NOCTURNAL PREDATION
OF CALIFORNIA LEAST TERNS AT A SOUTHERN CALIFORNIA LEAST TERN
COLONY

by

Paul P. Zimmerman

A Thesis
Presented to
The Faculty of Humboldt State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
In Natural Resources Wildlife

March, 2008
ABSTRACT

Nocturnal predation of California least terns at a southern California least tern colony.

Paul P. Zimmerman

Predation is difficult to observe and quantification of impacts have consequently been difficult, especially for predators active at night. Using night-capable cameras placed throughout a California least tern (Sterna antillarum browni) colony I examined rates of predation by a complex of potential predators. I identified and quantified direct and indirect effects for each potential predator observed in the colony at night. Small mammals, European starlings (Sturna vulgaris), great horned owls (Bubo virginianus), opossum (Didelphis virginiana), and coyotes (Canis latrans) were observed in the colony. Coyotes were the most frequent potential predator and were observed on 12 nights in each of the two nesting seasons of investigation. Great horned owls, opossum, and coyotes predated on terns at night (n = 34, total from both seasons) and coyotes alone were observed predating more than other species (n = 31, total from both seasons). Predator presence in the tern colony resulted in a mean of 15.5 ± 3 minutes (X ± SE) of temporary nest desertion (n = 41 predator events). Anthropogenic disturbances resulted in a mean of 150 ± 25 minutes of temporary nest desertion (n = 13). The mean number of nests observed during these disturbances was 20.3 ± 1.3 nests and varied with time in the season between 2 – 41 nests. All observable nests flushed during every anthropogenic disturbance, whereas 86 ± 0.02% of observable nests flushed during predator caused disturbances. No association was found between abandoned nests and distance to predated nests in either season. Although coyotes were associated with the greatest
number of observed predations, the total number of predations could have been greater if coyotes were not present. Smaller predators such as red fox (*Vulpes vulpes*), black rats (*Rattus rattus*), and California ground squirrels (*Spermophilus beecheyi*) may have greater access to the colony in the absence of coyotes.
ACKNOWLEDGEMENTS

This research would not have been possible without the cooperation, support, and generosity of many individuals and organizations. I first thank the United States Navy Region Southwest for funding this research. My graduate committee, Drs. Richard Brown and David Kitchen for their insight and support throughout the entirety of this research. I especially thank Dr. Richard Golightly, my major professor, for his unwavering support, determination, and friendship. This project would not have been successful without their contributions. I extend my appreciation to Tim Burr and Tiffany Shepherd of Naval Facilities Engineering Command Southwest for helping facilitate this research. I thank Martin Ruane of Naval Base Ventura County, Point Mugu for his assistance in project development and field activities. Additional field assistance was provided by Amanda Wilhelm, Kenneth Gilliland, and Nancy Fox Fernandez. I also thank Humboldt State University for loan of equipment, supplies, and staff Talitha Penland, Eileen Creel, Oliver Miano, Brendan Lynch and Meadow Kouffeld for support in the field and office. The duo of Dr. Richard Golightly and Eileen Creel were paramount in the development of my project development. This research was conducted with a protocol approved by Humboldt State University Institutional Care and Use Committee (IACUC Protocol #04/05.W.136A) and by a Memorandum of Understanding to Richard Golightly with the California Department of Fish and Game.

Lastly, I would like to recognize and extend my deepest gratitude to all the friends and family that made this possible. I thank my dear friends Gus Dumler, Brenda Peace, Ryk Robison, Jackie Tebeau, and Aaron Lebow for helping me keep things in
prospective and for all the hunting and fishing adventures. I thank Tim and Shawna Casey, Nate and Emilie Lang, and C. J. and Jodi Proehdel for a couch to crash on, a shoulder to lean on and an occasional cold one. I especially thank Nate and Emilie Lang for all their support; it was their support that helped to make this research a success. Most importantly I thank my mother and father, Bridget and Paul Zimmerman, for their love and support, my wife Shannon and daughter Cali for their unconditional love and the many sacrifices they endured to support my efforts. Shannon, you are my everything.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>ix</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>x</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>STUDY AREA</td>
<td>6</td>
</tr>
<tr>
<td>METHODS</td>
<td>10</td>
</tr>
<tr>
<td>RESULTS</td>
<td>17</td>
</tr>
<tr>
<td>Direct Effects of Predators</td>
<td>17</td>
</tr>
<tr>
<td>Indirect Effects of Predators</td>
<td>21</td>
</tr>
<tr>
<td>Flushing Events</td>
<td>21</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>25</td>
</tr>
<tr>
<td>Camera Assessment</td>
<td>25</td>
</tr>
<tr>
<td>Predators Observed in the Tern Colony</td>
<td>26</td>
</tr>
<tr>
<td>Direct Effects of Predators</td>
<td>28</td>
</tr>
<tr>
<td>Indirect Effects of Predators and Flushing Events</td>
<td>31</td>
</tr>
<tr>
<td>Diurnal Predation</td>
<td>37</td>
</tr>
<tr>
<td>MANAGEMENT CONSIDERATIONS</td>
<td>39</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>41</td>
</tr>
<tr>
<td>APPENDIX A</td>
<td>49</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (CONTINUED)

APPENDIX B ........................................................................................................... 50
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Species of predators, predator-nights, frequency of predator-nights, occurrence per night observed, events per occurrence, mean time per occurrence, total predations, and predations per occurrence for all potential predators observed at night during the 2004 and 2005 nesting seasons at Naval Base Ventura County, Point Mugu, California.</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Chi-square comparisons between years (2004 and 2005) based on the number of occurrences and the number of predations observed for each potential predator viewed at night at Naval Base Ventura County, Point Mugu, California (Means are in Table 1).</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>Median, mean (not including zeros), and range of temporary nest desertions from predators and from anthropogenic disturbances during 2004 and 2005 at Naval Base Ventura County, Point Mugu, California.</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>Fates of least tern nests within camera view and the percentage of the total nests in camera view for the Ormond East colony in the 2004 and 2005 nesting seasons at Naval Base Ventura County, Point Mugu, California.</td>
<td>29</td>
</tr>
<tr>
<td>5</td>
<td>Summary of all least tern nest fates, reclassified from unpublished Navy data, for the entire Ormond East colony for the 2004 and 2005 nesting seasons at Naval Base Ventura County, Point Mugu, California. Marschalek reports estimated fledgling numbers of 110 terns in 2004 and a range of 46-92 terns in 2005 for the Ormond East tern colony at Point Mugu (Marschalek 2004; Marschalek 2005, unpublished data, United States Navy: see Methods for criteria for reclassification).</td>
<td>32</td>
</tr>
</tbody>
</table>
**LIST OF FIGURES**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Map of locations of least tern colonies at Naval Base Ventura County, Point Mugu, California this research focused on the Ormond East tern colony</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Least tern nesting locations and camera views, depicted by polygons, for the 2004 nesting season at the Ormond East tern colony at Naval Base Ventura County, Point Mugu, California</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>Least tern nesting locations and camera views, depicted by polygons, for the 2005 nesting season at the Ormond East tern colony at Naval Base Ventura County, Point Mugu, California</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>Coyote and opossum activity for 2004 and 2005 nesting seasons, no opossums were observed in the 2004 nesting season at Naval Base Ventura County, Point Mugu, California. Vertical arrows in 2005 denote coyote removals. The specific dates for coyote removals in 2005 were June 2, 14, 25, and July 20. The second coyote removed was a probable territorial adult. The first, third, and fourth coyotes removed were juveniles.</td>
<td>36</td>
</tr>
</tbody>
</table>
INTRODUCTION

