# Use of Electronic Tag Data and Associated Analytical Tools to Identify and Predict Habitat Utilization of Marine Mammals

Daniel P. Costa
University of California, Santa Cruz
100 Shaffer Rd.
Santa Cruz, CA 95060
phone: (831) 459-2786 fax: (831) 459-3383 email: costa@biology.ucsc.edu

Barbara Block
Stanford University
Hopkins Marine Station
120 Ocean View Blvd
Pacific Grove, CA 93950-3024
phone: (831) 655-6236 fax: (831) 375-0793 email: bblock@stanford.edu

Award Numbers: N00014-08-1-1195 / N00014-08-1-1196

## LONG-TERM GOALS

Key to assessing the risk of naval activities (such as sound exposure) on marine animals is an understanding of where animals occur and what factors motivate these movements. The rapid advancement of electronic tracking and remote sensing technologies has enabled researchers to link pelagic predator movements and oceanic processes. This information is critical for understanding distribution and residence time of vertebrates within an ocean area and for managing interactions with anthropogenic activities. Marine predators interact with a dynamic ocean that change on time scales ranging from minutes to millennia. Knowledge of these movement interactions is incomplete but critical to understanding dynamic distributions, managing anthropogenic disturbance, and predicting responses to climate change. This project utilizes the largest database of existing marine vertebrate tracking and behavior data to build upon the significant advances in tag technology, data analyses and management accomplished under the Tagging of Pacific Predators (TOPP) program. This is accomplished by establishing a behavioral baseline to assess the potential costs of displacement in terms of reduced foraging success. The project also involves a synthesis of electronic tracking and remote sensing data, focusing on a cross-taxa examination of marine predator distribution and movement patterns to identify hotspots, foraging patterns and movement corridors in the California Current.

## OBJECTIVES

1) Identify and map focal feeding, breeding, and migration routes.

2) Model spatio-temporal oceanographic habitat utilization and predict regions of animal occupancy and use based on oceanographic features.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE<br>**30 SEP 2011** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2011 to 00-00-2011** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Use of Electronic Tag Data and Associated Analytical Tools to Identify and Predict Habitat Utilization of Marine Mammals** | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**University of California, Santa Cruz,100 Shaffer Rd,Santa Cruz,CA,95060** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR’S ACRONYM(S)<br>11. SPONSOR/MONITOR’S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **13** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

3) Utilize this model framework to assess the impact of displacement from primary feeding areas due to disturbances (such as acoustic disturbance).

## APPROACH

There are two distinct components to this effort, each of which addresses a project objective. First, we will use existing TOPP tracking data to generate overall utilization distributions as well as single species distributions and further categorize track segments by behavioral state using a combination of state spaced models and the fractal landscape method to determine regions of area restricted search (ARS) (Jonsen et al. 2003; Jonsen et al. 2006; Tremblay et al. 2007). Next, we will model the links between oceanographic parameters and animal movement patterns. The output from these models will be used to develop predictive models of marine vertebrate distribution based on oceanographic parameters.

The TOPP data management system, central to this approach, is comprised of a postgres database, geospatially enabled, with an automated tag data acquisition and processing front end, using a combination of in-house produced data processing tools and vendor provided tag decoding routines. Since we are mainly a linux-based, open source system, and the vendor tools are exclusively Windows-based, the vendor tools are generally run in a virtual Windows machine environment, (using the VirtualBox software package), and their operation is automated using the scripting tool AutoIt.

Our data flow starts with tag data input, automatic for satellite tag data and semi-automatic for archival tag data, where the tags must be manually downloaded. Once tag data are input to the system, they are passed through our QC processing system, geolocated where appropriate, and loaded into the database. Once the tag information is in the database we can provide track and profile data in combination with oceanographic parameters, such as SST, Chl-A, and sea surface height. For transmitting tags, this can all happen in near real-time.

## WORK COMPLETED

Deployments of 4,306 electronic tags yielded 1,791 individual animal tracks from 23 species, totaling 265,386 animal tracking days (Figure 1). Technologies had different location precisions, including: Argos satellite tags (n=1,183), archiving and satellite transmitting tags (n=1,008), and archival geolocation tags (n=2,115) the latter two of which provide estimates of position based on sunlight, time, and sea surface temperatures (SST). These different positions first required the estimates of the precision of each method, coupled with incorporation of all the data into a state based model. Once this was accomplished all tracking data were reduced to a single position each day for each individual animal. These data were then used in the final analysis.

