

**NORTHERN FUR SEALS (*CALLORHINUS URSINUS*) OF THE COMMANDER  
ISLANDS: SUMMER FEEDING TRIPS, WINTER MIGRATIONS AND  
INTERACTIONS WITH KILLER WHALES  
(*ORCINUS ORCA*)**

A Dissertation

by

OLGA ANDREEVNA BELONOVICH

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of  
DOCTOR OF PHILOSOPHY

August 2011

Major Subject: Wildlife and Fisheries Sciences

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## ABSTRACT

Northern Fur Seals (*Callorhinus ursinus*) of the Commander Islands: Summer Feeding Trips, Winter Migrations and Interactions with Killer Whales (*Orcinus orca*).

(August 2011)

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The northern fur seal (NFS) population on the Pribilof Islands (PI) is currently declining while the population on the Commander Islands (CI which includes Bering and Medny Islands) is stable. The reasons for the different population trajectories remain unknown. Comparing differences in behavioral ecology and predation pressure between these two populations could provide an explanation. This study examined lactating NFS female behavior to determine: 1) summer foraging patterns (trip duration, trip direction, dive depth) of animals from two nearby rookeries on Bering Island, 2) winter migration from Medny and Bering Islands relative to patterns of ocean productivity, and 3) the potential impact of killer whale predation on population dynamics. Data were collected from 2003 to 2010 using visual observations and telemetry. Twenty-one satellite transmitters, 29 time-depth recorders and 17 geolocation recorders were deployed. Shore-based observations of killer whale predation and photo-identification were conducted near the CI rookeries in 1999-2010. During lactation, both mean foraging trip

duration and mean maximum diving depth ( $3.4 \pm 1.3$  days and  $17.7 \pm 6.8$  m, respectively) for NFS adult females ( $n = 28$ ) did not significantly change among years. Although foraging areas of NFS from the two rookeries on Bering Island overlapped, the mean direction of travel from Severo-Zapadnoe rookery was significantly ( $p < 0.01$ ) different compared with Severnoe rookery. The foraging patterns suggested that these females had a reliable food source that did not change despite potential environmental changes or the effects of fisheries. During their winter migration, NFS females from the CI traveled to the Transition Zone Chlorophyll Front ( $32^\circ$  N- $42^\circ$  N) in the North Pacific Ocean. Their winter migration routes and the location of overwinter foraging areas were positively correlated with high ocean productivity (near surface chlorophyll a concentration). Over 82% ( $n=17$ ) of these females spent 3-8 months near the eastern coast of Hokkaido, Japan and followed the coastal high productivity areas on their way back to the CI.

Transient killer whales in groups of 2-12 individuals were repeatedly observed preying mostly on NFS males during the summer. The simulation model showed little impact on population dynamics as long as male fur seals were the primary prey. However, if the number of killer whales increased or they changed their diet to include females and pups, then the NFS population on the CI could decline.

The winter migration of NFS from CI and PI are similar. Lactating NFS from the PI exhibit greater summer foraging effort (longer average trip duration and bout duration; greater number of deep dives) compared with females from the CI.

## ACKNOWLEDGEMENTS

This work could not have been accomplished without the assistance of many people and the financial support from several organizations. I am very grateful to my Committee Chair and adviser, Dr. Randall Davis, for his support throughout the study and field research and for time he spent correcting my dissertation and abstracts. I greatly appreciate the help of my Committee Members. Thanks to Dr. William Grant who helped me throughout my studies at Texas A&M, for his kindness, his smile, and his wonderful “Russian” lessons. Dr. Grant also “opened a new world” of simulation modeling and spent many hours helping me with the adventure of constructing the killer whale – fur seal model. Also, Dr. Grant corrected most of my terrible English writing, especially during my first year in the U.S. Many thanks to Dr. Bernd Würsig and Mel Würsig for their support, help, warmth and kindness, and for the New Zealand visit. Bernd, thank you very much for your very interesting classes and for your great help with our field research. Thanks to Dr. Jane Packard for sharing her knowledge and experience, for the many field trips in which she involved me and for the amazingly interesting classes. I really enjoyed Dr. Doug Biggs classes, very well organized lectures where he explained even the most difficult thing in the easiest way. Many thanks to Dr. Russel Andrews for providing most equipment for this research, organization, his help and instructions during the field work. Also, he was the one who brought the idea for this research. I am very grateful to Dr. Andrews for his help in data analyses, writing and corrections for conferences abstracts and the dissertation.

This work could not be done without Dr. Vladimir Burkanov. He was the one who organized all the field work, introduced me to Dr. Davis and always helped in the most hopeless situations. Thanks for his optimism and his gift of making the world brighter.

This work could not have been done possible without the great help of the research teams from different projects, ship crew and local people. I am very grateful to Sergey Dackov, Olga and Andrey Stepanovi, Tatiana Shulezhko, Russ Andrews, Marina and Dmitry Shitovi, Aleksandr Generalov, Ivan Blokhin, Sergey Nikulin, Sergey Fomin, Ivan Usatov, and Vladimir Vertiankin for their help during field seasons on Bering Island, as well as to Evgeny Mamaev, Sergey Fomin, Aleksey Mukhin, Sergey Ryazanov, Lika Sagatlova, Genya Dolgova, Lilia Doronina, Aleksandr Shienok, Daria Zakharova, Svetlana Artem'eva, Olga Nanova, Aleksey Chetvergov, Katerina and Ivan Krupini, Aleksandra Mironova, Olga Titova, and Maria Ososkova for their invaluable help on Medny Island. Thanks to Valentina Burkanova and Dr. Don Calkins for their help with logistics. I am also very grateful to Dr. Olga Filatova for her comments and corrections on the chapter about killer whales.

I would like to especially thank Dr. Mamaev who made Medny Island a welcome home for all his students, who taught me how to conduct field research, how to observe animals and how to distinguish Steller sea lions from northern fur seals. Also, he provided data on killer whale predation on marine mammals for the period 1999-2004 (I started to collected this data from 2005), and I thank him for his valuable comments and corrections on the dissertation. Also, I am very grateful to Ivan Blokhin (Kamchat

NIRO) for providing me time-depth recorder data that he collected on NFS females on Severo-Zapadnoe rookery of Bering Island in 2003 and 2004. Many thanks to Dr. Ian Stainland for providing the geolocation recorders, programs to filter the data and his help during the first steps of data filtering.

It would not have been possible for me to study in the U.S. and conduct the research in the Commander Islands without the great help and support of my family. Special thanks to my husband Sergey for his patience, kindness and support during both field research and while living in Galveston; my parents Galina Belonovich and Andrey Belonovich, and my sister Valeria. Thanks to Dr. Dan and Elena Reeces and Sasha who became my lovely family in the U.S. I am also very grateful to my Russian friends, who were glad to see me whenever I came home and to hear me whenever I called from far away.

Finally, thanks a lot to Olivia Lee, Kendal Ball, Michaele Coyman, Aleksey Altukhov, Abner Salgado, Jeremy Sterling, and Ian Stainland for their great help in data analyses. Special thanks to Olga Sychenko, who became a good friend during these years and also spent many hours evaluating my dissertation. I am also very grateful to all students from Dr. Davis's and Dr. Würsig's labs.

Financing of the expeditions, logistics and equipment was provided by National Marine Mammal Laboratory, Alaska Fisheries Science Center National Marine Fisheries Service NOAA, USA; Alaska SeaLife Center, Seward, USA; and North Pacific Wildlife Consulting LLC, Seattle, USA. Additional funding was provided by Texas A&M University, TX, USA; Kamchatka Branch of the Pacific Geographical Institute, FEB,

RAS, Petropavlovsk- Kamchatsky, Russia; and Kamchatka Research Institute of Fisheries and Oceanography, Petropavlovsk-Kamchatsky, Russia. The work was conducted according to permits N 1194 in 2007, N79/2008-H in 2008 and N07-07/3756 in 2009 issued by Russian Federal Agency of Fisheries to Kamchatka Branch of the Pacific Geographical Institute, FEB, RAS.

## TABLE OF CONTENTS

	Page
ABSTRACT .....	iii
ACKNOWLEDGEMENTS .....	v
TABLE OF CONTENTS .....	ix
LIST OF FIGURES.....	xi
LIST OF TABLES .....	xiv
 CHAPTER	
I    INTRODUCTION .....	1
Objectives .....	7
Northern fur seal life history and distribution .....	8
Study area .....	10
Hypotheses .....	11
 II    LACTATING NORTHERN FUR SEALS SUMMER	
FORAGING TRIPS .....	17
Introduction.....	17
Methods .....	21
Data collection .....	21
Data analyses .....	22
Results.....	26
Female morphometrics .....	26
Duration of foraging trips .....	26
Dive depth.....	27
Diving bouts.....	31
Foraging trips direction.....	35
Chlorophyll-a concentration .....	41
Diet.....	43
Discussion.....	43

CHAPTER	Page
III WINTER MIGRATION OF NORTHERN FUR SEAL FEMALES FROM THE COMMANDER ISLANDS .....	50
Introduction.....	50
Methods .....	54
Tags.....	56
Reduction of GLS error .....	57
NFS locations and chlorophyll-a concentration.....	60
Consecutive years NFS migration .....	61
GLS data for NFS from Bering and Medny Islands .....	62
Results.....	62
Female winter migrations based on satellite locations .....	63
Females overwinter foraging areas obtained from GLS tags .....	66
Consecutive years of NFS female migration .....	72
Females migration from Bering and Medny Islands .....	74
Discussion.....	77
IV KILLER WHALE PREDATION ON NORTHERN FUR SEALS ON THE COMMANDER ISLANDS: OBSERVATIONS AND SIMULATION OF ALTERNATIVE HYPOTHESES REGARDING KILLER WHALE DIETS .....	81
Introduction.....	81
Background information .....	83
Methods .....	84
Field data.....	85
Model development .....	86
Results.....	89
Field data.....	89
Simulation model data .....	96
Discussion.....	97
V SUMMARY .....	102
LITERATURE CITED .....	106
VITA .....	135

## LIST OF FIGURES

FIGURE	Page
1. The geographic location of the Commander Islands and the Pribilof Islands .....	2
2. Geographic location of the Commander Island and the four main rookeries.....	10
3. Chlorophyll a concentration near the Commander Islands in July from 1999-A to 2010-O .....	13
4. NFS females from Severo-Zapadnoe rookery mean maximum diving depth in different years (>2 m, >15 sec).....	27
5. NFS females from Severo-Zapadnoe rookery mean maximum diving depth in different years (>5 m, >0.5 min).....	28
6. The mean maximum diving depth ( $\pm$ SD) of NFS females from Severnoe and Severo-Zapadnoe rookeries of Bering Island in 2009.....	30
7. Number of dives per foraging trip made by females from Severnoe and Severo-Zapadnoe rookeries in 2009 .....	31
8. Location of NFS bouts from Severnoe and Severo-Zapadnoe rookeries .....	33
9. Location of NFS deep and mixed bouts from Severnoe and Severo-Zapadnoe rookeries relative to bathymetry .....	34
10. Start time of NFS bouts .....	35
11. Maximum traveled distance by NFS females from Severnoe and Severo-Zapadnoe rookeries 2009 .....	36
12. Tracks (upper) and vectors (lower) of NFS foraging trips from Severnoe rookery.....	39
13. Tracks (upper) and vectors (lower) of NFS foraging trips from Severo-Zapadnoe rookery.....	40

FIGURE	Page
14. Area covered by foraging trips of NFS from Severnoe and Severo-Zapadnoe rookeries .....	41
15. The foraging bouts of NFS females from Severnoe and Severo-Zapadnoe rookeries in areas of different chl a concentration in July 2009 .....	42
16. The chl a concentration near the Commander Islands in July 2003, 2004, 2008 and 2009 .....	47
17. Frequency of occurrence of different prey species in juvenile male fur seal diet in 2003, 2004 and 2009 .....	48
18. The yellow plastic and GLS tags in a left front flipper of NFS .....	55
19. The satellite SPOT 5 tag (Wildlife Computers, Redmond, WA, USA) .....	56
20. Geolocation tag (GLS) Mk9 developed by British Antarctic Survey (UK) ...	56
21. The GLS location plotted as a function of the satellite locations for each female .....	59
22. The satellite tracks of NFS females from Severo-Zapadnoe rookery relative to average November chl a concentration .....	64
23. The geostrophic current magnitude map (November, 2007) and females migration paths .....	66
24. Travel vectors of females to their final destination during the 2007/2008 winter migration from Severo-Zapadnoe rookery of Bering Island .....	68
25. Travel vectors for females during the winter migration from the rookery to the first foraging area (upper) and from the first to the second foraging area (bottom) .....	70
26. Females winter migration locations during November, December, January, April, May and June relative to chl a concentration .....	71
27. The two winter (2007/2008 and 2008/2009) migration routes of NFSg07_SZ41 and NFSg07_SZ45 from Severo-Zapadnoe rookery of Bering Island .....	74

FIGURE	Page
28. Winter migration of females from Medny (red) and Bering (yellow) Islands.....	76
29. One of the four killer whales preying on an adult male fur seals near the Yugo-Vostochnoe rookery of Medny Island on July 10, 2010 .....	92
30. Killer whales preying on NFS bull near the Yugo-Vostochnoe rookery of Medny Island.....	93
31. The NFS bull killed by killer whales on Urilie rookery of Medny Island (2010) .....	94
32. The NFS carcass with killer whale teeth marks found on Urilie rookery of Medny Island.....	94

## LIST OF TABLES

TABLE	Page
1. Summary of lactating NFS foraging trips from Severnoe and Severo-Zapadnoe rookeries of Bering Island in 2003, 2004, 2008 and 2009 .....	29
2. Summary of NFS foraging trips from Severnoe and Severo-Zapadnoe rookeries.....	36
3. The frequency of occurrence of major (FO>5%) prey species in NFS males' diet.....	48
4. Summary of robust regression lines used to correct position error of GLS tags .....	58
5. Summary information on NFs tagged in November 2007.....	63
6. Summary of NFS winter migration parameters obtained from satellite tags.....	64
7. The 2007/2008 winter migration parameters of NFS females.....	67
8. Parameters of NFS winter foraging areas obtained from GLS tags .....	69
9. Summary data on NFSg07_SZ41 and NFSg07_SZ45 during consecutive years of migration .....	73
10. GLS tags number, female body mass and re-sighting in 2010.....	75
11. Summary of parameter values used in the model to represent the 12 different hypotheses regarding killer whale predation on NFS, including the proportions of killer whale food requirements met by feeding on different age- and sex- classes of NFS, and the proportions met by feeding on other species .....	87
12. Summary of transient killer whales predation activity near the Commander Islands in 1999-2010 .....	91

TABLE	Page
13. Minimum number of killer whales preying on the NFS population using all of the rookeries on the Commander Islands (in parentheses) only during summer month (May through September) that would cause the population to decline irrecoverably under the indicated combinations of NFS demographic parameters and killer whales diets (see Table 11 for diet details) .....	96
14. Summary and evaluation of the research hypotheses presented in Chapter I .....	102

## CHAPTER I

### INTRODUCTION

The northern fur seal (NFS, *Callorhinus ursinus*) is one of the most well studied marine mammal species. Scott *et al.* (2006) listed 1,939 publications on NFS, and this number is increasing every year. At the same time, some aspects of NFS biology still remain unknown. Currently, there is much interest in the cause(s) of the decline in the NFS population on the Pribilof Islands in the northeastern Pacific.

The estimated NFS population on the Pribilof Islands has decreased over 50% since the 1970's and continues to decline (Briggs and Fowler 1984, Fowler 1998, Kuzin 1999, Willis and Trites 2006, Trites 1992a). As a result, NFS have been designated as depleted under the Marine Mammal Protection Act, and further declines could result in a designation of threatened under the Endangered Species Act (Costa *et al.* 2002, Lea *et al.* 2009, Towell *et al.* 2006). At the same time, NFS population on the Commander Islands in northwestern Pacific is stable (Fig.1) (Ream and Burkanov 2006, Kornev *et al.* 2008).

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This dissertation follows the style of Marine Mammal Science.

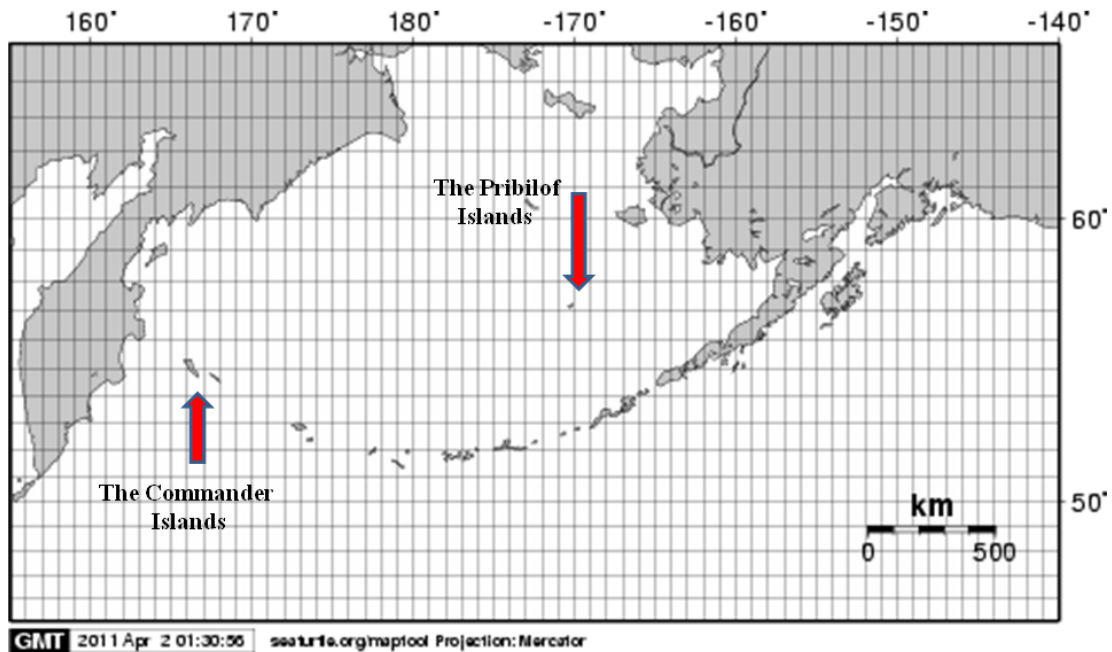


Figure 1. The geographic location of the Commander Islands and the Pribilof Islands.

Given the economic and political impact on commercial fisheries in the North Pacific that resulted from the decline of Steller sea lions (*Eumetopias jubatus*), sea otters (*Enhydra lutris*), harbor and spotted seals (*Phoca vitulina* and *Phoca larga*, respectively), research is urgently needed to understand why NFS are also declining in the eastern Bering Sea.

Scientists have focused their attention primarily on the possible roles of food limitation, environmental changes, pollution, and disease as causes of NFS decline (Trites *et al.* 1997, Towell *et al.* 2006). However, predation by killer whales has also been suggested as a potential cause for the decline (Hanna 1922, Newman and Springer

2008, Zenkovich 1938). None of these hypotheses clearly explains the reason for the decline, but none of them can be completely rejected.

To better understand the factors that might contribute to the decline of NFS in the northeastern Pacific, a comparison with the stable population in the northwestern Pacific may be helpful. In this study, I provide data on foraging ecology during the summer and winter for female NFS from the Commander Islands and evaluate the possible role of killer predation on different population trajectories.

The primary objective of this study was to investigate aspects of NFS summer foraging trips, winter migrations, and to estimate the killer whale predation pressure on the NFS population of the Commander Islands. Specifically, I investigated certain aspects of NFS biology that have not been adequately studied on the Commander Islands, but were studied or are currently being studied on the Pribilof Islands. The results of this study lead to other questions that could be answered only by additional parallel studies on both the Commander and the Pribilof Islands.

In Chapter II, the summer foraging trip parameters of NFS from two nearby rookeries on Bering Island are presented. For this Chapter, I used data collected in 2008 and 2009, as well as data collected by our collaborators (Blokin I.A., KamchatNIRO) in 2003 and 2004. The comparison was based on foraging trip characteristics of lactating NFS during different years and from different rookeries on Bering Island.

Differences in food availability, diet, environmental conditions and some other variables could affect NFS foraging trip characteristics and could be important for understanding differences with NFS on the Pribilof Islands. For example, Chapman

(1961) suggested that fishery effects on fur seal populations could possibly be measured through the pattern of female attendance on shore. His hypothesis was not supported by Gentry and Holt (1986), who found no significant difference between NFS foraging trip duration in years with different catch levels by the fishery. Studies of Antarctic fur seals (*Arctocephalus gazella*) showed that during periods of low food availability, females increased the number of dives throughout the day and night, while in highly productive areas these seals foraged at shallower depths for shorter periods of time and only during the night (Staniland *et al.* 2006). The foraging trip duration itself does not necessarily indicate the difference in prey abundance in these regions, but consideration of foraging trip and dive variables could reflect a significant difference.

Theoretically, to optimize foraging efficiency, predators would be predicted to concentrate their foraging effort in the most productive areas (Charnov 1976, Pyke 1984, Stephens and Krebs 1986, Page *et al.* 2005). In marine environments, these productive areas are unstable and depend on day time, season, weather conditions and many other parameters. These productive areas are often associated with upwelling zones, eddies and areas of high chlorophyll-a (chl a) concentration (Pond and Pickard 1983, Sverdrup *et al.* 2004, Miller 2004).

Correlation of foraging areas with the areas of high productivity has been described for many marine mammals and birds (Dragon *et al.* 2010, Lea and Dubroca 2003, Lea *et al.* 2002, Hlista *et al.* 2009, Brown 1988). Eddies, fronts, and upwelling zones are productive and therefore favorable foraging areas for southern elephant seals (*Mirounga leonina*), NFS, Antarctic fur seal (*Arctocephalus gazelle*), minke whales

(*Balaenoptera acutorostrata*), Humpback whales (*Megaptera novaeangliae*) and several dolphins species (Dragon *et al.* 2010, Boyd 1996, Fauchald 2000, Redfern *et al.* 2008, Tetley *et al.* 2008, Dalla Rosa 2010).

While data on NFS diving depth and other dive parameters, such as dive duration, number of dives, bottom time duration, etc., on the Commander Islands have been collected since 1990, there were almost no data on the at-sea location of these foraging trips. The limited location data that did exist were imprecise because they were obtained from geolocation (Global Location Sensing, GLS) tags (Boltnev 2002, Blokhin *et al.* 2007). Also, in previous years, NFS females were tagged on only one of the rookeries of the Commander Islands. In 2009, for the first time, NFS females were tagged on both Severnoe and Severo-Zapadnoe rookeries of Bering Island. These data allowed me to compare the NFS foraging trips parameters for fur seals from two nearby rookeries under the same environmental conditions.

Marine mammals often consume fish caught in fishing gear, not only causing fishermen conflicts, but also the potential risk of injury or death (Forney and Kobayashi 2007, Yates and Brickle 2007, Guclusoy 2008, Plaganyi and Butterworth 2005). There are many observations from fishing vessels confirming that NFS consume fish from fishing gear (Kuzin 1999, Nikulin and Mironova 2001). Also, sightings of NFS entangled in drift nets and other marine debris provide indirect evidence of NFS depredation associated with fishing gear (Artukhin *et al.* 2010). Fish and squid from fishing gear are easy prey for NFS, but this behavior could be dangerous due to the risk of entanglement. The satellite tags that were used in our studies provided sufficiently

accurate locations of NFS during foraging trips to compare the data with areas of commercial fishing.

In Chapter III, I present the NFS females' winter migrations obtained from the GLS tags in relation to their over-winter areas and oceanographic parameters. In general, NFS population dynamics greatly depends on NFS foraging success, health and survival during winter migrations, which in turn is associated with prey abundance and therefore with environment (Kuzin *et al.* 1977, York 1985, 1995, Trites 1992a, Trites and Bigg 1992). Recent studies on NFS pups during their winter migration showed that they followed high chl *a* concentrations in near shore areas (Lee 2011). I hypothesized that adult fur seals behave in a similar manner during their migration. However, there were no telemetry studies of NFS females during their complete winter migration from the Commander Islands. In this study, I used both satellite telemetry and GLS records to obtain the winter migration routes of NFS females from Bering and Medny Islands.

In Chapter IV, I combined visual observations, literature data, and simulation modeling to explore the possible impact of killer whale predation on the NFS population on the Commander Islands. The potential influence of killer whale predation on some marine mammal populations is controversial (Baird 1994, Estes *et al.* 1998, Ford *et al.* 2000, Saulitis *et al.* 2000, Matkin *et al.* 2010, Springer *et al.* 2003, DeMaster *et al.* 2006, Permyakov and Burkanov 2009). Even in some of the most intensively studied areas, killer whale predation on marine mammal populations remains unclear. I used visual observations and published data to construct the simulation model and predict how

variation in the number of fur seal-eating killer whales and their dietary preferences could affect the NFS population on the Commander Islands.