Predation is a structuring component of an ecosystem that affects the population dynamics of plant and animal communities (Holt 1977, Preisser et al. 2005, Miller et al. 2006). Predators and prey can limit each other (Peterson 1999). However, predation is but a single component of a complex functioning ecosystem. To accurately assess and quantify effects from predation, the interspecific and intraspecific interactions within the predator and prey community must also be examined (Paine et al. 1990). Direct effects of predators consist of mortality of prey from consumption or attempted consumption by the predator. Indirect effects of predators include behavioral changes in prey which can include abandonment of or neglect of young resulting in reduced reproduction (Preisser et al. 2005). Indirect effects also include competitive exclusion between and among predator species where large-bodied predators exclude and even kill other sympatric predators as well as influence transient and juvenile conspecifics (Crooks and Soulé 1999, Muller and Brodeur 2002). When large-bodied predators have been removed, smaller predators can flourish and gain access to prey (referred to as mesopredator release). Interactions between and among predators may impact predation risk through exclusion by larger predators of more specialized smaller predators. Potentially, these small predators are more specialized and can be a more damaging predator, to a specific population of prey.

Predator activity (nocturnal, diurnal, or both) is affected by prey availability, anthropogenic disturbances, and competition with sympatric predators (Fitch and Shiver
1970, Laundre and Keller 1984, Harrison et al. 1989, Shivek et al. 1997, Chamberlain et al. 2000, Kitchen et al. 2000, Neale and Sacks 2001). Impacts on prey result from predation by both diurnal and nocturnally active predators. Predation events are rarely observed (Miller et al. 2006) and even less so at night. Identification of predators that influence prey populations often relies on inference and educated guessing. Nest remains, tracks, and other traditional techniques (Moore 1983, Martin 1987, Lyver 2000) are not definitive evidence for associating specific predators with acts of predation (Major 1991, Major and Gowing 1994, Brown et al. 1998 Thompson et al. 1999, Sanders and Maloney 2002, Peterson et al. 2004). Predators active at night are especially difficult to identify because they are more difficult to observe than diurnal species and consequently the contribution of nocturnal predators to the total predation effect is unknown. Further, few studies have been conducted to address the impacts of predators active at night, especially large-bodied predators like coyotes (*Canis latrans*), which are often the emphasis in management strategies (Pitt et al. 2000). Thus, my first objective was to accurately estimate the numerical impact of specific predators at night.

Predation can be detrimental to prey populations if it exceeds recruitment, especially for isolated populations and species at low abundances, such as legally protected species threatened with extinction (Ebenhard 1988, Butchko 1990). Isolated populations are a result of fragmented landscapes often caused by anthropogenic effects, stochastic events, or natural processes (Bates 2000, Hoffmeister et al. 2005). Southern California is an extremely fragmented landscape (Bolger 2002) and many wildlife species have been limited to small isolated areas. These fragmented habitats can influence the
predator-prey interactions (Kareiva 1987). It has been suggested that fauna endemic to these areas can be heavily exploited through predation by native and non-native predators (Butchko 1990, Lewis et al. 1993). In order to manage these restricted or isolated populations, the role of predation and identification of sources of mortality or depression of reproduction must be known. Thus, I investigated the predators on a small isolated California least tern (Sternula antillarum browni) population along the southern California coast during the most difficult time of observation (night).

The California least tern was identified as a species in peril of extinction in 1970. California least terns nest on sandy beaches, ocean coastlines, bays, rivers, lakes, and salt flats from May to August (Thompson et al. 1997). They range from San Francisco Bay, California south to the border of Mexico (Small 1994, Thompson et al. 1992, Atwood and Massey 1988). Approximately 6,500 breeding pairs were reported range-wide in 2005 (Marschalek 2005).

California least terns are preyed upon by mammalian, avian, and reptilian predators as well as some invertebrates (Thompson et al. 1997). Predation can potentially compromise the chance for recovery to more stable population sizes at some sites (Massey 1988, Butchko 1990, United States Fish and Wildlife Service 1990, Lewis et al. 1993). Although well intentioned, removal of predators (to protect favored prey such as least terns) may have unpredicted consequences and may not significantly improve the overall population of terns (Ackakaya et al. 2003). Ackakaya et al. (2003) modeled California least tern populations and found that management of predators could result in a 1% to 8% decrease in the probability of population decline. The risk of predation is not
simply a function of the number of individual predators present at a site. Large-bodied predators may be avoided by smaller body-sized predators (mesopredators), or even smaller and younger conspecifics (Crooks and Soulé 1999, Muller and Brodeur 2002, Craig and Golightly 2005). Consequently the removal of one large predator may affect the exposure of prey to other predators and unnaturally change the risk of predation. Craig and Golightly (2005) and Romsos (1998) inferred that coyotes spatially and temporally excluded sympatric mesopredators in southern California. Disruption of this mutual avoidance, through the removal of large bodied predators, may result in increased occurrences of transient and juvenile conspecifics or mesopredators, which may reduce reproductive success of terns. For managers, the effects of a large-bodied predator must be balanced between their potential to cause mortality and the consequences of removing the large-bodied predator. Reducing mortality of terns through removing predators is only effective if negative indirect effects do not exceed the benefits. Klope (1989) reported that the expansion of coyotes to Point Mugu, California in the 1980’s resulted in displacement of non-native red foxes (*Vulpes vulpes*). Non-native red fox were known to cause severe damage to least terns. For example, Golightly et al. (1994) calculated that one non-native red fox could decimate an isolated tern colony in 2 to 10 days. To assess the potential risk to terns at night, I needed to identify which predators represented a risk and assess the relative risks of these different predators or management activities.

To quantify the effects of predators I used night-capable cameras to observe predators that entered the tern colony. Using objective means of identifying predators, like video cameras, was more reliable than traditional methods of predator identification
I examined the effects of different predators for a variety of conditions to determine potential versus actual threat to nesting terns. To quantify the direct and indirect effects by the complex of predators I needed to know: 1) the species of predators at the colony, 2) the behaviors of both predators and terns, 3) the number of times predators were seen in the colony, 4) the amount of time predators spent in the colony, and 5) associations between the fate of each nest and distance to the nearest predated nests. I used these variables to assess actual threats to terns versus perceived threats inferred simply by the presence of a predator.