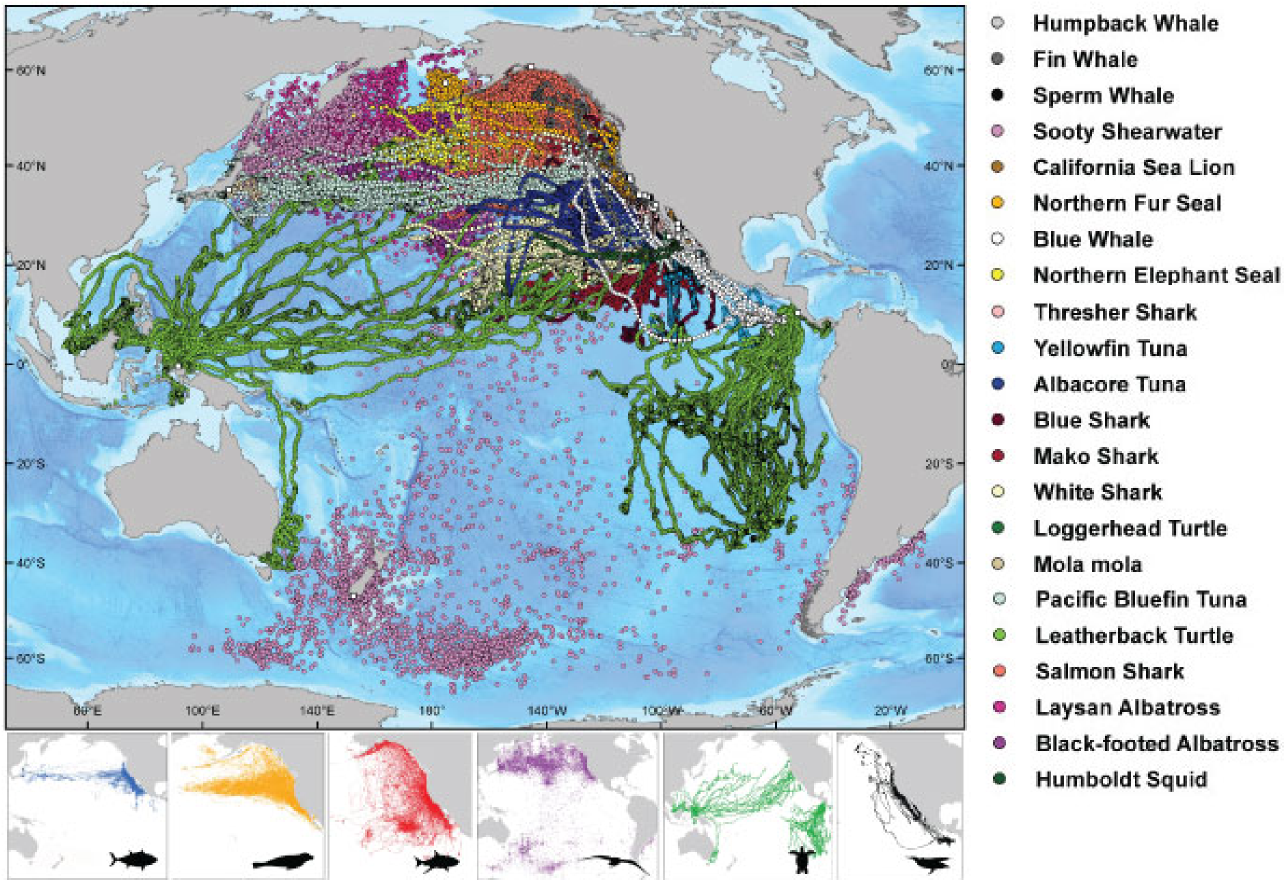
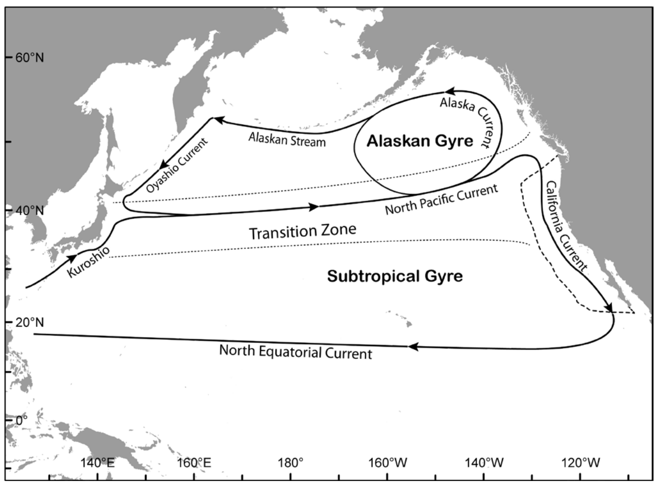



***Figure 1 | All TOPP species state space position estimates and distribution from electronic tagging. a, Daily mean position estimates (circles) and annual median deployment locations (white squares) of all tagged species. b, Daily mean position estimates of the major TOPP guilds (from left): tunas (yellowfin, bluefin and albacore), pinnipeds (northern elephant seals, California sea lions and northern fur seals), sharks (salmon, white, blue, common thresher and mako), seabirds (Laysan and black-footed albatrosses and sooty shearwaters), sea turtles (leatherback and loggerhead) and cetaceans (blue, fin, sperm and humpback whales).***

## RESULTS

The tracking data reveal that the California Current Large Marine Ecosystem (CCLME; Supplementary Figure 1) is an important habitat (Figures 2-4) for tunas (Pacific bluefin, *Thunnus orientalis*; yellowfin, *T. albacares*), sharks (shortfin mako, *Isurus oxyrinchus*; white, *Charcharodon carcharias*; salmon, *Lamna ditropis*; blue, *Prionace glaucus*; common thresher, *Alopias vulpinus*), cetaceans (blue whales, *Balaenoptera musculus*), pinnipeds (Northern elephant seals, *Mirounga angustirostris*; California sea lions, *Zalophus californianus*), seabirds (Laysan albatross, *Phoebastria immutabilis*; black-footed albatross, *P. nigripes*; sooty shearwaters, *Puffinus griseus*), and turtles (leatherback turtle, *Dermochelys coriacea*; loggerhead turtle, *Caretta caretta*). Annual migratory periodicity was evident in the movements of many tagged animals that showed fidelity to the cool, nutrient rich waters of the CCLME (Figure 2-3). Extended residency within the CCLME was revealed by examining tracks that spanned multiple seasons using a switching state-space model (Figure 3).

