LEAST TERN LITERATURE REVIEW AND STUDY PLAN DEVELOPMENT

Final Report

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File 3081 February 2012

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Introduction

San Francisco Bay (Bay) is relatively shallow and there are substantial sedimentary inputs from both large rivers and smaller creeks and subsequently, use of the Bay for maritime operations requires the removal and relocation of a large volume of sediment annually. Dredging operations are restricted in some areas of the Bay that are within the foraging range or are nearby breeding colonies of the endangered California Least Tern (*Sternula antillarum browni*). Restrictions were imposed due to concerns dredging operations could impair foraging or disrupt nesting birds by increasing turbidity and by generating high noise levels at breeding and foraging sites.

This project involved a review of existing literature as a means for evaluating uncertainties with regard to the scientific foundation on which dredging restrictions are based. What are the potential impacts of dredging induced turbidity relative to other anthropogenic and natural sources in the Bay and to what extent does turbidity actually affect foraging Least Terns' ability to locate and capture prey? How does dredging and dredging induced turbidity plumes affect prey distribution, health, and behaviors that could decrease or potentially increase Least Tern foraging success? There is also uncertainty with regard to distances Least Terns travel to forage and whether or not the areas where dredging is restricted are within the foraging range of known Least Tern breeding colonies.

Literature reviewed included a wide range of technical reports, journal articles, and datasets generated both directly from observations, monitoring, and research from around the Bay; as well as a wide range of information sources from around the world that provide insight into the behavioral and physiological response of analogous avian and fish species to turbidity, and provide insight into the ecological and environmental effects of dredging.

This report includes an overview of the current status of the California Least Tern, a summary of the history of California Least Tern occurrences within the Bay since the early 1970s, and a review of the species' ecology with a focus on aspects that potentially intersect with the goals of managing sediments in the Bay. The broad environmental effects of dredging on physical and biotic conditions are summarized as are specific potential impacts that dredging may have on Least Terns in the Bay. Finally, the existing management strategies are reviewed and recommendations are made for additional research that would inform the ongoing development and refinement of management strategies designed to ensure that dredging operations are conducted in a manner that is realistic and feasible and fully addresses the needs of shipping traffic in the Bay; while not resulting in significant impacts to breeding and foraging Least Terns, their prey, and the ecosystems on which both rely.

1. Current Status of the California Least Tern

1.1. Overall Population Status

The California Least Tern is endangered and was one of the first subspecies to be listed under the federal Endangered Species Act (FR notice: 35 8491, 1970). At the time, there were an estimated 300 pairs distributed among 14 nesting sites in San Diego and Orange Counties, and at a single northern California site at Bair Island in San Mateo County (Craig 1971). The subspecies was subsequently listed as endangered by the California Department of Fish and Game (CDFG 1973).

The California subspecies had declined precipitously over the decade previous to its being listed under the federal Endangered Species Act, as a result of what Craig (1971) described as "unrelenting human disturbance and development on its nesting sites." In fact, in 1970 there were near term plans to develop 10 of the 15 occupied breeding locations. Recommendations for reversing the trend were simple in concept: protect the existing breeding sites from disturbance and create new breeding sites at locations that could be permanently protected from disturbance and development (Craig 1971).

Actual implementation proved to be as complex and problematic then, as it is today, but even early on considerable success was apparent as the population quickly doubled. By 1976, the breeding population had increased to 674 pairs and the number of breeding sites had increased to 19 (Bender et al. 1976); including new Bay locations at Bay Farm Island and the Oakland Airport. Today, the population has increased substantially from the original 300 pairs and nesting birds are distributed over numerous sites. The successful and continued recovery of the California Least Tern population is in large part a result of intensive management of a limited number of sites; without which it is unlikely that even the observed level of recovery would have occurred.

1.2. Current Population and Distribution

1.2.1. Estimated Population Size and Number of Colony Sites

The 2009 breeding season survey revealed the highest number of breeding pairs observed in California since regular annual surveys began in 1969 (Marschalek 2010, Craig 1971), with an estimated 7124-7319 pairs occupying 46 sites (Marschalek 2010). Similar breeding population levels were observed during the previous 6 years, with the California breeding population consistently estimated at well over 6000 pairs (Marschalek 2009, 2008, 2007, 2006, 2005, Patton 2003).

Over the past 40 years the California population has steadily increased, but the pattern of population growth has been more stochastic then linear, with substantial short-term increases and declines occurring throughout this period. For example, in 1970 when the subspecies was listed under the federal Endangered Species Act the population was believed to include ~300 pairs (Craig 1971), the following year there was an estimated 200 pairs in the Bay alone, and by 1973 the statewide population had apparently more than doubled to an estimated 624 pairs (Bender 1974a). Although this rapid increase might have been in part due to improved survey coverage the population fluctuated around the 1973 level for the next 3 years. In 1977 the population again increased substantially (~17%) to 775 (Atwood et al. 1977) and then annually increased in relatively small increments (~25-75 pairs each year) until the population reached an estimated 1015 pairs in 1982. The next year there was another large increase in the population (~18%) to an estimated 1196 pairs (Gustafson 1986), followed by equally large declines; which were reversed when the population increased by ~33% in one year (Massey 1988). This has continued to the present with substantial increases or decreases in the annual statewide breeding population, interspersed with periods of incremental growth (Figure 1).

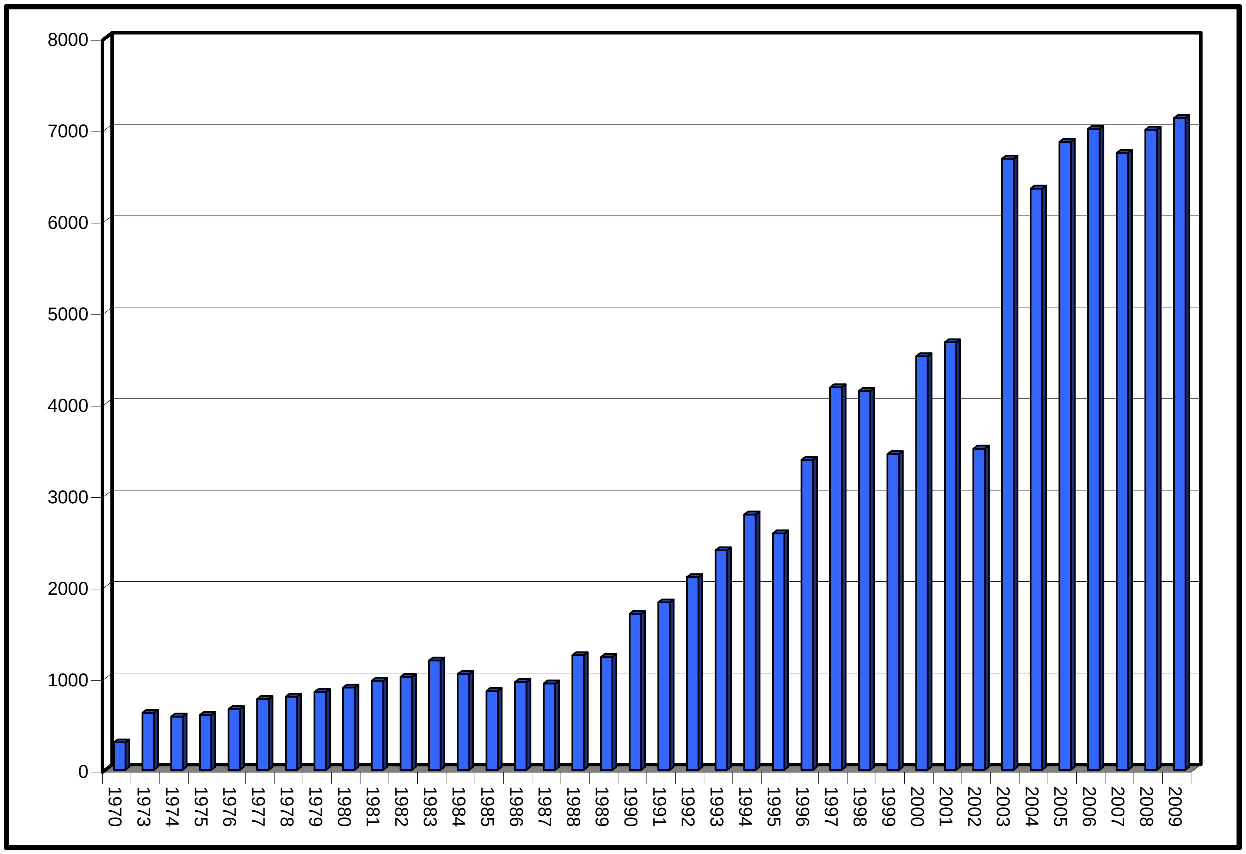


Figure 1. Statewide number of California Least Tern breeding pairs, 1970-2009.

1.2.2. California Least Tern Statewide Population Trends

Between 1970 and 2009, the annual percent change in the estimated statewide number of adult pairs ranged from ~2% to 108%, with an average annual change of 12% (s.d. 26%), and both small and large changes in the size of the population have occurred in positive and negative directions. Observed increases or decreases in the number of adult pairs appear to be the result of good or poor conditions at both breeding areas and wintering grounds. For example, the breeding population in California dropped precipitously from 4674 pairs to 3511 pairs, over the winter of 2001 and 2002. Yet this decline was completely offset with an increase to well over 6500 pairs in 2003, apparently as a result of exceptionally high fledging success during the summers of 2000 and 2001 (Patten 2003).

The U.S. Fish and Wildlife Service (USFWS) completed a 5-year summary and evaluation of the status of California Least Terns in 2006 (USFWS 2006) and recommended downlisting the subspecies to threatened status, as the original criteria for doing so had been met; at least 1200 pairs distributed among 15-23 coastal management areas, each with at least 20 pairs, and each with a 3 year mean of 1.0 young fledged per breeding pair (USFWS 1985). However, the USFWS also recognized a number of new issues and information that may be more relevant to the evaluation of recovery of the California subspecies, than were the original criteria for downlisting or delisting.

For example, the required productivity rate of 1.0 young fledged per breeding pair was never met at many colonies. Yet even though the fledging success rate was considerably lower and far more volatile these colonies remained relatively stable, and the overall statewide population has increased by an order of magnitude. Likewise, in 2009 there were 33 sites with more than 20 pairs, and 15 of these sites had hundreds of pairs (range – 206 to 1639 pairs), exceeding one of the original criteria for downlisting the subspecies. However the majority of the overall breeding population is concentrated at a relatively small number of sites. For example in 2009, 75% of all nesting pairs occurred at only 9 locations (Marschalek 2010).

In 2009 the 20 largest colonies included ~97% of the total breeding population, yet the remaining 3% of pairs occupied nearly as many sites (16). These apparently peripheral colony sites may play a central role in enabling the population to continue to expand in the future. In addition these apparently peripheral sites may enable Least Terns to respond to changing environmental conditions by moving among alternate breeding sites.

1.2.3. Wintering Sites

The non-breeding season ecology of the California Least Tern population is poorly understood, and is largely based on a limited number of incidental observations. Least Terns typically leave California breeding sites by September and apparently head towards wintering locations along Baja, mainland Mexico, and Central and South America (Thompson et al. 1997). Least Terns have been seen as far south as Peru (USFWS 2006, and references therein).

Although little is known about where the California Least Tern population winters, events and conditions on the wintering grounds apparently play a critical role in the population dynamics. This is evident in the considerable variability in the number of breeding adults returning to California during subsequent years. Annual estimates of fledged young and subsequent year-to-year estimates of the number of breeding adults also indicates that mortality of birds on the wintering grounds can be very high particularly during the first 2 years.

2. Least Terns in San Francisco Bay

Least Terns in the Bay region have thrived at stable locations and continue to occupy new breeding sites. The Bay population has been and continues to be an extremely import part of the overall statewide population. The disjunct distribution of the Bay breeding colonies, relative to all other known breeding centers, also suggests that the Bay population represents a once more widely distributed overall population.

Breeding may have occurred at inland locations such as the historic alkali ponds and salt flats of the San Joaquin Valley, as well as among salt flats of the back-Bay and delta regions of the San Joaquin and Sacramento Rivers. Although many of these locations are presently unsuitable as breeding sites, some of these areas could potentially be made suitable in the future.

2.1. Recent History of California Least Terns within the San Francisco Bay Region

At the time the California Least Tern was listed under the federal Endangered Species Act, Bair Island in San Mateo County was the only known breeding site within the Bay area and it was the only known colony north of Orange County (Craig 1971). Reports from the first several years of monitoring Least Terns in the Bay reveal the precarious condition of the Bay population.

The Bair Island colony was small with 8-15 pairs in 1969 and 1970, and while there was some success with 8 fledglings produced, a number of nests were destroyed by rats and a number of adults were apparently taken by an undetermined predator. The site was subsequently abandoned for a number of years. In 1972 there were reportedly nearly 200 pairs at a site on Bay Farm Island (Alameda County). That site was then evidently seeded with soil binding grasses and only 1 pair attempted to breed in 1973. The same year at least 40 pairs were documented at the Oakland Airport (Alameda County) and at the end of the year 171 birds were counted, of which a large number were juveniles (Bender 1974a).

The following year this pattern of instability persisted. The Oakland Airport site was abandoned and only 27 pairs were reported for the entire Bay region; 19 pairs at Bay Farm Island and 8 pairs at Bair Island. Productivity was believed to be low and the birds observed at Bair Island may have in fact been among the 19 pairs observed at Bay Farm Island earlier in the season, possibly attempting to re-nest after initially failing at the Bay Farm Island site (Bender 1974b).

In 1975, numbers remained low with only 28 pairs observed during surveys at the Oakland airport, Bay Farm Island, and Bair Island sites and productivity was also believed to have been low (Massey 1975). However in 1976, although pairs attempting to nest at the Bair Island, Bay Farm Island, and Oakland Airport continued to struggle the apparent future of the population within the Bay changed dramatically. A new colony of 20 pairs was discovered at the Alameda Naval Air Station (NAS). The following year the number of pairs at the Alameda site more than doubled with 45 pairs producing an estimated 20 fledglings (Atwood et al. 1977). That same year colonies at the other Bay sites were occupied by only 8 pairs.

