Diving Patterns and Paths of Female Northern Elephant Seals, *Mirounga angustirostris*

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Abstract

Recent progress in electronic tagging techniques have provided the ability to study the movements and long-distance migrations of marine mammals in relation to ocean processes, across a range of ecological scales. With technological advances on tracking equipment, we used compact and effective devices to track the dive patterns and paths of female Northern elephant seals (*Mirounga angustirostris*), to gain understanding on their survivorship success and foraging performance. The diving patterns of 10 adult female Northern elephant seals were examined from the winter breeding season to the spring molting season on Año Nuevo, California, in 2010. Diving and foraging behavior was recorded using advanced satellite tracking tags and smaller time-depth recorders. During time at sea, an average of 74.3 days, the deepest dive recorded was estimated at 1395 m below sea level. We found that there is a considerable relationship between maximum dive depth and size of the seal, and no significant relationship between time spent at surface water and time spent underwater, in the course of dives. The diving patterns of female northern elephant seals is associated with foraging success of marine mammals and the desired prey they exploit in the Eastern Pacific Ocean. The understanding of these patterns and behaviors can help promote the discussion on conservation and management of marine mammals, establish if anthropogenic stressors are hindering the foraging behavior of elephant seals, and lead to efforts to provide protection for these animals.

Introduction

Marine mammals are major consumers of production at various trophic levels, ranging from primary production to predatory fish. Their large body size and abundance influences size and structure of many marine communities. Observing the role of mammals in marine ecosystems provides context within which to evaluate the potential impact of their predation on prey populations and community structure, of harvesting by humans, and environmental change on the dynamics of marine mammals (Bowen 1997). It is important to understand changes to prey population distributions, as well as predator foraging behaviors, to predict how top predators will react to these alterations.

Top marine mammal predators are sensitive to prey moving to deeper depths and fluctuating in biomass because it limits their reach to prey abundance and can limit their nutrient availability. Nevertheless, northern elephant seals (*Mirounga angustirostris*) forage on a variety of prey species that range from squids, crustaceans, and tunicates in several pelagic zones, to ocropi, teleosts, elasmobranchs, and cyclostomes, occuring in the neritic and benthic areas of the sea (Antonelis et al. 1987). These findings indicate that northern elephant seals forage in a variety of marine environments and may only be limited by physiological restrictions, such as the depth and duration to which they can dive. Disturbances to prey populations could lead to extended efforts of foraging patterns, possibly causing increased metabolic rates and loss of body fat, needed for fasting periods. Studying their diving patterns and diet is important for interpreting their impacts on prey populations that are of commercial use to humans and are essential to marine ecosystems. These findings will shed light on unforeseen impacts that marine mammal populations can be affected by, including climate change and other disturbances to the dynamics of the ocean.

Due to their fidelity to prey from specific regions of the trophic system, elephant seal populations can be immensely affected by human impacts such as anthropogenic environmental changes. Prey remains from elephant seal stomachs, show that they feed on a variety of epi- and mesopelagic, bioluminescent cephalopods, teleosts such as Pacific Hake, *Merluccius productus*, crustaceans, elasmobranchs, cyclostomes, and tunicates (Le Boeuf et al. 2000). Changes in these prey populations or distributions can cause elephant seals to dive deeper or longer than they are capable of. In this study, we also obtained data on diving strategies and capabilities of female Northern elephant seals to compare the time spent at the surface of the water in contrast to the amount of time spent underwater. We hypothesized that a the amount of time spent at surface positively correlates to the amount of time spent diving and foraging underwater. This will help us understand if these mammals will need more time to recover from longer dives, in case their prey distributions were affected.