## OBJECTIVES

The main objectives of the study were to:

- 1) Determine summer feeding areas, prey preference, dive effort and habitat-associations of lactating NFS on Bering Island, including:
  - a) Monitoring the movements, diving behavior and attendance patterns on the rookery of lactating NFS females from June to August 2008 -2009 using satellite telemetry.
  - b) Collect NFS scats on rookeries of Bering Island to determine NFS diet.
  - c) Combine the lactating NFS satellite tracks and dive data with oceanographic parameters to investigate habitat-associations.
- 2) Determine winter migration routes and association with oceanographic features including:
  - a) Monitor the NFS migration routes during winter 2007/2008, 2008/2009 and 2009/2010.
  - b) Assess the NFS migration routes during consecutive years.
  - c) Combine the NFS routes with chl a concentration to investigate habitat-associations.

- 3) Estimate the potential impact of killer whale predation on the NFS population of the Commander Islands including:
  - a) Use land-based and vessel- based observations on mammal-eating killer whale behavior near the pinniped rookeries of the Commander Islands;
  - b) Construct a simulation model of different hypotheses by varying of killer whale numbers and diet.

## NORTHERN FUR SEALS LIFE HISTORY AND DISTRIBUTION

NFS biology, behavior and ecology has been very well studied and described in many publications and monographs in Russia (Kuzin 1999, Karsheninikov 1948, Vladimirov 1983,1991, 1998, Boltnev 1991, Boltnev and Stus 1998, Chelnokov 1982, Lisitsyna 1973, Marakov 1964, 1974, and many others) and the U.S. and Canada (Gentry 1981,1998, 1975, Antonelis *et al.* 1990, 1994, 1997, Antonelis 1976, Bigg 1990, DeLong 1982,1990, Fowler 1982, 1987,1990, Gentry and Goebel-Diaz 1989, Gentry and Kooyman 1986, Kooyman *et al.* 1976, Loughlin 1989, Loughlin *et al.* 1987, Trites 1991a,b, 1992a,b, York 1983, 1987, 1991). Results from these studies are valuable for making comparisons with the data collected in my research.

NFS inhabit the Northern Pacific Ocean, with a total population of ca. 1.2 million: about 53 % on the Pribilof Islands, 21% on the Commander Islands, and 12%, 10%, 5%, and 1% on the Robben, Kuril, Bogoslof, and San Miguel islands, respectively (Ream and Burkanov 2006). Each year, adult males begin arriving at rookeries to

compete for breeding territories during May. Females begin arriving in mid-June, give birth to young conceived the previous year and mate again within a few days. Females nurse their pups for three-to-four months while making regular foraging trips to sea, and then begin their southward migration in October or November (Gentry 1998, Kuzin 1999). The offspring and majority of males begin their southward migration at approximately the same time.

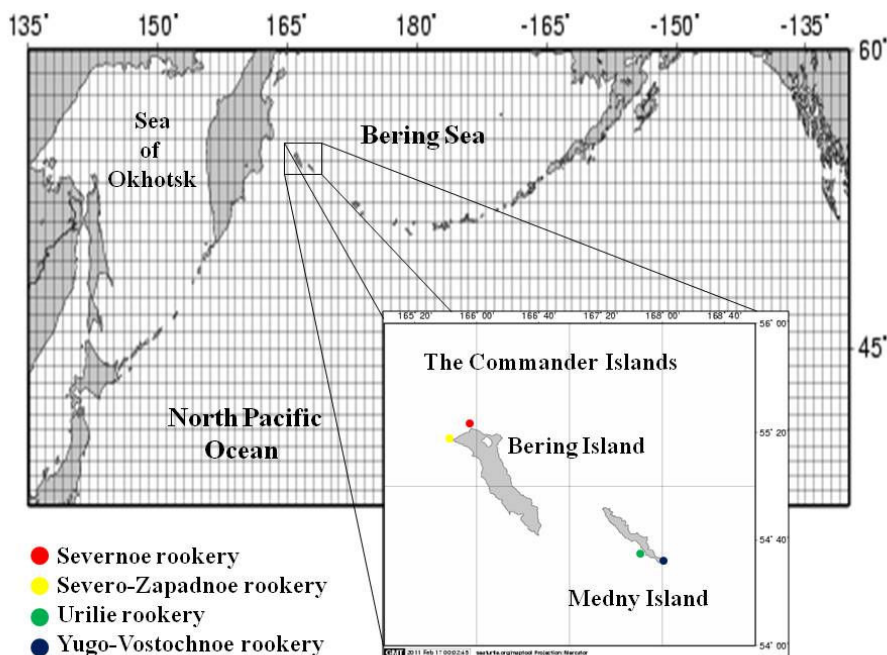
Males do not participate in rearing the offspring. Females feed themselves and nurse their pups during the breeding season, which requires proximity to foraging areas within a certain distance from breeding sites. The number of these sites is limited (Gentry 1998). There are more than 70 different species of fish and squid that have been described as a prey of NFS. Based on a scat analysis, Antonelis *et al.* (1997) showed that oceanic squid were the most common prey for seals from Medny Island. Also using scat analyses, Blokhin (2010) showed that NFS from Bering Island prey on both fish and squid. In contrast, NFS in the northeastern Pacific forage mostly on fish (pollock) during summer (Zepelin and Ream 2006).

As a polygynous species, NFS exhibit extreme sexual dimorphism. Males are 30-40% larger than females, weighing about 250 - 320 kg and reaching a length of 2.2 -2.5 m. Females can weigh up to 71 kg, but usually no more than 50 kg and reach a maximum length of 1.4 m (Kuzin 1999). Females give birth to one pup annually, which weighs about 5 kg at birth and is about 60 cm in length. Females reach sexual maturity at two-to-three years of age. Males reach sexual maturity at three-to-four years of age but

do not begin to breed until they reach seven-to-eight years of age (Kuzin 1999). Both sexes can live for 20-30 years.

## STUDY AREA

The Commander Islands ( $54^{\circ}56'N$ ,  $166^{\circ}32'E$ ) are located at the western edge of the Aleutian Islands. Two NFS rookeries Severnoe and Severo-Zapadnoe located on Bering Island. Medny Island also has two NFS rookeries: Urilie and Yugo-Vostochnoe (Fig. 2). Both islands are less than 40 km north of the Aleutian Trench which places them in close proximity to very deep oceanic water. The relative size of the neritic zone is small, which makes the Commander Islands more similar to St. George Island.



*Figure 2.* Geographic location of the Commander Islands and the four main rookeries.

The Commander Islands are surrounded by the Bering Sea and North Pacific Ocean. These islands are located in a subarctic region and are covered by tundra. Weather on the Commander Islands is usually windy (sometimes  $>30 \text{ m s}^{-1}$ ), and the air temperature is moderate. The average August temperature is  $+10^{\circ} \text{ C}$ , and the average February temperature  $-4^{\circ} \text{ C}$ . The annual average precipitation is ca. 500 mm (Mochalova and Yakubov 2004).

The flora and fauna are very rich. Steller sea lions, northern fur seals, harbor seals and spotted seals inhabit the coastal areas of the Commander Islands. Many cetaceans including killer whale (*Orcinus orca*), sperm whale (*Physeter macrocephalus*), minke whale (*Balaenoptera acutorostrata*), humpback whale (*Megaptera novaeangleae*), and Baird's beaked whale (*Berardius bairdi*) are common species in this area (Marakov 1964).

## HYPOTHESES

Research on NFS female foraging trips on the Pribilof Islands suggests that they exhibit mostly deep dives over the continental shelf and shallow bouts over the deep waters (Gentry and Kooyman 1986, Goebel *et al.* 1991, Goebel 2002, Call *et al.* 2008, Boltnev 2002, Loughlin *et al.* 1993). In the present work, satellite tags were used to assess the location of dives and to compare them with the ocean bathymetry. My hypothesis was:

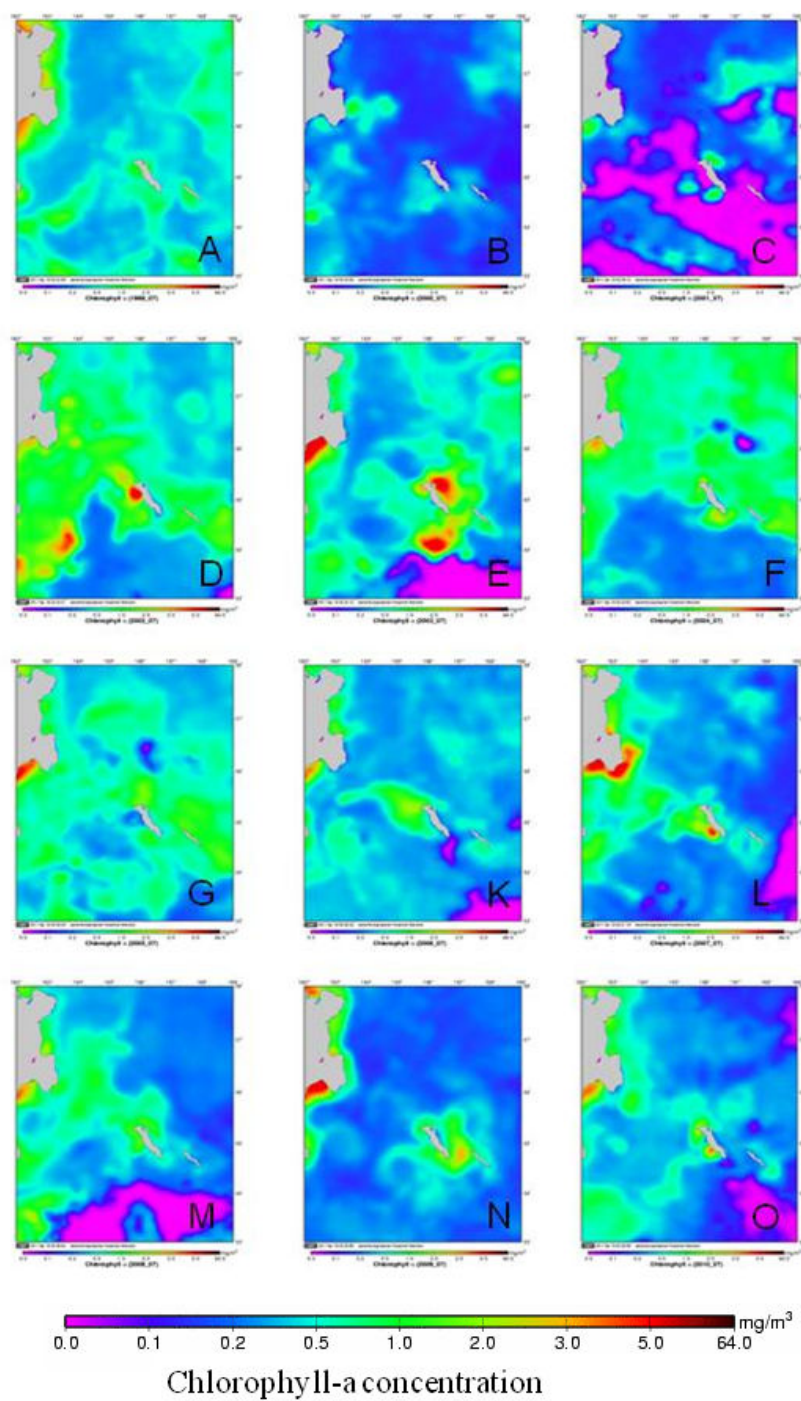
*Ho<sub>1</sub>: Lactating NFS on the Commander Islands make shallow dives at night over*

*deep water and deep dives over the continental shelf.*

Time-depth recorders (TDRs, Mk-5 and Mk-7, Wildlife Computers, Redmond, WA) were used on both Severnoe and Severo-Zapadnoe rookeries on Bering Island but in different years (Blokhin 2008). The ambient light level data obtained from the TDRs suggests that NFS from these two rookeries tend to forage mostly in different areas (Blokhin 2008). Satellite tag data from five NFS females from Severnoe rookery indicated that these seals made their foraging trips in different directions (Boltnev 2002). Location data for foraging trips made by NFS from different rookeries of the Pribilof Islands suggests foraging area segregation between seals from different locations (Robson *et al.* 2004). Therefore, the second hypothesis was:

*Ho<sub>2</sub>: Lactating NFS from the different, nearby rookeries of the Commander Islands feed in different areas.*

Differences in prey availability affect several parameters of NFS foraging trips (Gentry and Kooyman 1986, Chapman 1961, Boltnev 2002). In turn, differences in prey availability and species diversity directly depend on environmental conditions and fishery intensity (Hunt *et al.* 2010, Watermeyer *et al.* 2008, Coll *et al.* 2009). The oceanographic conditions in 2003, 2004 and 2008, 2009 were different. The strong La Niña in 1999-2001 changed to El Niño in 2002, 2003 which weakened to neutral condition in 2004 (Shwing *et al.* 2000, Assaf *et al.* 2002, Bond *et al.* 2003). The years 2008 and 2009 (up to July) were characterized by La Niña (Bond and Overland 2009, <http://sealevel.jpl.nasa.gov/science/elinopdo/elmino/>). These events affected the chl a concentration near the Commander Islands (Fig.3).



*Figure 3.* Chlorophyll a concentration near the Commander Islands in July: from 1999-A to 2010-O.

There is little information about fisheries in the Commander Islands region. Also, the published data do not necessarily report the real catch, and illegal fisheries almost impossible to verify. However, the fisheries magnitude and success probably were different among these years: the catch in 2009 was much greater than in 2003, 2004 and 2008 (Shuntov and Temnikh 2009). I formulated the third hypothesis:

*Ho<sub>3</sub>: Prey availability and environmental conditions affect NFS female foraging trip duration and diving depth.*

Most of the data on NFS winter migrations from the Commander Islands came from the pelagic collections (Kuzin 1999). Along with limited telemetric studies conducted on Bering Island, these studies suggest that most NFS migrate southwest along the Kurile Islands and Kamchatka. The winter migration of NFS from Medny Island has not been studied, but distance between these rookeries is only 100 km and probably should not affect the winter migration routes. My hypotheses were built according to these data.

*Ho<sub>1</sub>: NFS females from the Commander Islands migrate mostly southwest along the Kurile Islands and Kamchatka and stay near east coast of Japan during winter.*

*Ho<sub>2</sub>: NFS females from Medny and Bering Islands have similar winter migration routes and overwintering areas.*

For many species of pinnipeds, foraging areas and migration routes at some scale positively correlate with high chl a concentration (Lander *et al.* 2010, Hlista *et al.* 2009). There are no data on the relationship between NFS female winter migration from the Commander Islands with any of the oceanographic parameters, but it is known that NFS

pup feeding areas during their first winter migration from the Commander Islands positively correlates with chl a concentration (Lee 2011). I suggested the same correlation for NFS females.

*Ho<sub>3</sub>: Overwintering areas and migration routes of NFS females from the Commander Islands positively correlate with chl a concentration.*

Mamaev and Burkanov (2008) have observed killer whales near Medny Islands preying exclusively on NFS since 2000. Killer whales are known to prey on different seals and cetacean species in the northeastern Pacific, but near the Pribilof Islands the primary prey of killer whales is NFS (Matkin *et al.* 2007, Newman and Springer 2008). My last hypothesis focused on the potential role of killer whale predation on the Commander Island NFS population:

*Ho<sub>1</sub>: Mammal-eating killer whales prey on NFS near the Commander Islands rookeries during summer time.*

The NFS population on the Commander Islands has remained stable during the last several decades (Kornev *et al.* 2008, Ream and Burkanov 2006, Blokhin 2010). At the same time, killer whale predation on NFS has been observed near the Commander Islands and appears to have increased during the last several years (Mamaev and Burkanov 2008). Observations of killer whale predation on marine mammals are rare and most of the action occurs underwater where it could not be observed. Also, the observations were conducted during day time only, and observers could monitor only the nearshore area. The opportunity of spotting killer whales and making detailed observations of their behavior depends much on weather conditions, observer

experience, equipment and many other parameters. Therefore, most of the details of killer whale behavior are uncertain and require very careful analyses and interpretation. One way to fill in the data gaps is to construct a simulation model based on known data and run it with data for different scenarios.

I used the published data on NFS body mass and caloric value and the estimated killer whale energy requirements to construct a model that simulates predation rate based on different diets (published data and our field data). Two hypotheses were formulated concerning the killer whales' possible influence on NFS population and their prey choice:

*Ho<sub>2</sub>: The current rate of mammal-eating killer whale predation does not negatively affect the NFS population on the Commander Island.*

*Ho<sub>3</sub>: Mammal-eating killer whales prey equally on all sex and age categories of NFS.*

## CHAPTER II

### LACTATING NORTHERN FUR SEALS SUMMER FORAGING TRIPS\*

#### INTRODUCTION

The stability of any mammalian population depends on successful pup production (Clutton-Brock 1988, Krebs and Davies 1993), which is energetically demanding for the female (Iverson 2009). NFS females, as with other Otariidae, use an income-based strategy to rear a pup; that is, female milk production depends on endogenous reserves of fat that are replenished during frequent foraging trips between nursing periods on the rookery (Kovacs and Lavigne 1992, Boyd 1998, Burns *et al.* 2004). Since the pups cannot fast for long periods, the females have limited time to feed before returning to the rookery to nurse their pups (Burns *et al.* 2004). Therefore, prey availability near the rookery is a major factor affecting pup survival and health which in turn will affect overall population stability (Orians and Pearson 1979, York and Hartley 1981, Gentry 1998).

The study of NFS foraging ecology and behavior in a stable population on the Commander Islands is important not only for monitoring purposes, but because it could explain why the population on the Pribilof Islands is declining.

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\*Reprinted with permission from “Foraging ecology of lactating northern fur seals (*Callorhinus ursinus*) on Bering Island” by Belonovich, O. A., I. A. Blokhin, R. Andrews, V. N. Burkanov, and R.W. Davis. 2010. Investigation of Biological Resources of Kamchatka and North-West Pacific (19):104-115, Copyright 2010 by Kornev S.I.

Comparing female foraging behavior and habitat associations could identify critical factors that explain the different population trajectories. To identify these variables, I reviewed previous research on NFS conducted on the Commander Islands and the Pribilof Islands.

Telemetry studies of NFS on the Commander Islands began in 1990 as part of a Russia - USA agreement on environmental conservation. From July-August 1990, Gentry *et al.* (1998) equipped 20 lactating females with time-depth recorders (TDRs, MK3, Wildlife Computers, Redmond, WA) at the Urilie rookery on Medny Island. In their analysis, they used only dives  $\geq 5$  m in depth and  $\geq 0.5$  min in duration (the rest of the dives he considered as non-foraging). On average, the females made 15.9 dives (20-63 m) per hour (Gentry *et al.* 1998).

Boltnev and Stus (1998) attached TDRs (Mk5, Wildlife Computers) to 15 lactating females at Severnoe rookery on Bering Island in 1995. The data showed that the females foraged at night at depths of 10-20 m. The average maximum dive depth (for dives  $\geq 2$  m) was  $11.3 \pm 0.56$  m (all error will be presented as SD), and the maximum dive depth was 153 m (Boltnev and Stus 1998). Average foraging trip duration was 5.23 days during which the females reached the Eastern Kamchatka shelf and Olutorsky Gulf (Boltnev and Stus 1998). This research continued in 1996 and 1997 (Boltnev *et al.* 2002) when 26 females were instrumented at the same rookery. The results were similar: the mean maximum dive depth was  $11.0 \pm 1.0$  m in 1996 and  $12.9 \pm 0.5$  m in 1997, and 90% of all dives occurred between 20:00 and 07:00 hr local time (Boltnev *et al.* 2002).

From 2000 to 2004, researchers from KamchatNIRO instrumented seven females

with TDRs (Mk5 and Mk7, Wildlife Computers) on Bering Island. Their results were similar to previous studies: females foraged mostly between 21:00 and 07:00 hr local time, and most dives were shallower than 18.5 m (Blokhin 2008). Average foraging trip duration was 4.08 days (range 1.69-7.63). Light level data indicated that the NFS foraged mostly near Bering Island and in Kamchatsky Bay. Data from six females at Severo-Zapadnoe rookery on Bering Island in 2003 and 2004 (provided by I.A. Blokhin) were included in my study.

In the northeastern Pacific and especially on the Pribilof Islands, telemetry studies of NFS foraging ecology and behavior have been more extensive. At night, females make mostly shallow dives in deep water beyond the continental shelf and feed mostly on squid, which migrate upward to a relatively shallow depth (Kajimura 1985, Gentry *et al.* 1986). Females that forage on the continental shelf make deeper ( $>75$  m) dives throughout the day and night and feed primarily on fish (Kajimura 1985, Gentry *et al.* 1986).

Loughlin *et al.* (1987, 1993) and Robson *et al.* (2004) observed that on the Pribilof Islands, individuals fed in similar locations during 6-8 trips to sea. NFS females moved to and from these locations over nearly the same routes, and those animals from different islands fed in different locations.

Goebel (2002) divided NFS foraging trips into three types: shallow ( $\geq 90\%$  of dives  $\leq 30$  m), deep ( $\geq 60\%$  of dives  $\geq 50$  m) and mixed (all other). He described a large deviation in milk fatty acid signatures between shallow and deep diving patterns, indicating that animals foraged on different prey. Also, he found a significant difference

in foraging trip duration between 1995 and 1996, but trip duration did not differ between St. Paul and St. George Islands. The average foraging trip duration by females on St. George Island was  $8.6 \pm 2.2$  days in 1995 and  $7.5 \pm 1.9$  days in 1996. During these periods, females traveled up to  $258 \pm 71.3$  km and  $226 \pm 76.1$  km from the rookery, respectively.

In 2004, Call *et al.* (2008) examined 167 foraging trips from 39 females from six rookeries on the Pribilof Islands. Most females traveled to the same type of environmental site and followed the same general direction during consecutive trips. Females from St. George Island traveled a mean maximum distance of  $177 \pm 63$  km from the rookery, and the average foraging trip duration was  $6.5 \pm 1.6$  days.

In 2005 and 2006, Trites *et al.* (2009) used dead reckoning technology to study the foraging behavior of NFS on St. Paul Island (Pribilof Islands) and how it might overlap with fisheries. On average, the females' foraging trips were 7.5 days ( $n=8$ , range 5.6 – 11.2 days), during which they covered a wide area of the Bering Sea. The maximum linear distance they traveled from St. Paul averaged 279 km (range 194 – 391 km), and consecutive trips were to different areas. For dives deeper than 2 m, the fur seals made about 400 dives per day to a median depth of 6 m (Trites *et al.* 2009).

In the present study, I analyzed the same parameters of NFS foraging trips that were described above for the NFS from Pribilof and Commander Islands. This study covered two, two-year periods (2003, 2004 and 2008, 2009) which exhibited different in chl a concentrations (primary productivity) (Fig3). The fisheries intensity was also different in these years. CPUE (catch per unit effort) of salmon reached a maximum in

2009 (Shuntov and Temnikh 2009). Therefore, the difference in NFS foraging trip dive parameters were expected to differ between these periods.

## METHODS

### *Data collection*

This study was conducted in 2008 on Severo-Zapadnoe and in 2009 on Severnoe and Severo-Zapadnoe rookeries on Bering Island. Similar studies were conducted in 2003 and 2004 on Severo-Zapadnoe rookery by I.A. Blokhin and his collaborators from KamchatNIRO, and they allowed me to use their data (n=6).

Three types of TDRs were used: Mk-7, Mk-9, Mk-10 (Wildlife Computers, Redmond, WA). All TDRs had similar sensors:

- 1) depth (pressure): accurate to 1,000 m with 5 m resolution and an accuracy of  $\pm 1$  m;
- 2) temperature: accurate to  $\pm 0.1^{\circ}\text{C}$  over a temperature range of  $-40^{\circ}$  to  $+60^{\circ}\text{C}$  with  $0.05^{\circ}\text{C}$  resolution;
- 3) light: logarithmic range from  $5 \times 10^{-12}$  to  $5 \times 10^{-2} \text{ W cm}^{-2}$  which was sufficient to detect dawn/dusk down to 300 m in clear waters;
- 4) wet/dry sensor that recorded when the females hauled out;
- 5) the Mk10-F had a fast acquisition Global Positioning System (GPS).

Each female was also instrumented with a VHF radio transmitter. The TDRs and

radio transmitters were mounted on pieces of neoprene rubber and glued to the fur on the animals head or back with 5 min epoxy.

Females were captured between June 28 and July 5 after they gave birth. A protective wood box was used to approach a female on the rookery, and then the female was dragged into the box using a telescoping pole with a loop of rope on the end. Instrumentation of each female was done either in the box (2009) or on a restraining board outside of the rookery (2008). In addition to attaching instruments, we made morphometric measurements, and the entire procedure took 30-40 minutes (from time of capture to release). In 2009, each female's pup was captured, weighed, sexed, and tagged (metal tags on the fore flippers). The females were recaptured and tags removed 3-4 weeks after.

