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Publication Date

2007-06-05

Foraging Ecology of the California Sea Lion: Diet, diving behavior, foraging locations, and predation impacts on fisheries resources

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CA Sea Grant Final Report – 29 May 2007

INTRODUCTION

Recent revisions of the federal Magnuson-Stevens Fishery Conservation and Management Act, vigorous implementation of the Endangered Species Act, and the enactment of the California Marine Life Management Act of 1998 have placed a new emphasis on restoring the health of coastal ecosystems and fisheries resources. Increases in many formerly depleted pinniped populations, coupled with declining fish resources, have intensified competition between humans and pinnipeds (Harvey 1987, Mate and Harvey 1987, Weise and Harvey 2005, MMC 2002). California sea lions (*Zalophus californianus*) compete with almost all commercial and recreational fisheries along the California coast by directly interacting with fisheries causing entanglement and damage to fishing gear and loss of catch (Beeson and Hanan 1996, NMFS 1997, Weise and Harvey 2005), and indirectly by competing for fisheries resources (Harvey 1987, Mate and Harvey 1987, Olesiuk 1993, Weise 2000).

Detailed information on the foraging ecology of the California sea lion is necessary to quantify where and how sea lions compete with humans for commercially and recreationally important fisheries resources. Since the passage of the Marine Mammal Protection Act (MMPA) in 1972, the California sea lion population has increased at an annual average of 5% to 6.2% along the West Coast (Caretta *et al.* 2000). There are an estimated 204,000 to 214,000 sea lions in U.S. waters (Caretta *et al.* 2000), and possibly an additional 80,000 to 100,000 animals along Baja, Mexico (DeLong 1997). Increasing pinniped populations have resulted in greater direct interactions between sea lions and fisheries, as well as an increase in indirect competition with fisheries by consumption of commercially important species (Beeson and Hanan 1996, NMFS 1997).

Understanding the competition between sea lions and humans requires insight into the foraging ecology of California sea lions, which in turn, is necessary for effective management of fish populations. However, the lack of data on sea lion foraging behavior makes it difficult to recognize how and to what extent this competition may affect both predator and prey. An evaluation of this relationship is essential for fisheries managers to more accurately estimate current predation levels, predict future levels of predation, and thereby effectively manage marine fisheries in an ecosystem context.

Foraging Behavior

Marine mammals have evolved diverse life history patterns to accommodate fluctuations in the physical and biological environment (Costa *et al.* 1989, Trillmich and

Ono 1991, Costa 1993a, Costa and Crocker 1996). As they are long-lived animals they must be able to withstand variations in food resources over large spatial and temporal scales. A basic understanding of the foraging behavior and habitat utilization of predators requires knowledge of this spatial and temporal variation, coupled with information on how organisms respond to these changes. This project will examine the foraging behavior and habitat utilization of the California sea lion along the California coast.

Apex predators forage in areas where oceanographic features, such as frontal systems, thermal layers, sea mounts and continental shelf breaks increase the availability of prey (Hui 1979, Schneider 1982, Springer and Roseneau 1985, Haney 1986, 1991, Costa 1993b, Elphick and Hunt 1993, Decker and Hunt 1995, 1996, Mehlum and Hunt 1996, Hunt 1997). All of these oceanographic features and processes are thought to impact marine predator distributions by physically forcing prey aggregations and, thus, creating areas where foraging efficiency can be increased (Ainley and Jacobs 1981, Croxall *et al.* 1985, Boyd and Arnbohm 1991, van Franeker 1992, Wilson *et al.* 1993, Veit *et al.* 1993). Indeed, for many marine predators, regions of highly localized productivity may be essential for reproduction and survival (Haney 1986, Costa *et al.* 1989, Fraser *et al.* 1989, Hunt *et al.* 1992, Costa 1993b, Croll and Tershy 1998). At the same time, the distribution of both predator and prey is influenced by physiological constraints, which help to determine habitat preferences (Block *et al.* 1997, Boyd 1997, Ainley *et al.* 1998, Ponganis *et al.* 1998, Costa and Gales 2001, Costa *et al.* 2002, Costa and Gales 2003).

Our understanding of these associations is primarily limited to population level studies where animal abundance has been correlated with oceanography. While these studies are informative they cannot provide insights into the strategies employed by individual animals nor can they provide insights into the spatial or temporal course of these interactions (Gilbert and Erickson 1977, Ribic *et al.* 1991, Joiris 1991, Hunt *et al.* 1992, Veit *et al.* 1993, Bester *et al.* 1995, Boyd 1996, Trathan *et al.* 1998). Recent advances in technologies such as satellite telemetry, electronic tags, and remote sensing methods are providing new insights into the links between predators, prey, and the oceanic environment (Costa 1993b, Block *et al.* 2002). These new tools are making it possible to extend our understanding beyond the simple correlation of prey and predator distributions with environmental features. Key to understanding the processes that lead to high predator abundance is the identification of the specific foraging behaviors associated with different environmental conditions. This project accomplished this objective by combining accurate positional data, animal-derived water-column temperature data, remotely sensed oceanographic data, and for the first time measures of diving and foraging behavior coupled with foraging success.

Our proposed studies of California sea lion foraging ecology have only recently become possible due to advances in tag technology. Time-depth recorders (TDRs) are optimized to gather and digitally record large amounts of data, and the memory capacity and resolution of these instruments have improved dramatically in recent years (Block *et al.* 2002). Many parameters, including depth and duration of dives, swim velocity, environmental temperature, and light level (which is used for determining geographic location and potentially primary productivity) can be sampled for diving animals at user-defined time intervals. Some microcomputer packages can also simultaneously measure

and record heart rate and stomach temperature in conjunction with diving behaviors (Andrews *et al.* 1997). Data from TDRs provide continuous dive records allowing examination of individual dives, with the aim of elucidating their function and physiological basis in foraging, traveling, and locomotion (Bengston and Stewart 1992, LeBouef *et al.* 2002, Asaga *et al.* 1994, Crocker *et al.* 1997).

A limitation with TDRs is that the unit needs to be retrieved in order to obtain the data. A solution to this problem is to relay the data through the Service Argos system, which is a satellite-based location and data collection system (Service Argos Inc). A variety of technologies are available that telemeter behavioral data, in addition to at-sea locations. However, the Argos system is limited in that it can only receive 256 bits of information per transmission, which restricts the amount and quality of information that can be transmitted from a diving animal. There are currently two methods of summarizing these data for transmission; the first is a Satellite Data Relay (SDR Wildlife Computers Inc). This system summarizes information on maximum dive depths, dive durations, and the amount of time animals spend at certain depths (“time-at-depth”; Hill, 2000). These data summaries result in the loss of important information about individual dives as well as dive pattern. The second and preferable system was the recently developed Satellite Relay Data Logger (SRDL) designed by the Sea Mammal Research Unit (SMRU; Gatty Marine Laboratory, University of St. Andrews). The SRDL tag compresses the data in such a manner that the most important aspects of the diving pattern are retained. Data compression is accomplished by recording the inflection points during the dive, and these data are then transmitted (Fedak *et al.* 2001).

In this project, we used a variety of tags to optimize our data acquisition. In studies with female sea lions we will use TDRs, stomach temperature recorders and satellite location tags. As lactating females alternate between suckling their pup on the beach and foraging at-sea, we can reliably recover tags. The non-breeding seasonal range of adult females extends from the Channel Islands northward to the Farallon Islands (Melin 1995), although most animals remain near rookeries on the Channel Islands year-round; therefore female sea lions will be studied on San Nicolas Island.

In contrast, adult male sea lion movements are unpredictable as they migrate northward to central and northern California, Oregon, and Washington during the non-breeding season (Lowery *et al.* 1992). For this reason the SRDL were ideal for male studies as we can retrieve data on diving behavior without having to recover the instruments. Male sea lions will be tagged in the Monterey Bay region as they pass through on their bi-directional seasonal migration. Working with male sea lions in the Monterey Bay region is advantageous because we can obtain data on both the northward and southward migration and because it is possible to capture them, whereas capture methods on the Southern California rookeries have yet to be refined. Given the relative accessibility and need for data on the diving behavior of California sea lions it is quite surprising that there are only two published reports. These studies were limited to lactating adult females and found that dive times averaged 1.5 to 2.8 minutes, and mean depths ranged between 20 to 50 m in depth (Feldkamp *et al.* 1989, Melin and DeLong 1999). The proposed study will be the first time adult males sea lions will be tagged with SRDLs and the first time we will be able to investigate their spatially explicit foraging

behavior. This is important because adult male sea lions directly interact with fisheries in central (Weise and Harvey 2005) and northern California (Beeson and Hannan 1996), and adult female and male sea lions indirectly compete for fishery resources along the California coast.

A significant shortcoming of studies on the foraging patterns of marine predators is the lack of understanding of the function of the various behaviors observed. For example, it is critical to know when and where animals forage. Although the methodologies listed above provide substantial information on diving behavior and movement, they do not provide information on the success rates of recorded dives. Stomach temperature telemetry, which has been used successfully in harbor seals, Steller sea lions, penguins, and other seabirds, can provide information about the timing and location of foraging events (Wilson *et al.* 1992, 1995, Gales and Renouf 1993, Putz and Bost 1994, Hedd *et al.* 1995, Ancel *et al.* 1997, Andrews 1998, Bekkby and Bjorge 1998). California sea lions, feeding on poikilothermic prey, will experience a drop in their stomach temperature along with an exponential recovery with the consumption of food and/or water. Additionally, the absolute magnitude or duration of this drop in temperature should be in proportion to the amount of prey consumed. A stomach temperature logger can be used to record these changes in temperature and can be used to determine when, where and how often animals feed. Data from a pilot study recently collected at Los Islotes, Mexico, clearly identifies for the first time at-sea feeding events using stomach temperature telemetry in California sea lions. Using state of the art technology, foraging success can now be determined in sea lions by measuring capture success per dive or unit time.

A combination of accurate positional data, measurements of foraging behavior and success, and available remotely sensed oceanographic data, is the key to identifying the foraging strategies used by large marine predators. These data are vital to examine how sea lions alter foraging strategies in response to seasonal or annual changes in oceanographic features and distribution of prey (Boyd 1999). Because pelagic prey are often patchily distributed, marine predators face an additional foraging decision of how long to utilize a suitable prey patch, once it is located. One approach to studying these decisions is to derive hypotheses from the assumption that animals are optimizing their foraging decisions. Marine predators are likely to make these decisions at the level of individual dives (how long to remain submerged) and at the level of patch residence (how long to remain within a patch before leaving to find another). Our preliminary data from Los Islotes show that after a series of initially successful dives the sea lion continued to make unsuccessful dives before it ceased to forage in that patch. In examining foraging strategies, models will be developed for the proposed study to assess what oceanographic conditions are influencing the foraging behavior of California sea lions.

Food Habits & Consumption Models

Studies of food habits also provide information on feeding locations, seasonal prey utilization, and prey availability. Obtaining accurate information on the type and quantity of prey consumed, including geographic and temporal variation in foraging patterns, is the cornerstone of evaluating the affect of diet on prey populations (Rosen and Trites

2000). Traditionally, competition between pinnipeds and fisheries, and pinniped food habits was evaluated through the visual analysis of fish sagittal otoliths and cephalopod beaks found in gut contents or fecal samples of pinnipeds (Harvey 1987, Cottrell *et al.* 1996). In recent years, all prey skeletal structures have been used for prey identification, which is known as the ‘all structures’ method (Olesiuk 1993, Weise 2000, Weise and Harvey *In Review*). When prey structures in addition to otoliths were identified, frequency and number of individual prey were at least two times greater for many prey taxa (Olesiuk 1993, Cottrell *et al.* 1996). Large fishes often are underestimated because they are less likely to be consumed whole, and their otoliths may not appear in fecal samples (Pitcher 1980). Fishes with small or less robust otoliths have lesser recovery rates due to the increased probability of complete digestion. This project investigated California sea lion food habits using all prey hard parts, which helped discern whether the increasing sea lion population is consuming quantities of commercially important prey that may limit the recovery of listed stocks or require the evaluation of commercial harvest quotas.