Numerous species exhibited a strong attraction to the CCLME and undertook long migrations (> 2,000 km) from the western, central, or south Pacific basin (leatherback sea turtles, black-footed albatrosses, sooty shearwaters, bluefin tuna, and salmon sharks; Figure 2b). Species exhibited a seasonally recurring north-south migration (bluefin and yellowfin tunas, mako, white, and salmon sharks, blue whales, male elephant seals and leatherback sea turtles; Figure 3g-l) in the North Pacific and within the CCLME. Other taxa undertook movements between nearshore and offshore waters, with a residency period within the CCLME or Gulf of Alaska, followed by an offshore migration that ranged into the North Pacific Transition Zone (female elephant seals, salmon sharks, Laysan albatrosses), the Subtropical Convergence Zone (blue and mako sharks, leatherback turtles), or the eastern Pacific and Hawaiian Islands (white sharks, albacore tuna, and black-footed albatrosses). The mechanisms and cues underlying fidelity to seasonally-modulated migration pathways are not entirely known, but may represent a capacity to discriminate among areas of seasonal significance for foraging, or reproduction.




***Supplementary Figure 1: Schematic of dominant ocean current features in the north Pacific Ocean. The California Current Large Marine Ecosystem is outlined (dashed line). The north Pacific Transition Zone is delineated by the dotted lines.***

The CCLME is a highly retentive area for many species tagged there, and an attractive area for animals undergoing long migrations from the western and central North Pacific and Gulf of Alaska (Figures 2; 4a,b). Pacific bluefin and yellowfin tunas spent significantly more time in the CCLME than expected based on null model simulations. Several species - tunas; lamnid sharks; leatherback turtles; and blue whales had substantial residency periods within, or were return migrants to the CCLME based on behavioral inferences from a switching state-space model (Figure 4c). Additionally, all species tagged outside the CCLME spent significantly more time on average in the CCLME than expected based on null model simulations. Representatives from several guilds exhibited cross-basin migrations (> 2,000 km) into the CCLME from the western (leatherback turtle, bluefin tuna), central (black-footed albatross, salmon shark), and south Pacific basins (sooty shearwaters; Figure 2b).

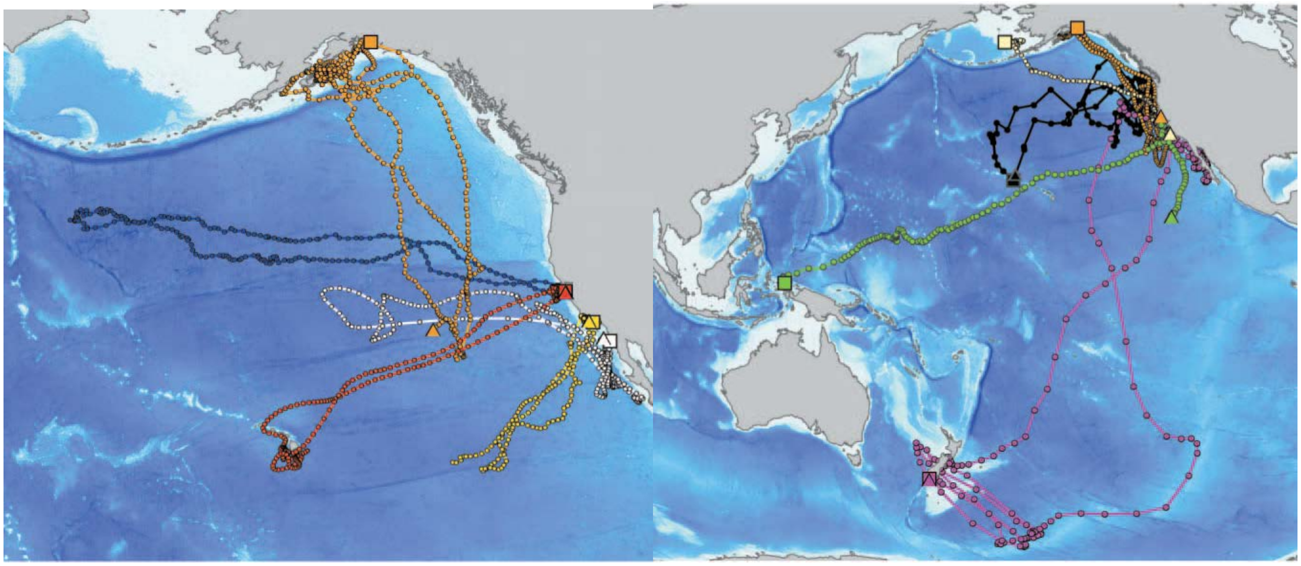


***Figure 2 | Fidelity and attraction to the CCLME. Left, Examples of pelagic predators released and electronically tracked in the CCLME that show fidelity to deployment locations and the CCLME. We show the release locations (square), pop-up satellite end point locations (triangle) and daily mean positions (circles) of the following species: yellowfin tuna (yellow), bluefin tuna (white), white shark (red), elephant seal (blue) and salmon shark (orange). Right, Individual tracks of pelagic animals released .2,000km away from the CCLME that are indicative of cross-basin or ecosystem attraction to, and temporary residency within, the eastern North Pacific. Symbols are as in a, for leatherback sea turtles (green), sooty shearwaters (pink), fur seals (pale yellow), black-footed albatrosses (black) and salmon sharks (orange).***

