

**Evaluating the Impacts of Military and Civilian Overflights and Human Recreation on Least Terns, Common Terns, Gull-billed Terns, and Black Skimmers at Cape Lookout National Seashore, North Carolina**

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**Abstract**

Due to variability in aircraft overflight type and associated animal responses, there is a lack of consensus on the effects of overflights on wildlife populations. My objectives were to 1) evaluate the potential impacts that reduced-altitude tactical speed military aircraft might generate on nesting colonial waterbirds, and to place any impacts in the context of other human events, 2) a) identify key least tern (*Sternula antillarum*) demographic drivers, b) evaluate the accuracy of assigning nest fates without using remote cameras, and c) assess the effects of camera-monitoring on nest survival, and 3) evaluate the agreement between two techniques used to estimate peak least tern breeding abundance. I conducted my study at Cape Lookout National Seashore, North Carolina from May-August 2010-2012. I surveyed colonies once every 3-5 days and deployed audio recorders and time-lapse cameras at individual nests in 9 colonies. Birds did not incubate less or engage in alert behaviors during overflights compared with control periods. Least terns reduced incubation by a mean of 12% when pedestrians were observed near nests ( $S = -2.2, p = 0.04$ ). Demographic effects from overflights or recreation are unlikely given the patterns of use in this study. Least tern demographic rates were driven by raccoon depredation. Cameras reduced daily nest survival (SE) from 0.85 (0.06) to 0.79 (0.08). However, cameras also decreased the frequency of unknown or misclassified nest fates by > 30%. Incubating adult counts were effective in assessing peak nest abundance at colonies where topography did not impede scanning from the perimeter.

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**Chapter Two:**

Evaluating the Impacts of Military and Civilian Overflights and Human Recreation on Least Terns, Common Terns, Gull-billed Terns, and Black Skimmers at Cape Lookout National Seashore, North Carolina

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Target journal: *Journal of Wildlife Management*

**Chapter Three:**

Effects of Camera Monitoring on Least Tern Nest Success at Cape Lookout National Seashore, North Carolina

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**Chapter Four:**

Assessing the Bias and Variance of Least Tern Survey Procedures

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## TABLE OF CONTENTS

Acknowledgments.....	iv
List of Tables .....	viii
List of Figures.....	x
Chapter 1 - Introduction.....	1
Chapter 2 - Evaluating the Impacts of Military and Civilian Overflights and Human Recreation on Least Terns, Common Terns, Gull-billed Terns, and Black Skimmers at Cape Lookout National Seashore, North Carolina .....	4
ABSTRACT .....	4
STUDY AREA .....	9
METHODS .....	11
RESULTS .....	18
DISCUSSION.....	21
MANAGEMENT IMPLICATIONS .....	29
ACKNOWLEDGMENTS .....	29
LITERATURE CITED.....	30
TABLES AND FIGURES.....	41
Chapter 3 - Effects of Camera Monitoring on Least Tern Nest Success at Cape Lookout National Seashore, North Carolina .....	62
ABSTRACT .....	62
STUDY AREA .....	66
METHODS .....	66
RESULTS .....	68
DISCUSSION.....	70
LITERATURE CITED.....	74
Chapter 4 - Assessing Bias and Variation in Survey Methods and the Window Census Protocol for Least Terns .....	83
ABSTRACT .....	83
STUDY AREA .....	88
METHODS .....	89
RESULTS .....	92
DISCUSSION.....	95
MANAGEMENT IMPLICATIONS .....	99
ACKNOWLEDGMENTS .....	100
LITERATURE CITED.....	101
TABLES AND FIGURES.....	105

Chapter 5 – Conclusion: Recommendations for Management and Future Studies of Colonial Waterbirds at Cape Lookout National Seashore.....	111
Appendix A.....	115
Table A1. Study species .....	115
Figure A1. Study species .....	118
Appendix B. The types of stressors associated with aircraft and the habitat or animal properties likely to influence the impact of each stressor on birds (adapted from Efroymson et al. 2000).	119
Appendix C. Field and laboratory methods and visual illustrations of results for the Core Military Operations Area overflight study at Cape Lookout National Seashore, North Carolina, 2010-2011. ....	120
Appendix D. Least Tern ( <i>Sternula antillarum</i> ) behaviors commonly observed while performing incubating adult counts from the colony perimeter. ....	126
Appendix E. Institutional Animal Care and Use Committee (IACUC) approval letter. ....	128

## List of Tables

### Chapter 2:

Table 1. Military overflights through the Core Military Operations Area (Core MOA) over Cape Lookout National Seashore, North Carolina, 2010-2011: ‘Reported’ – total overflights for which the U.S. Marine Corps provided data; ‘nesting season’ – overflights during the colonial waterbird nesting season; ‘audible’ – overflights audible from the study site while digital audio recorders and cameras were deployed; ‘sequences’ – uniquely identifiable singular overflights, simultaneous overflights, or non-independent overflights in rapid succession; ‘sequences < 3,000 m’ – overflight sequences between 900 m and 3,000 m above ground level, which corresponds to the reduced Core MOA floor for tactical flight speed between these two altitudes. .... 41

Table 2. Descriptive statistics of military overflights through the Core Military Operations Area (Core MOA) over Cape Lookout National Seashore (CALO), North Carolina, including fixed-and-rotary-wing overflights with associated climatic variables, from April-August 2010-2011. Audio data were recorded from Samson Zoom H2 Digital Audio Recorders (DAR) at North Core Banks, CALO, and post-processed using Larson Davis 831 Sound Level Meters, Audio2NV SPL software, and Acoustic Monitoring Toolbox (Natural Sounds Program, National Park Service, Fort Collins, CO). All overflights are represented irrespective of active camera-nest monitoring. .... 42

Table 3. a) Models explaining variation in received Sound Exposure Levels (SEL) of 70 Core Military Operations Area (Core MOA) fixed-wing overflights using generalized linear models (proc GENMOD, SAS Institute, Cary, NC) and Akaike weights ( $w$ ). Rotary-wing (CH-53) and turboprop (C-130) aircraft were excluded from the analysis. b) Relative importance of each variable in models of received SEL. ... 45

Table 4. Mean proportion of time spent incubating by least terns (*Sternula antillarum*, Table 4a), common terns (*Sterna hirundo*, Table 4b), gull-billed terns (*Gelochelidon nilotica*, Table 4c), and black skimmers (*Rynchops niger*, Table 4d) ‘pre’, ‘during’, and ‘post’: overflights through the Core Military Operations Area (Core MOA); non-Core MOA military fixed-wing overflights; civilian fixed-wing overflights; military and civilian rotary-wing overflights; off-road and all-terrain vehicle events; and pedestrian events, with relevant data subsets by Sound Exposure Level (SEL) and distance from nest at North Core Banks, Cape Lookout National Seashore, North Carolina, April-August 2010-2011. .... 47