Relevance

According to the Sea Grant Implementation Plan for 2004-05 human population growth will place severe demand on remaining fishery resources, and therefore, improved resource management needs to be implemented to prevent the unsustainable use of marine resources. Growing marine predator populations are placing similar demands upon the same marine resources. The goal of this study was to develop quantitative tools, such as foraging models and consumption estimates that managers can use to evaluate predator impacts on marine resources, and thereby effectively manage marine fisheries. Furthermore, quantitative estimates of marine predator impacts in marine fisheries management embody the Sea Grant goal of ecosystem-based resource management.

Finally, the use of state-of-the-art technology such as SRDLs and stomach temperature recorders allow us to investigate foraging strategies of California sea lion in response to seasonal or annual changes in oceanographic features and distribution of prey. An exciting, recent development from observing diving predators such as marine mammals, fish and birds has been the realization that electronic tag-bearing animals can be employed as autonomous ocean profilers to provide environmental observation data in diverse ocean regions (Wilson 1992, Costa 1993b, Weimerskirch *et al.* 1995, McCafferty *et al.* 1999, Campagna *et al.* 2000, Boehlert *et al.* 2001, Block *et al.* 2001, Charrissin 2002, Wilson *et al.* 2002). A significant advantage of these electronic tags is that the scale and resolution of the oceanographic data matches that of the animals’ behavior thus, making it possible to couple immediate environmental conditions with foraging activity. When the biological and physical data are merged, a new understanding of the relationship between the movements and behaviors of marine predators, their prey resources, and the influence of oceanographic processes will become apparent.

PROGRESS TO DATE

Field Sites

Investigations of California sea lion diving and foraging behavior occurred simultaneously in the Channel Islands and the Monterey Bay region of the Monterey Bay National Marine Sanctuary. Carey Kuhn, who was a Sea Grant trainee and UCSC graduate student, lead the work on adult female California sea lions, which was conducted on San Nicolas Island (SNI), 33°14'N, 119°27'W. SNI is the most northwesterly of the four southern Channel Islands located off the west coast of California. Michael Weise, a Sea Grant Trainee and former graduate student at UCSC, lead the work on the adult male sea lions in the Monterey Bay and the sea lion food habits work on Año Nuevo Island, 37°6'N, 122°20'W. Año Nuevo Island, is a 3.2 ha island situated approximately 0.3 km offshore and 30 km north of Santa Cruz, California (Le Boeuf and Kaza 1981).

Female Foraging Behavior

Research examining female foraging behavior was conducted at San Nicolas Island, CA in winter of 2003, 2004, and 2005. Instruments were deployed in October/November and recovered in December/January. A total of thirty two adult female California sea lions were instrumented: eight in 2003, and twelve in both 2004 and 2005. Each animal was equipped with a satellite tracking transmitter (PTT, Sirtrack, New Zealand or Wildlife Computers, WA) and a time-depth recorder (TDR, MK8 or MK9, Wildlife Computers, WA). A sub-sample of females also received a stomach temperature recorder and telemeter to measure feeding events (N=24).

For all years combined, trip durations averaged 47.9 ± 2.0 hours (range 15.7 – 96.5 hours) and females traveled an average distance of 66.3 ± 11.0 km from the rookery (range 8.3 – 291.4 km, Table 1). Average transit rate was 0.84 ± 0.1 m s⁻¹ (range 0.5 – 1.6 m s⁻¹). Concentrated foraging occurred in an area 60 km northwest of San Nicolas, south of the northern Channel Islands (Figure 1). Females also dispersed eastward to the coast, and north of the Channel Islands towards Monterey Bay. Most satellite locations were along the continental shelf within the 500 m isobath (Figure 1). However, marked individual variation was seen in all of the movement parameters measured (Table 1). Using data collected for multiple years, this study found the variation measured between individuals in at sea distributions and movement was similar across all years. The only movement parameter that showed greater variability among years was total distance traveled, which is discussed further in relation to environmental variation.

Female California sea lions have previously been described as shallow water divers that feed on a variety of epipelagic species (Antonelis, Fiscus & Delong, 1984; Feldkamp *et al.*, 1989; Lowry & Carretta, 1999; Lowry *et al.*, 1991). The diving behavior of sea lions from San Nicolas Island supports this description, as females spent a large amount of time at relatively shallow depths (Table 2). Average dive depths and durations were similar to those measured at San Miguel Island (Feldkamp *et al.*, 1991; Feldkamp *et al.*, 1989). However, this study also measured extensive variation in dive behavior among female California sea lions (Table 2). This variation was similar in all three years, with some females diving on average under 30 m and others diving on average over 100 m.

Individual differences were also measured in dive durations, bottom time, and dive rate (Table 2).

In addition to describing at-sea behavior a primary goal of this study was to also measure feeding events in order to identify when and where females were finding prey. To measure stomach temperature and identify feeding events it is necessary for the stomach temperature telemeter to be retained in the stomach. Although we had high success rates in captive studies with California sea lions, it was difficult to obtain retention times long enough to measure feeding events in free-ranging females. Maximum retention time was 4.8 days and mean was 32.5 ± 9.8 hours. Since most females spent one to two days on shore after the tagging procedure this resulted in only five females retaining a stomach temperature telemeter while at-sea. Four of the five lost their telemeters early in the foraging trip (7.8 ± 6.3 hours) and no feeding events were recorded. One female retained her telemeter for the duration of one complete foraging trip and 15 feeding events were identified. The female only occasionally consumed prey during her initial transit to foraging grounds and continuous feeding did not occur until 9.7 hours after the female left the rookery, at a distance of 44.5km. The female showed three distinct periods of bout feeding with a minimum success rate of 9.1%, 14.3%, and 28.6% in each dive bout. After three periods of bout feeding, no feeding events were identified for the remaining 18.5 hours of the foraging trip as the female transited back to the rookery. With this small sample size it is difficult to draw conclusions about overall feeding behavior of female sea lions but these data do support the assumption that females transit to foraging grounds at the distal end of their trip and forage little during the transit period.

Interannual behavioral and environmental variation

While extensive variability was found among individuals for at-sea distribution, movements, and diving behavior, there were still significant differences in at-sea behavior among years. It appears California sea lions are able to respond to environmental variability by demonstrating flexibility in foraging locations and time at-sea. In addition to the differences in foraging locations and time at sea, females in 2004 also spent more time in transit and traveled more extensively during foraging trips (Figure 2). Due to the increase in total distance traveled, this suggests in 2004 females were foraging in an environment with decreased prey availability when compared to 2003 and 2005. In addition to the significant differences among years, females in 2004 also showed the greatest variability in total distance traveled suggesting the decreased prey availability impacted individual females differently.

In contrast to the changes in movement patterns, there were no significant differences in dive behavior among years. The large amount of variation between individuals in the present study may have obscured the ability to measure interannual differences in dive behavior. However, the extent of behavioral change should be considered with respect to the intensity of the environmental variation.

In late 2004 continuing into 2005, there were notable changes to oceanographic features in the eastern Pacific. Although signals are mixed, the Climate Prediction Center at the National Centers for Environmental Predictions described late 2004 and early 2005 as weak warm episode conditions defined by an increase in water temperature and

decrease in upwelling (Figures 3; <http://www.cpc.ncep.noaa.gov>). Sea surface temperatures in the Channel Islands region were up to 2.0°C warmer in 2004 and 2005, as compared to 2003. In addition, while upwelling appears consistent among years in November and December, decreased upwelling in 2004 and 2005 was noted earlier in the year (June and July). Since upwelling is directly linked to an increase in primary productivity, we would expect a delayed impact on sea lion foraging behavior as sea lions consume prey farther up the food chain (Antonelis *et al.*, 1984; Lowry *et al.*, 1999; Lowry *et al.*, 1991).

Overall it appears 2003 was the most productive year, based on both environmental data and sea lion behavior. In 2003, there was above average upwelling, which results in increased nutrients for primary producers, and likely more prey for large predators, such as California sea lions (Barber *et al.*, 1981; Croll *et al.*, 2005; Hutchings *et al.*, 1995). Females in 2003 spent the least amount of time at sea and the greatest amount of time on land (Figure 2). In 2004 and 2005, sea surface temperatures warmed, upwelling decreased, suggesting decreased prey resources. During these years, females spent a significantly greater amount of time at sea and in 2004, females travelled more extensively, spending the greatest amount of time in transit and making foraging trips to much further destinations (Figure 2, 4). This suggests that female California sea lions are able to alter their foraging behavior annually in order to find sufficient prey resources to support both themselves and their pups.

Male sea lion foraging behavior

During the first four years of CIMT, we developed a reliable system for capturing and deploying satellite linked dive recorders on adult male California sea lions, tested several new tag designs to optimize data collection, and discovered previously undocumented behavior in this species. We deployed a total of 22 SRDL (Satellite Relay Data Loggers) in 2002-03, 3 newly designed SRDL-CTD tags in 2004-05, and 5 SRDL, 3 SRDL-CTD, and 4 prototype SRDL-GPS tags in 2005-06. The CTD and GPS tags were developed and supported while deployed with funding augmented by ONR-NOPP and Packard Foundation through the Tagging of Pacific Pelagics Program. During anomalously warm waters resulting from the delayed onset of upwelling in 2005, 2 of 3 tagged animals ventured repeatedly up to 450 km offshore, which was not previously described in this species (Fig. 5). Trips during 2004-05 were more than twice the distance and three times the duration of trips during 2003-04, and diving patterns shifted with increased search time underwater with deeper and longer duration dives (Fig.6). Again in 2006, upwelling was delayed along central California and a number of males traveled up to 650 km offshore (Fig. 5). This highlights not only the importance of multiyear studies that can track changes in behavior, but the relationship between an apex predator and shifts in coastal oceanographic process.

Visualization of tag data and track information has progressed with it routinely being posted on the Tagging of Pacific Pelagics (TOPP) program website (<http://toppcensus.org/>), and sent to the Pacific Fisheries Environmental Laboratory (PFEL) of NOAA. As part of the Tagging of Pacific Pelagics (TOPP) program (D. Costa, PI) PFEL is currently hosting a “Live Access Server” (LAS) for ocean integration of the

animal collected data. Individual animals can be selected, and their tracks can be viewed in relation to SeaWiFS and MODIS sea surface temperature and ocean color to visualize the relationship between animal movements and oceanographic features (Fig. 7). An important advantage of the LAS structure, and a recently developed feature, is the ability to extract environmental data in a variety of formats that can be readily imported into analysis and visualization programs.

Males in this study recorded the deepest (575m) and longest (20.1min) dives for California sea lions, and for any otariid species to date. This was surprising given that the overall diving behavior of males was consistent with the hypothesis of a shallow epipelagic foraging strategy with a strong diurnal pattern as previously described for this species. Mean dive depth for all male sea lions was 32.2m (± 44.3) and dive duration was 1.86 min (± 1.55). Mean individual dive depths ranged from 19m to 96m, with 86% of all dives less than 50m (Table 4). Only 2.5% of dives were greater than 150m, and six individuals exceeded 450m. Mean individual dive durations ranged from 0.8 to 3.4 minutes (Table 4), while the maximum dive duration exceeded 18.0 minutes for five individuals. In general, males spent an approximately equal time hauled out (49.7%) and at sea (51.3%). While at sea, animals spent 31.8% of their time swimming at the surface, with the remainder of their time spent diving (18.5%; Table 4).

Body size had an influence on diving behavior with larger males diving longer ($r^2=0.31$, $P=0.009$; Fig. 8a) while spending less time at sea ($r^2=0.22$, $P=0.034$; Fig. 8b) and more time hauled out ($r^2=0.22$, $P=0.034$; Fig. 8c). In general, diving occurred at all times of day although strong diurnal patterns were apparent. While variability was high when pooling dive behavior of all individuals, there was decreased mean frequency of dives, shallower dives, shorter dives, with increased surface intervals during nighttime hours approximately between the hours of 1800 and 0600 local time (Fig. 9 a, b, c, d).

