.0	0	0	0.0	0	0	0.0	99	38	60.7
Jul	0	0	0.0	0	0	0.0	0	0	0.0	58	58	58.0
Aug	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Sep	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Oct	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Nov	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Dec	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0

Appendix B: Changes in maximum distributions of marked Steller sea lions by age and sex

Observed changes in dispersal range by age and sex:

Pup dispersal from the natal rookery occurred in stages. The first stage started around the end of July with dispersal to neighboring offshore rookeries. Beginning in September mother-pup pairs started to show up at haulouts in central Oregon and northern California. By mid October pups were observed from Klamath, California through southern Vancouver Island, British Columbia (Figure A1). During the winter most resights of pups occurred at Sea Lion Caves. The mean maximum dispersal distance for males and females was 285.2 km (SE = 11.4 km). Each year between 9% and 22% of observed individuals were seen >500 km from their natal rookery. Seventy-five percent of observed marked pups were only seen at one site suggesting high site fidelity. During the late spring and early summer, some pups returned with their mothers to their natal rookery. Some of these pups appeared weaned at the rookery while others continue to nurse. Pups that remain with their mothers but do not return to the rookery may also continue to nurse as one-year-olds.

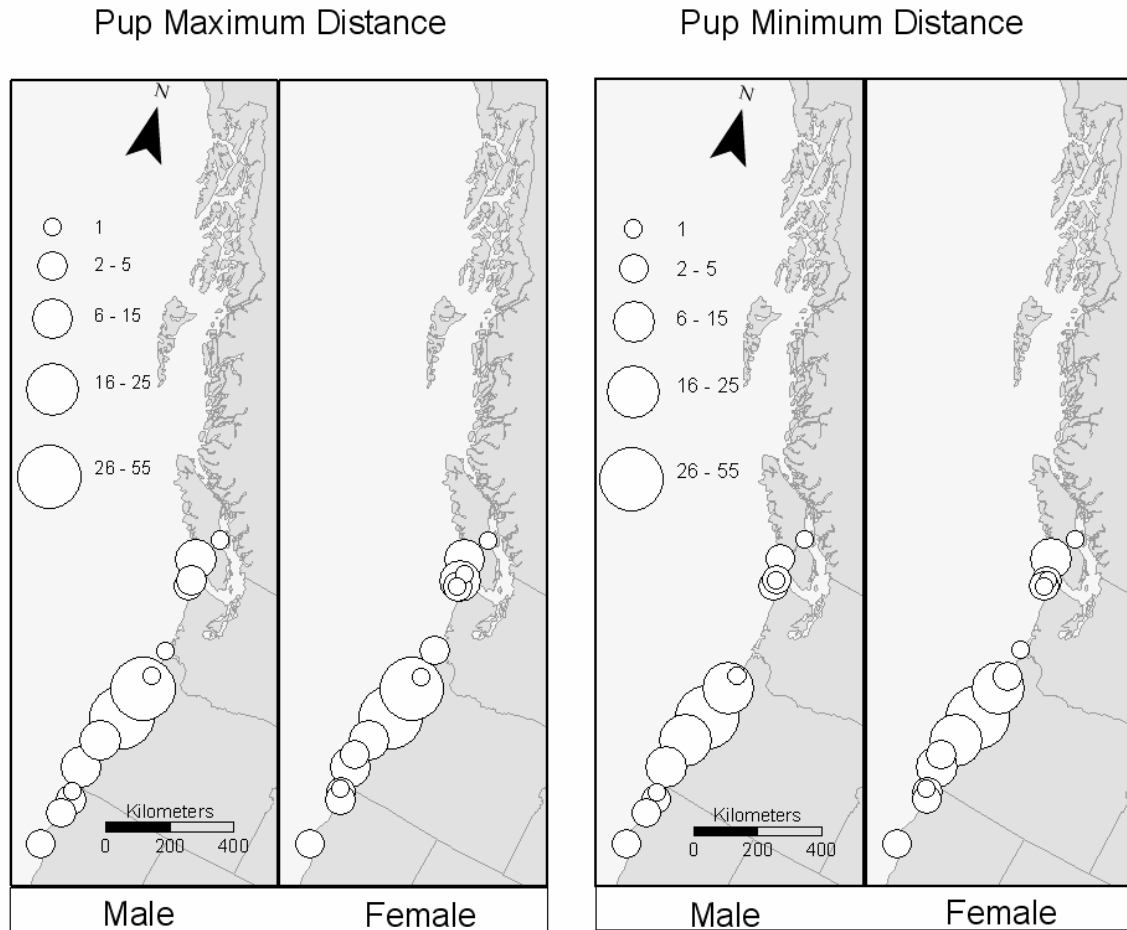


Figure A1: Map of maximum and minimum dispersal distance of individual Steller sea lion pups marked at Rogue Reef, Oregon and St. George Reef, California as observed from resights.

One-year-old individuals had an expanded northward range utilizing more haulouts in British Columbia, Canada and Alaska as compared to pups. Males and females had similar mean maximum dispersal distances (415 km (SE = 25.8), 423 km (SE = 42.4), respectively), although different patterns in site use and dispersal distances were observed (Figure A2). Many one-year-old females utilized the haulouts at the mouth of the Strait of Juan De Fuca. Males were observed to disperse further into Canada and Alaska. One male individual (228R from Rogue Reef) was observed at Chiswell Island, Alaska. Chiswell Island was calculated as 2,560 km from Rogue Reef, Oregon using the great circle distance method. If 228R stayed within 3 miles of shore on his trip he would have traveled about 2,900 km.