What was potentially even more important then the numbers of pairs, at the newly documented Alameda site, was the fact that according to accounts of NAS personnel the colony had persisted at the site over the previous 10 years and appeared to be relatively stable (Atwood et al. 1977). The site was somewhat atypical in that nests were located on a gravel covered asphalt area between aircraft runways. The setting however inherently removed a number of stressors typical of most breeding sites in California. Although there was considerable potential for collision with aircraft and vehicles the secure nature of the military base prevented access by most people and base personnel had taken precautions to limit disturbance of the birds during the nesting season. Furthermore, military activities at the site limited mammalian predator access to the colony. In fact a large area cleared of vegetation, in hopes of luring birds away from the existing and potentially hazardous location between the runways, was never utilized by Least Terns (Atwood et al. 1977) quite possibly due to the presence of feral cats (*Felis domesticus)* along the periphery of the airfield.

Early management of the Alameda NAS site included installation of a barrier between the nests and the aircraft runways, elimination of vehicle traffic within the colony site, and placement of cement blocks that provided shelter for chicks. In 1978, the colony again nearly doubled to an estimated 80 pairs (Atwood et al. 1979). The same year birds did not nest at Bair Island, Bay Farm Island, or at the Oakland Airport. The colony on Bair Island was flooded after a berm failed. Construction and overgrown vegetation had rendered the breeding site at Bay Farm Island unusable, and the Oakland Airport was abandoned by both Least Terns and Western Snowy Plovers (*Charadrius alendrinus novosus*) for undetermined reasons. Atwood et al. (1979) also reported that the Redwood City Salt Ponds, which apparently supported a couple of pairs in 1976, were not used by Least Terns for breeding in 1978. These birds however may have been part of a new colony discovered in 1978 at the Alvarado Salt Ponds, where 4 pairs were observed. The Alvarado Salt Ponds was known as a site where post-breeding flocks congregated, but breeding had not previously been observed (Atwood et al. 1979).

For reasons that were unexplained CDFG did not conduct surveys of Least Tern colonies within the Bay in 1979 (Gustafson 1986). However the results of surveys conducted in 1980, 1981, and 1982 indicated a new level of stability for the Bay colonies. In 1980, there were at least 77 breeding pairs at the Alameda NAS, with ~12 pairs at Coyote Hills Regional Park, and another 38 pairs at Bair Island. Similarly in 1981 and 1982 there were reportedly 70 pairs at Alameda NAS, and at Bair Island there were 17 and 50 pairs observed in 1981 and 1982, respectively (Gustafson 1986).

The following year, 1983, appears to have been problematic in terms of breeding success throughout the Bay. There were very few birds observed at the Alameda NAS site, and although 56 pairs occupied the Oakland Airport colony site, they produced only 6-9 fledglings (Gustafson 1986). At Bair Island there were an additional 22 pairs, but no chicks apparently survived. Nonetheless, during the 1983 breeding season another important trend in the Bay population emerged for the first time; a new colony was formed at Port Chicago near Suisun Bay in Contra Costa County, making it the northernmost known breeding location for this subspecies. It was later discovered that Least Terns had also nested that same year at the Pacific Gas and Electric power plant at Pittsburg just a few miles to the east of the Port Chicago colony (Gustafson 1986).

Over the next few years, birds apparently moved between Bay sites, particularly the Alameda NAS and Oakland Airport sites, while new sites were explored and colonized (Collins 1984, 1986, 1987, Massey 1988, 1989). Between 1984 and 1989 the number of Least Terns reported for the Alameda NAS site ranged from an estimated 36-49 pairs (1986) to a high of 72-75 pairs (1989). Use of the Oakland Airport by Least Terns essentially reflected their use of the Alameda NAS site, with birds selecting one or the other site for undetermined reasons. The Pittsburg PG&E site was consistently occupied during this period, though the site supported only a small number of pairs. The Port Chicago site was occupied for 3 of the 6 years during that period, and a few new sites were apparently explored including the Bay Bridge Sand Spit and Baumberg Salt Ponds, in Hayward (Collins 1984, 1986, 1987, Massey 1988, 1989). Bair Island, where Least Terns had bred with some success since the early 1970s, was last used in 1984 (Figure 2).

This period was particularly important at the Alameda NAS site because a very active management program had been implemented, and the results were becoming apparent. A number of problems had been identified and addressed including predation by American kestrel (*Falco sparvarius*) and feral house cats, as well as human impacts associated with vehicle and aircraft traffic (Collins 1984, 1986, 1987). Trapping and relocation of kestrels substantially reduced avian predation (Collins 1984). Trapping of feral cats and the installation of electric fencing around the colony essentially eliminated mammalian predation and trampling of nests (Massey 1989).

As a result of this intensive management effort the Alameda NAS colony continued to increase in size and degree of reproductive success. By 1992 the colony included as many as 130 pairs that produced as many as 221 fledglings, which was ~10% of the total number of fledglings produced in California that year. The number of breeding birds steadily increased over the next several years reaching 208 pairs in 1996 (Caffrey 1998), 301 pairs in 2003 (Patton 2003), and 424-495 in 2005 (Marschalek 2006). The number of pairs breeding at the Alameda site declined over the next few years to 323 in 2008 (Marschalek 2008), and 318 in 2009 (Marschalek 2010). However, the overall number of pairs observed at Bay colonies has remained relatively high and remarkably consistent and Least Terns have now occupied several sites.

In 2009, between 479 and 522 pairs were observed at 7 locations in and around the Bay, and they produced between 326 and 537 fledglings. Sites in the south Bay that were occupied during the early years of monitoring have been for the most part abandoned as breeding sites (Figure 2). The southernmost locations in the Bay are now at Hayward Regional Seashore (69 pairs) and Eden Landing (1 pair) and in more recent years Least Terns have established new colonies at several locations throughout the back-Bay.

A significant majority of birds continue to nest at the Alameda site, which is currently managed by USFWS and is now referred to as Alameda Point. The relatively secure nature of the Alameda NAS and management of the base by the U.S, Navy enhanced the ability to control human activities around the colony and allowed for the implementation of an intensive management program. The successful management of this site early on is primarily responsible for the increase and relative stability of the Bay breeding population of Least Terns (Collins 1986, Massey 1988, 1989, Johnston & Obst 1992, Caffrey 1993, 1994, 1995, 1996, 1997). Without this core breeding colony, Least Terns may not have survived the range and degree of disturbance and disruption of breeding sites that occurred in the Bay during the 1970s and 1980s (Craig 1971, Bender 1974a, Bender 1974b, Massey 1975, Bender et al. 1976).

2.2. Contribution to the Overall Statewide Population

Currently the contribution of fledglings from Bay colonies, to the overall statewide population is substantial. The 2009 breeding population at Bay colonies was estimated at between 479 and 522 pairs, which is equivalent to ~7% of the total estimated population (7124-7319 pairs; Marschalek 2010). The Bay population was also estimated to have produced between 326-537 fledglings, comprising ~19-25% of the total number of fledglings observed at California breeding sites that year; and the Alameda Point site alone produced between ~15-22% of the statewide total number of fledglings for the year.

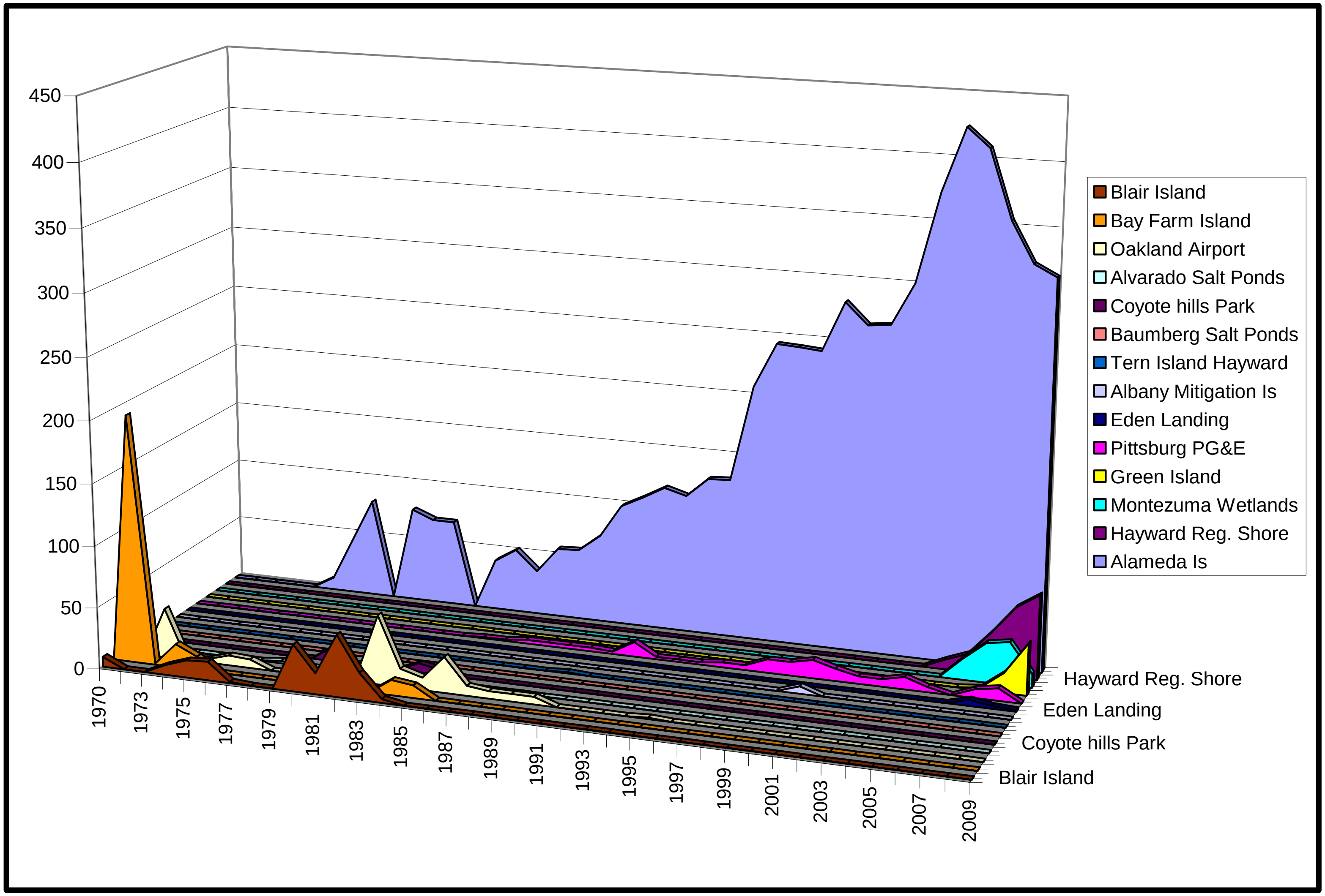
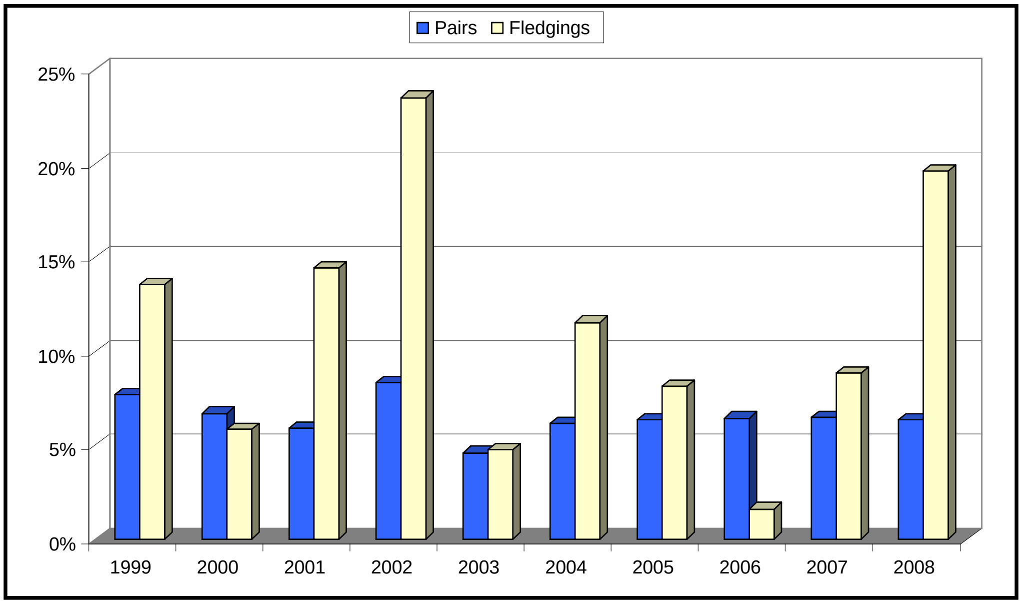


Figure 2. Abundance of Least Tern pairs at San Francisco Bay breeding colonies 1970-2009.

Over the 10-year period from 1999 to 2008, the contribution of fledglings from Bay colonies, relative to the statewide population has varied widely, ranging from a minimum of ~2% in 2006 to ~24% in 2002 (Figure 3). However these statistics may mask the real contribution of the Bay breeding population to the overall population. During the past decade the statewide population experienced substantial fluctuations in total number of adult birds, while the Bay population has remained remarkably stable; typically consisting of ~6% of the total population with a range of ~5% to 8%. That stability may have been critically important in years when the overall population trends indicate instability. For example, between 2001 and 2002 when the overall population declined by nearly 25%, the Bay population increased by about 7% and contributed ~24% of the total number of fledglings for the year. Furthermore, the pattern described here is based on the minimum number of fledglings reported. The differences in reported estimates of minimum and maximum number of fledglings from the Alameda Point colony alone is often substantial, suggesting the actual contribution of the Bay Least Tern population to the overall population growth may be even greater.



Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Pairs SF Bay	266	303	275	293	307	391	436	451	436	443
Pairs Statewide	3451	4521	4674	3511	6688	6354	6865	7006	6744	6998
Fledglings SF Bay	91	217	357	104	105	156	140	41	202	442
Fledglings Statewide	671	3710	2471	442	2206	1351	1721	2571	2293	2254

Figure 3. Number of breeding pairs and fledglings observed at Bay breeding colonies, expressed as percentages of the total numbers of breeding pairs and fledglings observed statewide, 1999-2008; the associated table shows absolute numbers for each category.

3. Least Tern Natural History & Ecology

3.1. Foraging Ecology

Least Terns feed on small fish species occurring in a wide variety of freshwater and marine aquatic habitats. They are highly opportunistic in exploiting food resources and respond quickly to changing conditions.