This is the first study of California sea lions to identify alternative foraging strategies among individuals. Extensive population level variation in diving behavior was best explained by variation in dive patterns, diving effort, and surface behavior (Table 2). Of the three individual strategies identified among individuals, animals in group 1 were smaller and exhibited shallow, short dives, followed by short surface intervals, and the most effort (frequency of dives, time at sea, trip duration). Group 2 and 3, were similarly large animals that were primarily adult males, although each group had one sub-adult each. Group 2 exerted more effort by diving more frequently and spending a greater percentage of time at sea diving for longer trips than group 3. Whereas, group 3 was distinguished by the least amount of diving effort with the fewest dives, least amount of time at sea diving, shortest trips, and consequently the greatest amount of time hauled out.

Water temperatures recorded by SRDLs indicated that males dived to depths that were related to the thermal structure of the water column (Fig. 10). This behavior was not only consistent with the epipelagic foraging strategies employed by female sea lions (Feldkamp et al. 1989, Costa et al. 2004), but more importantly, was consistent with the known distribution of sea lion prey species relative to thermal structure of the water column (Morejohn et al. 1978, Vaughan & Recksiek 1978, Chess et al. 1988, Reynolds 2003, Helser et al. 2006, Hill K.T. et al. 2006) Variation in the foraging behavior of

diving birds and mammals has been related to prey that are distributed at different depth within the water column (Costa 1991). Males with shallow diving behavior (or individuals that primarily dive shallow) with short durations, and in close relationship to the thermoclines were likely pursuing prey species such as market squid, sardines, and anchovies that are distributed relative to the thermocline. Whereas deeper dives (or deeper diving individuals) moving closer to the bottom or shelf break well below the thermocline were likely pursuing prey distributed more mesopelagically and possibly benthically including certain rockfish species, certain age classes of hake, and flatfish species.

Dispersal of males from rookeries may be explained by an animals ability to meet their energetic needs with more efficiently (shallow dives of less duration with less overall foraging effort) in central and northern California than southern California. Concomitantly, dispersal of males was possible because they were not constrained to foraging in close proximity to rookeries following the breeding season because of their lack of parental care. Male diving depth in southern California ($63.7\text{m}\pm 94.0$) was within the range recorded for females (20-90m); however, males were diving for greater durations ($3.3\text{min} \pm 2.3\text{min}$) than females (1.5-2.8min), with less effort (202 dives/day), and less time at sea diving ($24.8\%\pm 28.7$) than females (32.7%, Feldkamp et al. 1989; 41.5%, Kuhn In Prep). Because male dive depth was similar to females in southern California, they were likely feeding on similar prey species, and therefore, not exhibiting niche divergence. The difference among sexes was the greater foraging efficiency of males compared to females given the greater dive durations and less time spent at sea diving.

Food Habits & Consumption Models

With support from the National Marine Fisheries Service West Coast Pinniped Predation Program, information on prey composition and temporal changes in diet of California sea lions in Central California were obtained through the examination and identification of prey hard parts found in fecal samples. Approximately 1,600 fresh fecal samples have been collected monthly at haul out sites used exclusively by California sea lions on Año Nuevo Island from October 2001 through December 2006. To detect changes in sea lion diet in relation to climatic forcing, each prey species in the diet for each year was expressed as an anomaly of the mean percentage of the total estimated mass (%M) of prey ingested.

The diet of California sea lions during 2006 in central California was similar to 2005 with anomalous oceanographic conditions resulting in positive anomalies in the percentage mass consumed of rockfish (*Sebastes* spp.) and sardines (*Sardinops sagax*), and negative anomalies in market squid (*Loligo opalescens*; Fig. 11). Increased percentage mass anomalies of rockfish and sardine were consistent with these species dominating the overall diet with rockfish constituting 27.5% of the total mass consumed and sardines 25.6%. Whereas northern anchovies (*Engraulis mordax*) had a slightly positive percentage mass anomaly in 2006, they decreased in the total percentage mass consumed from the most important prey item in 2005 (31.2%) to the third most important in 2006 (20.6%). Decreased percentage mass anomaly of market squid and increased

anomaly of sardine in the diet during 2005 and 2006 were similar to trends observed in sea lion diet during the 1997-98 El Niño and subsequent La Niña in 1999 (Fig. 11). Sizes of rockfish consumed in 2006 were similar to those eaten during 2005, but larger than fish consumed during the 1997-98 El Niño; whereas sardine consumed in 2006 were adults (27-36 cm) and similar in size to those eaten during 1997-98 El Niño, but larger than the juveniles (12-18 cm) identified during 2005 (Fig. 12). Similar diet anomalies during 2005 and 2006 in central California indicated there were likely similar climatic shifts or conditions during both years, which has been borne out by the late onset of upwelling during both years. This work highlights the plasticity of the sea lion diet, and how this apex predator can serve as a sentinel of shifts in climatic and biological conditions.

Development of quantitative estimates of sea lion consumption of prey species from 2001 to 2006 is ongoing and expected to be completed during the summer of 2007 with a manuscript to be submitted for publication.

THE OVERALL PROJECT GOAL

The goal of this project was to investigate the foraging and diving behavior, timing and location of foraging, food habits, and at-sea distribution of California sea lions along the California coast and to estimate the impacts of those behaviors on listed stocks of salmonids, other protected fish species, and commercially important fish species.

PROGRESS TOWARD OVERALL GOAL

We have made significant strides toward achieving the overall goal of this project including the following:

- Successfully tagged and monitored the movement and diving patterns of adult female, and sub-adult and adult male sea lions at several locations along the coast of California.
- Determined the at-sea distribution of foraging activities of different size classes of sea lions, which encompass virtually the entire California coast. Documented the inter-annual changes in movement patterns and diving behavior in relation to changing oceanographic conditions, and presumably shifting prey distributions.
- Identified the 'hotspots' or areas where sea lions (males and females) diving or foraging activity is located along the coast, and how these hotspots vary among years.
- Evaluated the diving patterns and effort of sea lions along the coast.
- Identified different foraging strategies among individuals that likely accounted for much of the variation on the population level among males. These different strategies likely reflect differences in targeted prey.
- Developed an understanding of what may be driving male dispersal from breeding rookeries in southern California, which is possible because of the lack of parental involvement. As males moved into central and northern California they increased

- their foraging efficiency (shallower, shorter dives with less effort) compared to males that returned to breeding rookeries in southern California.
- Visualization of tag data and track information has progressed with it routinely being posted on the Tagging of Pacific Pelagics (TOPP) program website (<http://toppcensus.org/>), and sent to the Pacific Fisheries Environmental Laboratory (PFEL) of NOAA. Individual animals can be selected, and their tracks can be viewed in relation to SeaWiFS and MODIS sea surface temperature and ocean color to visualize the relationship between animal movements and oceanographic features.
 - Collected, processed, identified and analysis of California sea lion fecal samples to determine their seasonal and annual food habits.
 - Developed quantitative models to estimate sea lion consumption of prey species to evaluate the impact of sea lions on listed stocks of salmonids, other protected fish species, and commercially important fish species.

Although the chief objectives of this project have been achieved, additional analyses of the data are currently ongoing with support from TOPP and funded by the National Marine Fisheries Service through the WCPMP. Additional objectives include:

- 1) Define the locations and predominant oceanographic conditions and/or habitats used by foraging California sea lions.
- 2) Develop models to predict sea lion foraging behavior and locations based on oceanographic conditions.

During 2006/07, we expect to complete these objectives and prepare manuscripts for publication. Further, analysis of how apex predators utilize their environment and movements of all animals will be assessed using ArcView 9.0 (ESRI, Redlands, CA), MAMVIS (SMRU), and Matlab 7.0. We will complete the quantitative modeling of sea lion predation on salmonid populations and commercial fisheries stocks, using annual consumption models, which include population size (based on ground counts), dietary data, sea lion energetics, and prey energy content.

INFORMATION DISSIMINATION

Results or data from this study have been published or in review in the following papers:

- Weise, M.J., and D. P. Costa. *In Review*. Diving behavior and foraging strategies of the male California sea lion (*Zalophus californianus*). *Journal of Animal Ecology*. Submitted July 2006.
- Goericke R, Venrick E, Mantyla A, Bograd SJ, Schwing FB, Sydeman WJ, Weise, MJ, et al. *In Review*. The State of the California Current, 2005-06. CalCOFI Reports, Volume 48.
- Weise, M.J., and D. P. Costa. 2007. Total Body Oxygen Stores and Physiological Diving Capacity of California Sea Lions as a Function of Sex and Age. *Journal of Experimental Biology*. 210:278-289.

- Kuhn, C.E. (2006) Measuring feeding to understand the foraging behavior of pinnipeds, University of California, Santa Cruz, Santa Cruz.
- Kuhn, C.E. and D.P. Costa 2006. Identifying and quantifying prey consumption using stomach temperature change in pinnipeds. *Journal of Experimental Biology*. 209: 4524-4532.
- Weise, M.J., D.P. Costa, and R. Kudela. 2006. Movement and diving behavior of male California sea lion (*Zalophus californianus*) during anomalous oceanographic conditions of 2005 compared to those of 2004. *Geophysical Research Letters*. Vol. 33, L22S10, doi:10.1029/2006GL027113.
- Weise, M.J. 2006 Foraging ecology of male California sea lion (*Zalophus californianus*): movement, diving and foraging behavior, and diving capacity. Ph.D. dissertation, University of California Santa Cruz.
- Goericke R, Venrick E, Mantyla A, Bograd SJ, Schwing FB, Sydeman WJ, Weise, MJ, et al. (2006) The State of the California Current, 2004-05. CalCOFI Reports, Volume 47, 176 pp.
- Tremblay, Y., S. Shaffer, S. Fowler, C.E. Kuhn, B.I. McDonald, M.J. Weise, C. Bost, H. Weimerskirch, D.E. Crocker, M.E. Goebel, and D. P. Costa. 2006. Interpolation of tracking data in a fluid environment. *Journal Experimental Biology*. 209:128-140.
- Debiec C., Ylitalo G.M, Weise M., Gulland F, Costa D.P., Le Boeuf B.J., de Tillesse T. and Larondelle Y., 2005. PCBs and DDT in the serum of juvenile California sea lions: Associations with vitamins A and E and thyroid hormones. *Environmental Pollution*.134(2):323-332.
- D. P. Costa, C.E. Kuhn, M.J. Weise, S.A. Shaffer, and J.P.Y. Arnould. 2004. When Does Physiology Limit the Foraging Behavior of Freely Diving Mammals? *In Proceedings of the Third International Conference of Comparative Physiology and Biochemistry*. Edited by S. Morris and A. Vosloo. 1275C, pp 359-366.

In Prep:

- Kuhn, C.E. and D. Costa. Hierarchy in variation of foraging behavior of a marine predator, the California sea lion. For submission to *Ecology*.

Results from this study have been presented at the following conferences:

- Kuhn, C.E. and D. P. Costa. 2007. Interannual variability in the foraging behavior of California sea lions: behavioral responses to environmental variation. Oral Presentation. Society for Integrative and Comparative Biology Conference. Phoenix, Arizona.
- Kuhn, C.E. 2006. Spatial and temporal variation in the foraging behavior of California sea lions. Invited presentation. Sonoma State University Biology Colloquium.
- Kuhn, C.E. and D. Costa. 2005. Foraging behavior of the California sea lion: Population differences, annual differences and individual foraging strategies. Oral Presentation. 2nd International Bio-Logging Science Symposium.