I conducted this investigation at the same study site (Point Mugu, California) as reported by Craig and Golightly (2005). The beach habitat at the site contained both nesting California least terns and western snowy plovers (Charadrius alexandrinus nivosus). Densities of plovers sympatric with terns were too low to test the effect of predation on their overall reproduction. Thus most of my investigation was restricted to examination of tern predation. Also, because there was ongoing management at my study site that was intended to protect terns, I needed to evaluate and control for the interaction between predation rates and the active predator control program at this site. Concurrent with my measurement of predator and prey activity, I recorded management activities (i.e. shooting and spotlighting of predators) and assessed potential alterations of predator or prey behavior and reproduction.
STUDY AREA

Point Mugu is a United States naval air station located in Ventura County, California, approximately 93 km north of Los Angeles. The naval installation is 1,817 ha and is made up of 1,012 ha of wetlands, 552 ha of urbanized or industrial areas, 149 ha of paved roads, 72 ha of disturbed open area and 32 ha of airfields (United States Navy 2002). Point Mugu is bordered to the southwest by the Pacific Ocean (approximately 9.7 km of shoreline), the Pacific Coast Highway to the north, Ventura County Game Reserve and Ormond Beach to the west, and Point Mugu Rock State Park to the east. Point Mugu had four California least tern colonies (unpublished data, United States Navy). The Ormond East colony was located on the northwest corner of Point Mugu, the Eastern Arm colony was located on the southeast end of the base near the confluence of Callegus Creek and the Pacific Ocean, and the Holiday Beach tern colony was located southwest of the Ormond East colony, all of which were active in 2004 and 2005 (Figure 1). The fourth colony, known as the Nesting Islands, was located in the interior of the naval base and was only active in 2004. Of all the colonies, Ormond East has had the greatest number of nests per year since 1998, ranging from 278 nests in 1998 to 476 in 2005 (unpublished data, United States Navy). Colonies with greater than 100 nests tend to be more susceptible to predation than smaller colonies (Brunton 1999). Because the Ormond East colony was the largest colony and had more than 100 nests, I used it as the site of my investigation. The landscape at the Ormond East colony consisted of beach with driftwood, anthropogenic refuse, sand dunes and intermittent open sandy areas. The
Figure 1. Map of locations of least tern colonies in 2005 at Naval Base Ventura County Point Mugu, California. This research focused on the Ormond East tern colony.
dominant vegetation types included sand verbena (*bronia maritime*), sea rocket (*Cakile maritime*), European beach grass (*Ammophila arenaria*), beach primrose (*Camissonia cheiranthifolia*), and ice plant (*Capobrotus edulis*). The colony was located on the beach and was bordered to the north and south by sand dunes and the Pacific Ocean. To the west of the colony was Ormond Beach. Military storage facilities bordered the Ormond East tern colony to the east. Predators at the naval air station that could have potentially preyed on least terns at night included: great blue heron (*Ardea herodius*), black-crowned night heron (*Nycticorax nycticorax*), great horned owl (*Bubo virginianus*), barn owl (*Tyto alba*), red fox, gray fox (*Urocyon cinereoargenteus*), coyote, bobcat (*Felis rufus*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), opossum (*Didelphis virginianus*), long-tailed weasel (*Mustela frenata*), black rat (*Rattus rattus*) and domesticated dogs and cats (Jenks-Jay 1980, Minsky 1980, Burger 1989, Rojas et al. 1999, United States Navy 2002).
METHODS

I used weatherproof infrared cameras (Model EX26NX, Extreme CCTV, Burnaby, British Columbia, Canada) to observe predators within the Ormond East tern colony at night. The camera dimensions were 9 x 9 x 17 cm. Cameras were routed to a single digital video recorder (DVR; Model 16-IP, Speco Technologies, Amityville, New York) using siamese RG-59U 18/2 coaxial cable 95% (Arrow Wire and Cable, City of Industry, California). All cables and lines connecting cameras to the DVR were buried. Power was supplied by a 3000-watt generator engineered for quiet operation (EU 3000, Honda, Tallapoosa, Georgia). Two cameras at greater than 100 m from the generator were powered by deep cycle Absorptive Glass Mat 12 Volt batteries (MU-1 SLD M, MK Batteries, China). An amplifier (Compu Video Systems, Peekskill, New York) located at the DVR was used to sharpen images for cameras set at greater than 100 m from the DVR. The DVR and associated hardware were enclosed in a weatherproof container placed near the generator behind the dunes so they were not visible from the tern colony. Generator noise did not exceed 60 db at full power (measured at the source) and apparently did not disturb the colony. Images were archived onto a removable hard drive within the DVR, which was retrieved daily and moved to an office for processing. Images of predator disturbances were transferred from the DVR hard drive to a computer hard drive. Images were processed the day following the collection. Approximately 5-8 hours with 1-2 observers were necessary to review each night’s images.
I used two camera types: “close-range” cameras with 4.3 mm lenses and “long-range” cameras with 8 mm lenses to record images of predators and prey. All cameras operated continuously throughout the night to capture visits by predators. Close-range cameras allowed detailed observations of subjects within 10.5 m of the camera and were necessary to observe specific behaviors of predators such as details of prey consumption. Detail was also sufficient to observe smaller mammals such as rats and mice. Close-range cameras were uniquely numbered and placed throughout the colony on small mounts not exceeding 1 m above ground. The cameras and mounts were wrapped in camouflage netting and placed within the highest concentration of nests. Predation rates have been reported to be greater where nests were concentrated (Brunton 1997) than predation rates of outlying nests where nests were less dense (Zavalaga et al. 2001).

Long-range cameras were used to monitor a greater area of beach in order to observe movement of predators beyond the view of close-range cameras or between close-range cameras. Long-range cameras could not continually view detailed events but allowed constant surveillance of predators on specific areas of the beach. Long-range cameras were erected away from the colony and elevated on the dunes. Infrared illuminators (IR2-110, Vitek, Sun Valley, California) were used to supplement illuminators already in the cameras to maximize the field of view for the cameras. Neither cameras nor infrared illuminators produced any visible light or sound. Every camera and illuminator was equipped with anti-perching spikes (Nixalite of America Inc., East Moline, Illinois) to deter raptors from perching.
Video images sent to the DVR from both camera types were used to calculate time in the colony and predatory behavior. Direct effects of predation at night from each species of predator were quantified by determining the number of times predators were in the colony, time spent in the colony, and number of observed predation events. Visits from potential predators were categorized into three temporal scales for analysis. First, each visit of a potential predator between 2000 hours and 0600 hours (the following day) was categorized as a predator-night. Secondly, each observation of a predator recorded on any of the cameras within a 2-hour time period was termed an occurrence. If an individual was seen in the same camera or multiple cameras at different times but all within a 2-hour time period, it was treated as a single occurrence. Thus, a coyote seen at 2100 hours and 0400 hours were considered two occurrences and one predator-night. Events were defined as anytime a predator was recorded on a single camera within a 10-minute period even when the animal was momentarily out of view of the camera. Multiple observations on a single camera within a ten-minute time period were considered a single event. Predators seen more than once on the same camera, but at intervals exceeding 10 minutes between recordings, were considered separate events. Multiple predators observed simultaneously in the same camera or separate cameras were treated as separate events.