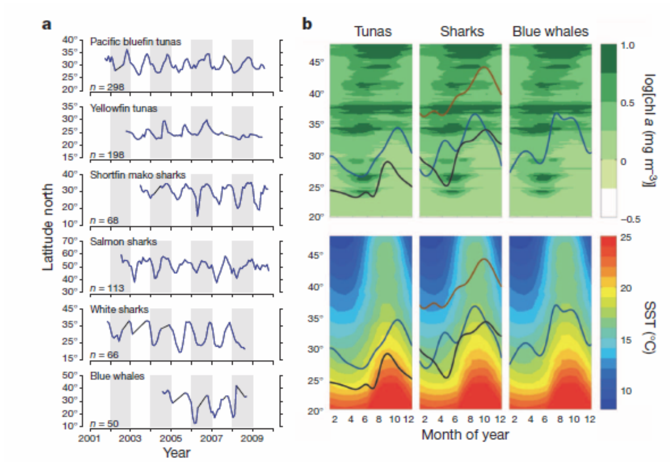



***Figure 3 | Latitudinal migration cycles and seasonal climatologies within the CCLME. a, Monthly mean latitudes of predators residing within or migrating to the CCLME. Black line segments denote gaps where no data were available. Sample sizes indicate the numbers of individual tracks contributing to the time series. b, Seasonal climatologies in the California Current for tunas (Pacific bluefin, blue; yellowfin, black), sharks (salmon shark, brown; shortfin mako, black; white shark, blue) and blue whales relative to median chlorophyll a densities and SST values between 2000 and 2009.***

The retention with and attraction to the CCLME is consistent with the high productivity of this region that supports large biomasses of krill, sardines, anchovies, salmon, groundfish, and squid providing a predictable forage base for top predators. The NPTZ is another important region, serving as an east-west migration corridor (Figure 4a) and foraging region for elephant seals, salmon and blue sharks (Figure 4c), Laysan and black-footed albatrosses, and bluefin tuna (Figure 1). This is a complex region encompassing an abrupt north-to-south transition between subarctic and subtropical water masses with dynamic frontal regions.

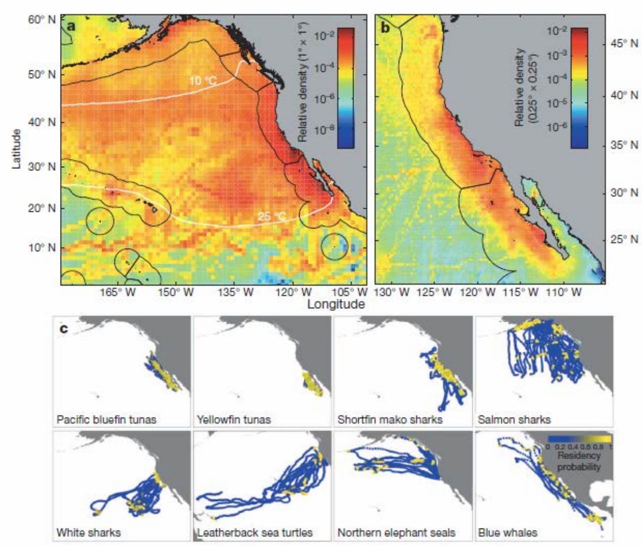



***Figure 4 | Predator density maps and residency patterns. a, Density of large marine predators within the eastern North Pacific. Densities of the time-weighted and species-normalized position estimates of all tagged individuals were summed within 1u31u grid cells. b, Density of large marine predators within the CCLME at a 0.25u30.25u resolution. c, Patterns of resident (slow, arearestricted movements) versus transient (fast, directed movements) behaviours of predators that primarily occupied or migrated to the CCLME, estimated using a switching state-space model. The coloured points grading fromblue to yellow display the posterior mean probability of the resident behaviour associated with each daily mean position estimate. Each panel displays residency patterns for ten individuals. Uncertainty in position estimates in a and b is included by calculating densities using all 2000 Markov chain Monte Carlo samples from the joint posterior distributions of the daily positions, rather than using only the posterior means. SST contours in a are denoted by solid white lines. Exclusive economic zones are delineated by solid black lines.***

The second component of this effort was to identify the oceanographic parameters responsible for the distribution of these predators. To investigate which aspects of the biophysical environment putatively attract these predators, we explored both presence/absence and relative habitat use with generalized additive mixed models. We examined the collective response of 16 marine predator species to environmental covariates. In the binary presence/absence model, predator incidence showed a strong positive relationship with SST, across a broad temperature range and peaking near 15˚C. Tagged animals occupied a small portion of cool, nutrient-rich water in coastal regions and northern latitudes compared to the broadly available warm oligotrophic waters in lower latitudes. The strong positive relationship between relative density and Chl-*a* suggests the suite of tagged species are preferentially occupying regions of high productivity. The observed patterns of predator distribution in this study may be indicative by trade-offs between thermal tolerances, either directly by the predators or indirectly on lower trophic levels, and access to areas of higher productivity.