Least Terns are plunge divers (Eriksson 1985) dropping from heights of 10 – 20 feet, to capture fish in the surface layer. Exploitation of prey is limited by the size and shape of the fish and the size of prey captured also coincides with the developmental stage of chicks; smaller fish are offered to young chicks and as chicks grow the size of prey offered also increases.

Least Terns apparently optimize travel between foraging locations and nesting sites, but also change their behavior to respond to concentrations of prey. Atwood and Minsky (1983) demonstrated this experimentally when they released several thousand mosquitofish (*Gambusia affinis*) into a small artificial pond near the Huntington Beach colony site. Within 10 minutes of the release, the number of Least Terns foraging on the pond increased from 2 to 24 individuals.

Time of day also affects choice of foraging locations. At the Santa Ana River colony site, Collins et al. (1979) found that Least Terns tended to forage more frequently at a pond and in the river mouth in the morning, and then switched to foraging in the ocean in the afternoon and evening; possibly in response to changes in light conditions that might affect visibility.

Selection of foraging habitats has been shown to also vary as the breeding season progresses. Collins et al. (1979) found that when chicks are small, adult Least Terns tended to focus on catching very small fish in shallow marsh channels. As the majority of chicks reached fledgling age, the focus shifted to foraging in the ocean, presumably pursuing larger prey.

Least Terns exhibit the same level of behavioral plasticity in their foraging ecology as with their selection of nesting substrate and location, and respond to differing conditions by utilizing different habitats and prey resources. Initially it appeared that proximity to an estuarine environment was a critical element of nest site selection (Massey 1974), as prior to the species decline 87% of Least Tern colonies were located within 1 mile of an estuary (see Atwood and Minsky 1983). Subsequent observations indicate that Least Terns utilize a wide variety of foraging locations and habitat types (Marschalek 2010), which may provide significant advantage in exploitation of available resources as conditions change.

3.1.1. Prey Choice

Much of what is known about Least Tern prey preferences comes from identification of fish that are either inadvertently dropped or simply not eaten. Dropped fish collected at 10 southern California coastal nesting sites included 49 species, of which 30 were considered unsuitable food items (Atwood and Kelly 1984). Unsuitable prey items included fish with body lengths greater then 5.0 cm, deep-bodied fish with a girth diameter greater than 1.5 cm, or fish that have spines or other hard features. Nonetheless, the most abundant fish species dropped do appear to represent the principal prey species consumed based on direct observation and stomach contents of Least Terns that were found dead (Atwood and Kelly 1984).

Prey species captured and consumed by Least Terns are remarkably similar across a broad geographic range including the Bay, southern California, and the Gulf of California off Baja Mexico (Elliot et al 2007, Zuria and Mellink 2005, Atwood and Kelly 1984). The most abundant prey species selected by Least Terns breeding in California are northern anchovies (*Engraulis mordax)*, topsmelt (*Atherinops affinis*), jacksmelt (*Atherinopsis californiensis*), deepbody anchovies (*Anchoa compressa*), and slough anchovies (*Anchoa delicatissima*). For coastal birds, preference for nearshore foraging habitats is apparently related to prey species selection as northern anchovies, topsmelt, and jacksmelt (all marine species) comprise 92% of captured fish considered to be suitable prey (Atwood and Kelly 1984). Elliot et al. (2007) collected and identified dropped fish at Alameda Point in the Bay and found very similar results, with topsmelt and jacksmelt comprising the primary prey, and northern anchovy making up either the most important or third most important species varying between years. Pacific Herring (*Clupea pallasi*) and surfperch (family Embiotocidae) were also abundant in collections of dropped fish.

3.1.2. Foraging Habitat Types and Selection

Least Terns utilize a wide range of habitats for foraging, including nearshore marine, estuarine, rivers and creeks, canals and ditches, and inland freshwater lakes. Habitat selection appears to be primarily in response to prey availability and abundance, although seasonal and even daily preferences are apparent.

Although Least Terns were initially considered to be primarily reliant on estuarine foraging habitats (Massey 1974), more in-depth studies have revealed that the primary foraging habitat of coastal breeding Least Terns is the nearshore marine environment. Atwood and Minsky (1983) found that birds from colonies at Venice Beach, Huntington Beach, and the Santa Margarita River, utilized nearshore marine habitat for ~75% of foraging trips.

Collins et al. (1979) found that Least Terns from the Santa Ana River area utilized specific areas in the ocean, and that use of the ocean for foraging varied at different times of the day. Least Terns were concentrated in 3 main areas: 1) just beyond the surfline, 2) up to ~0.5 mile offshore, and 3) further offshore (Collins et al. 1979). Atwood and Minsky (1983) found that while 90-95% of foraging forays were within 1 mile of shore, Least Terns occasionally foraged 1-2 miles offshore.

3.1.3. Foraging Range

Foraging range varies dependant on the availability and location of appropriate prey species and colony location. Atwood and Minsky (1983) found that 60% of foraging forays were limited to an area within 2 miles of nesting sites, although large numbers of Least Terns were occasionally observed at locations more than 2 miles from a nesting site. This has been observed at other sites as well. During most years Least Terns nesting near Santa Maria River in southern San Luis Obispo County forage offshore or on the river, yet at times they will forage at Oso Flaco Lake more then 5 miles to the north. Least Terns nesting at Oceano Dunes, within a half mile of Oso Flaco Lake, will typically forage immediately offshore or at Oso Flaco lake, and yet occasionally they concentrate a majority of their foraging activities on the inland Dunes Lakes located more then 2 miles to the north and ~1 mile inland of the nesting area (Burton, unpubl.).

Foraging locations of Least Terns from the Alameda NAS colony were observed in 2003 and 2004. Foraging commute distances for Least Terns in the Bay appear to be considerably greater than for the coastal birds described by Atwood and Minsky (1983), with birds regularly foraging up to ~3.5 miles from the colony (Elliot et al. 2004). Steinbeck et al. (2005) also monitored Least Terns over the water during the breeding season and reported observing birds up to 5 miles from the colony, however 91% of birds were observed within 3.5 miles of the colony and 98% were observed within 4 miles (Figure 4). Most of the birds observed over the Bay in 2003 and 2004 were observed south and east of the colony with a few birds venturing just northwest of the colony (Elliot et al. 2004, Steinbeck et al. 2005).

Distances traveled from the colony for 2003, reported here, are based on calculated distances between GPS locations of the observations and the Alameda colony (data provided by Meredith Elliot pers. comm.). These observations represent a subset of all observations and are exclusively for foraging birds. Distance in meters were converted to miles and grouped in 0.5 mile data bins for comparison.

Steinbeck et al. (2005) reported numbers of Least Terns observed at increasing distance from the Alameda NAS colony in 500 meter data bins (Steinbeck et al. 2005). For comparison these data were also converted from meters to miles, and grouped in 0.5 mile data bins. Least Tern activity at the time of the observations was not reported by Steinbeck et al. (2005) and their sightings likely include some observations of birds not engaged in foraging activities.

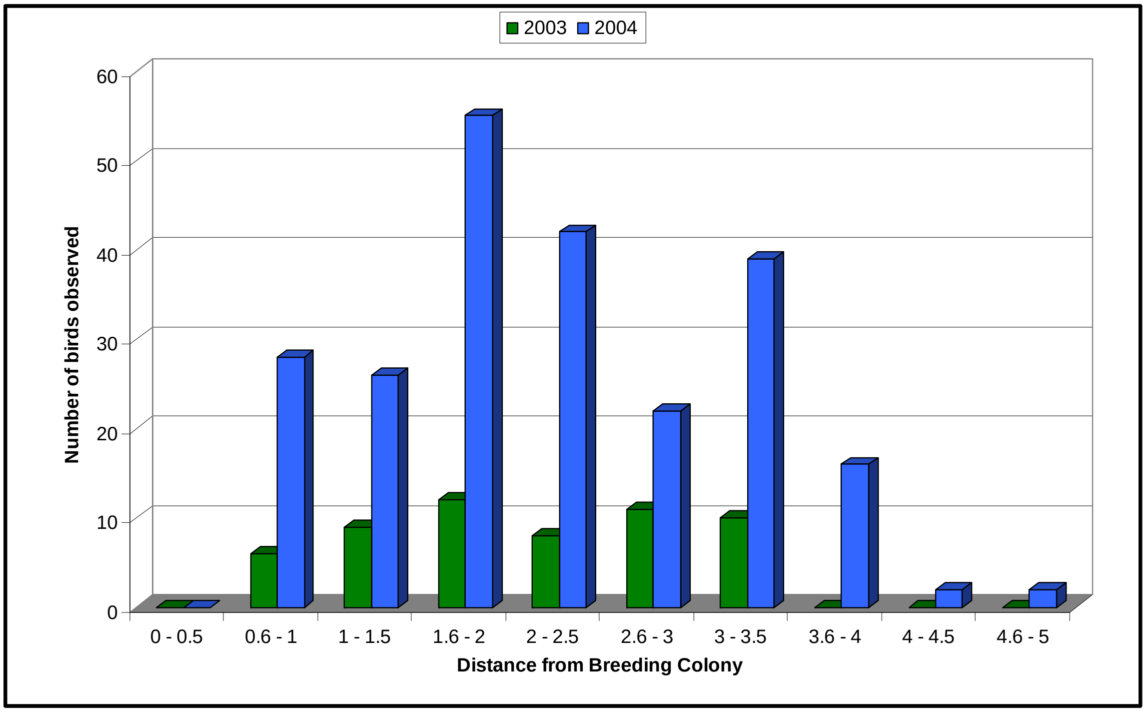


Figure 4. Distance in miles Least Terns were observed from the Alameda Point colony 2003-2004 (adapted from Elliot et al. 2004 and Steinbeck et al. 2005).

In 2003 all Least Terns observed foraging were within 3.5 miles of the colony (Elliot pers comm.). In 2004, 91% of birds observed were within 3.5 miles of the colony and 98% were observed within 4 miles of the colony. In fact only 4 of 232 birds detected in 2004 were further than 4 miles from the Alameda Point colony (Steinbeck et al. 2005). There were no other colonies reported for the southern portions of the Bay in 2003 and 2004 (Marschalek 2005, Patten 2003), and given that many of these observations occurred well into the breeding season these birds must have come from the Alameda Point colony.

The similarity in frequency of observations from 2003 and 2004, and the fact that in 2003 all foraging birds were observed within 3.5 miles of the Alameda Point colony, strongly suggests the typical foraging distance for Least Terns on the Bay is up to ~3.5 miles from the colony.

3.2. Breeding Ecology and Migration

At present Least Terns breed at over 50 locations in California, ranging from the Tijuana Estuary near San Diego, north to San Francisco Bay and inland at sites near Sacramento and Kettleman City. In 2009 alone more than 7000 pairs established more than 8000 nests, producing more than 1600 fledglings (Marschalek 2010). Although, these are remarkable statistics, when compared to 300 pairs at 15 largely unprotected sites in 1970 (Craig 1971), many of the threats present 40 years ago remain, and are abated only through vigilant monitoring and active implementation of management strategies designed to ameliorate these threats during the breeding season.

3.2.1. Timing of Arrival at Breeding Locations

Along the California coast Least Terns typically begin to arrive from wintering grounds, reaching the southern most colony sites in early April and they continue to arrive through the later part of May. In, 2008 the reported first observation of Least Terns at breeding sites occurred on 9-April at the Chula Vista Wildlife Reserve, San Diego County and first arrivals continued at colonies throughout the State through the end of May (Marschalek 2009). The precise timing varies somewhat from year to year but the basic pattern remains fairly consistent, particularly when comparing a single site between successive years.

Least Terns typically return to Bay breeding sites starting from mid-April through the later part of May. The southern Bay sites including Alameda Point and the Hayward Regional Shoreline are usually occupied earlier, often in April, and the northern sites such as the Pittsburg Power Plant and Montezuma Wetlands sites are typically first occupied later into May. The timing of arrival at Alameda Point is remarkably consistent. Between 2004 and 2008, first arrivals ranged from 13-April to 25-April, which is a relatively narrow window of time given that first observations of birds at breeding sites throughout the state may range over a period of up to 3 months (Marschalek 2008, 2007, 2006, 2005, 2004). During the period from 2004-2008 there have been a few cases when birds first arrived at Bay breeding sites as late as 21-June, suggesting that second wave nesting birds (Massey and Atwood 1983) may occasionally utilize Bay sites. These birds may also have moved from other Bay sites if not successful with earlier nest attempts.

3.2.2. Habitat Selection

3.2.2.1. Physical Criteria

The characteristics of nesting sites used by Least Terns are fairly restrictive; open, relatively flat, sparsely vegetated areas in proximity to aquatic features with a supply of appropriate prey species. Yet Least Terns seem to be able to exploit a wide range of habitats that meet these narrow criteria.

In California, they are now nesting at the Kettleman City evaporation ponds, in salt encrusted basins, foraging on mosquitofish in canals at a place where summer air temperatures exceed 100° F (Jeff Seay, pers. comm.). They nest at a major off-highway motor vehicle recreation area at Oceano Dunes, at nearly pristine sites on Vandenburg Air Force Base, among some of the most human impacted beaches in southern California, and until recently between active runways at what was the Alameda Naval Air Station. In recent years, California Least Terns have even managed to successfully nest near freeway ponds in Glendale Arizona (Marschalek 2010).

Although human activities have resulted in considerable degradation or alteration of suitable nesting sites, some activities have created new nesting substrates. Least Terns are known to utilize artificial habitats created by deposition of dredged materials (Krogh and Schweitzer 1999, Mallach and Leberg 1999), fill areas such as at Oakland Airport (Bender 1974a), sand pits created by commercial gravel and sand mining operations (Sidle and Kirsch 1993), and even rooftops (Forys and Borboen-Abrams 2006).

Even though the characteristics of nesting habitats are fairly restrictive, the degree of variation within that restricted range complicates efforts to clearly identify suitability characteristics. Thompson and Slack (1982) measured 12 physical characteristics at 39 sites along the Texas coast and concluded that elevation and spatial orientation is of primary importance in site selection, followed by substrate composition, and surface vegetative cover. Gochfield (1983) found that although physical characteristics are important in the selection and use of nesting sites, other factors including biotic conditions and level of disturbance were of equal importance.