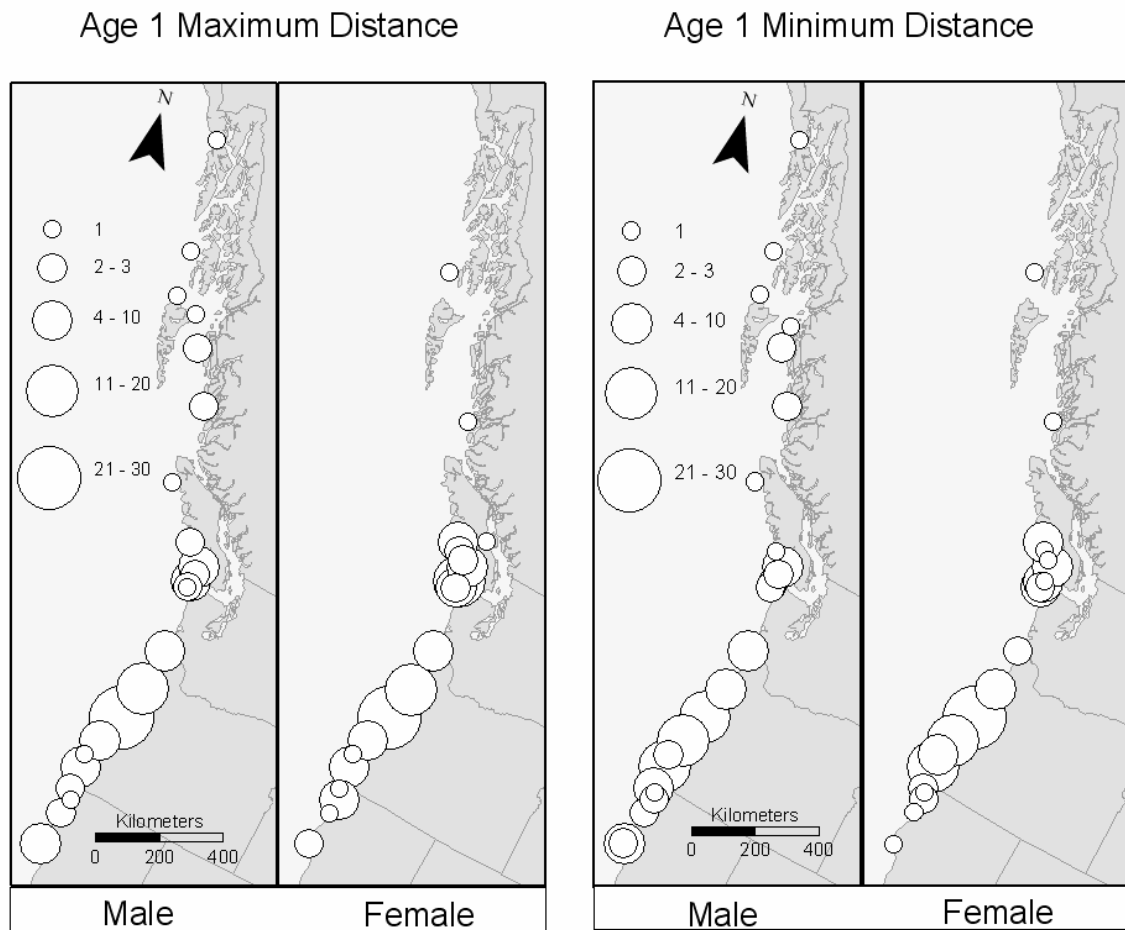


Figure A2: Maps showing mean maximum and minimum dispersal distance of individual yearling Steller sea lions marked at Rogue Reef, Oregon and St. George Reef, California as observed from resights.

As two-year-olds male and females start showing sexually dimorphic dispersal patterns (Figure A3). On average males were seen 110 km further from their natal rookery than females (females $x = 460.5$ km SE = 29.1; males $x = 570.0$ km SE = 54.8). Females were more likely to return to their natal rookeries than males (24.5% and 9.2%, respectively).