- Kuhn, C.E. and D. Costa. 2005. Examination of the foraging strategies of a top marine predator: the California sea lion. Poster Presentation. Society for Integrative and Comparative Biology Conference.
- Kuhn, C.E., Aurioles, and D.P. Costa. 2004. Differences in Foraging Behavior Between Two Populations of California sea lion. Kenneth S. Norris Marine Mammal Research Symposium. UC Santa Cruz, CA.
- Kuhn, C.E. and D. Costa. 2004. California sea lion foraging ecology: Habitat utilization, diving and foraging behavior. Oral Presentation. 84th Meeting of the American Society of Mammalogists.
- Kuhn, C.E., Aurioles-Gamboa, D., and D. Costa. 2004. Habitat utilization, diving and foraging behavior of adult female California sea lions. Poster Presentation. XXIX Reunión Internacional para el Estudio de los Mamíferos Marinos.
- Kuhn, C.E., Aurioles-Gamboa, D., and D. Costa. 2003. Habitat utilization, diving and foraging behavior of adult female California sea lions: Pushing physiological limits. Oral Presentation. 15th Biennial Conference on the Biology of Marine Mammals.
- Weise, M.J., and D. P. Costa. 2007. *Tagging of Pacific Pelagics (TOPP): From the Bottom Up*. Oral Presentation. Animal Tracking and Physiological Monitoring workshop. Princeton University. Princeton, NJ.
- Weise, M.J., and D. P. Costa. 2007. *Individual-based foraging strategies in male California Sea Lions (Zalophus californianus)*. Oral Presentation. Society for Integrative and Comparative Biology Conference. Phoenix, Arizona.
- Weise, M.J., and D. P. Costa. 2006. *Animal Platforms for the Collection of Oceanographic Data as Part of an Integrated Ocean Observation System*. Oral presentation. California and the World Oceans Conference. Long Beach, California.
- Weise, M.J., and D. P. Costa. 2006. *Diving Behavior of Male California Sea Lion (Zalophus californianus) in relation to Coastal Upwelling Systems*. Oral Presentation. International Ocean Sciences Meeting. Honolulu, Hawaii.
- Weise, M. *The forgotten sex: Foraging ecology of male California sea lions*. Sonoma State University Biology Colloquium Fall 2006. Rohnert Park, CA. October 2006.
- Weise, M. *Foraging ecology of apex predators and ecosystem-based fisheries management*. Departmental Seminar. California State University Monterey, Marina, CA. March 2006.
- Weise, M. *Pinniped foraging ecology*. Departmental Seminar. Oregon State University, Hatfield Marine Station. Newport, Oregon. June 2005.
- Weise, M. *Future opportunities in pinniped foraging ecology*. Departmental Seminar. Oregon State University, Corvallis, Oregon. June 2005.
- Weise, M. *Pinniped foraging ecology : Consideration of predator impacts in ecosystem-based fisheries management*. NOAA Fisheries, Santa Cruz, CA. December 2005.
- Weise, M. and D.P. Costa. *The influence of inter-annual environmental fluctuations on the foraging behavior of male California sea lions*, 16th Biennial Marine Mammal Conference, San Diego, CA. December 2005.
- Weise, M.J., and D. P. Costa. 2004. *Are all sea lions created equal? Comparison of oxygen storage capacity of adult female California sea lions in California and*

- Mexico*. Poster presentation. Sea Lions of the World Symposium. Alaska Sea Grant. Anchorage, AK.
- Weise, M.J., D. P. Costa, and D. Aurióles-Gamboa. 2004. *Comparison of the diving physiology of adult female California sea lions in California and Mexico*. Oral presentation. American Mammalogy Society, Arcata, CA.
- Weise, M.J., D. P. Costa, and D. Aurióles-Gamboa. 2004. *What's unique about Mexican females? Diving physiology of adult female California sea lion, Zalophus californianus*. Poster presentation. XXIX Reunion Interenacional para el Estudio de los Mamíferos Marinos. La Paz, Mexico.
- Weise, M.J., and D. P. Costa. 2003. *Oxygen Stores and Diving Ability in California Sea Lion, Zalophus californianus*. Poster presentation. 14th Biennial Conference on the Biology of Marine mammals. Greensboro, S.C.

Carey Kuhn and Michael Weise completed their research in 2006 and all sea lion work has been published in their dissertations, and is published, In Review, or In Preparation for peer reviewed journals. This information will also be disseminated within the fisheries and management communities. Results from the proposed study will be integrated into the West Coast Pinniped Predation Program. The WCPPP includes federal and state fisheries managers from California, Oregon, and Washington. Additionally, all the animal derived oceanographic data will be archived with the NODC and become part of the World Ocean Data Base.

Finally, as Dr. Costa is a PI in TOPP and Center for Integrated Marine Technologies (CIMT), our sea lion work has been incorporated into the existing public education and outreach efforts, directed by the Monterey Bay Aquarium for TOPP (www.toppcensus.org) and UCSC for CIMT (<http://cimt.ucsc.edu/>).

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Table 1. Summary of mean movement parameters for 26 adult female California sea lions from 2003-2005. Last two digits in animal ID represent the year of study. ‘All females’ is the mean of the mean values for each individual. Percent deviation from the overall mean is presented for each dive parameter. Statistical differences between years are summarized in Table 3.3.

Animal ID	Max. distance (km)	% dev	Mean distance (km)	% dev	Total distance (km)	% dev	Transit rate (m/s)	% dev	Home range 95% (km ²)	% dev	Home range 50% (km ²)	% dev
SN1-03	97	-3.2	61.6	-7.1	301	-30.1	1.10	30.5	1726	-79.4	82	-91.1
SN2-03	37	-63.3	22.9	-65.5	174	-59.6	0.96	13.5	11551	37.7	1123	22.4
SN3-03	105	4.7	60.9	-8.1	722	67.3	0.95	12.4	2711	-67.7	249	-72.9
SN5-03	73	-27.1	42.2	-36.4	428	-0.8	0.98	15.9	1521	-81.9	160	-82.5
SN6-03	31	-69.7	8.3	-87.4	409	-5.2	0.96	13.5	408	-95.1	24	-97.3
SN8-03	119	17.9	82.9	25.0	505	17.1	1.17	38.7	4618	-45.0	373	-59.3
SN9-03	85	-15.6	59.8	-9.9	316	-26.6	0.79	-6.7	1121	-86.6	221	-75.9
SN1-04	96	-4.4	76.3	15.0	1875	334.9	0.66	-21.3	38293	356.3	3952	330.9
SN3-04	401	297.9	291.4	339.3	1301	201.6	1.08	28.1	1653	-80.3	233	-74.6
SN6-04	74	-26.9	48.9	-26.3	348	-19.2	0.85	0.8	5546	-33.9	538	-41.3
SN7-04	112	11.2	61.2	-7.7	642	48.8	0.90	6.4	12976	54.6	984	7.3
SN8-04	249	147.5	157.7	137.8	567	31.5	0.88	3.9	2067	-75.4	246	-73.1
SN10-04	81	-19.4	46.1	-30.5	400	-7.2	0.73	-12.8	1554	-81.5	141	-84.6
SN11-04	54	-46.5	39.7	-40.1	155	-64.0	1.57	85.8	1574	-81.2	205	-77.7
SN12-04	126	25.6	96.3	45.2	474	10.0	1.03	22.3	767	-90.9	84	-90.9
SN100-05	55	-45.9	30.4	-54.1	155	-64.1	0.53	-37.5	2673	-68.1	145	-84.2
SN101-05	94	-6.2	56.3	-15.1	273	-36.7	0.55	-35.3	20046	138.9	4011	337.4
SN102-05	180	79.1	112.9	70.3	457	6.0	0.88	4.2	12420	48.0	864	-5.8
SN104-05	64	-36.9	39.6	-40.3	206	-52.1	0.60	-28.3	2280	-72.8	333	-63.7
SN105-05	57	-43.0	38.9	-41.4	167	-61.4	0.55	-34.8	671	-92.0	69	-92.5
SN107-05	63	-37.9	44.9	-32.4	200	-53.7	0.55	-34.5	3213	-61.7	348	-62.0
SN108-05	68	-32.5	39.1	-41.1	199	-53.9	0.63	-25.5	337	-96.0	61	-93.3
SN109-05	126	24.9	95.0	43.2	340	-21.1	0.75	-11.0	1716	-79.5	188	-79.5
SN110-05	37	-63.0	23.2	-65.1	124	-71.2	0.83	-1.9	2127	-74.7	364	-60.3
SN111-05	92	-8.8	61.8	-6.8	334	-22.4	0.65	-22.8	1160	-86.2	131	-85.7
SN140-05	42	-58.6	26.1	-60.6	139	-67.7	0.81	-3.8	1476	-82.4	194	-78.8
All females	101 (15)		66 (11)		431 (75)		0.84 (0.1)		5239 (1628)		589 (203)	

Table 2. Summary of dive parameters for 25 adult female California sea lions from 2003-2005 [Mean (SE)]. Last two digits in animal ID represent the year of study. ‘All females’ is the mean of the mean values for each individual. There were no significant differences among years for all dive parameters and there were no significant differences in individual variation between years. Percent deviation from the overall mean is presented for each dive parameter.

Animal ID	Mass (kg)	Depth (m)	% dev	Duration (min)	% dev	Bottom time (min)	% dev	Surface interval (min)	% dev	Time at sea (%)	% dev	Percent diving	% dev	Dive rate (dives/hr)	% dev
SNI1-03	96.0	31.4 (0.4)	-46.0	1.9 (0.02)	-11.0	0.8 (0.01)	33.1	4.9 (0.9)	16.9	51	-24.0	53.8	29.4	16.5	24.6
SNI2-03	73.2	26.2 (0.3)	-55.0	1.4 (0.01)	-36.9	0.4 (0.01)	-7.2	4.0 (0.7)	-48.3	61.2	-8.8	41.6	0.1	18.4	38.9
SNI4-03	87.8	103.7 (2.5)	78.3	2.9 (0.05)	33.7	0.6 (0.01)	-33.9	8.8 (1.8)	-11.2	66	-1.7	37.0	-10.9	7.7	-41.7
SNI6-03	85.4	17.1 (0.2)	-70.7	1.3 (0.02)	-41.7	0.6 (0.01)	110.6	4.0 (0.7)	-18.6	52.7	-21.5	44.5	7.1	21.3	60.9
SNI8-03	83.8	34.1 (0.4)	-41.5	1.8 (0.01)	-14.5	0.9 (0.01)	20.2	3.6 (0.6)	22.7	71.7	6.7	47.3	14.0	15.4	16.6
SNI9-03	87.0	54.6 (1.0)	-6.2	2.0 (0.02)	-7.8	0.6 (0.01)	-23.7	5.3 (1.0)	-22.4	60.1	-10.4	45.2	8.8	13.0	-1.7
SNI1-04	82.2	35.4 (0.5)	-39.3	2.0 (0.02)	-7.5	1.0 (0.01)	24.5	6.6 (0.9)	37.7	64.8	-3.4	37.2	10.4	11.2	-15.2
SNI2-04	90.6	114.3 (2.3)	96.4	3.7 (0.05)	71.2	1.1 (0.02)	-30.6	12.6 (2.6)	55.6	74.5	11.0	29.4	29.2	4.8	-63.9
SNI4-04	87.0	13.6 (0.1)	-76.7	1.3 (0.01)	-38.5	0.6 (0.01)	62.5	2.5 (0.3)	-9.3	70.6	5.2	48.9	17.7	22.2	67.4
SNI7-04	61.8	53.9 (0.7)	-7.3	2.0 (0.02)	-8.0	0.7 (0.01)	-1.5	4.2 (0.6)	-6.1	63.9	-4.8	48.2	16.1	14.6	10.4
SNI8-04	109.0	42.4 (0.4)	-27.2	1.8 (0.01)	-17.0	0.7 (0.01)	8.5	5.3 (1.0)	-4.2	67.5	0.5	36.4	-12.3	12.2	-7.5
SNI9-04	88.2	32.5 (0.3)	-44.2	1.6 (0.01)	-23.9	0.6 (0.01)	13.8	3.9 (0.6)	-15.7	74.4	10.8	38.4	-7.5	14.1	6.3
SNI11-04	94.2	171.3 (2.2)	194.4	4.3 (0.04)	98.4	1.3 (0.02)	-31.9	18.8 (2.4)	87.6	71.7	6.7	24.4	-41.1	3.4	-74.0
SNI12-04	94.8	32.0 (0.2)	-45.0	2.0 (0.01)	-8.7	1.0 (0.01)	-14.2	3.7 (0.6)	49.1	74.3	10.7	46.5	12.1	14.2	7.4