Female Northern elephant seals, among other mammals, mainly use fat storage for reproductive processes, while male mammals spend most of their energy on mating behaviors (Le Boeuf et al. 1986). In a study on Southern elephant seals, results showed that female of these species aim to live longer and reproduce efficiently, while male elephant seals tend to live shorter lives and aim to mate with as many females as they can to increase breeding success (Hindell 1991). Female seals need more fat storage to account for the cost of reproduction and nursing, while male seals use their energy on practicing dominance and breeding. We chose female elephant seals as observational subjects because male seals have risky behaviors and are less likely to survive or return to the research sites. We used tracking devices on 10 adult female elephant seals, to understand their diving strategies, such as depth and durations on surface and underwater, and the effects on their survivorship and foraging success.

The physiological adaptations of marine mammals that help them dive to deep depths and hold their breath during long dives is astonishing, but poorly understood. Female elephant seals are mostly pelagic divers and only spend about 1 month on land to breed and another month on land to molt (Le Boeuf 1989). Pregnant females arrive on the beaches early December and return to the sea by early March, after nursing their offspring and mating. Immediately after a 4-week lactation period, where they lose about 42% of their body mass, they go back to sea to feed for about 70 days (Costa et al. 1986). During their first couple of weeks at sea, they dive continuously, deeper than any other pinniped, spending as much as 90% of the time underwater (LeBoeuf et al. 1986, 1988). They return to beaches around early May for molting season and fur growth. Analyzing foraging behavior during this time period is crucial for recognizing their diving mechanisms and exploitation of their prey populations.

Marine mammals are equipped with lungs and need to take in oxygen from the atmosphere through their blowholes or snouts. This oxygen is carried in the hemoglobin proteins of their red blood cells and passed throughout their bodies (URMC). Blood volume increases with mass and size to support metabolic and respiratory functions within the body. We hypothesize that large body size and mass can supply increased oxygen-intake capacity, due to having higher amounts of red blood cells. We will test this hypothesis by comparing body length and body mass with maximum dive duration and dive depth data and expect to see deeper depths and extended durations for seals of larger size.

It can be very tough to obtain data and measurements from wild marine species, especially those like elephant seals, because of their ability to dive deep and independently. Robert L. DeLong et al. (1991) observed six adult male northern elephant seals (*Mirounga angustirostris*) by using tracking devices to understand their behavior and diving patterns. This study focused solely on a small number of males, making it difficult to apply the same findings to female seals. Le Boeuf et al. (1992) studied the swim speed in female elephant seals by using depth recorders to measure swim speed, depth, and duration of free-ranging dives to observe their diving mechanisms and performance, as well as their metabolic rate. Both studies used tracking devices that may have been disruptive to the seals due to their size and lack of advance technology at the time, which could cause major changes in behavior and diving patterns. Propitiously, modifications to tracking instruments are providing increasingly detailed descriptions of the dive pattern and diving environment of some pinnipeds. Modifications such as continuous recording for months and measurements of ambient temperature and migratory path are shedding light on foraging strategies and are challenging physiological interpretations of diving mechanisms derived from laboratory research (Boeuf et al. 1992). In this study, we reduced the impact of those factors for better data collection and assessed health of elephant seals to maximize foraging and survivorship success.

We are investigating relationships between body length and body ratio versus maximum dive depth and maximum dive duration, as well as time spent at surface of the water between foraging dives versus dive durations underwater. We will also compare maximum dive depths of female northern elephant seals with dive depths of male elephant seals, with data obtained from other studies. These findings will shed light on elephant seal foraging behavior and will provide insight on impacts of future environmental and anthropogenic stressors.

Methods

In DeLong's study, elephant seal bulls were immobilized in late February at San Miguel Island, California, with intramuscular injections of ketamine hydrochloride to attach tracking devices to their dorsal hair with quick-setting epoxy glue and mesh netting. When the seals returned to land for molting season in July, they were chemically immobilized again to remove the instruments (DeLong et al. 1991). We used the same methods and timeline in this study, with more advanced and compact instruments that were less disruptive and had the capability to record data for longer periods of time.

