Coastal Environmental Quality Initiative Fellowship Report

Project Title: Assessing the Feeding Behavior of California sea lions

Carey E. Kuhn
Advisor: Daniel P. Costa
University of California, Santa Cruz

Understanding the foraging ecology of large marine predators presents a unique challenge as most feeding occurs underwater and therefore outside the scope of observational studies. With the development of time-depth (dive) recorders a wealth of information on the at sea behavior of marine mammals and seabirds is available (Kooyman 1989, Costa 1993, Boyd and Croxall 1996). Satellite telemetry has also proven to be a valuable tool to understand movement patterns, allowing researchers to follow the tracks of animals at sea. These tools are commonly used to understand behavior, however, there are limitations when using these instruments to examine foraging. Dive records and satellite locations lead to predictions about where prey are found, but definitive evidence of feeding is crucial to identify important foraging areas and critical habitats. Stomach temperature technology can provide evidence of feeding, making to possible to understand the foraging ecology of these elusive predators.

For California sea lions, a dominant species that spans the western coast of the US, understanding foraging is essential. Populations have increased severely with the ending of commercial hunting (1940's) and following the passage of the Marine Mammal Protection Act (1972). Recently, populations have been increasing over 6.0% annually and it is estimated there are up to 214,000 sea lions in U.S. waters alone (Caretta *et al*. 2001). The impact of this increase in population size on the coastal environment is not completely understood. Conversely, the conflict between fisheries and sea lions over a limited resource is evident, with interactions occurring between sea lions and virtually all of the California fisheries (Harvey and Weise 1997).

Given the growing population, relative accessibility, and need for data on the foraging behavior of California sea lions it is quite surprising that there are only two published reports on at sea behavior. These studies on adult females found that dive times averaged 1.5 to 2.8 minutes, and mean depths ranged between 30 to 90 m (Feldkamp *et al.* 1989, Melin and DeLong 1999). Yet, it is still not known where during these trips females are finding prey, a critical limitation for understanding foraging ecology. Researchers have used indicators such as increased time in a location or changes in swim speed to presume feeding is occurring but these indicators have not been validated. This leads to many unanswered questions about California sea lion foraging behavior and their impact on the coastal environment. What locations and/or habitats are used to find prey? How much is consumed when feeding? Do certain behaviors accurately reflect foraging? How successful are these animals at catching prey (captures/dive)? The answers to these questions and others are vital to understand foraging ecology.

Using measurements of stomach temperature it is now possible to identify and potentially quantify feeding events in California sea lions. Since sea lions forage on ectothermic prey, their prey is significantly colder than the animals' core temperature. The result of this is that each time an animal feeds there will be a drop in stomach temperature and the magnitude of this drop should be proportional to the quantity consumed (Figure 1, Wilson *et al.*1992, Hedd *et al*. 1996). Captive feeding trials using stomach temperature technology have been conducted with many marine bird and some seal species (Wilson *et al.* 1992, Hedd *et al.* 1996, Bekkby and Bjorge 1998). However, these studies focused only on true seals and were unable to quantify prey consumed due to small samples sizes or few feeding trials.

To validate the use of stomach temperature technology to understand foraging, I began feeding studies with California sea lions in August 2001 and have now completed over 500 trials with 9 animals from Moss Landing Marine Labs and the Marine Mammal Center, CA. This research was support by a year of fellowship funding from the California Coastal Environmental Initiative. These trials were designed to determine a method for quantifying prey consumed. Data analysis conducted thus far suggests quantity can be estimated by a simple equation when animals consume prey in discrete feeding events. Thus, stomach temperature can be used to identify and potentially quantify feeding events in free-ranging animals.

Objectives and Methods:

The overall objective of this project was to gain an understanding of the foraging ecology of the California sea lion. Specifically, the study objectives were to provide information on distribution and movements, and identify specific foraging locations and/or habitats used by female sea lions. Another goal of the study was to identify at sea feeding events and use this information to determine the foraging success (captures/dive) of individuals.