The duration of time each predator was observed during one or multiple events within an occurrence was used to quantify time spent in the colony. Occurrences with a single event used the time frame of the single event only. For occurrences with multiple events, total time in the colony was calculated using the start time of the first event and
the end time of the last event including time between events. For example, if a predator was seen in camera one for 10 seconds and seen again in camera two for 10 seconds with a 10 second interval between events, the total time was calculated at 30 seconds. In instances where multiple predators were seen simultaneously in the same camera view, time was recorded separately for each individual.

Lastly, I recorded the total number of predations that were observed in both camera types from each predator species in each event, occurrence, and predator-night. Predation events were defined as a mortality at a nest (the nest was the sample unit to avoid pseudoreplication of multiple deaths at a single nest) and were described as an egg-stage nest or chick-stage nest. The frequency of visitation was calculated by dividing the number of predator-nights for each species by total sample nights within a study year. Mean and standard errors for occurrences per night observed, events per occurrence, length of occurrence, and predations per occurrence were calculated. I quantified the direct effects and reported the number of occurrences, time observed in the colony, and number of predations for each potential predator species observed at night. I used a chi-square test to identify statistical differences between years for occurrences and predations for each potential predator viewed. The expected values for occurrences and predations were calculated proportionally to the number of sample nights (camera nights) for that year. Inactive cameras were not included in total camera nights (e.g. one camera night was defined as one camera operated for one night). Two sample t-tests were used to identify statistical differences for time observed in the colony for each potential predator observed at night. Although cameras were in the densest parts of the colony, cameras
could not observe the entire colony. Consequently calculations of predators and occurrences were limited to the area and nests observable by the cameras.

Indirect effects of predators were evaluated using spatial analyses and flushing events. For the spatial analyses, I needed to know the position of each nest and the nest’s corresponding fate. Using a global positioning system (GPS; GEO Explorer, Trimble, Sunnyvale, California) I acquired positional data for each nest and corresponding nest fate data was supplied by the Navy (United States Navy, Point Mugu, California).

As part of their monitoring of least terns during the nesting season, Navy personnel performed diurnal nest searches in the Ormond East Colony twice each week or when possible. Nest searches used three to five personnel searching the beach for a period of approximately two hours. During nest searches some adult terns flushed from nests for a portion of that time. Each located nest received a unique number written on 15 x 2 cm wooden tags placed in the sand within 1 m of the nest. Navy personnel updated the status of each nest after every search. Nest fate was classified as hatched, abandoned, predated, washed out, blown out, or unknown. Nests with one or multiple chicks or empty nests, but without indication of predation, were classified as hatched. Nests with eggs that had surpassed a realistic hatching date (>28 days, 21 days of incubation plus some period of possible nest neglect) were considered abandoned. Those nests that had shell fragments, yolk present, and predator tracks were considered predated. Washed out and blown out nests were those that had been destroyed by tidal water or buried in the sand from wind. Lastly, if eggs disappeared without sufficient
evidence to assign other classifications to the nests, they were considered an unknown fate. These unknown fates may have included hatching and predation.

I refined the fate classifications and reclassified nests based on camera observations and strict criteria. Nests missing status information for more than two consecutive weeks in the Navy data were reclassified to an unknown category. Further, Lariviere (1999) reported that presence of eggshells or yolk at a nest site was not by itself adequate to conclude nest fate after prolonged gaps in observations. Nests that were classified as “abandoned then predated” in the Navy documents were reclassified scavenged. Lastly, nests classified as unknown or hatched that were observed to have been predated by my cameras were reclassified as predated.

After the nesting season a Geographic Information System (GIS) was used to calculate the shortest distance from every abandoned nest in the colony to the nearest predated nest in the colony and from every hatched nest in the colony to the nearest predated nest in the colony. If predator presence caused abandonment of nests, an association between nest fate and distance to predated nests should have been statistically detectable. Logistic regression (NCSS Statistical Software 2004, Kaysville, Utah) was used to test for association between nest fate (hatched or failed) and distance to predated nest. I relied on these statistics to detect patterns given that the exact chronology for each nest was uncertain. Abandoned and hatched nests greater than 50 m from predated nests were not included to reduce effects of outliers in the logistic regression analysis. Further, I only used nests that occurred in synchrony (e.g. nests that had already been documented
as predated could not be compared with nests that had not been initiated). This colony-wide analysis was performed separately but identically for each nesting season.

Flushing events from both seasons were used to further quantify the indirect effects of nocturnal predators. A flushing event was anytime an adult tern temporarily left the nest in response to a disturbance. Flushing events were classified by the cause (predator presence or anthropogenic disturbance). A predator-presence flushing occurred when terns flushed as a result of a predator being present, regardless of whether it was foraging in the colony. Anthropogenic disturbances included shooting or other activities associated with predator control. I recorded the number of times and length of time that incubation was interrupted from predator presence for each nest within view of a camera. Additionally, other disturbances, natural or anthropogenic that occurred in camera view, and associated tern or predator responses were also recorded. These disturbances were also incorporated into flushing events. Two sample t-tests were used to identify statistical differences between the duration of temporary nest desertion caused by predator presence and anthropogenic disturbances. Again, I limited evaluation of flushing to the area viewed by the cameras.
RESULTS

The Ormond East Colony was observed for 132 nights totaling 1,316 hours of nocturnal video observations, in two consecutive nesting seasons. Each close-range camera had an area of view approximately $0.07 \pm 0.01$ ha ($\bar{x} \pm SE$) each, while long-range cameras encompassed approximately $1.36 \pm 0.25$ ha each, or 20 times the area of close-range cameras. In 2004, the colony was videoed from June 6 to August 6 (59 nights of observation) totaling 590 hours of observation and 531 camera-nights. Eight close-range cameras and two long-range cameras viewing 55 of 452 nests in the Ormond East Colony were used in 2004 (Figure 2). In 2005, the colony was observed from May 20 to August 3 (73 nights of observation) totaling 726 hours, and 876 camera-nights using eight close-range cameras and four long-range cameras to observe 69 of 475 nests (Figure 3).

