KAHILTNA
RESEARCH GROUP

Prepared for
Naval Base Coronado under
Cooperative Agreement # N62473-08-2-0027 with
Naval Facilities Engineering Command Southwest
San Diego, California

by Patricia Baird, Ph.D.
Kahiltna Research Group
Simon Fraser University Centre for Wildlife Ecology
Burnaby, B.C.

Citation: Baird, Patricia. 2010. Foraging study of California Least Terns in San Diego Bay and Near Ocean Waters, San Diego, California. Unpublished Rept. U.S. NAVFACENGCOM, San Diego

Part 1
Foraging Study of California Least Terns in San Diego Bay and Near ocean Waters
Appendix I
Detailed Methods and Data Sheets
Appendix II
Banding Data submitted to the U.S. Geological Survey
Patricia Baird, Ph.D.

Part 2

Analysis of Fecal Samples of California Least Terns Collected on U.S. Navy Least Tern Colonies, San Diego Bay 2008
Appendix III
Detailed Methods and Data Sheets
Daniel J. Pondella, II, MA, Ph.D. and Jonathan P. Williams, MS.

Part 3

Summary and Analysis of Past Fish Collection Data,
with Comparison to past Tern Productivity, San Diego Bay
Appendix IV
Detailed Methods and Data Sheets
Daniel J. Pondella, II, MA, Ph.D. and Jonathan P. Williams, MS.

Project managed by Friends of Colorado Lagoon

FRIENDS OF COLORADO LAGOON

Part I

FORAGING STUDY of CALIFORNIA LEAST TERNS IN SAN DIEGO BAY AND NEAR OCEAN WATERS SAN DIEGO, CALIFORNIA, 2009

FINAL REPORT

Patricia Baird, Ph.D.

Kahiltna Research Group
Centre for Wildlife Ecology
Simon Fraser University
125A-1030 Denman Street
Vancouver, B.C. V6G 2M6
Canada

Photo: Center for Biological Diversity

Citation: Baird, P. 2010. Part 1. Foraging study of California Least Terns in San Diego Bay and Near ocean Waters, San Diego, California, 2009. Unpubl. Rept. U.S. NAVFACENGCOM, San Diego. 91 pp

TABLE OF CONTENTS

PART I

List of Tables

List of Figures

ABSTRACT and EXECUTIVE SUMMARY

Part 1

The purpose of the project was to provide the U.S. Navy with an understanding of the foraging activities of the federally endangered California Least Tern (*Sternula antillarum browni*) in and around San Diego Bay in 2009, so that the U.S. Navy could comply with the Endangered Species Act (16 USC 1531 et seq.), the Sikes Act Improvement Act (16 USC 670 et seq.), and the Migratory Bird Treaty Act (16 USC 1361 et seq.) in their agreements with the US Fish and Wildlife Service, including the formal endangered species consultation on the Fiddler's Cove Marine Repairs and Improvements Project at Naval Amphibious Base Coronado (FWS-SDG-4032.6) and the MOU between USFWS and the U.S. Navy Concerning Conservation of the endangered California Least Tern in San Diego Bay. Both the consultation and the MOU recommended further study of the Least Tern foraging behavior around San Diego Bay and the near ocean waters. This research project also fulfills the research goals set forth in the San Diego Bay Integrated Natural Resources Management Plan.

We found that California Least Terns foraged most frequently in and around San Diego Bay in 2009, in the following areas.

1) in inlets and mooring areas and along shorelines near their colonies in San Diego Bay,

2) within 400 m offshore in the Pacific Ocean beyond the breakers adjacent to their colonies, 3) offshore up to 24 km in upwelling areas along Nine Mile Escarpment and Colorado Canyon.

Terns used these different areas in different frequencies throughout the three breeding stages, egg, chick, and fledge, and foraged nearest the colonies during the chick stage. Major prey for both chicks and adults were silversides (silverside smelt-*Atherinops spp.*) and anchovy (*Anchoa spp.*), and also included kelpfish (most likely Giant Kelpfish, *Heterostichus rostratus*) for adults. Silversides and anchovy were the same prey consumed in the 1990s, but kelpfish were new to their diet in 2009.

All fish were of Age Class 0, young of the year, for both chicks and adults, which corresponds with what Pondella (2008) found in his study on fecal samples from 2008, and what Baird et al. (1997) found in the 1990s in both bill loads and concurrent fecal samples. Adults consumed larger prey than did chicks, and dropped fish were different in proportions of prey type and size than were fish known to be consumed by Least Terns, verifying work done in the 1990s in San Diego and Camp Pendleton. Prey types consumed by Least Terns also did not correspond with the large variety of potential fish prey caught in San Diego Bay, although terns are known to consume some of the same genera of fish caught in fishing gear.

This is the first time that regular pelagic foraging, as far as 24 nautical miles from the coast, has been documented for Least Terns, via systematic surveys. Preferred foraging areas in San Diego Bay and the nearshore area were consistent with where they had foraged in the 1990s.

Conclusions from this report are limited, because they are based on only one year of data collection, and in a year where there was heavy predation on eggs and chicks.   Because of these limitations, the specific questions posed in the goals could not be answered definitively and completely. This study should be considered a baseline study for Least Tern foraging in San Diego Bay and other ocean areas for the early part of the 21st century. If continued studies are conducted, they will be a good contrast to studies from the 1990s, the methods of which were used in 2009 in this study.

Part 2

Part 2 is written by personnel from Occidental College, Vantuna Research Laboratory, who were subcontractors to Kahiltna Research Group (Dan Pondella, Jonathan Williams). Part 2 identifies fish species from otoliths found in fecal pellets of Least Terns on U.S. Navy colonies, from collections in the year prior to this foraging study.   Out of 149 fecal samples, collected during the fledge period in 2008, only 34 contained otoliths. From these pellets, 139 otoliths were recovered, and of these, 21 were unidentifiable. Of the remaining 118 otoliths, the majority were from slough anchovy and topsmelt.

Part 3

Part 3, also written by personnel from Occidental college, summarizes current and historical studies (1995-1998, 2005, 2008, and 2009) on fish caught in the course of research surveys in the months of April and July in San Diego Bay. Part 3 presents biomass, numbers, species, and densities of fish.   It compares these data with eight oceanographic indices, and with Least Tern breeding success (number of fledglings, number of fledglings per breeding pair, and the average clutch size).

Years of poor reproductive success in California Least Terns were also compared with timing of fish hatch.   In summary, no relationship was found between the breeding success of least terns and fish types, abundance, and distribution, or with missed timing of fish hatch. There was also no significant correlation between eight oceanic indices and Least Tern breeding success.

In contrast, eight of 112 correlations of 14 fish standing stock estimates were significantly correlated with the eight oceanographic indices. Cold-water fishes increased during cool phases and warm water fishes increased during warm phases. This accounts for the consistency among years in the overall stock estimates of forage fish.

INTRODUCTION

Summary

Part 1 describes a foraging study of California Least Terns in and around San Diego Bay, California, USA in 2009. Boat surveys of foraging flock distribution took place in San Diego Bay, in the ocean waters adjacent to their colonies, and in the pelagic area beyond the breakers near their colonies, out to the Nine Mile Escarpment and Coronado Canyon (~32.68 ° N, -117.15 ° W). Part 1 also summarizes other foraging parameters such as the direction of return from foraging bouts of birds carrying fish, or the type of fish fed to adults and chicks, which might be used as indicators to determine where Least Terns fed. Part 2 describes the identification, by personnel from Occidental College, of fish parts found the previous year (2008) in fecal pellets of Least Terns, and collected by Elizabeth Copper. The final section, Part 3, describes current and historical research on what fish have been sampled, via fishing gear, in San Diego Bay in an effort to determine if there was any relationship between types and numbers of fish caught, oceanic parameters, and the reproductive success of Least Terns.

Information in this report is provided to aid managers in their analysis of Least Tern reproductive success to see if these data might be useful to them predict good and bad years for Least Terns. This determination and prediction is outside of our scope of work and is not discussed in this report.

Goals of Project

The purpose of the project was to gather information so that the U.S. Navy could comply with the Endangered Species Act (16 USC 1531 et seq.), the Sikes Act Improvement Act (16 USC 670 et seq.), and the Migratory Bird Treaty Act (16 USC 1361 et seq.) in their agreements with the US Fish and Wildlife Service, including the formal endangered species consultation on the Fiddler's Cove Marine Repairs and Improvements Project at Naval Amphibious Base Coronado (FWS-SDG-4032.6) and the MOU between USFWS and the U.S. Navy Concerning Conservation of the endangered California Least Tern in San Diego Bay. Both the consultation and the MOU recommended further study of the Least Tern foraging behavior around San Diego Bay and the near ocean waters. This research project also fulfills the research goals set forth in the San Diego Bay Integrated Natural Resources Management Plan.

The goal of this project was to provide the U.S. Navy with an understanding of the foraging activities of the federally endangered California Least Tern (*Sternula antillarum browni*) in and around San Diego Bay in 2009. U.S. Navy Least Tern colonies at San Diego Bay, are at Naval Base Coronado, including those at: 1) Naval Amphibious Base Coronado, (NAB), consisting of the Delta Beach colonies, and the ocean colonies (NABO), and 2) the Naval Air Station North Island (NASNI) colony at the MAT site, heretofore referred to as "the MAT site," (Figure 1).

Our objective was to determine if primary foraging habitat exists for the California Least Tern within San Diego Bay, as well as ocean waters adjacent to the NAB Ocean colony. We achieved these goals via boat surveys and via on-colony surveys of incoming birds with fish.

Boat Survey Work --Goals (Baird)

1. Do Least Terns nesting on Naval Base Coronado preferably forage in areas closer to the nesting colony or do they forage in more distant areas?
2. Do Least Terns forage more frequently in particular areas of San Diego Bay?
3. During the breeding season, how far do California Least Terns forage offshore?
4. Do observed California Least Tern foraging patterns vary throughout the breeding season?
5. Do California Least Terns from the same colony repeatedly utilize the same area of the bay for foraging, or do individual foraging patterns vary randomly throughout the day/breeding season?

Colony Work-- Directional or Vector Observations—Goal (Baird)

To determine from what direction adults with fish were returning to the colony. This indicates the general area they had fed just prior to their return.

Colony Work-- Prey of Least Terns—Goals (Baird, Pondella)

1. To determine what prey genera California Least Terns ate via visual observations of incoming adults with prey in their bills (Baird).

2. To identify prey in fecal pellets collected simultaneously with bill load data for analysis by a subcontractor on this project, Daniel Pondella, Occidental College. This analysis would verify

whether visual identification of prey species in bill loads is an accurate means of determining what species and size of fish Least Terns eat (Pondella).

3. To collect dropped fish, shown in prior studies to be prey that terns rejected, in order to compare with fish eaten. (Baird).

4. To identify prey in fecal pellets collected in 2008. Work to be done by Daniel Pondella, Occidental College (Pondella).

5. To compare fish caught via fishing gear in April and July among the years 1995-1998, 2005, 2008 and 2009 (Pondella).

Conclusions from this report are limited, because they are based on only one year of data collection. Because of this limitation, the specific questions posed in the above goals could not be answered definitively and completely. For trends, the same methods should be used in a continuing study of Least Tern foraging over a longer time. This study should be considered a baseline study for Least Tern foraging in San Diego Bay and ocean areas for the early part of the 21st century. If continued studies are conducted, they will be a good contrast to studies from the 1990s.

Natural History of the California Least Tern

The Least Tern is a seabird, with three currently described subspecies (Thompson et al. 1997). The subspecies we studied is *Sternula antillarum browni*. Recently, genetics research has demonstrated that all three subspecies are genetically similar, such that their classification as endangered in one subspecies and not in others may eventually change (Draheim et al. 2010, 2011). Therefore, in this report, the species name for the California Least Tern, *Sternula antillarum browni*, will be interchanged with the equivalent name, Least Tern, (*Sternula antillarum*).

The Least Tern has breeding colonies on coastal beaches in North America, and large rivers in the interior of North America. Its winter range is along the marine coastlines of Central and South America. The Least Tern's coastal nesting habitat is often the same habitat used by humans for various kinds of recreation and residential or commercial development, and most of their habitat has been developed for these purposes. Thus, alternate colony sites are absent if a current site is disturbed.

Preferred habitat inland is often in areas altered by water diversion, e.g. along the Mississippi River. Terns of all species are adapted to shift their breeding colonies annually, especially if there is disturbance or change, yet disappearance of natural alternate habitat where they could move a colony has made disturbance a primary factor to address in management (Thompson et al. 1997). It has also been found that Least Terns are most productive at colony sites that have endured for several years (Thompson et al. 1997).

The Least Tern feeds mostly on small, shallow-bodied fresh- and saltwater fish, by plunge-diving up to half a meter deep, but its diet is varied and can include small crustaceans and insects. Once Least Terns capture fish to feed to either an adult or chick on the colony, they fly directly back, not fishing on the way, such that directional data indicate the area where birds have just fed. Unlike other seabirds, like puffins, (*Fratercula* spp.) which can carry multiple fish in their bills, and which capture fish in various locations before they return to the colony, Least Terns are obligate carriers of a single fish only, and thus cannot continue foraging on their return to the colony.

Predators specializing on specific prey types ('specialists'), such as a single fish species, search for specific prey by returning to locations known to have an abundance of that particular prey item (Davoren et al. 2003, Weimerskirch et al. 2005, Wilson et al. 2005). Yet, it is unclear whether predators that prey on a variety of prey types ('generalists') also change their behavior to search for and capture specific prey items or move randomly through a habitat and consume prey items as they are encountered (Barrett 2002, Tremblay et al. 2005). Comparing where Least Terns forage over multiple years would help determine if terns exhibit either or both of these behaviors.

Thus defined for analysis purposes, and realizing that there is indeed an overlap between stages and not a sharp cutoff date, courtship stage in this study is April 17-May 8, egg stage is May 9-June 1, chick stage is June 2-June 24, and fledgling stage is June 25-August 17. Because of heavy loss of eggs and chicks to predation, much of the season's dates were skewed , which means that when we would usually expect there to be eggs or chicks present on the colony, there were often no eggs or chicks, or else there was mating and egg-laying still going on long after it would have ceased in a normal year. The dates of all these stages are about two weeks earlier than we observed in the 1990s (Baird et al. 1997). We have no explanation for this difference.

Our observations are only through July, because the terns had abandoned their colony by the end of July. All colony-based data in this report begin at the chick stage, and start on 5 July 2009.

Definitions and detailed sampling methods by Dan Pondella's team are in Appendices 2 and 3.

METHODS

Determination of breeding stages of California Least Terns

We used the first and last sightings of nests, eggs, chicks, and fledglings determined by the monitoring team chief (E. Copper, pers. comm.), and then applied standard USFWS methodology used by other tern researchers to determine dates of these breeding stages (Bartonek and Gibson 1972). This is the same method used to determine dates in the 1990s (Baird et al. 1997). To be consistent, we use the same methods in data analysis in this report.

The standard methodology for the definition of dates is:

Courtship stage-- from when Least Terns were first seen at the colony until one week past the first nest.

Egg stage-- from the end of courtship plus one day to either 22 days later (incubation time +2 days) or till three weeks before the last clutch is laid, whichever is greater.

Chick stage-- from the end of the egg stage plus one day till 22 days later (time till fledge).

Fledge stage-- the end of the chick stage plus one day till the end of the season.

Boat Surveys

We conducted surveys for foraging California Least Terns, from a 13’9” Mark II Classic Zodiac, throughout the egg, chick, and fledgling stages (defined above). We used tracklines from surveys in the 1990’s in San Diego Bay (Baird et al. 1997). Tracklines followed the contour of the shore, and covered the entire San Diego Bay, and the coastline to a latitude of 32° 40' N. These tracklines were 100 m offshore, with an extra trackline at 400 m from shore added in the widest parts (Fig. 1).

These survey distances from shore and surveying techniques conform to standard methods adopted by the U.S. Fish and Wildlife Service/ USGS (United States Geological Survey) which were used on NOAA, (National Ocean and Atmospheric Association), surveys of the Gulf of Alaska, the Alaska Peninsula, Kodiak Island, and the Bering Sea, and were modified for small boat work in these and areas (Bartonek and Gibson 1972). On a survey, observers near the bow scan the water on either side of the boat as it continues on a steady course (Forsell and Gould 1981, Gould et al. 1982, Gould and Forsell 1989). There is at least one person driving the boat and one observer, but preferably there are two observers, each surveying one side of the boat for birds. We had no speedometer. Speeds were very slow and variable, dependent on wind conditions, and were certainly below the speed limit of 8 km/hr in South San Diego Bay and could increase to ~15 km/hr-- slow enough to detect all foraging flocks of terns. However, we have no idea of what the actual speed was. An estimate of maximum speed would be < 28-33 km/hr, but this was probably never reached.

We surveyed on the tracklines two to three times per week from dawn to dusk, dependent on weather conditions. Wind had to be less than Beaufort 4 for viewing ability and for safety. We randomized start times, route, and starting locations such that all sections of the bay, nearshore, and ocean tracks were covered equally weekly to reduce time or space bias.   When we saw Least Terns diving, we stopped the boat, counted them, and determined their location. Data gathered were: location of foraging flock by GPS, (latitude and longitude degrees), species of birds, and number of birds of each species, in each foraging flock. A foraging flock is defined as one or more least terns plunge-diving, or hovering over the ocean.

Figure 1 shows the tracklines. Tracklines with an abrupt end, not connected to another line, means that we stopped recording at that point, and then traveled to the next trackline and started recording again.   Figure 11 shows exact colony locations.

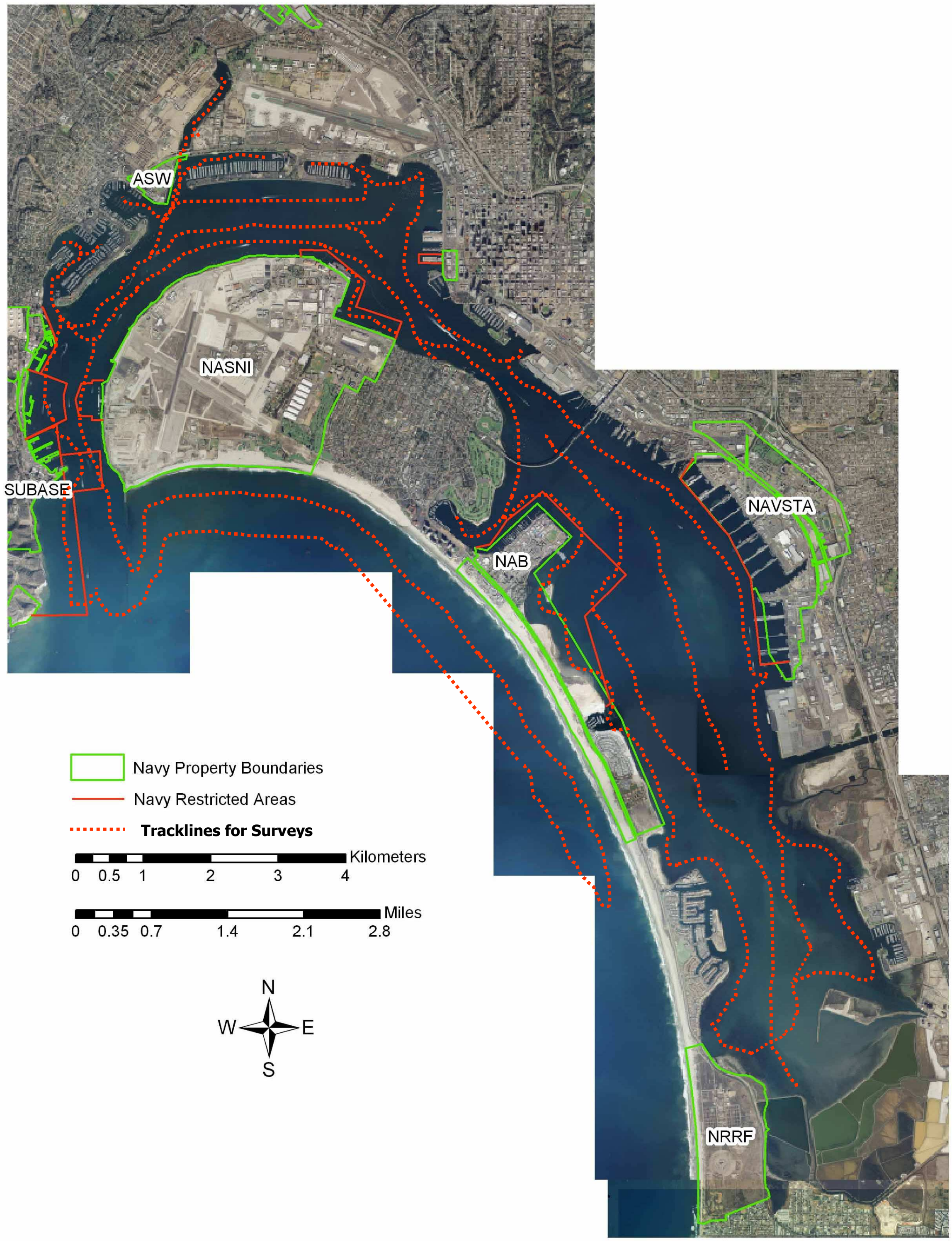


Figure 1. Survey tracklines in San Diego Bay and nearshore, 2009.
ASW = anti-submarine warfare, NAB=Naval Air Base, NABO = Naval Air Base Ocean, NASNI = Naval Air Station North Island, NAVSTA = Naval Station, NRRF = Naval Radio Receiving Facility, SUBASE = submarine base

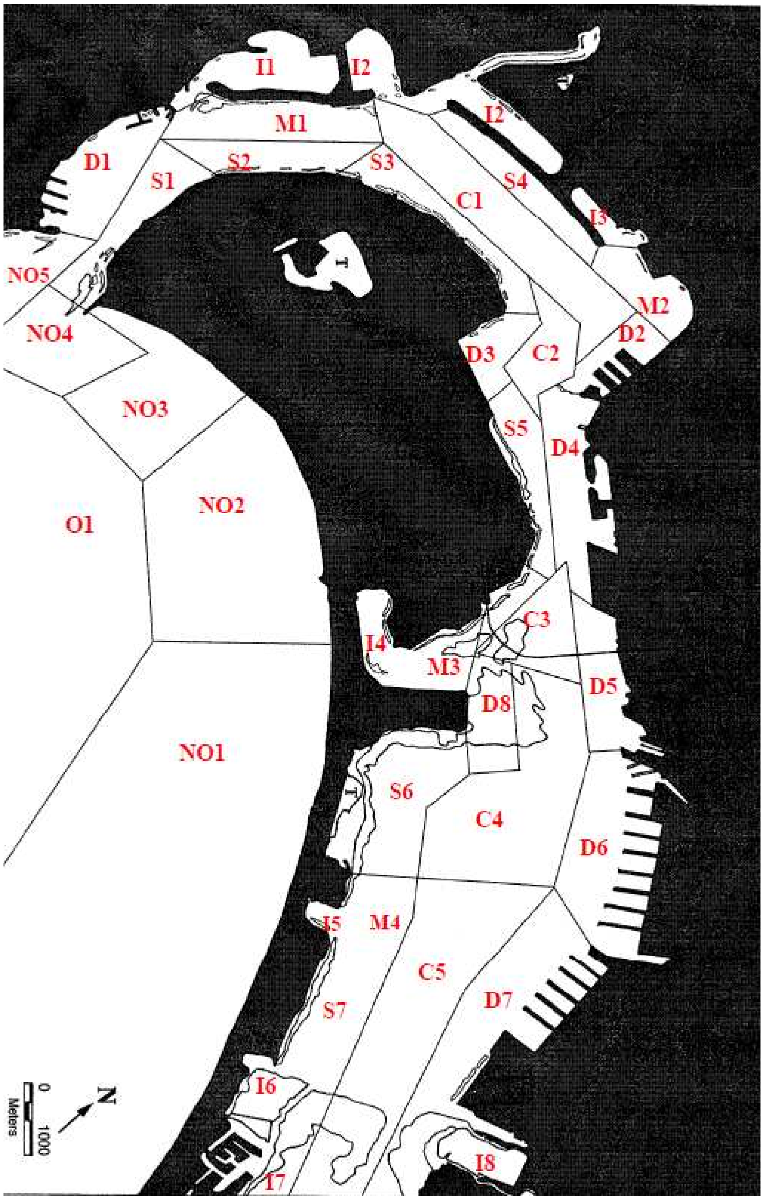
Habitat

We defined geographical areas of San Diego Bay according to the most dominant type of habitat or anthropogenic structure in that area. We outlined these areas with straight lines, and thus created what we call "habitat polygons" of each of these defined general habitats over San Diego Bay and the near ocean. These areas were called " habitat polygons" or "habitat types" in the 1990s, and foraging data at that time was reported with respect those habitats (Baird et al. 1997). Therefore, for consistency, I have displayed the 2009 data in the same way.

We defined seven different major types of foraging areas based on similar contiguous habitat, and these are listed below. We determined their areas by an Arc GIS area function.