### Chapter 3:

Table 1. Differences between field-estimated nest fates and remote camera-confirmed nests fates for 163 Least Tern nests at Cape Lookout National Seashore, North Carolina in 2011. .... 78

Table 2. Models of the factors affecting survival of camera- and non-camera-monitored Least Tern nests at Cape Lookout National Seashore, North Carolina, May-August 2011. .... 79

Table 3. Parameter estimates from top-ranked model of the factors affecting survival of Least Tern nests from May-August 2011 at Cape Lookout National Seashore, NC. .... 80



**Chapter 4:**

Table 1. Sample size, covariance, concordance correlation coefficients, and 95% confidence intervals of:  
1) inter-observer variability by time of day for least tern incubating adult counts, and 2) sequential  
ground nest counts and. morning and afternoon incubating adult counts at North Core Banks, Cape  
Lookout National Seashore, North Carolina, 2010.....105

**Appendix A:**

Table A1: Study species.....115

**Appendix B:** The types of stressors associated with aircraft and the habitat or animal properties likely to  
influence the impact of each stressor on birds (adapted from Efroymsen et al. 2000).....119

## List of Figures

### Chapter 2:

- Figure 1. North Core Banks, Cape Lookout National Seashore (CALO), North Carolina, 2010-2011. Marine Corps Air Station Cherry Point, in cooperation with the Federal Aviation Administration, manages Special-Use Airspaces around Cape Lookout National Seashore, including the Core Military Operations Area (Core MOA) and adjacent restricted R-5306A and Warning W-122 Areas. The Core MOA, outlined by the dashed polygon, extends southwest of North Core Banks and terminates over South Core Banks (not shown); R-5306A is to the west and W-122 to the east. Waterbird colonies are denoted as follows: shaded circles - active in 2010 only (North Tip, Portsmouth Flats North); black circles - active in 2011 only (Blowfish Island, Old Drum South, High Hills); transparent circles with dotted line - active in 2010 and 2011 (Portsmouth Flats South, Old Drum Inlet, Dune Shell Beds, New Drum Inlet): smallest circle - < 10 nests at peak colony incubating adult count; largest circle - > 350 nests at peak colony incubating adult count. Mixed-species colonies occurred only at Blowfish Island, New Drum Inlet, and Old drum Inlet..... 52
- Figure 2. Schematic of a typical waterbird colony at Cape Lookout National Seashore, North Carolina. We deployed remote cameras at individual nests and audio recorders at 300 m intervals from April-August, 2010-2011. We randomly selected a nest within each block for camera placement and re-deployed cameras on additional random nests in each block as previous nests hatched or failed..... 53
- Figure 3. There was a strong positive relationship between Sound Exposure Level (SEL) and Maximum 1-s Average Equivalent Sound Level (MaxLEQ) for military overflights through the Core Military Operations Area ( $r^2 = 0.90$ ,  $n = 70$  overflights,  $RMSE = 2.11$ ,  $p < 0.001$ ,  $SEL = 26.8 + 0.78 * MaxLEQ$ ). The shaded region shows the bounds of the 95% confidence intervals on the regression line..... 54
- Figure 4. Sound Exposure Levels of overflights through the Core Military Operations Area ( $n = 70$ ) as related to altitude, lateral distance (i.e., Closest Point of Approach), and wind speed on North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011. .... 55
- Figure 5. Sound Exposure Levels (SEL) of: Overflights through the Core Military Operations Area (Core MOA); non-Core MOA overflights; and all-terrain vehicle events (sample sizes above box plots) recorded from digital audio recorders in waterbird colonies at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011. ‘Core MOA experimental’ denotes the 5 overflights flown from July-August 2011 by Marine Corps Air Station Cherry Point conducted near the 900 m Core MOA floor and within 0.97 km of closest point of approach to active nests. Audio data was calibrated using Larson Davis 831 Sound Level Meters and post-processed using AUDIO2NVSPL and Acoustic Monitoring Toolbox software programs (Natural Sounds Program, National Park Service)..... 56
- Figure 6. The number of nests for each colonial waterbird species from which behavior was sampled in response to all overflights (dark gray) and to other human events (off-road vehicles, all-terrain vehicles, and pedestrians, light grey). .... 57

Figure 7. Mean proportion of time spent incubating by least terns ‘pre’, ‘during’, and ‘post’ a) overflights and b) other human events at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011 (sample sizes above the symbols). \*indicates  $p < 0.05$  for Multi-Response Blocked Permutation (MRBP) test between ‘pre’, ‘during’ and ‘post’ samples. .... 58

Figure 8. Mean proportion of time spent incubating by common terns ‘pre’, ‘during’, and ‘post’ a) overflights and b) other human events at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011 (sample sizes above the symbols). .... 59

Figure 9. Mean proportion of time spent incubating by gull-billed terns ‘pre’, ‘during’, and ‘post’ Core MOA and rotary wing overflights at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011 (sample sizes above the symbols). .... 60

Figure 10. Mean proportion of time spent incubating by black skimmers ‘pre’, ‘during’, and ‘post’ a) overflights and b) other human events at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011 (sample sizes above the symbols). \*indicates  $p < 0.05$  for Multi-Response Blocked Permutation (MRBP) test between ‘pre’, ‘during’ and ‘post’ samples. .... 61

### Chapter 3:

Figure 1. We studied nest fates and daily nest survival rates of Least Terns at 7 colonies on North Core Banks, Cape Lookout National Seashore (CALO), North Carolina in 2011. Colony size is denoted as follows: Smallest circle -  $< 10$  nests at peak colony incubating adult count; largest circle -  $> 350$  nests at peak colony incubating adult count. Mixed-species colonies occurred only at Blowfish Island, New Drum Inlet, and Old Drum Inlet. .... 81

Figure 2. Schematic of the layout of camera, block, and transect line placement in a waterbird colony at Cape Lookout National Seashore, North Carolina. We deployed remote cameras at individual nests selected randomly within each block to study nest fates in May-July 2011. We also sampled nests along transect lines to estimate nest fate and nest survival of nests lacking cameras. Block width was 150 m at smaller or more vegetated colonies and up to 250 m at large, open colonies. .... 82

### Chapter 4:

Figure 1. We estimated least tern nest abundance at 9 colonies on North Core Banks, Cape Lookout National Seashore (CALO), North Carolina in 2010-2012. Waterbird colonies are denoted as follows: Smallest circle -  $< 10$  nests at peak colony incubating adult count; largest circle -  $> 350$  nests at peak colony incubating adult count. Mixed-species colonies occurred only at Blowfish Island, New Drum Inlet, and Old Drum Inlet. .... 106