Female attendance on the rookery was monitored every 2 -3 hours from 6:00 to 23:00 hr local time using a VHF radio receiver (Advanced Telemetry Systems, Isanti, MN) on Severo-Zapadnoe rookery. When at least one of the females was present, we visually located her and confirmed the presence of the pup. The radio receiver was deployed on Severnoe rookery and it scanned the required VHF frequencies every minute.

### *Data analysis*

The following variables were determined from the TDR and GPS data:

- 1) Duration of foraging trips (absence of at least 6 hours) and time on the

rookery

- 2) Mean maximum dive depth and maximum dive depth
- 3) Number of dives per foraging trip and per day
- 4) Maximum distance traveled from rookery
- 5) Total distance traveled (based on GPS data)
- 6) Direction of the foraging trips (based on GPS data) ;
- 7) Number of dive bouts, location and duration.

“DiveMove” software in R (Luque 2007) and Wildlife Computer software (v1.24.1010) were used to analyze dive variables. For the analysis, I excluded all dives < 5 m because they were likely associated with random noise that could not be corrected by the ZOC (Zero – Offset –Correction) procedure or were shallow, traveling dives (Gentry and Kooyman 1986, Gentry 1998). A second analysis was also conducted by excluding all dives  $\leq 2$  m and  $\leq 15$  sec (Goebel 2002, Trites *et al.* 2009, Boltnev *et al.* 2002).

Variables described by Gentry (1998) and Goebel (2002) were used to divide the foraging trips of each female into shallow ( $\geq 90\%$  of dives  $\leq 30$  m), deep (60% of dives  $\geq 50$  m) and mixed. Estimation of trip duration was based on the wet/dry sensor data. Bouts were defined following the methods described by Gentry and Kooyman (1986). A series of five or more dives made within 40 minutes were considered as a single bout. Each bout was classified separately into three types: shallow bouts- where 95-100% dives were  $\leq 30$  m; deep bouts-  $> 5\%$  dives over 50 m; all other bouts-were mixed.

GPS location and dive data were downloaded and analyzed with Wildlife Computers Software (v1.24.1010). Generalized linear/nonlinear models, general linear model and Mann-Whitney U tests (in R and Statistica 6.0) were used to test for differences in mean maximum dive depth, foraging trip duration, maximum traveled distance, bouts duration, number of dives per foraging trip, time of dives and NFS mass between rookeries and years.

Location data for NFS were obtained from Mk10-F (Fastloc<sup>tm</sup>) with an accuracy of +/- 55m (95%) (<http://www.wildtracker.com/>), then the data were exported to ArcView 9.2. The July average chl a concentration was obtained from <http://oceancolor.gsfc.nasa.gov/> through Seaturtle.org maptool for 2008 and 2009. The Mantel test in Passage (<http://www.passagesoftware.net>) was used to test for correlations for seals locations and with chl a concentration by comparing two different matrices (Mantel 1967, Mantel and Valand 1970). NFS locations were converted into a matrix with x and y coordinates to determine the Euclidean distance between points. The second matrix was the concentration of chl a at a scale 0.1° degree.

The mean direction of female fur seals departing on foraging trips was determined using the algorithm of Robson *et al.* (2004) to determine rectangular Cartesian coordinates:

$$X_i = d_i \sin(q_i); Y_i = d_i \cos(q_i)$$

where  $q_i$  is the polar coordinate of the direction in radians and  $d_i$  is maximum distance from the rookery in km (Robson *et al.* 2004, Mielke 1986). Rao's Spacing Test and Watson's  $U^2$  were used to determine data distribution. These tests measure spacing

between adjacent points to determine whether the distribution is uniform, von Mises or not. Watson-Williams F test in Oriana 3 software was used to test whether the mean bearings between the foraging trips of NFS females from Severnoe and Severo-Zapadnoe rookeries were different.

To analyze difference in diet from the two rookeries, scat and spews of females and juvenile males were collected from both rookeries in 2009. Female scats and spews were collected opportunistically when we recaptured tagged females and other animals were already disturbed. During the reproductive period, bulls do not eat, and females are present on a rookery only within a male's territory. Therefore, the scats collected from the harem area of the rookery were assumed to be from females. When possible, scats were collected from known tagged individuals. Juvenile male scats and spews were collected every 10 days from the non-reproductive areas of the rookeries. The juvenile male scats and spews were also collected in 2003 and 2004 by Blokhin I.A. (KamchatNIRO). Each scat was placed in a plastic bag filled with water and allowed to soak for 24–48 hr. The mixture was rinsed through a series of three, nested mesh sieves (1.000 mm, 0.710 mm, and 0.500 mm) and the remaining hard parts (bones, beaks, caviar, otolithes) were cleaned with a brush and labeled for later analysis (Treacy and Crawford 1981). Prey species were identified to the lowest possible taxonomic group by Blokhin I.A. at KamchatNIRO. The minimum number of each prey type was calculated from the number of otoliths, bones (for fish) and beaks, eyes (for squid).

## RESULTS

### *Female morphometrics*

The average body mass and standard length of adult female fur seals on Severo-Zapadnoe rookery was  $38.7 \pm 4.9$  kg and  $131.6 \pm 4.0$  cm, respectively, and there was no significant difference among years for 2003, 2004, 2008 and 2009 ( $n=38$ ,  $F=0.5$ ,  $p=0.7$ ). The average body mass and standard length of females on Severnoe rookery ( $36.8 \pm 5.6$  kg,  $133.3 \pm 7.0$  cm,  $n = 6$ ) and Severo-Zapadnoe rookery ( $37.3 \pm 4.9$  kg,  $136.2 \pm 7.7$  cm,  $n = 6$ ) in 2009 were not significantly different ( $n=38$ ,  $F=0.1$ ,  $p=0.8$ ).

### *Duration of the foraging trips*

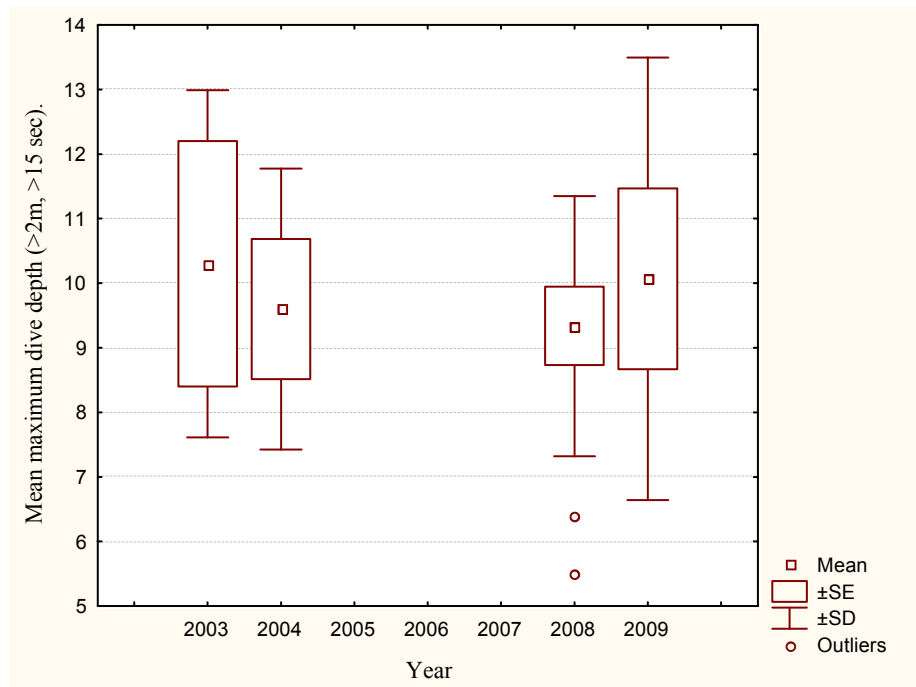
The average foraging trip duration for Severo-Zapadnoe rookery was  $3.4 \pm 1.3$  days, and there was no significant difference among the years 2003, 2004, 2008 and 2009 ( $n=114$ ,  $F=0.1$ ,  $p=0.9$ ). The average duration of the first foraging trip was  $3.3 \pm 1.3$  days, and there were no significant differences among years for 2003, 2008, and 2009, but initial trip duration ( $5.1 \pm 1.6$  days) in 2004 was significantly longer ( $n=114$ ,  $F=9.4$ ,  $p=0.004$ ).

In 2009, the average foraging trip duration of females from Severnoe rookery was  $4.4 \pm 1.9$  days and was not significantly different from the foraging trip duration ( $3.2 \pm 0.8$  days,  $n=114$ ,  $F=2.1$ ,  $p=0.2$ ) for females from Severo-Zapadnoe rookery. In

addition, the first foraging trip duration of females from Severnoe rookery ( $3.5 \pm 1.2$  days) was not significantly different from the first foraging trip duration ( $3.6 \pm 1.6$  days,  $n=114$ ,  $F=0.01$ ,  $p=0.9$ ) for females from Severo-Zapadnoe rookery.

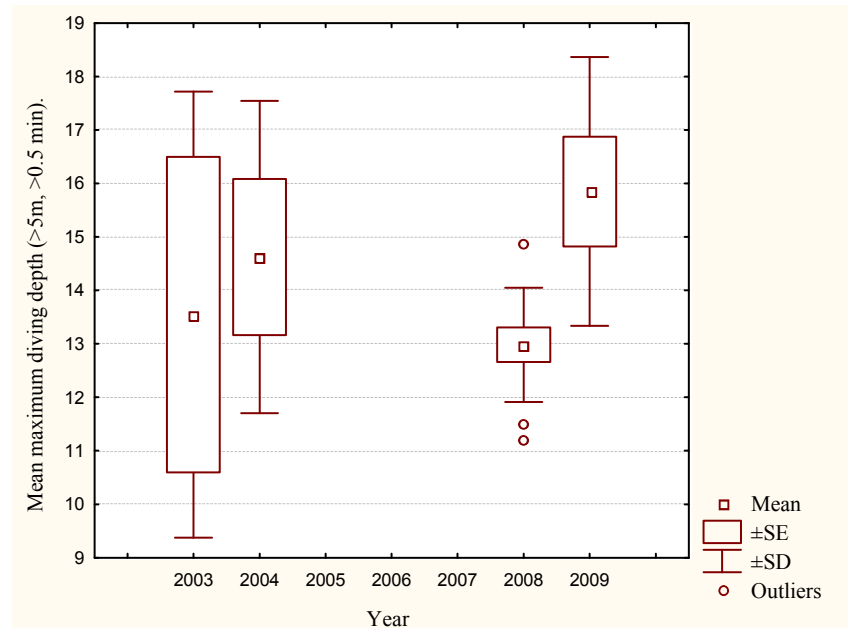
### *Dive depth*

When I considered all dives  $>2\text{m}$  and  $>15$  sec, there were no significant inter-annual differences in mean maximum dive depth for females from Severo-Zapadnoe rookery:  $10.3 \pm 8.6$  m in 2003;  $9.6 \pm 12.2$  m in 2004;  $9.3 \pm 7.5$  m in 2008;  $10.07 \pm 9.42$  m in 2009 ( $n=23$ ,  $F=0.16$ ,  $p=0.92$ ) (Fig. 4).



*Figure 4.* NFS females from Severo-Zapadnoe rookery mean maximum diving depth in different years (>2m, >15 sec).

For dives  $>5$  m and  $>0.5$  min, 11.6-89.0% of recorded dives were excluded from analysis which affected the mean maximum dive depth (Table 1). For Severo-Zapadnoe, mean maximum dive depth was:  $13.6 \pm 8.6$  m in 2003;  $14.6 \pm 17.7$  m in 2004;  $13.0 \pm 8.5$  m in 2008;  $15.8 \pm 9.8$  m in 2009 ( $n = 23$ ,  $F=2.48$ ,  $p=0.009$ ). In this case, the mean maximum dive depth in 2009 was significantly greater than in 2008 ( $F= 11.1$ ,  $p = 0.005$ ), but the average difference was just 2-3 m which is probably not biologically significant (Table 1, Fig. 5).



*Figure 5.* NFS females from Severo- Zapadnoe rookery mean maximum diving depth in different years ( $>5$ m,  $>0.5$  min).

Number of dives per foraging trip was not significantly different among the years 2003, 2004, 2008 and 2009 for seals from Severo-Zapadnoe rookery of Bering Island ( $F=1.05$ ,  $p=0.39$ ).

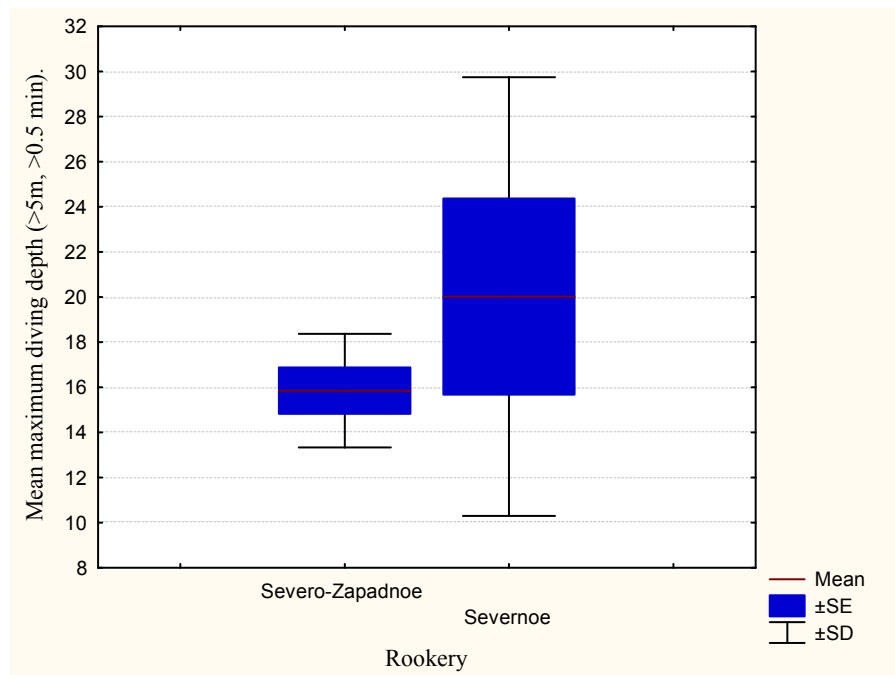
*Table 1.* Summary of lactating NFS foraging trips from Severnoe and Severo-Zapadnoe rookeries of Bering Island in 2003, 2004, 2008 and 2009.

ID	No. of foraging trips	% of excluded dives	Rookery	The average number of dives per foraging trip*	Mean maximum dive depth(m)*	Median maximum dive depth (m)
NFS04_SZ1	3	14.4	Sev-Zap	719.3	14.8±15.8	9
NFS04_SZ2	2	31.8	Sev-Zap	1 426.5	13.3±8.2	10
NFS04_SZ3	3	45.5	Sev-Zap	212.0	18.6±24.4	13
NFS04_SZ4	3	62.7	Sev-Zap	188.7	11.8±6.7	10
NFS03_SZ1	4	30.9	Sev-Zap	501.8	10.6±8.9	9
NFS03_SZ1	3	34.8	Sev-Zap	508.7	16.5±8.3	15
NFS08_SZ1	2	30.8	Sev-Zap	826.0	12.7±7.2	10
NFS08_SZ2	3	89.1	Sev-Zap	173.0	11.2±6.0	9
NFS08_SZ3	3	84.8	Sev-Zap	375.3	13.4±7.7	11
NFS08_SZ4	4	73.1	Sev-Zap	152.8	13.7±7.9	12
NFS08_SZ5	4	38.6	Sev-Zap	425.8	13.4±6.7	10
NFS08_SZ6	3	81.5	Sev-Zap	427.7	13.2±12.9	11
NFS08_SZ7	4	43.5	Sev-Zap	853.3	12.4±7.7	11
NFS08_SZ8	4	56.9	Sev-Zap	418.0	11.5±5.7	9
NFS08_SZ10	3	16.6	Sev-Zap	980.0	12.5±9.9	11
NFS08_SZ11	8	32.9	Sev-Zap	197.0	14.9±11.8	13
NFS08_SZ12	3	30.9	Sev-Zap	907.7	13.9±9.9	12
NFS09_SZ2	4	66.8	Sev-Zap	218.8	13.0±7.1	12
NFS09_SZ3	4	87.1	Sev-Zap	233.3	13.9±10.1	12
NFS09_SZ4	5	67.8	Sev-Zap	441.2	15.0±6.4	15
NFS09_SZ5	4	78.5	Sev-Zap	347.8	19.2±6.5	18
NFS09_SZ6	3	89.0	Sev-Zap	186.7	15.4±5.9	15
NFS09_SZ13	4	65.0	Sev-Zap	308.0	18.6±23.1	12
NFS09_S7	4	70.5	Severnoe	462.5	16.5±14.9	14
NFS09_S8	4	11.6	Severnoe	983.5	37.3±14.3	16
NFS09_S9	5	32.1	Severnoe	1947.0	14.3±7.4	12
NFS09_S11	4	65.3	Severnoe	548	16.9±6.9	16
NFS09_S12	3	40.2	Severnoe	984	15.0±12.7	13

\*dives ≤5 m and ≤0.5 min were excluded.

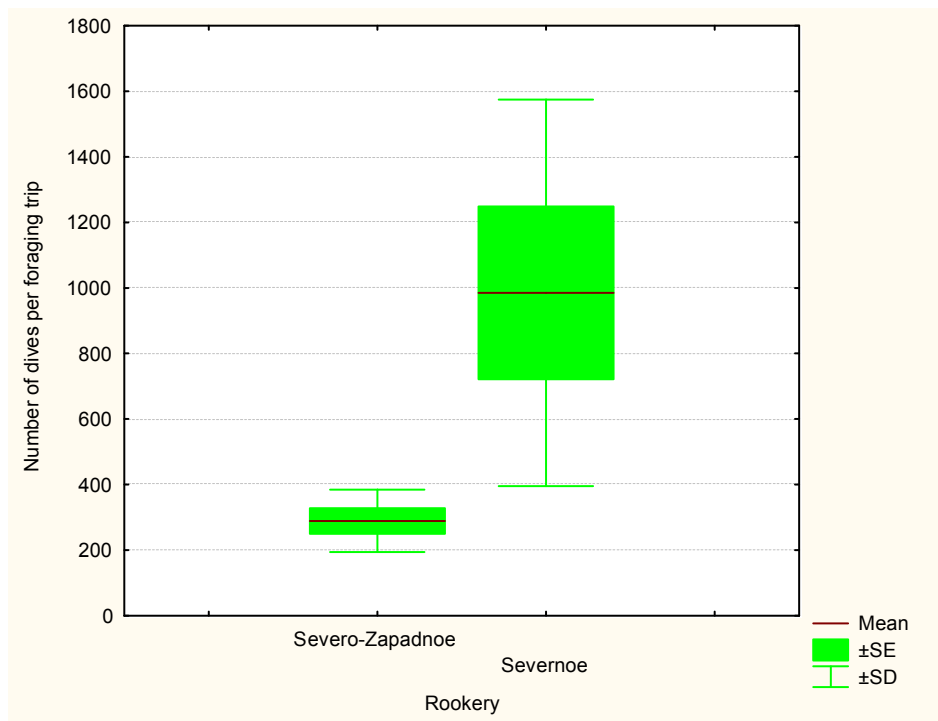
There was no significant difference ( $n=11$ ,  $F=1.04$ ,  $p = 0.33$ ) between mean maximum dive depths for females from Severo-Zapadnoe rookery ( $15.8 \pm 9.8$  m) and

Severnoe rookery ( $20.0 \pm 9.7$  m), but there was much more variation at Severnoe (Fig. 6). The mean maximum depth of one female (NFS09\_S8, 37.3 m) from Severnoe rookery was two times greater than for the other females, which ranged from 14.3-16.9 m.



*Figure 6.* The mean maximum diving depth ( $\pm$ SD) of NFS females from Severnoe and Severo-Zapadnoe rookeries of Bering Island in 2009.

The number of dives ( $>5$  m,  $>0.5$  min) per foraging trip was significantly different for NFS from Severnoe ( $\text{mean}_S = 985 \pm 589$ ) and Severo-Zapadnoe rookeries ( $\text{mean}_{SZ} = 289 \pm 95$ ;  $n=11$ ,  $F=8.3$ ,  $p=0.01$ ) (Fig.7).



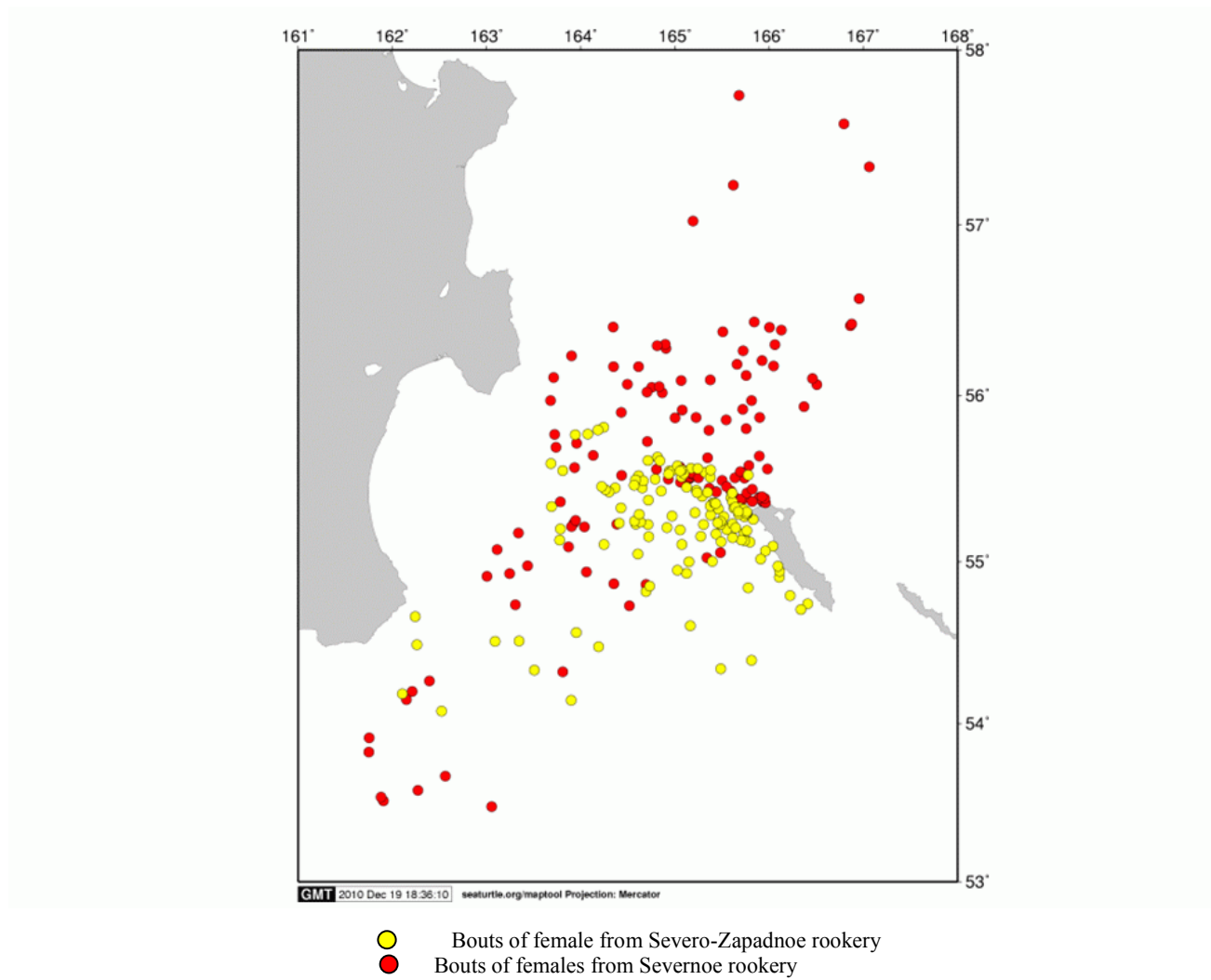
*Figure 7.* Number of dives per foraging trip made by females from Severnoe and Severo-Zapadnoe rookeries in 2009.