- Mooring areas: areas where boats were anchored outside of indentations in the shoreline and away from a dock or shoreline
- Inlets: natural indentations in the shoreline which often have small boats in marinas; they sometimes have fresh water entering them
- Docks: large anthropogenic wood or metal projections into the bay where ships are able to be secured
- Near ocean: the oceanic area 400 m and less from the shoreline, extending about 100 m beyond the breakers
- Channel: the deep water dredged area in the center of San Diego Bay, especially in the mid and north bays, where large ships travel
- Shoreline: any area along the shore, not docks, mooring, or inlets, with or without eelgrass, within 100 m of shore
- Ocean/Pelagic: the Pacific Ocean areas beyond 400 m from shore out to 24 km from shore

For analysis of the results, we used these geometrical polygons to delimit each of the above general habitats, superimposed over a map of San Diego Bay and the Near ocean. Figure 2 displays the polygons of these types of foraging areas in San Diego Bay area, and Figures 3-9 show the extent of each habitat polygon filled in color. Excluding the pelagic area, the areas of each of these foraging locations is: 4% mooring, 16.64% channel, 10.55% dock, 5.39% inlet, 25.75% shore, 37.66% near ocean.



C= channel, D= dock, I= inlet, M= mooring, NO= Near ocean, S= shore O = ocean
Numbers are to distinguish different areas within each type of foraging location, and are for analysis purposes only

Figure 2. Types of foraging areas in and around San Diego Bay, California

We surveyed all areas of San Diego Bay, including all dock and inlet areas, and within the safety barricades of U.S. Navy aircraft carriers. Other barricaded areas (e.g. at NAVSTA) had lower barricades, and we could see over them to detect foraging flocks. Additionally, we surveyed all marinas and mooring areas, deviating from standard USFWS/USGS protocol (100 m transect either side of the platform), because these transects were less than 100 m from shore. We could not physically cover the very south end of the bay because of shallow water, but when we were near the area on our southernmost tracklines in the bay, we surveyed these unnavigable waters via binoculars. Surveys conducted outside the bay, in the near-ocean coastal waters (one trackline 100 m and one 400 meters from shore), where we traveled from the mouth of San Diego Bay southwards towards Imperial Beach, west of the Naval Training Beaches (NABO) to a latitude of 32^{o} 40’. We recorded all foraging flocks of Least Terns, their size and species composition, and obtained a GPS location in latitude and longitude degrees for each. A forging flock is defined as “one or more terns diving.

Figures 3 to 9 show extent of each type of foraging area in San Diego Bay.

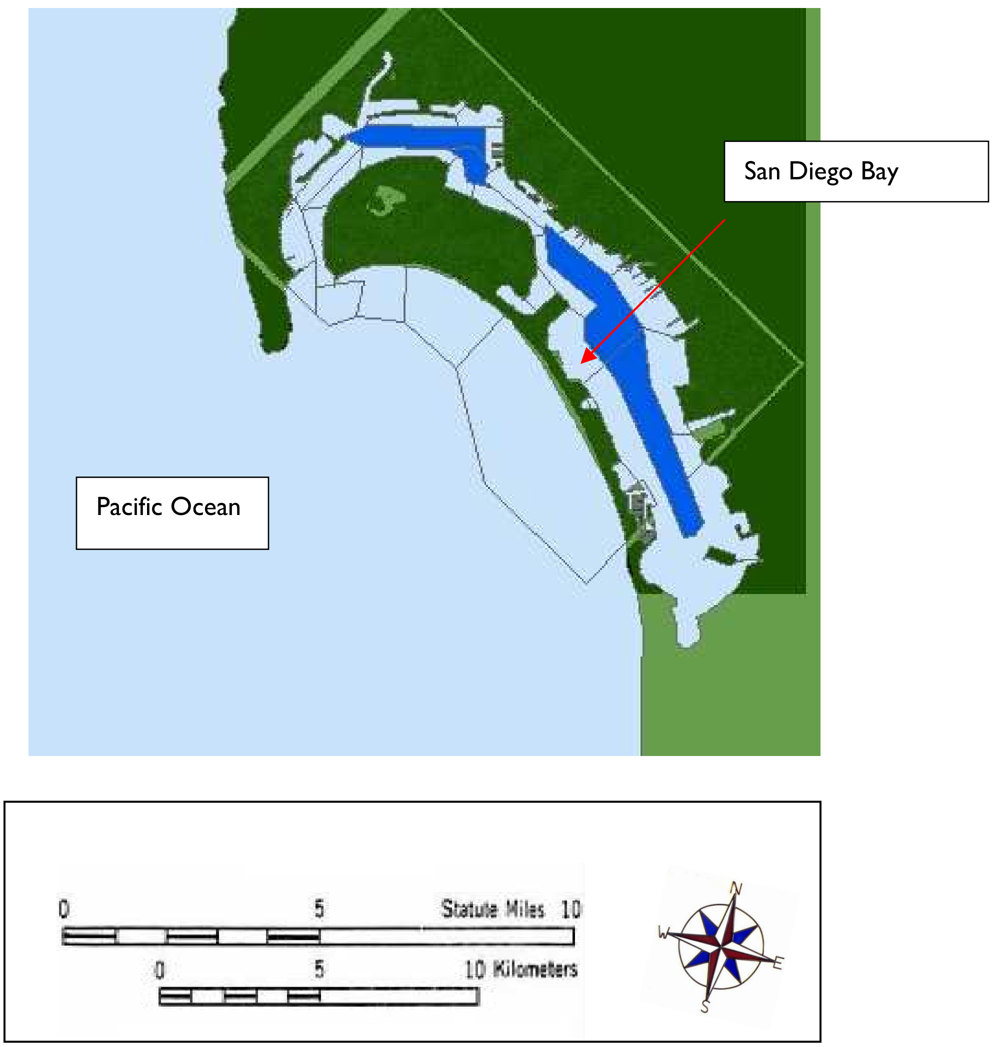


Figure 3. Extent of Channel Habitat in San Diego Bay, 16.6% of nearshore & bay area.

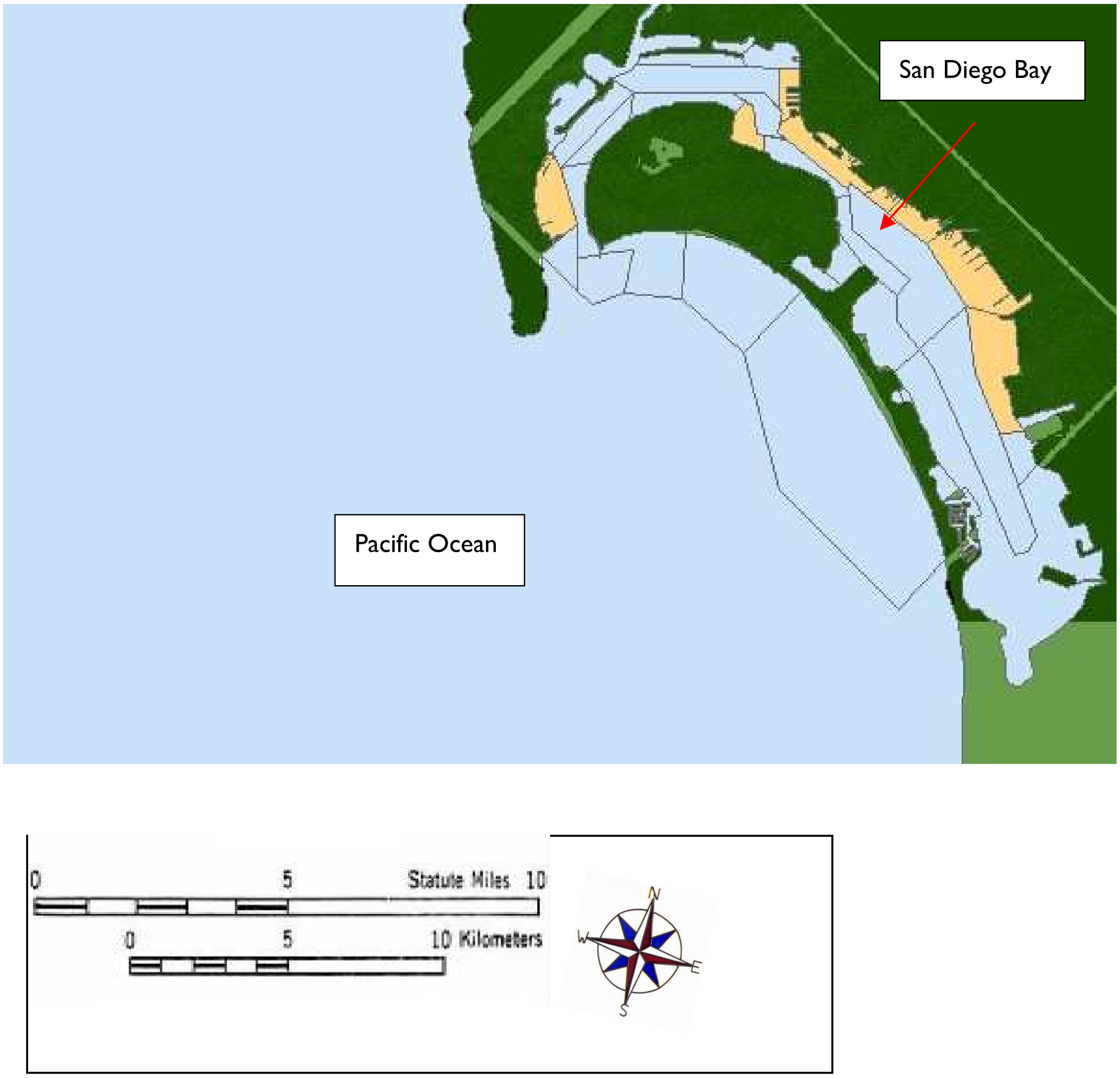


Figure 4. Extent of Dock Habitat in San Diego Bay, 10.6% of nearshore and bay habitat.

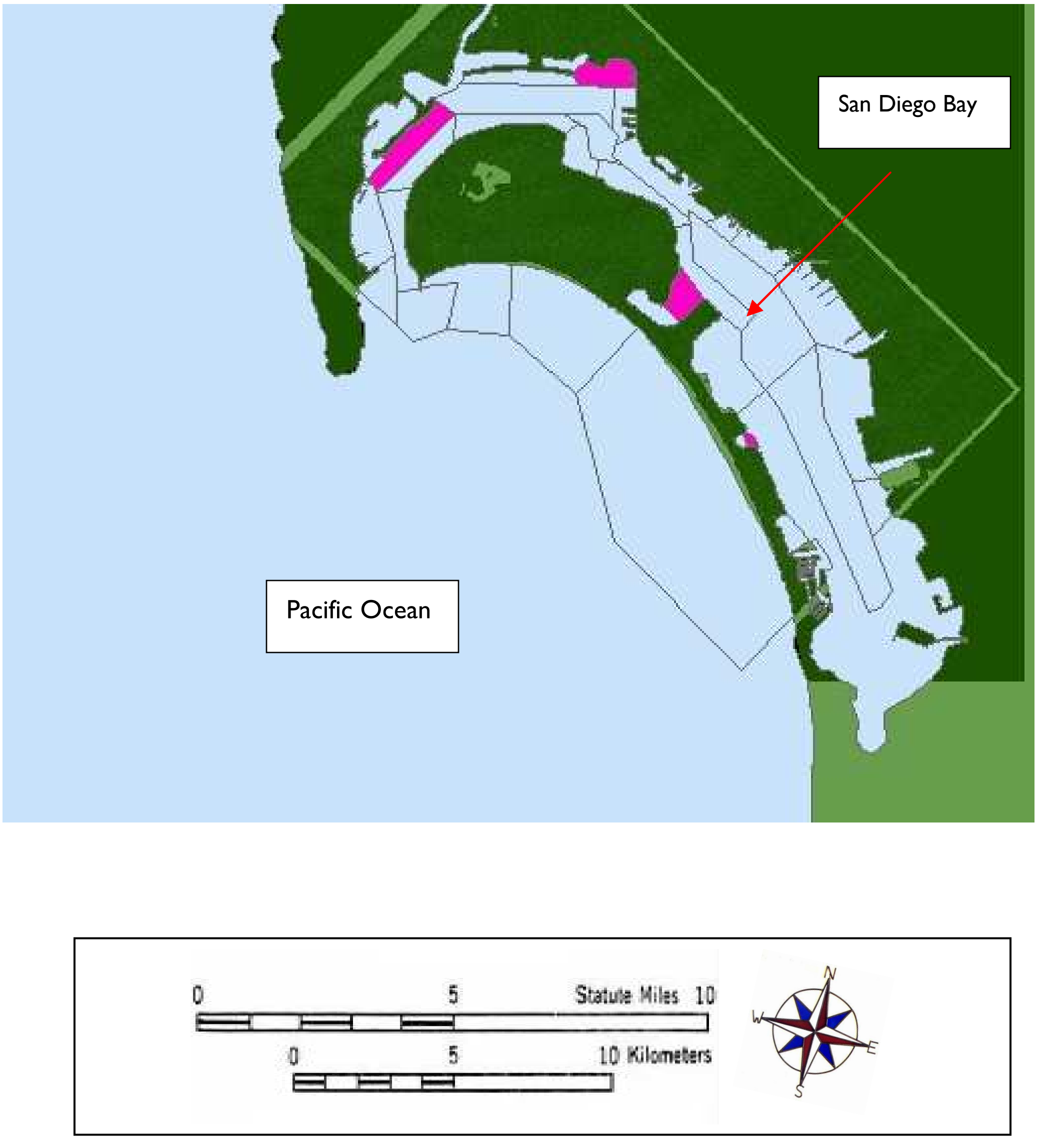


Figure 5. Extent of Mooring Habitat in San Diego Bay , 4% of nearshore and bay habitat.

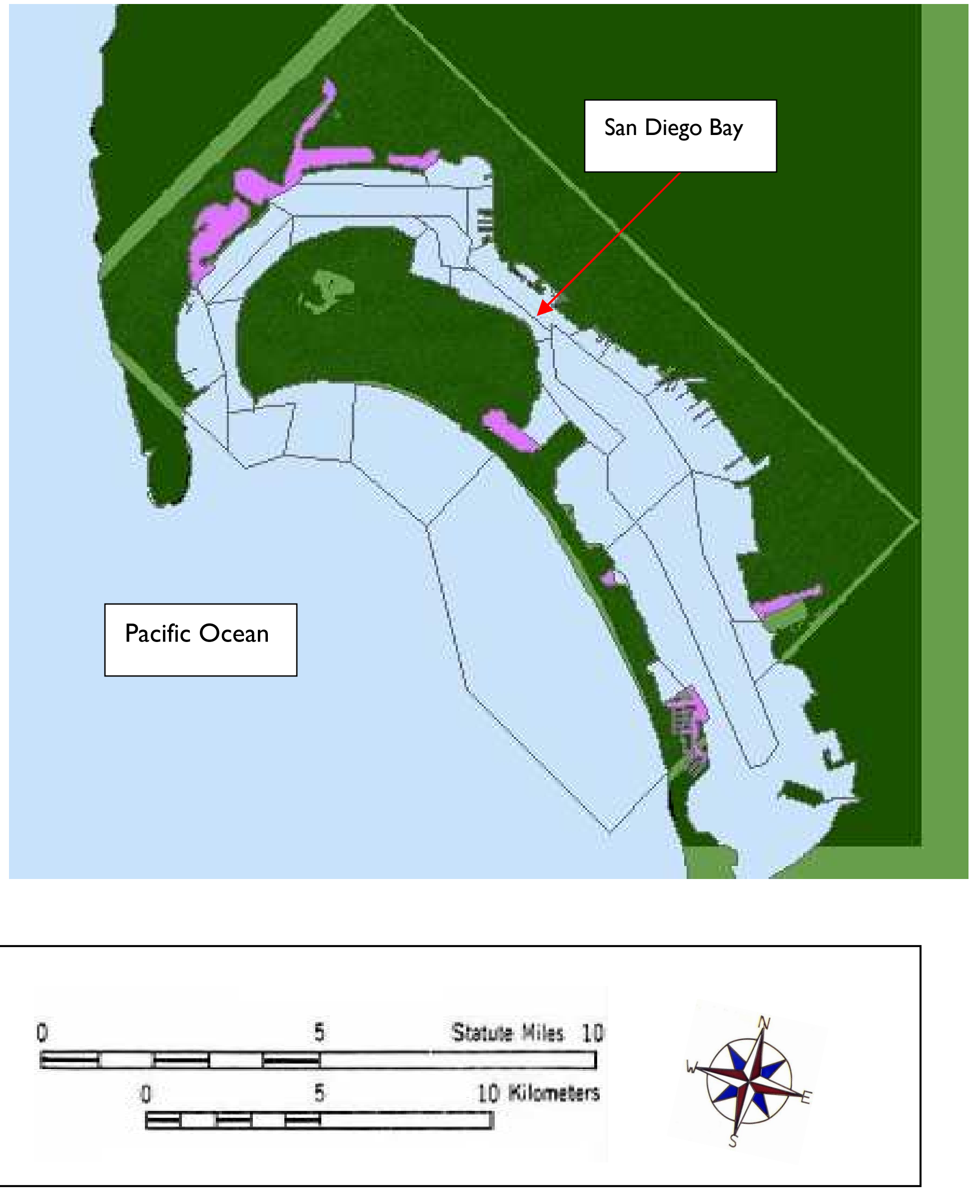


Figure 6. Extent of Inlet Habitat in San Diego Bay, 5.4% of nearshore and bay habitat.

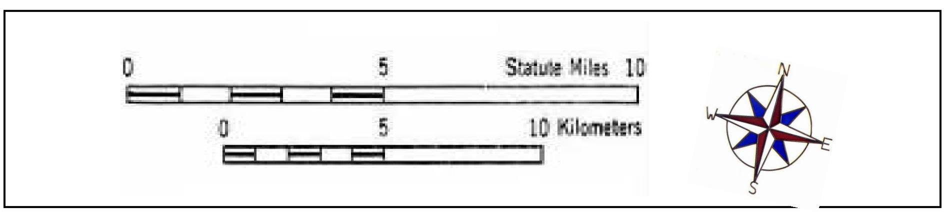
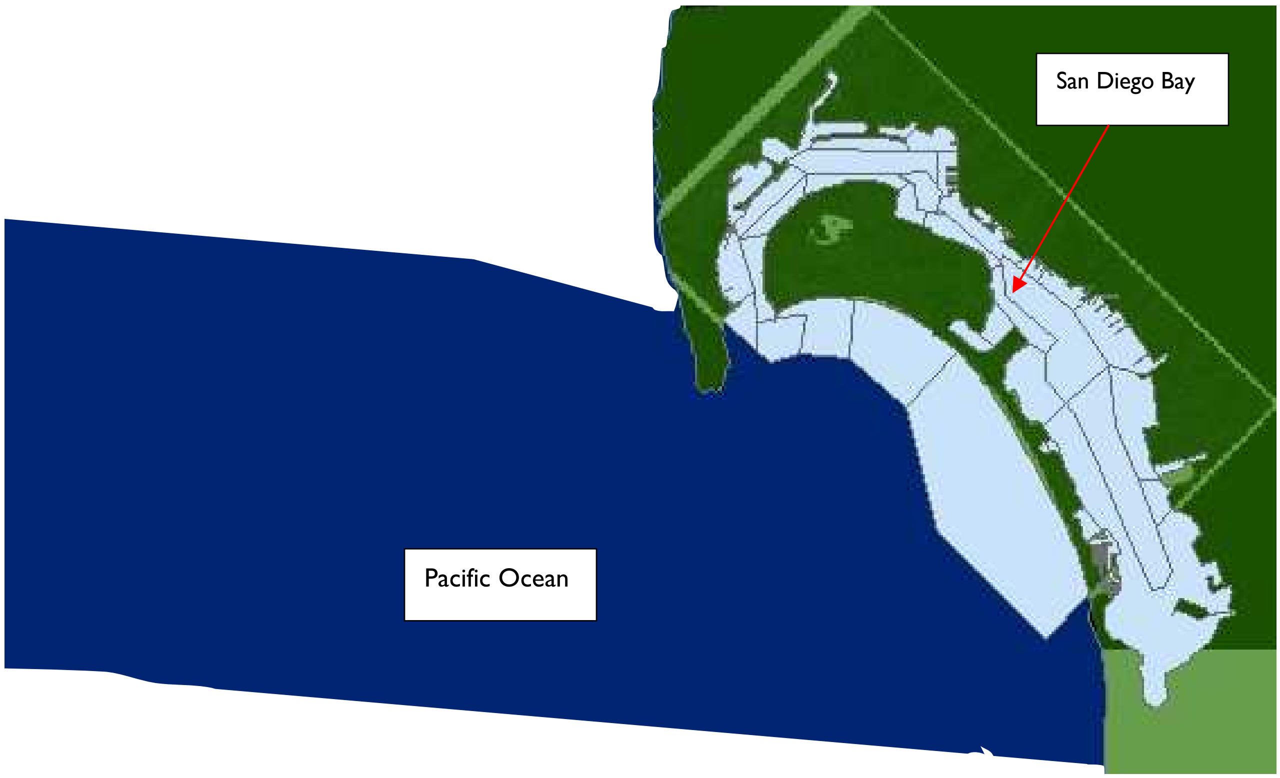


Figure 7. Extent of Near ocean Habitat in San Diego Bay, 37.7% of nearshore and bay habitat.



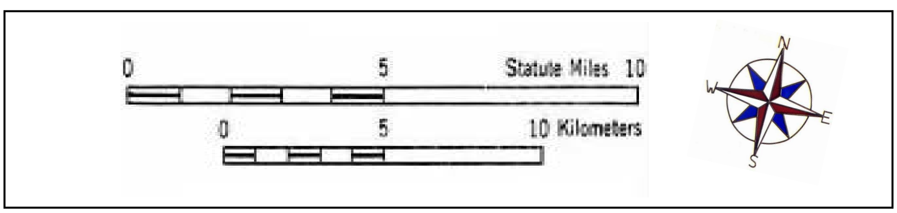


Figure 8. Extent of surveyed Ocean Habitat near San Diego Bay

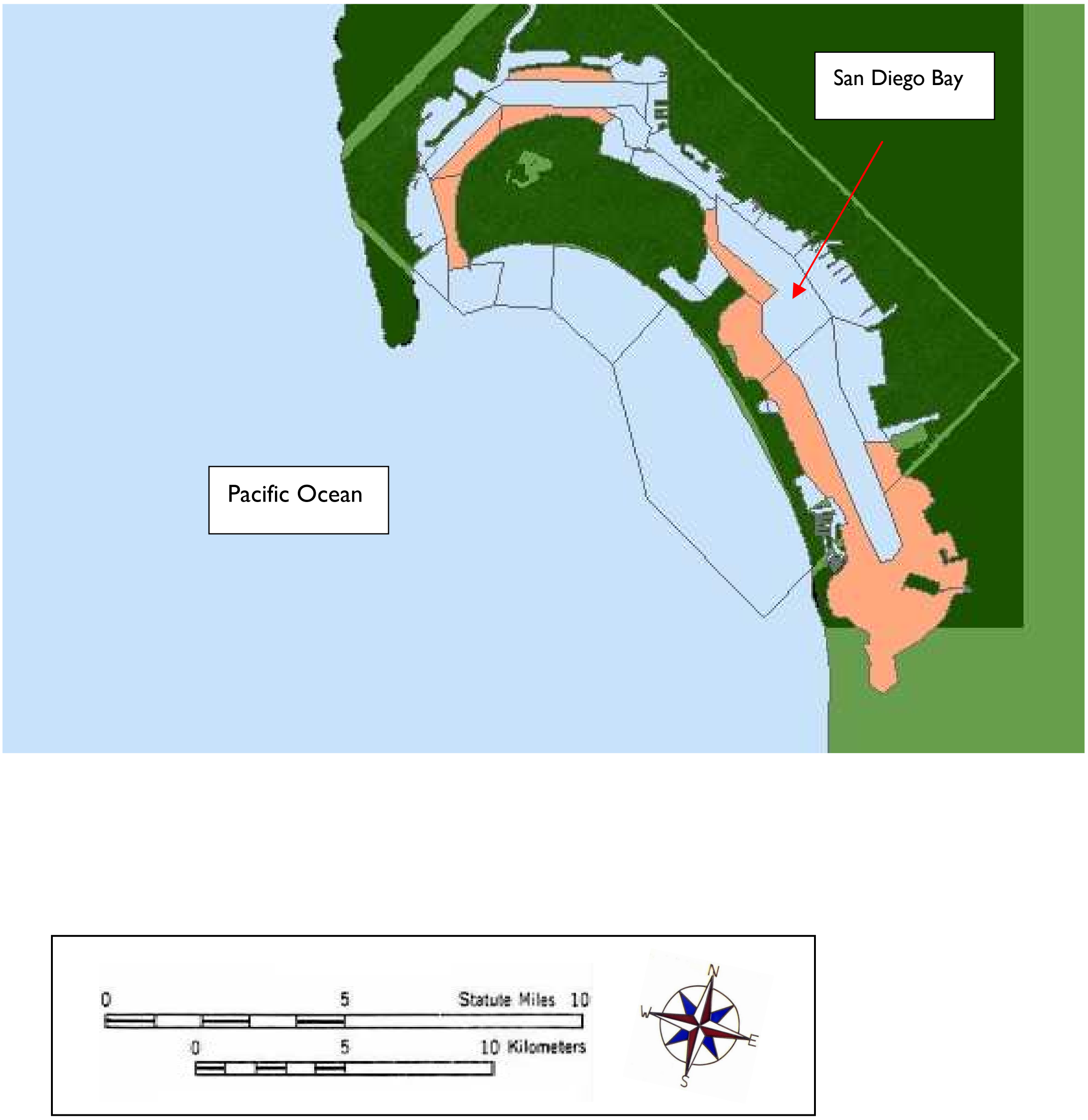


Figure 9. Extent of Shoreline Habitat in San Diego Bay

Pelagic Surveys

During studies in the 1990's, there were observations of terns flying westward from the colonies to the open ocean, but there was no watercraft available to safely follow them for a long distance (Baird et al. 1997). Thus, we designed this current study n 2009 with a pelagic component included. We chartered an ocean-going craft (20' Boston Whaler) from either Tierra Data, Inc., (driven by Derek Lerma), or from Dave Povey to be able to travel as far as a nearby major upwelling area, Nine Mile Escarpment, 24 km offshore. Pelagic surveys had never been conducted for Least Terns in the San Diego Bay area before the current study, and thus Tim Burr, Derek Lerma, and Pat Baird developed the protocol for ocean surveys.