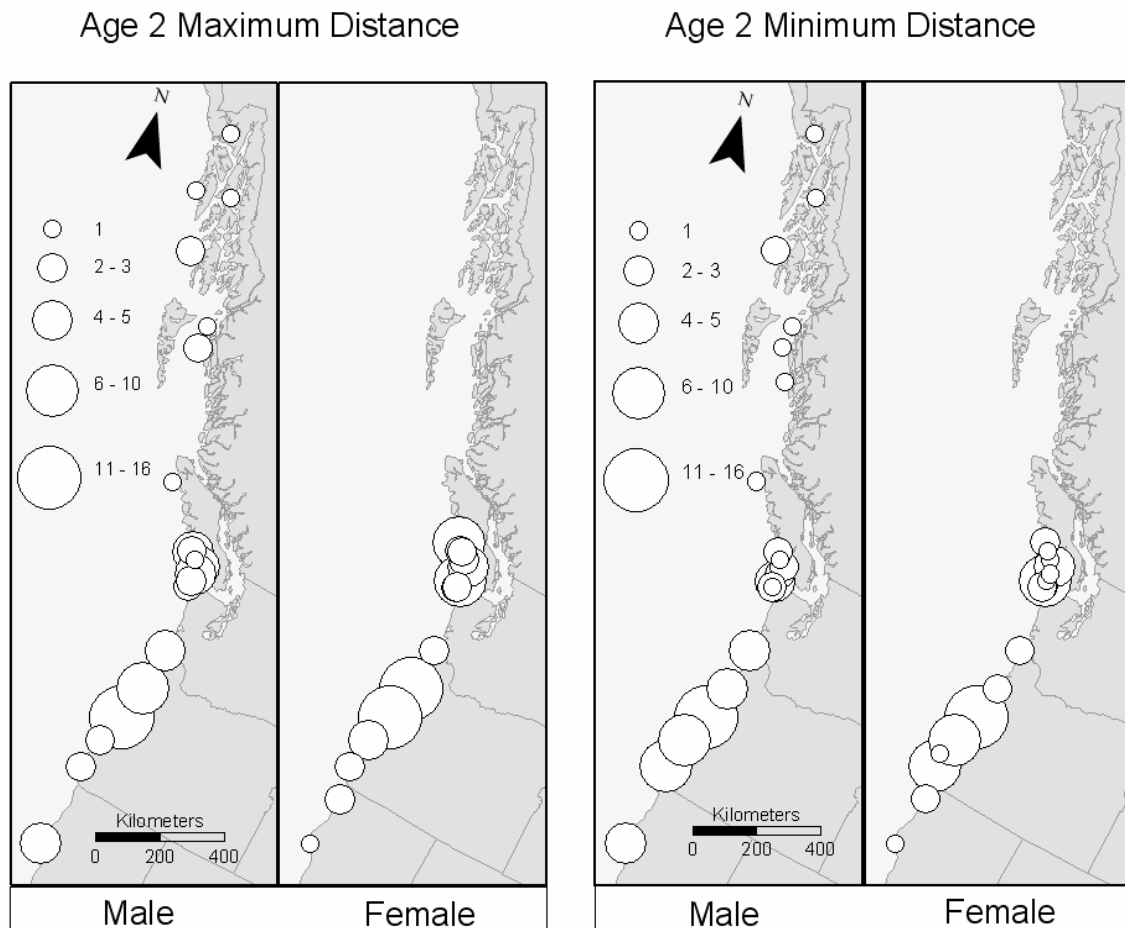


Figure A3: Map showing mean maximum and minimum dispersal distance of individual 2-year-old Steller sea lion marked at Rogue Reef, Oregon and St. George Reef, California as observed from resights.

Three-year-old males had the maximum dispersal range of sea lions in this study (Figure A4). Sexual dimorphism in dispersal range increased as males were sighted on average a maximum distance of 653 km (SE = 82.7 km) from their natal rookery compared to the reduced dispersal range of females of 365 km (SE = 44.1 km). Sexual dimorphism of behavior was also evident in the proportion of females, 46.2%, and males, 25%, observed at their natal rookery.

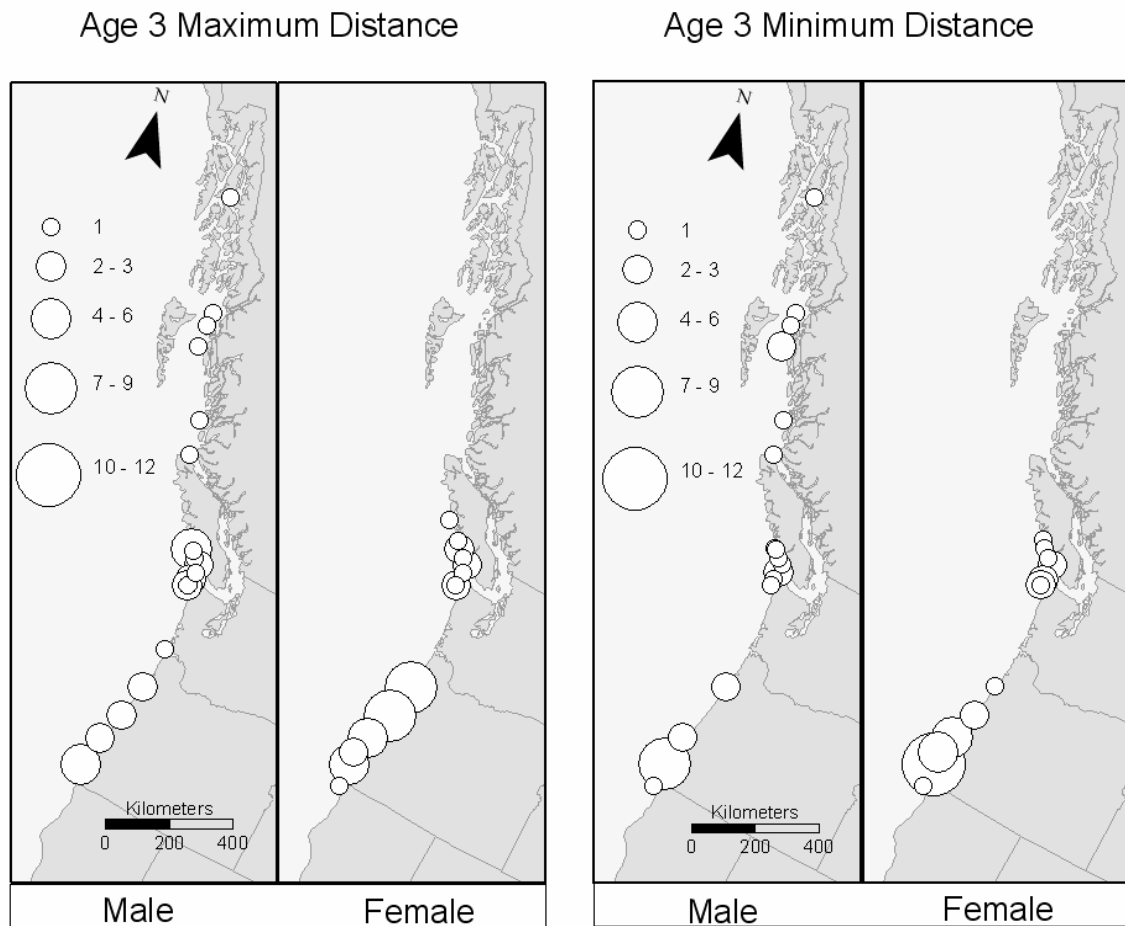


Figure A4: Maximum and minimum dispersal distance of individual 3-year-old Steller sea lions marked at Rogue Reef, Oregon and St. George Reef, California as observed from resights.

During their fourth year the mean maximum dispersal distance for females was very similar to when they were pups (Figure A5). Pups had a mean maximum dispersal distance of 297 km (SE = 17.3 km) which was comparable to 328 km (SE = 78.6 km) for four-year-old females (t-test, $df = 14$, $p = 0.70$). Furthermore, 90% of the four-year-old females observed were seen at their natal rookery during the breeding season. Mean maximal dispersal distance for males was 568.9 km (SE = 120.4 km). Fewer males returned to their natal rookery as four-year-olds (16.7%) than as three-year-olds (25%).