Research was conducted on 8 female sea lions at San Nicolas Island (CA), part of the Channel Island chain. Females were captured on the beach with hoop nets and sedated using gas anesthesia (isoflurane). To measure at sea behavior females were equipped with a time-depth recorder (TDR), satellite tag (PTT) and stomach temperature recorder (HTR). The TDR is used to follow underwater behavior, such as dive depth and duration. The PTT provided at sea locations making it possible to track animals during a foraging trip. To record stomach temperature, females were equipped with a stomach temperature transmitter (STT) and stomach temperature recorder (HTR). The STT was placed in the stomach (via stomach tube) and transmitted a pulse at intervals that vary with temperature. The HTR recorded the pulse rate of the STT and converted this to temperature. When used with dive recorders and satellite tags, HTR technology can provide data about where geographically and in the water column prey are captured. By combining the information from the stomach temperature and dive recorders it is possible to determine foraging efficiency (captures/dive) and quantify changes in efficiency over a foraging trip. Between one and two months after deployment, animals were recaptured and recording equipment was removed.

Results and Conclusions:

Due to United States security issues preventing researchers from being on San Nicolas during heightened security periods, research scheduled for Fall 2002 was postponed until November 2003. In November research was conducted on 8 adult breeding females. Dive records were recovered for 6 of the 7 females recaptured as one instrument failed to record. Satellite locations were recorded for 7 of the 8 females. Although one female was never recaptured, we were still able to use her satellite information to learn more about the at sea movements and distributions of female sea lions.

Mean dive depth and duration were calculated for each dive record. Maximum dive depth for all females ranged from 100m to 416m. However, mean maximum dive depths for all females show that most animals display short shallow diving behavior (Figure 2). Average dive depths ranged from 20.9m to 104.5m, with a mean of 45.0m for all females. This large range shows that females were using different areas of the water column for foraging, and this supports previous research that suggests they forage on a wide variety of prey species (Lowry et al. 1991). Average dive duration for all females was between 1.3 and 3 minutes. These results are similar to those measured for a population of sea lions at San Miguel Island (Feldkamp *et al.* 1989, Melin and DeLong 1999). Females displayed bout foraging behavior, displaying multiple dives followed by periods of surface time or hauling out (Figure 3). Bout length varied both between females and within foraging trips.

All animals remained in the Southern California Bight, traveling extensively throughout (Figure 4). Satellite tracks were used to measure distance traveled over a forging trip and maximum distance traveled from the rookery. Females foraged in a variety of areas close to the mainland shore to areas in the open ocean. From initial track analysis females also displayed differences in foraging trip durations. For example, one female (SNI 2) traveled on average only 10.5 km from the island while another female (SNI 9) traveled up to 90 km during foraging trips. The maximum distance traveled from all of the females was 184 km from the island.

Overall sea lion females remained close to the island during foraging trips (49km) and were shallow divers (45m). Although there was a wide range of trip durations (4 hours to 4.75 days) the average durations for females ranged from 16.5 hours to 1.8 days. This research also found significant differences between individuals for many parameters including distance traveled (range 11 to 90 km), and average dive depth (21 to 105 m). Our data indicate while females' foraging behavior varied between trips, the differences between females were greater. This is similar to foraging behavior measured in the Southern sea otter where individuals display distinct foraging behaviors based on prey types. Research on sea otters, where individuals can be readily observed feeding, has shown that the population is composed of animals that forage in fundamentally different ways. It is likely that this specialization occurs in other marine predators as well as a mechanism to reduce foraging competition.

Further analysis is continuing to look in more detail at diving behavior and at sea distributions. This analysis will include calculating time at sea, time spent diving, swim speeds, and using satellite tracks to describe foraging habitats based on bathymetry and oceanographic features. Dive and satellite data will also be examined with HTR records to evaluate the validity of foraging indicators (changes in swim speed, diving frequency, etc.). Finally, quantity consumed will be estimated using equations derived from captive validation studies (Kuhn unpublished) and foraging efficiency will be calculated from dive and stomach temperature profiles.