Our goal was to cover the largest ocean area from the shore, west to the Coronado Canyon and Nine Mile Escarpment, in the shortest time. We designed a grid of eleven survey tracks starting 400 m from shore, and stopping at the Nine Mile Escarpment-Colorado Canyon upwellings. We numbered the transects from 1 to 11, starting in the south, and set up a sampling scheme to cover all 11 transects, four per day, spaced 3 transects apart, (e.g., numbers 1, 4, 7, 10, and then 2, 5, 8, 11, Figure 10). We headed rapidly from shore to the latitude and longitude of the starting transect. Once on this transect, we slowed the boat to a speed where we could easily observe and count foraging birds, and we held a compass heading W/NW on the selected track until we reached the end of it. To arrive at the next track of the day, we traveled perpendicularly to the first transect until we reached the next one, and then headed S/SE until we reached 400 m offshore again. This sequence continued until we had covered all of the targeted transects of the day. We covered all transects equally during the entire survey season.

During the surveys, we followed our methods used in San Diego Bay, searching 100 m on either side of the boat for foraging flocks. To be consistent with bay surveys, we did not report birds just traveling and not plunge-diving, although we sighted many.

Surveys ceased in mid-July due to colony abandonment by the terns. We conducted pelagic surveys once every one to two weeks, for a total of seven transects (11, 20, and 28 May, 2 and 29 June, and 5 and 14 July). As in the bay surveys, all pelagic surveys were dependent on weather, and if the Beaufort was >3, we did not proceed. Pelagic surveys were less frequent than ones in the bay because they were more expensive. Likewise, their inclusion was not emphasized in the Request For Proposal.

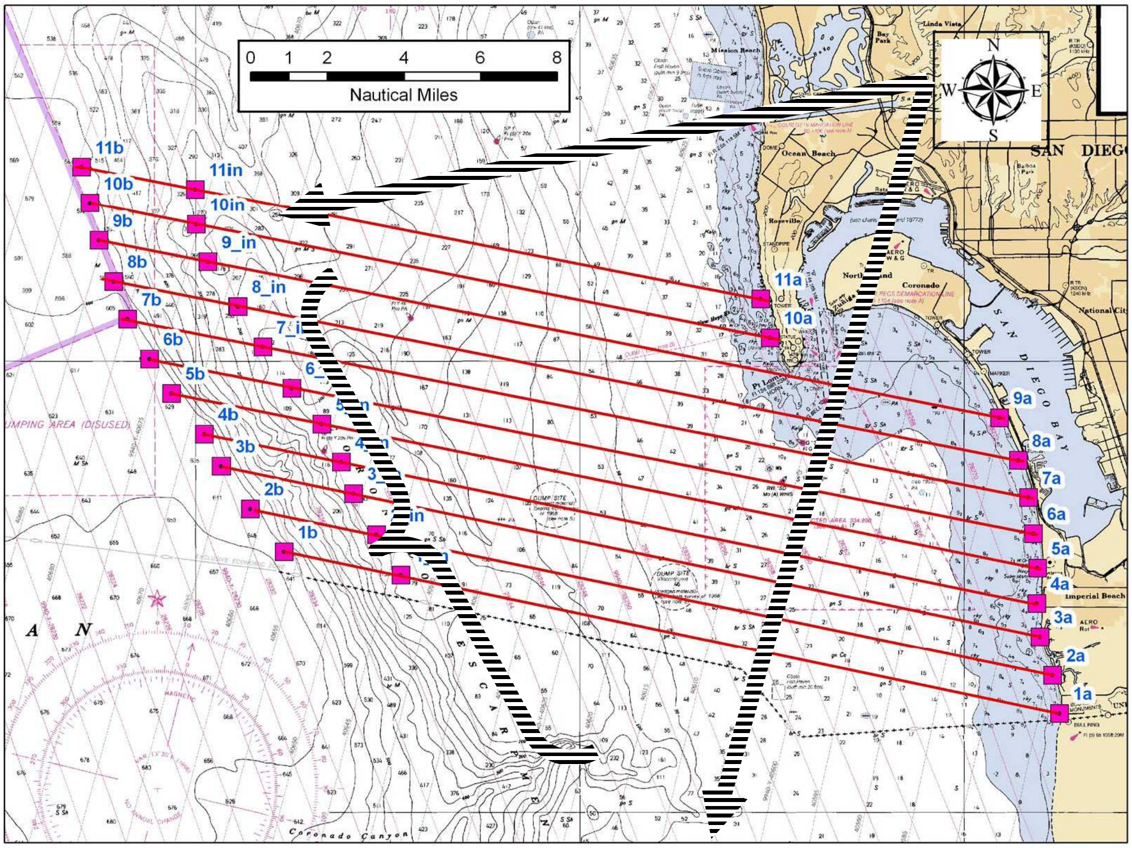


Figure 10. Pelagic transects off the coast of San Diego, 2009*
* Arrows show upwelling areas in Colorado Canyon and the Nine Mile Escarpment

Marking of terns and detection of marked birds on boat surveys

The original Scope Of Work requested that we radio-tag a sample of birds to determine where individuals foraged, and if they foraged repeatedly in one area. However, after conferring with other scientists who had radio-tagged Least Terns for other purposes, and who recommended not using telemetry to determine where an individual bird could feed, (Bluso, 2007, I. Nisbet, pers. comm., Jennifer Stucker, pers. comm.), we decided not to use this technique. Recommendations for not using telemetry were based on: a) the inability to determine if a radio-tagged bird was actually foraging (not just present or absent), and b) the fact that a true radio signal could be disrupted or not heard because of multiple electronic frequencies which were ever present as background noise in San Diego Bay.

Stucker and Nisbet (pers comm) used visual sightings, not telemetry, to determine if birds were foraging in areas they surveyed. J. Stucker started with, and then abandoned, radio telemetry because she could not get into a site fast enough to confirm foraging behavior. Forester's Terns (*Sterna forsteri*), the species that Bluso (2007) radio-tagged, are not a good model for telemetry on

Least Terns, because Least Terns move much more quickly than do Foresters' terns, and thus they are more difficult to track (J. Stucker, pers. comm.). Additionally, Bluso (2007) and Perrow et al. (2006, with the Little Tern, *Sterna albifrons*), found a large margin of error for geographic position using radio detection, and that positions can be "off" by a range of up to a hectare.

Background electronic nose is generated from many different sources throughout San Diego Bay. Examples are radio towers, ships, boats, airplanes, or hand-held radios. These radio signals can either mimic a radio frequency placed on a bird, or can generate a false positive because of canceling out or generating new signals. Because of this problem, we tested the radio background environment in November 2008, by operating a Lotek SRX 600 receiver to listen on a predetermined frequency. This frequency was originally from radios that had been placed on western sandpipers the year before. These radios' batteries not only had already expired over six months previously, but the radios, theoretically, had been molted off of the birds in Alaska the previous summer, and so could not have been a source on that frequency.

However, we heard, and the SRX recorded, this distinct radio frequency, which we determined was a false positive signal. This test verified that broad telemetry studies, such as Bluso's (2007), could not be used. Only telemetry from a fixed position, for instance on a colony, tracking the return of tagged birds would be advisable in such a noisy background, (C. Winchell pers. comm.).

Because of this, the telemetry portion of the SOW was not included in the Work Plan. Instead, the Work Plan proposed an alternative method, dyeing birds from different colonies in a unique colony color. This would demonstrate group adherence in foraging, and would give us information on whether birds from the same colony, dyed the same color, foraged in specific areas. It could not answer the question of where individual terns foraged.

To dye birds, we would have to trap them. Before we started the dye marking, I trained my field crew in capturing and handling birds using Potter traps (wire mesh traps with a trip wire and automatic door closure, placed over the nest). We took the eggs out of target nests we wanted to trap, placed them in sand in a covered box, and then replaced these with the same number of artificial eggs. Terns then entered the trap to incubate the eggs, tripped the wire, closing the door, and then they would sit on, or stand over, the artificial eggs until retrieved from the trap. We then banded the trapped bird with a USGS metal band and 3 color bands, and measured mass, exposed culmen, wing chord, and diagonal tarsus. Color bands represented year, colony, and a unique color marker for that individual, and colors for colony and year were coordinated with those used by Elizabeth Copper, the head of the monitoring team.

However, mainly because of depredation of Least Tern eggs and chicks by Gull-billed Terns (*Gelochelidon nilotica*) during the season, we abandoned all trapping (and thus dyeing), after only banding and marking two birds, because we did not want to disturb the Least Terns further.

Colony Studies

Vector (Directional) Surveys

To determine general foraging areas from land-based surveys, we conducted directional, "vector," surveys on all colonies from 5 June through 31 July, the chick and fledge stages (maps of colonies in Figs. 11, 12), recording from which direction adults with fish arrived. From many other seabird studies on birds that carry single prey like Least Terns, it is known that after adults have captured a fish, they either return immediately to the colony to feed it to a chick or an adult, or swallow the fish and continue foraging (Olton et al. 1981, Schreiber and Burger 2002). Thus, all incoming birds with fish are headed for a mate or potential mate, or for a chick to feed, and they are on a linear flight path from their last foraging bout. Therefore, we can extrapolate 180 degrees backwards to a general area where they last foraged. Coupled with data obtained on boat transects, directional studies help pinpoint where birds forage.

Vector observations took place three days a week at 1-3 sites per colony, over a 30 minute period of observation per site, weather permitting. We randomized times of day per colony so that all colonies were covered equally at all foraging times over the season. We chose the most densely populated areas in each colony as observation sites in order to maximize the potential number of birds in transit. We did not have permanent observation stations because densities varied daily. North and south Delta Beaches are one colony because or proximity.

During most of the breeding season, the densest nesting areas on the ocean colonies were at NABO Blue 2 and Red 1, and not Orange, as in 2008 (E. Copper pers. comm., Fig. 12) and that is where the majority of our observations at NABO took place. At South Delta Beach, the areas along the western path, and in the central cluster of nests, were consistently good for observation (please refer to the 2009 report of E. Copper, pers. comm., for maps). At North Delta Beach, the best viewing stations were near the northern-most low grid numbers, near the water. At the MAT site, all areas were good observation points.

We minimized our disturbance to the nesting birds by sitting low to the ground at least 3.5 m (20 ft) away from active nest sites. If a bird did not return to an active nest within ten minutes after we first sat down, we moved to a different location. We also did not remain on the colony if the wind was greater than Beaufort 3 or if the temperature was greater than 29.5 degrees C (85 F) at a point 7.2 cm (3 inches) above the ground. I wrote these conditions into my permit, based on my knowledge of tern biology, and consultations with other tern researchers.

Three observers sat back to back, each one observing a 120 degree section of sky for incoming birds with the naked eye. The observer in the least active section recorded data (this active section varied daily). The direction from which the bird was traveling was taken via a compass reading and recorded in intervals of 20 degrees. This sector was fine enough to accurately interpret from where the terns were coming. Narrowing the intervals to less than 20 degrees would have greatly increased the possibility of error due to the size, speed, and at times, sheer numbers of California Least Terns approaching the nesting sight with prey. More than 20 degrees would not pinpoint a foraging area as precisely. We ground-truthed this in May by mock trials of terns arriving from different angles.

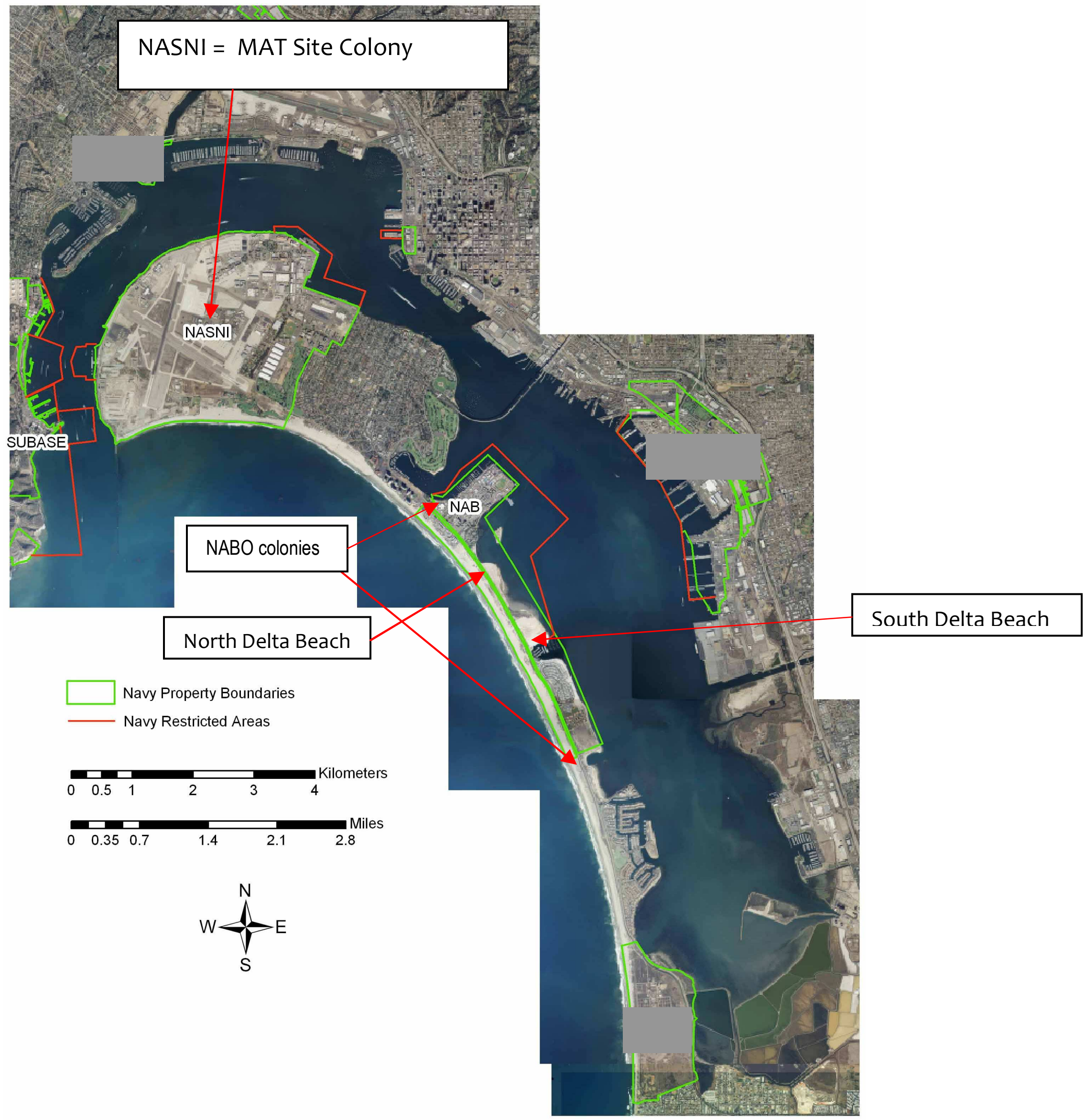


Figure 11. Map of U.S. Navy colony sites where we surveyed.

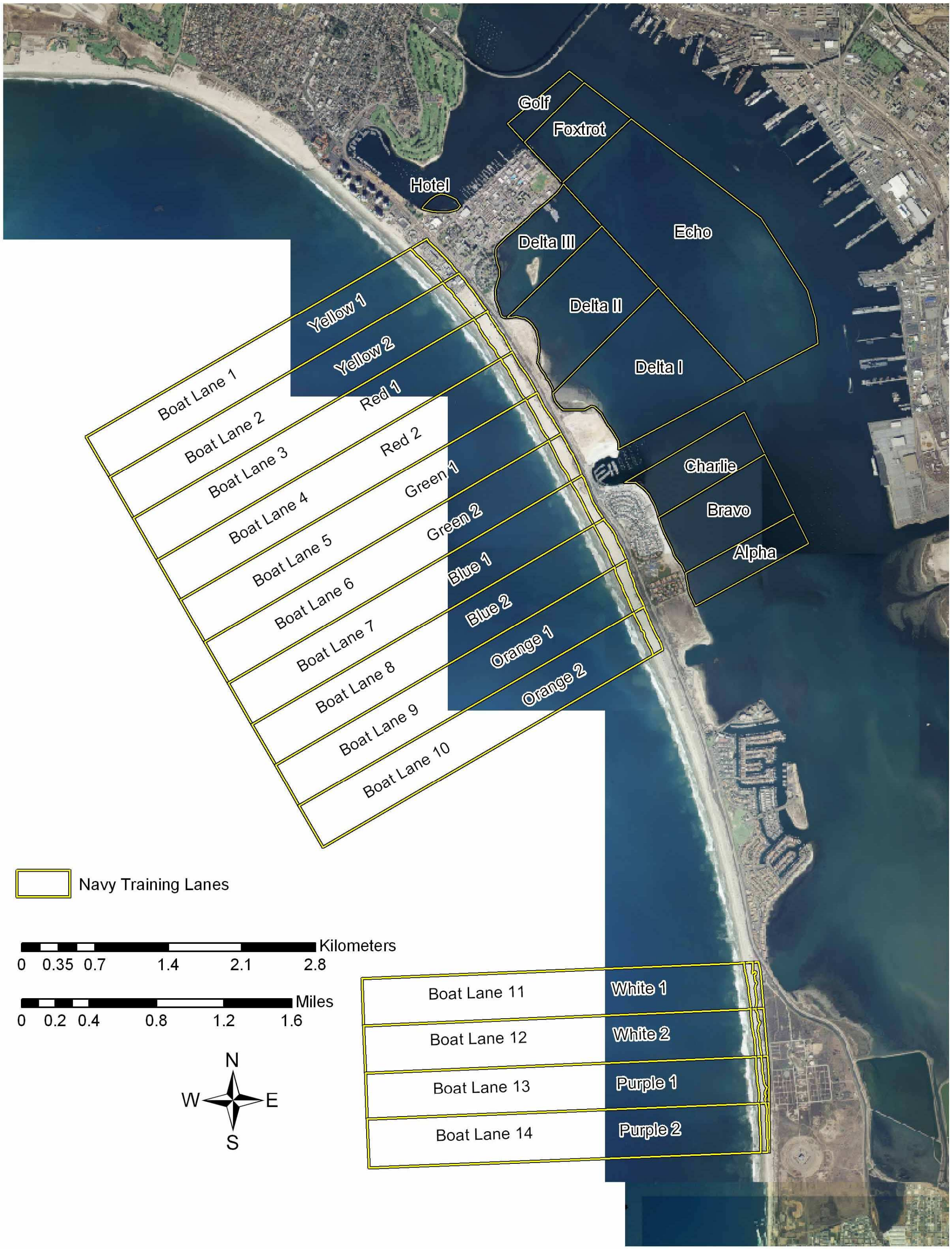


Figure 12. Sub-areas at NABO colony

Prey Identification

We conducted half-hour prey surveys, immediately after or before vector surveys, three times per week on all colonies at 1-3 sites per colony, from 5 June – 30 July. We used the same surveying strategy detailed above for vectors, with three observers surveying a 360 area for incoming birds with prey. We randomized start times and colonies, as in vector surveys. We identified prey to genus, determined length of the prey with respect to bill length, and noted whether the prey was fed to an adult or to a chick, or eaten by the providing birds. Prey were easy to identify, because the adult tern lands next to the bird it is about to feed, and holds the prey in its bill for a moment (see Photograph 1). This is a standard identification technique (Ainley and Boekelheide 1990, Hall et al. 2000, Collis et al. 2002). Later, we converted bill lengths to the length of the fish, using the average length of a Least Tern bill (Bayer 1985, Baird et al. 1997, Thompson et al. 1997). The identification of fish and length can help determine where the birds foraged, because different species and age classes of fish live in different habitats (Cannon 1970, Miller and Lea 1972, Love 1991, Moyle and Cech 1996),

Photograph 7. Least Tern ready to feed a chick (Photographer L. Addison 2009)

We identified prey by sight, with or without binoculars, and sometimes were aided by a 40 – 60 x spotting scope at the moment of feeding, using the differences in the size, color, rigidity and shape of the prey fish to determine genus. The characteristic morphological differences of the different genera allowed for easy identification (Miller and Lea 1972, Horn and Allen 1981b, Walker et al. 1987, Love 1991). Earlier in the season, we conducted identification trials with sample fish of various species and of the correct size for terns to consume taken from our collection of specimens, leant us by Jonathan Williams (Occidental College).

Greg McMichael, a graduate student in fisheries, was part of our team, and he made the final call on a fish identification. He was always able to identify all fish he could see. If he could not see a fish , then we did not use that observation. If we were unable to accurately and confidently assess the genus, species, or length of the fish, or the recipient of the feeding, we did not use the data point in our calculations or results.

Fecal Samples----Analysis from 2008-- See Part 2 for more details

The Vantuna Research Group at Occidental College analyzed fecal pellets, collected the previous year during the fledge stage by the nest monitor chief, Elizabeth Copper. They summarized prey length and type from otoliths in the pellets. It is not known how the fecal samples were collected. The results and discussion of this analysis are in detail in Part 2.

The main item in fecal samples that is very identifiable to species and length is the otolith, an ear bone of fish that has a specific morphology for each species and a size correlated with fish length. Pictures and descriptions of these are in Part 2 of this report, and Appendix III in Part 2 has the complete and detailed methodology of their analysis of otoliths.

We cannot compare this analysis of otoliths from 2008 with prey identified from bill load data in 2009, because they are from different years, and have no relationship to each other. A comparison of the two years would be misleading and would be prone to misinterpretation by readers of this report.

Fecal Samples—Analysis from 2009

We collected fecal samples at all colonies during the 2009 breeding season to verify accuracy of identification of bill load prey, caught during the same time as fecal collections. To collect fecal samples, we placed two 4' x 8' sheets of plywood on each colony. These were flat surfaces where fecal samples might be deposited by terns on the colony. Once a week, 5 June – 30 July), we collected fecal samples from each board, placed them in a bag labeled with colony and date, and then swept the board clean after each fecal sample collection and gave these samples to Dan Pondella, who was to analyze them. Our goal was to collect a minimum of 40 samples per colony (the NASNI MAT, the NAB Beaches--NABO).

The Occidental Lab did not analyze these samples, for this part of the study; they were told that there were no funds for analysis. I have now stored the samples at California State University Long Beach, and will analyze them as funds permit.

If Occidental had analyzed the fecal samples from 2009, collected concurrently with our observations of bill loads, we would have had a good comparison of the two methods to identify prey.

Fish Abundance in San Diego Bay---Part 3

Part 3 is a summary of types of fish caught by the Pondella lab and a summary of what fish have been found in the Bay in the past by other researchers. They summarized the years 1995-1998, 2005, 2008, and 2009 in the months of April and July. They compared biomass, numbers, and densities of fish caught over these years with eight oceanic parameters and with tern reproductive success from all years but 2009, (number of fledglings, number of fledglings per breeding pair, and average clutch size). It should be kept in mind that they analyzed their data from caught fish in the bay, not from what terns actually ate, i.e. not from bill load observations or from fecal pellet analysis. Part 3 also describes whether past years of poor reproductive success in California Least Terns are correlated with a missed timing of fish hatch. The results of this analysis are detailed in Part 3.

Colony Studies: Dropped Fish

Another extra analysis that did not take time away from our main studies was our collection of dropped fish (5 June – 30 July). We opportunistically collected fish that we found , "dropped fish," as we walked to our observation sites, in order to compare fish dropped on the colonies to fish actually consumed by Least Terns. We collected these fish weekly throughout all colonies over all breeding stages, as we walked through each colony. Since we did not know where a bird was going to drop a fish, we could not have a regular collection transect.

We noted date and place of collection per sample, placed them in plastic sealed bags with 10% ethanol, and froze them. At the end of the season, we gave them, still frozen, in a large plastic bag, to the Pondella team at Occidental College for final identification. They graciously identified all samples, *gratis*. They reported fish lengths in general range categories and combined all dates into one analysis.

RESULTS

The results, discussion, and conclusions are based on one year's sampling, and thus can only be considered as preliminary. They may not be reliable for trends.