Direct Effects of Predators

Five potential predators of terns were observed at night during the two seasons: coyotes, great horned owls, small mammals (probably rats), opossums, and European starlings (Table 1). Small mammals were observed in both years but were not observed to cause direct mortality to terns. Great horned owls were observed in both years and were observed causing mortality to terns in one year. On a single occasion in 2004 a great horned owl was observed perching on a camera. Subsequently the number of anti-perching spikes was increased at each camera and perching did not occur again. An opossum was seen in one year and caused mortality to terns. European starlings were observed in one year only but were not observed to cause direct mortality to terns.
Figure 2. Least tern nesting locations and camera views, depicted by polygons, for the 2004 nesting season at the Ormond East Tern Colony at Naval Base Ventura County, Point Mugu, California.
Figure 3. Least tern nesting locations and camera views, depicted by polygons, for the 2005 nesting season at the Ormond East Tern Colony at Naval Base Ventura County, Point Mugu, California.
Table 1. Species of predators, predator-nights, frequency of predator-nights, occurrence per night observed, events per occurrence, mean time per occurrence, total predations, and predations per occurrence for all potential predators observed at night during the 2004 and 2005 nesting seasons at Naval Base Ventura County, Point Mugu, California.

<table>
<thead>
<tr>
<th>Species</th>
<th>Predator-nights n (% of total nights)</th>
<th>Occurrences per predator-night $\bar{x} \pm SE$ (n)</th>
<th>Events per occurrence $\bar{x} \pm SE$ (n)</th>
<th>Time per occurrence (minutes) $\bar{x} \pm SE$</th>
<th>Total predations</th>
<th>Predation per occurrence $\bar{x} \pm SE$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2004</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small mammal</td>
<td>3 (5)</td>
<td>1.3 ± 0.3 (4)</td>
<td>1.0 ± 0.0 (4)</td>
<td>0.18 ± 0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great horned owl</td>
<td>5 (8)</td>
<td>1.0 ± 0.0 (5)</td>
<td>1.0 ± 0.0 (5)</td>
<td>6 ± 6</td>
<td>2</td>
<td>0.4 ± 0.2</td>
</tr>
<tr>
<td>Coyote</td>
<td>12 (20)</td>
<td>1.0 ± 0.0 (12)</td>
<td>2.7 ± 0.7 (32)</td>
<td>14 ± 7</td>
<td>17</td>
<td>1.5 ± 0.7</td>
</tr>
<tr>
<td><strong>2005</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opossum*</td>
<td>1 (1)</td>
<td>1.0 ± 0.0 (1)</td>
<td>1.0 ± 0.0 (1)</td>
<td>0.53</td>
<td>1</td>
<td>1.0 ± 0.0</td>
</tr>
<tr>
<td>Small mammal</td>
<td>1 (1)</td>
<td>1.0 ± 0.0 (1)</td>
<td>1.0 ± 0.0 (1)</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starling</td>
<td>2 (3)</td>
<td>1.0 ± 0.0 (2)</td>
<td>2.0 ± 0.0 (4)</td>
<td>0.65 ± 0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great horned owl</td>
<td>5 (7)</td>
<td>1.2 ± 0.2 (6)</td>
<td>1.0 ± 0.0 (6)</td>
<td>0.03 ± 0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coyote</td>
<td>12 (17)</td>
<td>1.1 ± 0.1 (13)</td>
<td>4.6 ± 1.2 (55)</td>
<td>10 ± 6</td>
<td>14</td>
<td>1.0 ± 0.6</td>
</tr>
</tbody>
</table>

*The opossum in 2005 was lethally removed during the occurrence as part of the Navy predator control program.
Cameras observed coyotes in both years, and coyotes predated 17 (14 egg-stage and three chick-stage nests) and 14 (nine egg-stage and five chick-stage nests) nests in 2004 and 2005, respectively. The number of occurrences for each potential predator observed in the cameras at night did not differ between years and the number of predations by coyotes was not significantly different between years (Table 2). Duration of time observed in the colony did not differ between years for coyotes ($t = 0.3, p = 0.74, df = 22$), small mammals ($t = 0.9, p = 0.5, df = 2$), or great horned owls ($t = 1.1, p = 0.3, df = 9$). Annual comparisons could not be made for opossums and starlings, because neither occurred in both years of my investigation.

**Indirect Effects of Predators**

The distance from abandoned to predated nests in 2004 was $47 \pm 18$ m and the distance from hatched to predated nests was $48 \pm 7$ m. I found no association between nest fate and distance to nearest predated nest ($r^2 = 0.08, p = 0.52$). During the 2005 season, the distance from abandoned to predated nests was $82 \pm 7$ m and the distance from hatched to predated nests was $67 \pm 3$ m. In 2005, there was no association between nest fate and shortest distance to predated nests ($r^2 = 0.002, p = 0.17$).

**Flushing Events**

Flushing events (one or multiple birds from a single source) occurred 54 times during both nesting seasons. Forty-one of these events resulted from the presence of a predator and 13 were from anthropogenic activities. Predators alone caused a mean of $15.5 \pm 3$ minutes of temporary nest desertion while anthropogenic activities caused a
Table 2. Chi-square comparisons between years (2004 and 2005) based on the number of occurrences and the number of predations observed for each potential predator viewed at night at Naval Base Ventura County, Point Mugu, California (Means are in Table 1).

<table>
<thead>
<tr>
<th>Species</th>
<th>Occurrences</th>
<th>Predation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\chi^2$</td>
<td>p</td>
</tr>
<tr>
<td>Coyote</td>
<td>1.2</td>
<td>0.28</td>
</tr>
<tr>
<td>Great horned owl</td>
<td>0.3</td>
<td>0.59</td>
</tr>
<tr>
<td>Small mammal</td>
<td>1.0</td>
<td>0.31</td>
</tr>
<tr>
<td>Starling</td>
<td>1.2</td>
<td>0.27</td>
</tr>
<tr>
<td>Opossum</td>
<td>0.6</td>
<td>0.43</td>
</tr>
</tbody>
</table>
mean of 150 ± 25 minutes of temporary nest desertion (Table 3). This was significantly longer than predator caused desertion time (t = 5.3, p = 0.002, df = 12). The number of nests included in each flushing event changed throughout our investigation because the number of available nests changed with asynchronous hatching or failure. The mean number of nests observable at each flushing was 20.3 ± 1.3 nests and ranged from 2-41. Anthropogenic disturbances caused 100% of observed nests to flush in all 13 events whereas predator related disturbances caused 86% ± 0.02 of observed nests to flush.
Table 3. Median, mean (not including zeros), and range of temporary nest desertions from predators and from anthropogenic disturbances during 2004 and 2005 at Naval Base Ventura County, Point Mugu, California.