3.2.2.2. Biotic and Environmental Factors

In general, while Least Terns prefer relatively flat and open areas, with sparse vegetation, nest sites are not randomly distributed within this habitat. Factors such as flooding and high tides, exposure, and predation also play an important role in nest site selection. There is a tendency to select areas in the center of large open areas, and to avoid the edges of beaches (Burger and Gochfield 1990). Elevation above potential flood zones is one of the most consistent factors observed (Thompson and Slack 1982, Gochfield 1983, Burger and Gochfield 1990), although at a dune backed beach this may be offset by avoidance of areas where mammalian predators may enter the beach and colony. Vegetation is an important element for chick survival in that it provides cover from predators and exposure to heat stress and cold weather, both of which are potentially important mortality factors (Overstreet and Reehack 1982, Storey 1987). However, if vegetation is too dense it will likely be avoided as denser vegetation may harbor mammalian predators and it reduces visibility and the ability to detect approaching threats.

A clear line of sight in all directions may be one of the most important factors in nest site selection, within areas that are otherwise suitable. Least Terns showed a significant preference for ridges and slopes over troughs and flat sections of beach (Burger and Gochfield 1990). The ability to detect predators or other threats at a distance may be as important a factor in the selection of elevated locations (Thompson and Slack 1982), as is flood avoidance.

3.2.3. Courtship

Pair bonds form shortly after birds arrive at breeding sites in California, and a large percentage of pairs re-mate in subsequent years (Collins et al. 1979). Courtship may or may not take place at the nesting site. Tompkins (1959) reported observing courtship at locations that were several miles from nesting sites. At Oceano Dunes, courtship typically takes place at Oso Flaco Lake just behind the foredunes and about a half a mile to a mile from nesting sites (Burton 1996). A boardwalk that extends over the lake now makes this an ideal location as courtship often takes place on some type of elevated platform. Males will capture a fish and then engage in aerial displays after which he typically feeds the fish to the waiting female. The male apparently selects the courtship site and the female selects the nest site (Thompson et al. 1997).

3.2.4. Nests

Nests are small shallow scrapes the adult birds excavate in the ground surface, with a diameter of ~3-4 inches and a depth of less than an inch. Nests are often decorated with shells, sticks, or other items, which may provide a complimentary background for cryptic colored eggs. Eggs match the substrate remarkably well, with a light tan to beige overall background and black, tan, and gray markings and blotches that visually break up the shape of the egg. Least Tern nests typically include 2-3 eggs, although 1 or 4 egg nests occur. Incubation may not start until the nest is complete (Burton 1996).

3.2.5. Activity Patterns

Both adults incubate the eggs although the female apparently spends more time at the nest (Thompson et al 1997). The bird that is not incubating eggs will deliver fish to their mate on the nest and when approaching will typically call and often the adult on the nest will respond by taking flight and vocalizing. Both birds may be present at the nest site at the same time during certain times of day, with one bird on the nest and one roosting nearby. The bird incubating the nest will watch for approaching predators or other dangers by constantly turning the head side to side. When a potential predator or other intruder is detected adults will take flight and vocalize, which usually invokes other birds to join in harassing intruders by diving at them, vocalizing, and defecating.

Although, there is limited quantitative data on how Least Terns partition their daily activities, observations reported by Burger (1988) indicate that a majority of time spent during the pre-incubation period is courtship, territorial defense, nest scraping, and foraging. With the onset of incubation, daily activities are focused on foraging and delivering fish to the mate, defense of the nest area against predators or other intruders, and resting. At Oceano Dunes, birds tended to be active starting early in the morning with foraging and delivering fish to the incubating bird, switching roles from time to time and continuing to fish through early afternoon, at which time both birds may remain at the nest for a period of a few hours; one bird incubating and one resting 5-10 yards from the nest. Birds were typically active again in the afternoon following the same routine, and then would once again settle down during the evening hours.

3.2.6. Colony Size and Nesting Density

In 2009, California colonies ranged in size from 1 to 914 pairs at a single site, and at Camp Pendleton the total number of nesting pairs was estimated at 1639 for 7 closely located sites (Marschalek 2010). Schweitzer and Leslie (1999) estimated nesting densities equivalent to ~0.04 – 0.3 nests/acre. Elliot et al (2007) reported the nesting area at Alameda point was expanded in 2004 to include ~9.6 acres, and that year the number of pairs at the site was estimated at 379, suggesting nest densities up to 41 nests/acre, which is the equivalent of 1 nest every 5-6 yards. In contrast to the high density of nests at the Alameda sites, nests at Ocean Dunes were typically separated by 10s to 100s of yards (Burton et al. 1996).

Burger (1988) investigated the effect of the numbers, distribution, and spacing of birds by mimicking various conditions with decoys. Least Terns were attracted to larger rather then smaller groups and found that birds were attracted to "colonies" where decoys were spaced at ~5 foot intervals and less interested when decoys were spaced at ~1.6 foot intervals. This suggests that birds may be attracted to established colonies more than startup colonies, but may also be deterred by what might be perceived as more crowded colonies.

Brunton (1999) found that with regard to predation the benefit of large colony size varied considerably dependant on types of predators. Overall hatching and fledging success did not increase with increased colony size, although the percentage of predated nests dropped. Larger colonies were beneficial in reducing the overall effect of predation by Herring Gulls (*Larus argentatus*), American Crow (*Corvus brachyrhnchos*) and by small mammals that tended to hunt the periphery of the colony. Large colonies on the other hand tended to attract predation by Black-Crowned Night Herons (*Nycticorax nycticorax*), which may fly directly into the center of the colony.

In 2009, there appears to have been little correlation between colony size and nesting success among California sites (Marschalek 2010). The top five most successful sites, in terms of estimated minimum number of fledglings per pair, were in order Vandenburg AFB (30 pairs), Oceano Dunes (25 pairs), Hayward Regional Shoreline (88 pairs), Alameda Point (314 pairs), and Hollywood Beach (4 pairs). Some of the largest colonies exhibited the lowest success rates, such as the NAB Ocean site (San Diego Bay) where 1093 nests produced only 22 fledglings (0.02 fledglings/pair).

Given that colonies in the past may have been much larger than even the largest colonies that exist today, the optimal colony size may not be discernible. Other factors appear to have a much greater effect on nesting success, of which management appears to be the most significant at this point in time.

3.2.7. Nesting Site Fidelity

With a species such as the Least Tern where individuals cannot be readily differentiated from one another, quantifying site fidelity for individuals requires marking them for identification, which in this case involved banding chicks at several colonies. Atwood and Massey (1988) examined both natal site fidelity and year-to-year colony site fidelity in southern California, and found that Least Terns return to their natal breeding sites more frequently then would be predicted had birds selected sites at random. At the one site where they were able to identify nearly all nesting birds over a 4-year period, they found the mean annual rate of return to be 78%. Other researchers have considered the year-to-year stability in the number of pairs and the locations of nests to also be an indication of a high degree of site fidelity (Burger 1984).

Nesting site fidelity is however dependant on a number of ecological factors that may render the site unsuitable or have a negative effect on reproductive success during the previous year (Burger 1984). Factors shown to affect year-to-year site fidelity include geomorphic stability of the site (e.g., shape of back beach dunes, extent of sandbars), level of predation, and disturbance (primarily by humans). Sites may become useless as a result of changes in vegetation, as Least Terns will avoid areas of dense vegetation that can harbor predators (Burger and Gochfield 1990). Site fidelity can be encouraged through management of sites to maintain suitability, such as control of vegetation (Atwood and Massey 1988). Alternatively, management of habitats for other purposes can have devastating unintended affects on site fidelity. For example, at Bay Farm Island colony declined from nearly 200 pairs to 1 pair after the site was seeded with soil binding grasses (Bender 1974a). Sites may also be abandoned due to natural changes in the substrate as a result of flooding, wind, or other natural processes.

Predation may also affect site fidelity and colony stability, however the impacts of predation are complex and not well understood. Atwood and Massey (1988) documented abandonment of a colony site following a single season where 15 of 16 nests were destroyed by red fox (*Vulpes vulpes*). In comparison they described another colony where although nearly 100% of nests were predated by coyotes (*Canis latrans*), there was little apparent affect. Control of predation has been employed at many intensively managed sites, and this has positively affected colony stability and site fidelity (See annual breeding surveys 1971-2008).

Disturbance of colony sites by people can have a profoundly negative effect on site fidelity, while some types of human disturbance are highly tolerated. Burger (1984) reported that at one colony more than 50% of reproductive failure resulted from human disturbance, primarily off-road vehicle and pedestrian traffic through a colony, and this resulted in abandonment of the site. Yet Least Terns were highly tolerant of aircraft landing and taking off at the former Alameda NAS, where terns repeatedly nested even before there was any active management or protection of the colony (Atwood 1977). Atwood and Massey (1988) noted that "intense levels of disturbance associated with research activities" had no apparent negative affect on year-to-year site fidelity. At Oceano Dunes, Least Terns on nests protected with small single-nest exclosures (~30 feet in diameter) typically ignored all-terrain vehicles and motorcycles even when they passed nearby (Burton 1996). In recent years the Oceano Dunes colony, though small, is relatively stable and birds regularly return to nest within a large seasonally constructed exclosure fence where pairs consistently have among the highest fledging success rates in the state (Marschalek 2008).

Least Terns naturally exhibit a high level of both natal site fidelity and year-to-year site fidelity if conditions allow. There are several factors that can affect site-fidelity including changing physical and biotic conditions, predation, and disturbance. Persistence, consistency, and growth of carefully managed sites (e.g., Alameda Point, Oceano Dunes, and Venice Beach) suggests that at this time colony stability and site fidelity is most significantly benefitted by human protection efforts or impacted by human disturbance.

3.2.8. Age of Adults and Reproductive Success

Most Least Terns return to first breed during their third year, yet many do breed during their second year (Massey et al. 1992). Massey et al. (1992) also found that the majority of breeding adults (80%) are between 2 and 7 years of age; with a few birds continuing to breed up to at least age 13. Least Terns have not been known to breed during their first year. Massey et al. (1992) estimated the expected individual breeding life to be 9.63 years with a lifetime breeding productivity of 1.49 fledglings per breeding adult bird.

Reproductive success at colonies in California, measured as the number of fledglings produced per pair annually, varies widely among sites and between years. For example in 2009, the estimated minimum number of fledglings/pair ranged from 0 to 1.19 for single colonies and may have been as high as 1.47 fledglings/pair at Alameda Point. Statewide the 2009 average productivity was between 0.24 and 0.29 fledglings/pair.

Between 1999 and 2009 the estimated statewide average fledgling/pair ratio ranged from 0.13 to 0.84 with an overall estimated average of between 0.34 - 0.40 (S.D. 0.19). Colony sites at Alameda Point, Oceano Dunes, and Venice Beach are all locations that are actively managed and although very different in terms of colony size and setting, have some important commonalities and differences in terms of reproductive success.

Between 1999 and 2009, at the Alameda Point colony there were on average 327-335 pairs (Range 250-495 pairs; SD – 58-71). At the colony at Venice Beach there was an average of 235-236 pairs during the same period (Range 2–698 pairs; SD 169– 212), and at Oceano Dunes during the same period there were on average 34–35 pairs (Range 4–59; SD 18). At the two sites that supported larger colonies the average number of fledglings/pair ranged from 0.6–0.9 at Alameda Point, and 0.3–0.5 at Venice Beach, while at Oceano Dunes, a relatively small colony, the average number of fledglings/pair was between 0.8–0.9 (Table 1). At all sites the standard deviation of the fledgling/pair average was relatively large, and similar (0.4–0.5).

What is apparent is that reproductive success is highly varied among colonies and within individual colonies over successive years, and there does not appear to be a correlation with colony size. The Revised Least Tern Recovery Plan (USFWS 1985) identified a minimum reproductive success rate of 1.0 fledgling/pair as one of the criteria for downlisting the California Least Tern from a status of endangered to threatened. The USFWS 5-year review evaluation of the California Least Tern acknowledged that the reproductive success rate of the California population, though considerably lower on average than 1.0 fledgling/pair, had clearly resulted in an increase in the population from a few hundred pairs in 1970 to several thousand in 2009.

Table 1. Low and high estimates of fledglings/pair at three managed California Least Tern colonies 2009-1999.

	Alameda Point		ODSVRA		Venice Beach	
	Low	High	Low	High	Low	High
2009	0.8	1.5	1.2	1.3	0.0	0.0
2008	1.1	1.6	1.3	1.3	0.4	0.6
2007	0.4	0.6	1.3	1.3	0.9	1.0
2006	0.0	0.3	1.2	1.2	0.5	1.2
2005	0.3	0.9	0.4	0.4	0.0	0.0
2004	0.4	1.0	0.5	0.5	0.0	0.0
2003	0.4	0.8	0.6	0.7	0.5	1.1
2002	0.4	1.3	0.5	0.5	0.0	0.0
2001	1.3	1.3	0.4	1.2	0.9	1.2
2000	0.7	0.8	1.0	0.8	0.5	0.7
1999	0.3	0.3	0.3	0.2	0.0	0.0
Average	0.6	0.9	0.8	0.9	0.3	0.5
St. dev.	0.4	0.4	0.4	0.4	0.4	0.5

3.2.9. Least Tern Chick Growth and Development

At the time of hatching, Least Tern chicks weigh between 0.16 and 0.25 ounces and will increase in weight to ~0.18 to 0.39 ounces within the first day (Thompson et al. 1997, and references therein). Chick weight increases substantially to more than 1.3 ounces over the next 2.5 - 3 weeks. Wing growth is delayed for the first few days and then continues steadily until chicks are fully grown. Newly hatched chicks are fairly helpless and unable to regulate their body temperature, so adults will brood chicks for the first couple of days protecting them from exposure to both high and low temperatures (Thompson et al. 1997, and references therein).

After the first couple of days chicks are active and are able to move about and find cover on their own. Both adults provide food to the chicks, and examination of fish dropped by adults revealed that adults capture much smaller fish for the young than for mates or large chicks (Atwood and Kelly 1984). Adults typically deliver 1-2 fish per hour to young and continue to feed them even after they've fledged, which occurs after chicks reach the age of ~20 days (Thompson et al. 1997). Once the chicks are able to fly they are led to foraging areas, where the adults continue to feed the fledged chicks which will often follow the adult birds, vocalizing and harassing them until fed. Studies of banded Least Tern chicks indicate that most young birds leave the colony within ~3 weeks of fledging (Thompson and Slack 1984).