To examine how closely related taxa partition marine resources, we compared thermal preferences from *in-situ*, tag-based SST measurements for sympatrically occurring species within three guilds (albatrosses, tunas, sharks). Differences in habitat utilization evident among congeneric species illustrate how recently divergent species partition the oceanic environment (Figure 5). During the June to November post-breeding phase, black-footed albatrosses were associated with a broader and warmer range of SST primarily in the eastern Pacific, whereas Laysan albatrosses were associated with a narrower and colder range of SST in the western and central North Pacific (Figure 5a). Bluefin tuna ranged farther north in the colder waters of the CCLME, whereas yellowfin occupied warmer waters in the southern CCLME (Figure 5b). These differences are consistent with physiological specializations in bluefin tuna cardiac performance. The lamnid sharks had a more complex separation of habitats. Salmon sharks, with their cold tolerant cardiac physiology, occupied the cooler, subarctic waters in the North Pacific. Most salmon sharks, but not all, migrated seasonally into the warmer NPTZ and CCLME waters (Figure 5c). White sharks overlapped with salmon sharks in the nearshore CCLME, but also migrated into warmer, offshore waters of the Subtropical Gyre and the Hawaiian Islands (Figure 5c). Shortfin makos were distributed throughout the CCLME and into the Subtropical Gyre, but occupied a thermal range intermediate to the two modes of the white shark range (Figure 5c).

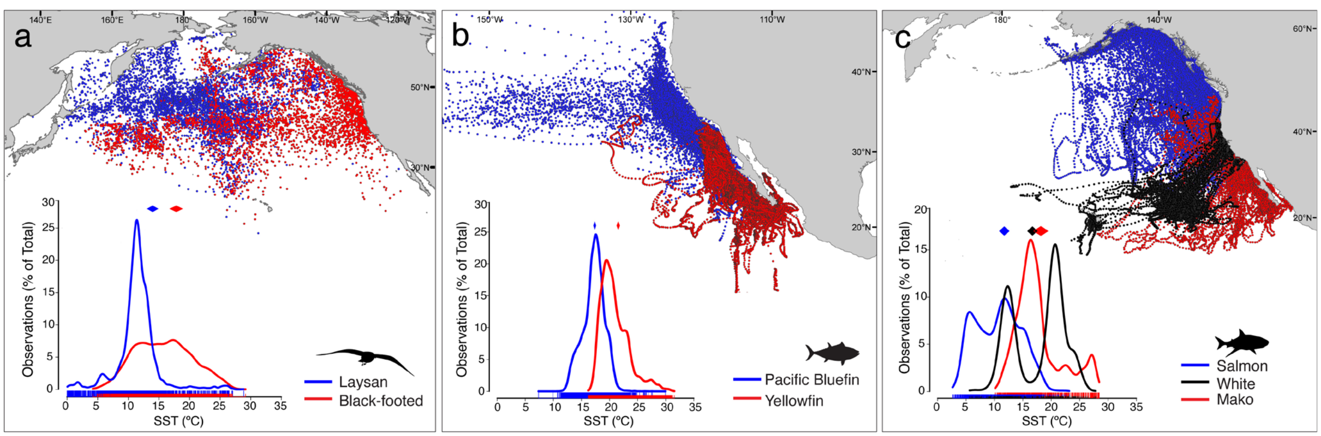



***Figure 5 | Niche separation within three predator guilds. Spatial distribution and thermal habitat use (insets) across three guilds of sympatric species: Laysan and black-footed albatrosses (n555 individuals, 8,743 daily SSTs; a), Pacific bluefin and yellowfin tunas (n5376 individuals, 75,177 daily SSTs; b), lamnid (salmon, mako and white) sharks (n5137 individuals, 12,971 daily SSTs; c). SST profiles are daily means of tag-derived SSTs. Linear mixed-effects model estimates of mean (695% confidence interval) SST for each species are displayed as diamonds at the top of each inset graph.***

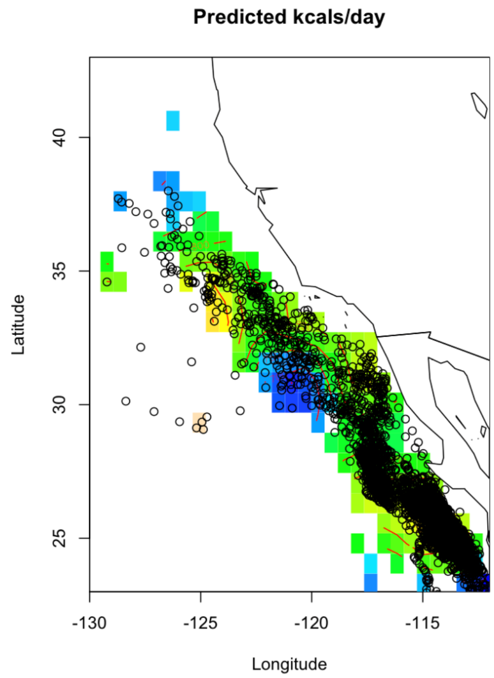



***Figure 6. An energy landscape for Pacific Bluefin Tuna between March and May 2004. Warm colors represent areas with higher energy acquisition, while cooler colors represent areas with lower energy acquisition (kcals/day). The overlaid black dots show daily positions.***

To study the ability to use electronic tagging to investigate building energetic landscapes in the wild we ran validation experiments in a captive feeding study. Bluefin tuna warm their viscera during digestion. This warming is thought to be due to a combination of factors, foremost among which is specific dynamic action (SDA), the heat produced by digestion, absorption and anabolic processes within the stomach and caecal mass. The duration of the elevated visceral temperature is strongly correlated with the caloric value of an ingested meal. We have conducted an experiment using archival-tagged captive bluefin tuna in the Tuna Research and Conservation Center to quantify the magnitude of visceral warming associated with differing ration sizes of squid and sardine, at different ambient temperature levels. The data collected from these experiments were used to develop a model which can be applied to archival tag data collected from wild Pacific bluefin tuna, in order to estimate daily energy intake. This measure of foraging success is now being used to identify environmental/oceanographic correlates of foraging success as well as characterizing foraging "hotpots" for Pacific bluefin tuna. So far, Generalized Additive Models (GAMs) have been used to produce seasonal energy maps for the California Current, highlighting areas where daily energy intake is highest (Figure 6).