Significance:

Such measurements of foraging in California sea lions are of academic interest, but more importantly can provide relevant information to wildlife managers. A key factor in understanding the foraging ecology of this species is knowing how animals use the environment and the key foraging habitats. In addition by measuring the rate of consumption of these animals researchers can better predict the impact on the fish stocks and environment that will result from the continuing population growth. Using this technology it is possible to determine foraging efficiency (catch per unit time) as well as time spent foraging. These baseline measures of foraging success could be a crucial factor in recognizing the current and future impacts of pinnipeds in the marine environment and promising tool to monitor population status (Gremillet, 2000).

This research can also be beneficial to managers of sea lion populations. California sea lions, as with other pinniped species, has been shown to be significantly impacted by environmental change. During the 1982 El Niño all coastal pinnipeds were notably affected, with reduced foraging ability, and increased pup/juvenile mortality (Trillmich *et al*. 1991). Crocker *et al.* (In press) were able to show that the foraging behavior of female northern elephant seals is strongly impacted by El Niño events. Females spent a longer time locating prey patches and returned with significantly lower mass gain than for non-El Niño years. By measuring feeding rates of California sea lions it will be possible to quantify the impacts of a changing environment as well as determine where foraging difficulties are occurring. Knowledge of non El Niño foraging efficiency provides researchers with a tool to measure the impacts of future environmental change either natural or anthropogenic. This project is a exciting step forward, not only towards understanding the foraging ecology of the California sea lion but also to address foraging ecology of other species of marine predators.

Research Participants:

As with any field research effort a large number of people are involved to ensure the completion of the work. For this research I worked closely with the US Navy, specifically Grace Smith, Resource Manager at San Nicolas Island. She was responsible for completing the cooperative agreement with the US Navy, and gave final approval for research conducted on the island. As a part of the cooperative agreement the Navy covered the costs of the flights for all researchers and the shipment of the field gear on the cargo flights. In addition, she provided a great deal of assistance with logistics while on the island including daily transportation, storage of gear, and lodging of the field crew. The research team included a veterinarian from the San Diego Zoo and Wild Animal Park, Dr. Nancy Boedeker. She volunteered her services for the work and was able to collect data on blood gases of California sea lions while under anesthesia. Finally the team included graduate students, post-doctoral researchers, and other volunteers from the University of California, Santa Cruz and from the Marine Mammal Center, CA.

Figures:

Figure 1:

Change in stomach temperature due to a feeding event with a sea lion held at the Marine Mammal Center, CA. Animal was fed 1.0kg of herring at 13:20 (denoted by arrow). Initial temperature was 38.6°C and recovery time to initial temperature was 1 hour 20 min post feeding.