### *Diving bouts*

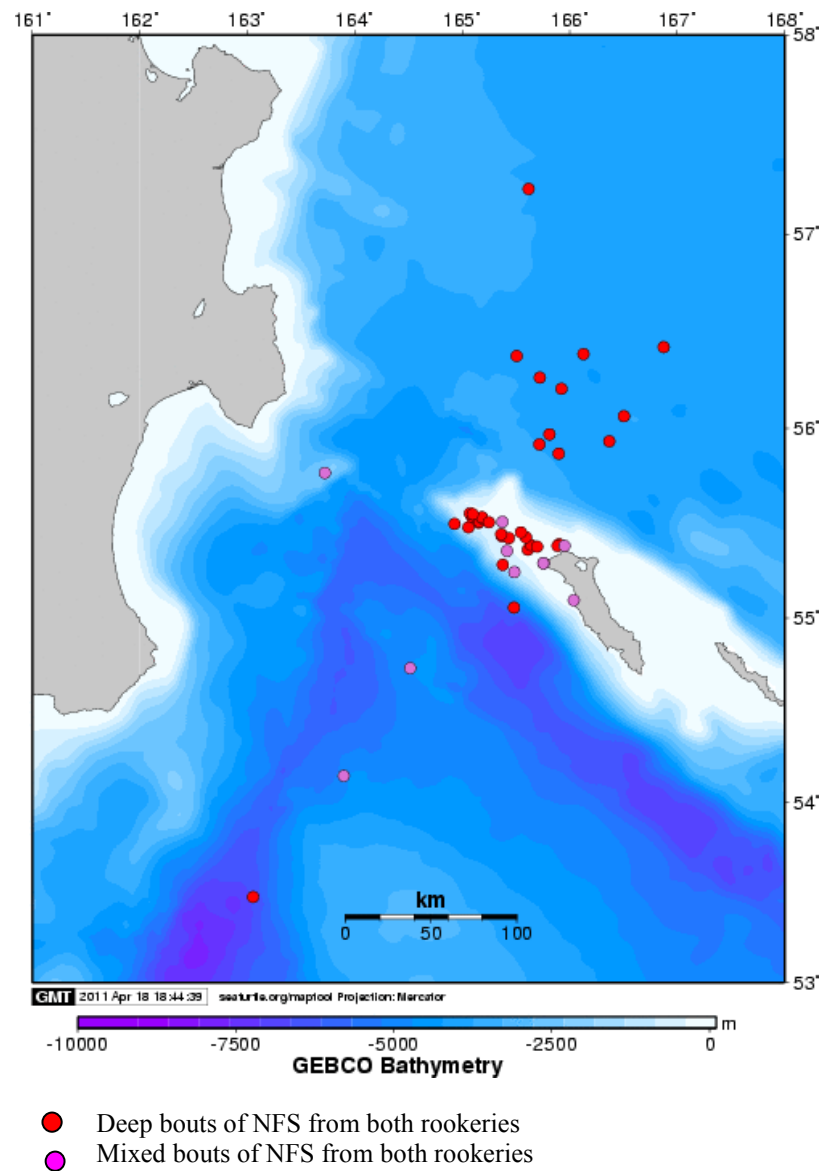
Based on the classification of Goebel (2002), all Bering Island NFS were “shallow” ( $\geq 90\%$  dives in a single foraging trip were  $\leq 30$  m). When I classified each bout separately (shallow bouts- where 95-100% dives were  $\leq 30$  m; deep bouts-  $> 5\%$  dives over 50 m; all other - mixed), then 83.9% of bouts were shallow and 16.1% were deep and mixed. Shallow dives occurred over the continental shelf as well as over the deep oceanic waters. Deep and mixed bouts occurred mostly over the continental shelf, but NFS from Severnoe rookery also made deep dives in an area 70-100 km north of

Severnoe rookery (deep waters). Shallow bouts dominated for NFS from each rookery, although almost every female made several deep dives on the continental shelf prior to returning to her rookery.

Most (> 97%) NFS dives from both rookeries occurred in bouts. On average, females from Severo-Zapadnoe rookery made 8 (range 5 -11) dive bouts per foraging trip, and females from Severnoe made 9 (range 4-14). The average bout duration was not significantly different between the rookeries;  $4.6 \pm 3.0$  hours, and  $4.9 \pm 2.7$  hours for Severo-Zapadnoe and Severnoe rookeries, respectively ( $n=315$ ,  $F=4.5$ ,  $p=0.04$ ). Dive bouts for females from both rookeries were concentrated in near-shore (< 30 km) areas west of the island and over the continental shelf where females from both rookeries overlapped. However, in deeper water, dive bouts for females from these two rookeries were mostly separated spatially (Fig. 8). Deep dive bouts were mostly located over the continental shelf and in deep waters north from Severnoe rookery (Fig. 9).



*Figure 8.* Location of NFS bouts from Severnoe and Severo-Zapadnoe rookeries.



*Figure 9.* Location of NFS deep and mixed bouts from Severnoe and Severo-Zapadnoe rookeries relative to bathymetry.

The bouts began mostly ( $67 \pm 12\%$ ) at night (21:00 to 6:00 hr) rather than during day time (6:00 to 21:00 hr) ( $33 \pm 4\%$ ,  $n=303$ , Wald statistics = 82.9,  $p < 0.001$ ) (Fig.10).

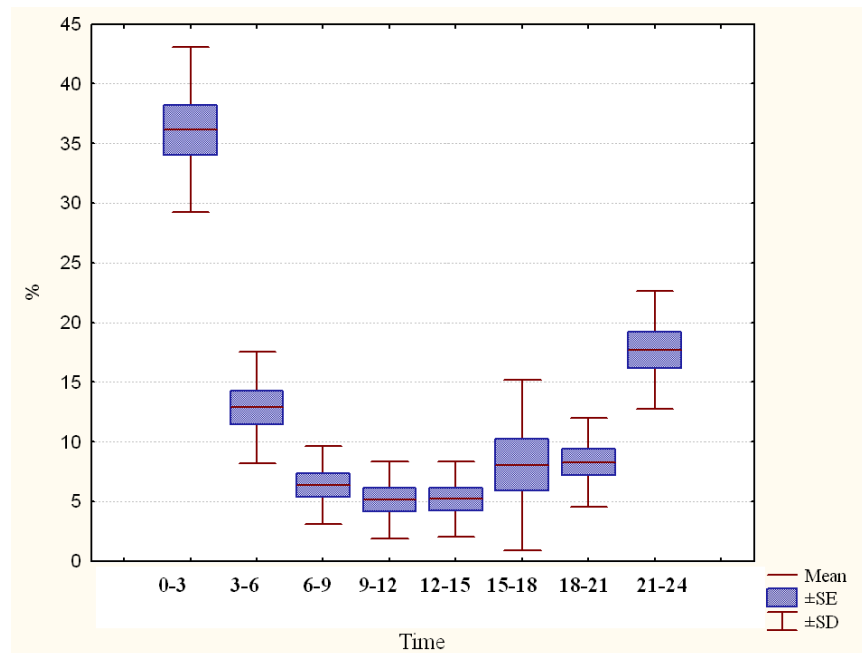


Figure 10. Start time of NFS diving bouts.

### *Foraging trip direction*

In 2008, we collected information for 12 foraging trips made by four females from Severo-Zapadnoe rookery. The direction of the majority of foraging trips was between 207°-304° or in a west and south-westerly direction. The average maximum distance from shore was  $75.9 \pm 50.0$  km (range 17-153 km).

In 2009, data were collected from 40 foraging trips made by six females from Severo-Zapadnoe rookery and five females from Severnoe rookery. On average, the maximum foraging distance from Severo-Zapadnoe and Severnoe rookeries were  $84.8 \pm 59.6$  km and  $159.1 \pm 70.8$  km, respectively (Table 2), and they were significantly different ( $n=40$ ,  $F=14.3$ ,  $p = 0.0005$ ) (Fig. 11).

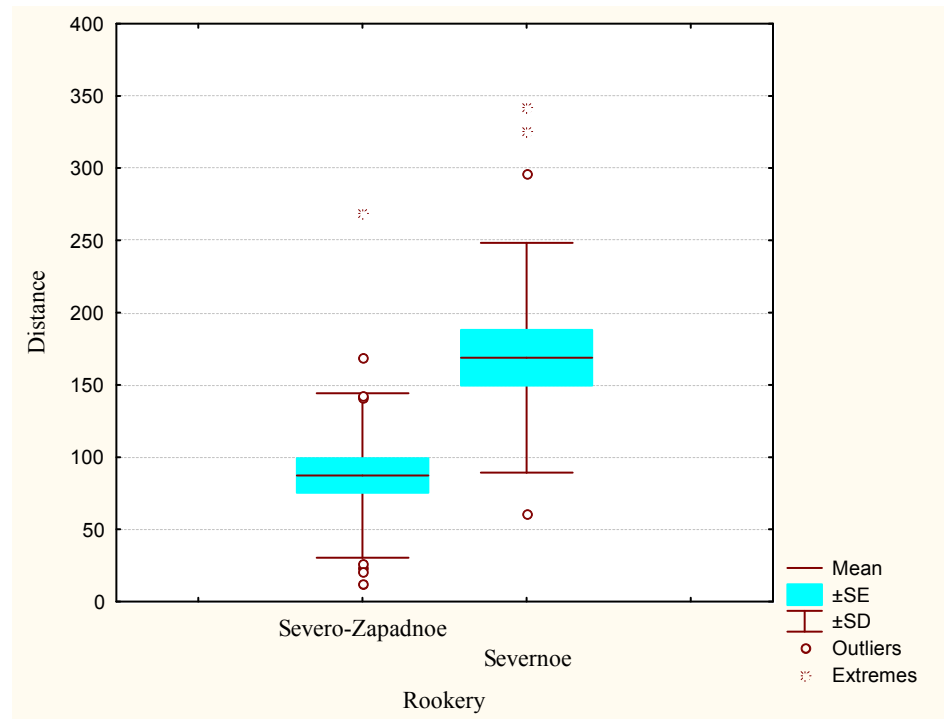


Figure 11. Maximum traveled distance by NFS females from Severnoe and Severo-Zapadnoe rookeries in 2009.

Vectors for each animal's foraging trip was calculated based on the mean bearing and maximum distance from the rookery (Table 2) (Robson *et al.* 2004).

Table 2. Summary of NFS foraging trips from Severnoe and Severo-Zapadnoe rookeries.

Seal ID	Rookery	Foraging trip	Average Bearing	Maximum distance ( $d$ , km)	Average bearing ( $q$ , radians)	$X_i = d_i \sin(q_i)$	$Y_i = d_i \cos(q_i)$
NFS09_SZ2	Sev-Zap	1	287	52	5.01	-49.7278	15.2033
NFS09_SZ2	Sev-Zap	2	208	109	3.63	-51.1724	-96.2413
NFS09_SZ3	Sev-Zap	1	185	24	3.23	-2.09174	-23.9087

Table 2 Continued

Seal ID	Rookery	Foraging trip	Average Bearing	Maximum distance (d, km)	Average bearing (q, radians)	$X_i = d_i \sin(q_i)$	$Y_i = d_i \cos(q_i)$
NFS09_SZ3	Sev-Zap	2	146	41	2.55	22.93	-33.99
NFS09_SZ3	Sev-Zap	3	152	74	2.65	34.74	-65.34
NFS09_SZ3	Sev-Zap	4	149	78	2.60	40.17	-66.86
NFS09_SZ4	Sev-Zap	1	283	101	4.94	-98.41	22.72
NFS09_SZ4	Sev-Zap	3	260	105	4.54	-103.41	-18.23
NFS09_SZ4	Sev-Zap	4	275	90	4.80	-89.66	7.84
NFS09_SZ4	Sev-Zap	5	234	123	4.08	-99.51	-72.30
NFS09_SZ4	Sev-Zap	6	222	169	3.87	-113.08	-125.59
NFS09_SZ5	Sev-Zap	1	282	26	4.92	-25.43	5.41
NFS09_SZ5	Sev-Zap	2	242	21	4.22	-18.54	-9.86
NFS09_SZ5	Sev-Zap	3	2427	269	4.24	-239.04	-123.38
NFS09_SZ5	Sev-Zap	4	265	143	4.63	-142.46	-12.46
NFS09_SZ6	Sev-Zap	1	289,5	81	5.05	-76.35	27.04
NFS09_SZ6	Sev-Zap	2	283	13	4.94	-12.67	2.92
NFS09_SZ6	Sev-Zap	3	225	88	3.93	-62.23	-62.23
NFS09_SZ13	Sev-Zap	1	314	58	5.48	-41.72	40.29
NFS09_SZ13	Sev-Zap	2	301	72	5.25	-61.72	37.08
NFS09_SZ13	Sev-Zap	3	307	71	5.36	-56.70	42.73
NFS09_SZ13	Sev-Zap	4	313	60	5.46	-43.88	40.92
NFS09_S12	Severnoe	1	314	131	5.48	-94.24	91.00
NFS09_S12	Severnoe	2	307	170	5.36	-135.77	102.31
NFS09_S11	Severnoe	1	3237	156	5.65	-92.35	125.72
NFS09_S11	Severnoe	2	265	150	4.63	-149.43	-13.07
NFS09_S11	Severnoe	3	273	146	4.76	-145.80	7.60
NFS09_S11	Severnoe	4	3077	143	5.37	-113.15	87.45
NFS09_S8	Severnoe	1	2	132	0.03	4.61	131.92
NFS09_S8	Severnoe	3	288	61	5.03	-58.01	18.85
NFS09_S8	Severnoe	4	290	93	5.06	-87.39	31.81
NFS09_S7	Severnoe	1	323	134	5.64	-80.64	107.01
NFS09_S9	Severnoe	1	337	97	5.88	-37.91	89.29
NFS09_S9	Severnoe	2	269	145	4.69	-144.98	-2.53
NFS09_S9	Severnoe	3	299	146	5.22	-127.69	70.78
NFS09_S9	Severnoe	4	262	203	4.57	-201.02	-28.25
NFS09_S9	Severnoe	5	234	342	4.08	-276.68	-201.02
NFS09_S9	Severnoe	6	242	325	4.22	-286.96	-152.58

The mean vector of foraging trips for NFS from Severo-Zapadno ( $\mu = 256.49^\circ \pm 51.85^\circ$ ) was in a westerly direction, while that for Severnoe rookery was in west-northwesterly direction ( $\mu = 300.81^\circ \pm 35.16^\circ$ ) (Fig. 12, Fig. 13). The foraging trips of all females from each rookery were concentrated in one direction (Rao's Spacing Test  $U_{SZ} = 202.7$  ;  $U_S = 217.5$ ,  $p < 0.01$ ).

A Watson-Williams F-test showed a significant difference ( $n=40$ ,  $F=7.3$ ,  $p = 0.01$ ) between mean vectors of Severnoe and Severo-Zapadnoe foraging trips (Fig. 11, Fig. 12). Each female displayed individual variation in parameters for its foraging trips. While several females made all of their foraging trips in one general direction and approximately to the same distance offshore, others dramatically changed bearing and total distance travelled among trips. At the same time, the foraging areas for NFS from Severnoe and Severo-Zapadnoe rookeries overlapped (Fig. 14).

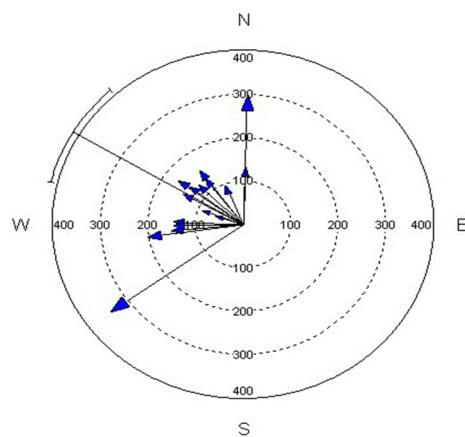
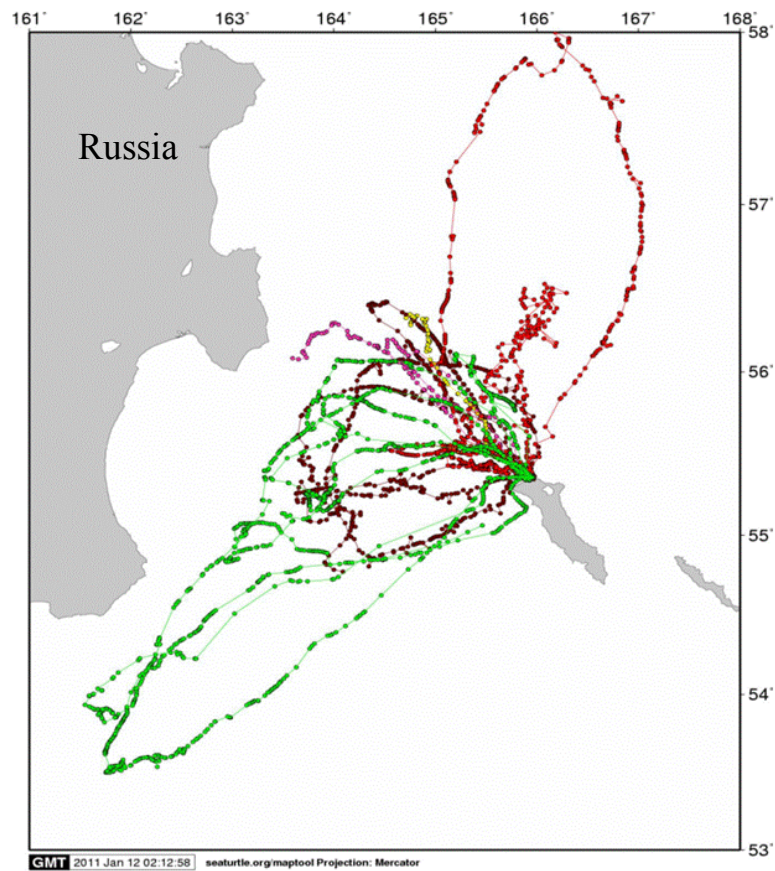
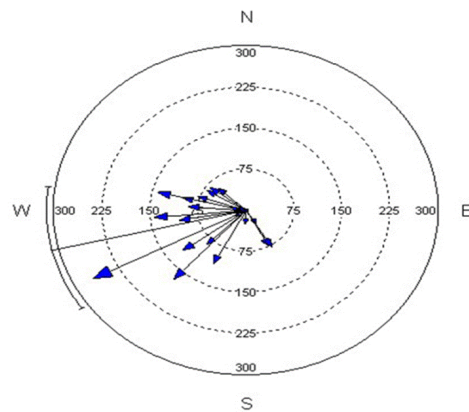
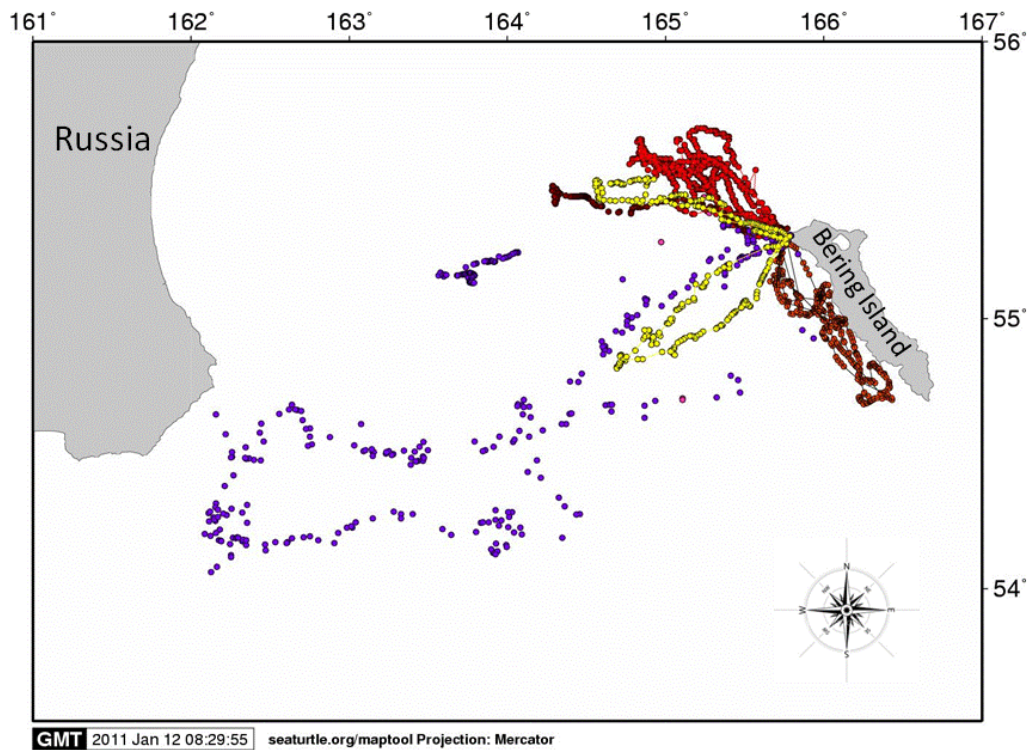
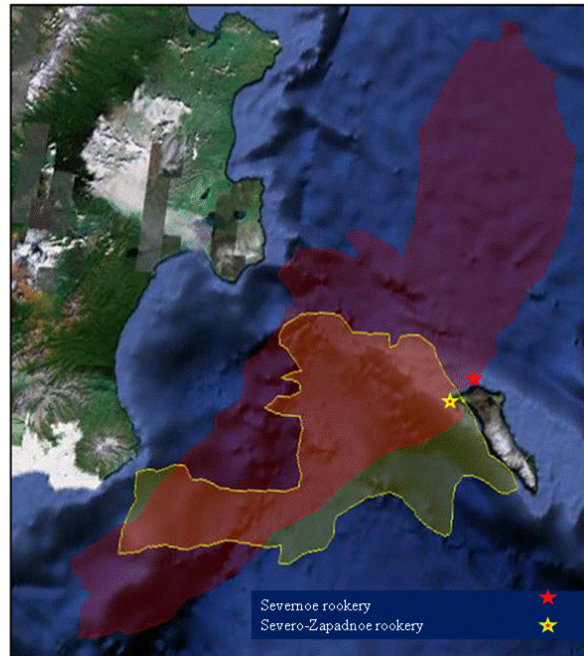


Figure 12. Tracks (upper) and vectors (lower) of NFS foraging trips from Severnoe rookery. The vectors were calculated from a mean bearing and maximum distance. Differently colored tracks represent different animals. Length of the vectors represent the maximum traveled distance (km).



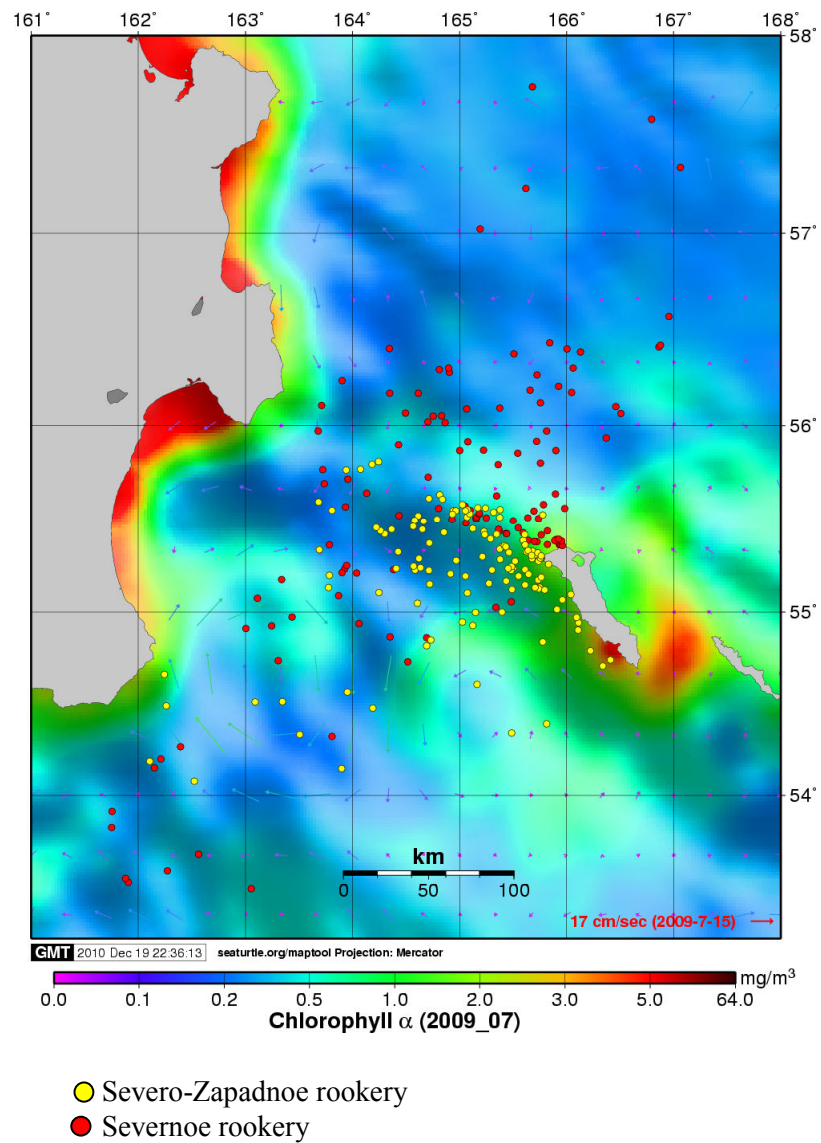
*Figure 13.* Tracks (upper) and vector (lower) of NFS foraging trips from Severo-Zapadnoe rookery. The vectors were calculated from a mean bearing and maximum distance. Differently coloured tracks represent different animals. Length of the vectors represent the maximum traveled distance (km).