California Least Terns may also use non-breeding sites during the post-breeding season where they will gather and roost, and continue to feed fledglings up to 8 weeks of age. At these roosts, adult birds and fledglings from multiple colonies may intermingle until setting out on their southward migration. Pre-migration flocks normally begin to form in late July and early August, though birds may not migrate from California until late September (Thompson et al. 1997).

3.3. Quality of Food Resources on Reproductive Success

3.3.1. Anchovies Verses Smelt Species

Elliot et al (2007) reported a remarkable effect related to increased consumption of northern anchovy that suggests there is a significant benefit in quality of this food resource. They found that a small increase in the abundance of anchovy in the diet had a very dramatic effect on fledging success. When the percentage of anchovy in Least Terns diet increased from 1% to 5%, the fledging success rate increased from 0.16 to 0.67 fledglings per breeding pair. The authors attributed the significant advantage apparently gained by consuming larger quantities of anchovy, to the elevated lipid content in this species which would provide substantially more energy to growing chicks (Dahdul and Horn 2003).

4. Factors that Limit Least Tern Population Growth

The California Least Tern is an unusual species in terms of management and recovery of the population from near extinction, in that little is known about the biology of the species during the non-breeding season. Large annual declines in the number of breeding pairs, such as was observed in 1998 - 1999, and 2001-2002 (Figure 1), suggests that hazards faced by wintering birds may be substantial. Likewise there are numerous problems faced at breeding colonies and considerable effort has been focused on ameliorating these threats and improving reproductive success.

California Least Terns breed in habitats that are also very attractive to people and as a result these habitats have been highly impacted by urban development and recreational activities. Nests established on the ground are extremely vulnerable as are the flightless chicks. Nests can prove to be extremely difficult to locate even for people who are experienced doing so, making them hard to avoid and even the most innocuous activity can be potentially devastating. People walking on the beach or through a colony can be as damaging as equestrian or off-road vehicle traffic. In addition, exotic red fox, domestic dogs (*Canis familiaris*) and cats, and black rats (*Rattus rattus*) have increased predation pressure on both chicks and adults, and in some cases have resulted in abandonment of colonies (Burger 1984, Craig 1971).

4.1. Available Habitat

The vast majority of what historically would have been suitable nesting habitat for Least Terns along the California coast is no longer suitable as a result of urban development, recreation, and beach maintenance activities. Grinnell and Miller (1944) described the geographic range of Least Terns in California as extending from the Mexican/U.S. border to Monterey Bay, with the northernmost breeding colony at Moss Landing in Monterey County. They also however reported incidental sightings of birds in the Bay area including sightings at Alameda.

In 1944, when Grinnell and Miller published their account, the perimeter of the Bay was already highly developed as was Alameda Point which by 1864 was the terminus of the trans-continental railroad. By 1879 there was an oil refinery on the island, and the Alameda Naval Air Station was opened in 1940. The opening of the Alameda Naval Air Station was also preceded by dredging of shallow tidal channels around the island; an area that would likely have supported eel grass beds and abundant forage species. Given the prehistoric ecological condition of the Bay region, which received huge inflow of freshwater that supported vast wetlands and tidal sloughs, it is likely that Least Terns were abundant in the region during the breeding season in the past.

Recent documentation of Least Terns at inland sites near Sacramento and Kettleman City and relatively frequent sightings throughout the Central Valley (Marschalek 2010) suggests the species may have formerly bred at a wide range of inland sites as well. The site where Least Terns are now breeding near Kettleman City was at one time the west edge of the former Tulare Lake (Jeff Seay pers. comm.). Tulare Lake filled seasonally from runoff off the southern Nevada and given the rapid and regular expansion and contraction of the lake’s surface there would likely have been large open areas, free of vegetation which would have been ideal Least Tern nesting substrates. Furthermore, there would have been abundant suitable prey (Moyle 2002).

At present, Least Terns are known to nest at only 58 locations and the majority of these are located in southern California (Marschalek 2010). While this is a remarkable increase from the 15 sites known in 1970 (Craig 1971), it is most likely a mere fraction of the pre-historic breeding range of the species. Furthermore, many of these sites are highly compromised by the proximity of high density urban areas, disturbance by people, exotic predators that survive in these modified habitats, pollution, and degradation of freshwater and nearshore aquatic habitats. The largest colonies, and often the most productive are currently located at military installations, were they have presumably persisted at least in part due to the fact that military security procedures precluded access by the general public to the breeding sites. Furthermore, as these sites became more actively managed for the benefit of Least Terns, control of access to the sites could be assured.

4.2. Anthropogenic Disturbance at Breeding Sites

As described above (Section 3.2.7), certain types of anthropogenic disturbance can severely impact Least Terns at breeding colonies and at foraging locations. Pedestrians and equestrians may trample eggs or may flush the adults exposing checks to increased predation and excessively high or low temperatures; off-road vehicle traffic may result in mortality of adults and chicks as well as destroy eggs; uncontrolled dogs may cause adults to flush as may toy kites; and boat or jet-ski traffic may disrupt foraging birds.

At most of the California breeding sites, managers and monitors have developed and implemented measures to reduce disturbance by people with fencing, signage, and regular monitoring. At many locations implementation of these types of measures has significantly reduced direct effects of anthropogenic disturbance, but the problem has not been completely eliminated. In 2008, 3 of 58 colony sites were abandoned, due in part to human disturbance (Marschalek 2009). While human disturbance is not currently a major mortality factor for Least Terns, it undoubtedly was in the past, and would likely be a significant problem without the intensive management and protection of colony sites that is currently carried out.

4.3. Presence of Natural and Introduced Predators

Currently a far more important issue is predation by both natural and introduced predators. There are 25 species that have been documented preying on Least Terns (including adults, chicks, and eggs) ranging from Argentine ants (*Linepithema humile*) to coyotes (Marschalek 2009). Of the 25 documented species of predators, 19 are avian, 5 are mammals, with 1 invertebrate. Of the 25 all are considered to be native to North America with the exception of the European starling (*Sturnus vulgaris*). There are an additional 21 species that are suspected to prey on Least Terns though not confirmed. Unconfirmed yet suspected predators include an undetermined species of snake, and 12 avian species of which only the rock pigeon (*Columba livia*) is exotic. There are an additional 8 species of mammals that are suspected to prey on Least Terns, including exotic red fox and domestic dog and cat (Marschalek 2009).

Although the vast majority of species identified at potential predators of Least Terns are native many of these are species whose population levels have dramatically risen and distributions have substantially expanded, in response to anthropogenic changes in habitats and ecological communities. For example, important predators of Least Terns include coyote, striped skunk (*Mephitus mephitus*), Northern Raven (*Corvus corax*), American Crow (*Corvus brachyrhyncos*), and numerous species of gulls (*Larus spp.*). Though native these species have benefitted from human activities that either eliminated competition and predators, such as wolves (*Canis lupus*) in the case of coyotes (Smith et al 2009), or created new foraging opportunities such as garbage piles and dumps; which have benefitted gulls, ravens, and crows (Marzluff et al. 2001). Increased concentrations of these predators can have devastating affects such as causing complete reproductive failure and colony abandonment (Burger 1984).

Active predator control measures have been implemented at numerous sites. These include physical barrier fences such as has been constructed around the Alameda Point colony (Elliot and Sydeman 2007). Electric fencing can also prevent mammalian predator access to the colony, but requires extraordinary vigilance to ensure the fence remains charged. Elimination of avian predators, many of which themselves are protected, can prove to be more difficult and may require removal from the site using lethal methods for common or exotic species and relocation of protected species. Even with the current level of effort predation continues to be one of the most significant decimating factors and eggs, chicks, fledglings, and adult birds are taken (Marschalek 2009).

5. Known Effects of Dredging on Least Terns

Dredging within the vicinity of breeding or foraging Least Terns may potentially result in direct impacts related to operation of equipment as well as secondary impacts related to plumes of re-suspended sediments that may impact foraging success, prey species and their habitats, and increase risk of contamination.

5.1. Direct Impacts on Nested Least Terns

Noise produced by dredging equipment has the potential to directly impact Least Terns both while on the nest and while foraging. If dredging equipment is operated close to a nesting site birds could be flushed off nests and noise may interrupt communication between the adult birds or discourage use of foraging areas.

5.1.1. Noise

There is little information in the literature regarding direct impacts to Least Terns resulting from noise generated by dredging operations. There is however considerable evidence that anthropogenic noise can result in significant impacts to wildlife and to birds in particular in terms of affecting auditory detection levels and communication. Francis et al. (2009) found that increased noise levels resulted in reductions in species richness and shifts in forest avian communities. Yet, they also found that in some cases increased noise levels can benefit reproductive success by disrupting predator prey interactions, for tolerant species.

Least Terns at California breeding sites likely experience a wide range of noise levels. Those breeding at colonies at Vandenburg AFB are remotely located and may not experience any anthropogenic disturbance beyond those created by colony monitors (Robert K. Burton, personal observation). Least Terns breeding near industrial centers such as at Alameda Point or Long Beach Harbor on the other hand regularly encounter relatively high ambient sound levels (Atwood et al. 1977).

Elevated ambient noise levels may affect the ability of individual Least Terns to detect approaching predators and potentially more important may mask alarm calls of birds that do detect an approaching predator. Disruption of alarm call behaviors, which typically result in a mobbing response aimed at the intruder, would have potentially significant impacts throughout the colony. Least Tern pairs are highly communicative, particularly when on nests. Birds returning to the nest with a fish will call and their mate will respond and often take flight alighting away from the nest. High levels of ambient noise may interfere with communication between the pair and may also interfere with territorial defense and mate attraction (Slabbekoorn and Ripmeester 2008, Francis et al. 2009).

5.2. Direct Effects of Dredging Operations on Foraging birds

Potential sources of impacts related to dredging operations that may affect Least Terns, also include increased noise and activity levels if dredging operations take place in foraging areas. Elevated noise levels may cause avoidance of foraging area and decreased communication between foraging birds.

5.2.1. Noise Deterring Birds from Utilizing Foraging Locations

If noise associated with dredging operations is sufficient to partially or completely deter birds from utilizing a foraging location birds may have to fly significantly farther too alternate forage locations. Disruption of foraging could result in increased energetic expenditure to locate and utilize potentially more distant foraging sites. Increased energetic output by foraging adults along with increased commute time would be expected to result in decreased rate of delivery of food to chicks, which would have a cascading affect of reducing chick growth and potentially survival.

5.2.2. Noise Affecting Communication

Least Terns are highly vocal while foraging and apparently communicate while travelling between foraging and nesting sites (Atwood and Minsky 1983) so even if noise levels associated with the dredging operation are not sufficient to deter birds from the dredge site, the noise may be sufficient to disrupt this communication. If dredging operations are conducted at locations where Least Terns normally forage, birds may also be impacted during courtship. Courtship activity often takes place at locations nearby the colony, and vocalization and the capture and offering of a fish are an important part of the ritual (Tompkins 1959). Any disruption of courtship could potentially have significant impacts on breeding within an entire colony.

Of equal concern is the potential impact of noise from dredging on fledglings learning to forage. Adults will lead fledglings to foraging areas during the post season where fledged chicks are fed by the adults while developing their own foraging skills (Thompson and Slack 1984). Communication between the adult birds and fledglings during this period is active and critical to maintaining contact between the adults and young, who are too young to efficiently feed themselves. Fledged chicks will attempt to capture fish, but will also follow the adult birds, vocalizing and harassing the adults until fed. Disruption of foraging at this stage would likely have significant impacts on the survival of fledged chicks.

5.2.3. Impact of Dredging Noise in Areas with Elevated Background Noise Levels

If noise or activity associated with dredging operations were to result in repeated disturbance of nesting Least Terns this disturbance would likely result in increased exposure for eggs or chicks. Likewise, if dredging operations disrupt foraging efficiency the impacts on nested birds could be significant in the form of reduced energy intake by adults and chicks, which would likely reduce reproductive success. However by definition dredging occurs in places where ambient noise levels are already expected to be elevated well above natural background levels. The need for dredging in coastal waters is driven primarily by the desire to maintain relatively deep water channels necessary to facilitate shipping traffic in and out of large industrial ports. Least Terns that occur in areas, such as Alameda Point, where dredging is required to facilitate movement of very large ships, by default already experience elevated levels of anthropogenic noise; and noise levels produced by dredging operations are not likely to result in significant increase in cumulative impacts unless the dredging operations were to take place immediately adjacent to the colony.

5.3. Effects of Turbidity Plumes Created by Dredging or Dumping of Dredged Sediments

Turbidity in the Bay is the result of a wide range of natural processes and anthropogenic sources. In the Bay tidal currents, wind-waves, and circulation may re-suspend sediments in shallow areas and transport suspended particles to other locations (Schoellhamer 2002). Runoff water from more than 60,000 mi^2 of California drains through San Francisco Bay, most of which starts as runoff from the Sierra Nevada Mountains eventually joining the Sacramento and San Joaquin Rivers which ultimately deliver large quantities of suspended sediments to the Bay (McKee et al. 2006). In fact studies of suspended sediment concentrations at San Pablo Bay, a northern subembayment of San Francisco Bay, suggests that over a basin-wide scale these natural processes have a substantially greater influence on suspended sediment concentrations in the Bay, then does dredging (Schoellhamer 2002).

Nonetheless, physical and biotic impacts in the vicinity of dredging operations may be very significant. Unnaturally high levels of turbidity may affect productivity of phytoplankton, photosynthesis in macrophytes, benthic invertebrates, fish, and the foraging success of Least Terns and other piscivorous birds.

5.3.1. Effects of Turbidity on Least Tern Foraging Success

The US Fish and Wildlife Service programmatic Biological Opinion (BO) identified increased turbidity as an impact in that it may negatively affect Least Tern foraging success, by decreasing visual detectability of fish in the surface layer (USFWS 1999). The California Department of Fish and Game also recognized turbidity affects on foraging success as a potential impact of dredging activities on Least Terns (CDFG 1998).

While the relationship between water clarity and foraging mode and success has been studied to some extent, the conclusions are mixed. Ainley (1977) first proposed that foraging mode was a function of water clarity with pursuit divers (such as underwater swimming cormorants [*Phalacrocorax spp.*]), preferably occurring in turbid waters where prey would be less likely to detect their approach. Alternatively he proposed that plunge divers would be expected to occur in clear waters where prey would be more easily detected from the air.