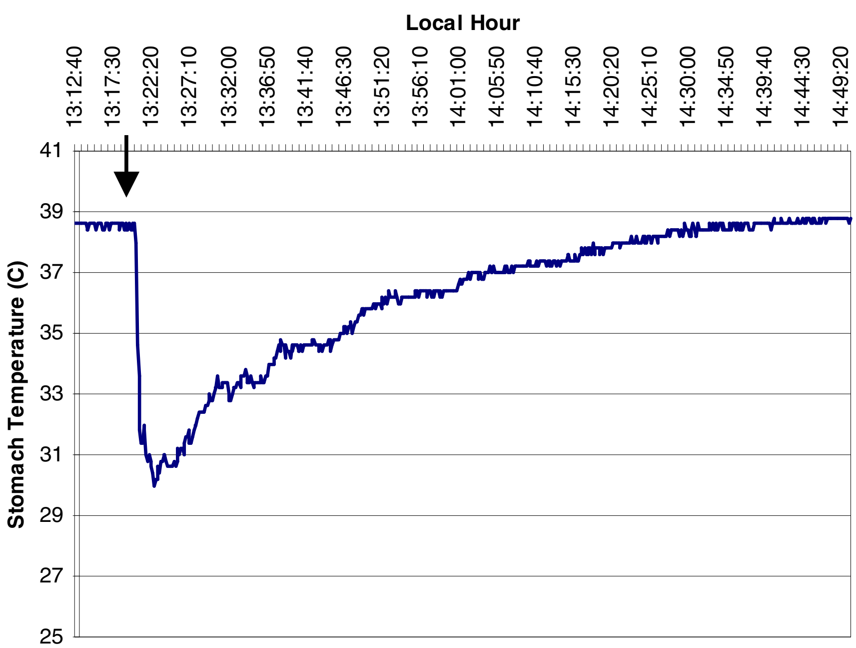


Figure 2:
Dive depths for all adult female California sea lions. Note over 70% of dives were 50m or less. Although females displayed deep dives over 300m this was rare in the overall dive records.

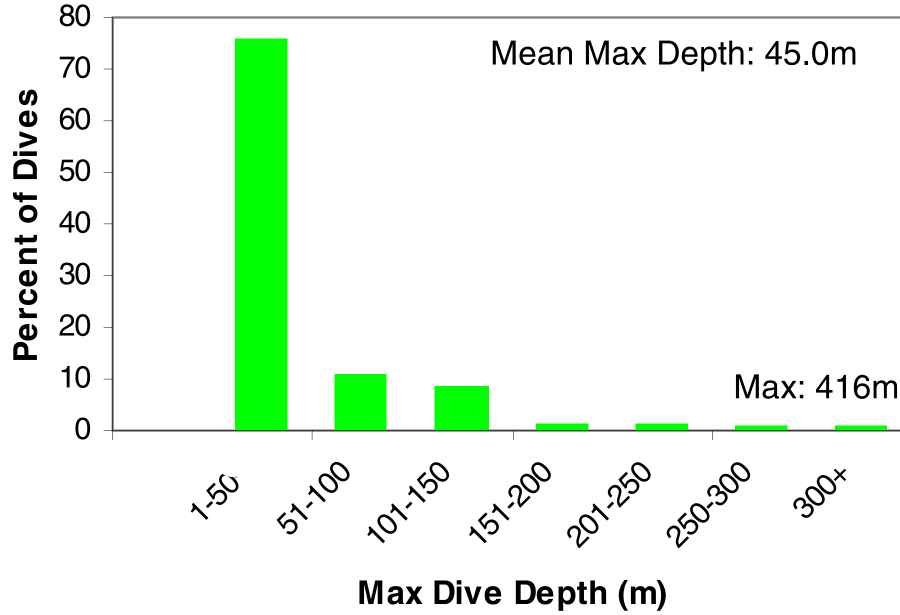


Figure 3:
Representative dive behavior of one adult female California sea lion from San Nicolas Island. All females showed diving behavior in bouts, multiple dives followed by periods of rest. This bout was followed by a 12-hour period where no dives occurred.