We observed and took advantage of fasting seasons on shore to attach devices. Devices were attached during late January to late February on individuals assessed based on their health to maximize survivorship success in sample size. After immobilizing ten female northern elephant seals with ketamine hydrochloride, we attached the tracking devices. Advanced Smart Position and Temperature (SPOT) transmitting tags and compact Time-Depth Recorders (TDR-Mk9), acquired from Wildlife Computers, were attached near the top of the head and on the dorsal hairs, where they are not disruptive to the animal. To be able to recognize the seals, we also attached flipper tags. To easily identify the seals, we used boxed hair dye solution to create markings on their fur with the corresponding flipper tags. When our seals returned during the molting season, we tracked them via VHF instruments to recover tags and recorders. We collected diving data including dive depths, dive durations, post dive intervals, and location from devices attached, as well as those obtained from ARGOS satellites. Other measurements, such as standard length, curve length, and weight, were taken at the time of deployment and recovery.

To narrow down and organize the collected time-depth recorder data, we used MatLab 7.1. We seperated dive count, time (s), depth (m), duration (s), and post dive interval time (s) from data. To get the average size of the seals, we took the mean of standard lengths from deployment and recovery procedures for each individual. The elephant seal dive parameters were organized using the Microsoft Office Excel program. Comparisons were made between maximum dive depth, dive duration, post dive interval (PDI) time, standard lengths, and masses. To be able to compare blubber thickness of the seals, we obtained a ratio of mass divided by standard length, to create an index much like the body mass index (BMI) used for human health analysis.

To visualize the correlations observed, scatter plots with trend lines were used to calculate y-intercept and R^2 values. We performed a paired t-test and regression test in Excel for each dive measurement to calculate the significance between diving patterns and physiology of the elephant seals. To understand the correlation between time spent at surface of the water and time spent underwater, we plotted a PDI versus dive duration graph. Due to a large number of data collection, we used Rstudio program to study the relationship between PDI time and dive duration, where the p-value was also calculated to identify the significance of this correlation.

Results

The maximum dive depths analyzed show that our elephant seals can dive to depth of an average of 1234.95 meters. During their time at sea, which was an average of 74.3 days, the deepest dive recorded was approximately 1395 m below sea level. Compared to Delong's study on Diving Patterns Of Northern Elephant Seal Bulls, we observed that Female elephant seals have an average of deeper dive depths than male elephant seals. Delong's data showed that the deepest dives of elephant seal bulls ranged from 978 m to 1,529 m, while our data of female maximum dive depth ranged from 1138 m to 1395 m (Fig. 1).

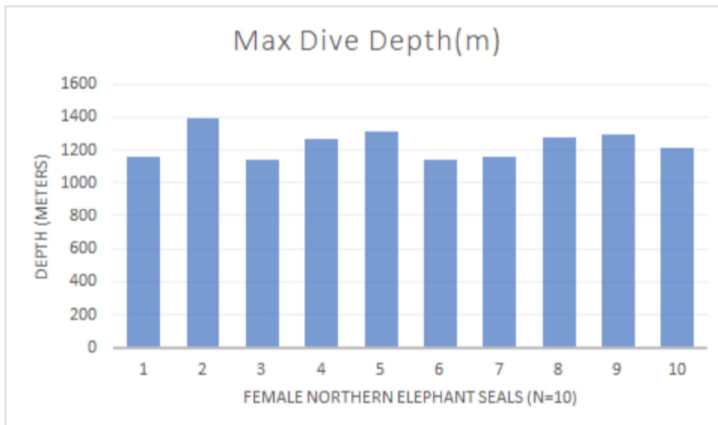

Figure 1. Maximum dive depth parameters (n=10) of female northern elephant seals' foraging trips, during 2010 migration. Maximum dive depths ranged from 1138 to 1395 m. Dive depths of all female seals averaged to 1234.95 m.