Figure 2. Schematic of a waterbird colony at Cape Lookout National Seashore, North Carolina. We deployed remote cameras at individual nests selected randomly within each block to quantify incubation behavior from April-August, 2010-2011. We summed incubating adult counts from each block to estimate nest abundance over the course of the season, and validated the accuracy of incubating adult counts by conducting intensive ground-nest counts at one block for direct comparisons between methods. Block width was 150 m at smaller or more vegetated colonies and up to 250 m at large, open colonies. .... 107

Figure 3. The mean proportion of time spent incubating by least terns, with standard error bars, by sampling period and time of day from a random sample of 156 camera-monitored nests from May - July, 2010-2011, North Core Banks, North Carolina .....108

Figure 4. Least tern incubating adult counts, North Core Banks, Cape Lookout National Seashore, North Carolina: a) 2010 bi-weekly counts by colony, b) 2011 twice-weekly counts by colony, and c) 2010 -2012 island-wide bi-weekly counts for all colonies combined. Shaded rectangles denote the 5-20 June annual window census period. Colony codes: BFI – Blowfish Island, DSB – Dune Shell Beds, NDI – New Drum Inlet, HHL – High Hills, ODI – Old Drum Inlet, ODS – Old Drum South, PFS – Portsmouth Flats South.....109

**Appendix A:**

Figure A1. Study species.....118

**Appendix C:**

Figure C1: Nest-monitoring methods.....120

Figure C2: Audio-monitoring methods.....121

Figure C3: Spectrograms.....122

Figure C4: A-weighting.....123

Figure C5: Core Military Operations Area overflight tracks.....124

Figure C6: Human events.....125

**Appendix D:**

Figure D1: Typical Least Tern Incubating postures.....126

Figure D2: Non-incubating Least Tern postures.....127

**Appendix E:** Institutional Animal Care and Use Committee (IACUC) approval letter. ....128

## Chapter 1 - Introduction

The U.S. Marine Corps (USMC) has long conducted training flights in the Core Military Operations Area (Core MOA) over Cape Lookout National Seashore (CALO), North Carolina. The Core MOA is a special use airspace managed by Marine Corps Air Station (MCAS) Cherry Point and the Federal Aviation Administration (FAA). Its purpose is to provide connectivity between two restricted airspaces (Restricted Area R-5306A and Warning Area W-122) and to permit military aircraft to safely conduct realistic training maneuvers within the combined special use airspaces.

Before this study, training flights at tactical speed ( $> 250$  kt) through the Core MOA were conducted at  $> 3,000$  m (i.e., 10,000 ft) above ground level (AGL). Overflights  $< 3,000$  m AGL were permitted down to the 900 m (i.e., 3,000 ft) Core MOA floor, but those lower aircraft were required to fly below tactical speeds. In response to evolving training needs, in 2008 the USMC and the National Park Service (NPS) agreed to lower the minimum allowed altitude for tactical flight speeds in the Core MOA from 3,000 m to 900 m AGL beginning in March 2009. At that time, the NPS requested a 3 yr study to assess the possible impacts of a reduced Core MOA floor for tactical speed overflights on state-protected beach-nesting bird species; specifically the American oystercatcher (*Haematopus palliatus*), Wilson's plover (*Charadrius wilsonia*), least tern (*Sternula antillarum*), common tern (*Sterna hirundo*), gull-billed tern (*Gelochelidon nilotica*), and black skimmer (*Rynchops niger*; letter dated 17 September 2008 from David Vela, Southeast Regional Director, NPS, to Colonel Ruvalcaba, FAA SE Region, USMC).

In particular, the NPS asked: “(1) does noise from low flying aircraft disrupt adults from incubating nests?; (2) how long does it take for the adult to return to the nest?; (3), if adults are disturbed during incubation on several occasions, will they eventually abandon the nest?; (4)

*does the noise from low flying aircraft cause adults to leave the area while 'guarding' flightless chicks?; and (5) what will be the level of disturbance based on the altitude of the aircraft?"*

The NPS' questions, and the subsequent study, was pursuant to NPS Management Policy 4.4.2.3., which states that *"The National Park Service will inventory, monitor and manage state and locally listed species in a manner similar to its treatment of federally listed species to the greatest extent possible. In addition, the Service will inventory other native species that are of special management concern to parks (such as rare, declining, sensitive, or unique species and their habitats) and will manage them to maintain their natural distribution and abundance."*

The NPS is also congressionally mandated to protect migratory birds (Migratory Bird Treaty Act), ensure wilderness values, comply with the National Environmental Policy Act (NEPA), and comply with the National Parks Overflight Act (1987). In accordance with these statutory responsibilities, the NPS requested that the USMC fund a study to determine the effects, if any, that a reduced Core MOA floor for tactical speed overflights would generate on nesting waterbirds. The NPS did not object to implementing these changes from May-July on an interim basis of 3 years during which this study took place.

Subsequently, the USMC contracted Virginia Tech to conduct a portion of this study focusing on Wilson's plovers (DeRose-Wilson, *in prep*), terns, and black skimmers, with a companion study conducted by North Carolina State University addressing similar questions for American oystercatchers (Borneman, *in prep*). My study focused on the above-mentioned tern and skimmer species, hereafter referred to as colonial waterbirds (see Appendix A for description and photographs of study species).

To meet the need for information on the effects of aircraft on colonial waterbirds, and to maximize the application of my data to the varied management needs of the NPS, USMC, and

other local, state, and federal agencies charged with managing these protected species, I organized my study around three main objectives:

- 1) To determine if military overflights through the Core MOA changed the behavior of nesting colonial waterbirds, and to place any responses associated with military overflights in the context of other natural and human disturbances common to CALO (Chapter 2);
- 2) To understand the colony dynamics and demographic parameters of the focal species, including researcher-induced effects on nest survival (Chapter 3); and
- 3) To evaluate the bias and variance of two commonly used techniques to estimate least tern peak nest abundance (Chapter 4).

This thesis includes the results from a portion of Virginia Tech's contractual agreements with the NPS and the USMC. Data collection with respect to bird-banding/resighting operations is ongoing and is therefore not fully reported in this thesis; I will present these results as part of a supplemental final report to the USMC no later than 2013 July, and in additional publications.