Becker et al. (1985) studied the foraging success of Common Terns (*Sterna hirundo*) and found that increased turbidity resulted in limited feeding efficiency. These observations however were made during a period of intense weather involving extended periods of heavy rain and high winds. The authors noted the cause of decreased foraging success may also have been due to high winds, and loss of visibility caused by raindrops hitting the water surface. Furthermore decreased foraging success could have been due to the expected movement of prey species to deeper waters, avoiding the choppy surface water. Likewise Benninkmeijer et al. (2002) reported that for little terns, prey mass, capture rate, and therefore food intake rate were higher in clearer water. They reported similar patterns for Sandwich Terns (*S. sandvicensis*) and Royal Terns (*S. maxima*), but also noted that water clarity had a more pronounced effect on the size of fish that were captured then on the capture rate. Nonetheless, overall food intake (g/hr) was higher in clearer water.

Cyrus (1991) described the influence of turbidity resulting from river outflow, on the foraging behavior of Little Terns. He observed terns foraging at the margin between sediment laden river water and the clear marine water, and found that terns were focused on fish that had concentrated among vegetative debris trapped between opposing currents. He also reported that Little Terns appeared to forage within turbid and clear water on either side of the margin, with equal frequencies.

In contrast, Haney & Stone (1988) found that Least Terns were more frequently found in more turbid water than would be expected were they distributed randomly. However these results are probably more a function of the nearshore/offshore turbidity gradient, as Least Terns are known to feed at more inshore locations, at least while breeding (Atwood and Minsky 1983). Their results do however suggest that Least Terns are capable of foraging in turbid water, as do the observations of Atwood and Minsky (1983) who noted that Least Terns often feed immediately offshore of the wave crash zone.

Similar to the findings of Haney & Stone (1988), Common Terns show an apparent preference for turbid water (Safina & Burger 1988), as do Forster's Terns (*S. forsteri*) foraging on Monterey Bay (Henkel 2006). There is also some evidence that turbidity may provide some advantage to plunge divers by attracting juvenile fish seeking refuge from fish predators (Blaber and Blaber 1980). Fish then tend to rise to the surface in more turbid waters making them more vulnerable to aerial predation (Safina & Burger 1988).

There is evidence that increased turbidity resulting from dredging operations could potentially decrease foraging success of Least Terns in the Bay, as a result of decreased visibility. There is also evidence that higher turbidity may benefit Least Tern foraging by concentrating prey in the surface layer. Given the relatively short duration of turbidity plumes generated by dredging (Ruffin 1998), overall impacts resulting from visual impairment of foraging Least Terns may not be significant.

Nonetheless, secondary impacts resulting from repeated disturbance, re-suspension, and deposition of sediments may have significant secondary effects on Least Terns, their prey and the habitats and ecological communities on which they rely. Potentially the most significant of which is the increased risk of contamination by pollutants archived in the sediments.

5.3.2. Effects of Turbidity on Prey Species

When compared to pelagic environments, nearshore waters are expected to naturally be more turbid due to greater wind wave mixing of bottom sediments, and higher concentrations of heterochthonous inputs from both the land and freshwater systems. As a result the evolved ecological tolerance to turbid water is expected to be higher for nearshore species than would be the case for epipelagic or deepwater benthic species.

5.3.2.1. Direct Effects of Turbidity on Prey Species

Natural background turbidity levels in estuaries typically range from a few mg/L to several tens/hundreds of mg/l. For example, measured suspended sediment concentrations at Mallard Island, near the outfall of the Sacramento River into the Bay, ranged from 5-420 mg/L (McKee et al. 2002). Suspended sediment concentrations in the immediate vicinity of dredging operations may exceed several thousand mg/L (Auld & Schubel 1978), although extremely high concentrations of dredge induced suspended particles are expected to persist for relatively short durations and over a limited area.

The majority of research on the effects of elevated turbidity levels on fish has been largely focused on salmonids and the secondary impacts of logging on freshwater systems (Berry and Hill 2003). Wilber & Clark (2001) have focused attention specifically on the impacts of turbidity generated by dredging operations in estuarine environments and concluded that the impacts on fish and shellfish are not well understood.

Auld & Schubel (1978) examined the effects of suspended sediments on fish eggs and larvae by experimentally exposing them to increasing concentrations. The found little affect on the hatch rate of fish eggs exposed to suspended sediment concentration of up to 1000 mg/L for some species, while concentrations above 1000 mg/L significantly reduced hatch rate. Morgan et al. (1973) found no significant increase in mortality of eggs held at suspended sediment concentrations of ~2200 mg/L. In fact they found no significant decrease in hatch rate when up to 50% of the egg surface was buried in sediments. Morgan et al. (1973) did however find that when concentrations of suspended sediments exceeded 1500 mg/L, hatch time increased as a result of decreased rate of embryonic development. While the fish species these authors studied are not typical prey species of Least Terns, they do occur in similar environments.

Although the affects on eggs were limited the affects on fish can be much greater. Auld & Schubel (1978) found that exposure to suspended sediment concentrations, exceeding 500 mg/L for 48 and 96 hours, significantly reduced the survival of striped bass (*Marone saxatilis*) and yellow perch (*Perca* flavescens). Conversely Cyrus & Blaber (1987) found that anchovy (*Thryssa vitrirostris*) from African estuarine environments showed a strong preference for very turbid water, and although the composition of suspended particulates from African river outfall is expected to be very different then particulates re-suspended by dredging in the Bay, it does suggest that anchovy may have high tolerance for turbid water. Kiorboe et al. (1981) found no effect on Pacific herring (a known prey species of Least Terns), when fish were exposed to suspended sediment concentrations of up to 500 mg/L. Boehlert& Morgan (1985) found that suspended particle concentrations ranging from 500mg/L to 1000mg/L actually enhanced feeding rates in Pacific herring, although at higher concentrations feeding rates were reduced.

Life stage may also be important in terms of turbidity related impacts. Johnston & Wildish (1982) found that feeding success of younger larvae was more affected by increased suspended sediment concentrations, than for older larvae. They also observed fish moving higher in the water column as turbidity increased, presumably as a function of decreased light levels at greater depths.

5.3.3. Fish Avoidance Behavior

Turbidity may affect behavior of fish both in their response to a turbidity plume as well their movement within turbid water.

5.3.3.1. Movement out of the Plume Region

Fish clearly show an ability to avoid or enter turbid water, and are expected to avoid areas where particulate concentrations are high enough to be lethal. Blaber & Blaber (1980) found that turbidity was the most important factor governing the distribution of juvenile fish in estuaries. Fish either occurred almost exclusively in turbid waters, almost exclusively in clear water, or appeared indifferent to water clarity. What is apparent is that fish are able to detect differences in some physical characteristic that enables them to respond to differences in concentrations of suspended particulate matter; which is most likely the decrease in light intensity and visibility (Johnston & Wildish 1982). Furthermore, fish may actively seek out or avoid turbid waters for a number of reasons, including predator avoidance and food resources, and this pattern is observed for juvenile as well as adult fish (Cyrus & Blaber 1987).

5.3.3.2. Movement within the Water Column

While turbid waters may provide refuge from predation by piscivorous fish, the response of fish to turbid waters while feeding may increase the potential they will be detected by avian predators. Mous (2000) reported that smelt (*Osmerus eperlanus*) aggregate within the top of the water column when in turbid water, and occur at much deeper levels when the water is clear. Presumably, occupying surface waters to take advantage of available light when turbidity results in darkness at depths, and they utilize deeper water when light penetrates further due to water clarity. Johnston and Wildish (1982) found a similar pattern in an experimental setting. While examining the relationship of suspended sediment concentrations and forage visibility for herring they found that as suspended sediment concentrations were artificially increased, herring larvae moved into the upper, illuminated portion of the water column. These observations suggest that foraging success of plunge diving birds could in fact be enhanced by increased turbidity.

In the immediate vicinity of dredging operations suspended sediment concentrations may be sufficiently high to displace fish or even increase fish mortality. Elevated turbidity, resulting from dredging operations, may in some cases also enhance foraging for Least Terns in areas where suspended sediment concentrations are sufficiently dissipated; by concentrating larval fish seeking cover from aquatic predators and by forcing fish to the surface where they would be more readily accessible to avian predators.

5.3.4. Dredging Related Impacts to Water Quality

Dredging equipment is mechanical and motorized and therefore requires the use of fuels, oil, grease, hydraulic fluids, solvents, and numerous other chemicals. Undoubtedly some of these chemicals and petroleum based products will be leaked into the surrounding water, although the extent of leakage and subsequent impacts are expected to be limited. What is likely to result in far more significant impacts for Least Terns is exposure to chemical constituents archived in Bay sediments, which are re-suspended by dredging and subsequently incorporated into biological processes.

For the past two centuries, the sediments in the Bay have been the largely unintended repository of waste resulting from human activities within a massive watershed that includes most of the San Joaquin Valley and Sierra Nevada mountains and foothills. Essentially every constituent introduced into waterways that reach the San Joaquin and Sacramento Rivers eventually reaches the Bay where relatively low hydraulic velocities result in settling of particulates out of the water column. In addition to inputs from these far reaching sources local inputs from industry, shipping, and extensive urban development continue to be significant.

5.3.5. Chemical Constituents in Bay Sediments

Measurable disturbance of Bay sediments apparently dates as far back as the middle 1700's with a rise in the deposition of polyaromatic hydrocarbons, possibly resulting from widespread burning of native vegetation by Spaniards clearing land for livestock and farming (Pereira et al. 1999). Large scale inputs of sediments and chemical constituents began in the 1850's with the discovery of gold in the Sierra Nevada Mountains. Between 1852 and 1914, the volume of sediments transported to the Bay increased by an order of magnitude as a result of widespread use of hydraulic mining techniques and large deposits of these sediments remain in the Bay today (van Geen & Luoma 1999). This large influx of sediment also transported a substantial load of mercury, commonly used in mining operations to extract gold from ore, much of which was deposited with sediments in the Bay (Hornberger et al. 1999). In addition, most of this mercury was mined from the coast range, where it was processed and shipped to inland sites, activities that also contributed to contamination of the Bay (Rytuba 2000).

Sediments deposited in the Bay between 1940 and 1980 contain a wide variety of contaminants including industrial metals (Ritsen et al. 1999) and high levels of DDT, PCBs and other organochlorine based biocides (Venkatesan et al. 1999). These compounds are also accompanied by a new rise in polyaromatic hydrocarbon levels resulting from the development of petroleum extraction and processing facilities within the watershed (Hostettler et al. 1999, Pereira et al. 1999). Measurements of chemical compositions in sediment cores from Richardson Bay indicate the most severe contamination of Bay sediments occurred between 1950 and 1970 (van Geen & Luoma 1999). Although the use of a number of chemicals such as DDT began to decline after the 1970s, contamination of Bay sediments continued as these constituents were mobilized from large historic deposits; in runoff from mines, industrial sites, and agricultural lands (Venkatesan et al. 1999).

5.3.6. Chemical Constituents in Re-Suspended Sediments

Disturbance or erosion of bottom sediments remobilizes contaminants in the sediments contributing to contaminant loads in the water column (Turner & Millward 2002), where they are incorporated into biochemical processes (Turner & Millward 2002). Of particular concern, with regard to Least Terns, is re-suspension and bioaccumulation of DDT and its breakdown products (e.g., DDE, DDD), which have long been known to disrupt reproduction by causing deformation of eggshells (Crump 1991), and chick mortality (Coulter & Risebrough 1973).

5.3.7. Chemical Constituents in Fish

Fairey et al. (1997) found mercury, PCBs, DDT, chlordane, dieldrin, and dioxins in sport fish caught in the Bay. Ohlendorf et al. (1988) found that relative to other fish in San Diego Bay, topsmelt had the highest levels of DDT breakdown products. Davis et al. (2002) reported finding mercury, PCBs, DDTs, chlordanes, dieldrin, and other compounds in jacksmelt; and both of these species are common prey of Least Terns. The highest concentrations of these compounds in jacksmelt were from a sampling location at the Oakland Harbor, findings which are consistent with measurements of elevated levels of these compounds in sediments along the landward side of the Bay (Schoelhamer et al. 2007).

Seelye et al. (1982) demonstrated experimentally that fish accumulate PCBs, DDE, and metals released from re-suspended dredged sediments. Contaminants may be ingested directly from the water or taken up through gill tissues. Stehr et al. (1997) however, found a lack of relationship between localized sediment contaminant loads and contaminant levels in fish, and they suggested that larger fish integrate contaminants differently due to mobility, bioavailability, sources of exposure, and diet. Their findings also indicate that chemical concentrations in Bay water are not solely attributable to contaminants archived in sediments, but are also the result of contemporary aquatic inputs to the Bay.

5.3.8. Contaminants in Least Terns

Hothem and Zador (1995) analyzed contaminant levels in Least Tern eggs collected at the Oakland airport and Alameda Point colonies, and from 5 colonies along San Diego Bay. Mercury and selenium were detected in all eggs, but concentrations were higher in eggs from San Francisco Bay. Eggs collected from the colony at the Oakland Airport had higher mercury levels then those collected from the Alameda Point colony, and selenium was equally high for the two locations. They also detected a number of organochlorines including DDE in eggs from both San Diego and San Francisco Bays, however DDE concentrations were lower for Least Terns than for Caspian terns (*Sterna caspia*) and Forster's Terns from San Francisco Bay (Ohlendorf et al. 1988); potentially due to the fact that Least Terns forage on smaller fish that occupy lower trophic levels.

Although there is no direct evidence that contaminants re-suspended by dredging are the source of contaminants found in Least Tern eggs, there are indicators that dredging may contribute to the recirculation and ultimate bioassimilation of these compounds. The chemical constituents found in Least Tern eggs are also found in sediments and suspended particulate matter and it has been demonstrated that fish uptake these chemicals directly from the water column. Furthermore, these contaminants are found in Bay fish species that are known prey of Least Terns.

These contaminants are also among the most prevalent found in water, soils, and air throughout California, and most of the planet. Dredging of sediments, particularly in the area of the Oakland Airport, Oakland Harbor, and Alameda has undoubtedly contributed to re-suspension and re-circulation of these compounds. However, the significance of the impacts of these localized dredging operations, when compared to larger circulatory, depositional, and erosional processes in Bay is largely unknown.