Table 2. Continued

Animal ID	Mass (kg)	Depth (m)	% dev	Duration (min)	% dev	Bottom time (min)	% dev	Surface interval (min)	% dev	Time at sea (%)	% dev	Percent diving	% dev	Dive rate (dives/hr)	% dev
SNI100-05	69.4	40.1 (0.2)	-30.4	1.7 (0.01)	-21.8	0.5 (0.01)	-11.8	3.0 (0.3)	-31.4	70.2	4.5	51.3	23.6	18.3	38.4
SNI101-05	86.4	30.1 (0.3)	-48.3	1.6 (0.01)	-25.3	0.5 (0.01)	3.4	4.0 (0.5)	-29.5	62.1	-7.5	45.9	10.4	17.1	29.4
SNI102-05	73.6	31.8 (0.2)	-45.4	1.7 (0.01)	-20.7	0.5 (0.01)	-4.9	3.0 (0.4)	-22.5	70.6	5.1	50.5	21.5	17.8	34.1
SNI104-05	86.2	33.1 (0.4)	-43.1	1.6 (0.01)	-25.0	0.5 (0.01)	14.9	4.1 (0.5)	-30.3	66.8	0.5	41.7	0.3	15.5	17.1
SNI105-05	91.4	63.3 (0.9)	8.8	2.1 (0.02)	-1.7	0.5 (0.01)	-28.5	7.5 (0.8)	-30.2	70.0	3.8	30.5	-26.5	8.7	-34.5
SNI107-05	96.0	133.1 (1.3)	128.7	3.7 (0.03)	73.8	1.2 (0.01)	-12.8	12.1 (1.1)	71.8	75.7	12.7	30.8	-25.8	5.0	62.6
SNI108-05	72.0	56.7 (0.4)	-2.6	1.9 (0.01)	-11.3	0.4 (0.01)	-42.5	3.2 (0.3)	-49.2	75.6	12.6	48.4	16.5	15.2	15.0
SNI109-05	78.6	23.0 (0.1)	-60.6	1.5 (0.01)	-30.7	0.6 (0.01)	17.4	4.2 (0.5)	-10.8	65.7	-2.2	39.4	-5.0	15.9	19.9
SNI110-05	90.0	135.3 (1.6)	132.5	3.4 (0.03)	56.5	0.7 (0.01)	-33.0	9.3 (1.1)	6.5	60.1	-9.3	42.5	2.3	7.6	-42.8
SNI111-05	63.6	54.0 (0.5)	-7.2	2.1 (0.01)	-3.9	0.7 (0.01)	-2.3	4.1 (0.4)	-4.6	69.5	3.5	47.2	13.7	13.7	3.6
SNI140-05	87.4	91.8 (1.3)	57.7	2.6 (0.02)	22.3	0.7 (0.01)	-29.9	9.8 (1.2)	-3.5	67.4	0.4	31.2	-24.9	7.1	-46.2
All females	84.6 (2.2)	58.2 (8.4)		2.2 (0.2)		0.7 (0.05)		6.0 (0.8)		67.1 (1.3)		41.5 (1.6)		13.2 (1.0)	

Table 3. Summary of movement parameters by year for 26 adult female California sea lions in 2003 (N=7), 2004 (N=8), 2005 (N=11). Trip duration is for 25 females (2003, N=6). Means are presented \pm SE, NS= not significantly different.

	2003	2004	2005	Significant differences	
Maximum distance (km)	78.2 (12.7)	149.2 (41.7)	79.8 (12.7)	Trend: 2004 > 2003=2005	$F_{2,23}=2.6$ $p=0.09$
Mean distance (km)	48.4 (9.7)	102.2 (30.2)	51.6 (8.6)	Trend: 2004 > 2003=2005	$F_{2,23}=2.6$ $p=0.09$
Total distance traveled (km)	407.9 (65.9)	720.3 (203.6)	235.9 (31.3)	2004 > 2005	$F_{2,23}=5.6$ $p=0.01$
Mean transit rate (m/s)	0.98 (0.04)	0.96 (0.10)	0.67 (0.04)	2005 < 2004=2003	$F_{2,23}=11.0$ $p<0.01$
Trip duration (hours)	27.5 (3.2)	53.9 (1.5)	54.7 (1.4)	2003 < 2004=2005	$F_{2,22}=5.2$ $p=0.01$
Home range area 95% (km²)	3379 (1454)	8054 (4549)	4375 (1858)	NS	--
Home range area 50% (km²)	319 (140)	798 (462)	610 (347)	NS	--

Table 4. Summary of diving patterns and effort for 25 tagged male California sea lions. Foraging strategies grouped by number (1-3). Data collected from males tagged in 2004 were insufficient to include in analysis of individual foraging strategies.

Foraging Strategy	Animal ID	Body mass	Dive depth ± SD (m)	Dive duration (min)	Surface duration (min)	Dive frequency (# dives / 4 hrs)	Trip duration (hrs)	Ratio dive depth to bottom depth	Residual dive depth to thermocline depth	Time surface (%)	Time diving (%)	Time HO (%)
Group 1	28588	79	24.1 ± 33.9	1.1 ± 1.0	1.1	47.5	11.3	0.3	54.3 ± 56.2	37.4	20	42.7
	28589	70	27.6 ± 11.9	2 ± 0.9	1	41.2	23.2	0.3	25 ± 30.7	31.6	34.7	33.8
	37588	119	24.3 ± 28.9	1.6 ± 1.1	1.4	32.7	13.4	0.2	49.5 ± 71.4	36.2	21.3	42.4
	37589	117	23.1 ± 15.3	1.5 ± 0.8	1.1	34.5	5.4	0.3	22.5 ± 10.8	25.5	20.6	53.9
	37590	122	31.5 ± 31.1	1.4 ± 1.0	1.6	31.5	14.7	0.4	45.8 ± 38.9	43.4	17.7	39
	37591	168	19.2 ± 22.0	1.3 ± 1.0	1.5	28.3	10.2	0.3	38.1 ± 41.7	40.2	13.6	46.3
	37592	145	30.3 ± 25.0	1.5 ± 1.0	1.4	29.4	10	0.3	30 ± 20.6	34.9	17.4	47.7
	44634	129	32.3 ± 31.5	1.8 ± 1.2	1.6	27.2	10.5	0.3	58.9 ± 58.8	37	20	43.1
	44635	156	37.3 ± 40.1	2 ± 1.4	1.8	34.3	12.3	0.2	67.8 ± 63.4	45.3	25.8	29
	Mean	122.8	27.7 ± 26.6	1.6 ± 1.1	1.4	34.1	12.3	0.3	43.5 ± 43.6	36.8	21.2	42.0
Group 2	28587	311	37.4 ± 52.7	3.8 ± 2.6	1.5	26.9	8.8	0.3	64.1 ± 85.8	23.6	25.1	51.3
	28590	183	48.2 ± 87.6	1.7 ± 1.9	1.3	36.2	11.8	0.3	116.4 ± 117.1	37.2	18.4	44.3
	44637	200	21.7 ± 16.3	2.1 ± 1.7	1.4	27.1	10.2	0.3	37 ± 75.4	24.5	21.8	53.8
	44639	192	25.3 ± 40.2	1.5 ± 1.4	1.5	24.2	18.3	0.5	53.1 ± 90.9	29.2	15.1	55.7
	44640	124	46.6 ± 71.1	2.1 ± 1.8	1.6	26.1	15.2	0.2	108.6 ± 122.8	38.4	21.7	39.9
	Mean	173.6	35.8 ± 53.6	2.2 ± 1.9	1.5	28.1	12.9	0.3	75.8 ± 98.4	30.6	20.4	49.0
Group 3	37593	191	22 ± 20.4	1.6 ± 1.2	1.7	18.2	9.1	0.3	60.5 ± 72.3	29.9	12.7	57.4
	37597	145	24.4 ± 21.8	1.6 ± 1.2	1.6	23.1	8	0.4	30.1 ± 19.7	26.4	15.4	58.2
	37598	202	24.3 ± 12.7	1.9 ± 1.1	1.3	22.8	4.6	0.3	22.3 ± 15.0	22.5	17.9	59.6
	44632	153	34.4 ± 29.5	2.1 ± 1.3	1.7	22.4	9.2	0.4	37.3 ± 22.3	28.7	17.7	53.6
	44633	156	28.7 ± 28.3	2 ± 1.4	1.5	23.5	8.2	0.3	45.9 ± 34.3	27.4	19.3	53.3
	44636	155	96.3 ± 103.2	3.4 ± 2.7	2.8	12.2	12.8	0.3	171.4 ± 110.9	37.9	16.8	45.3
	44638	274	39.9 ± 47.9	2.4 ± 2.0	2	17.7	10.1	0.4	65.8 ± 78.9	32.2	17.3	50.5
	Mean	174.8	38.6 ± 37.7	2.1 ± 1.6	1.8	20.0	8.9	0.3	61.9 ± 50.5	29.3	16.7	54.0
2004/05	26343	163	40.3 ± 43.9	2.0 ± 1.6	1.8	35.4	44.4	0.3	na	38.9	18.2	42.9
	28588	178	62.0 ± 67.2	3.1 ± 2.1	2.6	22.4	50.2	0.2	na	15.5	50.8	22.4
	28599	191	61.0 ± 62.3	2.7 ± 1.8	2.5	24.1	45.8	0.1	na	17.3	33.8	24.1
Overall Mean			32.2 ± 44.3	1.9 ± 1.6	1.6	27.9	15.4	0.3	74.2	31.8	18.5	49.7

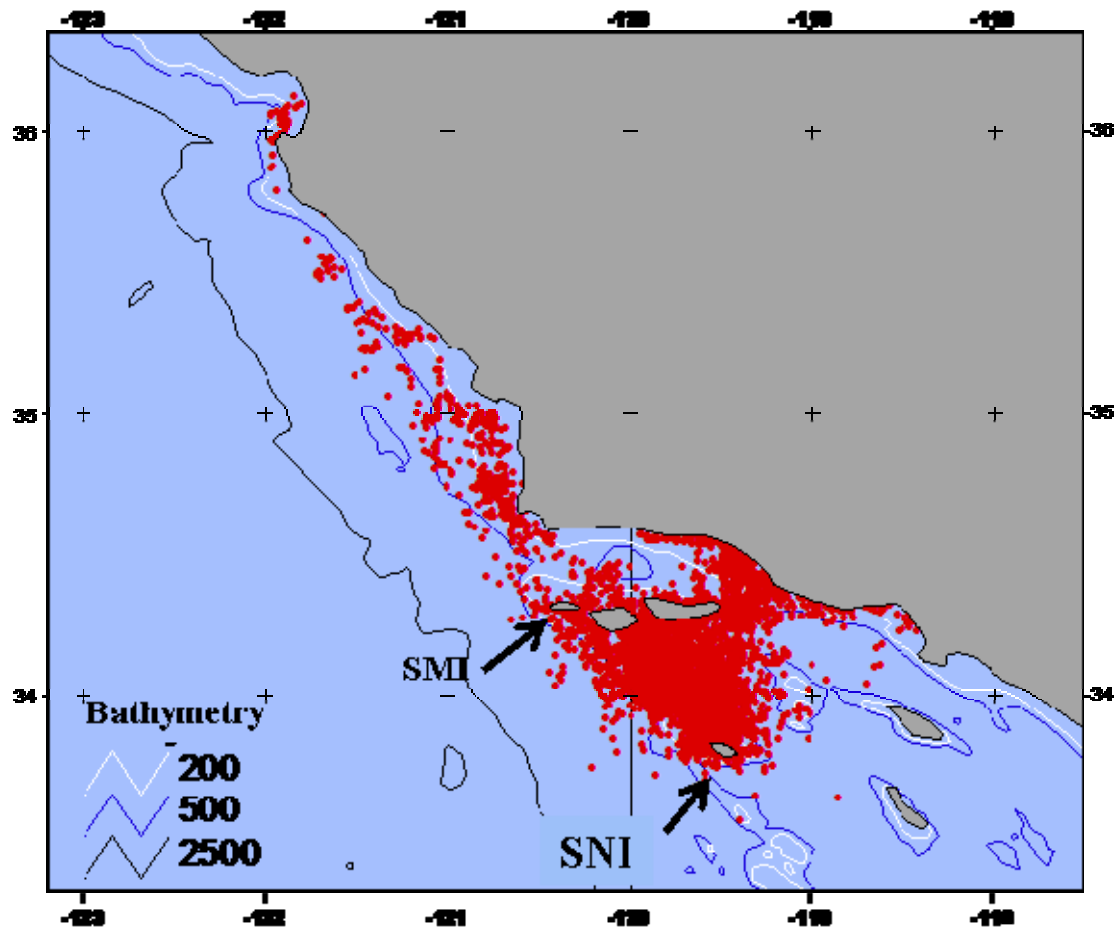


Figure 1. Distribution of all filtered at sea satellite locations for 26 adult female California sea lions from San Nicolas Island (SNI). Most locations were along the continental shelf within the 500 m isobath. Females concentrated foraging to the northwest of the island and along the mainland coast to the northeast. Previous research examining California sea lion at sea behavior was conducted at San Miguel Island (SMI).