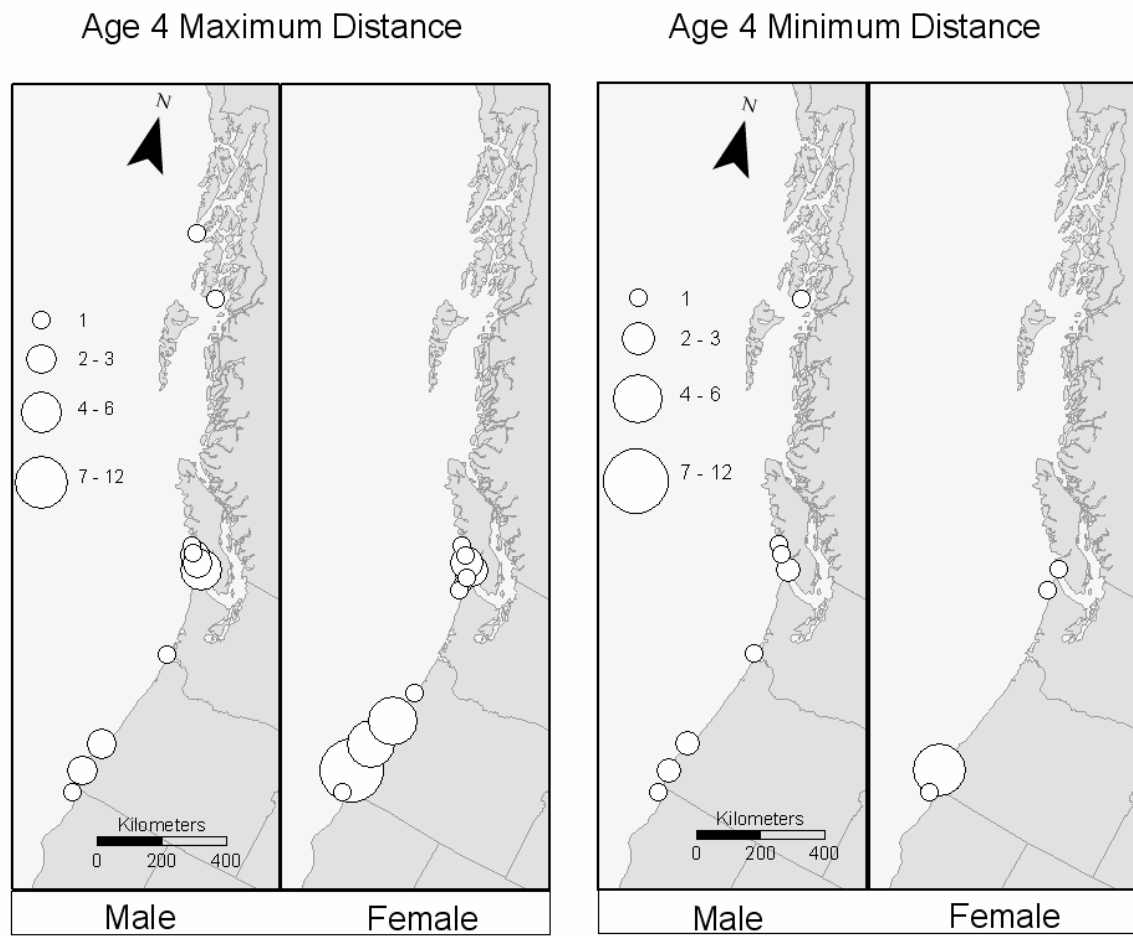


Figure A5: Maximum and minimum dispersal distance of individual 4-year-old Steller sea lions marked at Rogue Reef, Oregon as observed from resights.

Appendix C: Published Studies Utilizing Hot-Iron Branding

Seals and sea lions have been branded since the turn of the 19th century. Branding provides a permanent, individually identifiable marker that has been used by many studies. Presented below are published studies with the species, number branded, when branding occurred, purpose, where, and the published source. Some studies utilizing branding have never been published and are not reported here.

Table A3: Table to show how branding has been used in pinniped studies. For each published branding event the species, number branded, years of marking, published source, reason for branding, and where branding took place is reported if available in literature. Many branding studies are not reported in this table because they have not yet been published.

Species	Number branded	When	Source	Why	Where
California Sea Lion	97	1980-82	Aurioles <i>et al.</i> 1988	pup mortality	Los Islotes Rookery, Mexico
California Sea Lion	20	1981-82	NOAA 1993	Brand Evaluation	San Nicolas, California
California Sea Lion	560	1994-Present	Tennis <i>et al.</i> 2005	Fisheries interactions	Astoria, Oregon
Grey seal	??	1959-68	Summers and Witthames 1978	Movements site fidelity	North Rona, Scotland
Grey seal	~4,000	1969-89	Schwarz pers. comm.	life history	Nova Scotia
Grey seal	59	1987-89	Twiss <i>et al.</i> 1994	male site fidelity	North Rona, Scotland
Harbor Seal	??	1946	Scheffer 1950	??	British Columbia, Canada
Leopard seal	several	1951	Erickson <i>et al.</i> 1993	???	Heard Island
Northern Fur Seal	25,000	1896-1903	Scheffer 1950	scar pelts	Pribilof Islands, Alaska
Northern Fur Seal	5,800	1912	Scheffer 1950	growth; known age	Pribilof Islands, Alaska
Northern Fur Seal	5,047	1923	Scheffer 1950	Mark male breeding reserve	Pribilof Islands, Alaska
Northern Fur Seal	1,400	1925, 1927-30	Scheffer 1950	movements, site fidelity	Pribilof Islands, Alaska