We ran regression and paired t-tests for the dive parameters observed (Table 1). In comparing the standard size versus maximum dive depth, we predicted that larger size will result to deeper dives due to physiological advantages. In this analysis, the y-intercept was positive, showing a positive correlation between the variables, with R^2 value of 0.307 and p-value of 0.096. This p-value is much greater than the optimal value of 0.05 or less, therefore, we cannot conclude any significant relationship between size and dive depth. However, there is a considerable positive correlation due to the R^2 value and positive y-intercept, that could be of biological importance.

In analysis between the standard size versus maximum dive duration, we predicted that larger size will result to more oxygen capacity, therefore the seals would spend more time underwater. Calculated y-intercept was negative, with a very weak R^2 value of 0.005 and extremely high p-value of 0.84. These findings were surprising due to the nature of the background information provided on relationship between oxygen-capacity and body size.

To further investigate these findings, we investigated the ratio of mass over standard size (similar to a body mass index ratio) of the seals, instead of solely looking at their standard size. Using this ratio can be a more efficient way of calculating data because it considers both weight and size of the animal. Calculated results revealed that maximum dive depth had p-value of 0.30 and maximum dive duration had p-value of 0.71 compared to the ratio of body mass. These values remain too high to conclude any significance between observed variables, but show that dive depth and size of seal have the most notable association.

Additionally, we observed post dive interval duration versus underwater dive duration of one of our subjects (seal O203) to distinguish if there is a link between time spent to catch a breath at surface and time spent during foraging trips (Fig. 2). We obtained a p-value of 0.71, and concluded that there is no significant parallel between the two variables.

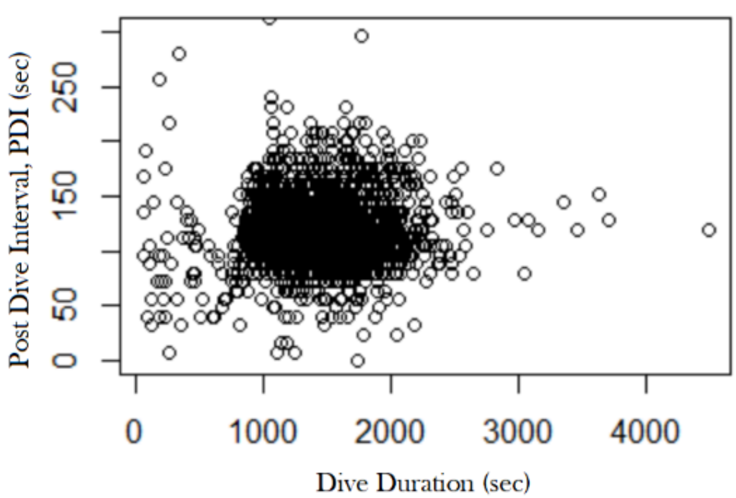

Figure 2. Dive duration parameters of one female northern seal's (seal O203) foraging trip, during 2010 migration. No significant correlation shown between post dive interval duration (sec) and underwater dive duration (sec).

	Max Dive Depth vs Size	Max Dive Duration vs Size	Max Dive Depth vs Ratio	Max Dive Duration vs Ratio	PDI vs Dive Duration
p-Value	0.09609	0.8422	0.3035	0.7083	0.7082
R^2	0.3077	0.005257	0.1498	0.02124	
y-intercept	4.3832	-8.0094	291.83	1557.6	

Table 1. Calculated results of regression test and paired t-tests for each dive parameter (n=10)
Our results cannot conclude a significant correlation between dive behaviors.