## IMPACT/APPLICATIONS

Critical to determining the impact of exposure to naval operations on marine animals is relating the intensity and duration of an exposure to the time animals spend in proximity to the source, and the biological function of that time. The proposed predictive models of critical marine animal habitat utilization are the essential behavioral components to determine whether and where naval operations might impact marine mammals and other marine vertebrates.

**RELATED PROJECTS**

JIP: Relating Behavior and Life Functions to Populations Level Effects in Marine Mammals: An empirical and modeling effort to develop the PCAD model. Contract JIP 22 07-23

**REFERENCES**

Jonsen, I.D., Myers, R.A. and Flemming, J.M. 2003. Meta-analysis of animal movement using state-space models. Ecology 84 (11): 3055-3063

Jonsen, I. D., Myers, R.A. and JamesS, M.C. 2006. Robust hierarchical state–space models reveal diel variation in travel rates of migrating leatherback turtles. Journal of Animal Ecology, 75: 1046–1057. doi: 10.1111/j.1365-2656.2006.01129.x

Tremblay, Y., Roberts, A.J. and Costa, D.P. 2007. Fractal landscape method: an alternative approach to measuring area-restricted searching behavior. The Journal of Experimental Biology 210: 935-945

**PUBLICATIONS**

Winship, A.J., Jorgensen, S.J., Jonsen, I.D., Robinsons, P.W., Costa, D.P. and Block, B.A. 2011. State-space framework for estimating measurement error from double-tagging telemetry experiments. Methods in Ecology and Evolution. In press.

Villegas-Amtmann S, Simmons SE, Kuhn CE, Huckstadt LA, Costa DP (2011) Latitudinal Range Influences the Seasonal Variation in the Foraging Behavior of Marine Top Predators. PLoS ONE 6(8):e23166. doi:10.1371/journal.pone.0023166

Block, B.A., Jonsen, I.D., Jorgensen, S.J., Winship, A.J., Shaffer, S.A., Bograd, S.J., Hazen, E.L., Foley, D.G., Breed, G.A., Harrison, A-L., Ganong, J.E., Swithenbank, A., Castleton, M., Dewar, H., Mate B.R., and Costa, D.P. 2011. Tagging of Pacific Predators: Tracking Apex Marine Predator Movements in a Dynamic Ocean. Nature 475:86-90

Maxwell, S.M., Frank, J.J., Breed, G.A., Robinson, P.W., Simmons, S.E., Crocker, D.E., Gallo-Reynoso, J.P., Costa, D.P. 2011.Benthic foraging on seamounts: a specialized foraging behavior in a deep diving pinniped. Marine Mammal Science in press.

Maxwell S.M., G. A. Breed, B. A. Nickel, J. Makanga-Bahouna, E. Pemo-Makaya, R. J. Parnell, A. Formia, S. Ngouessono, B. J. Godley, D. P. Costa, M. J. Witt, and M. S. Coyne. 2011. Using Satellite Tracking to Optimize Protection of Long-Lived Marine Species: Olive Ridley Sea Turtle Conservation in Central Africa. PLoS ONE 6:e19905

Žydelis, R., Lewison, R.L., Shaffer, S. A., Moore, J.E., Boustany, A.M., Roberts, J.J., Sims, M., Dunn, D.C., Best, B. D., Tremblay, Y., Kappes, M.A, Halpin, P.N., Costa, D.P., Crowder, L. B. 2011. Dynamic habitat models: Using telemetry data to project fisheries bycatch. doi:10.1098/rspb.2011.0330

Breed, G.A., Costa, D.P., Goebel, M.E. and Robinson, P.W. 2011. Electronic tracking tag programming critical to data collection for behavioral time-series analysis. Ecosphere 2(1):1-12

Matsumura, M., Y. Y. Watanabe, P. W. Robinson, P. J. O. Miller, D. P. Costa, and N. Miyazaki. 2011. Underwater and surface behavior of homing juvenile northern elephant seals. Journal of Experimental Biology **214**:629-636.

Costa, D.P. 2011. How Electronic Tags Are Helping to Understand the Movements, Behavior and Habitats of Marine Vertebrates. Online publication ActionBioscience.org Institute of Biological Sciences (AIBS). http://www.actionbioscience.org/biodiversity/costa.html

Robinson, P.W., Simmons, S.E., Crocker, D.E., Costa, D.P. 2010. Measurements of Foraging Success in a Highly Pelagic Marine Predator, the Northern Elephant Seal. Journal of Animal Ecology 79, 1146–1156

Costa, D. P., L. A. Huckstadt, D. E. Crocker, B. I. McDonald, M. E. Goebel, and M. A. Fedak. 2010. Approaches to Studying Climatic Change and its Role on the Habitat Selection of Antarctic Pinnipeds. Integrative and Comparative Biology **50**:1018-1030.

Simmons, S. E., D. E. Crocker, J. L. Hassrick, C. E. Kuhn, P. W. Robinson, Y. Tremblay, and D. P. Costa. 2010. Climate-scale hydrographic features related to foraging success in a capital breeder, the northern elephant seal Mirounga angustirostris. Endangered Species Research **10**:233-243.