Species	Number branded	When	Source	Why	Where
Northern Fur Seal	1,028	1925-32	Scheffer 1950	Japanese study	Ohkost Sea
Northern Fur Seal	??	1936	Scheffer 1950	Mark male breeding reserve	Kamchatka Peninsula
Northern Fur Seal	5,000	1940	Scheffer 1950	known age specimens	Pribilof Islands, Alaska
Northern Fur Seal	10,000	1941	Scheffer 1950	???	Pribilofs, Alaska
Ring Seal	121	1971	Smith <i>et al.</i> 1973	dispersal	Herschel Island, Yukon Territory
Southern Elephant Seal	2,000+	1920s	Erickson <i>et al.</i> 1993	no result	South Georgia Island
Southern Elephant Seal	8,249	1951-65	Ingham 1966	dispersal, life-history	Macquarie Island
Southern Elephant Seal	14,000	1993-99	McMahon <i>et al.</i> 2006	life history	Macquarie Island
Southern Fur Seal	??	1948	Scheffer 1950	??	Guano Islands
Steller Sea Lion	7,046	1975-76	Calkins 1979	movements, site fidelity	Alaska
Steller Sea Lion	8,596	1978-2002	Raum-Suryan <i>et al.</i> 2002	life history	Alaska
Steller Sea Lion	203	1986-88	ODFW unpub. data	movements, site fidelity	Rogue Reef, OR
Steller Sea Lion	761	2001-05	This study	life history, movements	Rogue and St. George, OR and CA
Steller Sea Lion	1,995	2001-05	Pendleton <i>et al.</i> 2006	Life history	SE Alaska
Weddell Seal	??	1928-29	Scheffer 1950	??	Antarctica
Weddell Seal	243	1934-35	Scheffer 1950	growth; known age, fidelity	Antarctica

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Appendix D: A Priori Model Parameters for Program MARK Analysis

Table A4: List of a priori resight model components used in brand evaluation analysis. Formula symbol is reported in model output tables. Parameter is a description of what the formula symbol represents. Hypothesis is what inclusion of that parameter in the best model would imply.

Resight Probability Parameters		
Formula Symbol	Parameter	Hypothesis
t	Variable time	Capture probabilities vary by day for such reasons as weather, observer effort, and other factors.
T	Linear trend in time	An increase in resight probability as observer gradually gets more efficient, or decrease as observer fatigues.
TT	Quadratic trend in time	Changes in pup behavior can make them more easily sighted mid study as they begin to play followed by lower resight probability as pups play further from Pyramid Rock.
lnT	Log-linear trend in time	Periods of rapid change in resight probability caused by observer effects or changes in pup behavior.
.	Constant	Constant resight probability for all groups through time
Brander	Each brander separated as a group and unbranded pups as another group	Branding is a lot like handwriting. Each person is unique in ability to be legible. Therefore, who brands the pup can affect resight probability. The field brander includes a group for unbranded pups.
Treatment	Brand or no brand	Unbranded pups and branded pups have unequal size of markers for an observer to resight. This can lead to unequal resight probabilities.
Sex	Sex	Males and females likely behave differently causing different resight probabilities.

Table A5: List of a priori apparent survival (Φ) model components used in brand evaluation analysis. Formula symbol is reported in model output tables. Parameter is a description of what the formula symbol represents. Hypothesis is what inclusion of that parameter in the best model would imply.

Apparent Survival Probability Parameters		
Formula Symbol	Factor	Hypothesis
t	Variable time	Survival is dictated by individual days. This can be caused by storms, stampedes, or other events that reduce the survival of all pups at a given time.
T	Linear trend in time	Survival increases or decreases in a linear manor following branding. This may be possible if pups emigrate away from Rogue Reef at a steady rate.
TT	Quadratic trend in time	A convex curve would show that following marking survival is low. Survival would then increase to such a point that temporary emigration of pups leaving Pyramid Rock would make survival look like it is decreasing. A concaved curve would show that survival is initially high followed by a time of low survival caused by infection or some other mechanism which is followed by period of increasing survival rates.
lnT	Log-linear trend in time	Survival probability may increase or decrease in a rapid manner. This could be caused by a disturbance causing rapid emigration or it could be the time period of healing when pups are no longer susceptible to infection following branding.
.	Constant	With this factor survival rate is assumed to be constant for time or treatment effects
Brander	Each brander separated as a group and unbranded pups as another group (a substitute for treatment)	Each brander responds to different cues on when a brand is complete (Erickson <i>et al.</i> 1993). This results in some brander's marks being of greater risk of infection than others. The brander field also includes a non-branded group.
Treatment	Brand or no brand	This is the main point of study. To test if branding causes a difference in survival of pups as compared to a reference group.
Sex	Sex	Past studies in other species of pinnipeds have noted that female pups have higher survival rate than males (Hall <i>et al.</i> 2001; Beauplet <i>et al.</i> 2005).

Apparent Survival Probability Parameters		
Formula Symbol	Factor	Hypothesis
Mass	Mass	Mass played a critical role in estimating survival of harbor seals (Harding <i>et al.</i> 2005) and is likely to in Steller sea lions as well.
AnTime	Anesthetic time	Defined as time of anesthesia cone on till cone off (Troy <i>et al.</i> 1997). Efforts were made to anesthetize each pup for equal lengths of time. However, even with our best efforts some pups were drugged for longer periods in response to unforeseen events. Researchers have had concern that animals can be overdosed or overheated when sedated (Gales 1989)

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Appendix E: Data Input File for Program MARK Apparent Survival Analysis

This is the input file used for the analysis in this paper. The first two letters of the group labels signify the brander or if they were unbranded; the last letter in the group labels are for the sex of the pups marked. Pups were monitored on seven occasions of unequal time intervals. The numbers following the label of occasions states the input of days for the unequal differences in sampling occasions. Individual covariates were mass, anesthetic time, and post marking time. Pup mass is recorded in kilograms. AnTime is our label for anesthetic time in minutes. We defined anesthetic time as time the isoflurane administering cone was placed over the snout of the pup until it was removed. Time post marking is the recorded time of the release of the last pup minus the release time of each individual pup. Time post marking is recorded in seconds.