Discussion

Female elephant seals may spend more time in search of food to store energy for offspring production, while male elephant seals use this storage of fat differently, often for mating and dominating behavioral characteristics. During their foraging trips, male elephant seals travel through benthic regions where more predators are present, while female elephant seals appear to forage on less densely aggregated prey in the open ocean, where predation can be avoided (Le Boeuf et al. 2000). This sexual segregation between the two causes a dissimilarity in migration, foraging patterns, and diving paths. Although Delong's findings show that male seals have the capacity to dive to deeper than our female seals, it is important to consider that the average dive depths of females is higher than males. It is significant to recognize that female elephant seals may have a limited range of prey accessibility than males, due to their narrow diving depth range, and can be more susceptible to changes in prey populations and distributions during foraging dives. These finding could also mean that female elephant seals spend more time at these ranges, due to favorable prey populations and distributions. Different food beds are important for different sexes and individuals, and we need to protect both for a thriving population. Further studies are needed to provide information on sexual dimorphism of northern elephant seals to gain insight on favored foraged regions of both sexes in order to promote distinct conservation efforts for male and female seals. Further studies are also needed to fully understand the prey populations exploited by Northern elephant seals.

Although our data analysis did not display a significant relationship between the selected diving behaviors, these correlations are of biological importance. Larger data samples in further studies could influence the correlations of data analysis between variables.

We investigated the ratio of mass over standard size (similar to a body mass index ratio) of the seals, instead of solely looking at their standard size. Using this ratio can be a more efficient way of calculating data because it considers both weight and size of the animal. For these calculations, however, we had to exclude one of our seals due to missing mass data. This individual was a bad breather and to avoid causing harm during anesthesia, we skipped measuring the weight during recovery procedure.

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References

"Innovative Tags for Innovative Research." *Wildlife Computers Inc.*, wildlifecomputers.com/.

"What Are Red Blood Cells?" *Health Encyclopedia*, University of Rochester Medical Center (URMC).

Antonelis, George A., et al. "Assessing Northern Elephant Seal Feeding Habits By Stomach Lavage." *Marine Mammal Science*, vol. 3, no. 4, 1987, pp. 308–322., doi:10.1111/j.1748-7692.1987.tb00318.x.

Bowen, Wd. "Role of Marine Mammals in Aquatic Ecosystems." *Marine Ecology Progress Series*, vol. 158, 1997, pp. 267–274., doi:10.3354/meps158267.

Boyd, I L, et al. "Dispersal of Male and Female Antarctic Fur Seals (Arctocephalus Gazella)." *Canadian Journal of Fisheries and Aquatic Sciences*, vol. 55, no. 4, 1998, pp. 845–852., doi:10.1139/f97-314.

COSTA, D. P., LE BOEUF, B. J., HUNTLEY, A. C., and ORTIZ, C. L. 1986. The energetics of lactation in the northern elephant seal, Mirounga angustirostris. J. Zool. (London), 209: 2 1 - 33.

Delong, Robert L., and Brent S. Stewart. "Diving Patterns Of Northern Elephant Seal Bulls." *Marine Mammal Science*, vol. 7, no. 4, Oct. 1991, pp. 369–384., doi:10.1111/j.1748-7692.1991.tb00112.x.

Hindell MA , Slip DJ Burton HR (1991) The Diving Behavior of Adult Male and Female Southern Elephant Seals, Mirounga-Leonina (Pinnipedia, Phocidae). *Australian Journal of Zoology* 39, 595-619.

Le Boeuf, B. J., COSTAD, . P., HUNTLEY, A. C., KOOYMAN, G. L., and DAVISR. . W. 1986. Pattern and depth of dives in northern ele- phant seals, Mirounga angustirostris. J. Zool . (London), 208: 1-7.

Le Boeuf, Burney J., et al. "Continuous, Deep Diving in Female Northern Elephant Seals, Mirounga Angustirostris." *Canadian Journal of Zoology*, vol. 66, no. 2, 1988, pp. 446–458., doi:10.1139/z88-064.

Le Boeuf, B . J., NAITO, Y., HUNTLEY, A. C., and ASAGA, T. 1989. Prolonged, continuous, deep diving by northern elephant seals. Can. J. Zool. 67: 2514 -2519.

Le Boeuf, Burney J., et al. “Swim Speed in a Female Northern Elephant Seal: Metabolic and Foraging Implications.” *Canadian Journal of Zoology*, vol. 70, no. 4, 1992, pp. 786–795., doi:10.1139/z92-111.