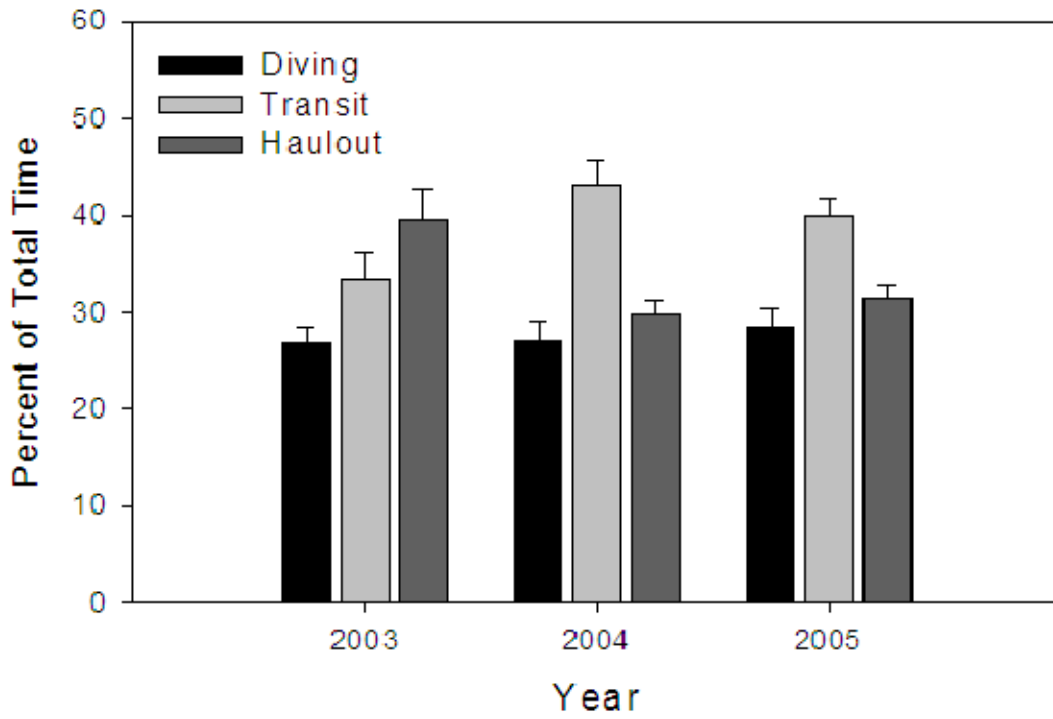


Figure 2. Distribution of time spent between diving, transit (or rest), and haulout for female California sea lions in 2003, 2004, and 2005 (N=25, Mean \pm SE). In both 2004 and 2005 females spent more time in transit. Note percent of time diving is similar among years.

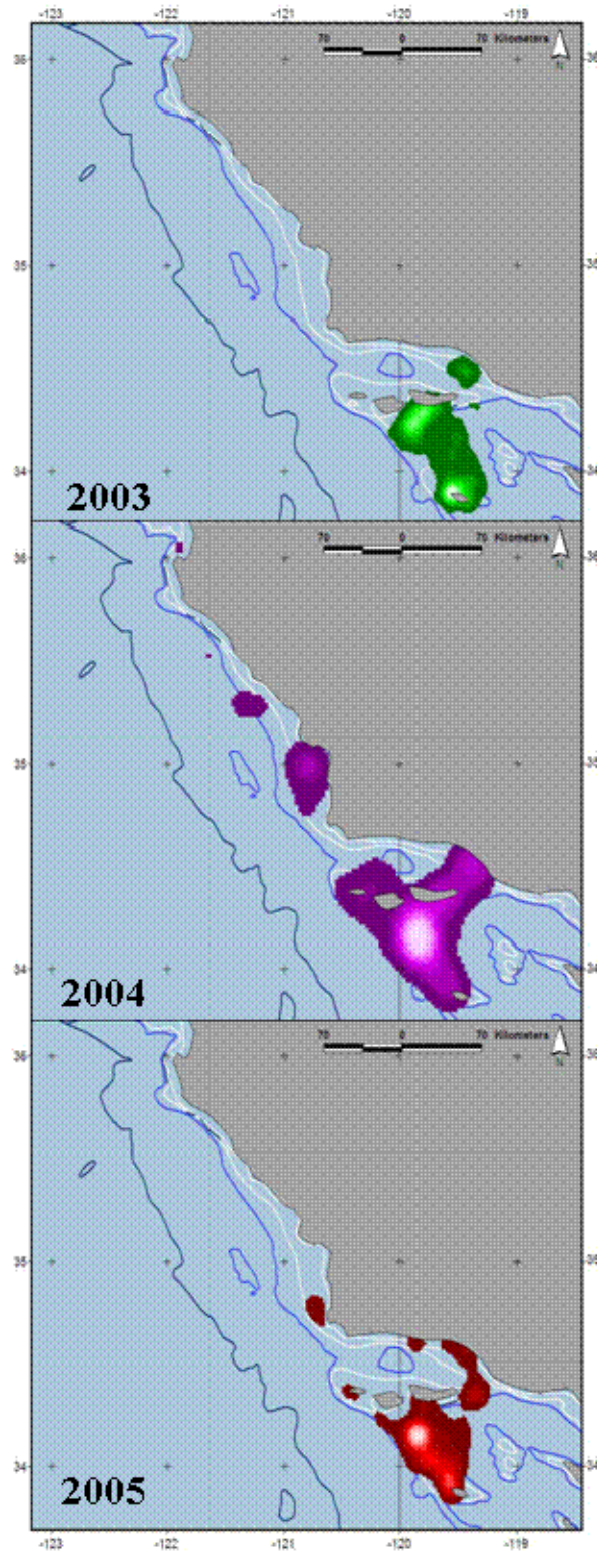


Figure 3. Kernel home range contours for all females within each deployment year (2003-2005). Home range was calculated using only satellite locations associated with diving. In 2004 (N=8), the 95% home range was 2.3 and 2.1 times larger than 2003 (N=7) and 2005 (N=11).

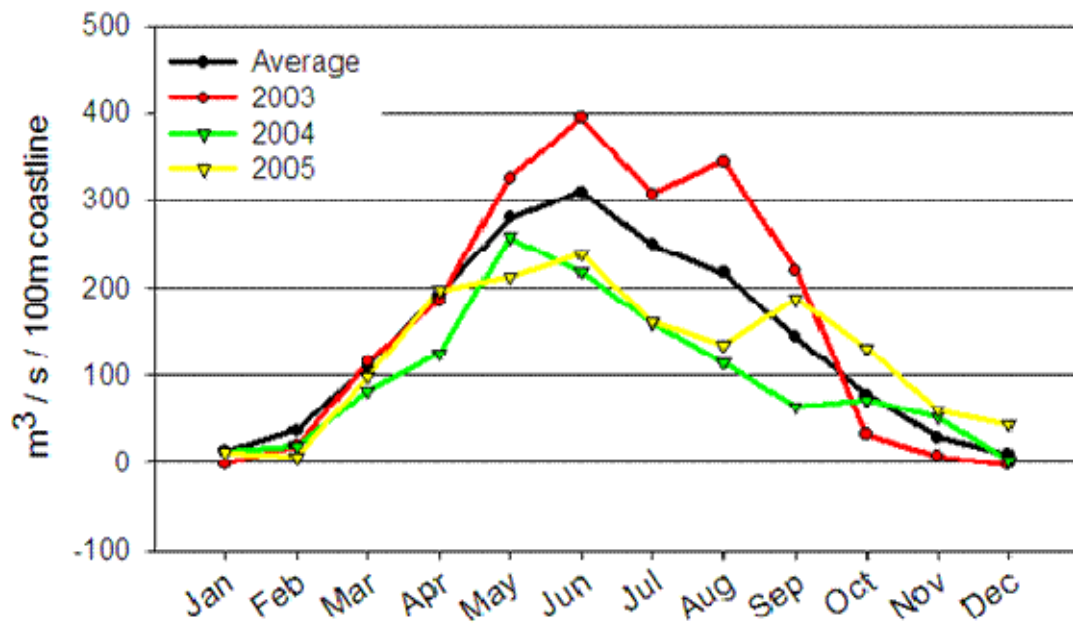


Figure 4. Upwelling index for 33°N, 119°W derived by the Environmental Research Division of the National Marine Fisheries Service. Both 2004 and 2005 show a decrease in peak upwelling for the year compared to average (1946-2005) and 2003.

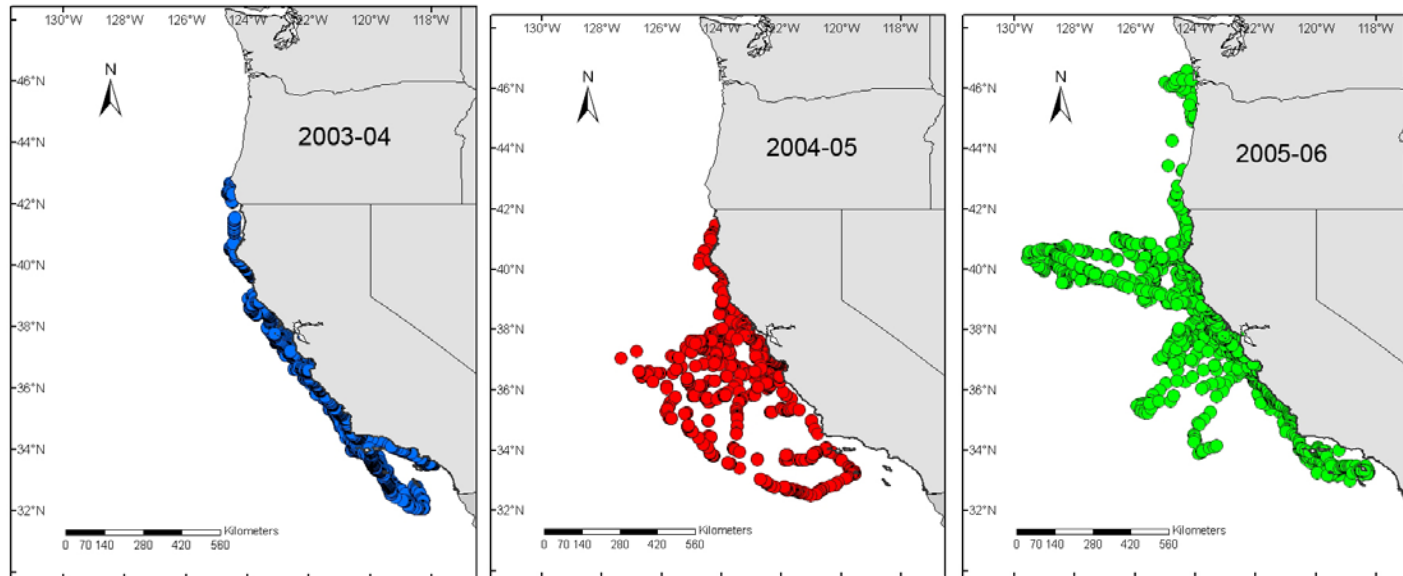


Figure 5. At-sea dive positions of male California sea lions tagged in Monterey California during 2003-04 (n=21), 2004-05 (n=3), and 2005-06 (n=11).