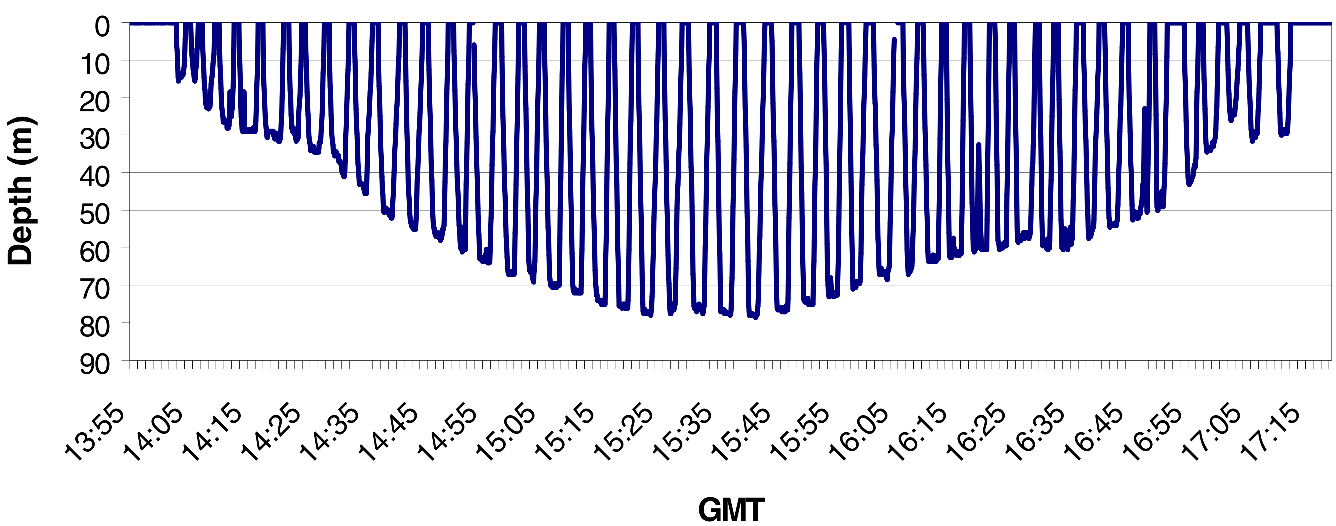
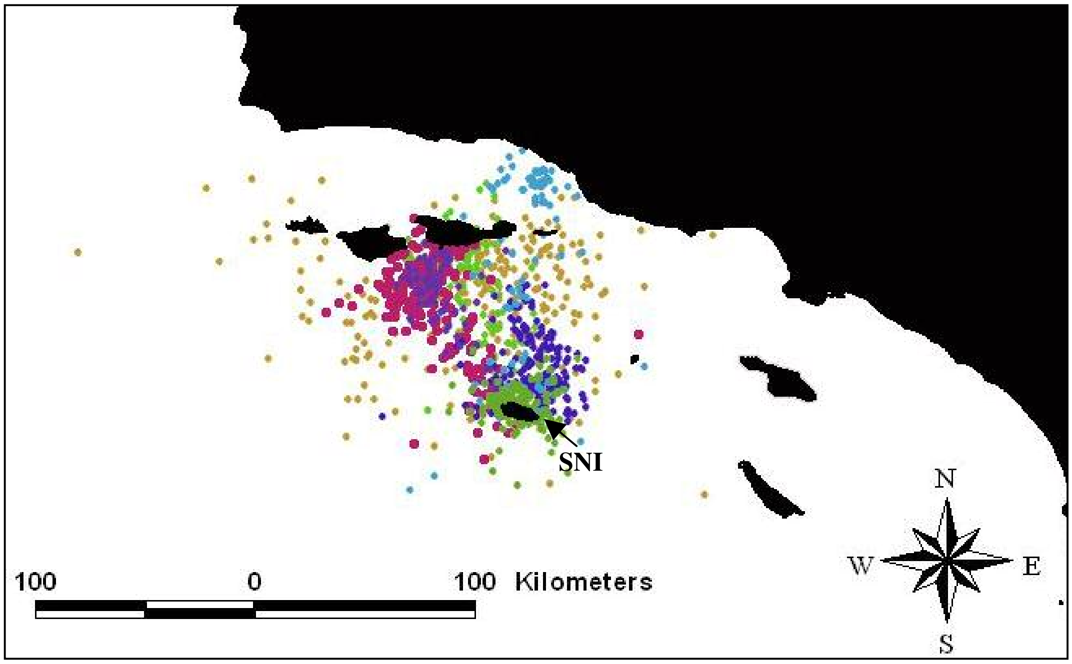


Figure 4:
All satellite locations for 7 adult female California sea lions. Each color represents an individual animal. Note that the majority of locations are north of San Nicolas (denoted by arrow).