*Figure 14.* Area covered by foraging trips of NFS from Severnoe and Severo-Zapadnoe rookeries. Polygons were drawn by connecting the furthest points of seals tracks.

### *Chlorophyll-a concentration*

At a 0.1 degree scale, there was no correlation between female foraging location and ( $> 5 \text{ mg m}^{-3}$ ) chl a concentration in 2009 ( $p = 0.7$ ). Only one of 11 fur seals traveled towards an area of high chl a concentration. Most (51.9%) dive bouts for fur seals occurred in areas of low  $< 0.5 \text{ mg m}^{-3}$  chl a concentration (Fig. 15). About 17% of all dives were in relatively high chl a concentration (from 1 to  $3 \text{ mg m}^{-3}$ ), but these occurred near shore (Miller 2004) where NFS traveled to and from the rookeries.



*Figure 15.* The foraging bouts of NFS females from Severnoe and Severo-Zapadnoe rookeries in areas of different chl  $a$  concentration in July 2009.

## *Diet*

Two scats were collected from known individuals (animals NFS09\_SZ 13 and NFS09\_SZ5) that carried Mk10-F tags. Both scats had remains of squid and several *Gadidae* otoliths. During their last foraging trip, these females fed in different areas. Female NFS09\_SZ13 made all foraging trips (including the last one prior to recapture) in a northwesterly direction to about 40-60 km from Severo-Zapadnoe rookery and exhibited shallow and deep dives over the continental shelf and shelf break. This female fed on squid (at least 8 individuals of *Gonatus fabricii*) along the slope of the continental shelf and also consumed at least 18 pollock (*Theragra chalcogramma*), at least one greenling (*Hexagrammos stelleri*) and two sandlance (*Ammodytes hexapterus*).

NFS female NFS09\_SZ5 traveled to the Kamchatka coast and on the way back to the rookery completed three, 4-6 hour shallow dive bouts and one deep bout with several dives to 80 m. Based on the scat analyzed, this female consumed squid and *Gadidae*. Probably, it foraged on squid during the shallow dives and on *Gadidae* during deep dives.

## DISCUSSION

Lactating NFS on the Commander Islands made mostly shallow dives during night time. Using the classification of Goebel (2002), all females in this study were shallow-diving (from 93 to 99% of their dives  $\leq 30$  m), including those that spent most

of their time over the continental shelf and those that went to deeper water. In the study by Goebel (2002) on the Pribilof Islands from 1995-1996, only 24.3% of females were shallow divers, and the others were either deep (16.4%) or mixed divers (41.3%) divers.

The difference in diving depths between the Commander and Pribilof Islands may be due to diet. NFS from the Pribilof Islands prey mostly on pollock, while those from the Commander Islands prey primarily on squid (Chugunkov and Khromovskih 1970, Panina 1970, Antonelis and Perez 1984, Shpigalskaya 1999, Goebel 2002, Blokhin 2004, Zepelin and Ream 2006). NFS preying on squid mostly exhibit relatively shallow dives (most < 20 m) at night when squid rise towards the surface at depths less than 20 m (Bower and Takagi 2004). In contrast, NFS preying on fish may make deeper dives throughout day and night (Gentry and Kooyman 1986). Goebel (2002) found a significant diet difference between deep and shallow diving NFS. Based on milk composition, he suggested deep diving females prey more on fish than shallow diving NFS, which prey mostly on squid. Using a similar definition of a dive bout as deep, mixed or shallow in this study, the majority of deep and mixed dives occurred over the continental shelf, and shallow dives occurred over the deep oceanic waters and over continental shelf. At the same time, based on scat analysis, we found that females from Severo-Zapadnoe rookery consumed both squid and fish during a single foraging trip. Feeding on different types of prey may increase the effectiveness of each foraging trip and also make the females more resistant to fluctuations in prey abundance that could be related to environmental changes.

In 2009, the mean vectors for foraging trips from Severnoe and Severo-Zapadnoe rookeries were significantly different, although the foraging areas overlapped near the continental shelf. It appears that females from the two rookeries travel in different directions when foraging in deep water (probably preying mostly on squid), but both use the limited continental shelf area (probably preying mostly on fish). Using different foraging areas by animals from adjacent, nearby rookeries is an effective way to minimize competition.

There was no significant difference between NFS foraging trip duration in 2003, 2004, 2008 and 2009. The average foraging trip duration (range  $3.2 \pm 0.8$  -  $3.6 \pm 1.3$  days) for females in this study was less than half of that reported for females from the Pribilof Islands (range  $3.7 \pm 0.1$  -  $9.8 \pm 1.7$  days;  $7.5 \pm 1.9$  -  $8.8 \pm 2.0$ ;  $7.4 \pm 0.2$ ) (Call *et al.* 2008, Robson *et al.* 2004, Kuhn *et al.* 2010, respectively). My results agree with Gentry (1998) who suggested a direct correlation between the continental shelf width and duration of NFS foraging trips. The continental shelf is narrower near Bering Island than near the Pribilof Islands.

The mean maximum dive depth of females from Bering Island and from the Pribilof Islands was similar and ranged between 10-18 m. The mean maximum dive depth of females from Severo-Zapadnoe rookery was significantly greater in 2009 than in 2008, but the difference ( $15.8 \pm 9.8$  m and  $13.0 \pm 8.5$  m, respectively) was small and probably not of biological significance. These data are also similar to those of Gentry *et al.* (1998), who studied NFS foraging ecology on Medny Island (Commander Islands) and on St. George Island (Pribilof Islands) from 1987-1990. They found that females

from St. George Island made much longer foraging trips than females from Medny Island, but the mean maximum dive depth was not significantly different. There was no difference in mean maximum dive depth between NFS females from the Commander Islands in 2009 ( $17.7 \pm 6.8$  m,  $n = 11$ ) and in 1990 ( $16.1 \pm 2.5$  m,  $n = 14$ ) (Gentry *et al.* 1998). This dive depth corresponds well with squid distribution at night, when *Gonatidae* rise from deep water to the upper 20 m of the water column (Bower and Takagi 2002). Squid represent the major part of NFS females' diet on the Commander Islands (Antonelis *et al.* 1997). The preliminary analyses of NFS females scats and spews collected in 2010 on the Commander Islands agreed with the previous data: from 82 samples collected, frequency of occurrence ( $FO = (N_i / N_t) \times 100$ , where  $N_i$  is the number of samples containing prey type  $i$  and  $N_t$  is the total number of samples, Waite 2010) for squid was about 51%. If we consider only the samples which contained hard parts, then FO of squid was 78%.

The oceanographic conditions in 2003, 2004 and 2008, 2009 were different. The El Niño that occurred in 2003 weakened in 2004. The years 2008 and 2009 (up to July) were characterized by La Niña (Bond *et al.* 2003, Bond and Overland 2009, (<http://sealevel.jpl.nasa.gov/science/elinopdo/elinino/>)). As a result, primary productivity near the Commander Islands (near surface chl  $a$  concentration) was relatively high in 2003/2004 and relatively low in 2008/2009 (Fig. 16).

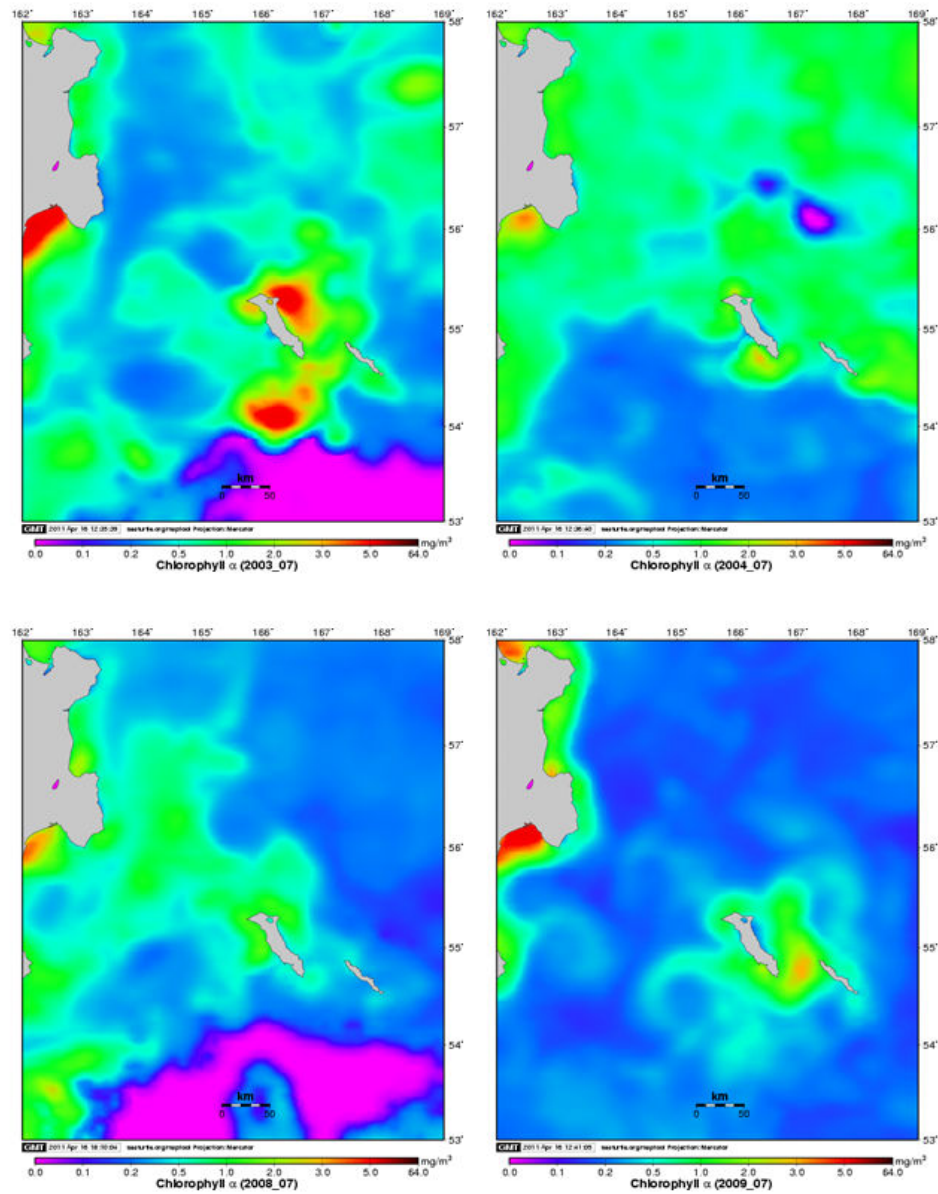
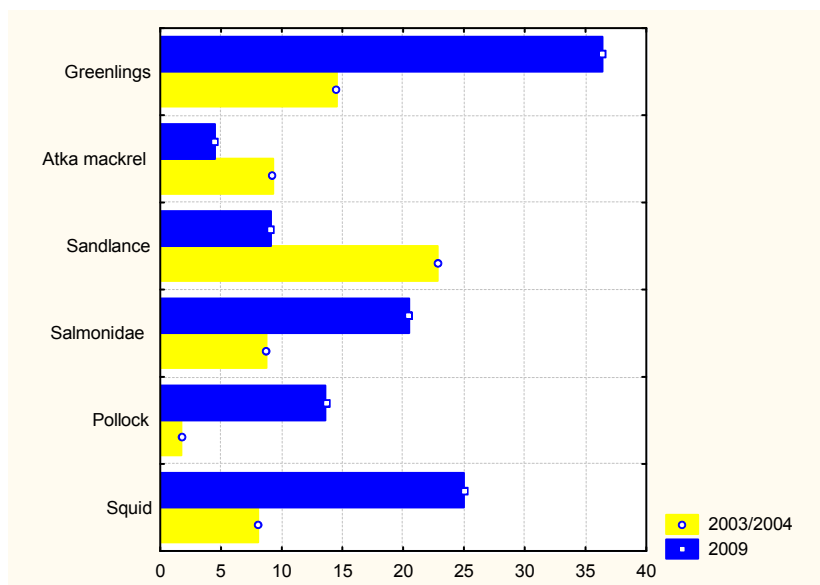


Figure 16. The chl a concentration near the Commander Islands in July 2003, 2004, 2008 and 2009.

The analyses of NFS male scats and spews collected in 2003, 2004 and 2009 suggests that prey availability near the Commander Islands changed over this period. FO of squid, pollock, salmon and greenlings were higher in 2009 than in 2003 and 2004, while FO of Atka mackerel and sandlance were lower in 2009 than in 2003/2004 (Table 3, Fig. 17).

*Table 3.* The frequency of occurrence of major (FO>5%) prey species in NFS males' diet.

	English name	Latin name	2003/2004	2009
1	Squid	<i>Berryteuthis magister</i>	8.1±8.1	25.0
2	Pollock	<i>Theragra chalcogramma</i>	1.8±1.2	13.6
3	Salmonidae sp.	<i>Oncorhynchus nerka</i>	8.8±6.0	20.5
4	Sandlance	<i>Ammodytes hexapterus</i>	22.9±7.8	9.1
5	Atka mackerel	<i>Pl. monopterygius</i>	9.3±0.9	4.5
6	Greenlings sp.	<i>Hexagrammidae</i>	14.6±19.3	36.4



*Figure 17.* Frequency of occurrence of different prey species in juvenile male fur seal diet in 2003, 2004 and 2009.

The changes in abundance of non-commercial species (e.g., sandlance) near the Commander Islands may have been associated with the environmental changes. Changes in fish abundance for NFS could be influenced by fisheries (Eggers and Irvine 2007, Bailey *et al.* 2006). Chapman (1961) suggested that fishery effects on fur seal populations could possibly be measured through the pattern of female attendance on shore, but Gentry and Holt (1986) compared their data with a previous 26 year study, and they found no difference in feeding trip duration. Our results were similar: while the fishery intensity and success were different in 2003, 2004, 2008 and 2009, there was no significant difference in NFS foraging trips duration.

High chl a concentrations reflect high primary productivity which may be associated with enhanced prey availability. For several seal species in the Southern Hemisphere, foraging behavior has been linked to high chl a concentration (Dragon *et al.* 2010, Guinet *et al.* 2001, Lea and Dubroca 2003). However, we did not find a significant correlation between high chl a concentration and the location of dive bouts at a resolution of  $0.1^{\circ}$  (only one female traveled towards an area with high chl a concentrations). For the majority of dive parameters, the strength of the correlation decreased with increasing scale suggesting that fur seals were responding to small-scale changes in these features (Lea and Dubroca 2003). Considering the difference in environmental conditions and different prey abundance in 2003-2004, and 2008-2009, foraging trip parameters for the females in this study did not change much. Probably, these changes are normal for the species. Also, the diverse diet (squid and fish) of NFS females could allow them to be more resistant to these changes.

### **CHAPTER III**

## **WINTER MIGRATION OF NORTHERN FUR SEAL FEMALES FROM THE COMMANDER ISLANDS**

### **INTRODUCTION**

NFS health and body condition during and after the winter migration are very important for successful breeding and could influence regional population levels and trajectories (Trites 1992b, Boltnev *et al.* 1998). The winter migration occupies three-quarters of the annual cycle for this species. In general, many factors influence the winter distribution and migration routes of fur seals at sea, including physiographic and hydrographic characteristics, prey distribution, and predation. Previous studies demonstrated correlations of marine mammal distribution with physiographic features such as ocean depth and seafloor slope (Evans 1975, Sutcliffe and Brodie 1977, Whitehead *et al.* 1992, Davis *et al.* 2006, Lea *et al.* 2002, 2003). Some studies also suggest correlations between marine mammal distribution and hydrographic characteristics that may secondarily affect prey availability (Jaquet and Whitehead 1996, Griffin 1999, Lea and Dubroca 2003). Sterling (2009) reported a correlation between NFS winter migrations and cyclonic eddies.

Determining foraging areas is difficult when tracking NFS on a large spatial and temporal scale. Furthermore, they probably exhibit seasonal prey preference that makes it difficult to assess habitat associations related to specific prey. The major prey of NFS

includes species of fish and squid that are fairly mobile (Panina 1966, Vladimirov 1980, Makhniry *et al.* 1982, Kajimura 1984, Antonelis and Perez 1984, Zepelin and Ream 2006). Prey may be concentrated in regions of high oceanic productivity with enhanced chl a concentration, which can be remotely sensed by satellite. For coastal, pelagic and upwelling areas, the next trophic level is approximately 15%, 10%, and 20%, respectively, of the previous trophic level's biomass (Sverdrup *et al.* 2004). Therefore, chl a concentration should correlate with zooplankton and fish biomass, which may attract female NFS. I hypothesized a positive correlation of the NFS female's locations during their migration from the Commander Islands with areas of high chl a concentration.

Information on NFS distribution during winter migration is known mostly from pelagic collections. Kuzin (1999) suggested that one-third to one-half of the fur seals from the Commander Islands population migrated to the Japanese coast. He suggested that these fur seals traveled along the Kurile Islands to the Japanese coast, while the rest of the seals traveled in south-south-easterly direction, where they mixed with the Pribilof Islands NFS (Kuzin 1999, Kuzin *et al.* 1977). Kuzin concluded that about 7 % and 27 % of NFS observed in the Sea of Japan during winter came from the Commander and Pribilof Islands, respectively. About 1 % of NFS from the Commander Islands migrated to the North American coasts. Distribution and abundance of NFS from different islands changed between years and mostly depended on abundance, sex and age parameters (Kuzin 1999, Aschepkov and Kuzin 1987).

Kiyota *et al.* (1992) were probably the first to use satellite telemetry to track NFS

females from the Pribilof Islands during their winter migration, but only for the first 2-3 months. A more detailed study tracked the winter migration of 13 females from the Pribilof Islands for at least 160 days; two of these animals ultimately returned to the rookery the next year (Ream *et al.* 2005). One of these two females traveled 9,272 km over 233 days, and the other traveled 9,732 km over 244 days with an overall average transit speed of  $2.2 \text{ km h}^{-1}$ . Their movements were associated with the Alaska Gyre and the North Pacific Current. Seven females were tracked to coastal areas in the eastern North Pacific, while three traveled to the North Pacific Transition Zone Chlorophyll Front where they may have encountered more consistent levels of productivity (i.e., chl a, Ream *et al.* 2005).

Studies of NFS winter migration from the Commander Islands are very limited. From 1991-98, Baba and Kiyota (1995) and Baba *et al.* (1999) tagged 48 NFS near the Japanese coast and Bering Island. They discovered that NFS tend to stay near northern Japan as long as they can where they foraged mostly on myctophids and gonatid squid. In 1995, Baba and Kiyota also tagged three females on Severnøe rookery on Bering Island and tracked them for 26-67 days. These females traveled 732-2,744 km with transit speed of  $1.1\text{-}1.7 \text{ km h}^{-1}$ . One animal traveled towards Japan, while two traveled eastwards to an area 518 km southeast of Unimak Island and 592 km southwest of Attu Island, respectively. All three animals eventually reached the Transition Zone ( $32^{\circ}\text{N}$ - $42^{\circ}\text{N}$ ), where they foraged mostly on a myctophids and gonatid squid (Baba *et al.* 2000).

The goal of this study was to track NFS females from Bering and Medny Islands during their entire winter migration using satellite telemetry and GLS recorders.

Specifically, my objectives were:

- 1) Investigate the validity of using GLS recorders to track large scale movements at sea,
- 2) Determine the migration routes and over-winter areas,
- 3) Assess habitat associations with oceanographic variables such as chl a concentration, sea surface temperature (SST) and ocean currents,
- 4) Compare winter migration routes during consecutive years
- 5) Compare winter migration areas of females from Bering and Medny Islands.

Based on previous research, I hypothesized that the females would ultimately migrate southwest-to-southeast towards the Transition Zone Chlorophyll Front located between 32° N and 42°N latitude (Seki 2004, Wetherall 1988), which occurs across the North Pacific. I also hypothesized that they would take advantage of the Oyashio current to facilitate their southward migration. Ream *et al.* (2005) suggested that females from the Pribilof Islands show clear directional preferences when traveling to feeding areas during the winter. I hypothesized that adult females from the same rookery would exhibit preferred feeding locations and that migration routes would be similar for consecutive winters.

## METHODS

Fur seal capture sites were located on the Severo-Zapadnoe rookery of Bering Island (*ca.* 55°29' N, 165°77' E) and Urilie rookery of Medny Island (*ca.* 54°34' N, 167°56' E), the Commander Islands, Russia. The first field season occurred from October 30<sup>th</sup> – November 1<sup>st</sup> 2007 on Bering Island, just before the females departed the rookery on their winter migration. Six lactating females were instrumented with SPOT5 satellite telemeters (Wildlife Computers, Redmond, WA). They were captured with a hoop net and anesthetized prior to gluing the telemeters to the fur on the head with epoxy. Each animal also received an Mk9 GLS (British Antarctic Survey, Cambridge, England) recorder (2.4 g) that was attached via a metal tag holder (3.8 g) to a plastic, fore flipper tag (3.0 g). In addition to the six females that had both satellite and GLS tags, an additional six females received GLS tags only. The second field season occurred from May 20<sup>th</sup> - September 1<sup>st</sup>, 2008 on both Medny and Bering Islands. Thirty-four lactating NFS were equipped with GLS tags only: 16 on Medny Island and 18 on Bering Island.

The GLS tags are archival and must be recovered to obtain the data, which was possible for this study because NFS females return to the same rookery after their winter migration (Kuzin 1999). These animals were identified visually by the numbers on their plastic tags (Fig. 18) and recaptured with a hoop net. The females were then re-weighed and the left flipper tag with the GLS recorder removed, leaving the right plastic tag with a number for future identification.



*Figure 18.* The yellow plastic and GLS tags in a left front flipper of NFS.

From the satellite telemeters, at-sea locations calculated from the Doppler effect of the satellite passing across the horizon were obtained from Service Argos. The accuracy of the estimated locations depends on the number of satellite uplinks during a single satellite overpass. Accuracy for each location class (LC 3, 2, 1) has an estimated 1-sigma error radius of 250, 500, and 1,500 m, for LC 3, LC 2, and LC 1, respectively. All locations were filtered using the Douglas filter for SAS<sup>TM</sup> and the STAT tool (Coyne and Godley 2005) to remove erroneous locations that included travel speeds greater than  $7 \text{ km h}^{-1}$ , points greater than 1,000 km apart and locations on land. The Argos filter methodology also removes locations based on rates and bearing among consecutive movements vectors. The filter moves through the tracking data and evaluates 3 locations at a time. Location data were exported to ArcView 9.2 for the analysis of habitat associations.

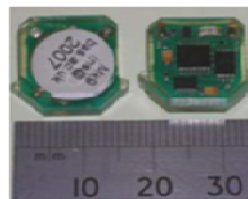
## Tags

The SPOT 5 is designed specifically for the marine environment (Fig. 19).



*Figure 19.* The satellite SPOT 5 tag (Wildlife Computers, Redmond, WA, USA). Picture by Olivia Lee.

The GLS tags record data that enable the calculation of location twice a day based on ambient light level and time, and are a highly effective tool for the tracking of a long distance migratory species (Phillips *et al.* 2004) (Fig. 20). Although, their accuracy is less than the satellite telemeters, they can record data for years.



*Figure 20.* Geolocation tag (GLS) Mk 9 developed by British Antarctic Survey (UK).

The GLS tag measures light level every minute and stores the maximum level every 10 min. The accuracy of this technique is influenced by a number of factors including season, latitude, cloud cover, ‘pollution’ from artificial light sources, shading, changes in sensor orientation, distance travelled over one day, etc. The GLS tags provide a rough location, and the actual position of animal is located in a square with a minimum side length of about  $185 \pm 115$  km (Hill 1994, DeLong *et al.* 1992, Phillips *et al.* 2004). Moreover, the calculation of latitude is impossible near the equinox (when day length is approximately equal everywhere). All data for 30 days around the equinox were excluded from the analysis.

#### *Reduction of GLS error*

Data from the GLS tags were corrected by filter and smoothing techniques. The BAS Track software provided by British Antarctic Survey was used to decompress and convert light data to latitude and longitude. All sunrises and sunsets were manually corrected using the Trans Edit 2 program (BAS Track). The Great Circle Distance formula was used to determine approximate speed between two points and delete all locations where the animals’ speed was greater than  $50 \text{ km h}^{-1}$ . All points located on land were deleted. GPS Visualiser and [seaturtle.org/ maptool](http://seaturtle.org/maptool) functions were used to plot the location data.

Of seven females were recaptured in July 2008, four of them had been instrumented with satellite and GLS tags, although the satellite tags had since fallen off.