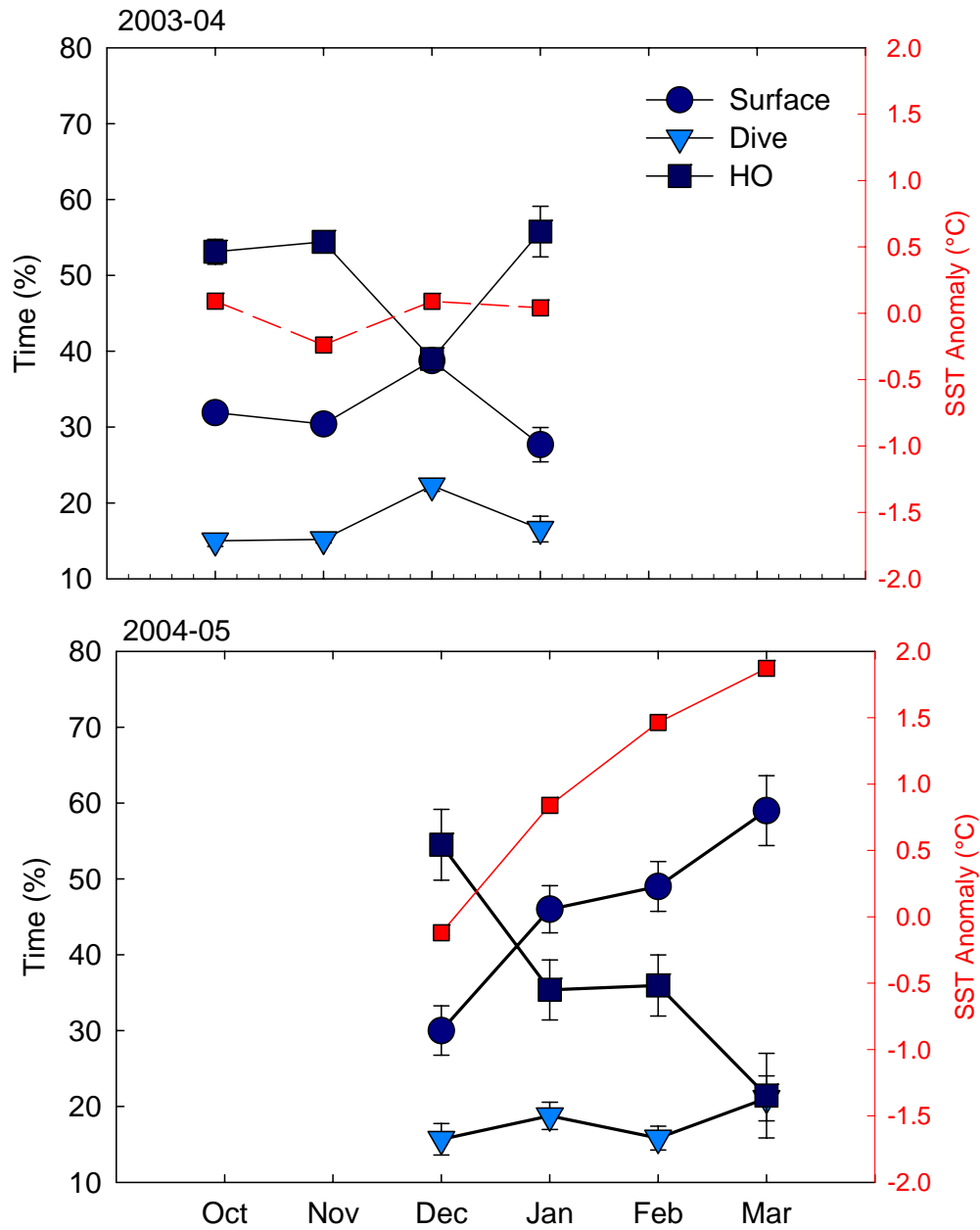


Figure 6. Monthly trends in the percentage time spent surface swimming at sea, diving at sea, and hauled out on land resting during 2003-2004 and 2004-2005. Red line indicates the monthly integrated SST anomaly for the region with greatest density of sea lions diving activity during 2003-2004 (36° N-39° N, offshore 0.5°). Error bars indicate one standard error, and small error bars may be obscured by data point.

Male California Sea Lion 25955 2105016 17 Nov 2005 to 4 Mar 2006

Sea Surface Temperature

Chlorophyll-a

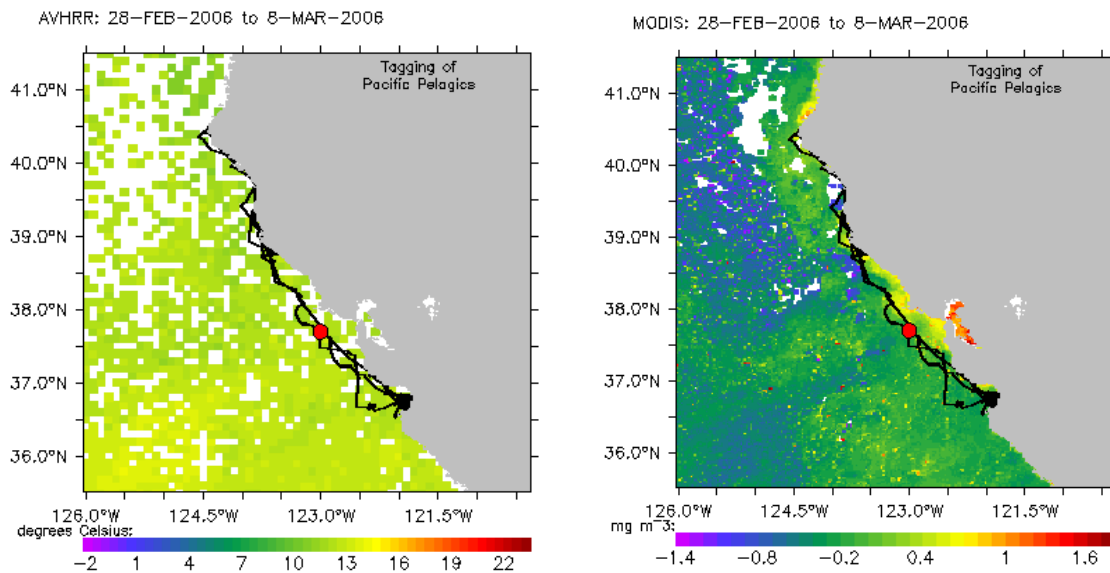


Figure 7. Image of male sea lion tracks overlaid on sea surface temperature (left) and sea surface color or Chlorophyll-a (right). Daily images of sea lion tracks are posted on the Live Access Server (LAS) as part of a collaborative effort between the NOAA Pacific Fisheries Environmental Lab and the Tagging of Pacific Pelagics (TOPP) program. The LAS allows us using an internet browser (www://toppcensus.org) to subset, visualize, and download, in a variety of formats, the oceanographic data pertinent to the analysis of relationship between animal movements and oceanographic features.

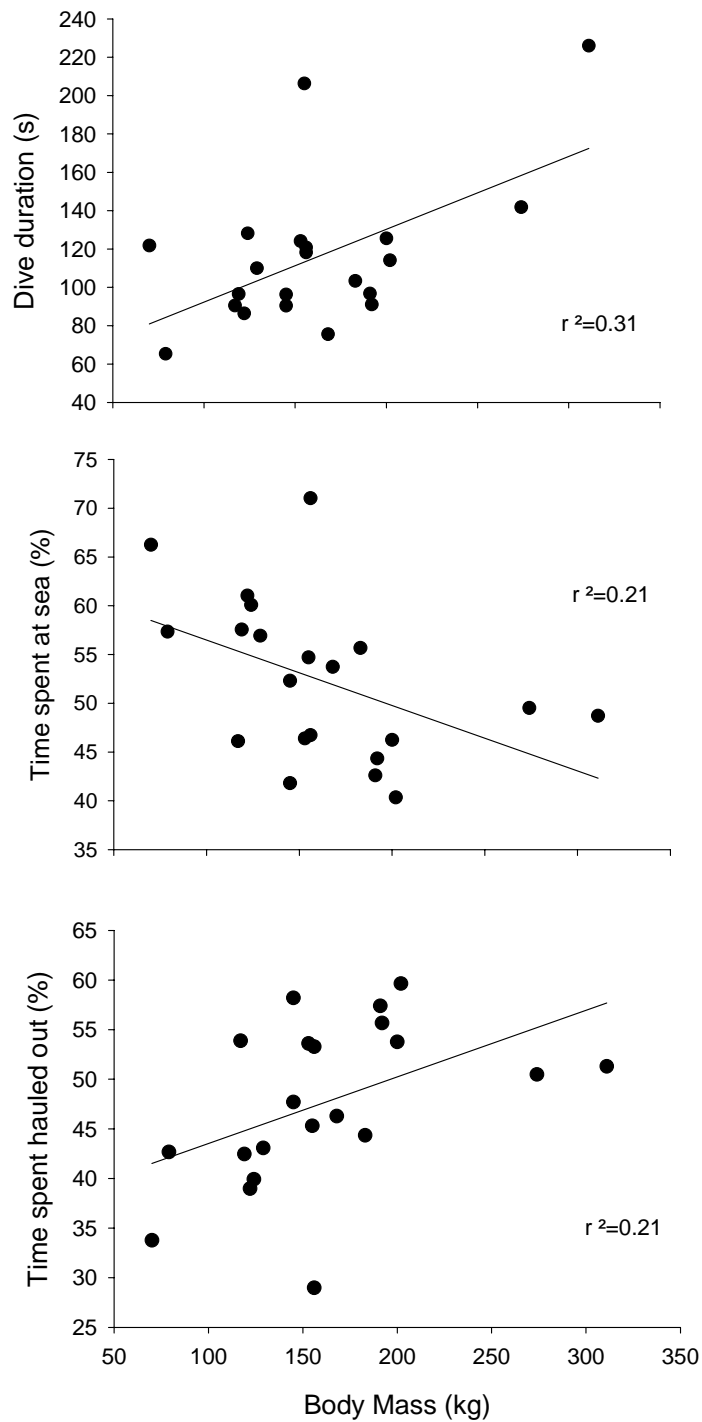


Figure 8. Relationship of mean a) dive duration, b) time spent at sea (diving and surface swimming combined), and c) time on land hauled out; as a function of body mass for each individual male sea lion.

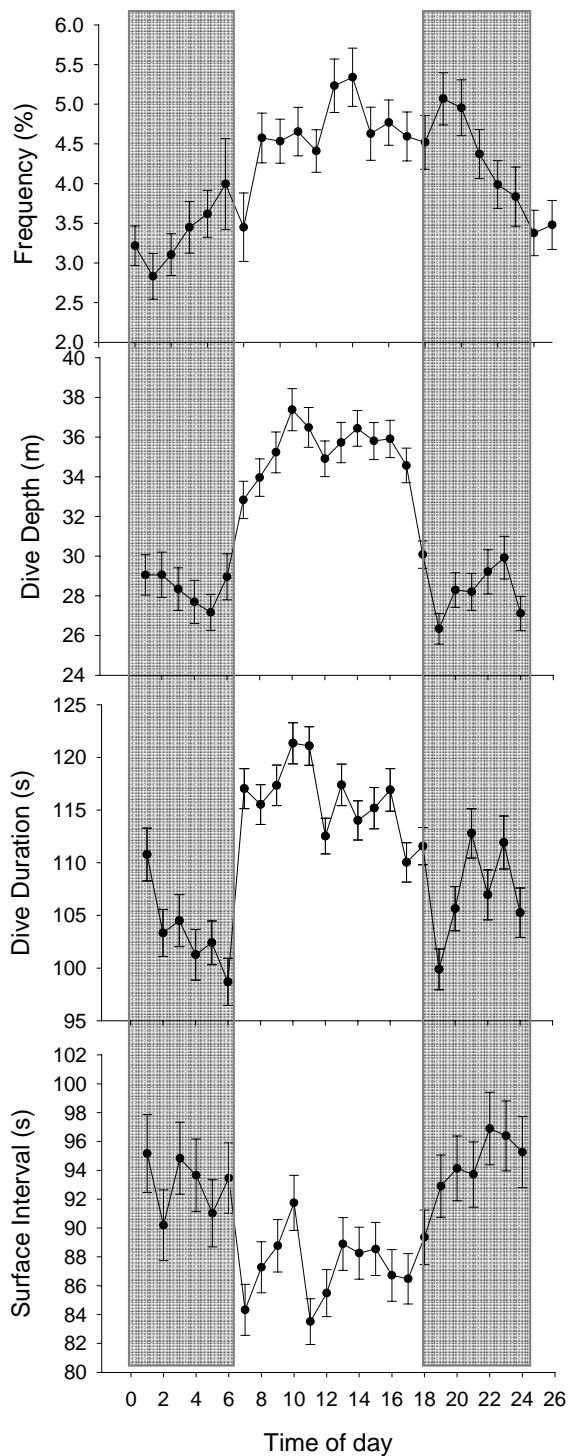
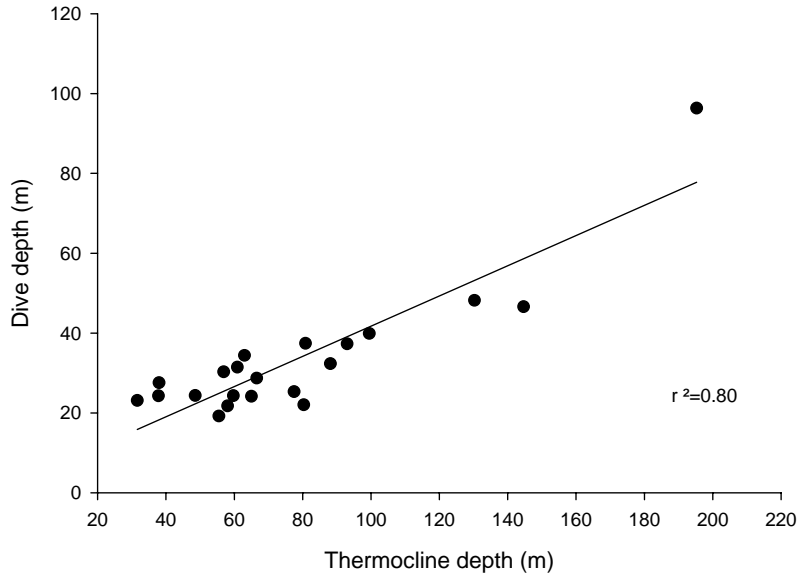