5.3.9. Direct Effects of Turbidity on Habitats

Beyond the obvious physical disturbance to the seabed the most significant impact to habitats, resulting from dredging in the Bay, is increased turbidity and deposition of suspended particles. Habitats most likely to be affected by dredging operations in the Bay are shallow benthic mudflats and eelgrass (*Zostera marina*) meadows, both of which support high levels of species diversity (Duarte 2002, Snelgrove 1998), and both are also important nursery habitats for fish species (Barry & Calliet 1981) that comprise the majority of Least Tern diet.

5.3.9.1. Dredging Related Impacts to Benthic Habitats

Dredging directly impacts benthic habitats through mechanical removal and disturbance of substrate and organisms, the latter of which may be taken up with the sediments. The excavation of sediments also increases water depth which can alter species composition. Overburden and settling of suspended particulates may also bury organisms or foul the feeding mechanisms of benthic organisms. Newell et al. (2004) found that dredging can result in the depression of biodiversity, population density, macrofaunal body mass, and overall biomass; however these effects are typically localized to the immediate vicinity of the dredged sediments, with little effect beyond the excavated site.

The recovery of benthos can be relatively rapid when re-colonization is enhanced as nearby sediments slump into the excavated area (Dolah et al. 1984). Oliver et al. (1977) found that in a nearshore setting re-colonization of dredge impacted areas was two phased with more mobile and opportunistic species re-establishing early on, followed by gradual larval re-colonization of more sedentary species.

Rates of recovery of benthic macrofaunal communities to perturbations also depends in large part on whether the impacted community occurs in a habitat where disturbance and environmental variability are relatively frequent natural occurrences (Oliver et al. 1977). For example, in shallow nearshore settings wind waves, storm waves, and riverine process constantly remodel the substrate through erosive and depositional processes; and communities that occupy these more volatile habitats can be more resilient in their response to disturbance than are those that occupy more stable environments such as deep water habitats where natural disturbances occur with lower frequency.

Harbor maintenance dredging operations are not expected to significantly alter entire benthic mudflat communities within the Bay given the geographic extent of the benthic communities that are typically affected by dredging operations, the existing degree of disturbance in the Bay, localized extent of direct impacts, and the ability of nearby undisturbed populations to rapidly re-colonize disturbed areas. Dredging related affects to less common communities such as those associated with eelgrass beds can however be more significant and the impacts may reach well beyond the immediate vicinity of dredging operations, particularly as a result of increased turbidity.

5.3.9.2. Dredging Related Impacts on Eelgrass Habitats

Degradation and destruction of seagrass beds is a global ecological problem and most of the identified sources of impact are anthropogenic (Erftemeijer and Lewis 2006). Eelgrass beds may be directly impacted if unearthed along with dredged sediments or if buried. Eelgrass beds can be impacted from reduction in water clarity, which may result from localized sources such as dredging, as well as from much broader sources such as increased watershed erosion and plankton blooms resulting from nutrient loading (Short & Wyllie-Echeverria 1996).

The depth that photosynthetically available light penetrates water limits the depth at which eelgrass can grow, and that depth is directly proportional to water color and clarity (Erftemeijer and Lewis 2006). The introduction of high concentrations of suspended particulate matter can therefore significantly alter the aquatic environment, affecting photosynthetic efficiency, which in turn decreases plant robustness and survival.

Not surprisingly, given the range of conditions under which various eelgrasses have adapted, the range of variation of tolerances amongst species or even populations is quite high. Published reports on light levels that eelgrasses require in order to survive, range over an order of magnitude from as high as 37% of surface irradiance to as low as 2.5% of surface irradiance. An equally important factor is the duration over which plants are exposed to decreased light levels.

Tolerances of eelgrass species to light limited conditions vary depending in large part on the range of conditions to which each species is adapted. Backman & Barilotti (1976) shaded eelgrass (*Z. marina*) in a coastal lagoon and observed an effect after just 18 days. After 9 months, they observed a 95% reduction in the surface area of eelgrass in the shaded areas compared to nearby areas. Moore et al. (1997) report the complete loss of established transplanted eelgrass beds in Chesapeake Bay after exposure to a month long period of increased turbidity. Longstaff & Dennison (1999) measured tolerance to lowered light levels in two sympatric eelgrass species (*Halodule pinifolia*) and

(*Halophila ovalis*), exposed to pulsed turbidity events along the coast of Australia. The found that while one species (*H. ovalis*) did not survive beyond ~38 days under lowered light condition, another species (*H. pinifolia*) survived for 2-3 times longer under the same conditions.

Physiological differences may play an important role in tolerance to reduced light levels. Of the various species of eelgrass for which tolerance to extended exposure to suboptimal light induced by turbidity was studied, *Z. marina* was found to be one of the least tolerant species. Lack of tolerance or well developed tolerance to decreased light level appears to be correlated with below-ground biomass (Erftemeijer and Lewis 2006), which may function in much the same way that large tubers do, in enabling desert adapted plants to survive long periods with little or no external inputs of moisture.

6. Dredging in San Francisco Bay

Dredging sediments in the Bay has taken place for more than 100 years, and currently involves the excavation and relocation of ~6 million cubic yards of material annually. As a result of concerns regarding the potential impacts associated with dredging in areas where Least Terns nest or forage in the Bay, the Long-Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region (LTMS; 2001) established Environmental Work Windows that define temporal and geographic limits to dredging in areas where Least Terns were known to forage and nest.

For dredging operations conducted within the framework of the Environmental Work Windows no additional Endangered Species Act consultation for the covered species is required. Likewise, for dredging operations conducted outside of the geographic areas identified under the LTMS Environmental Work Windows, no additional Endangered Species Act consultation for the covered species is specifically required, even though the species may now be present.

6.1. Potential Impacts of Dredging Operations on Least Terns

The USFWS Biological Opinion on the significance of environmental impacts potentially associated with implementation of the LTMS identified direct and indirect impacts that dredging in the Bay may have on Least Terns. The impacts that were identified in the BO are primarily related to disruption of foraging and food resources. The most significant impacts that were identified are primarily a consequence of increased turbidity affecting abundance and distribution of prey and foraging success.

In addition, eelgrass beds that function as nursery habitats for Least Tern prey, may by excavated or buried during dredging operations; or may be damaged as a result of reduction of photosynthetic productivity which may result from decreased water clarity. Re-suspension of Bay sediments may also increase contaminant levels in both prey species and Least Terns, resulting in mortality of prey and physiological affects such as egg-shell thinning as a result of DDT bioaccumulation in adult terns. The CDFG Biological Opinion further identified the need to consult with USFWS and CDFG if dredging impacts eelgrass beds throughout the Bay including the east Bay and Suisun Marsh areas.

6.2. Locations of Existing Dredging Restrictions in Relation to Known Least Tern Colonies

During the 10 years that preceded publication of the USFWS BO, addressing impacts associated with implementation of the LTMS, Least Terns bred at only 4 locations around the Bay. These included the Oakland airport (1989, 1990, & 1995), Tern Island in Hayward (1990), the Pittsburg PG&E power plant (1989 to 1998), and Alameda Point (1989 to 1999).

The Oakland Airport colony, which had been a relatively important breeding site in the 1970s and 1980s, was largely unused during the 1990s. During this later period there were never more than 6 pairs and during most years the site was not used. Likewise the Tern Island site supported only one pair during one season between 1989 and 1999. During this same period however, the Alameda Point site increased from 72 to 242 pairs and the Pittsburg PG&E power plant colony, though only supporting up to 11 pairs, was occupied every year during this period.

During the 10-year period following the publication of the USFWS BO, 2 of the 4 sites active during the previous decade were not occupied at any time and 5 additional colonies were formed at new sites (Table 2). Two of these new colonies (Hayward Regional Shoreline and Eden Landing) are within established dredging Environmental Work Widow zones, yet are located just south of the South Central San Francisco Bay region where dredging is restricted within 3 miles of active nesting Least Terns or when prey species are at a critical life stage (NOAA 2010). Likewise, the Caltrans Albany Mitigation Island colony is located just north of the area where these additional restrictions are imposed.

Along with the Pittsburg PG&E power plant colony, which has persisted and has been occupied during all but 2 years (2006 and 2009) over the past decade, there are 2 additional sites (Green Island and Montezuma Wetlands) supporting colonies in areas where no restrictions on dredging are specified to address potential impacts to Least Terns. These new colonies represent a significant portion of the Bay population of Least Terns, increasing from ~3% in 2005 to ~37% in 2009 (Marschalek 2007, 2009). It appears that many of the birds that now occupy these back Bay sites likely relocated from the Alameda Point colony, as the overall numbers of pairs reported for the Bay region has not changed appreciably during this period; and the Alameda Point colony has decreased in proportion to the increase at these other sites.

6.3. Dredging Restrictions in Relation to Known Least Tern Foraging Sites

Foraging locations for Least Terns from the Alameda colony were studied in 2003 and 2004 and these observations indicate that Least Terns use most areas of the Bay around the colony location (Figure 5) and that foraging is concentrated within ~3.5 miles of the colony site (Figure 4). The locations of birds observed also indicates that Least Terns are not foraging in areas where there are eelgrass beds at least in the shallow water habitats around the Alameda Point colony (Figure 5). Eelgrass beds may not necessarily be important foraging areas for Least Terns, but the habitat nonetheless plays a key role as a nursery for Least Tern prey species.

Table 2. Environmental Work Window Restrictions on Dredging to Avoid Impacts to Least Terns.

Location	Dredging Restrictions for Least Terns	Potential Impact	Terns Present 1999-2009	Consult. Required
Bair Island	All eelgrass beds and salt ponds Jan 1 - Dec 31	Loss of eelgrass bed foraging habitat	No	Yes
Bay Farm Island	All eelgrass beds and waters and sloughs within 1 mile of coast from Berkeley Marina south through San Lorenzo Creek- Jan 1 to Dec 31	Loss of eelgrass bed foraging habitat	No	Yes
Oakland Airport	All eelgrass beds and waters and sloughs within 1 mile of coast from Berkeley Marina south through San Lorenzo Creek - Jan 1 to Dec 31	Loss of eelgrass bed foraging habitat	No	Yes
Alvarado Salt Ponds	All eelgrass beds and salt ponds Jan 1 - Dec 31	Loss of eelgrass bed foraging habitat	No	Yes
Coyote Hills Park	All eelgrass beds and salt ponds Jan 1 - Dec 31	Loss of eelgrass bed foraging habitat	No	Yes
Baumberg Salt Ponds	All eelgrass beds and salt ponds Jan 1 - Dec 31	Loss of eelgrass bed foraging habitat	No breeding, may use site after breeding	Yes
Tern Island Hayward	All eelgrass beds and salt ponds Jan 1 - Dec 31	Loss of eelgrass bed foraging habitat	No	Yes
Albany Caltrans Mitigation Island	All eelgrass beds Jan 1 - Dec 31	Loss of eelgrass bed foraging habitat	Yes	Yes
Eden Landing	All eelgrass beds and salt ponds Jan 1 - Dec 31	Loss of eelgrass bed foraging habitat	Yes	Yes
Hayward Reg. Shoreline	Located south of restricted area between Berkeley Marina and San Lorenzo Creek	Loss of eelgrass bed foraging habitat	Yes	Yes
Alameda Point, Alameda Island	All eelgrass beds and waters and sloughs within 1 mile of coast from Berkeley Marina south through San Lorenzo Creek - Jan 1 to Dec 31	Loss of eelgrass bed foraging habitat	Yes	Yes
Pittsburg PG&E	No restrictions specified for Least Terns	None identified	Yes	No
Green Island, Napa River	No restrictions specified for Least Terns	None identified	Yes	No
Montezuma Wetlands	No restrictions specified for Least Terns	None identified	Yes	No

Note: Table 2 is based on information provided online by National Marine Fisheries Service Southwest Regional office at: http://swr.nmfs.noaa.gov/overview/sroffice/2Dredge_work_windows.html

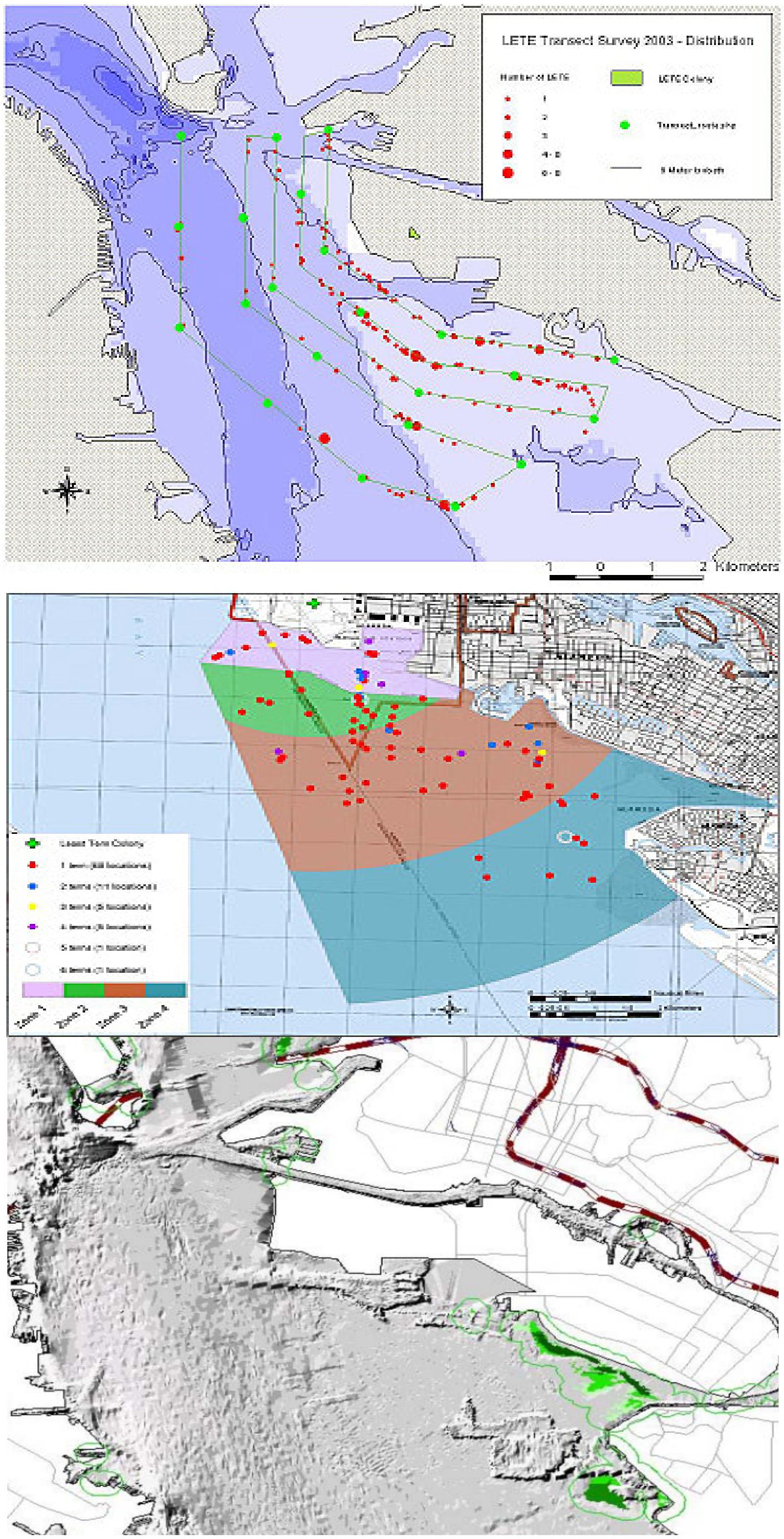


Figure 5. Least Tern foraging locations 2003 (top; Elliot et al. 2004) and 2004 (middle; Steinbeck et al. 2005) in relation to eelgrass bed locations (bottom; Merkel 2004).