**Chapter 2 - Evaluating the Impacts of Military and Civilian Overflights and Human Recreation on Least Terns, Common Terns, Gull-billed Terns, and Black Skimmers at Cape Lookout National Seashore, North Carolina**

**ABSTRACT** Due to high variability in the types of aircraft overflights and the associated responses by different species of animals, there is a lack of consensus on the effects of overflights on wildlife behavior and demography. In response to a request by the U.S. Marine Corps (USMC) to the National Park Service (NPS) to conduct low-altitude tactical training operations in the special-use airspace above Cape Lookout National Seashore (CALO), North Carolina, we studied the effects of military air traffic on the nesting behaviors of least terns (*Sternula antillarum*), common terns (*Sterna hirundo*), gull-billed terns (*Gelochelidon nilotica*), and black skimmers (*Rynchops niger*) at North Core Banks, CALO. We compared the effects of military aircraft to other human activities at CALO, including civilian fixed-and-rotary-wing aircraft, all-terrain vehicles, off-road vehicles, and pedestrians. We deployed digital audio recorders within colonies and time-lapse cameras at individual nests at 9 waterbird colonies from May-August 2010-2011. We supplemented USMC-provided military overflight data (aircraft type, altitude, velocity, coordinates of ingress/egress, and time of ingress/egress) with data collected opportunistically for all other types of human events. We post-processed audio recordings and analyzed one-third octave band spectrograms to examine the effects of overflight altitude on received sound levels. The average altitude (SE) of audible military overflights ( $n = 80$ ) was 3,291 m (179) and the mean Sound Exposure Level (SEL) and Maximum 1-s Equivalent Average Sound Level (MaxLEQ) were 77.8 dBA (0.77) and 65.5 dBA (0.93), respectively. Controlling for closest point of approach (CPA), lower-altitude overflights—i.e., overflights below the 3,000 m floor for tactical flights speeds ( $>250$  kt,  $n = 8$ )—were, on average,  $> 10$  dBA



louder in received SEL and  $> 14$  dBA louder in MaxLEQ than overflights at or above the 3,000 m floor ( $n = 11$ ). We used generalized linear models to analyze how received SEL of fixed-wing military overflights varied with altitude, CPA, colony, and climatic variables. All top-ranked models included altitude and CPA; wind speed and wind direction were also important. There was no evidence that the behavioral responses of colonial waterbirds to the acoustic and/or visual stimuli of military or civilian aircraft impacted demographic rates. The mean proportion of time spent incubating by least terns was less during pedestrian events compared to control periods (0.91 versus 0.79,  $S = -2.2$ ,  $p = 0.04$ ). The current patterns of aircraft operations are unlikely to affect colonial waterbird demographics, and NPS beach management policies mitigated adverse impacts to colonial waterbirds associated with human recreation.

**KEY WORDS** acoustics, beach, black skimmer, common tern, disturbance, gull-billed tern, incubation, least tern, military overflights, North Carolina, recreation

Human activity in natural areas is an increasingly pervasive threat to wildlife (Bowles 1995; Carney and Sydeman 1999; Christ et al. 2003). While aircraft or vehicle collisions may have immediate demographic consequences to wildlife populations, behavioral responses to human activities are varied and complex. Whether human activities include visual stimuli such as transient hikers, auditory stimuli such as distant fixed-wing aircraft, or both such as low-flying helicopters, an animal's behavioral response to these real or perceived threats may indirectly affect its reproduction or survival.

For example, a bird that flushes from its nest in response to a disturbance may increase its probability of being detected by a predator (Skutch 1949; Tewksbury et al. 2002; Weston and Elgar 2007; Chalfoun and Martin 2010), increase intraspecific aggression in colonial species

(Burger 1981), expose chicks and eggs to adverse environmental conditions, such as high radiant heat that can cause embryo death (Conway and Martin 2000; Weston et al. 2011), and/or divert energy from feeding or reproduction (Frid and Dill 2002; Pepper et al. 2003). Acoustic stimuli may alter or mask the auditory signals that birds use for information exchange, such as singing or contact/alarm-calling to defend territories or locate mates or offspring, and, particularly for colonial species, to alert neighbors of nearby threats and maintain group cohesion (Lack 1968; Awbrey and Hunsaker 1997; Marler 2004; Caro 2005; Barber et al. 2009; Ortega 2012). Sufficiently loud events may damage hearing (Bowles 1995; Larkin et al. 1996). Birds may also avoid otherwise suitable habitats as a result of aircraft or human presence (Fraser et al. 1985; Andersen et al. 1989; Buehler et al. 1991; Tarr et al. 2010), potentially forcing displaced individuals to use inferior habitats, thereby decreasing productivity or survival. Each of these behavioral responses to human presence may negatively impact wildlife populations.

The existing body of literature on the effects of human activities on avian behavior is varied, and the results are often species and context-dependent. Therefore, it often is not appropriate to extrapolate the results from one study to another species, habitat, season (i.e., breeding vs. non-breeding), or type of activity under investigation. For example, aircraft overflights, or simulated aircraft noise, altered avian behavior in some studies (Andersen et al. 1989; Brown 1990; Conomy et al. 1998a; Conomy et al. 1998b; Delaney et al. 1999; Brown 2001; Goudie and Jones 2004) but had no effects in others (Snyder et al. 1978; Fraser et al. 1985; Trimper et al. 1998; Delaney et al. 2002); the associated effects on reproduction or survival were also mixed. Plumpton (2006) reviewed overflight studies and concluded that birds were more likely to respond to rotary-wing aircraft than to fixed-wing aircraft, and to slow-moving turboprop aircraft than to fast-moving turbofan aircraft; however, the magnitude of response in

these studies varied considerably and could not be generalized across guilds or habitats. Moreover, studies on the effects of human activity on wildlife may be confounded by concurrent effects on co-occurring species, including predators. For example, while close proximity (< 100 m) to off-road vehicle (ORV) trails increased songbird nest abandonment, it also decreased nest predation rates, presumably because both nesting birds and their predators were sensitive to ORV disturbances (Barton and Holmes 2007). Contrary to their expectations, McGowan and Simons (2006) found that reduced time spent incubating by American Oystercatchers resulted in increased daily nest survival; the authors hypothesized that increased time spent away from a nest following a human disturbance decreased the total trips to and from the nest, which reduced the probability that a predator would locate the nest. What is clear from a review of the literature on the effects of human activities on avian behavior is that caution should be taken when extrapolating findings between disparate study species or habitats.

Four state-listed colonial waterbird species nest on North Core Banks, Cape Lookout National Seashore (CALO), North Carolina, including least terns (*Sternula antillarum*), common terns (*Sterna hirundo*), and black skimmers (*Rynchops niger*)—each listed as a species of special concern—and gull-billed terns (*Gelochelidon nilotica*), listed as threatened (North Carolina Wildlife Resources Commission 2008, Appendix A). All species are regularly exposed to a variety of human activities, including military and civilian air traffic, ORVs (i.e., pickup trucks and sport utility vehicles), all-terrain vehicles (ATVs, defined here as either single-or-multi-rider ATVs or utility terrain vehicles), pedestrians, and, to a lesser extent, motorized and non-motorized watercraft. The beach habitat that these species require is particularly prone to human activity during the summer nesting season.