Bay and Ocean Surveys

Over the entire breeding season, we observed a total of 282 foraging flocks, ranging from 1 to 30 birds, with a median flock size of one, and a mean flock size of 2.2 birds, S.E. = 0.19. The distribution of numbers of birds in flocks is shown in Figure 13, below.

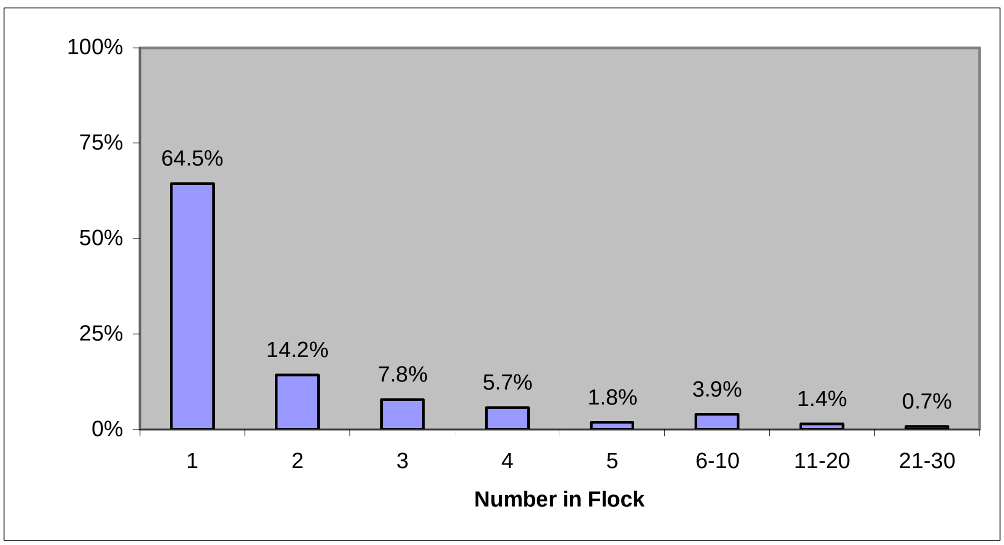


Figure 13. Distribution of numbers of birds per foraging flock, San Diego Bay, 2009, n=282.

The majority of flocks had one bird. Over 92% of flocks had one to four birds. Large flocks were rare. Only one flock (of 25 Least Terns) included Forester's Terns (4 birds). All of the rest were Least Tern-only flocks.

The proportional areas of the different kinds of habitat in San Diego Bay and the Near ocean, represented by habitat polygons, and their proportional use in foraging by California Least Terns are displayed in Figure 14. Ocean habitat is not included in this graph because we did not collect the data there on as regular a schedule as we did in the Bay and Near ocean.

Birds did not forage equally in all areas proportionally to the distribution of habitat types ($\chi^2 = 345.315$, $\nu = 5$, $p < 0.005$). Foraging frequency most closely matched proportions of shore and dock habitat polygons. Our defined habitats that had greater than expected use due to their low abundance were inlets (marinas) and mooring areas.

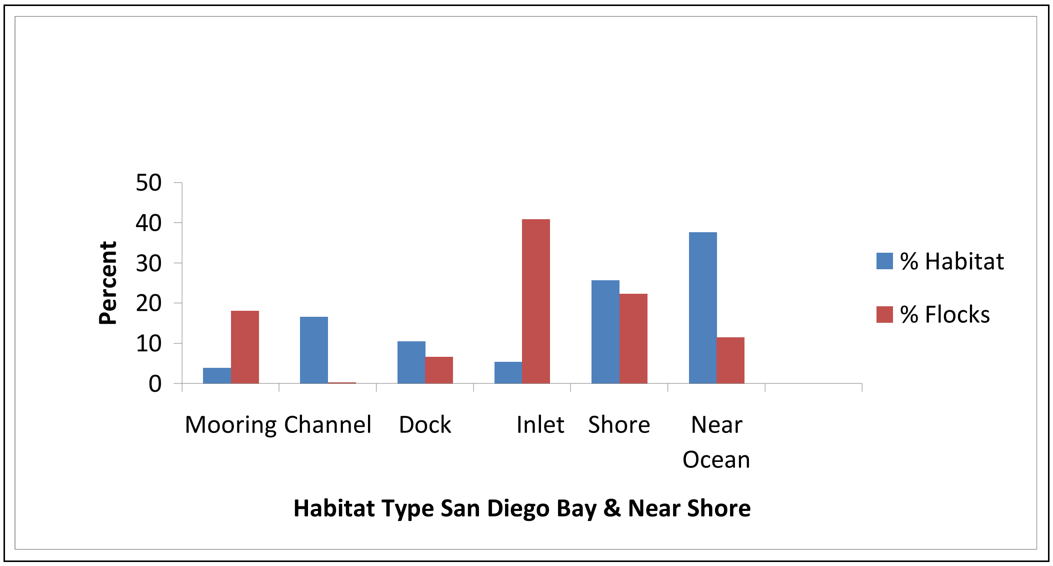


Figure 14. Proportional distribution of habitats, and proportion of feeding flocks seen in these habitats in San Diego Bay and the near ocean environment over the entire breeding period*

* " %Habitat" = of the area birds could forage, what percent does each habitat comprise
"% Flocks" = of all foraging flocks sighted, what percent was seen in each habitat

For finer detail of where flocks occurred, Figures 15- 19 display where every foraging flock was found. Each dot represents a flock, although at the displayed scale, some of the flocks are on top of each other. Different sizes of flocks are in different colors. For ocean bathymetry, see figure 10. These figures cover the entire breeding period.

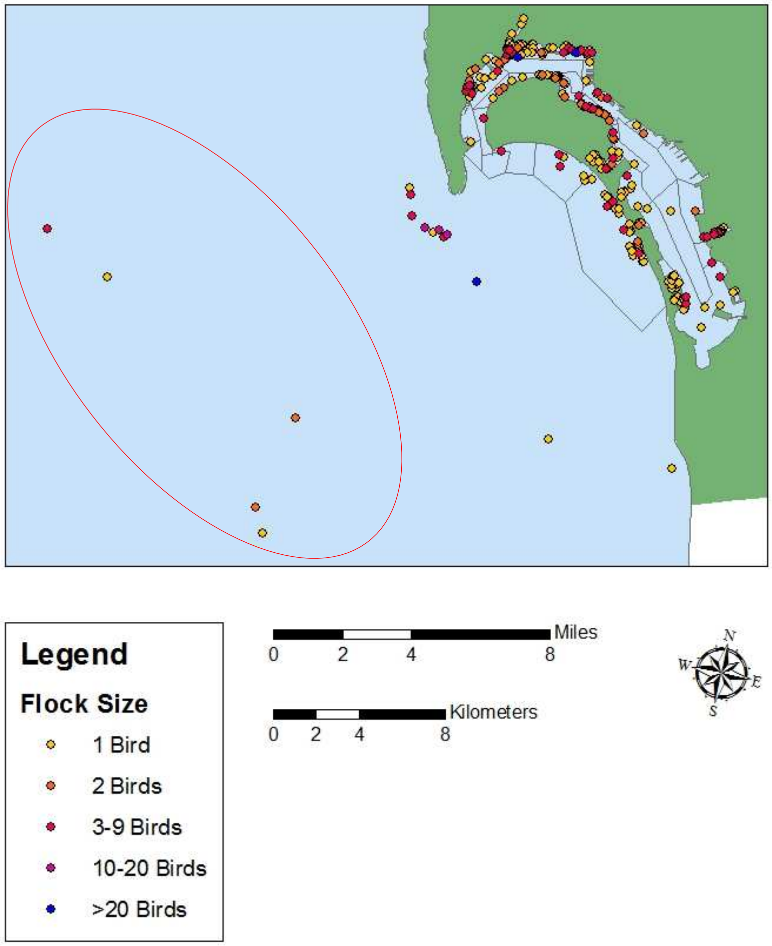


Figure 15. All locations of California Least Tern foraging flocks in nearshore areas of San Diego Bay and the Pacific Ocean, superimposed on to habitat polygons as identified in Figs. 3-9. Narrow solid dark lines represent habitat boundaries (see Figs. 3-9), and the red line is the approximate location of pelagic upwelling areas: Nine Mile escarpment and the Coronado Canyon. Flocks are displayed for 7 May – 30 July 2009 for all habitat types. More birds than are displayed were seen flying over pelagic areas, but these are not depicted, for we only recorded diving, not searching, birds.

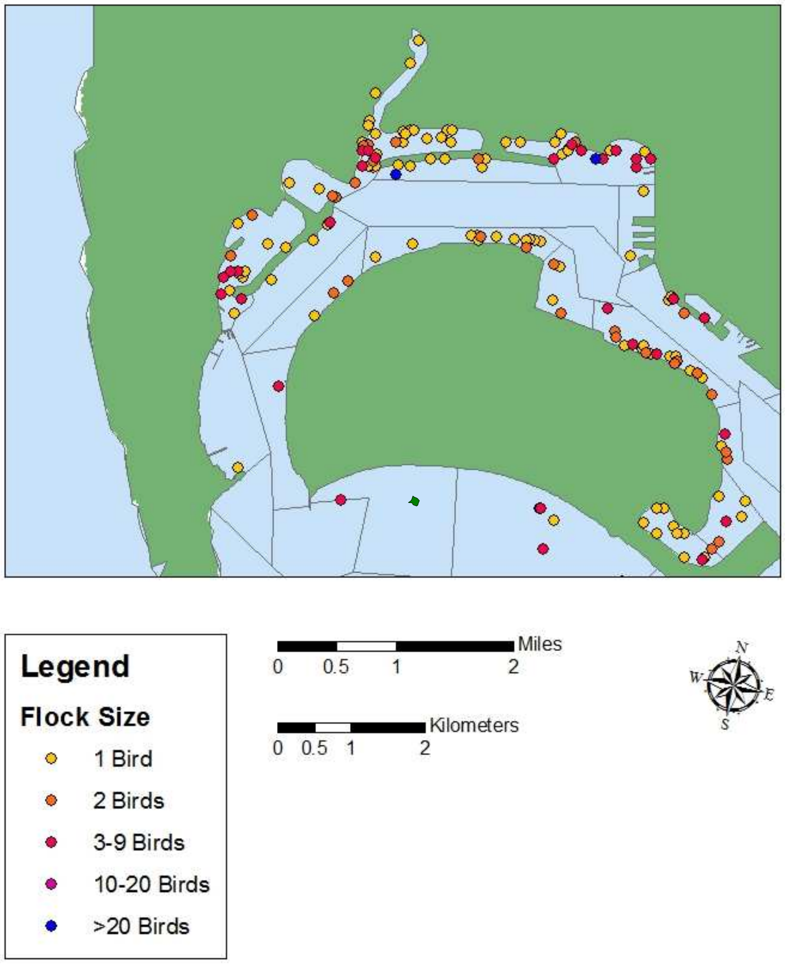


Figure 16. Locations of California Least Tern foraging flocks in North San Diego Bay , superimposed on to habitat polygons as identified in Figs. 3-9. Narrow solid dark lines represent habitat boundaries (see Figs. 3-9). Flocks are displayed for 7 May – 30 July 2009 for all habitat types.

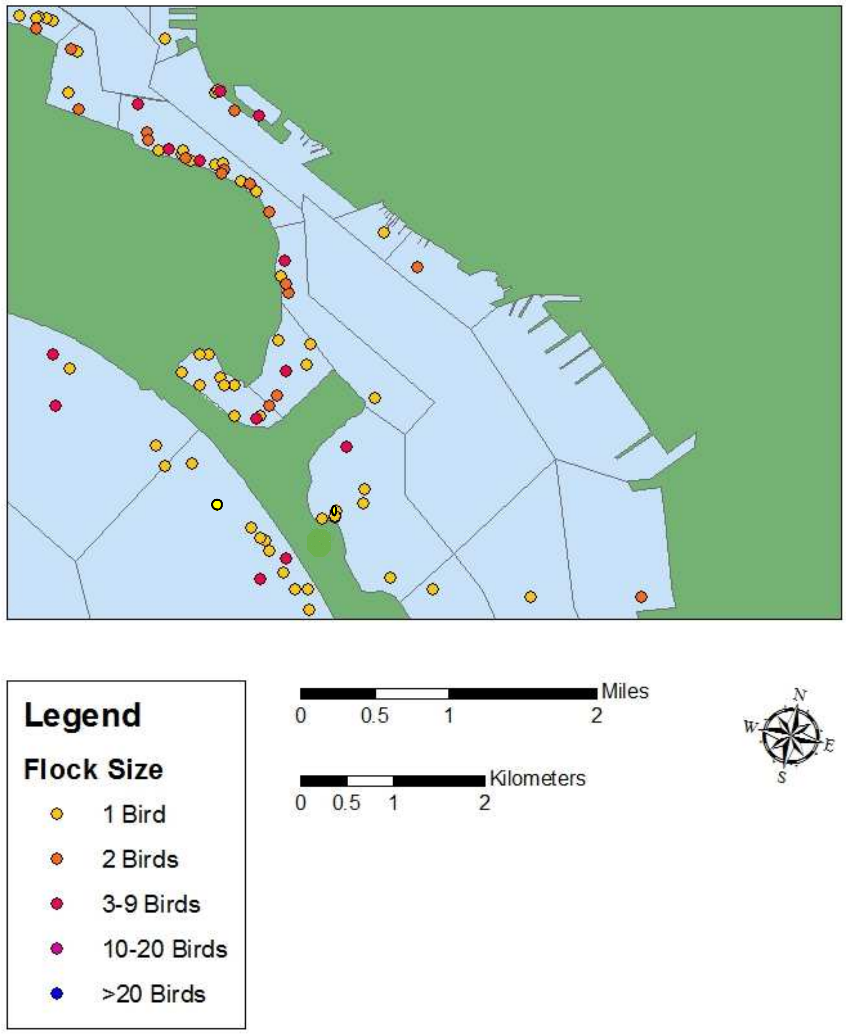


Figure 17. Locations of California east tern foraging flocks in Mid San Diego Bay , superimposed on to habitat polygon as identified in Figs. 3-9. Narrow solid dark lines represent habitat boundaries (see Figs. 3-9). Flocks are displayed for 7 May – 30 July 2009 for all habitat types.

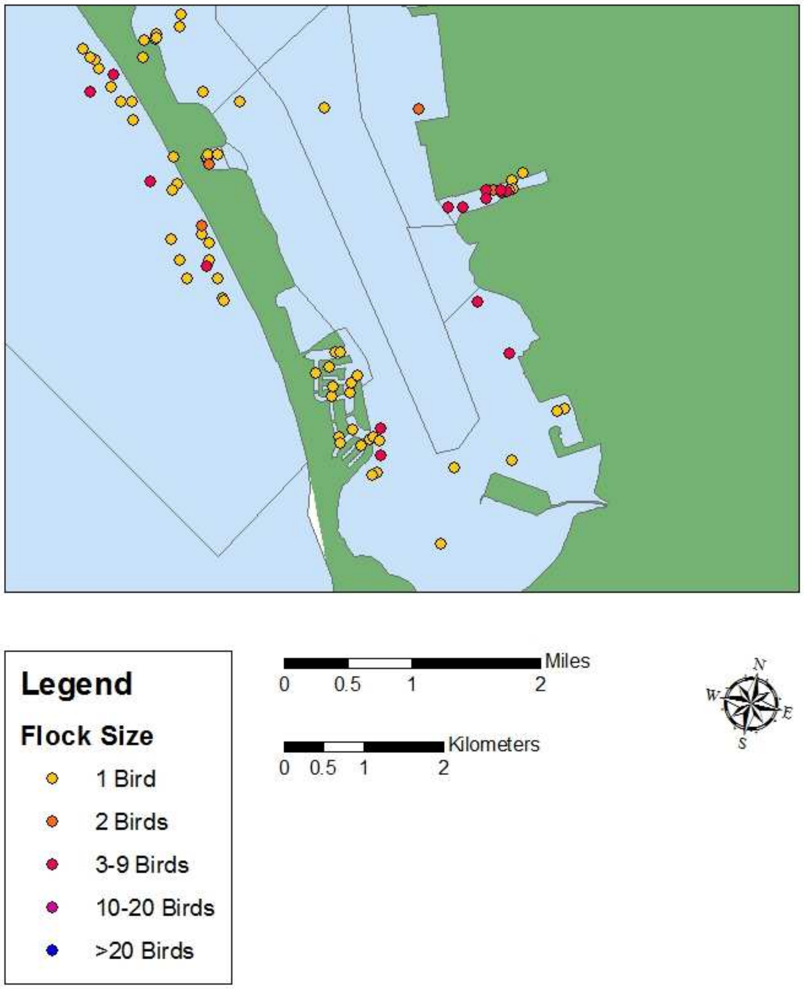


Figure 18. Locations of California Least Tern foraging flocks in South San Diego Bay. Narrow solid dark lines represent habitat boundaries (see Figs. 3-9). Flocks are displayed for 7 May – 30 July 2009 for all habitat types.

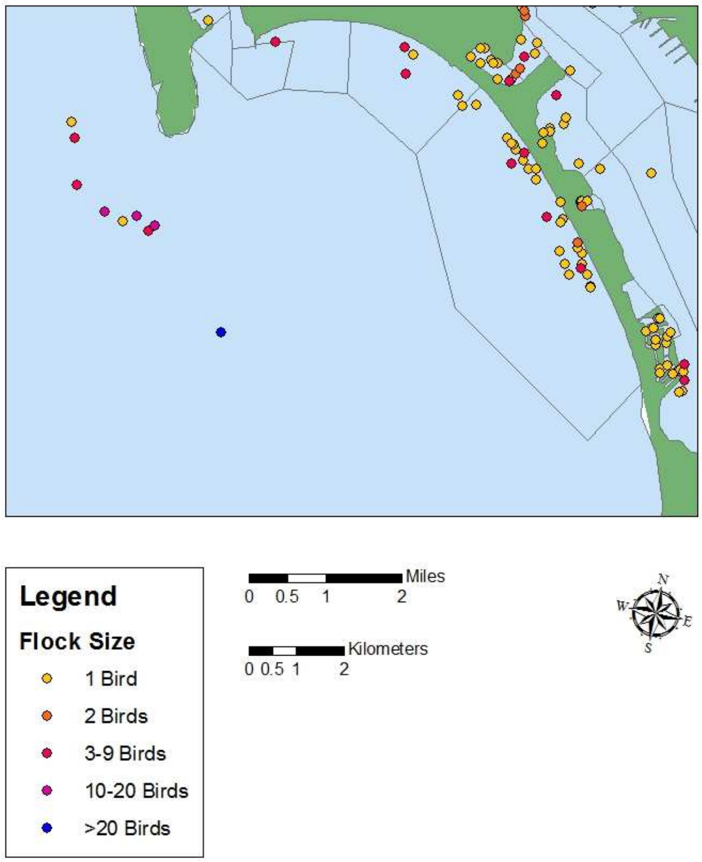


Figure 19. Locations of California Least Tern foraging flocks in nearshore areas of San Diego Bay and the Pacific Ocean, superimposed on to habitat polygon as identified in Figs. 3-9. Narrow solid dark lines represent habitat boundaries (see Figs. 3-9) . Flocks are displayed for 7 May – 30 July 2009 for all habitat types.

Figures 20-22, display the use of habitats at different breeding stages. As in the previous maps, the total number of foraging flocks shown in pelagic areas cannot be compared to the number in the flocks shown in the Bay and Near ocean because we did not survey this area as frequently.

During the Egg stage (9 May – 1 June), foraging flocks concentrated at areas near the colonies, in the western and northern shoreline, and in inlets/marinas and moorings in the south bay. Several foraging flocks were in the kelp beds just off of Point Loma. During the Chick stage (2-24 June), more foraging activity occurred on the east side of the colonies in the bay and in sheltered bays and inlets. During the Fledge Stage (25 June – 31 July), the near ocean was used frequently as well as Shelter and Harbor Island marinas and inlets. However, mass colony abandonment by adults due to depredation by gull-billed terns, curtailed a survey of the entire fledge stage.

It was clear that during the pelagic trips we were seeing breeding birds, for we saw terns heading towards the colonies with prey.

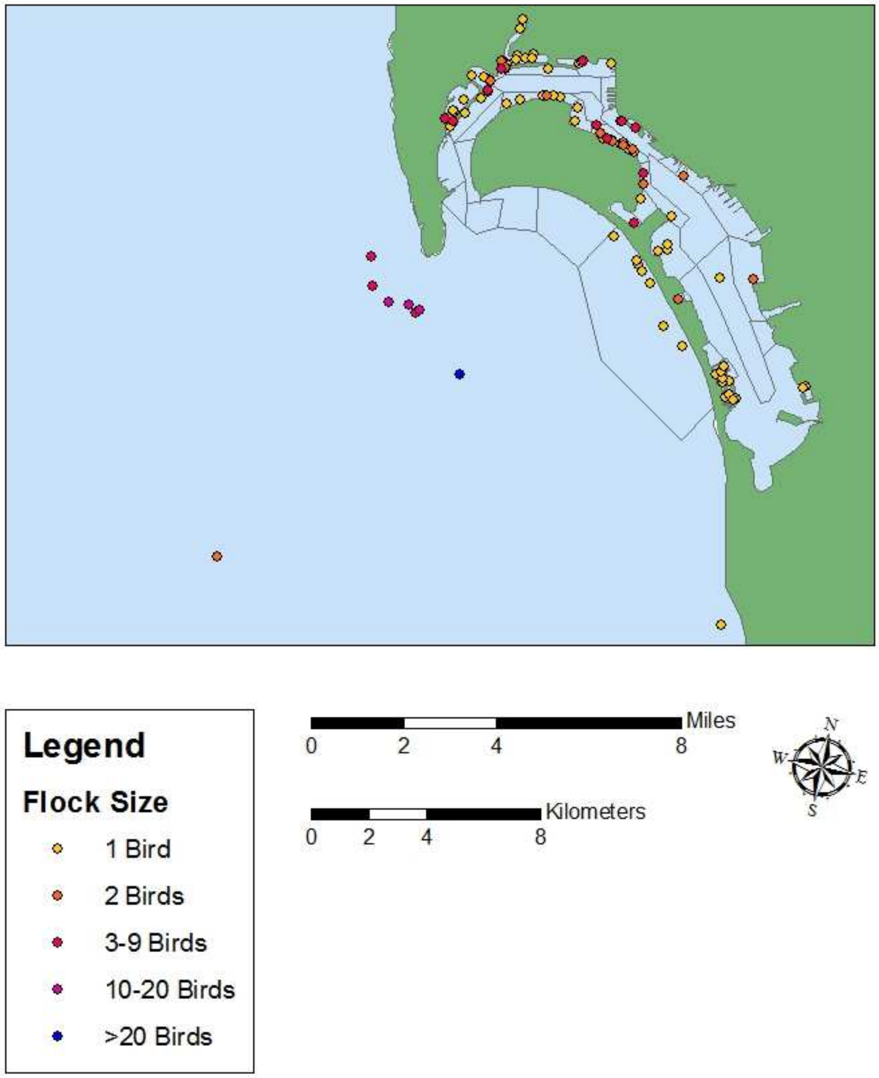


Figure 20 Foraging locations during the Egg stage (9 May – 1 June).

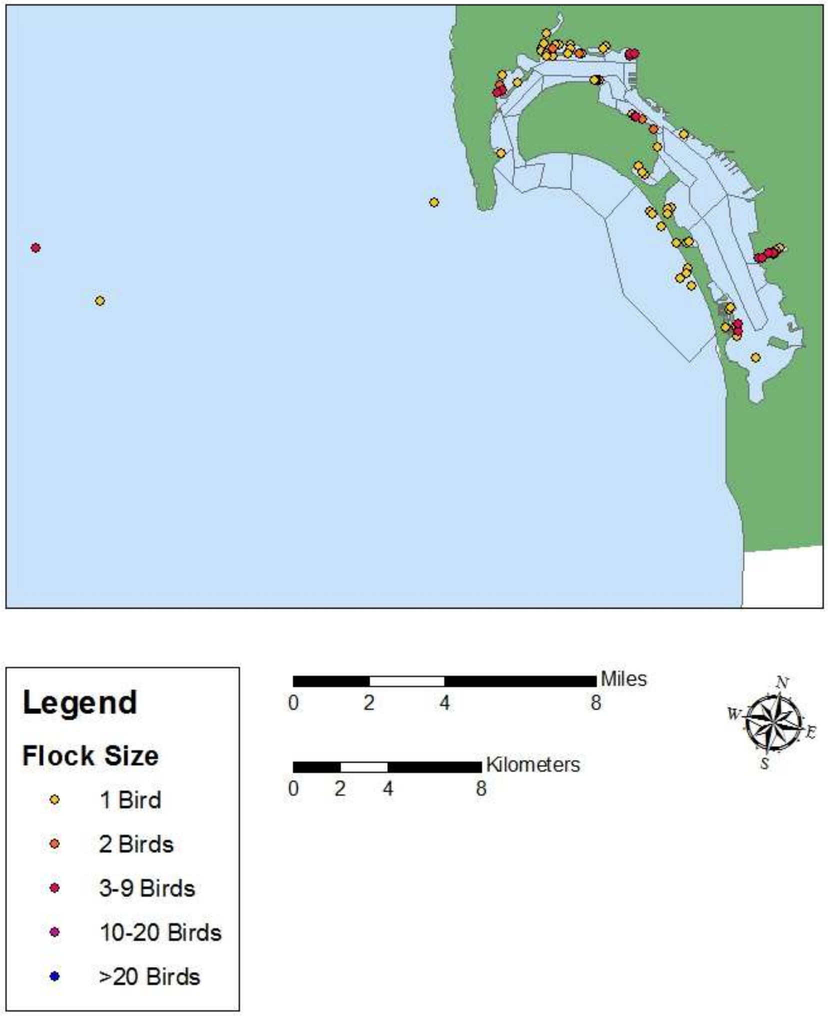


Figure 21 Foraging locations during the Chick stage (2-24 June).