<table>
<thead>
<tr>
<th>Disturbance Source</th>
<th>n</th>
<th>Median (minutes)</th>
<th>Duration of Nest Desertion (minutes)</th>
<th>Range of Desertion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\bar{x} \pm SE$</td>
<td>Minimum (minutes)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maximum (minutes)</td>
</tr>
<tr>
<td>Predator</td>
<td>41</td>
<td>6.6</td>
<td>15.5 ± 3</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>83</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>13</td>
<td>182.7</td>
<td>150.0 ± 25</td>
<td>20.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>281</td>
</tr>
</tbody>
</table>
DISCUSSION

Camera Assessment

Night-capable video cameras provided an objective means for observing predators at night at Point Mugu. Use of cameras eliminated disturbances to the colony caused by investigative procedures. Additionally, night-capable video cameras were more effective than single photographs because there was no shutter noise or flashes. In addition, video captured entire events whereas still photographs would have lapses in time. Night-capable cameras have not been reported to increase nest predation on nesting passerines, northern quail (*Colinus virginianus*), banded dotterels (*Charadrius bicinctus*), black stilts (*Himantopus novaezelandiae*), or black-fronted terns (*Sterna albostriata*) (Brown et al. 1998, Pietz and Granfors 2000, Sanders and Maloney 2002, Renfrew and Ribic 2003, Staller et al. 2005). Cameras likely did not affect the terns in my investigation. Further, my system did not require researchers to approach cameras to retrieve film or other storage media. Video cameras archived images through a remote DVR to a hard disk drive. Digital images archived on the hard disk drive allowed us to edit images and store them on mass media such as compact disks. However, camera effectiveness could be compromised by power source limitations or failure, weather obscuring the cameras lens, and limited hard disk drive storage capacity. Because I was on a remote beach at Point Mugu and lacked a permanent power source I used a generator as a temporary means to power my equipment. Fog as well as sand from strong winds caused loss of a
portion of the view areas at times. Lastly, storage capacity of the hard disk drive was limited to less than 26 hours of archived images without transfer to other media.

**Predators Observed in the Tern Colony**

Five species of potential predators were observed at night. Coyotes were the most frequently observed potential predator of terns during both seasons. The frequency of coyote observation compared to other potential predators was influenced by four factors: the size of their home range, type of habitat used by coyotes, the timing of their activity, and their influence on other potential predator species. First, coyotes can have home ranges that can exceed 90 km² (Springer 1982). Coyotes at Point Mugu, California had home ranges of 18 km² (Craig and Golightly 2005), which was almost the size of the entire naval air station. Thus, any coyote whose home range included the beach, or a transient who used the beach as a travel corridor, would eventually be detected.

Secondly, within their home range, resident coyotes will actively patrol territory and forage (Gese et al. 1988, Holzman et al. 1992, Romsos 1998). They may exclude both other coyotes as well as other canids (Soule et al. 1988, Crooks and Soule 1999, Henke and Bryant 1999, Terborgh et al. 1999, Gompper 2002, Gehrt and Clark 2003). Coyotes may suppress the activity of other predators who would avoid open space due to a greater risk of encounter with a coyote. Coyotes use open habitats and naturally restricted habitats (like the beach habitat in my investigation) more than other available habitats and would be expected to be seen more often in areas that they frequent (Major and Sherburne 1987, Gese et al. 1988, Romsos 1998, Neale and Sacks 2001, Gosselink et al. 2003, Craig and Golightly 2005). Lastly, coyotes at Point Mugu were most active at
night (Craig and Golightly 2005) in order to avoid anthropogenic activity (Romsos 1998, Kitchen et al. 2000). The combination of these four factors may have increased the potential for coyotes to be within view of a camera or in view more than other potential predators, even though other potential predators may have been numerous in adjacent habitat with more cover (Craig and Golightly 2005).

In 2004, I estimated that two different individual coyotes accounted for the 12 predator-nights observed in the Ormond East colony. For 2005 I estimated that five separate individuals visited the colony. Archived images were analyzed for morphological characteristics that could be used to identify specific individuals. For example, in 2005 one individual coyote was identified by a matt of hair on its left flank. Additionally, the removal of four coyotes that occurred in 2005 followed by replacement by other coyotes allowed me to estimate the minimum number of individual coyotes observed.

Great horned owls were observed 11 times in the camera field-of-view during my investigation. I anticipated few observations of great horned owls because cameras were aimed at nesting terns on the ground while owls searched for food while flying or from elevated perches. Small mammals were also observed more than anticipated given their small size and small home range (Redman and Sealander 1958). The presence of driftwood, vegetation, and intermittent sand dunes present in the study area provided areas of cover for small mammals. Thus I had low anticipation for observation of small mammals. European starlings, primarily a diurnally active species (Kumar et al. 2000) were observed from 2000 to 2100 hours and 0500 to 0600 hours during my sampling
period (2000-0600 hours). The occurrence of an opossum following the coyote removals that occurred in 2005 was consistent with mesopredator release (Soule et al. 1988, Crooks and Soule 1999, Henke and Bryant 1999, Terborgh et al. 1999, Gompper 2002, Gehrt and Clark 2003) and expected given the removal of the larger-bodied coyote. Opossums, with radio transmitters, at Point Mugu were frequently detected adjacent to the beach but not on the beach (Craig and Golightly 2005). Removal of large-bodied carnivores may provide opportunities for smaller bodied predators to exploit previously unavailable prey.

Black-crowned night herons, raccoons, and long-tailed weasels were not observed during the two years of my investigation. Navy personnel did not observe tracks on the beach at Ormond East from any of these species. The absence of black-crowned night herons was likely explained by habitat considerations. Black-crowned night herons have been reported to use ponds, impoundments, and manmade structures more than undisturbed areas (Erwin et al. 1996). Raccoons and long-tailed weasels may have avoided my study area to reduce detection by coyotes (Soule et al. 1988, Crooks and Soule 1999, Henke and Bryant 1999, Terborgh et al. 1999, Gompper 2002, Gehrt and Clark 2003, Craig and Golightly 2005).

Direct Effects of Predators

My analysis of Navy-provided data indicated that predation caused 37% and 22% of the total observed nest failure in 2004 and 2005 respectively (United States Navy 2004, and 2005; Table 4), within the area viewed by the cameras. The actual direct effect
Table 4. Fates of least tern nests within camera view and the percentage of the total nests in camera view for the Ormond East colony in the 2004 and 2005 nesting seasons at Naval Base Ventura County, Point Mugu, California.