Colonial waterbirds, along with other species that require open habitats in which to nest and forage, may have a greater sensitivity to audible disturbances than species inhabiting structurally complex systems, due to the characteristics of sound propagation in the absence of physical barriers (Appendix B; Hill et al. 1997; Efroymson and Suter 2001; Pepper et al. 2003). Further, colonially-nesting birds may be more sensitive to disturbance than solitary species due to coordinated flushing and mobbing behaviors, particularly if the response of one individual elicits a colony-wide reaction (Owens 1977; Burger 1981; Erwin 1989; National Park Service 1994; Carney and Sydeman 1999). Therefore, beach-nesting colonial waterbirds may be especially vulnerable to exposure from aircraft or human recreation.

In addition to potential threats from aircraft or human recreation, beach-nesting birds are vulnerable to fragmentation and degradation of coastal habitats, increased competition with and predation from non-native and human commensal species (e.g. great black-backed gulls, *Larus marinus*, and raccoons, *Procyon lotor*), sea level rise, altered storm patterns, and changing forage fish populations and harvest (Burger 1984; Thompson et al. 1997; Rodgers & Smith 1995; Najjar et al. 2000, 2010; Erwin et al. 2006; Le V. dit Durell et al. 2006; Brinker et al. 2007). A combination of these threats has resulted in state-wide colonial waterbird declines documented in North Carolina (CALO 2006), the southeast region as a whole (Hunter et al. 2006), and the adjacent Chesapeake Bay region (Brinker et al. 2007). Therefore, it is important to view any potential effects of changes in frequencies or types of human activities in the context of the above-mentioned natural and human threats, many of which are novel, to colonial waterbirds.

In response to a request by the U.S. Marine Corps (USMC) to the National Park Service (NPS) to conduct low-altitude tactical training operations in the special-use Core Military Operations Area (Core MOA) above CALO, we studied the effects of military and civilian fixed-

and-rotary-wing aircraft, ORVs, ATVs, and pedestrians on the nesting behavior of least terns, common terns, gull-billed terns, and black skimmers. Before this study, training flights at tactical speeds (> 250 kt) through the Core MOA were conducted at > 3,000 m (i.e., 10,000 ft) above ground level (AGL). Overflights < 3,000 m AGL were permitted down to the 900 m (i.e., 3,000 ft) Core MOA floor but were required to fly below tactical speed. In response to evolving training needs, in 2009, the USMC and the NPS agreed to lower the minimum allowed altitude for tactical flight speeds in the Core MOA from 3,000 m to 900 m AGL with continuation contingent on the findings of this study.

In addition to responding to the specific management needs of the USMC and NPS, our study simultaneously addressed the behavioral, and the potential for demographic, effects of human activities on multiple co-occurring nesting colonial waterbird species. Our first objective was to compare received sounds levels from reduced-altitude (i.e., near 900 m AGL) tactical speed overflights with other audible human events, and to compare each human event type with ambient sound levels. Our second objective was to analyze the proportion of time spent incubating by the focal species before, during, and after military overflights, and to place these findings in the context of recreational activities and concurrently-studied drivers of demographic parameters.

## STUDY AREA

CALO (34.4°N, 76.3°W, Fig. 1) is located between Ocracoke, NC, USA and Atlantic Beach, NC, USA and is part of the barrier island ecosystem that extends along much of the Atlantic seaboard from Massachusetts to Florida. CALO consists of 12,000 ha of land and water. The islands routinely change in shape and number due to wind, waves, and currents. During our study, CALO consisted of 3 islands: Shackleford Banks, South Core Banks, and North Core

Banks, collectively spanning 90 km of ocean shoreline and averaging about 800 m in width (CALO 2008). Habitat included sandy beaches, vegetated dunes, shrub thickets, salt marshes, and maritime forest. Our study was conducted on the 37-km long North Core Banks.

Like the geomorphology, the vegetation of barrier islands is influenced by erosion and accretion of the shoreline, overwash from storm events, and the formation, migration, and closure of inlets (CALO 2008). However, beginning in the 1930s, seawall and jetty construction, artificial dune creation, and re-vegetation of open sand to protect infrastructure significantly modified the effects of these natural processes along the U.S. coastline and, as a consequence, resulted in the dramatic decline of shorebird habitat (Hosier & Cleary 1977). Beach and dune systems are therefore among the most highly imperiled habitats for coastal birds in the southeastern U.S. (Hunter et al. 2006).

CALO is unique in that relatively few measures, historically or presently, have been implemented to control erosion and protect human development. Therefore, human impacts on waterbird habitat are less pervasive at CALO than in many other regions of the U.S. Atlantic coastline. CALO also is isolated, relatively undeveloped, and not permanently inhabited by humans. There are a variety of structures throughout CALO (e.g. cabins, historic buildings, and service facilities), although these are concentrated around a few landing areas and their use is seasonal. Access is by public ferry or private vessel, and on-island transportation is by ATV and ORV (hereafter referred to collectively as ‘vehicles’). The NPS manages the park for multiple uses and seeks to preserve natural and cultural resources while providing recreational opportunities to the public (CALO 2006).

## METHODS

### Field Methods

*Nest searching and monitoring.*— To locate nest sites at which to deploy cameras for behavioral monitoring, we conducted systematic nest searches in waterbird colonies on North Core Banks throughout the 2010 and 2011 nesting seasons (27 April- 06 August). We demarcated colonies every 150-m into North-South rectangular blocks, which varied in width depending on the colony (Fig. 2), and visited each colony every 3-5 days to locate new nests and monitor existing ones. We began nest surveys near sunrise at 1-2 colonies per day. To minimize the potential for researcher-induced impacts, we conducted within-colony activities in fair-weather conditions during the cooler morning and/or evening hours (typically from 06:00-11:00 and 16:00-20:00), and kept disturbance to any individual bird (defined as total time off of nest) as a result of our surveys to a maximum of 45 min/day.

We located nests via ground nest counts conducted within the colony and incubating adult scans from the colony perimeter. We conducted ground nest counts with 2 observers, who walked 5-10 m apart depending on nest visibility as related to vegetation and substrate, which took 2-5 hours depending on nest density, nesting stage, and the area surveyed. For perimeter scans, one observer randomly selected an apparently incubating adult using a spotting scope (Bushnell Elite 20-60x80 mm, Overland Park, KS) and directed a second observer to the nest site.

When we located a nest, we marked it with a high sensitivity global positioning system (Oregon 450, Garmin International Inc., Olathe, KS). We recorded the number of eggs, floated each egg in water to estimate the date laid (Hays and LeCroy 1977; Alberico 1995), and assigned a unique nest identifier written on a tongue depressor that we placed in the sand 1 m south of

each nest (Appendix C, Fig. C1a). We monitored marked nests every 3-5 days until eggs hatched, were destroyed, or abandoned.