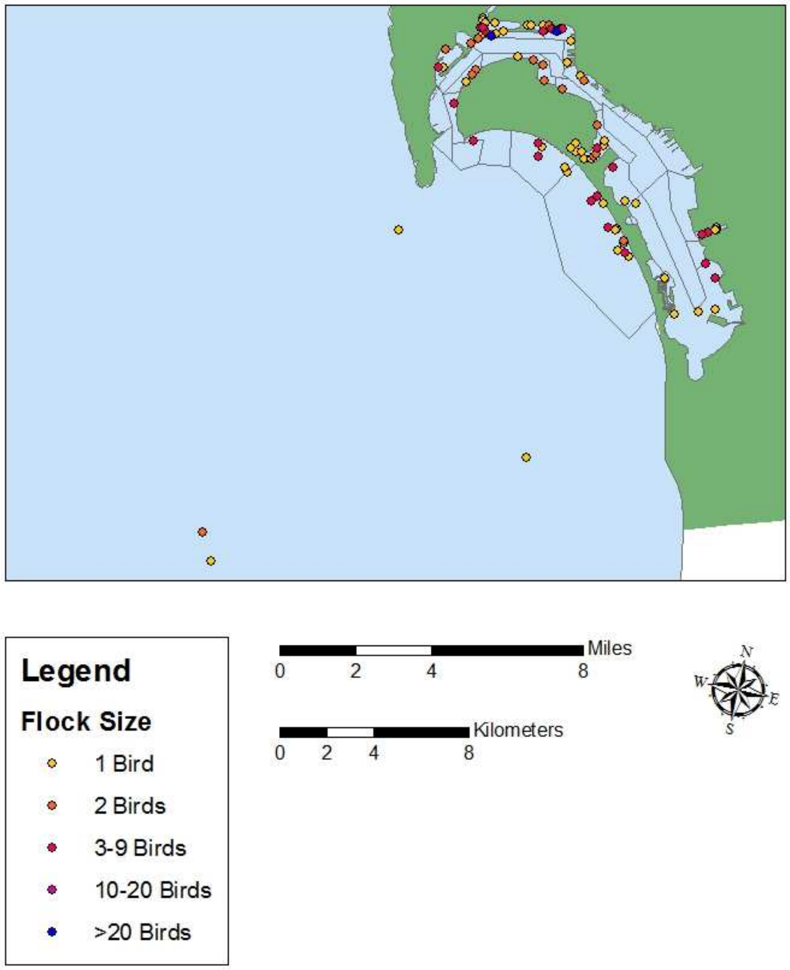


Figure 22 Foraging locations during the Fledge Stage (25 June – 31 July)

Colony Surveys

I. Vector Studies

Throughout the entire breeding period, birds from each colony did not forage equally throughout the bay and ocean, and preferred particular sectors of the available foraging area, (Figures 23– 31) Over all breeding stages, birds returned from the bay 57.5% of the time, and from the ocean, 42.5% of the time.

The following figures depict the percent of returning birds carrying fish, projected onto a compass rose, divided into 20 degree arcs, with their colonies in the center, and show likely foraging areas. The solid colors filling in the arcs represent the percent of birds returning with fish in their bills from that direction.

Each colony differed in which areas were used the most. A Chi Square Analysis revealed that foraging birds did not fly into the colonies from all directions with the same frequency (Delta Beaches $\chi^2 = 95.683$, $\nu = 17$, p = ~0.0000, MAT site $\chi^2 = 91.592$, $\nu = 17$, p = ~ 0.000, NABO, $\chi^2 = 63.414$, $\nu = 17$, p =~ 0.000).

Delta Beaches

During the egg stage at the Delta Beaches (9 May to 1 June), approximately 13% of the birds returned from southeast and east off the colony, (140-180 degrees), and 58.7 % returned from 200-340 degrees out from the colony center, an area that includes the nearshore and ocean, and could include Glorietta Bay, and the marinas near Shelter Island (Fig. 23).

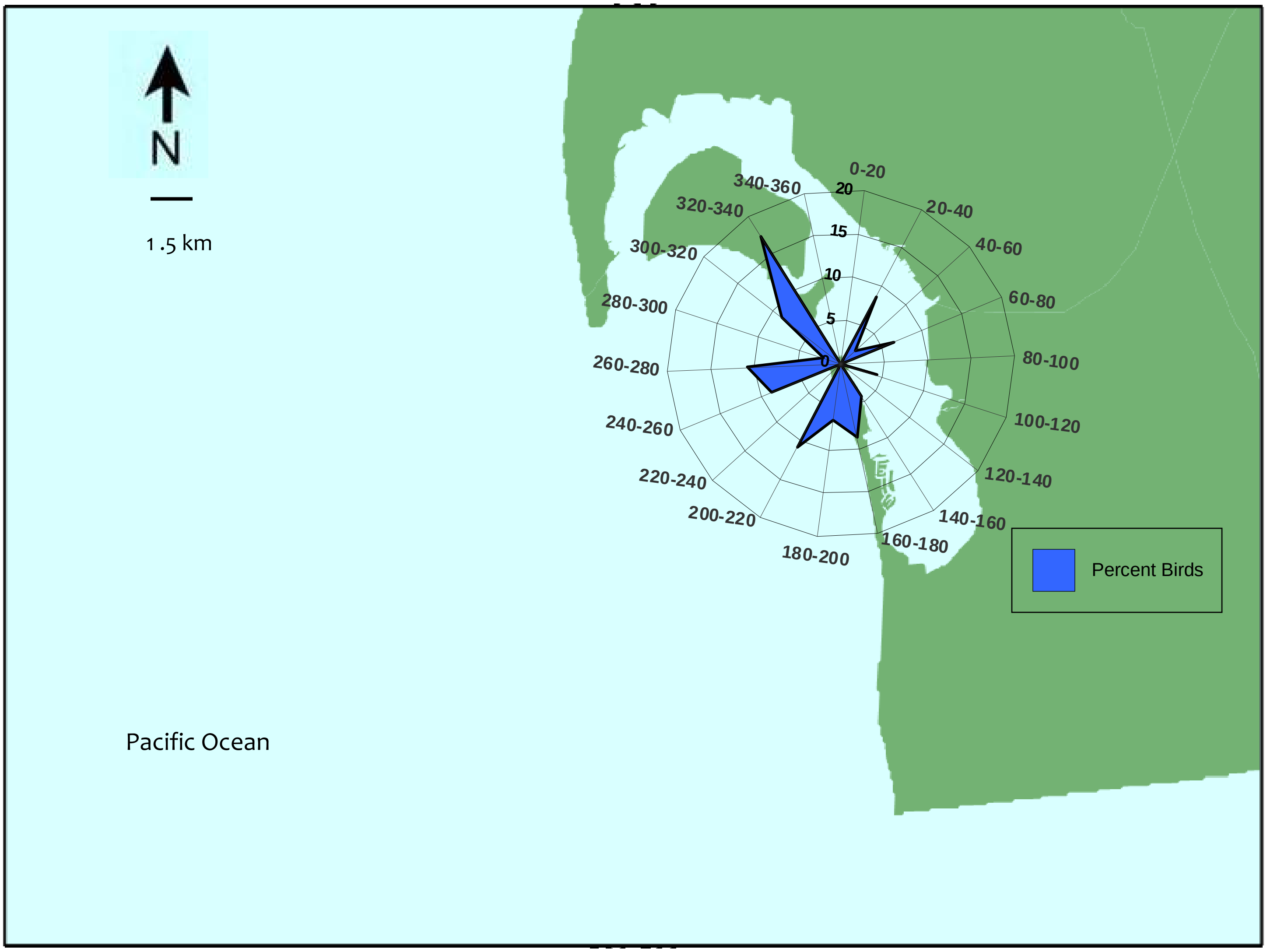


Figure 23. Directions of return of adult terns with fish to Delta Beaches, Egg stage, 9 May – 1 June 2009 (n=-46). Concentric inner circles represent percentages. Magnetic north is at zero degrees

During the chick stage (2-24 June), 35 % of the birds with fish returned from 200-360 degrees, the nearshore, ocean, and Glorietta Bay foraging areas; 50 % returned with fish from waters just east of their colonies, (20-120 degrees, Figure 24).

Figure 24. Directions of return of adult terns with fish to the Delta Beaches, chick stage, 2 June – 24 June, 2009 (n = 203). Concentric inner circles represent percentages. Magnetic north is at zero degrees.

During the Fledge stage (25 June – 31 July), 58.8 % of the birds with fish returned from the nearshore and ocean and mooring areas just north of the colonies, (200-360 degrees), and 21.9 % returned from waters just off of their colonies in San Diego Bay, (20-80 degrees Figure 25).

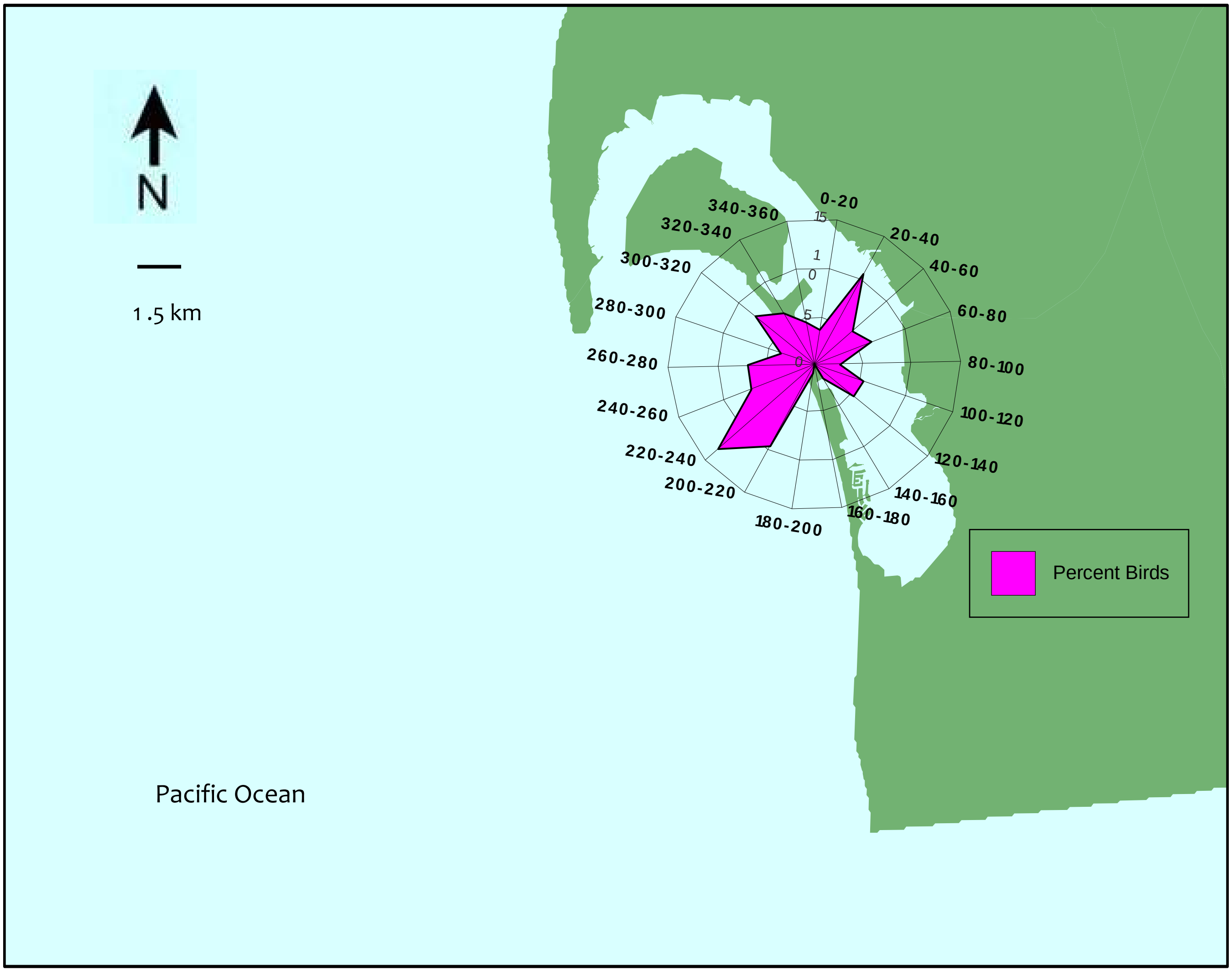


Figure 25. Directions of return of adult terns with fish to the Delta Beaches, Fledge Stage, 25 June –31 July, 2009 (n=114). Concentric inner circles represent percentages. Magnetic north is at zero degrees.

<u>NABO colony</u>

During the Egg stage, 28.6 % of the birds from the NABO colony returned from the area just southwest of the Delta Beach colonies, including the near ocean, (120-200 degrees), and 39.3 % returned from 240-360 degrees, which could represent the near-ocean areas, and the marinas near Shelter Island, Figure 26.

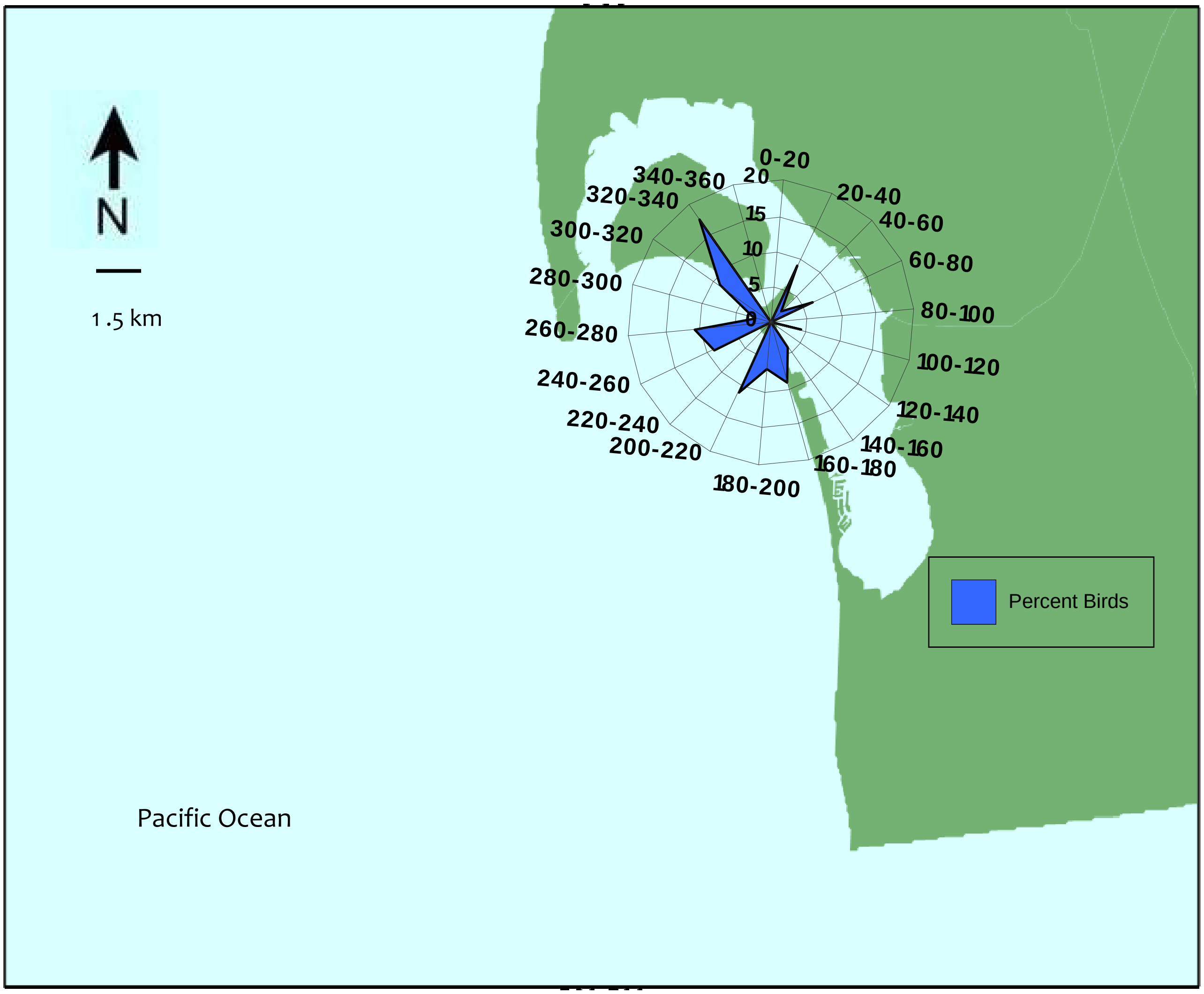


Figure 26. Directions of return of adult terns with fish to the NABO, Egg stage, 9 May – 1 June, 2009 (n=42). Concentric inner circles represent percentages. Magnetic north is at zero degrees.

During the Chick stage at NABO, 75.9 % of the birds returned from 160 to 300 degrees, which could be both the near ocean and pelagic areas, Figure 27.

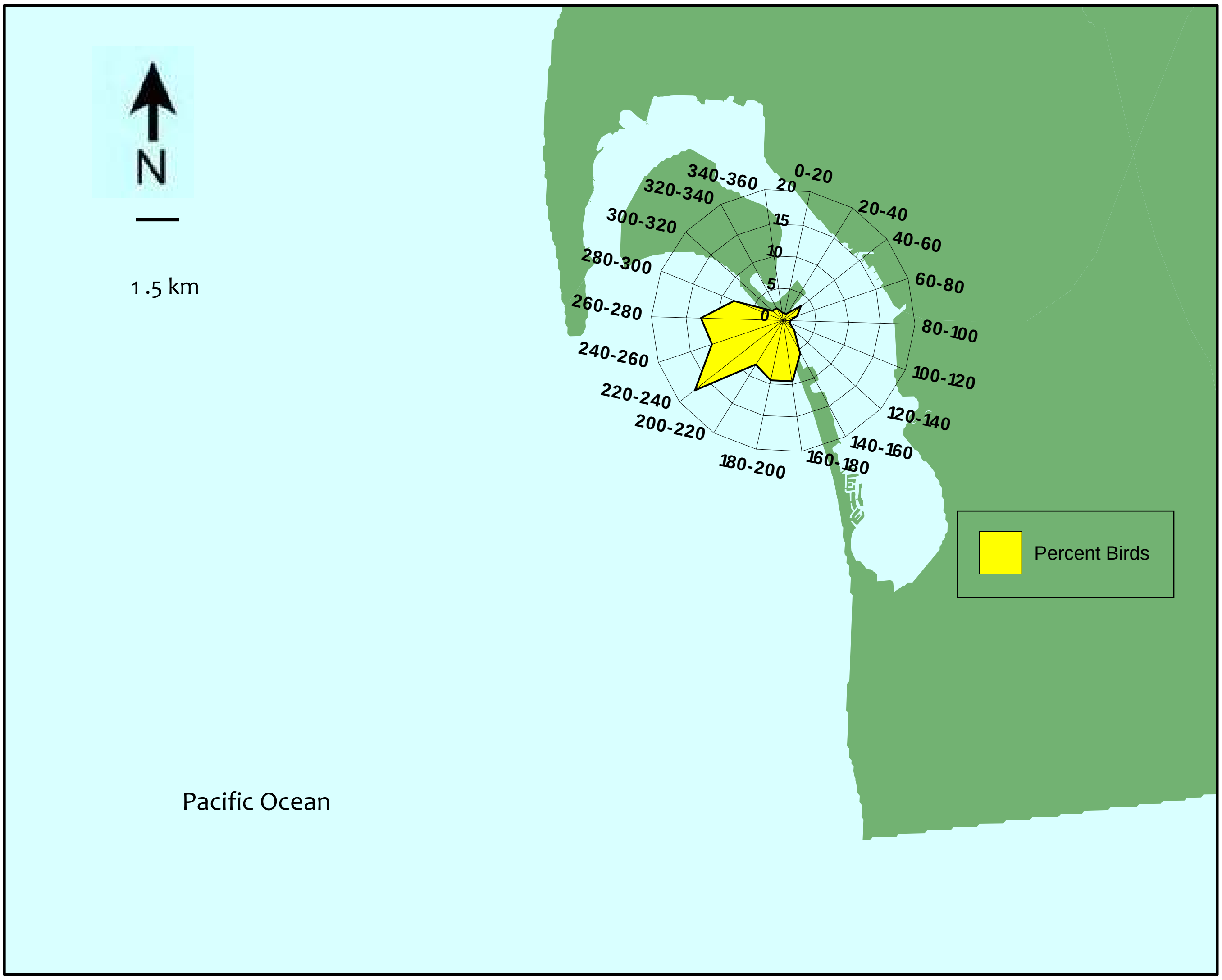


Figure 27. Directions of return of adult terns with fish to the NABO, chick stage, 2 June – 24 June, 2009 (n=87). Concentric inner circles represent percentages. Magnetic north is at zero degrees.

At the NABO colony during the Fledge Stage (25 June-31 July), 24.7 % of the birds returned from the areas in San Diego Bay near the Delta Beach colony, (140-200 degrees), and 52.7 % foraged from 220 to 320 degrees, indicating use of both the nearshore and ocean, Figure 28.

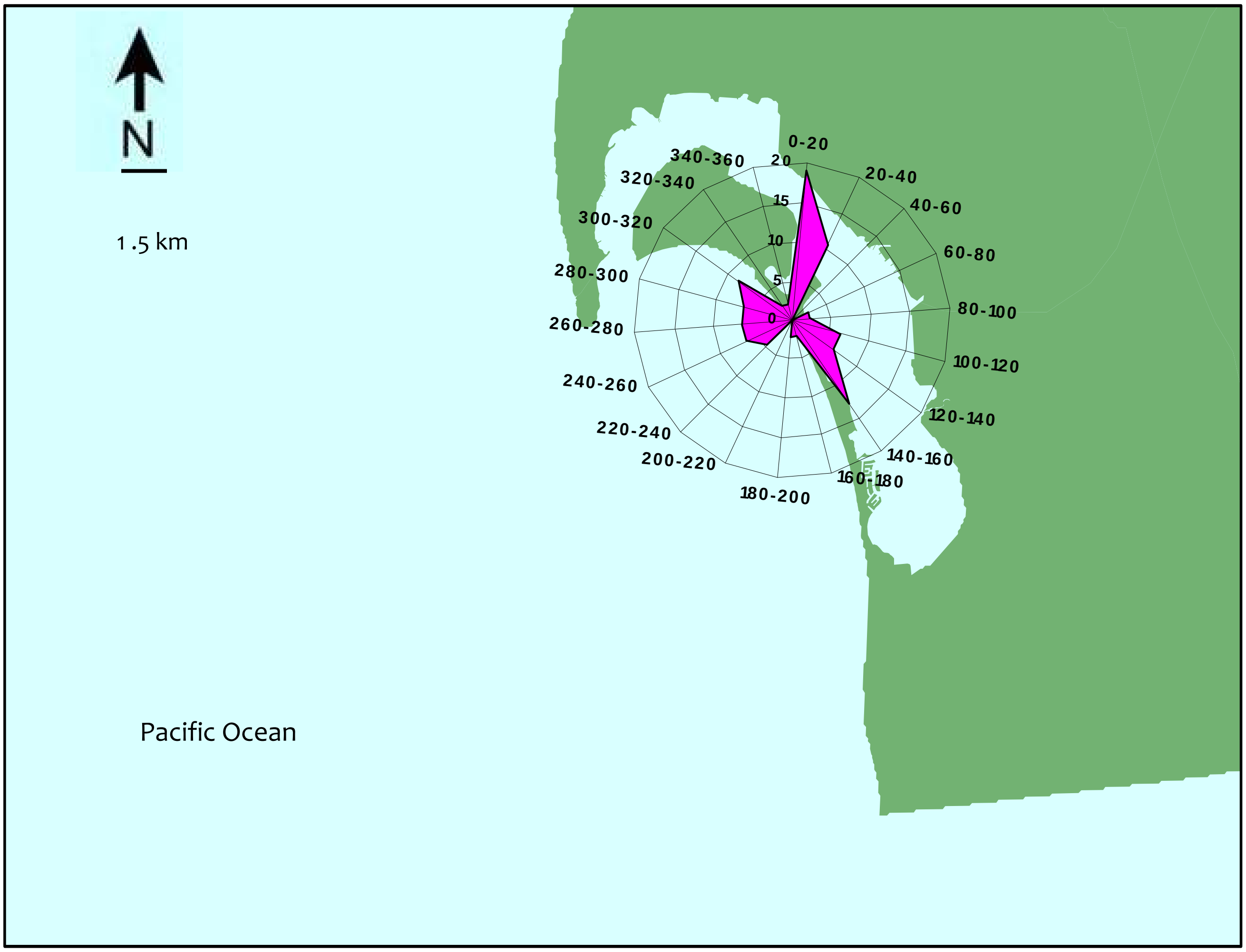


Figure 28. Directions of return of adult terns with fish to the NABO colony during the Fledge stage, 25 June –31 July, 2009 (N=93). Concentric inner circles represent percentages. Magnetic north is at zero degrees.