<table>
<thead>
<tr>
<th>Nest Classification</th>
<th>2004 Observed nests</th>
<th>Percentage of observed nests</th>
<th>2005 Observed nests</th>
<th>Percentage of observed nests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abandoned</td>
<td>5</td>
<td>10</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Blown out</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Hatched</td>
<td>16</td>
<td>31</td>
<td>27</td>
<td>39</td>
</tr>
<tr>
<td>Predated</td>
<td>19</td>
<td>37</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>Unknown</td>
<td>11</td>
<td>20</td>
<td>18</td>
<td>26</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
of predators must incorporate both the number of prey consumed and the rate at which
prey was consumed (Miller et al. 2006). I observed predations of tern nests by coyotes (n
=31 nests), great horned owls (n = 2 adults), and an opossum (n = 1 nest). Coyotes
predated in 31 of 89 coyote events (38%), great horned owls in 2 of 11 owl events (20%),
and opossum in a single opossum event (100%). This opossum event followed the
removal of 4 coyotes including a probable territorial resident. Coyote removal by the
Navy resulted in an opportunity for smaller and potentially more damaging
mesopredators to enter the beach. For example, when unrestricted by coyotes, opossums
have been shown to be effective predators of such ground nesting birds as least terns,
clapper rails (*Rallus longirostris*), northern bobwhite quail, scaled quail (*Callipepla
squamata*), and Passerines (United States Fish and Wildlife Service and United States
Department of Defense - Navy 1990, Crooks and Soule 1999, Rollins and Carrol 2001,
Staller et al. 2005). The small home range size of mesopredators (see Craig and
Golightly 2005) would concentrate an individual’s foraging activity on a specific portion
of the tern colony if the mesopredators were allowed to regularly access the colony (as in
red fox; see Golightly et al. 1994). In fact, the first observation of an opossum in the
cameras was associated with a predation by that opossum. Navy documents from 1998-
2004 had not identified any opossum predations in the Ormond East colony. In the 2004
Breeding Survey for California Least Terns, none of the 32 participating monitoring sites
in California had a documented predation from an opossum (Marschalek 2004), although
they were probably present in neighboring habitats at most
of the sites. It was probably unusual for this effective predator to be able to exploit nests in the tern colony.

The effects of predation on adult terns can have greater long-term effects than predation on young because of the poor survival of young compared to effective breeders. Great horned owls were observed predating only adult terns. This observation does not suggest great horned owls do not also predate chicks, but only that a chick predation was not observed by my cameras. Low fledgling production and removal of adult terns may have additive effects on mortality and exacerbate problems to tern population recovery.

Observed predation and the rates at which predators in view of the cameras took terns could not be extrapolated to the entire colony unless I assumed that predation risk was homogeneous across the entire colony. My cameras were placed in the highest concentrations of nests (see Appendices A and B) in order to maximize the likelihood of observing potential predators and predations. Nests within the interior of the colony have been reported to have higher predation rates than those of outlying nests (Brunton 1999). Therefore my observations probably represent the most severe predation risk in the colony. For perspective, while I observed 19 and 15 predations in 2004 and 2005, respectively in camera views, Navy personnel documented 53 and 41 predations colony wide (Table 5).

Indirect Effects of Predators and Flushing Events
Repeated and prolonged interruptions of incubation have been shown to cause embryonic mortality and hatching asynchrony in least terns and ring-billed gulls (*Larus delawarensis*) (Emlen et al. 1966, Hunter et al. 1975, Nisbet 1975, Atwood 1986, Burger
Table 5. Summary of all least tern nest fates, reclassified from unpublished Navy data, for the entire Ormond East colony for the 2004 and 2005 nesting seasons at Naval Base Ventura County, Point Mugu, California. Marschalek reports estimated fledgling numbers of 110 terns in 2004 and a range of 46-92 terns in 2005 for the Ormond East tern colony at Point Mugu (Marschalek 2004; Marschalek 2005, unpublished data, United States Navy; see Methods for criteria for reclassification).

<table>
<thead>
<tr>
<th>Season</th>
<th>Abandoned</th>
<th>Blown out</th>
<th>Hatched</th>
<th>Predated</th>
<th>Unknown</th>
<th>Washed out</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>35</td>
<td>11</td>
<td>113</td>
<td>53</td>
<td>233</td>
<td>6</td>
</tr>
<tr>
<td>2005</td>
<td>58</td>
<td>0</td>
<td>152</td>
<td>41</td>
<td>222</td>
<td>2</td>
</tr>
</tbody>
</table>
1989). In ring-billed gulls disturbances causing up to four hours of nest desertions resulted in egg and chick mortality as well as delayed hatching (Emlen et al. 1966). Atwood (1986) reported repeated attacks from great horned owls caused a colony of least terns to desert nests and chicks on a nightly basis. This can result in extended incubation, hatch failure, nest desertion, or entire colony abandonment (Nisbet 1975). In my study, temporary nest desertion due to predators ranged from no flushing (0 minutes) to a maximum of 82 minutes with half the cases being less than 6.5 minutes. I found no association between abandoned nests and distance to nearest predated nest. This suggested that disturbances from predation events may be limited to the predation itself and not cause significant negative effects to neighboring nests.

Conversely, anthropogenic disturbances such as shooting predators caused temporary nest desertion on every occasion from all nests in view of the cameras with half of the desertions lasting more than three hours. These management activities themselves have potential to indirectly affect nesting success of terns if they cause excessive interruptions of incubation. Flushing events also make adults (Burger 1989) and unattended eggs and chicks vulnerable to predators, especially smaller predators. For example, on two occasions, once in each season, small mammals were observed inspecting tern nests when adults were absent due to flushing caused by management activities. Additionally, flying from the nest can actually attract predator attention and expose the adult to predation (e.g. a hunting owl).

Direct effects of coyotes on nesting terns must be evaluated relative to their potential exclusion of juvenile or transient conspecifics or other mesopredators. Removal
of coyotes, especially residents, may not provide the intended result of greater overall
nest success. Knowleton et al. (1999) concluded that heavily exploited coyote
populations often increase numerically because of induced younger age structures,
increased litter sizes, and more individuals reproducing as yearlings. Small areas where
coyotes have been exploited have reported accelerated rates of repopulation by coyotes
(Knowlton et al. 1999) and have been most often repopulated by juvenile coyotes seeking
unguarded territories (Knowlton 1972). Importantly, Point Mugu is surrounded by the
Santa Monica Mountains National Recreation Area, agricultural fields, and duck hunting
clubs that may provide a continual source of young or transient coyotes. The removal of
coyotes at Point Mugu may result in rapid repopulation by juvenile coyotes.

Coyotes represent the largest mammalian predator in this ecosystem. Numerous
studies have shown that removal of large-bodied predators has resulted in an increase of
mesopredator abundance (Soule et al. 1988, United States Fish and Wildlife Service and
United States Department of Defense - Navy 1990, Crooks and Soule 1999, Henke and
density of smaller predators in neighboring habitats is greater (as indicated by smaller
and overlapping home ranges; see Craig and Golightly 2005), the number of foraging
predators in the colony has the potential to increase if these smaller predators can gain
access to the open beach. Presence of a large-bodied predator that restricts smaller
predators to other habitats has resulted in greater nest success in waterfowl, sandhill
cranes (Grus canadensis), northern bobwhite quail, and songbirds (Sieving 1992, Sovada
et al. 1995, Rollins and Carrol 2001, Littlefield 2003). If smaller-bodied predators are also allowed to increase in numbers, predation pressure would also increase.