*Camera monitoring.*— We deployed auto-triggered cameras (Reconyx Rapidfire PC-90, Reconyx Inc., Holmen, WI) at colonial waterbird nests (Appendix C, Fig. C1b) to quantify the behavioral responses of nesting birds to human events. We encased cameras in wood housing painted to mimic the color of the sand and placed each unit 1.5 to 3 m from the focal nest. We oriented nest-focused cameras in the direction that most human events took place, i.e. toward the ocean beach, such that low-flying aircraft and recreational activities could be observed in the background of the focal nest (Appendix C, Fig. C6).

We set cameras to take one frame every 5 s for 24 hr/day. We powered cameras with deep-cycle sealed lead-acid batteries (TD22-12, Tempest Batteries, San Jose, CA) which we placed in watertight containers buried in the sand. We revisited camera-nests every 3-5 d to ensure the equipment was functioning and to check nests, swap batteries and memory cards, and/or re-deploy cameras on new nests as circumstances dictated.

We calibrated each camera's internal clock to an atomic clock at deployment. We attempted to monitor most of the incubation cycle for each focal bird by deploying cameras on the newest nests in a given block. If necessary, we randomly re-sampled nests until a newer one was located (e.g., a 3 day old nest versus a 15 day old nest, as determined by floating eggs, Hays and LeCroy 1977). We removed cameras when 1) a nest hatched and chicks left the field of view, 2) a nest failed, or 3) a probable flooding event prompted its removal or relocation.

We selected nests on which to place cameras within each colony using a stratified random sampling design for least terns and black skimmers (Fig. 2), and we placed cameras at every common tern and gull-billed tern nest as these species were relatively rare at CALO during



our study (see Results). We oriented cameras such that 1-4 nests could be sampled simultaneously.

*Audio monitoring.*— We continuously recorded ambient sound and human-created sounds using digital audio recorders (Zoom H2, Samson Technologies Corp, Hauppauge, NY, Mennitt and Fristrup 2012). We placed recorders in weatherproofed, wind-and-sand-screened housing mounted on wooden stakes approximately 1.5 m AGL (Appendix C, Fig. C2) at 300 m intervals throughout each colony (Fig. 2). We calibrated the internal clocks of each recorder using atomic clocks and set a wristwatch that sounded an alarm at midnight on each wooden stake. The purpose of the alarm was to ensure that audio and camera data were synchronized during analyses; if they were not, we adjusted sampling time accordingly.

Because received sound level varies with respect to source emission strength, distance, directivity, atmospheric attenuation, and weather (Pater et al. 2009), we downloaded weather data from the National Oceanic and Atmospheric Administration’s Cape Lookout weather station (National Oceanic and Atmospheric Administration 2012). We used Core MOA overflight data provided by the USMC, including aircraft type, velocity, altitude, and coordinates of ingress/egress (Appendix C, Fig. C5) to analyze audio data and to calculate the closest point of approach (CPA, the perpendicular distance between overflight track and audio recorder) for each overflight.

### **Sampling Methods for Behavioral and Audio Data**

*Identifying events to sample.*— We used USMC-provided Core MOA overflight data and post-processed audio recordings to identify which overflights were audible at each colony. We defined a Core MOA overflight as any overflight that was reported by USMC Range Control, unless otherwise noted as a data subset; the majority of those overflights were USMC aircraft,

although the reports also included some U.S. Navy and U.S. Air Force aircraft. The USMC flew a series of Core MOA overflights near 900 m AGL to expose nests to the visual and acoustic cues of aircraft near the reduced Core MOA floor operating at tactical speed (hereafter referred to as ‘experimental overflights’).

In addition to the USMC-provided Core MOA data, we opportunistically collected information on all audible and visible overflights at the study site, including military fixed-wing aircraft (MFW), military rotary-wing aircraft (MRW), civilian fixed-wing aircraft (CFW), and civilian rotary-wing aircraft (CRW, Appendix C, Fig. C6). We compared field observations with Core MOA records such that ‘MFW’ in the analyses did not include any official Core MOA overflights. For each aircraft seen or heard from the study site, we recorded the date, time, closest mile marker or site name, and, if we observed the aircraft, the direction of travel, type of aircraft, and visually-estimated altitude.

We located beach-front human recreation events (Appendix C, Fig. C6) by sampling camera-monitored nests using a systematic random design. We conducted a behavioral sample of all active camera-monitored nests every 8<sup>th</sup> day from a random start date in early May until nesting ended in mid-August. We searched through the camera footage for human events during four 2-hr intervals per sampling day per nest: one interval each between 0600-0800, 1200-1400, 1800-2000, and 0000-0200.

*Audio and behavioral sampling design.*— We sampled behavioral and audio data to quantify avian behavioral responses to human events. For overflights, we sampled behavioral and audio data for the 5 min before, a variable time during, and the 5 min after the interval of audibility (hereafter ‘pre’, ‘during’, and ‘post’, respectively), with a 10 s buffer on either side (Appendix C, Fig. C3a). If/when we encountered a vehicle during our systematic random sampling for human

events, we conducted ‘pre’, ‘during’, and ‘post’ samples with a 30 s buffer from the time that the event was first and last seen in view of the camera. Unlike overflights and vehicle passes, which often were transient in nature, the presence of researchers and other pedestrians typically lasted several hours in a given area, so the ‘pre’, ‘during’, and ‘post’ sampling scheme was not always appropriate. Therefore, we did not sample behavior when researchers were within the colony and in view of cameras, and we sampled only the ‘pre’ and a 5-min ‘during’ sample when pedestrians—researchers or otherwise—were observed outside of the colony (i.e., exterior to NPS signage that provided a 50 m human buffer around colonies).

Within the sampling periods, we quantified behavior at 5-s intervals from time-lapse camera footage. Observers were not aware when they sampled an aircraft or recreation event versus a randomly selected control time with no event. We recorded 2 types of behavior for the 4 focal species: incubation (sitting on or shading eggs or chicks) and alert posture (head and neck extended above back); we did not record scanning behavior (lateral movement of the head), as birds scanned frequently even when not subjected to human stimuli. For each ‘pre’, ‘during’, and ‘post’ sampling period, we recorded the number of frames for which the focal bird was engaged in incubation and alert behaviors and the total number of frames sampled. We then calculated the proportion of time spent in each behavior for each sampling interval.

We used Audio2NVSPL Audio Converter and Acoustic Monitoring Toolbox to convert field-recorded mp3 files into text format and to view text files as one-third octave band spectrograms (v1.3877, NPS Natural Sounds Division, Ft. Collins, CO). We related spectrogram data to corresponding records of evidence (USMC data, photographic data, or field observations) of military and civilian overflights to determine the start/end times of behavioral sampling intervals (Appendix C, Fig C3). We used time and location data and direction of travel data

from field observations to track overflights across the study site by identifying their spectral signatures from spatially sequential audio recorders. We used a Type-1 Sound Level Meter (Larson Davis Model 831, PCB Piezotronics, Inc., Depew, NY) to retrospectively calibrate compressed audio recordings into 1-s, one-third octave band sound level measurements (Mennitt and Fristrup 2012).