Presentations:

Kuhn, Carey E., Aurioles, D., and D.P. Costa. Differences in Foraging Behavior Between Two Populations of California Sea Lions. Kenneth S. Norris Marine Mammal Research Symposium Nov. 2004. UC Santa Cruz, CA

Kuhn, Carey E., Aurioles, D., and D.P. Costa. Examination of the foraging strategies of a top marine predator: the California sea lion. Society of Integrative and Comparative Biology Symposium. Jan. 2005. San Diego, CA.

References:

Bekkby, T. and A. Bjorge. 1998. Variation in stomach temperature as indicator of meal size in harbor seals, *Phoca vitulina*. Mar. Mamm. Sci. 14(3): 627-637.

Boyd, I. L. and Croxall, J. P. 1996. Dive Durations in Pinnipeds and Seabirds. Can. J. Zool. 74, 1696-1705.

Carretta, J.V., Barlow, J., and K.A. Forney, 2001. U.S. Pacific marine mammal stock assessments. U.S. Dep. Commer., NOAA Tech. Memo NOAA-TM NMFS-SWFSC-317, 284 p.

Crocker, D. E., Costa, D. P., Le Boeuf, B. J., Webb, P. M. and D. S. Houser. In Press. Impacts of El Niño on the foraging behavior of northern elephant seals.

Costa, D. P. 1993. The secret life of marine mammals: Novel tools for studying their behavior and biology at sea. Oceanography 6, 120-128.

Feldkamp, S.D., Delong, R.L., and G.A. Antonelis. 1989. Diving patterns of California sea lions, *Zalophus californianus*. Can. J. Zool. 67:872-883.
Gremillet, D., Storch, S., and G. Peters. 2000. Determining food requirements in marine top predators: a comparison of three independent techniques in Great Cormorants, *Phalacrocorax carbo carbo*. Can. J. Zool. 78: 2567-1579.
Harvey, J. and M. Weise. 1997. Impacts of California Sea Lion and Pacific Harbor Seals on Salmonids in Monterey Bay, California. Stone, Goebel, and Webster eds. Pinniped Populations, Eastern North Pacific: Status, Trends, and Issues. New England Aquarium and Monterey Bay Aquarium, CA.
Hedd, A., Gales, R. and D. Renouf. 1996. Can stomach temperature telemetry be used to quantify prey consumption by seals. Polar Biology. 96: 261-270.
Kooyman, G. L. 1989. Diverse Divers: physiology and behavior. Berlin: Springer-Verlag.
Lowry, M.S., Stewart, B.S., Heath, C.B., Yochem, P.K., and J.M. Francis. 1991. Seasonal and annual variability in the diet of California sea lions, *Zalophus californianus*, at San Nicolas Island, California, 1981-1986. Fish. Bull. 89(2): 331-336.
Melin, S.R., and R.L. DeLong. 1999. A comparison of breeding and non-breeding season foraging behavior of lactating California sea lion. In: Abstracts of the 13th Biennial Conference on the Biology of Marine Mammals. Nov. 28-Dec. 3, 1999.
Trillmich, F., Ono, K.A., Costa, D.P., DeLong, R.L., Feldkamp, S.D., Francis, J.M., Gentry, R.L., Heath, C.B., LeBoeuf, B.J., Majluf, P. and A.E. York. 1991. The effects of El Niño on pinniped populations in the eastern Pacific. *In* F. Trillmih and K.A. Ono (editors). Pinnipeds and El Niño: Responses to environmental stress, p. 247-270. Springer-Verlag, Berlin.
Wilson, R. P., Cooper, J., and J. Plotz. 1992. Short Communication: Can we determine when marine endotherms feed? A case study with sea birds. J. Exp. Biol. 167, 267-275.