Satellite locations were filtered based on speed and turning angles using the Douglas filter. GLS light level data was converted to latitude and longitude using BASTrak, Trans Edit, and Bird Tracker software, and then a speed filter was applied. Satellite tag location error was estimated to be less than that for the GLS tags, so daily GLS positions were compared to the best daily satellite tag position to calculate an average GLS error. In an ideal situation, if satellite locations coincided in space with the GLS locations, then all points would fall on the same line. Moving average smoothing (using span 3 and 5), Lowess smoothing, Savitzky-Golay smoothing filter, and Robust regression were used to calculate the equation which best fit all of the data and would be the closest to the mean line (Huber 1981, McKean 2004).

The Robust regression line provided the best correction for the GLS data. The rest of the GLS locations for NFS were corrected using these equations (Table 4)

$$\text{Latitude } Y = (-1.05 \pm 0.06) X - (1.78 \pm 3.15)$$

$$\text{Longitude } Y = (0.95 \pm 0.14) X + (8.44 \pm 24.01)$$

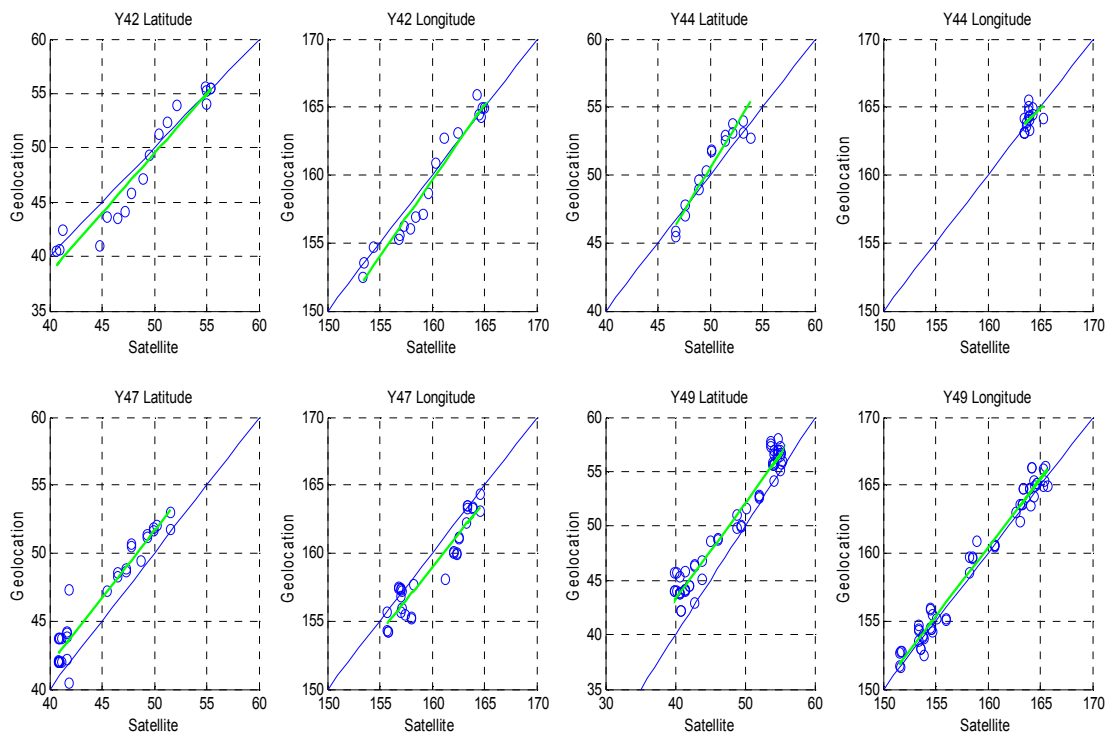
where X is the original GLS location and Y is the corrected location. The smoothing effectively reduced the mean error for GLS position from  $238 \text{ km} \pm 132 \text{ km}$  to as good as  $94 \text{ km} \pm 77 \text{ km}$  (Fig. 21).

*Table 4.* Summary of robust regression lines used to correct position error of GLS tags.

NFS ID	Latitude				Longitude			
	y42	y44	y47	y49	y42	y44	y47	y49
a	-5.31	12.5	2.62	8.08	-18.69	49.62	4.17	-1.34
b	1.10	1.26	0.98	0.88	1.11	0.70	0.97	1.01
SE <sub>a</sub>	4.13	5.10	2.05	1.35	10.83	70.55	10.87	3.80

Table 4 Continued

	Latitude				Longitude			
NFS ID	y42	y44	y47	y49	y42	y44	y47	y49
SE <sub>b</sub>	0.10	0.10	0.05	0.03	0.07	0.43	0.07	0.02
t <sub>a</sub>	-1.29	-2.46	1.28	6.01	-1.73	0.70	0.38	-0.35
t <sub>b</sub>	13.09	12.4	21.52	31.77	16.44	1.62	14.23	42.31
p <sub>a</sub>	0.22	0.02	0.21	0	0.10	0.49	0.70	0.73
p <sub>b</sub>	0	0	0	0	0	0.13	0	0



— - Robust regression line. — - The mean line.

Figure 21. The GLS locations plotted as a function of the satellite locations for each female.

The GLS location for each month was visually separated in two categories: traveling and foraging. Foraging areas were visually determined by high (>20 location for each seal) concentrations of animal locations in an area ( $\approx 10$  degrees). Traveling areas were defined as areas where animals passed more than 10 degrees in a month. Because of the large GLS tags error, time of departure/arrival from and to the rookery or foraging area was grouped into 10 day intervals for each month: A-1-10, B-10-20, C-20-30. The average monthly animal location before the northward migration was defined as a final destination. For the satellite location, the day of departure from the rookery, average speed and mean bearing were calculated for each animal in Statistica 6.0.

#### *NFS location and chlorophyll-a concentration*

For the analysis of migration routes and overwinter areas, the Mantel test in PASSAGE software (Wu and Mitsch 1998) was used to test the correlation of NFS locations with chl a concentration. The Mantel test was conducted by comparing two different matrices. One matrix was composed of X and Y coordinates and for calculating the Euclidean distance between points. Then the variable distance matrix is taken for the variable of interest in performing the Mantel test. For the satellite locations, the variable of interest was the concentration of chl a for November with a resolution of 0.1 degree from NASA's Goddard Earth Sciences Data and Information Services Center. However, the data for November had several gaps in the study area. This problem was solved using an interpolation technique of Kriging (Monte'gut *et al.* 2004, Inggs and Lord 1996).

For the GLS loggers, the correlation of chl a concentration was tested for all animal locations for each month. February and March were excluded due to the equinox and the poor latitude estimation associated with it. The chl a concentration were obtained from seaturtle.org and averaged for 2° of scale. The Mantel test was run in Passage for each month.

#### *Consecutive years NFS migration*

Two females that we tagged in November 2007 were seen but not recaptured during summer 2008. They were recaptured in July 2009 and provided data for two entire winter migrations: 2007/2008 and 2008/2009. The locations were parsed by month and compared between the two years. Data from the GLS tags were decompressed and filtered using the Trans Edit 2 program (BAS Track). NFS locations were entered into Google Earth using GPS Vizualizer and plotted using Seaturtle.org. Using the linear tool (Google Earth), I manually measured the bearing and distance to the mean location for each month for each animal. The bearings and distances were compared for December, January and April for 2007/2008 and 2008/2009 using Oriana 3 software. Distances were compared using the GLM test in Statistica 6.0. The correlation with chl a concentration was tested as described for the previous section.

*GLS data of NFS females from Bering and Medny Islands*

To compare the winter migrations of females from Bering and Medny Islands, females were tagged from both locations in August 2009 using GLS tags. In total, 34 females were tagged: 16 on Urilie rookery of Medny Island and 18 on Severo-Zapadnoe rookery of Bering Island. GPS Vizualiser and Google Earth were used to plot the data and calculate the mean bearing and maximum distance from the rookery. The mean bearing to a final destination, foraging area and maximum traveled distance for each seals were calculated for each seal in Google Earth. Oriana 3 was used to determine difference between vectors of NFS winter migration from Medny and Bering Island.

## RESULTS

Satellite tags transmitted for an average  $80 \pm 54$  days. Of 12 females tagged in November 2007, nine were seen, and seven were recaptured on the Severo-Zapadnoe rookery on Bering Island during July 2008. Two more were recaptured in July 2009. Two females (NFSg07\_SZ40 and NFSg07\_SZ46) were not seen during the years 2008-2010 and may have died during the winter migration (Table 5). NFSg07\_SZ40 and NFSg07\_SZ46 were not seen in 2008, 2009 and 2010.

*Table 5.* Summary information on NFS tagged in November 2007.

Seal ID	Serial number GLS	Satellite tag	Flipper Tag #	Tagging Date	Last satellite location	Seal mass (kg)	Date of GLS Recovery
NFSg07_SZ38	2467	-	y38	31-Oct-07	-	33.6	16-Jul-08
NFSg07_SZ39	2430	-	y39	31-Oct-07	-	34.2	30-Jul-08
NFSg07_SZ40	2486	-	y40	31-Oct-07	-	32.6	Never seen
NFSg07_SZ41	2451	-	y41	31-Oct-07	-	41.1	06-Jul-09
NFSg07_SZ42	2479	+	y42	31-Oct-07	26-Dec-07	36.4	15-Jul-08
NFSg07_SZ43	2476	-	y43	1-Nov-07	-	36.1	10-Jul-08
NFSg07_SZ44	2471	+	y44	1-Nov-07	03-Dec-07	38.0	31-Jul-08
NFSg07_SZ45	2464	+	y45	1-Nov-07	21-Nov-07	44.6	03-Jul-09
NFSg07_SZ46	2472	-	Y46	1-Nov-07	-	31.8	Never seen
NFSg07_SZ47	2465	+	y47	1-Nov-07	13-Mar-08	52.8	15-Jul-08
NFSg07_SZ48	2466	+	y48	1-Nov-07	31-Mar-08	40.0	Lost GLS tag
NFSg07_SZ49	2481	+	y49	1-Nov-07	20-Jan-08	24.0	22-Jul-08

*Female winter migration based on satellite locations*

Females were tracked for an average duration of  $80 \pm 54$  days (Table 6). The average transit speed was  $1.86 \text{ km h}^{-1}$ , and the mean bearing  $182^\circ \pm 26^\circ$  (Table 6). The Mantel test indicated that there was a spatial correlation between individual female locations and areas with chl a concentration  $> 0.1 \text{ mg m}^{-3}$  in November (Table 6, Fig. 22, 23).

Table 6. Summary of NFS winter migration parameters obtained from satellite tags.

Seal ID	Days	Day of departure	Speed (km/h)	Bearing (deg)	Chl a concentration	
					Mantel's R	p
NFSg07_SZ42	57	16/11/2007	2.10±1.5	214	0.5625	0.001
NFSg07_SZ44	33	17/11/2007	1.58±1.5	197	0.5263	0.001
NFSg07_SZ45	21	12/11/2007	1.46±1.4	149	0.6939	0.001
NFSg07_SZ47	134	12/11/2007	1.83±1.3	193	0.6136	0.001
NFSg07_SZ48	153	27/11/2007	2.12±1.2	152	0.1944	0.004
NFSg07_SZ49	81	21/11/2007	2.05±1.4	188	0.7035	0.001

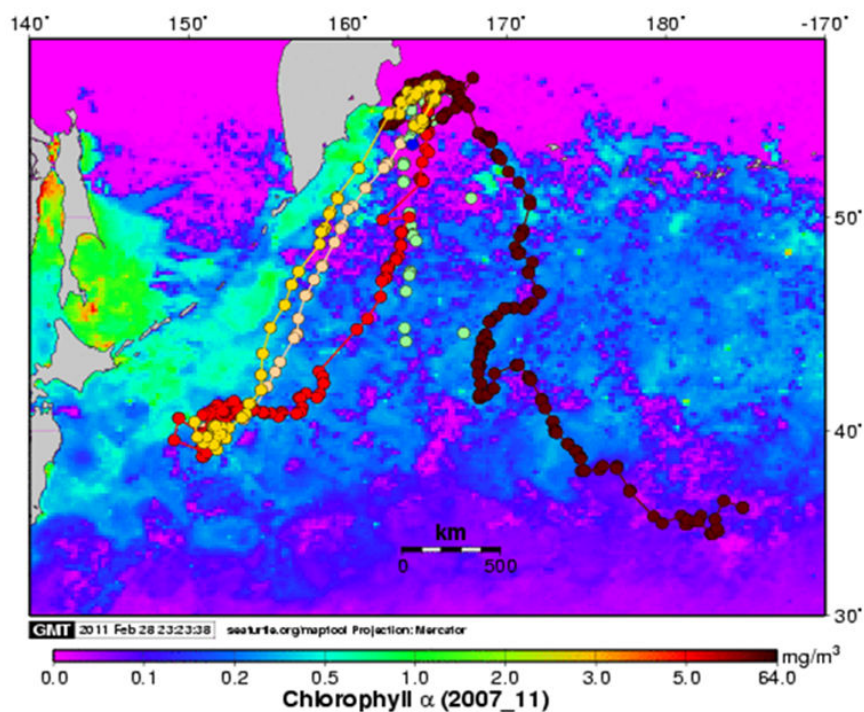
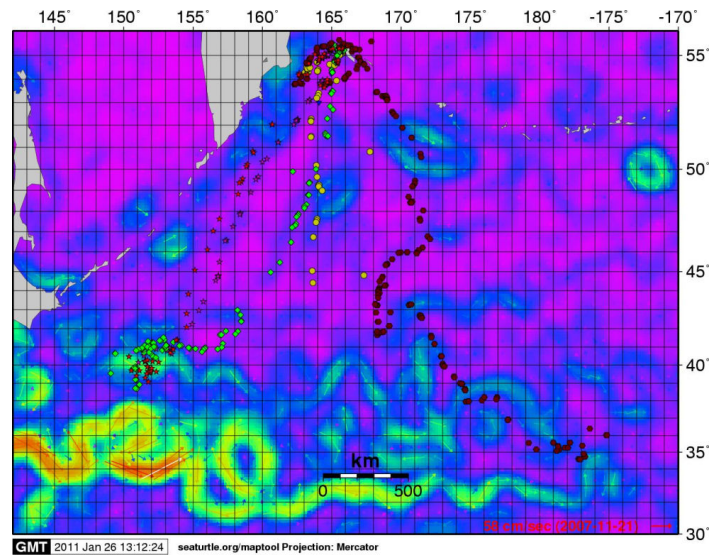


Figure 22. The satellite tracks of NFS females from Severo-Zapadnoe rookery relative to average November 2007 chl a concentration.

These females started their winter migration in mid-November. The satellite telemeters for five provided sufficient locations to show the direction of the migration. Four of these females traveled in a southerly direction and reached warm waters near 41°-42° N latitude at the beginning of December (December 3- 13). All females migrated over deep, oceanic water.

Female NFSg07\_SZ48 also reached warm waters but about 3 weeks later than the others, at the beginning of January. This female started her winter migration on November 27, about two weeks later than the others. This female did not travel directly south like the others, but spent almost a month (November, 1 -27) swimming near the Commander Islands. It appeared to forage over the Kitolovnaya Bank between Medny and Bering Islands and then migrated south-east and remained over the Aleutian trench between Medny and Attu Islands for at least one week (December, 4-10). This was the only female that traveled in a southeast-easterly (145°-131°) direction instead of south-southwesterly (194°-220°).

Three females (NFSg07\_SZ42, NFSg07\_SZ47 and NFSg07\_SZ49) reached the area of the strong, warm Kuroshio Current. They used a slightly different migration route, but by the beginning of December, they concentrated their foraging effort in a small area with warm water, strong currents and upwelling. NFSg07\_SZ45 and NFSg07\_SZ44 tended to travel in the same direction and most likely also reached this productive area (Fig. 23).



*Figure 23.* The geostrophic current magnitude map (November, 2007) and females migration paths.

Female NFSg07\_SZ48 also reached warm waters, but about 3,500 km east of the other females. In that area, the current is not strong compared to the western region. By the time all of the satellite telemeters ceased to transmit, NFSg07\_SZ48 had traveled about 1.5 times farther ( $\approx 7,300$  km) than y47 ( $\approx 5,000$  km) during the same period (up to mid-March).

#### *Females overwinter foraging areas obtained from GLS tags*

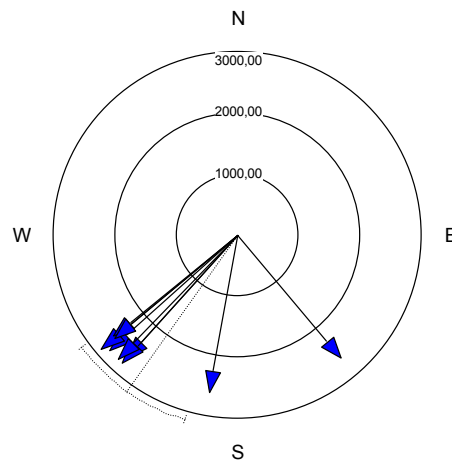
Eight of 12 females with GLS recorders were recaptured during summer 2008, but one had lost its tag. Two more females were recaptured during summer 2009, so that these recorders had data for two winter migrations. The average maximum straight-line

distance traveled from Severo-Zapadnoe rookery during the winter in 2007/2008 was  $2,711 \pm 117$  km, and the mean bearing to the final destination was  $215^\circ \pm 27^\circ$  (south-west direction from Bering Island). Due to the error of the GLS locations, the distances were rounded to 100 km. All females departed the rookery in November (Table 7) and returned between mid-June and mid-July. Rao's Spacing test indicated a significant directional preference of the bearings to the final destinations ( $U=239$ ,  $p<0.01$ ).

*Table 7.* The 2007/2008 winter migration parameters of NFS females.

Seal ID	Migration Started	Migration End	Maximum Traveled Straight Distance (km)	Mean Bearing
NFSg07_SZ38	Nov A	Jul C	2800	228
NFSg07_SZ39	Nov A	Jul B	2700	222
NFSg07_SZ41	Nov A	Jul B	2800	222
NFSg07_SZ42	Nov A	Jul A	2600	230
NFSg07_SZ43	Nov A	Jul B	2800	224
NFSg07_SZ44	Nov A	Jul B	2600	190
NFSg07_SZ45	Nov A	Jun C	2600	140
NFSg07_SZ47	Nov B	Jun B	2600	231
NFSg07_SZ49	Nov A	Jun A	2600	230

After departure from the rookery, most females traveled southward and stayed in two different, well separated areas. By mid-November to early December, these females reached the first foraging area, located  $1,666 \pm 224$  km from Bering Island with an average bearing of  $203^\circ \pm 21^\circ$  (Fig. 24).



*Figure 24.* Travel vectors of females to their final destination during the 2007/2008 winter migration from Severo-Zapadnoe rookery of Bering Island.

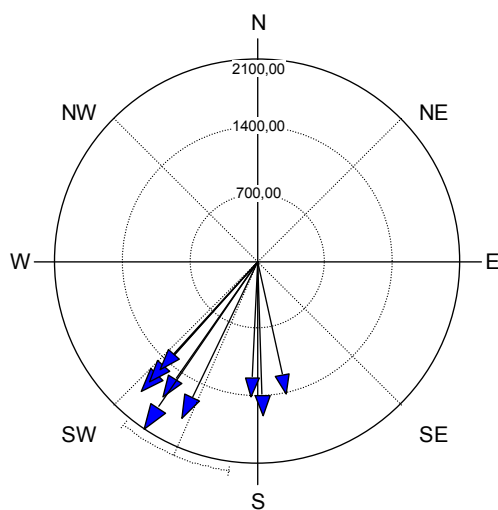
Except for two females, the females traveled to the same general area located between  $39^{\circ}$ - $45^{\circ}$ N latitude and  $150^{\circ}$ - $159^{\circ}$ W longitude and reached the area at approximately the same time. The other two females reached the first foraging area at approximately the same time, but in an area located more northeast (Table 8). All females departed the area in late December to early February, and eight of them traveled in southwest direction ( $222^{\circ} \pm 44^{\circ}$ ) towards Japan. One female (NFSg07SZ\_45) traveled in an east-south-easterly direction ( $113^{\circ}$ ) (Fig. 25).

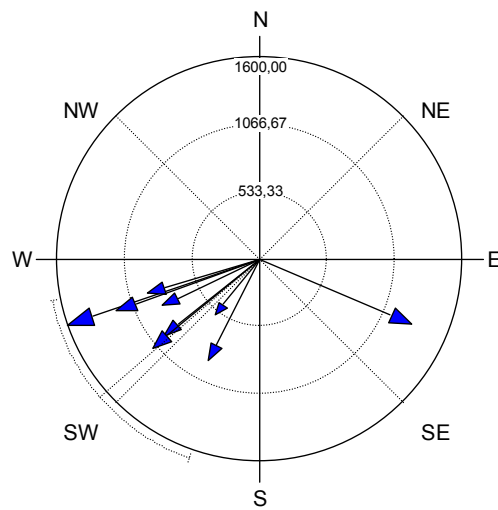
Table 8. Parameters of NFS winter foraging areas obtained from GLS tags.

Tag	Arrival 1st	Departure 1st	Distance (km)	Bearing	Approximate Location	
					Latitude	Longitude
NFSg07_SZ38	Nov C	Feb A	1800	222	40-45	148-153
NFSg07_SZ39	Dec A	Feb A	1400	183	41-45	162-168
NFSg07_SZ41	Dec A	Dec C	1717	215	40-43	153-156
NFSg07_SZ42	Dec A	Feb A	2100	214	38-41	151-155
NFSg07_SZ43	Nov C	Jan B	1800	206	39-44	154-159
NFSg07_SZ44	Dec A	Feb B	1600	178	39-56	163-168
NFSg07_SZ45	Dec A	Jan B	1400	168	41-44	166-171
NFSg07_SZ47	Dec B	Feb B	1680	222	41-45	150-157
NFSg07_SZ49	Dec A	Feb A	1500	222	43-47	150-156

Tag	Arrival 2nd	Departure 2nd	Distance (km)	Bearing	Approximate Location	
					Latitude	Longitude
NFSg07_SZ38	Apr A	Jun A	970	231	34-38	141-145
NFSg07_SZ39	Mar B	Jun A	1600	251	34-40	145-150
NFSg07_SZ41	Jan A	Feb A	560	219	36-40	147-151
NFSg07_SZ42	Apr A	Jun B	930	253	34-40	141-144
NFSg07_SZ43	Feb A	Jun B	1200	250	35-42	141-147
NFSg07_SZ44	Mar B	Jun A	900	207	32-38	159-164
NFSg07_SZ45	Feb A	May C	1300	113	35-41	172-180
NFSg07_SZ47	Mar B	Jun C	850	245	37-41	142-149
NFSg07_SZ49	Mar B	Jun A	1100	230	36-39	142-145





*Figure 25.* Travel vectors for females during the winter migration from the rookery to the first foraging area (upper) and from the first to the second foraging area (bottom).

The average distance between the first and second foraging areas was  $1,045 \pm 222$  km (Table 8). In November, December, January, April, May and June, NFS were found significantly more often in areas of high chl a concentration ( $p < 0.01$ ,  $> 0.1 \text{ mg m}^{-3}$ ) (Fig. 26).