Analysis of spectrograms to distinguish the noise of human activities from ambient levels for most overflights and for some vehicle events was relatively straightforward for a trained observer, although ORVs and higher-altitude turboprop aircraft were not as loud and therefore more difficult to detect in the spectrogram. We measured amplitude on the A-weighted scale (dBA, Appendix C, Fig. C4) to approximate the hypothesized hearing sensitivity of the avian ear (Meyer 1986; Conomy 1998a; Beason 2004; Dooling and Popper 2007; but see Delaney et al. 2011), and used Sound Exposure Level (SEL) and Maximum 1-s equivalent average sound level (MaxLEQ) to quantify aircraft noise. MaxLEQ is the peak 1-s amplitude extracted from a sample, while SEL integrates noise intensity with event duration and can be up to 15 dB higher than MaxLEQ for an overflight (Efroymson et al. 2000). Adequately quantifying transient noise events such as overflights often requires both metrics to meaningfully relate noise to an animal's response (Ward et al. 1988; Plumpton 2006; Pater et al. 2009; Barber et al. 2011).

### **Analytical Methods**

*Audio.*— We compared mean SELs among all audible Core MOA overflights and other human activities. We used linear regression (PROC REG, SAS 9.2, SAS Institute Inc., Cary, NC) to examine the relationship between SEL and MaxLEQ metrics of Core MOA overflights. We compared metrics of tactical speed Core MOA overflights conducted below 3,000 m (the previously-approved floor) to tactical speed Core MOA overflights at or near 900 m (the

proposed floor being evaluated with this study), while controlling for variation in CPA.

We analyzed received SEL of turbofan Core MOA aircraft (e.g., AV-8 Harriers and F-15 Eagles) using generalized linear models (PROC GENMOD, SAS 9.2). We evaluated how received SEL varied with overflight altitude and CPA, and incorporated hourly climatic data (wind speed, wind direction, and temperature) as covariates. We included a ‘Colony’ variable to determine whether received SEL from overflights varied according to the topographical features associated with each colony (open flats versus inter-dune). We ranked models using Akaike Information Criterion (AICc) and evaluated the relative importance of each variable by summing Akaike weights (Burnham and Anderson 2002).

*Behavior.*— We conducted separate analyses for each focal species and for each event type, and when sample size permitted, for subsets of event types as described below. We compared the proportion of time that birds spent in incubation and alert behaviors among ‘pre’, ‘during’, and ‘post’ intervals for each event type using multi-response permutation procedures for blocked data (MRBP) in Blossom (v.W2008.04.02, Cade and Richards 2008). MRBP is a non-parametric permutation test that can be used in lieu of generalized linear models when data do not meet the assumptions of parametric tests. MRBP allows comparing responses by group (i.e., ‘pre’, ‘during’, ‘post’) and by blocked data (i.e., colony). We blocked by colony and overflight for all aircraft events, and by nest for non-aircraft human events, because the latter were often present only at portions of a colony and nests within a colony were sampled at different time periods and thus assumed to be independent. If the overall MRBP test of significance among ‘pre’, ‘during’, and ‘post’ intervals for each event type was significant ( $p < 0.05$ ), we performed MRBP on each pair of groups (e.g., ‘pre’ vs. ‘during’) to assess how the behavior differed between the two-way comparisons.

## RESULTS

### **Quantity and acoustics of Core MOA overflights, non-Core MOA overflights, and human recreation events**

We received data from the USMC on 249 military overflights traversing the Core MOA during the colonial waterbird nesting season from April-August, 2010-2011 (Appendix C, Fig. C5). Of these 249 overflights, we detected 77 individual overflights of known altitude on at least one digital audio recorder (and often > 3 recorders) during the period of active camera deployment (Table 1).

The mean altitude (SE) for all audible overflights ( $n = 80$ ), irrespective of whether cameras were deployed, was 3,291 m (179) and the mean SEL and MaxLEQ were 77.8 dBA (0.77) and 65.5 dBA (0.93), respectively (Table 2a). The mean SEL and MaxLEQ of the 29 overflights conducted below 3,000 m were 78.9 dBA (1.8) and 67.7 dBA (2.2), respectively (Table 2b). The mean SEL and MaxLEQ of the 8 overflights below 3,000 m, and within 0.97 km CPA to audio recorders, was 88.3 dBA (2.1) and 79.7 dBA (2.5), respectively (Table 2c).

We removed 10 non-turbofan aircraft (e.g., C-130 Hercules, CH-53 Super Stallion) of the 80 audible Core MOA overflights of known altitude from acoustical modeling because these were below tactical flight speed and their sound profiles were considerably different than that of turbofan aircraft.

There was a strong linear relationship between SEL and MaxLEQ (Fig. 3,  $n = 70$ ,  $R^2 = 0.90$ ,  $RMSE = 2.11$ ,  $p < 0.001$ ,  $SEL = 26.8 + 0.78 * MaxLEQ$ ). Aircraft altitude, CPA, wind speed, and wind direction received support in all of the top-models ( $\Delta AICc < 2.0$ ) explaining received SEL of Core MOA overflights (Table 3a); the most important variables were altitude, CPA, and their interaction (relative importance = 1.00 for each of these variables, Table 3b).

SEL decreased with increasing altitude and CPA, but increased with increasing wind speeds and when the prevailing wind blew towards the audio recorder (Fig. 4).

The low-altitude experimental Core MOA overflights were conducted between 640 m and 1,067 m AGL in July and August 2011 and ranged from 0.16 - 0.97 km in CPA to the nearest audio recorder. These overflights had the highest received SELs ( $n = 5$ , mean dBA = 86.2, SE = 3.16), and ATVs had the lowest received SELs ( $n = 28$ , mean dBA = 65.3, SE = 1.02), of the audible human events. Rotary-wing aircraft had higher mean SELs than fixed-wing aircraft, and military aircraft, collectively, had higher mean SELs than civilian aircraft (Fig. 5).

We recorded approximately 105,000 hours of camera footage at 293 individual nests from 6 colonies in 2010 and from 7 colonies in 2011, for a combined 9 unique colonies. We extracted behavioral samples from 257 nests before, during, and after military and civilian overflight events and from 195 nests before, during, and after human recreation events. The total number of colonial waterbird nests sampled for behavior at least one time across all types of overflights and other human events was 280, with least terns comprising > 80% of all nests sampled (Figure 6).

We analyzed Core MOA data (Table 2) and field-collected data of 112 non-Core MOA fixed and rotary-wing overflights operating within or adjacent to Core MOA airspace. We also conducted 435 samples of human recreation events, including ORVs, ATVs, and pedestrians that were visible from camera-nests. While we sampled both incubation and alert behaviors, we did not analyze alert behaviors because these seldom occurred (only 33 instances out of > 4,000 subsamples with no apparent response to overflights or human activity in those 33 samples).