Figure 9. Diurnal patterns in male sea lion diving behavior based on hourly means (\pm SD) during daytime (no shading) and nighttime hours (shaded) for a) frequency of dives per four-hour summary period, b) diving depth, c) diving duration, and d) surface interval.

a)



b)

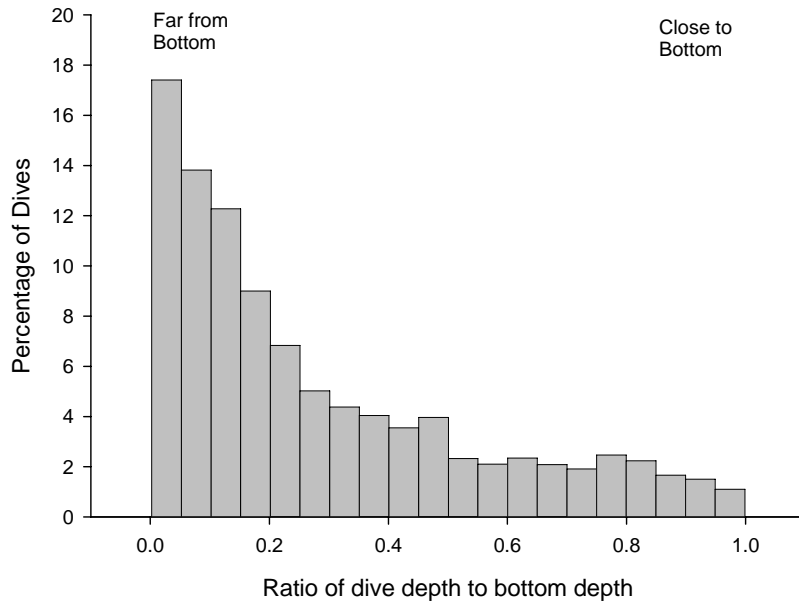


Figure 10. Male sea lion habitat use based on, a) relationship between mean diving depth as a function of thermocline depth for each individual, and b) frequency histogram of the percentage of dives based on the ratio of diving depth to bottom depth for all dives and all animals. A ratio closer to 0.0 is far from the bottom indicating dives in surface waters, and a ratio closer to 1.0 was closer to the bottom indicating dives toward the benthos.

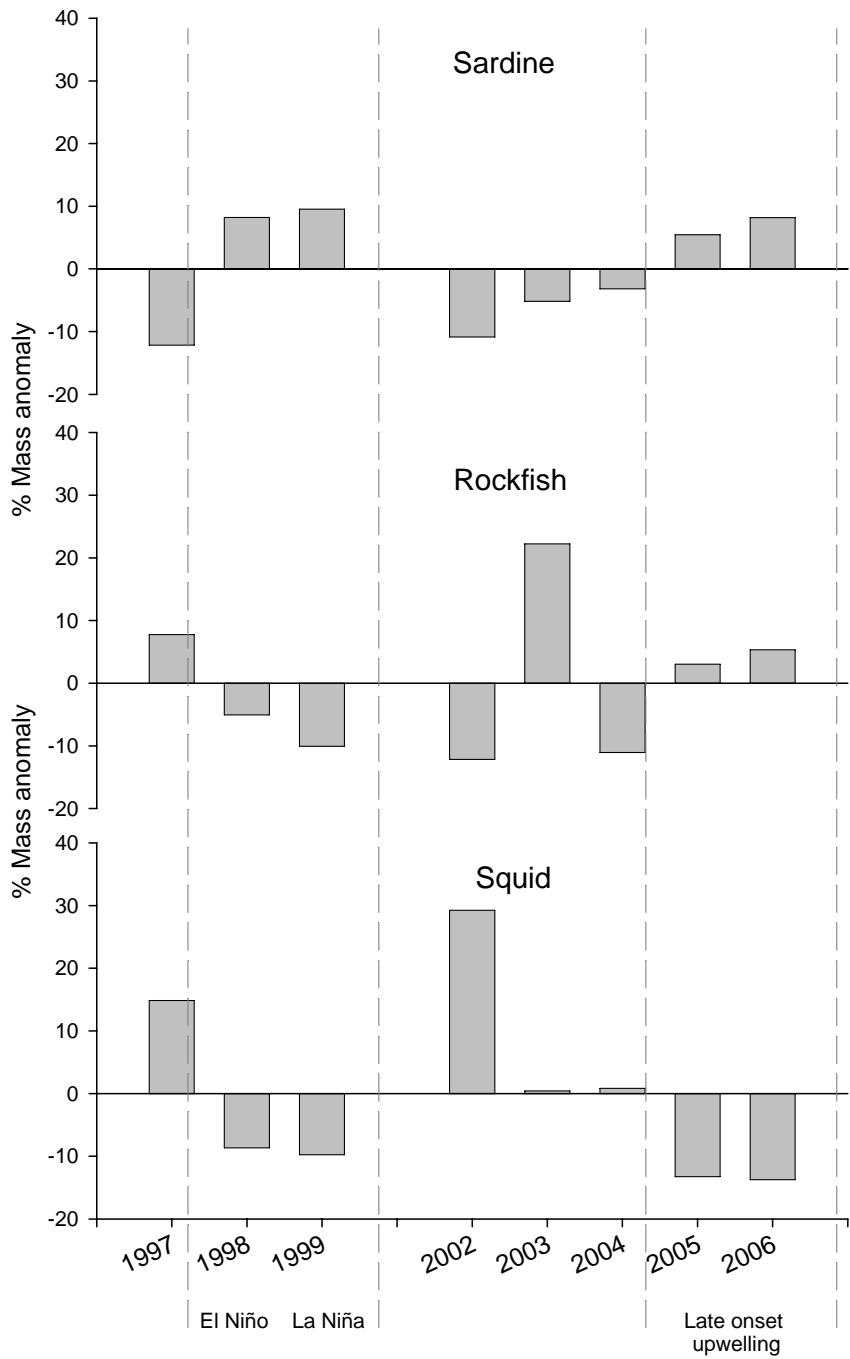


Figure 11. Time series of percentage mass anomaly of sardine, rockfish (*Sebastes* spp.), and market squid in the diet of California sea lions, Monterey Bay 1997 to 1999 (Weise 2000, Weise and Harvey In Review) and Año Nuevo Island 2002 to 2006 (Weise 2006, Weise and Harvey unpublished data). Dashed lines indicate period of El Niño and La Niña during 1998 and 1999, and the delayed onset of upwelling during 2005 and 2006.

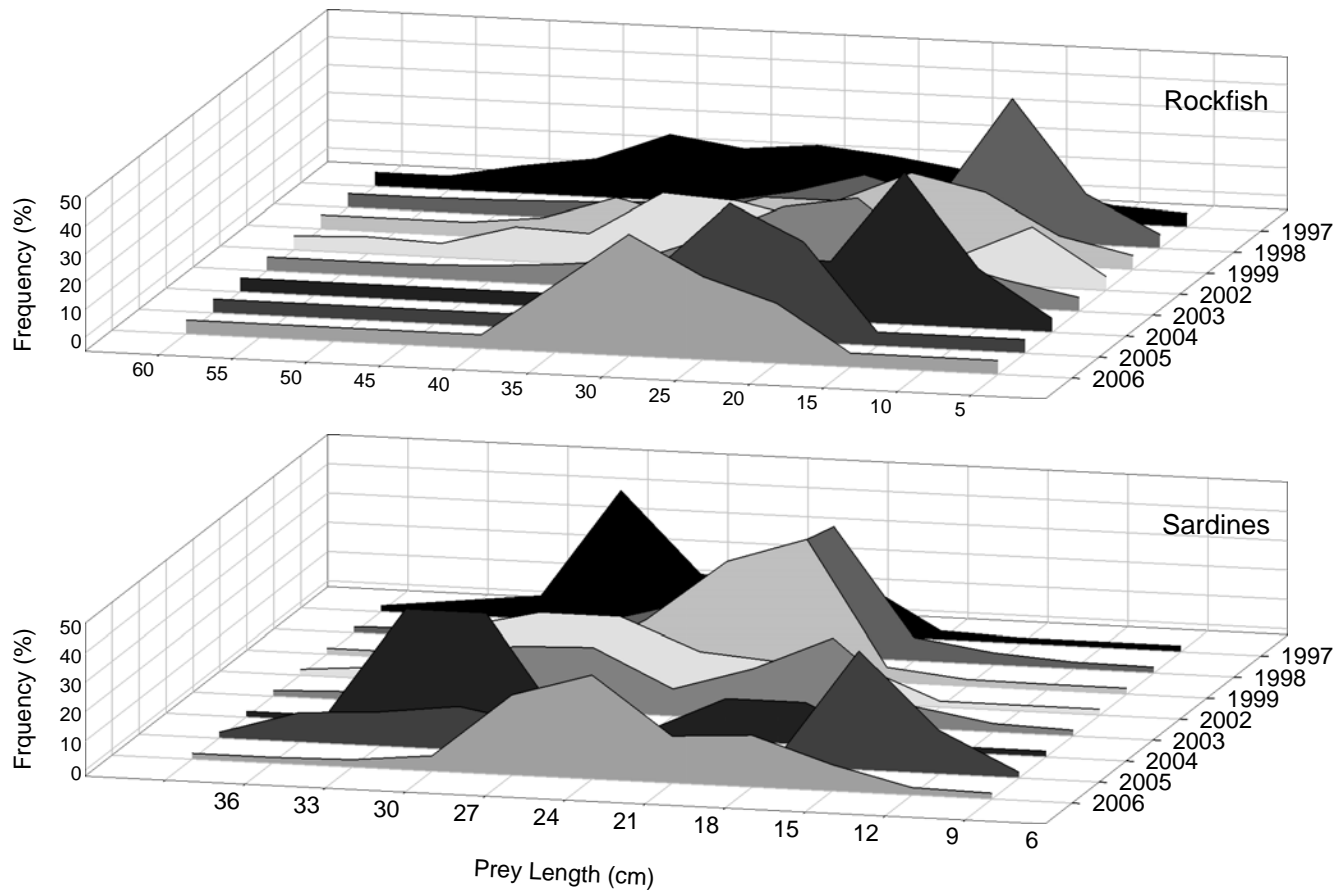


Figure 12. Time series of the size distribution of sardines and rockfishes (*Sebastes* spp.) reconstructed from California sea lion fecal samples collected in Monterey Bay 1997 to 1999 (Weise 2000, Weise and Harvey In Review), and Año Nuevo Island 2002 to 2005 (Weise 2006, Weise and Harvey unpublished data).