Bailey, H., Mate, B. R., Palacios, D. M., Irvine, L. Bograd, S. J., Costa, D.P. 2010. Behavioural estimation of blue whale movements in the Northeast Pacific from state-space model analysis of satellite tracks. Endangered Species Research 10: 93–106

Kappes, M.A., Shaffer, S.A., Tremblay, Y., Foley, D.G., Palacios, D.M., Robinson, P.W., Bograd, S.J., Costa, D.P. 2010. Hawaiian albatrosses track interannual variability of marine habitats in the North Pacific. Progress in Oceanography 86:246–260

Weise, M.J., Harvey, J.T., Costa, D.P. 2010. The role of body size on the foraging behavior of an apex predator, the California sea lion, *Zalophus californianus.* Ecology: 91(4), 2010, pp. 1004–1015.

Villegas-Amtmann, and D. P. Costa. 2010. Oxygen stores plasticity linked to foraging behaviour and pregnancy in a diving predator, the Galapagos sea lion. Functional Ecology 24, 785–795

Costa, D. P., Robinson, P. W., Arnould, J.P.Y., Harrison, A-L, Simmons, S.E., et al. 2010. Accuracy of ARGOS Locations of Pinnipeds at-Sea Estimated Using Fastloc GPS. PLoS ONE 5(1): e8677. doi:10.1371/journal.pone.0008677

Bograd, S. J., B. A. Block, D. P. Costa, and B. J. Godley. 2010. Biologging technologies: new tools for conservation. Introduction. Endangered Species Research 10:1-7.

Simmons, S. E., D. E. Crocker, J. L. Hassrick, C. E. Kuhn, P. W. Robinson, Y. Tremblay, and D. P. Costa. 2010. Climate-scale hydrographic features related to foraging success in a capital breeder, the northern elephant seal *Mirounga angustirostris*. Endangered Species Research 10:233-243.

Hassrick, J. L., Crocker, D. E., Teutschel, N. M., McDonald, B. I., Robinson, P. W., Simmons, S. E., and Costa, D. P. 2010. Age and mass impact oxygen stores and dive duration in adult female northern elephant seals. *Journal of Experimental Biology* 213(4):585-592.

Mitani, Y., Andrews, R., Sato, K., Kato, A., Naito, Y. Costa, D. 2010. 3D resting behavior of northern elephant seals: drifting like a falling leaf. Biology Letters 6:163-166.

Jorgensen, S. J., C. A. Reeb, T. K. Chapple, S. Anderson, C. Perle, S. R. Van Sommeran, C. Fritz-Cope, A. C. Brown, P. A. Klimley, B. A. Block. 2009. Philopatry and migration of Pacific white sharks. Proc. Roy. Soc. Lond. B, doi:10:1098/rsbp.2009.1155.

Villegas-Amtmann, S., Atkinson, S and Costa, D.P. 2009. Asynchronous breeding cycle in Galapagos sea lions revealed by seasonal progesterone concentrations. Journal of Mammalogy 90(5):1232-1237.

Tremblay, Y. Bertrand, S., William, R. H., Kappes, M.A., Costa, D.P. and Shaffer, S.A. 2009. A Review of Analytical Approaches to Investigate Seabird-Environment Interactions. Marine Ecology Progress Series. 391: 153–163.

Costa, D.P., Tremblay, Y. and Hayes, S. 2009. Research on Higher Trophic Levels. Oceanography in 2025: Proceedings of a Workshop http://www.nap.edu/catalog/12627.html Deborah Glickson, Editor; Committee on Oceanography in 2025: A Workshop; National Research Council ISBN: 0-309-13746-2, 198 pages

Costa, D. P., L. A. Huckstadt, D. E. Crocker, B. I. McDonald, M. E. Goebel, and M. A. Fedak. 2010. Approaches to studying climatic change and its role on the habitat selection of Antarctic pinnipeds. Integrative and Comparative Biology. doi:10.1093/icb/icq054

Kappes, M.A., Shaffer, S.A., Tremblay, Y., Foley, D.G., Palacios, D.M., Robinson, P.W., Bograd, S.J., Costa, D.P. 2010. Hawaiian albatrosses track interannual variability of marine habitats in the North Pacific. Progress in Oceanography 86:246–260

Weise, M.J., Harvey, J.T., Costa, D.P. 2010. The role of body size on the foraging behavior of an apex predator, the California sea lion, *Zalophus californianus.* Ecology: 91(4), 2010, pp. 1004–1015.

Villegas-Amtmann, and D. P. Costa. 2010. Oxygen stores plasticity linked to foraging behaviour and pregnancy in a diving predator, the Galapagos sea lion. Functional Ecology 24, 785–795

Costa, D. P., Robinson, P. W., Arnould, J.P.Y., Harrison, A-L, Simmons, S.E., et al. 2010. Accuracy of ARGOS Locations of Pinnipeds at-Sea Estimated Using Fastloc GPS. PLoS ONE 5(1): e8677. doi:10.1371/journal.pone.0008677

Bograd, S. J., B. A. Block, D. P. Costa, and B. J. Godley. 2010. Biologging technologies: new tools for conservation. Introduction. Endangered Species Research 10:1-7.

Simmons, S. E., D. E. Crocker, J. L. Hassrick, C. E. Kuhn, P. W. Robinson, Y. Tremblay, and D. P. Costa. 2010. Climate-scale hydrographic features related to foraging success in a capital breeder, the northern elephant seal *Mirounga angustirostris*. Endangered Species Research 10:233-243.