During the 2004 nesting season there was only one failed attempt to manage coyotes at Point Mugu. During the 2005 nesting season there were four removals of coyotes and one failed attempt. Coyotes were removed at night within the colony at the discretion of Point Mugu personnel using a 25.06 caliber rifle with a night vision scope. Of four coyotes removed in 2005, one was an adult male (which was presumed to be a territorial resident based on scars on its face and ears) and three were juveniles. Coyotes use physical contact as a means of territorial defense sometimes resulting in injuries. Thus territory holders have the most potential for physical indications of interspecific interactions (Gese 2001). Following the removal of the adult male, two juveniles were removed, there was a failed attempt at another coyote, and the opossum was observed predating terns. These observations were consistent with mesopredator release and coyote social organization. The greater number of coyotes observed in 2005 and the occurrence of an opossum may have been a consequence of the removal of the territorial coyote.

Following the removal of the adult male coyote, I also documented the three most active nights for coyotes in my two-year investigation. Further, 13 of 14 predations by coyotes for 2005 were observed during those three nights (Figure 4). In a post-hoc analysis I used a chi-square test to determine if the number of observed predations following the removal of this probable resident coyote was significant. I
Figure 4. Coyote activity for 2004 and 2005 nesting seasons and opossum activity in the 2005 nesting season at Naval Base Ventura County, Point Mugu, California. Vertical arrows in 2005 denote coyote removals. The specific dates for coyote removals in 2005 were June 2, 14, 25, and July 20. The second coyote removed was a probable territorial adult. The first, third, and fourth coyotes removed were juveniles.
calculated the expected number of predations based upon the distribution of the number of nest-days before and after the removal assuming 40 days of nest availability (21 days for incubation and 19 days to fledging: Thompson et al. 1997). The sum of these represented the total minimum number of days that a tern egg or chick would be expected to be in the colony and potentially predated. Each nest was assigned to before or after removal of the adult coyote. Expected predations were proportioned according to the sums of nest-days assigned to each category (before removal and after removal of adult coyote). The number of observed predations following the removal of the adult tended to be greater (although not significantly and the sample size was small) than the number observed prior to the removal ($\chi^2 = 2.9$, $p = 0.09$, df = 1).

The description of subtle influences of indirect effects in my study were in part possible because of the active management occurring concurrently, but independently in 2005. It should be recognized that although the 2004 nesting season was used as a comparison in my study, it does not represent a true control. Although the behavior of individual coyotes, when present on the beach did not differ between the two years (e.g. events per occurrence), the number of predations that would have occurred if no predator control had occurred in 2005 remain unknown. Further, I described the activity of predators at the Ormond East Colony only, comparing rates of predation (whole colony or colony subset), describes this single colony only. Ideally comparisons of multiple colonies where coyotes were controlled and colonies where they were not would provide further insight.
Diurnal Predation

Regular occurrences of loggerhead shrikes (*Lanius ludovicianus*), American kestrels (*Falco sparverius*), and California ground squirrels (*Spermophilus beecheyi*), in both the 2004 and 2005, nesting seasons were documented on the beach by Navy personnel. Diurnal predators may be having significant effects on tern success and the presence diurnal predators at Point Mugu warrants further evaluation in order to characterize the relative potential of each type of predator preying on terns. An American kestrel was observed in the Ormond East colony 11 times in nine consecutive days during the 2005 nesting season (unpublished data, United States Navy and personnel observations) and this bird was observed depredating chicks on 4 occasions. In response to the frequency of occurrences and predation events, the kestrel was trapped and relocated to the Ojai Raptor Center, Ojai California. Staff at the Ojai Raptor Center determined that the kestrel was most likely provisioning chicks based on fecal material found in the feathers.

American kestrels provisioning chicks in Massachusetts were observed depredating least tern chicks every 15 minutes for two hours (Jenks-Jay 1980). Given the recorded frequency by Navy personnel and reported predation rates elsewhere, American kestrels appear to represent a serious threat to nesting terns. For perspective, I extrapolated potential effects that a pair of provisioning American kestrels could have on a least tern colony with a predation rate of one tern chick every 15 minutes for two hours (Jenks-Jay 1980) over the entire 30-day nestling period (Smallwood and Smallwood 1998). Predation from a single pair of American kestrels would result in 240 tern chicks
taken. Although this was not the case at Ormond East, the potential could be more than seven times the total number of predations from coyotes in both seasons of my investigation. Loggerhead shrikes were also seen depredating chicks in both nesting seasons. Coyotes also took chicks but do not have the persistent presence at a feeding site that can be characteristic of some predatory birds (Jenks-Jay 1980, Thirgood et al. 2003).
MANAGEMENT CONSIDERATIONS

Predator management activities at Point Mugu have an important role in the overall protection of terns but must be evaluated on a case-by-case basis regarding potential benefits versus undesirable consequences. Transient coyotes, juvenile coyotes, and opossums can pose threats to tern recovery and commonly repopulate areas where coyotes, especially residents, have been removed (Knowlton 1972). Other mesopredators such as red fox, raccoon, or long-tailed weasel, as well as domestic or feral dogs and cats could potentially become threats to terns (especially in the absence of resident coyotes). The intense removal of coyotes in 2005 did not result in fewer visits by coyotes or fewer predations on terns, and coincidental with these removals was the discovery of a suspected but previously undocumented opossum that did predate terns. Additionally, management activities caused significantly greater durations of temporary nest desertion than did predators, thus increasing risks to adults and unattended nests from weather and other predators. Management of problem predators and non-native predators, maintenance of the predator community structure, and intensive monitoring have been shown to be the most effective means of predator management (Shwiff et al. 2005, Engeman et al. 2005). Predator control at night may have more harmful effects on tern success than diurnal control efforts. Further, predators active by day may also substantially contribute to tern predation.
The cameras used with this research provided access to continuous nocturnal monitoring and identified events in the tern colony that may have otherwise gone undocumented. However, power sources and technical expertise can be limiting factors for varied applications and require constant maintenance and timely review. Such systems could be devised that required approximately 50-60 hours of labor for a weekly operator (based on a 7-day week). The generator required continued maintenance and operational costs. A more permanent and consistent power source such as solar panels or direct utility connection should be considered for new research that uses video camera technology.
LITERATURE CITED


Appendix A. Location of California least tern nests, camera views, and density of nests in the Ormond East tern colony at Naval Base Ventura County, Point Mugu, California for 2004. Geographic information system software ArcGIS 9 was used to create a raster data layer of nest density for the Ormond East least tern colony. Using point density calculation, the number of points (in this case nests) were counted within one hectare of each raster cell. This number was divided by the area in order to assign a density value to each raster cell. The densest areas of the colony are depicted by the darkest shading and were classified into five categories of nests per hectare.
Appendix B. Location of California least tern nests, camera views, and density of nests in the Ormond East tern colony at Naval Base Ventura County, Point Mugu, California for 2005. Geographic information system software ArcGIS 9 was used to create a raster data layer of nest density for the Ormond East least tern colony. Using point density calculation, the number of points (in this case nests) were counted within one hectare of each raster cell. This number was divided by the area in order to assign a density value to each raster cell. The densest areas of the colony are depicted by the darkest shading and were classified into five categories of nests per hectare.