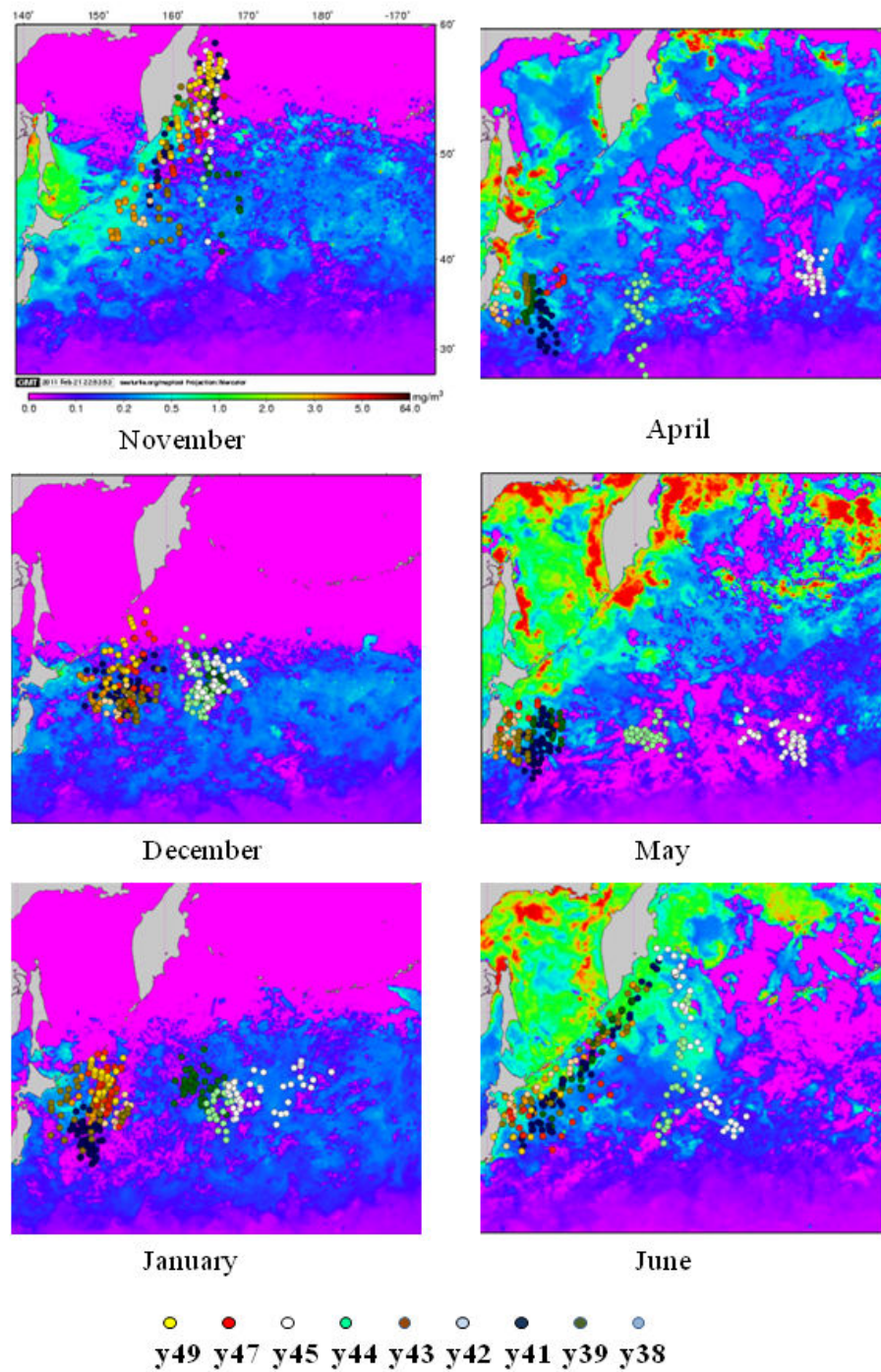


Figure 26. Females winter migration locations during November, December, January, April, May and June relative to chl a concentration.

*Consecutive years of NFS female migration*

Two females (NFSg07\_SZ41 and NFSg07\_SZ45) for which GLS data were obtained for two consecutive winter migrations showed similar movements between years. Both females started their winter migration within the first 10 days of November and returned to the rookery between late June and mid-July (Table 9).

These females used different migration paths during winter 2007/2008: NFSg07\_SZ41 migrated in a south-west direction while NFSg07\_SZ45 travelled south-east. During the next winter 2008/2009, these females repeated their previous migration routes. The straight line distance from the Severo-Zapadnoe rookery to the foraging areas for NFSg07\_SZ41 and NFSg07\_SZ45 were 2,800 km and 2,600 km, respectively, in 2007/2008. The further destination reached by NFSg07\_SZ41 was in the same area where most of our females spent the winter near the Japanese coast (bearing 222°), while the farthest destination of NFSg07\_SZ45 was in a south-easterly direction (bearing 140°). During the winter of 2008/2009, females NFSg07\_SZ41 and NFSg07\_SZ45 went in almost the same direction as in 2007/2008. Female NFSg07\_SZ41 went in the same south-west direction (bearing 214°) reaching a maximum distance about 2,900 km from Bering Island and NFSg07\_SZ45 in south-east direction (bearing 142°) to a maximum straight distance of 2,400 km (Fig. 27). As with the previous winter, both females left the rookery at the beginning of November and returned in late June-mid July (Table 9). Seal NFSg07\_SZ41 went to approximately the same areas and at the same time: it reached the 1st foraging area in the first week of December, stayed there about one month and then

traveled closer to Japanese coast (southwest) where it foraged up to the beginning of June. NFSg07\_SZ45 behaved differently: during its winter migration, I determined at least 3 different areas where this seal spent most of its time. It reached the first area with 1-2 weeks after it left rookery (mid-November), stayed there for a month and then moved south-westward to another area where it also stayed for about a month up to the late January- early February and then moved more west where it foraged up to the beginning of June (Table 9). At a 2° decimal degree scale (2x2 degree square), locations of both fur seals correlated with relatively high chl a concentration.

*Table 9.* Summary data on NFSg07\_SZ41 and NFSg07\_SZ45 during consecutive years of migration.

Year	Tag	Arrival	Departure	Distance (km)	Bearing	Approximate Location	
						Latitude	Longitude
<b>1st foraging area</b>							
07/08	NFSg07_SZ41	Dec A	Dec B	1717	215	40-43	153-156
08/09	NFSg07_SZ41	Dec A	Feb A	2000	214	37-43	151-157
07/08	NFSg07_SZ45	Dec A	Jan B	1400	168	41-44	166-171
08/09	NFSg07_SZ45	Nov A	Dec C	1200	171	43-46	164-169
<b>2nd foraging area</b>							
07/08	NFSg07_SZ41	Jan A	Jun A	560	219	36-40	147-151
08/09	NFSg07_SZ41	≈Apr A	Jun B	980	205	30-35	148-151
07/08	NFSg07_SZ45	Feb A	May C	1300	113	35-41	172-180
08/09	NFSg07_SZ45	Jan A	Jan C	780	123	39-42	173-177
<b>3d foraging area</b>							
08/09	NFSg07_SZ45	Feb A	May B	600	107	37-42	180-175

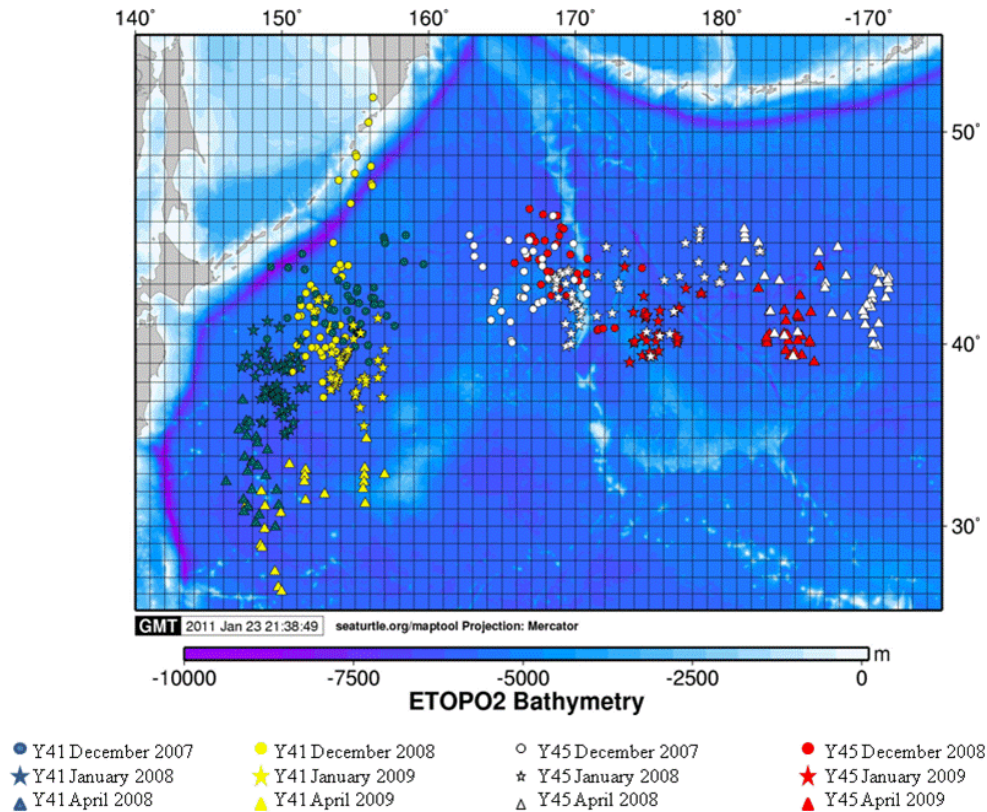


Figure 27. The two winter (2007/2008 and 2008/2009) migration routes of NFSg07\_SZ41 and NFSg07\_SZ45 from Severo-Zapadnoe rookery of Bering Island.

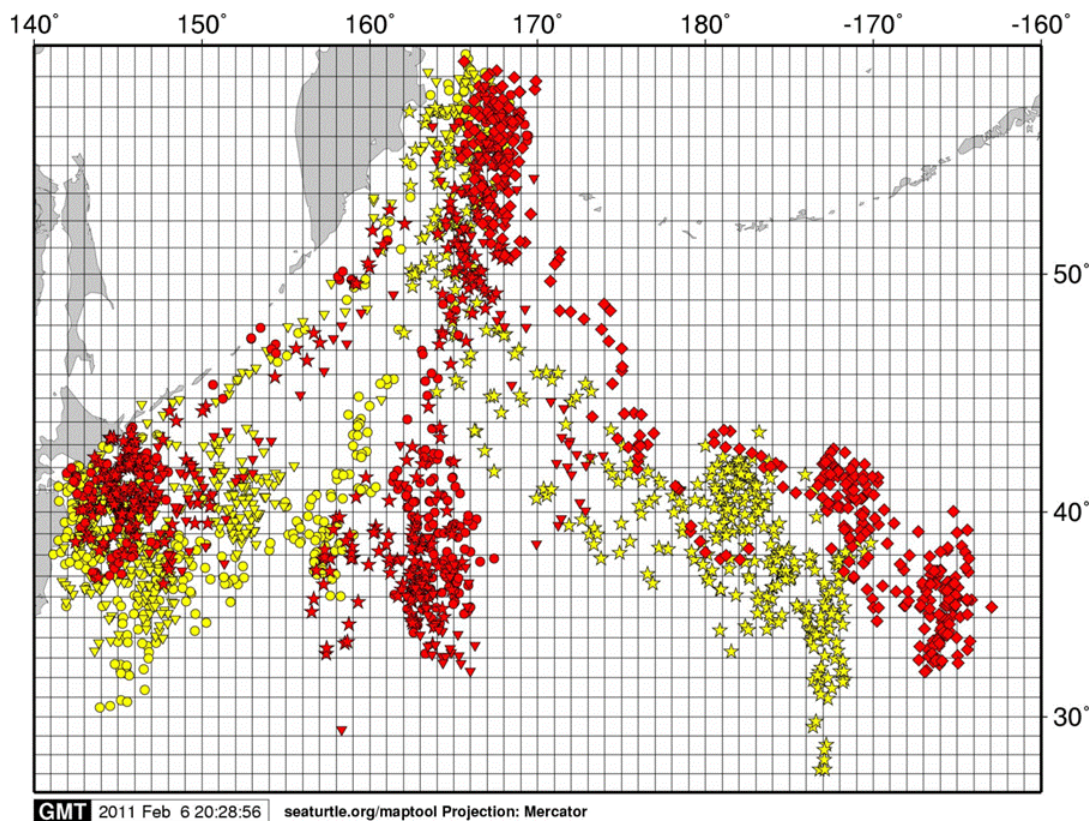
#### *Female migration from Bering and Medny Islands*

Four of 16 females tagged on Medny Island in August 2009 were recaptured during summer 2010. Four more females were seen, but 1 had lost the GLS tag and 3 others were not recaptured (Table 10).

Table 10. GLS tags number, female body mass and re-sighting in 2010.

Rookery	Seal ID	GLS serial number	Weight, kg	Seen or recaptured in 2010
Urilie	NFSg09_U77	2429	33.5	+
Urilie	NFSg09_U78	2469	39	+
Urilie	NFSg09_U79	2484	44.1	Recaptured
Urilie	NFSg09_U80	2455	36.1	Lost GLS
Urilie	NFSg09_U81	2463	44	Recaptured
Urilie	NFSg09_U82	2457	21.5	-
Urilie	NFSg09_U83	2454	22.4	-
Urilie	NFSg09_U84	2456	29.6	-
Urilie	NFSg09_U85	2467	24.5	+
Urilie	NFSg09_U86	2458	26.6	+
Urilie	NFSg09_U88	2474	30.2	Recaptured
Urilie	NFSg09_U89	2473	20.7	-
Urilie	NFSg09_U90	2461	27.5	+
Urilie	NFSg09_U91	2462	25	+
Urilie	NFSg09_U92	2460	28.1	+
Urilie	NFSg09_U93	2454	26.9	Recaptured
Severo-Zapadnoe	NFSg09_SZ101	2428	45.5	+
Severo-Zapadnoe	NFSg09_SZ102	2483	31.8	-
Severo-Zapadnoe	NFSg_SZ103	2487	37.5	Recaptured
Severo-Zapadnoe	NFSg_SZ104	2452	46.6	Recaptured
Severo-Zapadnoe	NFSg_SZ105	2485	38.6	-
Severo-Zapadnoe	NFSg_SZ106	2470	31.9	-
Severo-Zapadnoe	NFSg_SZ107	2477	35.1	-
Severo-Zapadnoe	NFSg_SZ108	2453	24.9	-
Severo-Zapadnoe	NFSg_SZ109	2450	34.3	+
Severo-Zapadnoe	NFSg_SZ110	2475	28.5	-
Severo-Zapadnoe	NFSg_SZ111	2449	45.1	-
Severo-Zapadnoe	NFSg_SZ112	2480	26.4	-
Severo-Zapadnoe	NFSg_SZ113	2468	39.9	+
Severo-Zapadnoe	NFSg_SZ114	2471	34.1	-
Severo-Zapadnoe	NFSg_SZ115	2481	45.2	-
Severo-Zapadnoe	NFSg_SZ116	2479	32.1	+
Severo-Zapadnoe	NFSg_SZ117	2430	34.6	-
Severo-Zapadnoe	NFSg_SZ118	2476	33.2	Recaptured
Severo-Zapadnoe	NFSg_SZ119	2465	29.2	Recaptured

Four females were recaptured on Bering Island during summer 2010. Females from both islands started their winter migrations in a mid-to-late November and reached the productive Transition Zone Chlorophyll Front in December. One female from Medny Island and one from Bering Island traveled in a south-easterly direction and stayed in an area 1,200 - 1,500 km south of the Aleutian Islands during the entire winter (Fig. 28). On their return to the Commander Islands, they retraced their original route north.



*Figure 28.* Winter migration of females from Medny (red) and Bering (yellow) Islands.

Three females traveled southward from Medny Island ( $\approx 180^\circ \pm 14^\circ$ ), but in March - April moved westward to towards the Japanese coast. Three females from Bering Island migrated more westerly ( $\approx 210^\circ \pm 13^\circ$ ) and swam along Kamchatka and the Kurile Islands. From December-February, these females were located near Hokkaido, and from March-April they moved closer to Honshu Island. From March-April, females from both islands were located near Honshu. Also, NFS from both Medny and Bering Islands migrated back to the Commander Islands along the Kurile Islands and Kamchatka ( $\approx 37^\circ \pm 4^\circ$ ).

## DISCUSSION

The GLS tag is a useful telemetry device for tracking the complete winter migration of NFS females. After filtering and smoothing techniques were applied, GLS tags provided accurate enough locations for the habitat-association analyses. Furthermore, these tags had a relatively high return rate ( $\approx 75\%$ , from 12 NFS tagged in 2007, 10 were recaptured, 1 of them lost its GLS tag) and provided unique data for two consecutive years of migration. These tags have many advantages including their very small size, long battery life and enough memory to record data for 3-4 years. In addition, they are inexpensive so that large numbers can be deployed, providing a sample size that is potentially much larger than would be possible using satellite telemeters.

Most of NFS females migrated southwest, although some of them migrated south and southeast. The early winter migration behavior of females appears to be strongly

related to the areas of  $> 0.1 \text{ mg m}^{-3}$  surface concentrations of chl a. Although all females reached the Transition Zone in North Pacific during the winter and remained in relatively warm waters and constant chl a concentration areas, I hypothesize that those that traveled closer to Japan (southwest and south direction) had some advantages over females that traveled south-east from the Commander Islands. First, these females traveled along Kamchatka and the Kurile Islands using the Oyashio Current, which probably facilitated their southward movement. Second, these females reached the most productive area east of Hokkaido Island, where cold Oyashio and warm Kuroshio currents meet and produce medium and small scale eddies that attract NFS (Sterling 2009).

NFS from Urilie rookery (Medny Island) migrated south, and moved west to the Japanese coast in February-March, where they intermixed with NFS from Bering Island. During their northward migration back to Medny Island these females along with NFS from Bering Island swam along the Kurile Island and Kamchatka peninsula. The highest productivity occurs close to shore along the western boundary area, especially during spring months (McKinnell 2004). High primary productivity attracts animals of all trophic levels. NFS from Medny Island moved to the coastal area also in spring. It is possible that NFS “know” that food becomes more concentrated in this area at certain times and purposely travel there. NFS from the Pribilof Islands lose weight during the early part of the winter migration and regain the mass just 1-3 months prior to the arriving on the rookery (Trites and Bigg 1992, Trites 1992b). I hypothesize that this is also true for NFS from the Commander Islands. During the final months of the winter migration, females should gain enough body mass to produce a pup and nurse it. When

the females swam back to the rookeries along the shore, they may have had more easily accessible prey during the entire northward migration. This would be a big advantage, especially just prior to the energetically costly period of pup rearing.

NFS females that were tracked during two consecutive years used similar routes each year. This may indicate that they traveled to a known location. I hypothesize that females migrate to the same general location each winter for their entire life. On a large scale, most of the oceanographic parameters (chl a concentration, SST, location of upwelling zones) depend mainly on physical and environmental forces (earth rotation, geostrophic currents, seasonal changes) and, therefore, may not change during the normal life span of a NFS. If females orient on one or some of these variables during their migration, they would likely use the same migration route each year. Both winters (2007/2008 and 2008/2009) were similar and occurred during a negative Pacific Decadal Oscillation phase that lasted from September 2007 through July 2009 (Peterson *et al.* 2010). On the other hand, on a smaller scale, the SST, upwelling regions, current magnitude and therefore chl a concentration and ocean productivity directly depend on ENSO events, regime shifts, global warming, etc. (McKinnell and Dagg 2010). Some of these events or a combination of them could affect ocean productivity in some local regions (meso- and small-scale). In this case, the northwestern Pacific probably has more concentrated NFS prey than the central North Pacific. The northwestern Pacific is a western-boundary, characterized by high primary productivity (Sverdrup *et al.* 2004, Miller 2004).

Lee (2011) found that most NFS pups during their first migration from Severo-Zapadnoe rookery on Bering Island moved along the Kamchatka coast and the Kurile Islands. These pups traveled through highly productive areas and, most likely, they had a better chance of survival than pups traveled in other directions (Lee 2011). Probably, the enhanced survival of these pups during their winter migration may explain the greater number of adult NFS migrating to this area.

**CHAPTER IV**

**KILLER WHALE PREDATION ON NORTHERN FUR SEALS ON**

**THE COMMANDER ISLANDS: OBSERVATIONS AND SIMULATION**

**OF ALTERNATIVE HYPOTHESES REGARDING**

**KILLER WHALE DIETS**

**INTRODUCTION**

The impact of killer whale predation on marine mammal populations is controversial. Due to the extreme difficulty of collecting data on the predator-prey relationships of marine mammals, field observations of killer whales and their prey can be interpreted from a variety of perspectives (Estes *et al.* 1998, 2009, Williams *et al.* 2004, Springer *et al.* 2003, Wade *et al.* 2009). Because of their size, mobility and energy requirements, coupled with the relatively low reproductive capacity of their mammalian prey, killer whales have the potential to drastically reduce prey populations. However, due to their relatively low numbers, rapid movements and large ranges, as well as the often cryptic nature of their foraging behavior, direct observation of killer whale predation is extremely limited. Nevertheless, information on their energy requirements and digestive efficiency, their whole body caloric value, and basic demography of their potential prey, and at least sketchy evidence regarding their prey preferences, permits a physiological-demographic approach for hypothesizing different scenarios regarding the impact of killer whale predation on prey populations (Williams *et al.* 2004).

NFS populations are stable in the northwestern Pacific (Burkanov *et al.* 2007, Blokhin *et al.* 2007, Kornev *et al.* 2008) but are declining in the northeastern Pacific (Costa *et al.* 2002, Towel *et al.* 2006). Scientists have focused attention primarily on the possible roles of food limitation, pollution, and disease as causes of the decline (Trites *et al.* 1997). However, predation by killer whales has been proposed as a potential reason for the population decline near the Pribilof Islands (Hanna 1922, Newman and Springer 2008), where predation events have been observed.

Killer whale predation on NFS has been observed rarely in the northwestern Pacific (Grebnitsky 1902, Bychkov 1967), although, over the past ten summers predation events were observed off Medny Island, (Mamaev and Burkanov 2006) and during the past two years off Bering Island. Although killer whales have demonstrated the behavioral flexibility to alter their diet opportunistically, their effect on marine mammal populations is uncertain. The main question of this study was: What are the possible implications of killer whale predation for the NFS population of the Commander Islands in particular and, by extension, for the NFS population on the Pribilof Islands?

In this study, I explored the potential impact of killer whale predation on NFS populations under various hypotheses regarding killer whale diets. First, two alternative versions of an age- and sex-structured model simulating the birth, maturation, and (non-killer whale) mortality of NFS based on published life history and demographic information were developed. Then I drew upon our field observations from the

Commander Islands, as well as information in the literature, to hypothesize 12 alternative killer whale diets.

### *Background information*

In the northeastern Pacific, killer whales are currently classified into three ecotypes: transient, resident or offshore. Resident killer whales live in large (>10) groups (or pods) and feed on fish and squid. Transient killer whales travel and hunt mostly in small pods of two-to-five individuals and feed primarily on marine mammals, including other whale species, dolphins, seals, and sea otters (Ford *et al.* 2000). Some pods hunt and spend more time in open water, whereas other pods prefer to travel near to shore and hunt near pinniped haul-outs and rookeries (Baird 1994). Data on killer whale populations in the North Pacific are controversial: based on photo ID catalogs, the transient killer whale population along the west coast of the United States has been estimated at 336 - 344 individuals (Matkin *et al.* 1999). Wade *et al.* (2000) suggested that at least several hundred transient killer whales occur along the Alaska Peninsula and Aleutian Islands. Little is known about offshore killer whales behavior and dynamics.

## METHODS

### *Field Data*

There are four main pinniped rookeries on the Commander Islands, two on Medny Island (Yugo-Vostochnoe and Urilie) and two on Bering Island (Severnoe and Severo-Zapadnoe). Our research team and I collected field data from the Yugo-Vostochnoe rookery during daylight hours (5:30- 23:30) in the summers (June-August) from 2005 to 2010 and on Urilie rookery on Medny Island during daylight hours in July 2006-2010, and occasionally (one every a 5-10 days) in June and August 2006-2010 and 2005. I also conducted continuous daily observations on Severnoe and Severo-Zapadnoe rookeries of Bering Island during July 2008 and May-August 2009. The additional observational data came from our collaborators and coauthors: Mamaev E.G. *et al.* (pers. comm.) conducted the observations on killer whales from 1999- 2004 on Medny Island; Blokhin I.A. (pers.comm) continued my observations on Severnoe rookery in 2010.

The Severnoe rookery is the most densely populated on the Commander Islands, located within 16 km of the smaller Severo-Zapadnoe rookery. The Yugo-Vostochnoe rookery is the largest rookery on the Commander Islands where both NFS and Steller sea lions breed. The Urilie rookery is the smallest rookery, located about 14 km from the Yugo-Vostochnoe rookery.

The NFS were counted on the rookeries at five-day intervals, Steller sea lions every day and harbor seals and sea otters every two hours during the day. The near-shore

area adjacent to the rookery and the largest haul-outs were visually scanned at hourly intervals for killer whales on Medny and Bering Islands during daylight hours. Under good weather conditions, killer whales could be detected up to 20 km from our observation point using binoculars and a telescope. Detailed behaviors of killer whales and their prey could be observed within about 1-2 km of shore. Whenever possible, we approached killer whales in a skiff and took digital images (Canon 40D, Canon 350 D) and skin biopsies.

### *Model development*

The model was formulated as an age- and sex-structured compartmental model based on difference equations ( $\Delta t = 1$  month, programmed in STELLA®7.3, isee systems, 2001) to represent the birth, maturation, and mortality of the NFS on the Commander Islands. Pups are born only in July and are classified as pups until they reach 12 months of age. Juvenile females and males become adults (sexually active) at 24 months and 84 months (seven years) of age, respectively (Kuzin 1999). I used estimates of age-specific natality and mortality rates based on data from Barlow and Boveng (1991) for NFS and Lima and Páez (1997) for South American fur seals to develop two alternative versions of the model. In the first version, the population remained stable, and in the second version the population grew slowly. I assumed the mortality estimates did not include killer whale predation.