Hassrick, J. L., Crocker, D. E., Teutschel, N. M., McDonald, B. I., Robinson, P. W., Simmons, S. E., and Costa, D. P. 2010. Age and mass impact oxygen stores and dive duration in adult female northern elephant seals. *Journal of Experimental Biology* 213(4):585-592.

Mitani, Y., Andrews, R., Sato, K., Kato, A., Naito, Y. Costa, D. 2010. 3D resting behavior of northern elephant seals: drifting like a falling leaf. Biology Letters 6:163-166.

Shaffer, S.A., Weimerskirch, H., Scott, D., Pinaud, D., Thompson, D.R., Sagar, P.M., Moller, H., Taylor, G.A., Foley, D.G., Tremblay, Y., and Costa, D.P. 2009. Spatio-temporal habitat use by breeding sooty shearwaters (*Puffinus griseus*). *Marine Ecology Progress Series*. Vol. 391: 209–220. doi: 10.3354/meps07932.

Weimerskirch, H., Shaffer, S.A, Tremblay, Y., Costa, D.P., Gadenne, H. Kato, A. Ropert-Coudert, Y. Sato, K., Aurioles, D. 2009. Species and sex specific differences in foraging behaviour and foraging zones in two sympatric seabirds: blue-footed and brown boobies in the Gulf of California. Mar Ecol Prog. Ser. Vol. 391: 267–278, doi: 10.3354/meps07981

Simmons, S.E. Tremblay, Y. and Costa, D.P. 2009. Pinnipeds as ocean temperature samplers: calibrations, validations and data quality. Limnology and Oceanography Methods 7:648-656.

Robinson, P. W., S. Villegas-Amtmann and Costa, D.P. 2009. Field validation of an inexpensive time-depth recorder. Marine Mammal Science 25 (1):199-205.

Teo, S.L.H., Kudela, R.M., Rais, A., Perle, C., Costa, D.P., Block, B.A. 2009. Estimating chlorophyll profiles from electronic tags deployed on pelagic animals. Aquatic Biology 5:195-207. doi: 10.3354/ab00152

Tremblay Y., Robinson P.W., Costa D.P. 2009. A Parsimonious Approach to Modeling Animal Movement Data. PLoS ONE 4(3): e4711. doi:10.1371/ journal.pone.0004711

Jorgensen, S. J., C. A. Reeb, T. K. Chapple, S. Anderson, C. Perle, S. R. Van Sommeran, C. Fritz-Cope, A. C. Brown, P. A. Klimley, B. A. Block. (in press. Site fidelity, homing and population structure in eastern pacific white sharks. Proc. Roy. Soc. Lond. B, in press.

Tremblay, Y. Bertrand, S., William, R. H., Kappes, M.A., Costa, D.P. and Shaffer, S.A. 2009. A Review of Analytical Approaches to Investigate Seabird-Environment Interactions. Marine Ecology Progress Series. 391: 153–163.

Shaffer, S.A., Weimerskirch, H., Scott, D., Pinaud, D., Thompson, D.R., Sagar, P.M., Moller, H., Taylor, G.A., Foley, D.G., Tremblay, Y., and Costa, D.P. 2009. Spatio-temporal habitat use by breeding sooty shearwaters (*Puffinus griseus*). *Marine Ecology Progress Series*). *Marine Ecology Progress Series*. Vol. 391: 209–220.

Costa, D.P., Tremblay, Y. and Hayes, S. 2009. Research on Higher Trophic Levels. Oceanography in 2025: Proceedings of a Workshop http://www.nap.edu/catalog/12627.html Deborah Glickson, Editor; Committee on Oceanography in 2025: A Workshop; National Research Council ISBN: 0-309-13746-2, 198 pages

Boustany, A.M, Matteson, R., Farwell, C.J., Castleton, M. and B. A. Block Movements of Pacific bluefin tuna (*Thunnus orientalis)* in the Eastern North Pacific revealed with archival tags. 2009. Progress in Oceanography 86 (1-2): 94-104.

Shillinger, G. L., D. M. Palacios, H. Bailey, S. J. Bograd, A. M. Swithenbank, P. Gaspar, B. P. Wallace, J. R. Spotila, F. V. Paladino, R. Piedra, S. A. Eckert, B. A. Block (2008). Persistent Leatherback Turtle Migrations Present Opportunities for Conservation. PLoS Biol 6(7): e171.

Bailey H , Shillinger G. Palacios D Bograd S. Spotila J. Paladino F. Block B. (2008) Identifying and comparing phases of movement by leatherback turtles using state-space models. Journal of Experimental Marine Biology and Ecology 356:128–135

Weng KC Foley D.G. Ganong J.E. Perle C. Shillinger G.L. Block B.A. 2008 Migration of an upper trophic level predator, the salmon shark *Lamna ditropis*, between distant ecoregions. Marine Ecology Progress Series 372:253–264

Shillinger, G. L., D. M. Palacios, H. Bailey, S. J. Bograd, A. M. Swithenbank, P. Gaspar, B. P. Wallace, J. R. Spotila, F. V. Paladino, R. Piedra, S. A. Eckert, B. A. Block (2008). Persistent Leatherback Turtle Migrations Present Opportunities for Conservation. PLoS Biol 6(7): e171.

Weng KC Foley D.G. Ganong J.E. Perle C. Shillinger G.L. Block B.A. 2008 Migration of an upper trophic level predator, the salmon shark *Lamna ditropis*, between distant ecoregions. Marine Ecology Progress Series 372:253–264