MAT Site

At the MAT site during the egg stage, (9 May-1 June), 27.27 % of the birds foraged each at 60-100 degrees and 120-160 degrees, indicating returns from the mid-Bay area. The greatest frequency of returning birds from any direction was 45.45 % foraged from the colony, the North Bay area, (from 300-340 degrees, Figure 29).

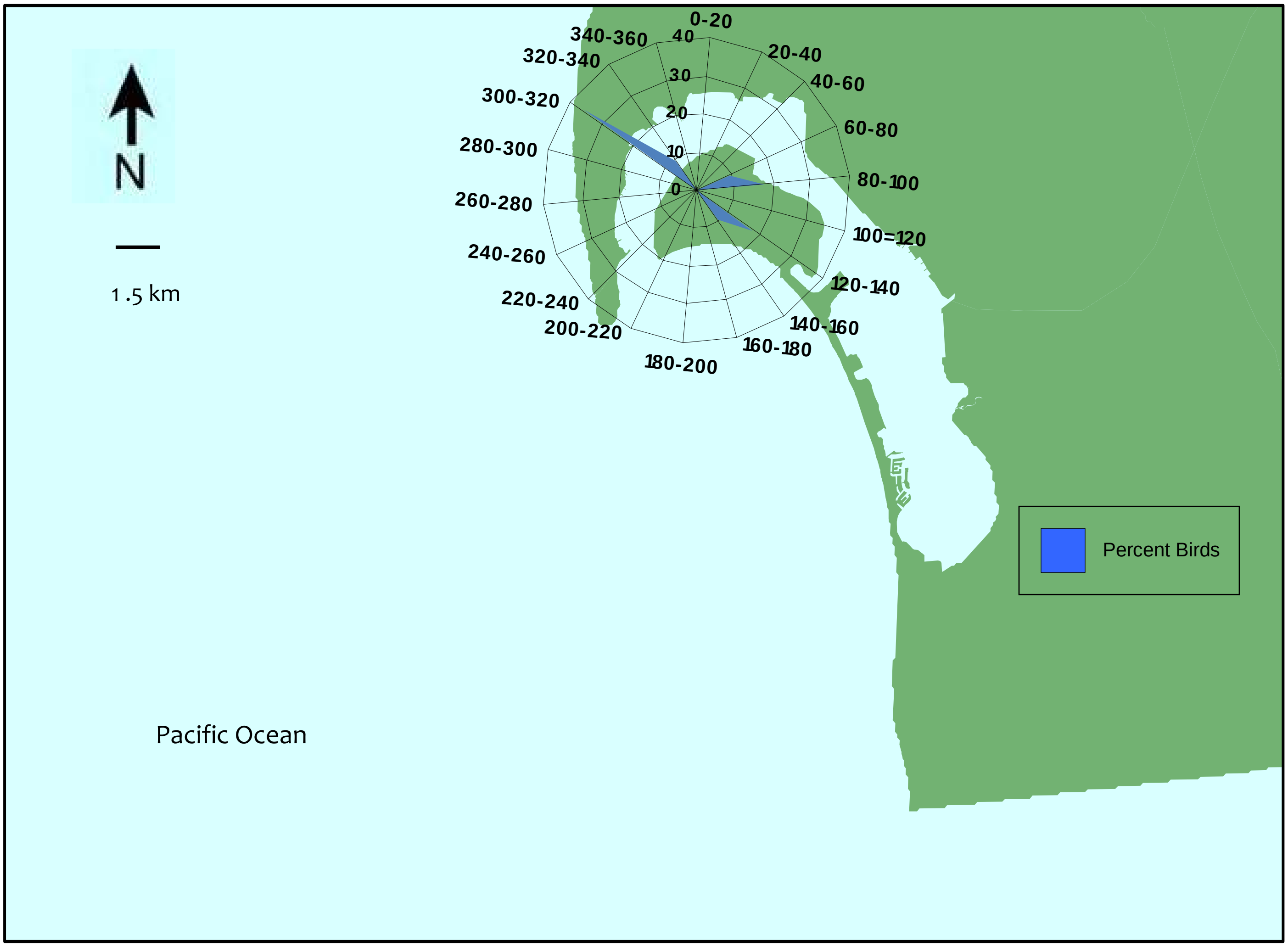


Figure 29. Directions of return of adult terns with fish to the MAT Site, egg stage, 9 May – 1 June, 2009 (n=11). Concentric inner circles represent percentages. Magnetic north is at zero degrees.

At the MAT Site during the c hick stage (2-24 June), over 52.4 % of the birds foraged between 260-340 degrees, along the eastern shore of Point Loma, the west-most shoreline of east North Bay. Only 7.1% foraged in the north bay nearest the marinas on Shelter Island off their colony, (20-40 degrees). A small proportion, 12.7%, foraged from 120-160 degrees, which could indicate nearshore foraging, Figure 30.

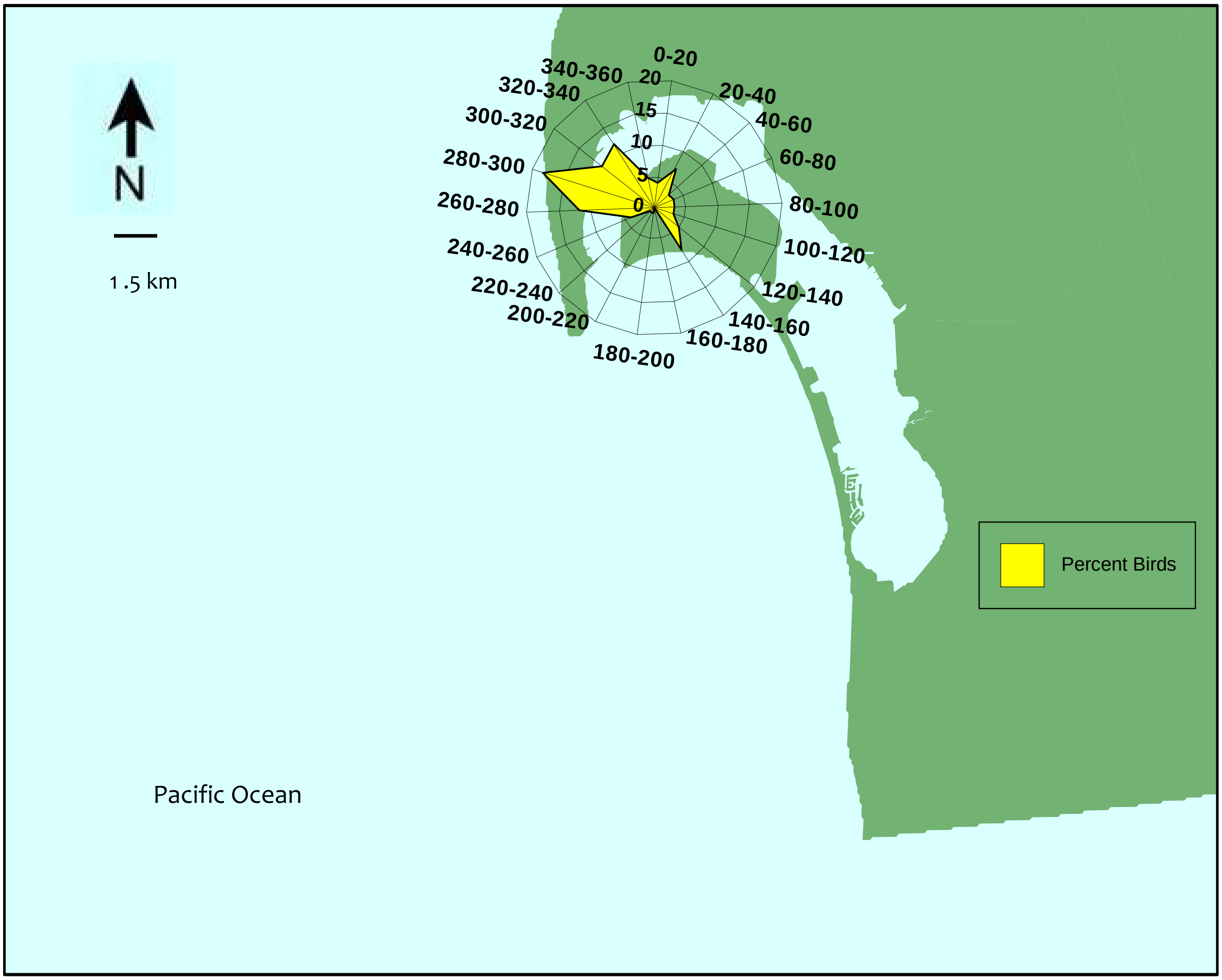


Figure 30. Direction of return of adult terns with fish to the MAT Site, Chick stage, 2 June – 24 June, 2009 (n=126). Concentric inner circles represent percentages. Magnetic north is at zero degrees.

During the fledge stage at the MAT site (26 June-31 July), 29.8 % of the birds foraged an area that might include the mooring and inlet areas of the north Bay, (0-40 degrees). An almost equal proportion, 25.5% foraged in the Mid-Bay, (100-160 degrees), and 27.7% foraged in the North Bay, (240-320 degrees), Figure 31.

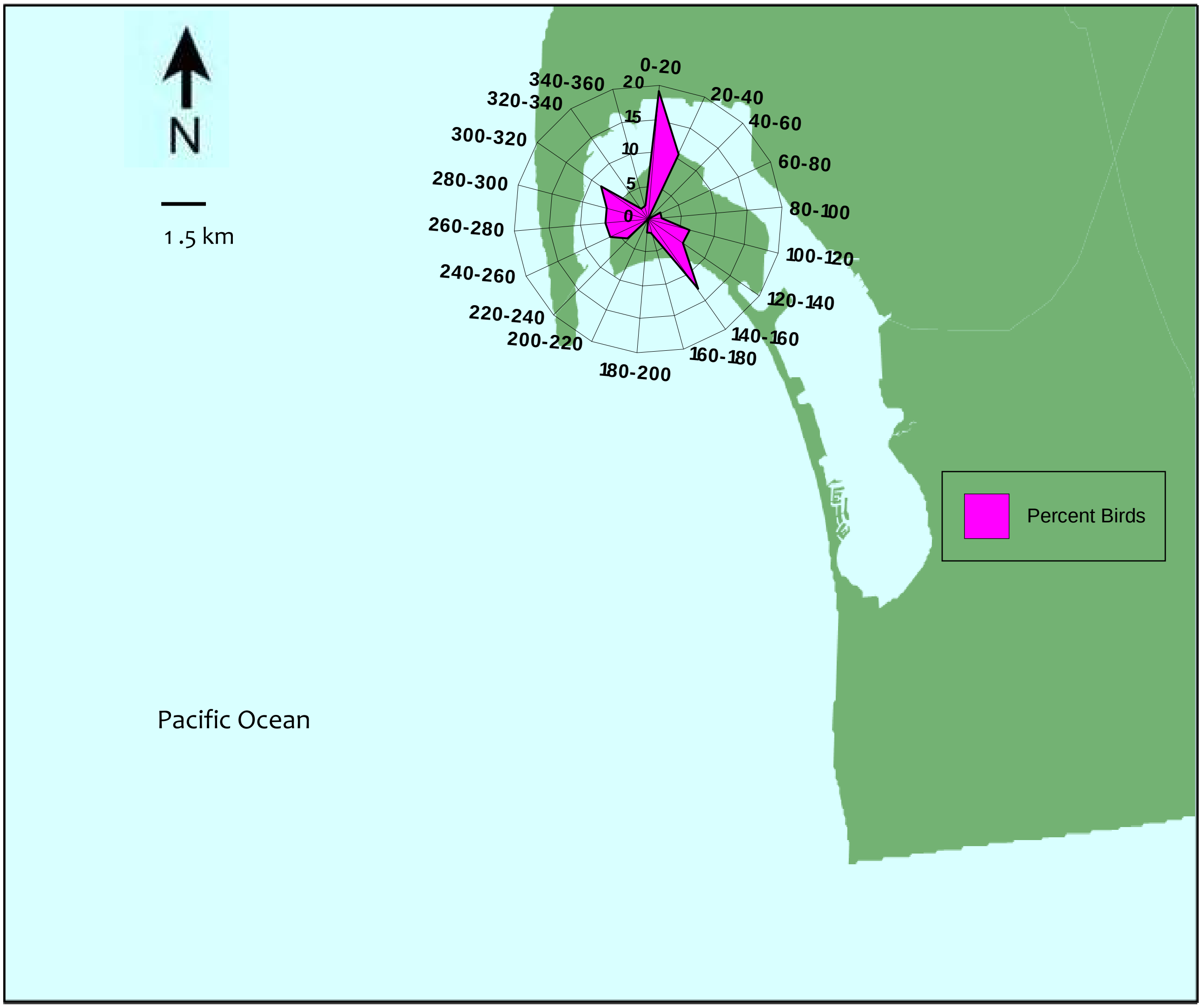


Figure 31. Directions of return of adult terns with fish to the MAT Site, Fledge stage, 25 June –31 July, 2009 (n=47). Concentric inner circles represent percentages. Magnetic north is at zero degrees

Description of foraging flocks over the breeding season.

During the egg stage, foraging flocks were regularly seen adjacent to the colonies, off of the Delta Beach colony in the bay and off the NABO in the nearshore ocean. Near the more inland MAT site, we saw no foraging in areas of the north bay adjacent to the closest land mass off that colony.

In more detail, the most used areas were the entrance to the west basin of Harbor Island, along the north shore near docks, in the Commercial Basin, the Convair Lagoon, City Marina entrance, Coronado Cays boat docks, and Fiddler's Cove. We saw many birds flying in the pelagic area during the egg stage, but observed little diving.

Areas just beyond the breakers in the nearshore ocean, off the NABO colonies, in the moorings and inlets of the marinas like Fiddlers Cove, Glorietta Bay, and Shelter Island were used frequently during the chick stage. These were the same areas where the birds foraged the most in the 1990's (Baird et al. 1997).

During the chick and fledge stages, inlets /marinas, moorings, the nearshore ocean area and areas adjacent to the Delta Beach colonies continued to be areas with high frequency of foraging. The east side of the bayside colonies and the near-shore ocean area began to have a high frequency of use during the chick and fledge stages. Least Terns also continued to forage offshore, up to 24 nautical miles and beyond, but during the chick stage, many foraged nearer to the colonies than they had during the egg stage.

Over all stages, there were few sightings of California Least Terns foraging along the northeast corner of NASNI and on the east side of the Bay between Coronado Bridge and the 7th Street Channel near NAVISTA. Mass colony abandonment by adults due to depredation by gull-billed terns, curtailed a survey of the entire fledge stage.

<u>Other influences on successful prey bouts</u>

Bay vs. Ocean Use

Determining whether a bird has returned from the bay or the ocean, and ignoring exact compass directions, is a way to demonstrate the frequency of use of each of these broad areas. During our on-colony surveys, we found that over both chick and fledge stages, 57.5% of birds with fish arrived from the bay and 42.5% came from the ocean (n=800).

2. *Prey*

<u>Summary</u>

The number of species of prey taken by Least Tern adults and brought back to the colonies were few for both courtship feeding and for food for chicks. We identified to genus 792 fish either fed to another tern or dropped. Of these, we identified all fish fed to either an adult or a chick (244). Data are from 5 June through 30 July.

Anchovies, silverside smelt, and kelpfish represented 84.6% of all adult prey (n=52). Sardines (3.8%) and perch (11.5%) were the other prey species eaten. The most common prey fed to chicks were anchovies and silverside smelt, comprising 75.0% of all prey (n=192).

Anchovies (most likely slough anchovies, *Anchoa delicatissima,* because they are the most common anchovy in and around San Diego Bay, and because they live near the surface) were identifiable by a very flexible structure, bright silver coloration, slender body, and an unusually large lower jaw with a protruding snout. Northern Anchovy (*Engraulis mordax*) and deepbody anchovies (*Anchoa compressa*) are not common in San Diego Bay, although Northern Anchovies are common in the near ocean surf zone (Moyle and Cech 1996). Northern Anchovies also have a nocturnal vertical migration to the surface; otherwise they remain in deeper waters and are less available to the daytime plunge-diving Least Terns (Love 1991). Sardines (likely *Sardinops sagax*), were similar in size and shape to anchovies, but with a noticeable blue coloration and a slightly thicker body. Kelpfish (most likely the Giant Kelpfish, *Heterostichus rostratus,* the most common kelpfish in San Diego Bay) were recognizable by their bright orange coloration, unusually shaped tail and a slender, almost transparent, body. Perch, (family Embiotocidae), have a conspicuous round flat shape, which makes them much wider than any of the other species. The two most common species in San Diego Bay are shiner surfperch (*Cymatogaster aggregat,)* and black surfperch (*Embiotoca jacksoni*). The shiner surfperch is bright orange and silver and also thinner than the black surfperch, which is a duller orange, red, gray, green, or various shades of brown, and which is noticeably wider. The most common species of fish identified in all bill loads was the silverside smelt (most likely topsmelt *Atherinops affinus,* the most available silverside for Least Terns). Silversides were the smallest of the fish identified, and were easily identified by their rigid, slender, and silver body. Topsmelt live near the surface during the day and occur from the surface down to 2.075 m (6.808 feet) (www.Fishbase.org). Jacksmelt tend to be lower in the water column, from 1.44 – 14.4 m (5 to 50 ft) below the surface (Love 1991).

<u>Bill Loads Chick and Fledge Stages</u>

Adult prey--Overall

We compared adults' prey to determine if there was a preference in prey types, via a Chi Square test. Adults consumed prey species disproportionally (Figure 32), with silverside, anchovy, and kelpfish making up 84.6% of all prey taken, (χ^2 = 16.951, ν= 4, p = 0.005). These were fish either consumed in courtship feeding, or eaten by the delivering adult.

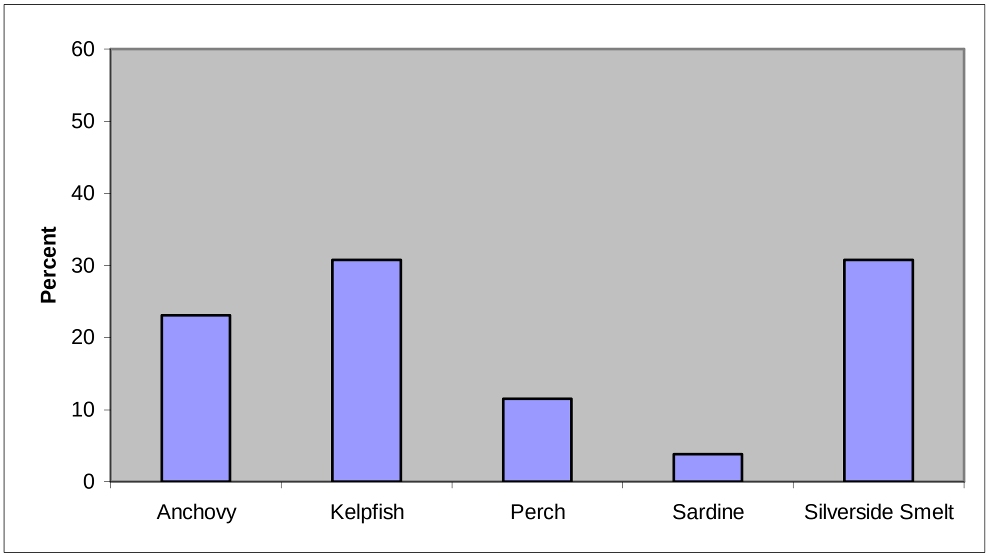


Figure 32. Proportions of fish prey eaten by adult Least Terns over chick and fledge stages, 2009 (n=52)*
* *includes self-feeding*

Adult Prey--By Breeding Stage

We then compared adults' prey types across the breeding stages via a Chi Square test to determine if prey species were captured in different proportions at each stage. There was a significant difference in the proportions of prey types delivered during the chick and fledge stages, $\chi^2 = 22.761$, $\nu = 8$, $p = .0037$, (Fig. 33).

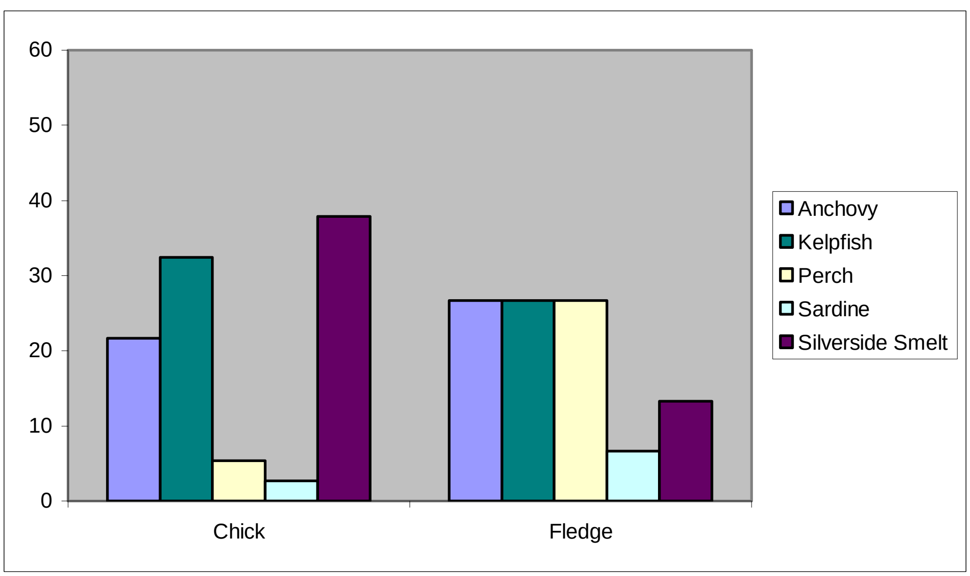


Figure 33. Proportion of fish prey eaten by adult Least Terns over each stage, 2009 (n= 37 chick, n= 15 fledge)*
* *includes self-feeding; chick stage=2-24 June; fledge stage=25 June-31 July*

Chick prey--Overall

We compared chicks' prey via a Chi Square test. Chicks were also fed the same prey genera as adults ate, but in different proportions (Fig. 34). Two genera, anchovy and silverside smelt, made up the majority of prey, 75.0%, (χ^2 = 68.375, ν= 9, p < 0.0001).

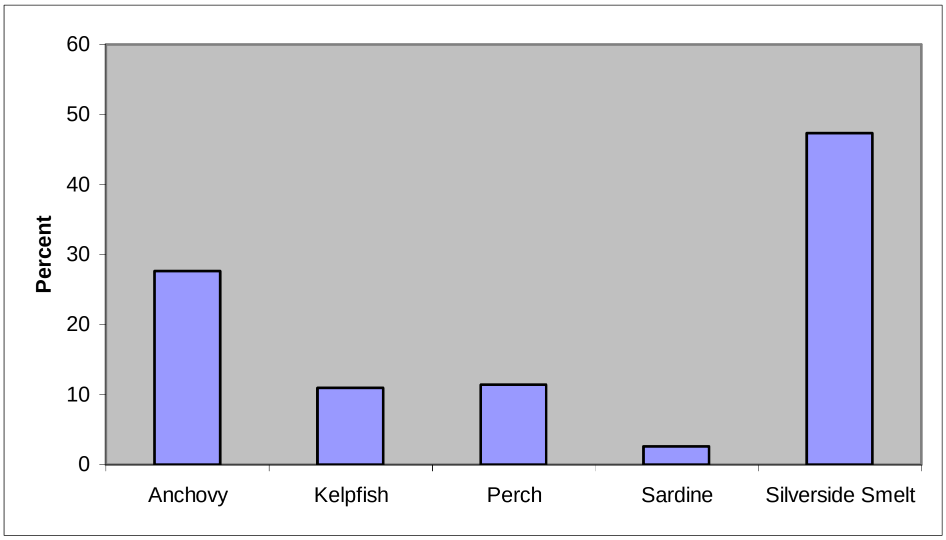


Figure 34. Proportions of fish prey fed to chicks by Least Tern adults over chick and fledge stages, 2009 (n = 192)

Chick Prey--By Breeding Stage

There was no difference in proportions of prey genera fed to chicks over both the chick and fledge stages in 2009, (Chi Square test χ^2 = 7.147, ν= 4, p = 0.128) , (Fig. 35).