The NFS mortality included killer whale predation in 12 (three sets of four) different hypotheses regarding their diets, and I assumed that killer whale predation was additive to other sources of mortality. I first hypothesized that killer whales satisfy: a. 100%, b. 39%, c. 18% respectively, of their food requirements by feeding on NFS during the five months (May through September) when the fur seals are on their breeding grounds (Table 11). Hypothesis A was the “most severe-case” scenario consistent with our own observations near the Commander Islands, where we have observed killer whale predation only on NFS. Hypothesis B was based on the supposition that NFS comprise a similar proportion of killer whale diets near Medny Island as occurs for several seal species near British Columbia and Alaska, where Guénette *et al.* (2007) suggested that 78% of killer whale diets were composed of various species of seals. I assumed that half of these seals ( $78\% / 2 = 39\%$ ) might belong to single species. Hypothesis C was based on the assumption that NFS comprise the same proportion of killer whale diets near Commander Islands as Steller sea lions do near British Columbia and Alaska, where Barrett-Lennard *et al.* (1995) calculated that 18% of killer whale diets were composed of Steller sea lions.

Under each of these three hypotheses, I further hypothesized that the NFS consumed by killer whales were of particular age and sex classes. The hypotheses were that killer whales consume (1) only adult and juvenile males, (2) almost exclusively pups but also a few juveniles, (3) primarily adults but also some juveniles and a few pups, and (4) all age and sex classes equally (Table 11).

*Table 11.* Summary of parameter values used in the model to represent the 12 different hypotheses regarding killer whale predation on NFS, including the proportions of killer whale food requirements met by feeding on different age- and sex-classes of NFS, and the proportions met by feeding on other species. See text for details regarding hypotheses.

Hypothesis		Proportion of diet						
		Northern fur seal age- and sex-class						Other species
A	1	0.5	0.5	0	0	0	1.0	0
	2	0	0.005	0	0.005	0.99	1.0	0
	3	0.347	0.111	0.347	0.111	0.083	1.0	0
	4	0.1665	0.1665	0.1665	0.1665	0.3334	1.0	0
B	1	0.195	0.195	0	0	0	0.39	0.61
	2	0	0.002	0	0.002	0.386	0.39	0.61
	3	0.1353	0.0433	0.1353	0.0433	0.0324	0.39	0.61
	4	0.0649	0.0649	0.0649	0.0649	0.1299	0.39	0.61
C	1	0.09	0.09	0	0	0	0.18	0.82
	2	0	0.0009	0	0.0009	0.1782	0.18	0.82
	3	0.0625	0.02	0.0625	0.02	0.0149	0.18	0.82
	4	0.03	0.03	0.03	0.03	0.0599	0.18	0.82

Hypothesis 1 represented the only type of predation we have observed near Medny Island and most likely near Bering Island. Hypothesis 2 was based on the assumption that killer whale predation on NFS near Medny Island is focused on the same age classes as killer whale predation on sea lions near Punta Norte, Argentina, where Hoelzel (1991) reported that killer whale predation of marine mammals was 99% pups and 1% juveniles. The predation losses were divided equally between males and females. Hypothesis 3 was based on the assumption that killer whale predation on NFS

near Medny Island was distributed across the same age classes as killer whale predation near British Columbia and Alaska, where Heise *et al.* (2003) reported that adults, juveniles, and pups comprised 50, 16, and 6%, respectively, of killer whale prey; the ages of 28% of the prey could not be identified. Thus, of the individuals that could be aged, 69.4, 22.2, and 8.3% were adults, juveniles, and pups, respectively. Again the losses were divided equally between males and females. Hypothesis 4 represented the “null model” that killer whale predation was spread equally across all age and sex classes.

To calculate killer whale food requirements in terms of the number of NFS consumed, I assumed that each killer whale needs or  $685,382 \text{ kJ day}^{-1}$  (Williams *et al.* 2004, estimated that an adult female killer whale needs  $685,382 \text{ kJ day}^{-1}$  and that an average-sized adult male killer whale needs  $1,018,808 \text{ kJ day}^{-1}$ ), the energy value of fur seals is  $10.5 \text{ kJ g}^{-1}$  (Williams *et al.* 2004), and that the average weights of NFS are 275, 50, and 10 kg for adult males, adult females and juveniles, and pups, respectively.

For each of the 24 combinations of fur seal demographic parameters and hypothesized killer whale diets (Table 11), the fur seal population started with 175,800 individuals (estimated population using all of the rookeries on the Commander Islands in the year 2000), distributed across the age classes according to the stable age-class distribution associated with the set of demographic parameters being used. Finite rates of population change ( $\lambda$ ) associated with the demographic parameters reported by Barlow and Boveng (1991) and Lima and Páez (1997) were 1.000889 and 1.004548, respectively. For each of the 48 different parameterizations of the model (two sets of demographic parameters x 12 killer whale diets x two initial northern fur seal population

sizes), first the impact of one killer whale was simulated, then two, then three, etc., until number that would be sufficient to cause the seal population to decline irrecoverably was reached.

Two additional scenarios were modeled in which it was assumed the number of killer whales preying on NFS increased from two to ten during the period from 1999 to 2009 (Mamaev and Burkanov 2006), that their number remained at ten thereafter, and that they consumed exclusively juvenile and adult males, as have been observed near Medny Island. For both scenarios, the demographic data of Barlow and Boveng (1991) were used. For one scenario, predation was assumed to occur only during the summer months (June through September), while for the other scenario predation was assumed to occur during the entire year. Finally, based on the latest observations during the summer-fall 2010 on Medny and Bering Islands, it was hypostasized that killer whales prey mostly on NFS adult males during summer months and mostly on pups during fall (October- November).

## RESULTS

### *Field data*

Since 1999, killer whales have been observed hunting near the Commander Island rookeries for about 53 days during the summer, with the number of individuals seen during a single sighting ranging from 2-12 and from 1-18 attacks per day. During

51 of these days, the prey type was identified as NFS. There were no observations of killer whale predation on the other marine mammals such Steller sea lions (*Eumetopias jubatus*), harbor seals (*Phoca vitulina*), sea otters (*Enhydra lutris*), humpback whales (*Megaptera novaeangliae*) and Dall's porpoise (*Phocoenoides dalli*) that were abundant in the area (Marakov1964, Mamaev 2010), although one unsuccessful attack on Dall's porpoise was observed (Mamaev and Burkanov 2008).

Mamaev (2002) observed the first killer whale attack on NFS in June, 2000. Each year, from the early July to August, the same killer whales (they were photo-identified and named as CI-t1, CI-t2) and other individuals were observed preying on NFS near Medny Island. The preliminary data analysis (Mamaev and Burkanov 2008) suggest that the observed predation events have generally increased during the ten-year period. At the same time, very many factors influence these opportunistic observations: effort, observer experience, and environmental conditions. Also, some rookeries are too large to be carefully observed by one person. All these factors were very different during the 1999-2010 period with a general increase in the observation effort and number of observers.

In 2006, for the first time, the same group (CI-t1, CI-t2 and two other killer whales) was observed about one month earlier (end of May) than usual; also, for a first time, another group of mammal-eating killer whales was observed preying on NFS. In 2009, whales CI-t1, CI-t2 and two other individuals were observed near Urilie rookery. In 2010, the same group was seen successfully preying on NFS near both Yugo-Vostochnoe and Urilie rookeries.

There were no focused killer whale observations near the rookeries on Bering Island until 2008. However, Ivan Blokhin (KamchatNIRO, Russia) recorded the appearance of cetaceans near the Severo-Zapadnoe rookery during daily seal counts (personal communication). Since 2002, he did not see any killer whales near the Severo-Zapadnoe rookery.

I did not observe killer whale attacks on marine mammals near Bering Island in 2008, but killer whales were observed hunting NFS twice in 2009. Moreover, Blokhin (personal communication) observed a group of six killer whales preying on NFS off the Severnoe rookery on Bering Island at least once a week during the end of July and beginning of August, 2010 (a single set of observations was conducted during each of the scheduled once every five-day census of NFS). The summary of observed killer whales predation on marine mammals is present in Table 12.

*Table 12.* Summary of transient killer whale predation activity near the Commander Islands in 1999-2010.

Location	Medny Island		Bering Island	
Rookery	Yugo-Vostochnoe	Urilie	Severnoe	Severo-Zapadnoe
Predation activity observed per day	from 1 to $\approx 18$	$\approx 4$	from 14 to $\approx 20$	2
Distance from shore (km)	0.1-10	0.1-3	0.1-3	0.3-1
Duration (min)	11.8 $\pm$ 15.5	5 $\pm$ 2	5.7 $\pm$ 3.9*	8.0*
Number of individuals	from 2 to 12	4	from 6 to 7	from 3 to 6
Prey item	NFS or unidentified	NFS	NFS	NFS

\* the numbers do not include data from 2010

The photo ID of the killer whales were possible only on some transient killer whales observed near the Medny Island's rookeries. In 2005-2010, the same killer whales individuals (CI-t1, CI-t2 always and CI-t3-CI-t5 occasionally) were seen preying on NFS near the Yugo-Vostochnoe during several days, and presumably the CI-t1, CI-t2 were seen preying on NFS in 2000-2004 (Mamaev and Burkanov 2008).

On July 10, 2010, a killer whale group hunting NFS close to shore (0.3-1.5 km) occurred near Yugo-Vostochnoe rookery, and the weather conditions allowed us to observe and image their behavior in detail (Fig. 29). From 16:20 to 22:04, the killer whales ate at least two fur seal bulls and attacked at least two more (based on visual shore observations).



*Figure 29.* One of the four killer whales preying on an adult male fur seal near the Yugo-Vostochnoe rookery of Medny Island on July 10, 2010.

All four killer whales hunted only bulls. They chased a group of fur seals underwater, then one killer whale turned perpendicular to the fur seals and at the same

time another killer whale grasped the hind part of the fur seal. It appeared that the killer whales bit several fur seals and then killed and consumed one. After a series of attacks, the killer whales bit off pieces of the fur seal and, when the fur seal could not resist any more, the killer whales took turns coming to the carcass to eat it (Fig. 30).



*Figure 30.* Killer whales preying on a NFS bull near the Yugo-Vostochnoe rookery of Medny Island. Left killer whale has a piece of fur seal in its mouth.

On July 15, 2010, this same group (CI-t1, CI-t2 and 2 others were not identified) was seen for the first time hunting NFS off Urilie rookery on Medny Island. They “patrolled” the rookery from 17:00 up to at least 21:00 and exhibited hunting behaviors at least six times. Three days afterwards, I found (for the first time) a beached NFS bull (1.9 m length and 1.3m chest circumference). The carcasses were very fresh and had evident scars from the killer whale attacks (Fig. 31). About one month later (August, 11), we found the carcass of another NFS that had been killed by killer whales (Fig. 32).



*Figure 31.* The NFS bull killed by killer whales on Urilie rookery of Medny Island (2010). The killer whales removed skin from the hind part of the seals (left). The scars from the killer whales' teeth on the carcass (right).



*Figure 32.* The NFS carcass with killer whale teeth marks found on Urilie rookery of Medny Island.

It was the same size (1.9 m in length and 1.3 m chest circumference) bull as the previous carcass and, based on the condition of the tissues, had been dead on the beach for about 4-5 days. Both carcasses had most of the scars on the hind part their bodies. The skin from the hind part of their bodies, their hind flippers, and most of their front flippers were torn off. None of the internal organs were removed. These carcasses also confirmed our visual observations that the group of killer whales preyed on adult NFS males.

I first observed a group of seven (including a calf) transient killer whales preying on NFS near Severnoe rookery (Bering Island) in 2009. It is likely that this was the same group of killer whales we had observed preying on fur seals almost every week in 2010 (the observations were not continuous but occurred every 5 days from 12:00 to 17:00). But, the observations were conducted from shore only, and we did not have identification images of the killer whales to compare the individuals between years.

Based on the latest observations conducted on Medny and Bering Islands during fall 2010, the killer whales in the group of 4-6 individuals were seen near Yugo-Vostochnoe and Severo-Zapadnoe rookeries (personal communication Ryazanov S.D., Usatov I.A.). Their prey type was identified in two of the six observed predation events near the rookeries; in both cases, a molted NFS pup. While observations near the rookeries were occasionally conducted during fall before 2010, these were the first documented cases of killer whale predation on marine mammals near the rookeries during the fall.

### *Simulation model data*

Under most of the 24 combinations of demographic parameters and diets we examined, a small number (< 18 for the population using all of the rookeries in the Commander Islands; Table 13) of killer whales was sufficient to cause an irrecoverable decline in the simulated fur seal population.

*Table 13.* Minimum number of killer whales preying on the NFS population using all of the rookeries on the Commander Islands (in parentheses) only during summer months (May through September) that would cause the population to decline irrecoverably under the indicated combination of NFS demographic parameters and killer whale diets (see Table 11 for diet details).

Demographic Parameters	Hypothesized Diet	A(100% of Diet)	B (39% of Diet)	C (18% of Diet)
Barlow and Boveng (1991) ( $\lambda = 1.000889$ )	1 (only adult and juvenile males)	75	191	416
	2 (almost exclusively pups)	1	1	2
	3 (primarily adults)	1	2	4
	4 (all age and sex classes equally)	1	2	3
Lima and Páez (1997) ( $\lambda = 1.004548$ )	1 (only adult and juvenile males)	115	295	639
	2 (almost exclusively pups)	1	3	6
	3 (primarily adults)	4	8	18
	4 (all age and sex classes equally)	2	6	11

In several cases, one killer whale was sufficient. However, under the six scenarios in which predation only on juvenile and adult males was simulated, the number of killer whales required to cause an irrecoverable decline was markedly higher (from 75 -639 for the entire NFS population on the Commander Islands). When the number of killer whales changed over time from two to ten and they preyed exclusively on juvenile and adult males on all rookeries of the Commander Islands, the simulated population could sustain itself, even if predation occurred during the entire year.

The killer whales have been seen preying on weaned pups in fall 2010 near the Commander Islands (I.Usatov, S. Ryazanov., pers. com). If the killer whales preyed mostly on adult males during summer (June-September) and switched their predation to pups during fall, about 20-30 killer whales could cause an irrecoverable decline in the population on the Commander Islands.

## DISCUSSION

The impact of killer whale predation on NFS remains debatable. The interactions we observed between killer whales and NFS on the Commander Islands over the past decade present apparent contradictions. On the one hand, the current predation rate under most of the hypotheses regarding killer whale diets that we simulated should have lead to a marked population decline. But, the field data shows the stable NFS population on the Commander Islands (Kornev *et al.* 2008).

Simulation results suggest that the observed population of mammal-eating killer whales from 2000-2009 (2 to 10 individuals) could cause a decline in the NFS population using all of the rookeries in the Commander Islands under most scenarios which were examined. However, if killer whales fed exclusively on juvenile and adult males during summer months, as was observed near Medny Island during 2000-2009 (Mamaev 2002, Mamaev *et al.* 2005, Mamaev and Burkanov 2008; our data), then the seal population could sustain itself in the presence of the currently observed number (about 10) of “NFS eating” killer whales in the area. If killer whale diet shifted toward young females, which have the highest reproductive value (York and Hartley 1981), or pups, the population-level impact of predation would increase markedly. If the currently-observed number of mammal-eating killer whales preyed mostly on NFS pups during fall, predation could have a significant additional effect on pup mortality.

There remains, of course, a good deal of uncertainty associated with our field observations and hypotheses about killer whale diets. Weather conditions on the Commander Islands prevented us from making observations on more than 50% of the days (due to visibility  $<0.5$  km). Although we have only observed killer whales preying on juvenile and adult male NFS near the Commander Islands, we could not observe the complete predatory behavior of each killer whale. For example, we know nothing about their nocturnal behavior. Research near the Pribilof Islands suggests that transient killer whales are more active during the night (Newman and Springer 2008).

Unfortunately, there is much more unknown than known in this study. How often the killer whales hunt fur seals; what proportion of their predation activity could be

observed; the number of killer whales near the Commander Islands and how many of them prey on fur seals; do killer whales prey on other marine mammals in my study area? –These are just some of the questions that have not been resolved, but which are very important and could have a key role in examining the affect of killer whale predation on NFS. Actually, there are just two certain facts: 1) that there were at least about 10 killer whales preying on NFS near the Commander Islands, and 2) the current level of killer whale predation does not markedly affect the number of NFS.

The fact that killer whales could dramatically affect the NFS population on the Commander Islands has been discussed since the mid 1930's (Zenkovich 1938, Ognev 1935), but there have been few documented observations of killer whales hunting NFS (Jefferson *et al.* 1991). If we consider killer whale predation as a possible cause of the decline of the NFS population on the Pribilof Islands (northeastern Pacific), the most interesting question is why killer whale predation has not caused a population decline on the Commander Islands (northwestern Pacific)?

It is interesting from an energetic perspective to consider why killer whales might prey upon different sex- and age-classes of NFS in different areas. Few estimates of killer whale energy requirements are available (Williams *et al.* 2004, Baird and Dill 1995). We used estimates based on resident (fish – eating) killer whales in captivity (Williams *et al.* 2004), and also used maximum weights for the different age- and sex-classes of northern fur seals. Transient killer whales may have different energy requirements. Calculations by Baird and Dill (1995) suggest that when a group of three killer whales hunts and consumes harbor seals, which are the most abundant pinniped off

the coast of British Columbia, each of them gain more energy than if they hunt and share any other prey. The mammal-eating killer whale group that preys on NFS near the Commander Islands usually consists of 4 individuals. Perhaps juvenile and adult male NFS, which are the largest individuals, are the “best” prey for the group from a net energy gain perspective. Adult NFS could a preferred prey that these killer whales choose. In near-shore areas off the Pribilof Islands, the mean group size for mammal-eating killer whales is often 3.3 individuals (median 3) (Robson *et al.* 2007). Perhaps these groups prey preferentially on smaller, female or juvenile NFS. Perhaps the killer whales return in the fall, when pups start to leave rookery. The removal of females and pups would have a much greater impact on population dynamics.

But these are just hypotheses that must be supported by many more field observations. To determine whether killer whale predation could be a significant cause for the NFS decline in the Pribilof Islands, and whether killer whale predation could cause the NFS population decline on the Commander Islands, permanent continuous day and night (or at least acoustic survey) observations on all rookeries on both the Commander and Pribilof Islands should be conducted.

Several authors have described feeding preferences for resident and for transient killer whales (Ford *et al.* 1998, Saulitis *et al.* 2000). Pitman and Durban (2009) studied killer whale predation on pinnipeds in Antarctic waters and found a strong preference for Weddell seals. Matkin *et al.* (2007) suggest that transient killer whales near the eastern Aleutian Islands (northeastern Pacific) prefer to consume NFS during the summer.

Considering the potential for NFS to migrate from the Pribilof Islands to the Commander Islands (Kornev *et al.* 2008, Vladimirov 1998), about 10%-15% (females) - 25% (juveniles) of the Commander Island population could come annually from the Pribilof Islands. If this migration occurs, the current effect of killer whale predation on the Commander Island population may not be apparent because immigrating animals replace those consumed by killer whales.

According to Barret-Lennard and Heise (2007) changes in killer whale hunting behavior and prey preferences occur in two phases: (1) innovation, in which one or a few individuals investigate a new feeding strategy and a new prey, and (2) cultural transmission of the new behavior. The innovation phase usually is much longer than the cultural transmission phase. Perhaps we currently are observing this sort of transition with killer whales and NFS. If the current population of killer whales preying on NFS continues to consume only juvenile and adult males, the population in the Commander Islands may not be affected noticeably. But, if the number of killer whales preying on NFS increases and they shift their diet toward females and pups, the Commander Island population could decline.

## CHAPTER V

### SUMMARY

This study utilized 4 years of telemetry data on NFS summer foraging trips, 3 years of NFS winter migrations, and 10 years of observations of killer whale predation on NFS near the Commander Island rookeries. Additionally, a conceptual model was developed to assess the possible influence of killer whales' predation on the NFS population under different hypotheses for the killer whales' diet. Evaluations of the hypotheses proposed in Chapter I was summarized in Table 14.

*Table 14.* Summary and evaluation of the research hypotheses presented in Chapter I.

	<b>Hypothesis</b>	<b>Evaluation</b>
	<b>Lactating NFS females summer foraging trips</b>	
<b>H<sub>01</sub></b>	Lactating NFS on the Commander Islands make shallow dives at night over deep water and deep dives over a continental shelf.	Accepted. NFS made shallow dives mostly during the night in both the open ocean and over the continental shelf. Deep dives mostly occurred over the continental shelf.
<b>H<sub>02</sub></b>	Lactating NFS from the different nearby rookeries of the Commander Islands feed in different areas.	Partially accepted. The mean vector of NFS foraging trips from two nearby rookeries of Bering Island were different. However, their foraging areas overlapped mostly over the narrow continental shelf.

Table 14 Continued

<b>H<sub>03</sub></b>	Prey availability and environmental conditions affect the NFS female foraging trips duration and diving depth.	Rejected. The observed changes in prey availability and environmental conditions seem to have little effect on NFS foraging trip duration and diving depth. But the sample size was small and results could be different with a larger sample size.
<b>NFS winter migration</b>		
<b>H<sub>01</sub></b>	NFS females from the Commander Islands migrate mostly southwest along the Kurile Islands and Kamchatka, and stay near east coast of Japan during winter.	Accepted. Most NFS from the Bering Island migrated southwest along the Kurile Islands and Kamchatka and spend 3-8 months near east coast of Japan.
<b>H<sub>02</sub></b>	NFS females from Medny and Bering Islands have similar winter migration routes and overwintering areas.	Partially accepted. Most NFS from Medny and Bering Island used different migration routes for the southward migration. During last 3-4 months NFS from both islands spent in a same area and used similar migration routes on the way back to the Commander Islands. Need to increase sample size for a stronger conclusion
<b>H<sub>03</sub></b>	Overwintering areas and migration routes positively correlate with chl a concentration.	Accepted. NFS winter migration routes and overwinter areas correlated with relatively high ( $>0.1 \text{ mg m}^{-3}$ ) chl a concentrations.
<b>Killer whale predation on NFS near the Commander Islands</b>		
<b>H<sub>01</sub></b>	Mammal-eating killer whales prey on NFS near the Commander Islands rookeries during summer time.	Partially accepted. Near the rookeries of the Commander Islands, killer whales have been observed preying on NFS and un-identified prey.

*Table 14 Continued*

<b>H<sub>02</sub></b>	The current rate of mammal-eating killer whale predation does not negatively affect the NFS population on the Commander Island.	Accepted. The NFS population on all rookeries of the Commander islands is stable. The simulation model results suggests that the currently observed number of transient killer whales potentially could cause the population to decline if the killer whales prey on NFS females and pups.
<b>H<sub>03</sub></b>	Mammal-eating killer whales prey equally on all sex and age categories of NFS.	Rejected. The killer whales have been observed preying mostly on NFS adult males.

There are some differences between NFS ecology from the Commander and Pribilof Islands in all three considered aspects: summer foraging trips, winter migration and interaction with killer whales. Summarizing the NFS summer foraging trips data: a) the NFS from two nearby rookeries of the Commander Islands forage mostly in different locations, but their foraging areas overlap mostly over the continental shelf; b) differences in environmental conditions and commercial fishing intensity (drift nets were not used in 2009) appear to have little impact on the duration of NFS foraging trips and mean maximum diving depth; c) the diet of NFS on the Commander Islands is variable and contains both squid and fish.

Probably NFS from the Pribilof Islands exhibit greater foraging effort than on the Commander Islands. Based on the published data (Goebel *et al.* 2002, Robson *et al.* 2004, Kuhn *et al.* 2010), foraging trips duration, maximum traveled distance, number of

dives per foraging trip and dive depth are greater on the Pribilof Islands than on the Commander Islands.

Summary of Chapter III: a) after post-processing, GLS loggers provide acceptable location data for analyzing NFS winter migration patterns; b) for the southward migration, over-wintering areas, and return migration to the Commander Islands, females appeared to exploit areas with enhanced chl a concentration; c) females from both Bering and Medny Islands stay in the Transition Zone in North Pacific during winter, with most of them traveling to the Japanese coast; d) during consecutive years, females followed almost the same migration routes. I suggest that females traveled towards the Japanese coast had enhanced survival during years of low primary productivity. If the suggestion is true for Commander Islands NFS, then probably the NFS from the Pribilof Islands that stay in Central Pacific during winter migration could be exposed to the same environmental pressures that affect their foraging success and thus survival.

Killer whales near the Commander Islands have been observed preying mostly on NFS adult males. Based on modeling, the current rate of killer whale predation does not affect the NFS population. If the killer whales switched predation to include females and pups, this would cause the NFS population to decline. If the transient killer whales near the Pribilof Islands prey on NFS females and/or pups, and their actual energy requirements agreed with published data, potentially they could cause the NFS population to decline.

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#### IV. Publications

**Belonovich**, O. A., I. A. Blokhin, R. Andrews, V. N. Burkanov, and R.W. Davis. 2010. Foraging ecology of lactating northern fur seals (*Callorhinus ursinus*) on Bering Island. Investigation of Biological Resources of Kamchatka and North-West Pacific (19):104-115.

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