Table A6: Data input file used in Program MARK for analysis of apparent survival rates of branded and unbranded pups.

```

/* GROUPS ARE BDF, BDM, JJM, JJF, MTM, MTF, RDM, RDF, U_M, U_F. 7
OCCASIONS 7,26,13,4,7,16. Covariates are mass, AnTime, post marking time */
1111000 1 0 0 0 0 0 0 0 0 0 0 26.2 16 31980 /*371R*/ ;
1110000 0 1 0 0 0 0 0 0 0 0 0 40 12 32340 /*372R*/ ;
1000000 0 1 0 0 0 0 0 0 0 0 0 25.2 14 31080 /*373R*/ ;
1011110 1 0 0 0 0 0 0 0 0 0 0 21.2 9 31260 /*374R*/ ;
1100000 1 0 0 0 0 0 0 0 0 0 0 23.1 12 30360 /*375R*/ ;
1000000 0 1 0 0 0 0 0 0 0 0 0 26 9 30540 /*376R*/ ;
1010010 0 1 0 0 0 0 0 0 0 0 0 33.3 14 29460 /*377R*/ ;
1000000 1 0 0 0 0 0 0 0 0 0 0 21.9 9 29880 /*378R*/ ;
1100000 0 1 0 0 0 0 0 0 0 0 0 22.4 12 28680 /*379R*/ ;
1000000 0 1 0 0 0 0 0 0 0 0 0 21 9 29340 /*380R*/ ;
1000000 1 0 0 0 0 0 0 0 0 0 0 25.8 14 27780 /*381R*/ ;
1100000 1 0 0 0 0 0 0 0 0 0 0 20.8 8 28560 /*382R*/ ;
1100000 1 0 0 0 0 0 0 0 0 0 0 23 12 27000 /*383R*/ ;
1110110 0 1 0 0 0 0 0 0 0 0 0 25.6 9 27960 /*384R*/ ;
1100000 1 0 0 0 0 0 0 0 0 0 0 21.6 11 26340 /*385R*/ ;
1111100 0 1 0 0 0 0 0 0 0 0 0 28.3 7 27300 /*386R*/ ;
1000000 0 1 0 0 0 0 0 0 0 0 0 29.5 11 25620 /*387R*/ ;
1000000 0 1 0 0 0 0 0 0 0 0 0 26.9 9 26400 /*388R*/ ;
1000000 1 0 0 0 0 0 0 0 0 0 0 25.8 8 25080 /*389R*/ ;
1100000 1 0 0 0 0 0 0 0 0 0 0 23.7 9 25680 /*390R*/ ;
1110000 0 0 0 1 0 0 0 0 0 0 0 32 11 23940 /*391R*/ ;
1000000 0 0 1 0 0 0 0 0 0 0 0 27.1 9 24180 /*392R*/ ;
1100000 0 0 0 1 0 0 0 0 0 0 0 26.8 8 23340 /*393R*/ ;
1100000 0 0 0 1 0 0 0 0 0 0 0 20.4 9 23340 /*394R*/ ;
1110001 0 0 1 0 0 0 0 0 0 0 0 21.6 5 22740 /*395R*/ ;
1111100 0 0 0 1 0 0 0 0 0 0 0 29.1 10 22620 /*396R*/ ;
1000000 0 0 0 1 0 0 0 0 0 0 0 30.3 7 21960 /*397R*/ ;
1111111 0 0 1 0 0 0 0 0 0 0 0 23.1 14 21720 /*398R*/ ;
1101000 0 0 1 0 0 0 0 0 0 0 0 27.8 8 21180 /*399R*/ ;
1100000 0 0 1 0 0 0 0 0 0 0 0 23.5 9 21060 /*400R*/ ;
1110000 0 0 1 0 0 0 0 0 0 0 0 26.9 7 20700 /*401R*/ ;
1100000 0 0 0 1 0 0 0 0 0 0 0 33.9 10 20400 /*402R*/ ;
1111110 0 0 0 1 0 0 0 0 0 0 0 27.4 7 20040 /*403R*/ ;
1100000 0 0 0 1 0 0 0 0 0 0 0 27.2 7 19860 /*404R*/ ;
1100000 0 0 1 0 0 0 0 0 0 0 0 33.5 7 19080 /*405R*/ ;
1111110 0 0 1 0 0 0 0 0 0 0 0 26.1 7 19380 /*406R*/ ;
1000000 0 0 0 1 0 0 0 0 0 0 0 30.8 11 18360 /*407R*/ ;
1011110 0 0 0 1 0 0 0 0 0 0 0 34.8 8 18720 /*408R*/ ;
1100000 0 0 1 0 0 0 0 0 0 0 0 29.4 8 17820 /*409R*/ ;
1100000 0 0 0 1 0 0 0 0 0 0 0 30.2 9 18060 /*410R*/ ;
1100000 0 0 0 0 1 0 0 0 0 0 0 33.5 8 15780 /*411R*/ ;
1110000 0 0 0 0 1 0 0 0 0 0 0 32.4 11 15840 /*412R*/ ;

```

/* GROUPS ARE BDF, BDM, JJM, JJF, MTM, MTF, RDM, RDF, U_M, U_F. 7
OCCASIONS 7,26,13,4,7,16. Covariates are mass, AnTime, post marking time */