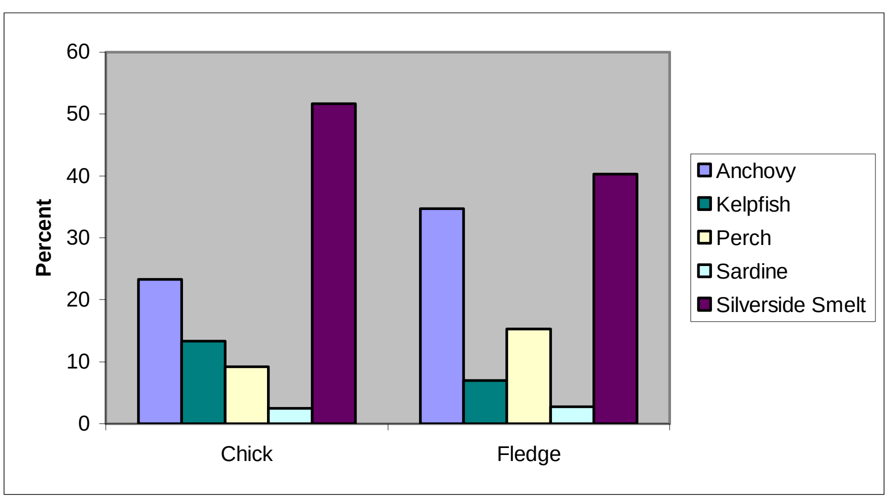


Figure 35. Proportion of fish prey fed to chicks over each stage, 2009 (n=120 chick, n= 72 fledge)*
* chick = 2-24 June; fledge= 25 June-31 July

Chicks vs. Adults—Prey Types

A Mann-Whitney U test on arcsine-transformed proportions showed no significant difference ($Z = -0.252$, $p = 0.80$, $\nu = 8$) between prey genera consumed by adults and chicks over the entire season.

Chicks vs. Adults—Prey Size

A Mann-Whitney U test showed a significant difference between the lengths of prey of chicks and adults, ($Z = -5.346$, $p < 0.001$, $\nu = 30$). Adults consumed fish that were of a greater length, but in the same age class as the fish they fed their chicks, Age Class Zero, young of the year fish, (Figure 36). Median length of fish for chicks was 26.0 mm, and for adults, it was 32.5 mm. Range of fish lengths for chicks was 13 - 52 mm, and for adults was 13 – 78 mm. There was only one 78 mm fish, a sardine, eaten by the providing bird. Eliminating that outlier, the largest mean prey eaten by adults was 65 mm. Mean fish length for chicks was 26.67 mm $\pm$ 0.667 mm, similar to the median. Mean fish length of adults was 33.8 mm $\pm$ 0.497.

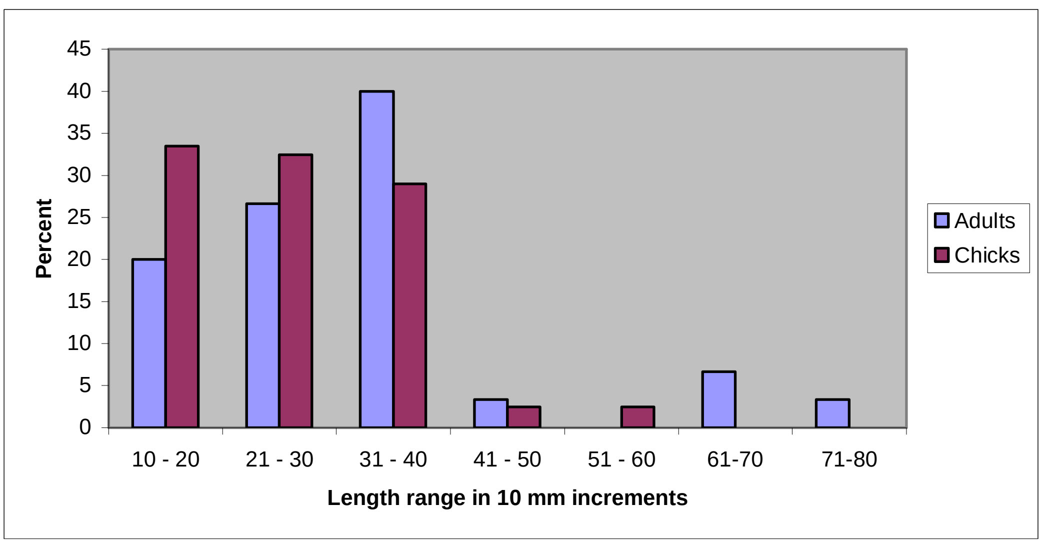


Figure 36. Percent frequency of fish lengths of prey consumed by Least Tern adults (n=52) and chicks (N=192), 2009*
* includes unidentified fish, but not unknown recipient

Tables 1 and 2 compare mean, standard error, and median for known fish species fed to adults and chicks. Where no standard error or median is listed, the sample size is one. The median is the most important value to compare when assessing different species.

Table 1. Lengths of fish eaten by adults, displayed by species

Species	Mean (mm)	S.E.	Median (mm)
Anchovy	34.36	2.337	39.7
Giant Kelpfish	32.5	3.578	29.25
Perch	45.5	--	--
Sardine	78.0	--	--
Silverside	30.88	5.859	26.08

Table 2. Lengths of fish fed to chicks, displayed by species.

Species	Mean (mm)	S.E.	Median (mm)
Anchovy	31.4	1.047	39.0
Giant Kelpfish	26.0	1.418	26.0
Perch	30.02	1.306	32.5
Sardine	31.2	6.302	32.5
Silverside	22.68	0.997	19.5

Dropped Fish

Figure 37 displays the large variety of dropped fish on the colonies. Dropped fish differed significantly in both genus and size from prey delivered to adults or chicks in 2009, (Chi Square = 68.26, $\nu = 18$, $p < 0.001$). Although some of the prey in dropped fish samples were of the same genus as consumed fish, the proportions were very different. Shiner perch and topsmelt dominated. Shiner perch are deep-bodied fish and may be too deep for a tern to swallow, and thus are dominant in the dropped numbers. Topsmelt are one of the most common fish in San Diego Bay, so it is not surprising that their numbers were also high.

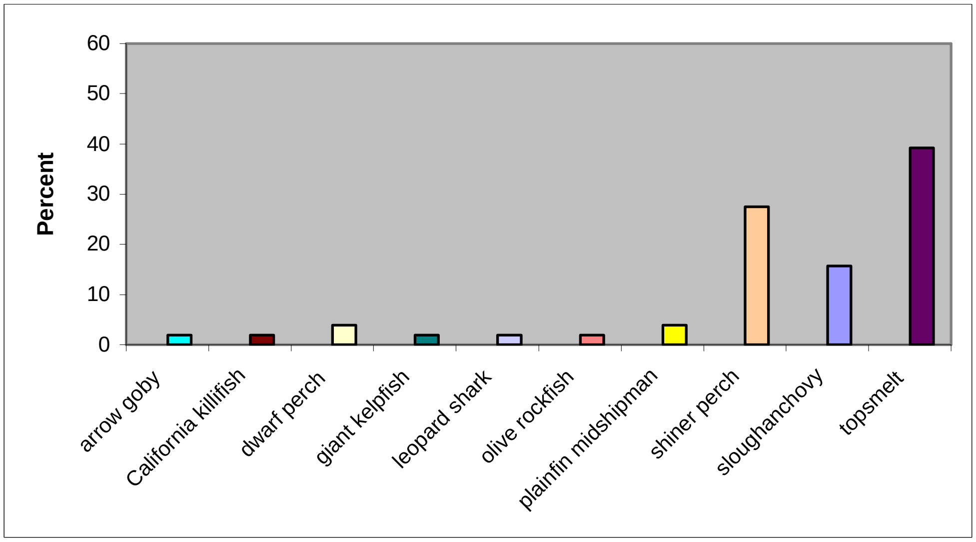


Figure 37. Proportions of dropped fish species found on Least Tern colonies, all stages, 2009 (n=49).

Figure 38 displays types of dropped fish by breeding stage. Over all breeding stages there was no difference in proportions of observed and expected dropped fish genera found on the colonies, Chi-square = 25.876, $\nu = 18$, $p > 0.05$.

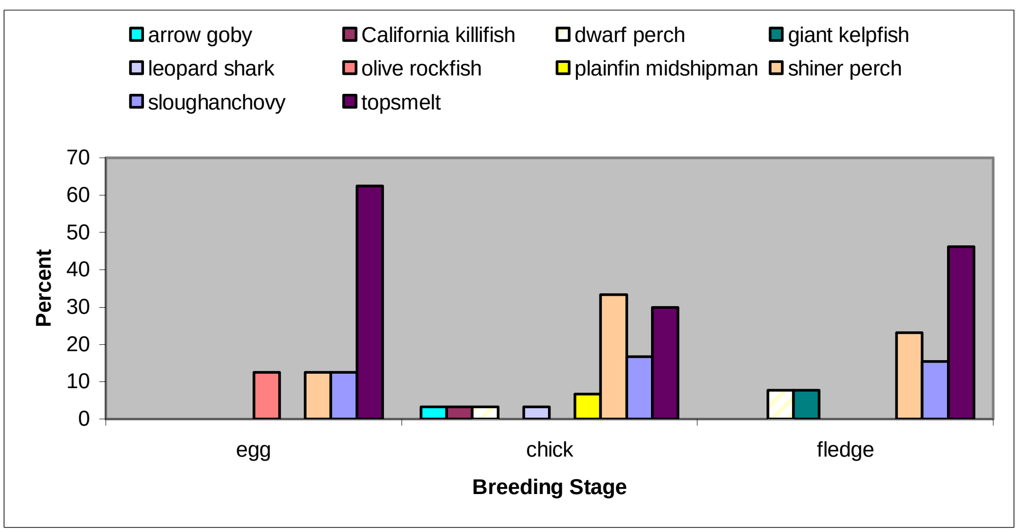


Figure 38. Proportions of dropped fish found on Least Tern colonies, by breeding stage, 2009.

The Pondella lab summarized length data for dropped fish qualitatively (Table 3), and thus we cannot compare mean prey lengths for bill loads exactly to lengths of consumed fish. Even with only qualitative data, it is clear that dropped fish were of different size classes from consumed fish, and these varied considerably: some smaller, and one much larger. These lengths do not match the frequency distribution of prey consumed by Least Tern adults and chicks.

Table 3. Length categories of dropped fish 2009 (This table directly from Pondella lab, Occidental College)

Species	< 10 mm	15 mm	20 mm	25 mm	30 mm	300 mm
Midshipmen (2)	X					
Topsmelt (“some”)	X					
Killifish					X	
Topsmelt (“rest of”)			X			
Perches (all juveniles)					X	
Goby (recently settled)		X				
Olive rockfish (juvenile)				X		
Anchovies (juvenile or subadult)				X		
Leopard shark (juvenile)						x

Fecal Samples--2008

These fecal samples are from the year prior to our study. Part 2 describes these results and discusses their significance. They have no relationship to bill load prey from 2009, and can only be compared with fecal samples for 2009 to detect any changes in prey.

Fecal Samples—2009

These data, to compare with, and validate, the 2009 bill load data for prey genera and size, have not yet been analyzed due to lack of funding. These data will be compared to fecal samples in 2008 once funding is approved. They are in storage at California State University Long Beach.

Colormarking and banding

We trapped birds as a training demonstration in preparation for colormarking. However, we were never able to mark birds with dye. We abandoned this part of the project because of heavy disturbance of the colony from depredation by Gull-billed Terns on Least Tern eggs and chicks. We banded the two birds that we trapped in this training exercise, with USGS metal bands and three color bands, the combination of which is unique for each bird. Results of banding data, submitted to the USGS Bird Banding Laboratory for the two birds that we banded, are in Appendix II.

Fish found in San Diego Bay—Refer to Part 3.

DISCUSSION

The way that marine predators forage and distribute themselves with respect to the environment depends on the distribution, abundance and predictability of prey (Bell 1991). Foraging strategies of seabirds are easy to study because seabirds are large and conspicuous predators and can be studied via boats or from their colonies during the breeding period. Our study addressed these strategies.

Bay and Ocean Surveys, including Pelagic Surveys in general

California Least Terns did not forage equally in all areas throughout San Diego Bay, the near ocean, or the pelagic area. Foraging frequency was not proportional to amount of type of foraging habitat. Their preferred foraging areas over all breeding stages. were inlets /marinas and mooring areas, especially the marinas in North San Diego Bay Although these areas made up a small part of San Diego Bay, Least Terns foraged more in them than would be expected by chance. There are many docks and boats in these areas, under which prey can hide or escape from aerial predators, and it is likely that many forage fish would live here. The area is shallow, and has more light for plankton growth than do areas where ships dock, or channels. An abundance of plankton in turn could attract more fish and therefore, more birds.

Terns foraged along the docks and shorelines in the same proportions as would be expected based on the amount of this habitat available to them. The only habitat they seemed to avoid was the channel area. These areas, in contrast, are deeper than most of the others in the bay.

The near ocean area was also heavily used, but because it is so big, its proportion diluted the apparent use of this habitat by terns. The Point Loma kelp beds off of Point Loma were used frequently during courtship displays, over all stages. Fish tend to hide in kelp beds (Moyle and Cech 1996), and these are also platforms for Least Terns to roost.

Pelagic areas > 400 m offshore, were used daily by Least Terns. This is the first documentation via systematic surveys of pelagic foraging of California Least Terns during the breeding season from San Diego Bay colonies. We only recorded birds diving, not searching for prey. We observed, but did not count, many birds flying over the pelagic area on our survey tracks, and it was clear that they were in the area to forage. We can therefore assume that the pelagic area probably had a greater number of foraging flocks than is depicted on the maps.

Our survey tracks ceased at 24 km offshore, over the upwelling areas at Nine Mile Escarpment and Coronado Canyon, but we continued to see terns flying westward from this farthest point of observation. Because the pelagic area is so vast, we most likely underestimated the number of foraging flocks present on any survey day.

The total number of foraging flocks shown in pelagic areas also cannot be compared to the number in the flocks shown in the bay and near ocean because we did not survey the pelagic area as frequently as we did the bay and near-shore areas. The number of foraging flocks is most likely an underestimate of the actual number of foraging flocks that we would have found pelagically, had we surveyed this area at the same frequency as we did the bay.

This is similar to how other seabirds forage. For example, albatrosses spend more time foraging farther from the colony during incubation than during the chick stage, when their energy requirement was highest, and some boobies adjust their foraging strategy to cope with changing prey stocks (Davoren 2003, Weimerskirch 2005a,b). Searching behavior is influenced by subsurface predators that chase prey to the surface (Weimerskirch 2005a).

Colony Studies in general

Land-based surveys of the number of birds returning from the bay vs. ocean indicate use of foraging areas; boat surveys are good for pinpointing exactly where birds forage. The downside of boat surveys is that observers are always in motion, as are the terns and their prey, and foraging flock activity can be missed. Vector surveys indicate most likely foraging areas, but the exact foraging location of returning birds is not known.

Ideally, data loggers would be the best method to determine where Least Terns forage. Their downside is that the bird has to be trapped twice, and the only approved method for trapping Least Terns is when they are on the nest. Data loggers then would only record foraging during the egg stage. Data loggers are costly, and thus the sample size of tagged terns would probably be low, and if the data varied a lot, not much could be said as to trends.

Colony Studies--Vectors

Data from our land-based vector observations on the colonies matched well the data from our sightings of foraging flocks on boat surveys, and thus can be used as an indicator of the general areas where Least Terns forage. They depicted a foraging area, in 20 degree increments, of the general habitat areas where the birds foraged.

In San Diego Bay tern colonies, information on direction that adults with fish return to the colony can be used as a predictor for breeding success, based on studies from the 1990s (Baird et al. 1997). In two successful years (1993, 1996), (>50% fledge success), 57% of Delta Beach birds returned from the near-ocean and pelagic directions (220-260 degrees). In this successful year, 12.5% each returned from foraging adjacent to the Delta Beach colonies and from the direction of the city mooring areas (0-60 and 320-360 degrees respectively), (Baird et al. 1997).

In two unsuccessful years (1994, 1995) , 47.3-49.0% of the birds returned from foraging in San Diego Bay near the colonies (0-60 degrees), and 10.3- 15.5% returned from the direction of the turning basin and city mooring areas, (320-360 degrees), (Baird et al. 1997). During these two years, only 17.3% to 22.3% returned with fish from the near-ocean and ocean areas (200-260 degrees).

Seabird foraging behavior and area may indicate prey type (Elliott et al. 2008). Prey like northern anchovy, for example, are present in the ocean, and not in the bay, and during successful years, they might move in towards land more than in other years (Baird et al. 1997). Likewise, in successful years, perhaps prey fed to chicks may have just the right combination of protein, fat, and carbohydrate, and size to enable chicks to grow faster and fledge successfully (Schreiber and Burger 2002).

Based on frequency of bay or ocean foraging, from observations in the 1990s (Baird et al. 1997), we would predict reproductive success to be high in 2009, if based on foraging area alone, without counting depredation by species like gull-billed terns. However, 2009 was a poor reproductive year because of the heavy depredation by Gull-billed Terns (field notes).

Vectors by breeding stage

<u>Egg stage</u>

Birds foraged in fewer sectors before chicks hatched, meaning that they had a narrow range of foraging areas. Coupled with the boat survey data, it appears, however, that they foraged farther afield in these more narrow foraging areas. We do not know why they had a more restrictive foraging area during the egg stage, but we can hypothesize that this is where the preferred prey were.

Chick stage

During chick-tending, Least Terns foraged more widely. Energy demands of the chicks may force parents to forage more broadly, even with two adults foraging (Balance et al. 1997).

Fledge Stage

The majority of birds with fish at the NABO and Delta Beach colonies returned from the ocean during the fledge stage. This concurs with data from pelagic observations of birds searching for food over the pelagic area on the pelagic and near-shore ocean boat surveys.

On-Colony Studies—Prey

A predictor of reproductive success for Least Terns in San Diego in the 1990s was the type of fish prey held in the bills of incoming birds, and whether or not the birds returned from the ocean or from the bay (Baird et al. 1997). Only fish types and sizes known to be eaten by terns, and not fish caught in fishing gear, can be used as indicators of whether or not chicks will successfully fledge from a colony, if there is indeed a relationship. We could not determine if there were such a relationship from our data in 2009 for two reasons: 1) the data only cover one year; 2) the main cause for fledging failure in 2009 was not lack of preferred food, but rather depredation by Gull-billed Terns.

Bill Loads to Adults

Over the chick and fledge stages, the suite of prey species eaten by courting adults were few: mainly silversides (*Atherinops*), and giant kelpfish (*Heterostichus rostratus*), 61.54% of all prey. Adding anchovies (most likely *Anchoa* spp.), these three genera made up 84.6% of all prey consumed by adults. There was a smaller contribution by sardines *(Sardinops sagax)*, perch (Embiotocidae, probably surfperch, *Cymatogaster aggregata*) or black surfperch (*Embiotoca jacksoni*). In the 1990s, 99% of adult prey were anchovy and silversides (Baird et al. 1997).

This narrow range of prey types was expected, for California Least Terns, like all birds, are limited in the kind of food they can catch and consume by their morphology: body and bill size, wing shape and mass (see Robinette 2002 and Robinette and Baird in review), as well as the depth to which they can dive. Terns likewise can only plunge-dive a maximum of a half a meter, and thus are limited in what they catch to surface prey. Likewise, the diurnal migration of the particular fish species that terns eat place these species in the first meter of the water column during the day when most Least Terns forage.

Their suite of prey differed throughout the breeding season. When adults foraged widely or offshore, (refer to Boat and Vector survey sections), they were exposed to additional prey, besides those limited to bays and estuaries. Perch, kelpfish, and anchovy were taken more frequently during the fledge stage, but the sample size was only 15 fish, so the proportions may not reflect the proportions of what was actually consumed. With this fact in mind, it appears that perch became more dominant in the suite of prey during the fledge stage, and that anchovies decreased. However, a larger sample size is needed to state this definitively.

It is important to note that not all possible forage fishes available in the bay were caught by adults for courtship feeding (refer to Parts 2 & 3 of this report for a list of these fishes). This kind of selective foraging is common in many seabirds (Schreiber and Burger 2002), and that is why only fish species identified from bill loads or from fecal samples should be noted as prey for California Least Terns. Fish caught by fishing gear in the bay or ocean or dropped fish should not be considered prey.

Bill Loads--Chicks

Types of prey consumed by chicks and adults may be restricted by fish and tern morphology. Prey genera of chicks were similar to that of adults, but proportions fed to chicks differed. Only two genera dominated, anchovy and silverside smelt. The dominance of thin species like silversides and anchovies in chick diets may be due to the smaller beaks and overall size of chicks, which limit what they can consume. Adults might be able to eat fish of a larger variety of shapes and sizes than can chicks, with respect to width, rigidity, or length.

Together, anchovies and silversides accounted for 75.0 % of all prey. In the 1990's, anchovy and silverside smelt made up 98-99% of all prey, (Baird et al. 1997). Three other genera in 2009 made up less than 12% each of the prey fed to chicks in 2009: sardines, kelpfish (most likely Giant Kelpfish), and perch. One goby (*Clevelandia ios*), sardines, and one opaleye (*Girella nigricans*) together made up less than 3% of the prey in the 1990's (goby and opaleye were one fish each) over both the chick and fledge stages. Anchovies were fed to chicks in slightly higher proportions in the 1990's than in 2009 (Baird et al. 1997).

The increase in the proportions of fish other than anchovies and silversides between the 1990s and 2009 may in part reflect the regime change in the Pacific Ocean that took place at the end of the 20th century (Kerr 1992, Mantua et al. 1997, Deser et al. 2004).

Prey consumed over breeding stages

Chicks were fed the same proportions of prey genera over both the chick and fledgling stages in 2009 , whereas the proportions of prey species of adults varied over these stages. This lack of difference in chick diet is expected, because tern chicks have small bills, and so they cannot consume as varied shapes and sizes as can adults. Fish grow and fish eggs hatch as the season progresses, and adults are exposed to a variety of shapes and sizes of fish over this time. They are able to be less selective when they feed themselves. Yet, even though chicks grew over the chick and fledge stage, there were many young chicks present during both of these stages due to relaying by adults whose eggs or chicks had been depredated. Small chicks need small, slender fish, so we would expect to observe this kind of morphology of prey fed to chicks during the entire period of observation. Adults forage more widely during the fledge stage and the change in prey type during this time may reflect this behavior.

Once the 2009 fecal samples are analyzed, we will have a better understanding of the terns' foraging on pelagic species, especially northern anchovies. At present, it is possible that both *Engraulis* and *Anchoa* anchovies are combined in our reporting of data. As in the 1990's during the fledge stage (Baird et al. 1997), the proportion of anchovies in the diet for both adults and chicks increased as the proportion of silversides decreased.

Fish caught in San Diego Bay

Part 3 states that California Least Tern reproductive success correlated positively significantly with the abundance of killifish. This correlation has no biological significance (Pondella and Williams this report Part 3), however, and the two variables of reproductive success and abundance of killifish can be considered two independent variables that co-vary. California Least Terns did not bring back any killifish in bill loads in 2009 (this study) or in the 1990s (Baird et al. 1997). Furthermore, killifish were not found in fecal samples in the 1990s. It is not known if killifish were found in the fecal samples of 2009. Thus, even though there is a relationship between these two variables statistically, there is no evidence to state that there is a biological relationship.

Where terns forage and what they eat are the best predictors of reproductive success, barring depredation or abiotic factors like unseasonal wind and rain (Baird et al. 1997) or disease. In contrast to the limited number of genera that terns feed their mates or chicks, the number of available species, "forage fish," of correct size and shape is large (Cross and Allen 1993, Allen et al. 2002). This is expected, because the majority of all seabird species selectively catch fish. Selectivity in foraging is typical of seabirds, and Least Terns are no exception (Ashmole 1968, Ashmole and Ashmole 1967, Croxall and Prince 1980, Balance et al. 1997). Thus, availability or abundance of forage fish does not indicate a food preference, and is not a useful indicator to predict breeding success.

There has been a regime change in the Pacific Ocean, meaning a change in temperature, salinity, flora, and fauna (Kerr 1992, Mantua et al. 1997, Deser et al. 2004), and forage fish from the 1990s differ from those in 2009. Because of this change, predictions of fish available for consumption by Least Terns in 2009 should not use data from the 1990s. Furthermore, even sequential years vary abiotically, and subsequently, the proportions of genera per year can vary. That is why we cannot compare 2008 prey from otoliths with bill load prey from 2009.

Part 3 data for both 2008 and 2009, are pooled from April and July sampling periods, and do not include the important egg (May) and chick (June) breeding stages of the terns. The April period when fish were sampled in the bay is pre-laying, and often terns do not arrive until May, so those data cannot be compared to what Least Terns bring back to the colony during the full breeding season.

Thus, not much can be said about what fish exactly were available to the terns during these two important stages. The types of preferred fish species available for Least Terns can change quite rapidly as the season progresses, as for all seabirds during the breeding season (Schreiber and Burger 2002).

In conclusion, sampling fish via fishing gear gives availability of prey; observations of bill loads and concurrent analysis of otoliths in fecal samples give what Least Terns eat.