6.4. Dredging Impacts on Fish in the Bay

Fish may be affected by both physical and chemical properties of materials re-suspended into the water column by dredging, particularly in calm relatively shallow water.

6.4.1. Direct impacts of Suspended Sediment Concentrations

Turbidity in the Bay caused by inputs other than dredging and ship traffic is substantial. Suspended sediments near the outfall of the Sacramento River can exceed 400 mg/L (McKee et al. 2002) and have been found to be as high as 600 mg/L in the estuarine "null zone" (Buchanan and Schoellhamer 1995).

The turbidity plume resulting from a bucket dredge at Oakland Harbor was measured and mapped acoustically by MEC Analytical System, INC. (2004). The entire plume covered an area of ~5 acres with most of the suspended material remaining at depth, and for most of the plume suspended sediment concentrations did not exceed 100 mg/L. Concentrations of total suspended sediments were highest near the dredge boat and dissipated to insignificant levels within less than 450 yards of the dredge site. The highest total suspended sediment measured at the site during dredging was ~389 mg/L (MEC 2004).

Auld & Schubel (1978) found little effect on the hatch rate of fish eggs exposed to suspended sediment concentrations below 1000 mg/L. Morgan et al. (1973) found no effect with regard to hatch rate when fish eggs were held in suspended sediment concentrations of 2200 mg/L, although they did find that concentrations above 1500 mg/L resulted in slowing of embryonic development.

Similarly Auld & Schubel (1978) demonstrated that exposure to suspended sediment concentrations exceeding 500 mg/L for 48 to 96 hours significantly reduced survival of striped bass and yellow perch. Conversely Kiorboe et al. (1981) found that suspended sediment concentrations off 500 mg/L had no effect on Pacific Herring, a species that has been shown to increase its feeding rate in turbid water with particle concentrations of up to 1000 mg/L(Boehlert and Morgan (1985).

The results of experimental exposure to suspended sediment concentrations along with measurements of these concentrations at the Oakland Harbor indicate that suspension of sediments by dredging does not result in concentrations of suspended particles sufficiently high enough to directly increase mortality in fish expected to occur in the areas of the harbor where dredging occurs. What may be of greater concern however is the assimilation of toxicants re-suspended by dredging into the base of Bay foodwebs; and the accumulation of these compounds in higher trophic levels.

6.4.2. Toxicological impacts of Suspended Sediment Concentrations

Contaminant inputs to the Bay have been widely documented as has the deposition of many of these compounds in Bay sediments (see Section 5.3.5.). Disturbance of sediments by dredging redistributes archived contaminants to dumping locations and potentially during transport and introduces contaminants into the water column particularly at the dredging site.

Oram and Melwani (2006) evaluated the impact of re-suspended contaminants on food-web bioaccumulation in the Bay by modeling the re-suspension and biological assimilation potential of DDT associated with dredging at the Oakland Harbor. Known concentrations of contaminants in

Bay sediments (see Oram and Melwani 2006) and measurements of suspended particulate concentrations (MEK, Inc. 2004) provided estimates of dredging related physical inputs to the water column, and a food web model for uptake of PCBs in the Bay (Gobas and Arnet 2005) provided a means for estimating biological uptake.

Their model predicted that at the dredge site DDT concentrations in biota would be 200% higher then before dredging. They predicted DDT concentrations in fish at the dredge site would be elevated from 10-15 ng/g to 50 ng/g; and DDT concentrations of 50 ng/g in fish tissues exceed the concentration threshold for protection of predatory birds (National Academy of Sciences 1973). However, beyond the dredge site, the predicted increase in concentration of DDT in fish was 2 orders of magnitude less then for the dredge site (Oram and Melwani 2006).

In summary, dredging does have potential for increasing contaminant levels in Least Tern prey species beyond threshold levels for predatory birds, however the area of highly elevated DDT concentrations in the water column are expected to be restricted to the foot print of the turbidity plume; and these are expected to decrease to ambient levels as the plume dissipates over a period of hours to days.

7. Summary

7.1. Current Status of Least Terns in the Bay

- The Bay Least Tern population has grown from an estimated 8 -15 pairs in 1970 to over 475 pairs in 2009.
- Over the past 2 decades the majority of Least Terns breeding around the Bay nest at Alameda Point, though in recent years the number of pairs occurring at other sites has increased.
- Recent declines in the Alameda Point population are matched by increases at other sites, suggesting observed recent declines at the Alameda Point colony represent emigration from the natal colony site to other sites and does not necessarily represent a population decline.
- The Alameda Point colony has consistently comprised ~6 - 7 % of the total statewide population, yet these birds consistently produce a disproportionately high percentage of total fledglings.
- The geographic area where birds are nesting has shifted from predominantly the south and central portions of the Bay to the central, northern, and northeastern regions of the Bay.
- The statewide population now exceeds 7000 pairs breeding at over 50 locations.

7.2. Ecology of Least Terns in the Bay

- Least Terns in the Bay forage primarily on topsmelt, jacksmelt and northern anchovies along with Pacific herring and surfperch,
- A small percent increase of northern anchovy in the diet may result in dramatic increase in fledge rate.
- Foraging range of Least Terns from the Alameda Point colony appears to include most of the offshore portions of the Bay within ~3.5 miles of the colony.
- Least Terns apparently do not regularly forage in existing eelgrass beds near the Alameda Point colony.

7.3. Factors that Limit Least Tern Population Growth

- The primary factor limiting population growth is the relative scarcity of secure nesting sites that meet physical and biotic nest site selection criteria and that can be effectively managed.
- Anthropogenic disturbance of nesting sites.
- Native and exotic predators, benefitted by human actions and developments.

7.4. Potential Direct Impacts of Dredging on Least Terns

- Direct effects on nesting birds may include equipment noise and human activity, although Least Terns nesting in areas where dredging is required are expected to have a high tolerance to human activities.
- Direct effects on foraging birds could include equipment noise and human activity disrupting access to foraging areas.
- There is limited and contradictory evidence in the literature regarding impacts of increased turbidity on Least Tern foraging success.
- Fish respond differently to turbid water; some are attracted while some fish show preference for clear water.
- Fish tend to move closer to the surface in turbid water and go deeper in clearer water, suggesting a benefit of turbid water for plunge diving birds unable to forage deep in the water column.

7.5. Potential Indirect Impacts of Dredging on Least Terns

- Reduced water quality as dredging re-suspends chemical contaminants archived in sediments.
- May contribute to contamination of fish.
- May contribute to contamination of Least Terns.

7.6. Dredging in San Francisco Bay and its Affect on Least Terns

- Dredging Environmental Work Windows may not accurately reflect current Least Tern breeding/foarging distributions.
- Foraging habitat value of eelgrass beds may be limited, though these habitats are important as nursery habitat for prey species.
- Dredging induced turbidity limited in space and time, and suspended sediment concentrations at the dredge site may not exceed tolerance limits of fish.
- Contaminant concentrations in fish at the dredge site may exceed tolerance levels for protection of predatory birds.
- Contaminant levels at a dredge site rapidly revert to ambient levels away from the dredge site.

8. Recommendations for Further Studies

GIS base map of dredging locations and tern colony, roosting, and foraging locations.
Least Tern breeding, and subsequently foraging sites, shifted significantly during the 10-year period following the establishment of seasonal restrictions on dredging in the Bay designed to limit impacts to breeding and foraging Least Terns. The established Environmental Work Windows (NOAA 2010) do not currently provide for seasonal dredging restrictions near least colonies in the northern and eastern regions of the Bay. Likewise, the Environmental Work Windows restrict dredging activities in southern regions of the Bay where Least Terns no longer breed and these areas are not currently used by foraging Least Terns (see Table 2).

Development of a GIS based monitoring program that clearly identifies dredging locations and Least Tern breeding and foraging sites would provide a basis for a more adaptive management strategy that would provide significantly greater protection to Least Terns and would relieve unnecessary restrictions on dredging operations in areas where Least Terns do not occur.

A GIS based mapping system would included a detailed map of dredging locations, extent, dredge volume, dredging operation frequency, method, dumping location, and seasonality. This information is readily available through the permitting review process. Additional GIS layers would include breeding colony locations, period of occupancy, colony size, foraging locations if known, post-breeding roosts, and post breeding foraging locations. This information is readily available from annual California Least Tern breeding season reports produced by the California Department of Fish and Game.

A GIS based mapping system would inform the establishment and management of Environmental Work Widows, required to avoid impacting Least Terns in areas where they currently are not imposed; and would ensure that Environmental Work Windows do not unnecessarily restrict dredging in areas where Least Terns do not occur.

Literature review and model of contaminant risks to Least Terns/foodwebs resulting from dredging in the Bay
Although the degree to which Least Tern foraging success is directly impacted by dredging appears to be limited there may be significant risk of exposure to anthropogenic contaminant inputs to the water column and subsequently Bay food webs on which Least Terns rely. Contaminant fluxes in the Bay are complex and involve a wide variety of contemporary inputs as well as through redistribution of substantial historic inputs archived in Bay sediments.

This report provides an overview of the extent of contaminants in Bay foodwebs, and specifically those which may result in contamination of Least Terns. A more extensive review of potential sources of contamination that could affect Least Terns would enable a more refined analysis of potential risk factors and contaminant sources. This information, combined with existing models of suspended sediment loads and contaminant re-suspension in the water column as a result of dredging, could be used to evaluate the relative contribution of dredging (including both individual dredging operations as well as the entire Bay wide extent of annual dredging) to contaminant levels in Bay foodwebs.

Determine contemporary contaminant loads in Least Tern eggs from the Alameda Point colon
Hothem and Zador (1995) examined contaminant loads in abandoned Least Tern eggs from colonies at the Oakland airport and Alameda Point and found elevated levels of mercury, selenium, and DDT. Over the past few decades considerable effort has been put forth to reduce the level of contaminant inputs to the Bay through improved treatment of pollution point source inputs. Hornberger et al (2000) report substantial declines in levels of copper and silver in bivalve mollusks between 1978 and 1998.

The Least Tern colony at the Alameda Point colony has thrived over the past decade suggesting that contaminant levels to which Least Terns are exposed may not be excessive. A comparison of current contaminant levels with those from the early 1990s would provide insight into trends in contaminant loads of Least Terns over time.

Hothem and Zador (1995) measured contaminant levels in non-viable or otherwise abandoned eggs, which is potentially biased towards predicting higher population-wide contaminant levels; as the eggs that may have been non-viable due to unusually high toxic chemical loads. Regardless, comparison of results from a similar analysis would provide an important incremental baseline.

Direct measurement of re-suspended chemical constituent concentrations in the water column resulting from dredging.
Similar contaminants have been detected in Bay sediments, fish and Least Tern eggs. Disturbances such as dredging result in the re-suspension of chemical constituents archived in Bay sediments. However, no direct link has been established between dredging and contamination of Least Terns or their prey.

Oram and Melwani (2006) modeled the impacts of re-suspended contaminants on food-web bioaccumulation in the Bay. Direct measurement of contaminant loads in turbidity plumes and in areas unaffected by dredging would further refine our understanding of how dredging may impact aquatic foodwebs in the Bay. This would also lead to a better understanding of the contribution to contaminant loads within the water column and subsequently foodwebs, which result from localized and region-wide dredging activities as well as from other anthropogenic sources.

Direct measurement of chemical uptake by fish exposed to dredging induced turbidity plumes.
Acoustic measurement of the extent and concentration of dredging turbidity plume (MEC 2004) suggests that the impact zone is limited to a relatively small area around the immediate dredge site. Modeling based in part on these measurements and known contaminant concentrations in Bay sediments (Oram and Melwani 2006) suggests the area of exposure is also limited to a relatively small area.

Experimental exposure of fish to the range of suspended sediment concentrations measured at a dredge sites, would refine our understanding of the relationship between exposure and contaminant loads in fish. Contaminant loads of fish exposed to Bay water but not exposed to simulated dredging turbidity plumes would refine our understanding of background contaminant exposure levels in the Bay.

Identify and quantify other sources of turbidity in the Bay

Very high concentrations of suspended sediments in the Bay are also caused by natural and anthropogenic processes other than dredging. Elliot et al. (2003) observed turbidity plumes created by ships turning in Oakland Harbor, which appeared to be as extensive as those created by dredging operations. Identification of other factors leading to increased turbidity would lead to a better understanding of the overall contribution of dredging activities, relative to other sources of turbidity.

A relatively small area such as the area around Alameda Point and the Oakland Harbor could be demarcated. Sources and extent of turbidity gradients could be determined by sampling water along transects through the area and through observations of potential sources of turbidity plumes. The relative contribution of each activity resulting in increased turbidity could then be determined. This information would refine management of dredging and other activities that may increase contaminant risks for Least Terns.

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