1111111	0	0	0	0	1	0	0	0	0	0	28.1	9	15180	/*413R*/	;
1111111	0	0	0	0	0	1	0	0	0	0	30.6	7	15180	/*414R*/	;
1100000	0	0	0	0	0	1	0	0	0	0	32.6	7	14460	/*415R*/	;
1000000	0	0	0	0	1	0	0	0	0	0	20	7	14460	/*416R*/	;
1100010	0	0	0	0	1	0	0	0	0	0	20.6	10	13620	/*417R*/	;
1110000	0	0	0	0	0	1	0	0	0	0	30.3	10	13680	/*418R*/	;
1100000	0	0	0	0	1	0	0	0	0	0	25.4	8	13020	/*419R*/	;
1100000	0	0	0	0	1	0	0	0	0	0	20.5	7	13200	/*420R*/	;
1100000	0	0	0	0	1	0	0	0	0	0	26.4	10	12120	/*421R*/	;
1100000	0	0	0	0	0	1	0	0	0	0	26	7	12540	/*422R*/	;
1101100	0	0	0	0	0	1	0	0	0	0	33.6	9	11520	/*423R*/	;
1100011	0	0	0	0	1	0	0	0	0	0	28.6	10	11760	/*424R*/	;
1110000	0	0	0	0	0	1	0	0	0	0	26.9	10	10860	/*425R*/	;
1101100	0	0	0	0	1	0	0	0	0	0	26.5	6	11280	/*426R*/	;
1101110	0	0	0	0	0	1	0	0	0	0	32.4	8	9120	/*427R*/	;
1100000	0	0	0	0	1	0	0	0	0	0	28.1	8	10680	/*428R*/	;
1011110	0	0	0	0	1	0	0	0	0	0	25	8	8460	/*429R*/	;
1100000	0	0	0	0	0	1	0	0	0	0	25.5	7	8880	/*430R*/	;
1100110	0	0	0	0	0	0	0	1	0	0	35.6	8	6540	/*431R*/	;
1100000	0	0	0	0	0	0	0	1	0	0	25.2	9	6480	/*432R*/	;
1110000	0	0	0	0	0	0	0	1	0	0	29.3	7	6000	/*433R*/	;
1100010	0	0	0	0	0	0	1	0	0	0	29.3	7	5940	/*434R*/	;
1100110	0	0	0	0	0	0	0	1	0	0	30.2	8	5400	/*435R*/	;
1100000	0	0	0	0	0	0	1	0	0	0	21.6	9	5340	/*436R*/	;
1101111	0	0	0	0	0	0	0	1	0	0	22.1	8	4860	/*437R*/	;
1111100	0	0	0	0	0	0	1	0	0	0	24.7	6	4920	/*438R*/	;
1101100	0	0	0	0	0	0	1	0	0	0	24.3	8	3600	/*439R*/	;
1110000	0	0	0	0	0	0	1	0	0	0	21.5	8	3600	/*440R*/	;
1100011	0	0	0	0	0	0	0	1	0	0	25.8	10	2940	/*441R*/	;
1111111	0	0	0	0	0	0	1	0	0	0	24.5	11	2940	/*442R*/	;
1101101	0	0	0	0	0	0	1	0	0	0	23.9	9	2340	/*443R*/	;
1000000	0	0	0	0	0	0	1	0	0	0	25.2	6	2340	/*444R*/	;
1100000	0	0	0	0	0	0	1	0	0	0	25.5	9	1680	/*445R*/	;
1000000	0	0	0	0	0	0	1	0	0	0	20.2	10	1620	/*446R*/	;
1110111	0	0	0	0	0	0	0	1	0	0	29.2	7	900	/*447R*/	;
1100000	0	0	0	0	0	0	0	1	0	0	25.6	9	900	/*448R*/	;
1110000	0	0	0	0	0	0	0	1	0	0	27.1	8	120	/*449R*/	;
1111010	0	0	0	0	0	0	0	1	0	0	32	9	0	/*450R*/	;
1000000	0	0	0	0	0	0	0	0	1	0	28.8	7	32040	/*P1*/	;
1110100	0	0	0	0	0	0	0	0	1	0	23.5	12	32160	/*P2*/	;
1110000	0	0	0	0	0	0	0	0	0	1	26.1	7	31560	/*P3*/	;
1110000	0	0	0	0	0	0	0	0	1	0	31.6	6	31560	/*P4*/	;
1101110	0	0	0	0	0	0	0	0	1	0	25.5	10	30660	/*P5*/	;
1111000	0	0	0	0	0	0	0	0	1	0	27	10	30720	/*P6*/	;
1100000	0	0	0	0	0	0	0	0	1	0	22	10	30060	/*P7*/	;
1100000	0	0	0	0	0	0	0	0	1	0	27.2	10	29880	/*P8*/	;
1000000	0	0	0	0	0	0	0	0	1	0	23	10	29160	/*P9*/	;

/* GROUPS ARE BDF, BDM, JJM, JJF, MTM, MTF, RDM, RDF, U_M, U_F. 7
OCCASIONS 7,26,13,4,7,16. Covariates are mass, AnTime, post marking time */