<u>Ecological description of prey niches</u>

Silverside smelt are most abundant within 2 km of the southern California coast (Barnett et al. 1984), and thus are readily available as prey to Least Terns. Extrapolating from their known ecology and the habitat preferences of silverside smelt, most silverside smelt eaten by Least Terns were probably topsmelt, which are diurnal schooling surface-dwelling fish in both adult and juvenile stages, commonly found in estuaries, kelp beds, and along sandy beaches (Love 1991). Jacksmelt are schooling pelagic fish as adults, occurring also near shore and in estuaries, bays and kelp beds as adults and juveniles. They are usually not found at the surface, but more commonly between 1.5-15 m (5-50 feet) below the surface (Love 1991). Thus, they would be unavailable to surface-feeding birds like Least Terns.

Jacksmelt likewise are not commonly found in the typical bays and estuaries in southern California (Cross and Allen 1993) and thus the majority of silverside smelt in the bill loads of terns were very likely only topsmelt. Topsmelt are one of the dominant species over soft substrates in bays and estuaries (Horn and Allen 1981 a, b). The otolith analysis from the previous year, 2008, (Part 2) showed no jacksmelt present.

Anchovies, the other main group taken by Least Terns, occur throughout the Southern California Bight (Cross and Allen 1993). The slough anchovy is a very common species in these estuaries and the backwaters of bays (Miller and Lea 1972). Juveniles and young of the year of this species are usually more common in bays than those of northern anchovies (northern anchovies are abundant schooling fish, occurring from the surface to as deep as 300 m, 1000 feet, as adults, Love 1991). They spawn in sandy surf (Cannon 1970). Adult northern anchovies school from the surf zone out to almost 500 km (300 mi), although most remain within 160 km (100 mi) of shore (Love 1991). The northern anchovy was the dominant fish by an order of magnitude from 1951 to 1985 in the California Current and the entire Southern California Bight within 100 km of the coast (Cross and Allen 1993) before major changes in ocean temperature at the end of the 20th century.

There is a high probability, that the of slough anchovy, was the species that the Least Terns were eating, because of their behavior. Slough anchovies become dispersed during the night; in the morning, they congregate at the surface, and during the day they start to descend the water column (Love 1991) . This behavior pattern matches our observations of Least Terns foraging more in early morning hours than during the remainder of the day.

Other studies on fish in areas other than San Diego Bay show that biomass of fish available to Least Terns are usually highest in the spring and summer months, due largely to heavy recruitment of juvenile surfperches, topsmelt, and northern anchovies, (Allen et al. 2002). This match of food abundance and breeding of the consumer is ubiquitous for all foraging relationships, and it is assumed that this holds true for the relationship between fish prey and breeding California Least Terns in and around San Diego Bay. In Allen's study, other species that were also abundant in July, (the important chick and fledgling stages), were Pacific sardines, and spotted sand bass. Least Terns did eat a few sardines, but did not consume sand bass. As stated before, species of prey vary from region to region, and thus what a Least Tern consumes in San Diego Bay is not always what a Least Tern consumes in San Francisco Bay.

Chicks vs. Adults—Prey Size

Adults consumed fish that were statistically a greater length (mean = 5 mm longer), but in the same age class as the fish they fed their chicks, Age Class 0, young of the year. This size reflects the size range of forage fish caught in other surveys in San Diego Bay (Cross and Allen 1993, Allen et al. 2002, Pondella 2009, Parts 2 and 3 this report). Age Class 0 fish that the terns consumed, have a large size range. Prey that are in the same age class theoretically occupy the same or similar niche as all members of that age class. No fish less than 13 mm were consumed by either adults or chicks in 2009. Largest prey for chicks was 52 mm, and for adults, was 65 mm, (except for one fish 78 mm), but for the rest,. Median size was 26.0 mm for chicks, and 32.5 mm for adults.

It is apparent that some prey selection by adults occurs with respect to size, depending on whether they are foraging for a chick or for a mate. This is common in other birds (Ashmole 1968, Baird 1990a, Ydenberg 1999). Adult Least Terns selected for larger fish for themselves for courtship feeding, and smaller fish for their chicks, over the same time period. Larger fish may be preferable when courtship feeding (Wiggins and Morris 1986), and smaller prey are easier for chicks to eat.

Fecal Samples—2008

This information is discussed in Part 2, and should not be compared to data from bill loads in 2009.

Fecal Samples 2009

These data will be analyzed in 2011. Once they are analyzed, the prey types found from the otoliths within the samples can be compared to those identified from bill loads, because they are from the same year. Fecal samples from the previous year, 2008 (Part 2), cannot be used in this comparison because of different years and non-comparable methods to determine species and size.

Dropped Fish

Some researchers assume that dropped fish represent what Least Terns eat. However, other studies have shown that this is not the case (Dunn 1971, Le Croy 1972, Baird 1990b, Baird et al. 1992, 1997, and E. Kirsch, I. Nisbett, J. Spendelow, pers. comm.). Dropped fish usually differ in both genus and size from fish consumed by seabirds, and thus dropped fish are poor indicators of what prey type and size that Least Terns eat. In 2009, we found this to be true in the San Diego tern colonies. Comparing genera actually consumed by adults and fed to chicks, (bill loads), there is no correspondence between dropped and consumed fish, although some of the prey types consumed were also found dropped on the colony. This may just mean that these species were common. The difference between the dropped and consumed fish is in proportional representation of prey types and in size. Common fish like silverside smelt and slough anchovies are expected to have a high representation in both bill loads and in dropped fish.

However, this is not the same as stating that a fish caught frequently in fishing gear is a common prey. The behavior of the fish and the bird predator must also be taken into account (Elliott et al. 2008), and some fish are just behaviorally unavailable to least terns. Killifish were cited as one of the fish that Least Terns might consume, because they are found in large numbers in San Diego Bay, and have been found as dropped fish in the Least Tern colonies, yet they are not known prey of Least Terns in San Diego Bay.

SUMMARY

Least Terns forage throughout San Diego Bay, the nearshore area of the ocean, and pelagically. They forage both close to the colonies as well as beyond 24 nautical miles. They forage preferentially in mooring and inlet areas. They also frequent the nearshore ocean just beyond the breakers. They forage along the shoreline and docks in proportion to the amount of this habitat present. They seldom forage in channels. Pelagic foraging needs to be examined further because from the seven pelagic trips conducted, we saw numerous birds flying areas offshore to forage.

Where Least Terns forage depends on the breeding stage. They stay closest to the colony during the chick stage, expanding foraging bouts more pelagically during the fledge stage. They forage beyond 24 nautical miles throughout all stages of the breeding season, and likewise continue to use mooring and inlets preferentially during all stages.

Depending on the colony, birds with fish return from the most probable foraging areas in that direction:

Delta Beaches: Off the Delta Beach colony in the Bay 22-30%, Nearshore and Ocean 48-58%

NABO: Off the Delta Beach colony 25-29%, Nearshore and ocean 39-67%

MAT SITE: mid-Bay and near Glorietta Bay 26-27%, north bay off colony 28-52% , north bay and mooring areas and inlets 30-45%.

The ocean was used for foraging slightly less than was the bay: ocean = 42.5%, bay = 57.5%.

The main prey, for chicks, as in the 1990s, were Age Class 0 anchovies and silverside smelt. Adults brought back anchovies, kelpfishes, and silversides in high frequencies in 2009. They forage most frequently in the same areas they used in the 1990s. Prey of chicks, silversides and anchovies, are similar in size and type to what they ate in the 1990s. Adults in 2009 also consumed kelpfish frequently, in addition to silversides and anchovies, although in the 1990s, the two latter fish dominated.

This study is based on one year of data collection and may not be reliable for trends.

LITERATURE

Ainley, D. and R. Boekelheide (Eds.). 1990. Seabirds of the Farallon Islands: structure and dynamics of an upwelling-system community. Stanford University Press, Stanford, California.

Allen, L., A. Findlay, C. Phalen. 2002. Structure and Standing Stock of the Fish Assemblages of San Diego Bay, California from 1994 to 1999. Bulletin of Southern California Academy of Sciences 10 (2): 49-85.

Ashmole N. Philip, 1968. Body Size, Prey Size, and Ecological Segregation in Five Sympatric Tropical Terns (Aves: Laridae). Systematic Zoology, 17, (3): 292-304

Ashmole NP and MJ Ashmole, 1967. Comparative feeding ecology of sea birds of a tropical oceanic island. Peabody Museum of Natural History, Yale University Bull. 24.

Baird, P. 1990 a. Influence of Abiotic Factors and Prey Distribution on Diet and Reproductive Success of Three Seabird Species in Alaska. Ornis Scand. 21:224-235.

Baird, P. 1990 b. Relationship between Adult Diet and Weight and Clutch size in the California Least Tern, with Special Reference to Three-bird Nests. Amer. Ornith. Union 108th meeting, Los Angeles, CA.

Baird, P., C. Collins, B. Massey 1992. Summary of five years of observations of movements of California Least Terns, and adult demographics at Camp Pendleton, California. Unpubl. Report, Natural Resources Office, Camp Pendleton Marine Corps Base.

Baird, P., S. Hink, and D. Robinette, 1997. A foraging study of California Least Terns in San Diego Bay and the Nearshore Pacific Ocean. Final Rept. to U.S. Navy, Southwest Division, San Diego, CA (unpubl.)

Ballance, L. , R.. Pitman, and S. Reilly, 1997. Seabird Community Structure along a Productivity Gradient: Importance of Competition and Energetic Constraint. Ecology. 78:1502—1518.

Barnett, A. M., A. E. Jahn, P. D. Sertic and W. Watson. 1984. Distribution of ichthyoplankton off San Onofre, California, and methods for sampling very shallow coastal waters. Fish. Bull. U.S. 82: 97–111.

Barrett RT, K. Camphuysen, T. Anker-Nilssen , J. Chardine , R. Furness , s. Garthe , O. Huppop , M. Leopold, w. Montevecchi, AND R. Veit, 2007. Diet studies of seabirds: a review and recommendations. Ices Journal of Marine Science 64:1675-1691.

Bartonek, J. and D. Gibson, 1972. Summer distribution of pelagic birds in Bristol Bay, Alaska. Condor 74: 416-422.

Bayer, R. 1985. Bill Length of Herons and Egrets as an Estimator of Prey Size. Colonial Waterbirds 8: 104-109.

Bell, W. 1991. Searching Behavior. Chapman and Hall, London.

Benowitz-Fredericks, Z. M., A. Kitaysky, C. W. Thompson, 2006. Growth and allocation of Common Murre (Uria aalge) chicks. Auk 123, (3): 722-734.

Bluso, J. , 2007. Sex-specific differences in space use of Forster's Terns (*Sterna Forsteri*) breeding in the South San Francisco Bay, California. Master's Thesis, Humboldt State University, California.

Cannon, R. How to Fish the Pacific Coast, 1970. Lane Publishers, 160 pp.

Collis, K., D. Roby, D. Craig, S. Adamany, J. Adkins and D. Lyons. 2002. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: Implications for losses of juvenile salmonids to avian predation. Transactions of the American Fisheries Society 131: 537-550.

Cross and Allen, 1993. in: Dailey, M.D. , D.J. Reish, J.W. Anderson, 1993. Ecology of the Southern California Bight, A synthesis and Interpretation. Univ. Calif. Press, Berkeley, 926 pp.

Croxall, J. , P. Prince 1980. Food, Feeding Ecology and Ecological Segregation of Seabirds at South Georgia. Biological Journal of the Linnean Society 14 (1) : 103-131

Davoren, G., W. Montevecchi, and J. Anderson. 2003. Search strategies of a pursuit-diving marine bird and the persistence of prey patches. Ecol. Monog. 73:463–481.

Deser, C., A. Phillips, J. Hurrell, 2004. Pacific Interdecadal Climate Variability: Linkages between the Tropics and the North Pacific during Boreal Winter since 1900. Journal of Climate 17 (15): 3109–3124.

Draheim, H, M. Miller, P. Baird, S. Haig, 2010. Subspecific Status and Population Genetic Structure of Least Terns (*Sternula antillarum*) Inferred by Mitochondrial DNA Control Region Sequences and Microsatellite DNA. The Auk 127(4):807–819.

Draheim,, H. M., P. Baird, and S. M. Haig, 2011. Temporal analysis of mtDNA variation reveals decreased genetic diversity in Least Terns. Condor, in press.

Dunn, Euan K. , 1971. Effect of Age on the Fishing Ability of Sandwich Terns *Sterna sandvicensis*. Ibis 114: 360-366.

Elliott, K., K. Woo, A. Gaston, S. Benvenuti, L. Dall'Antonia, G. Davoren, 2008. Seabird foraging behaviour indicates prey type Marine Ecol. Prog.r Ser. 354: 289–303.

Forsell, D. J. and P.J. Gould 1981. Distribution and Abundance of Seabirds Wintering in the Kodiak Area of Alaska, USFWS OBS Report No. USFWS/OBS -81/13.

Gould, P.J., D.J. Forsell, and C.J. Lensink, 1982, Pelagic Distribution and Abundance of Seabirds in the Gulf of Alaska and Eastern Bering Sea, USFWS OBS Report No. USFWS/OBS-82/48.

Gould, P.J. and D.J. Forsell, 1989, Techniques for Shipboard Surveys of Marine Birds, USFWS, Fish and Wildlife Technical Report No. 25.

Hall, C., S. Kress and C. Griffin. 2000. Composition, spatial and temporal variation of Common and Arctic Tern chicks in the Gulf of Maine. Waterbirds 23: 430-439.

Harris, M. , and S. Wanless, 1985. Fish fed to young guillemots, *Uria aalge*, and used in displays on the Isle of May, Scotland. Journal of Zoology, London, 207: 441–458.

Harrison, I., M. Laverty, E. Sterling, 2004. Connexions Module m 12155 .Open Educational Resource, www.cnx.org.

Horn, M.H. and L.G. Allen, 1981a. Ecology of Fishes in Upper Newport Bay, California: Seasonal dynamics and community structure. Calif. Dept. Fish Game, Mar. Res. Tech. Rept. 45: 102 pp.

Horn, M.H. and L.G. Allen, 1981 b. A Review and Synthesis of Ichthyofaunal Studies in the Vicinity of Los Angeles and Long Beach Harbors, Los Angeles County, California. Final Rept. To US Fish and Wildlife Service

Kerr, R. A. (1992), Unmasking a shifty climate system, Science, 255

Krebs, C. , 1989. Ecological Methodology. Harper and Row, New York. 654 pp.

LeCroy, M. 1972. Young Common and Roseate Terns Learning to Fish. Wilson Bull. 84 (2): 201-202.

Love, R.M., 1991. Probably More Than You Want to Know about the Fishes of the Pacific Coast. Really Big Press, Santa Barbara, 215 pp.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis, 1997. A Pacific interdecadal climate oscillation with impacts on salmon production, Bull. Am. Meteorol. Soc., 78, 1069– 1079.

Miller, D.J. and Lea 1972. Guide to the Coastal Marine Fishes of California. Calif. Dept. of Fish and Game, Fish Bull. #157, 249 pp.

Morris, W., Editor, 1978. The American Heritage Dictionary of the English Language, New College Edition. Houghton Mifflin, Boston.

Moyle, P. and J. Cech, Jr., 1996. Fishes, An Introduction to Ichthyology. Prentice Hall, New Jersey, 590 pp.

Olton, D.S., G.E. Handelmann, J.A. Walker, 1981. Spatial memory and food searching strategies, pp. 333-354 in: A.C. Kamile, J.T. D. Sargent. Foraging Behavior: Ecological, Ethological, and Psychological Approaches. Garland STPM Press, New York.

Onuf, C.P. and M.L. Quammen, 1983. Fishes in a California Coastal Lagoon: Effects of Major Storms on Distribution and Abundance. Mar. Ecol. Prog. Ser. 12:1-14.

Perrow, M., E. Skeate, P. Lines, D. Brown, and M. Tomlinson, 2006. Radio telemetry as a tool for impact assessment of wind farms: the case of Little Terns *Sterna albifrons* at Scroby Sands, Norfolk, UK. Ibis 148, 57–75.

Pondella, D. and J.P. Williams, 2008. Fisheries inventory and utilization of San Diego Bay, San Diego, California for surveys conducted in April and July 2008. Unified Port of San Diego. 68p.

Ricklefs, R. , 1982. Ecology. Chiron Press, New York, 966 pp.

Robinette, D. 2002. Resource Partitioning by Four Sympatric Terns. Unpubl. Master's Thesis, California State University, Long Beach, California.

Robinette, D and P. Baird, In Review. Forage-Related Ecomorphology of Four Sympatric Terns (Aves: Laridae) Breeding in Southern California.

Schreiber, E.A. and J. Burger, eds., 2002. Biology of Marine Birds. CRC Press, New York, 722 pp.

Sokal, r. and F.J. Rohlf, 1969. Biometry, the Principles and Practice of Statistics in Biological Research. W.H. Freeman and Company. San Francisco. 776 pp.

Spendelow, J. , 1999. Cooperative Long-term Roseate Tern Metapopulation Project Handout, USGS Patuxent Wildlife Research Center (PWRC), Patuxent MD.

Thompson, B., J. Jackson, J. Burger, L. Hill, E. Kirsch and J. Atwood, 1997. Least Tern (*Sterna antillarum*), The Birds of North America, A. Poole, Ed., Cornell Lab of Ornithology, Ithaca , NY.

Triola, M.M., and M F. Triola, 2006. Biostatistics for the Biological and Health Sciences. Addison Wesley, New York. 699 pp.

Walker, H, Jr., W. Watson and A. Barnett, 1987. Seasonal occurrence of larval fishes in the nearshore Southern California Bight off San Onofre, California. Estuarine, Coastal, and Shelf Science: 25 (1) : 91-109.

Weimerskirch, H., M. Le Corre, S. Jaquemet, F. Marsac, 2005a. Foraging strategy of a tropical seabird, the red-footed booby, in a dynamic marine environment. Mar. Ecol. Progr. Ser. 288: 251–261.

Weimerskirch,H., A. Gault, and Y. Cherel, 2005b. Prey distribution and patchiness: factors in foraging success and efficiency of Wandering Albatrosses. Ecology, 86: 2611-2622.

Wiggins, D. and R. Morris, 1986. Criteria for Female Choice of Mates: Courtship Feeding and Paternal Care in the Common Tern. The American Naturalist, 128: 126-129 .

Ydenberg, R.C. 1994**.** The behavioral ecology of provisioning in birds. Ecoscience 1: 1-14.

Personal Communication

Jennifer Stucker, USGS Minnesota, I. Nisbett, icnisbet@verizon.net, Jeff Spendelow, USGS, E. Copper, Clark Winchell, USFWS, Carlsbad.

PERSONNEL AND ACKNOWLEDGEMENTS

Report Citation: Patricia Baird, 2010, Foraging Study of California Least Terns in San Diego Bay and Near ocean Waters, San Diego, California, 2009. Unpubl. Rept. U.S. NAVFACENGCOM, San Diego. 91 pp

Kahiltna Research Group
Patricia Baird, Ph.D., Principal Investigator
Centre for Wildlife Ecology
Simon Fraser University
Ron Ydenberg, Ph.D., Chair: Centre for Wildlife Ecology

<u>Research Assistants and their contributions to this report</u>

Research Associates, Breeding Phase Main Field Crew: June and July: **Tern Foraging Study: planning, follow-through and data collection , data entry, map-making, data analyses**
The following main personnel gathered the majority of the data in this report. Tyler Willsey wrote parts of the sections on "at-colony surveys," and helped with data analysis on vectors. Mel Kirkby aided in editing graphics.

Tim Burr, M.A., liaison
Melody Kirkby, B.S., field biotech
Greg McMichael, M.A., field biotech
Tyler Willsey, B.S., field biotech

Student Assistants, Pilot Phase Short-term Field Crew: May Preliminary Scoping and Setup
Lisa Haney: entered preliminary data from the month of May, Kate Goodenough: broke in the engine, Lindsay Addison: made Potter traps. This phase one group also undertook preliminary boat surveys in May to work out any problems, which was important to do before the project started in full. I appreciate their valuable help. We did not use any of their on-colony preliminary data.

Acknowledgments

I am very grateful for the assistance and support from the U.S. Navy, Naval Base Coronado. I am especially thankful to Jacqueline Rice, NAVFACENGCOM, Southwest Division, and Tiffany Shepherd, Wildlife Biologist, Naval Base Coronado, for their knowledge, encouragement, and input on the project. Arlene Arnold and Jessica Bredvik had good input on the final draft. I thank the Friends of Colorado Lagoon for their help in managing the project—we could not have done it without them. I especially thank Eric Zahn and Taylor Parker for the day-to-day management of the project, and Dave Pirazzi, President, for having the foresight to realize this was a valuable project to manage. I thank my colleagues, Dan Pondella and Jonathan Williams of Occidental College, for their valuable additions to Part 1 of this report, as well as their ability to work so well together with our team, and for their cooperation.

I am especially grateful to the "can-do" attitude, enthusiasm, knowledge, creativity, and "ability to think on their feet" of my incredible main field crew, Tyler Willsey, Mel Kirkby, and Greg McMichael. Their attitude made work fun, and each person brought a suite of intelligence, rare to find in three people at one time. Tim Burr was invaluable as a liaison, willing assistant, collaborator, "guy-Friday", and all around "go-for", as well as our safety link when we went on surveys. The project would not have happened without him. Derek Lerma was a pleasure to have on the team.

For their help in fish ID training, I thank the Museum of Vertebrate Zoology at Los Angeles, especially Jeff Seigel, and also Dan Pondella, and Jonathan Williams from Occidental College. Derek Lerma, Tierra Data Inc., and Dave Povey were key in the pelagic surveys. I appreciate their professionalism and excellent help in the design and follow-through of the surveys. Tierra Data Inc. was generous with providing maps for the project. I thank the staff at Fiddler's Cove for all of their help and assistance. I would also like to thank Mitch Perdue for his review of this project's safety plan, and Derek Lerma for his help in finalizing the safety plan. And finally, all maps produced were because Jenn Barrett, Simon Fraser University, gave me such great insights in using ArcGIS.

APPENDIX I

Methods and data sheets foraging study

This can be found on the CD included with this report, labeled

"FORAGING STUDY of California Least Terns in San Diego Bay 2009, Part 1, Foraging Study of California Least Terns in San Diego Bay and Near ocean Waters, Appendix I"

and in the section on that CD called **"Detailed Methods and Data Sheets."**

APPENDIX II

Banding Data submitted via Bandit to the U.S. Geological Survey by Patricia Baird

This Appendix can be found on the CD included with this report, labeled:
"s Part 1, Foraging Study of California Least Terns in San Diego Bay and Near ocean Waters, Appendix II"

and in the section on that CD called **"Banding Data."**

PART 2

ANALYISIS OF FECAL SAMPLES OF CALIFORNIA LEAST TERNS COLLECTED ON U.S. NAVY LEAST TERN COLONIES SAN DIEGO BAY in 2008

Dan Pondella
Occidental College
Los Angeles California

GOALS OF PROJECT: Analysis of Fecal Samples

The Pondella Lab at Occidental College were given California Least Terns' fecal samples from 2008 and they were to determine the fish prey species' abundance during that year.

EXECUTIVE SUMMARY: Out of 149 fecal samples given to them by Elizabeth Copper, collected during the fledge period in 2008, on U.S. Navy Least Tern colonies, they found only 34 of them to contain otoliths to identify. From these, they recovered 139 otoliths, and of these, 21 were unidentifiable for various reasons. The majority of the otoliths were from slough anchovy and topsmelt.

This report can also be accessed through the Occidental website:
http://departments.oxy.edu/vrg/baird/CLTSDBreport.pdf

APPENDIX III

Detailed methods of data collection and analysis, data sheets, and raw data from the fecal study.

This can be found on the CD included with this report, labeled:
"Part 2, Analysis of Fecal Samples of California Least Terns Collected on U.S. Navy Least Tern Colonies, San Diego Bay 2008, Appendix III, Detailed Methods and Data Sheets ."

PART 3

SUMMARY AND ANALYSIS OF PAST FISH COLLECTION DATA WITH COMPARISON TO PAST TERN PRODUCTIVITY

Daniel Pondella
Vantuna Research Lab
Occidental College
Los Angeles California

This is a summary of Part 3, An Analysis and Summary of Past San Diego Bay Fish Collection Data , with a comparison of these prior data to past tern productivity and success in the Bay.

The report is 210 pages long, is very detailed, with 187 pages of tables and graphs, and thus should be read in its entirety.

Note that samples of what terns actually consumed were not used as a comparison with Least Tern reproductive success. Rather, the abundance of fish captured with fishing gear in San Diego Bay over a number of years, and which were of the correct size for Least Terns to eat, were compared with eight oceanic parameters and with Least Tern success. These fish of the correct size are defined as "forage fish. " This report has no relationship to Part 1, the Foraging Study of California Least Terns in San Diego Bay, and thus there was limited discussion in Part 1 concerning Part 3.

Please refer to the complete report for a comprehensive description of all fish species found, methods, tables, graphs, statistical analyses, data sheets, and raw data. Likewise, this report can be accessed via the Occidental College website, below:

http://departments.oxy.edu/vrg/baird/11MAR2011_CALT.zip

APPENDIX IV

Detailed methods of data collection and analysis, data sheets, and raw data from the foraging study.

This can be found on the CD included with this report, labeled:

"Part 3, Summary and Analysis of Past Fish Collection Data, with Comparison to past Tern Productivity, San Diego Bay, Appendix IV, Detailed Methods and Data Sheets. "