1101000	0	0	0	0	0	0	0	0	0	1	24.1	10	29280	/*P10*/	;
1100000	0	0	0	0	0	0	0	0	1	0	26.6	10	28440	/*P11*/	;
1000000	0	0	0	0	0	0	0	0	1	0	27	10	28680	/*P12*/	;
1111111	0	0	0	0	0	0	0	0	0	1	23.6	10	27660	/*P13*/	;
1110000	0	0	0	0	0	0	0	0	0	1	19.4	10	28020	/*P14*/	;
1101111	0	0	0	0	0	0	0	0	0	1	28.9	10	27060	/*P15*/	;
1000000	0	0	0	0	0	0	0	0	0	1	29.5	10	26760	/*P16*/	;
1100000	0	0	0	0	0	0	0	0	1	0	25.8	10	26400	/*P17*/	;
1100110	0	0	0	0	0	0	0	0	1	0	24.5	10	26160	/*P18*/	;
1100000	0	0	0	0	0	0	0	0	0	1	28	10	25500	/*P19*/	;
1111110	0	0	0	0	0	0	0	0	0	1	26.6	10	25320	/*P20*/	;
1111111	0	0	0	0	0	0	0	0	1	0	25.5	10	23880	/*P21*/	;
1000001	0	0	0	0	0	0	0	0	1	0	21.2	10	23880	/*P22*/	;
1100000	0	0	0	0	0	0	0	0	0	1	30.8	10	23280	/*P23*/	;
1101110	0	0	0	0	0	0	0	0	0	1	28	10	23280	/*P24*/	;
1111111	0	0	0	0	0	0	0	0	1	0	26	10	22680	/*P25*/	;
1100000	0	0	0	0	0	0	0	0	0	1	24.3	10	22620	/*P26*/	;
1101110	0	0	0	0	0	0	0	0	0	1	30.8	10	22080	/*P27*/	;
1110010	0	0	0	0	0	0	0	0	0	1	24.3	10	21960	/*P28*/	;
1110100	0	0	0	0	0	0	0	0	1	0	25.2	10	21480	/*P29*/	;
1001100	0	0	0	0	0	0	0	0	0	1	25.2	9	21420	/*P30*/	;
1000010	0	0	0	0	0	0	0	0	0	1	35	10	20820	/*P31*/	;
1111101	0	0	0	0	0	0	0	0	0	1	33.1	10	20700	/*P32*/	;
1101100	0	0	0	0	0	0	0	0	1	0	21.6	10	19980	/*P33*/	;
1111010	0	0	0	0	0	0	0	0	0	1	25.4	10	20040	/*P34*/	;
1001110	0	0	0	0	0	0	0	0	1	0	24.9	12	19320	/*P35*/	;
1100100	0	0	0	0	0	0	0	0	0	1	25.7	10	19260	/*P36*/	;
1110011	0	0	0	0	0	0	0	0	1	0	30.9	8	17880	/*P37*/	;
1010111	0	0	0	0	0	0	0	0	0	1	24.6	10	18360	/*P38*/	;
1101100	0	0	0	0	0	0	0	0	0	1	24.2	6	17460	/*P39*/	;
1000111	0	0	0	0	0	0	0	0	0	1	32.1	10	17640	/*P40*/	;
1101111	0	0	0	0	0	0	0	0	1	0	29.5	6	16020	/*P41*/	;
1110110	0	0	0	0	0	0	0	0	1	0	20.2	5	16080	/*P42*/	;
1101110	0	0	0	0	0	0	0	0	0	1	30.8	9	15240	/*P43*/	;
1110000	0	0	0	0	0	0	0	0	1	0	23.8	8	15120	/*P44*/	;
1100000	0	0	0	0	0	0	0	0	0	1	27.3	8	14220	/*P45*/	;
1000000	0	0	0	0	0	0	0	0	0	1	30.8	9	14580	/*P46*/	;
1000000	0	0	0	0	0	0	0	0	0	1	30	8	13680	/*P47*/	;
1000110	0	0	0	0	0	0	0	0	0	1	33.2	8	13740	/*P48*/	;
1110000	0	0	0	0	0	0	0	0	1	0	28.1	8	13200	/*P49*/	;
1111000	0	0	0	0	0	0	0	0	1	0	21.9	8	13140	/*P50*/	;
1111000	0	0	0	0	0	0	0	0	0	1	21.7	8	12720	/*P51*/	;
1100010	0	0	0	0	0	0	0	0	1	0	20.4	8	12660	/*P52*/	;
1101110	0	0	0	0	0	0	0	0	0	1	31.9	8	11820	/*P53*/	;
1100110	0	0	0	0	0	0	0	0	1	0	23	8	12180	/*P54*/	;
1001100	0	0	0	0	0	0	0	0	1	0	24.1	8	11160	/*P55*/	;
1010011	0	0	0	0	0	0	0	0	0	1	26.4	8	11340	/*P56*/	;

/* GROUPS ARE BDF, BDM, JJM, JJF, MTM, MTF, RDM, RDF, U_M, U_F. 7
OCCASIONS 7,26,13,4,7,16. Covariates are mass, AnTime, post marking time */

1100000	0	0	0	0	0	0	0	0	1	0	30.3	8	10620	/*P57*/	;
1100000	0	0	0	0	0	0	0	0	1	0	22.1	9	9420	/*P58*/	;
1100010	0	0	0	0	0	0	0	0	0	1	29.8	9	9240	/*P59*/	;
1100000	0	0	0	0	0	0	0	0	1	0	27	8	8880	/*P60*/	;
1100000	0	0	0	0	0	0	0	0	0	1	25.5	8	6960	/*P61*/	;
1011000	0	0	0	0	0	0	0	0	0	1	35.5	8	7020	/*P62*/	;
1100000	0	0	0	0	0	0	0	0	1	0	27.1	8	6420	/*P63*/	;
1110011	0	0	0	0	0	0	0	0	0	1	29.5	8	6540	/*P64*/	;
1100000	0	0	0	0	0	0	0	0	1	0	24.2	8	5640	/*P65*/	;
1111000	0	0	0	0	0	0	0	0	0	1	24.3	8	6060	/*P66*/	;
1110001	0	0	0	0	0	0	0	0	1	0	22.7	9	4980	/*P67*/	;
1001011	0	0	0	0	0	0	0	0	1	0	20.5	8	5160	/*P68*/	;
1101000	0	0	0	0	0	0	0	0	1	0	24.8	8	4320	/*P69*/	;
1100000	0	0	0	0	0	0	0	0	1	0	22.1	8	4320	/*P70*/	;
1100110	0	0	0	0	0	0	0	0	1	0	23.2	8	3720	/*P71*/	;
1101100	0	0	0	0	0	0	0	0	0	1	25	8	3300	/*P72*/	;
1111000	0	0	0	0	0	0	0	0	1	0	21	9	2640	/*P73*/	;
1000000	0	0	0	0	0	0	0	0	1	0	21.9	8	2820	/*P74*/	;
1110110	0	0	0	0	0	0	0	0	0	1	21.8	8	1800	/*P75*/	;
1101010	0	0	0	0	0	0	0	0	1	0	21.9	7	1980	/*P76*/	;
1100000	0	0	0	0	0	0	0	0	0	1	20.7	7	1320	/*P77*/	;
1011101	0	0	0	0	0	0	0	0	0	1	31.3	8	1260	/*P78*/	;
1110110	0	0	0	0	0	0	0	0	0	1	29.7	8	780	/*P79*/	;
1100000	0	0	0	0	0	0	0	0	1	0	23.2	8	660	/*P80*/	;