## Behavioral Responses

*Least terns.*— The mean proportion of time that least terns incubated eggs ranged from 0.80 to 0.95 across all military and civilian overflight events, and from 0.79 to 0.98 for all human recreation events, irrespective of ‘pre’, ‘during’, or ‘post’ sampling interval. There was a difference ( $p < 0.05$ ) between ‘pre’ and ‘post’ samples only for Core MOA events in the top 10% of SEL (SEL  $\geq 90.8$  dBA, pairwise MRBP comparison of ‘pre’ versus ‘post’:  $n = 14$ ,  $S = -2.89$ ,  $p = 0.02$ , Table 4a, Fig. 7a). Percent time incubating increased by a mean of 9% for the ‘post’ sample, whereas the ‘during’ sample was not significantly different from either ‘pre’ or ‘post’ samples. ORVs passing within 100 m of incubating least terns increased percent time incubating by 3% in the ‘during’ sample as compared to the ‘pre’ sample (MRBP pairwise comparison of ‘pre’ vs. ‘during’:  $n = 24$ ,  $S = -3.53$ ,  $p = 0.01$ ), and pedestrians in view of incubating least terns decreased mean percent time incubating by 12% ( $n = 24$ ,  $S = -2.2$ ,  $p = 0.04$ , Table 4a, Figure 7b).

*Common Terns.*— The mean proportion of time that common terns incubated eggs ranged from 0.92 to 1.00 across all military and civilian overflight events, and from 0.89 to 1.00 for all human recreation events, irrespective of sampling interval. There was little variation in percent time incubating for samples conducted ‘pre’, ‘during’, or ‘post’ overflight or other human event (Table 4b, Fig. 8).

*Gull-Billed Terns.*— Our sample size was small for gull-billed terns because few pairs nested at CALO in 2010 and 2011 ( $n = 10$ ) and sporadic nesting behavior decreased the probability that Core MOA or other human activity coincided with an active nest. Of the few overflights that did expose nesting gull-billed terns, there were no significant differences in proportion of time spent incubating among any sampling intervals (Table 4c, Fig. 9). There were no random samples where vehicles or pedestrians were within sight of a Gull-Billed Tern nest.



*Black Skimmers.*— The mean proportion of time that black skimmers incubated eggs ranged from 0.86 to 1.00 across all military and civilian aircraft event types and from 0.85 to 1.00 for all human recreation events, irrespective of sampling interval. There was little variation in percent time incubating among ‘pre’, ‘during’, or ‘post’ Core MOA overflight samples and no significant differences for any other overflight type (Table 4d, Fig. 10). Black skimmers incubated on average 15% less after an ATV event compared to before or during the event ( $n = 5$ ,  $p = 0.04$ ), although pairwise comparisons were not significant (Table 4d, Fig. 10).

## DISCUSSION

We found no evidence during this study that visual or acoustic stimuli from Core MOA and non-Core MOA military aircraft elicited behavioral stress responses that would negatively impact nesting colonial waterbird demographic rates. Similarly, although there were some alterations in incubation behavior by the focal species to human recreation activities, mainly to pedestrians, we do not believe that these responses are of a magnitude as to affect demography. The main drivers of nest and chick survival at CALO were flooding and mammalian predation in 2010 and 2011 (Hillman et al. *in prep*, see Ch 3 in this thesis). In the sections that follow, we discuss in more detail how Core MOA overflights, and in particular reduced-altitude overflights, affected the sound environment and behavior of colonial waterbirds at CALO. We place these findings in the context of other military overflights, human recreation, and the demography of these species.

### **Effects of overflights on the sound environment**

Existing literature on the relationship between received sound and aircraft type, altitude, and CPA is inconsistent, in part because of the many physical and environmental sources of variation in sound propagation (Pepper et al. 2003; Pater et al. 2009). For example, although counter intuitive, received sound from high-altitude aircraft may be greater than that of lower-altitude

aircraft because attenuation due to the interaction of sound waves with the ground may be less for aircraft operating at higher altitudes (Ward et al. 1988; Derksen et al. 1992; Plumpton 2006). Understanding if and how a reduced floor for Core MOA aircraft operating at tactical speed affects the sound environment at CALO is an important step in assessing the potential behavioral responses of nesting colonial waterbirds to Core MOA aircraft.

We found a strong linear relationship between SEL and MaxLEQ, suggesting that either metric may be suitable when modeling received sound levels and when inferring relationships between aircraft noise and behavioral responses in an open, barrier island system. However, we used SEL, and not MaxLEQ, to model received sound in waterbird colonies, because sporadic, high-frequency bird call pulses close to (i.e., several meters) audio recorders (Appendix C, Fig. C3b) often exceeded MaxLEQ amplitude for ‘pre’/‘post’ samples and for relatively low-noise-intensity ‘during’ samples, including distant aircraft, turboprop aircraft, and ATVs. Therefore, analyzing SEL, where total sound energy is calculated over a finite time period, reduced the potential source of error related to sporadic, high-frequency bird calls in our specific system. However, both metrics should be considered when it is appropriate to do so (Pater et al. 2009).

The most important variables explaining received SEL for audible Core MOA overflights were aircraft altitude and CPA. While the sample size for experimental overflights, and other Core MOA overflights that approximated their characteristics, was low ( $n = 8$ ), these events had the highest SELs of any other, despite being, on average, shorter in duration than overflights of greater altitude and CPA. Accounting for CPA as within 0.97 km, the low-altitude (i.e. 900 m - 3,000 m AGL) tactical speed Core MOA overflights were, on average, > 3 times ambient SEL compared to that of overflights > 3,000 m, yet we did not find evidence of an effect of either overflight type on the behavior of the focal species.

MRW overflights had the highest median SELs of any non-Core MOA event type, despite being of shorter duration above ambient than MFW overflights. CRW aircraft, while only slightly lower in SEL than MRW aircraft, often flew directly over CALO, its nesting waterbirds, and our sound-monitoring devices, rather than flying adjacent to CALO as military aircraft often did. This pattern likely influenced not only received sound levels of these events, but also the behavioral responses by nesting birds attributed to them.

### **Effects of overflights and human recreation on colonial waterbird behavior**

Most studies documenting avian responses to overflights have been conducted on raptors and waterfowl, and responses have differed depending on species, reproductive state, activity, age, and exposure frequency (Kushlan 1979; Black et al. 1984; Larkin 1996; Conomy et al. 1998a, 1998b; Efroymsen et al. 2000; Fleming 2000; Murphy 2000; Goudie 2006; Ortega 2012). Our study is the first exploration of the concurrent effects of overflights, both military and civilian, and human recreation on multiple ground-nesting colonial waterbird species.

As social animals, colonial waterbirds rely on information transfer, the dilution effect, and coordinated anti-predator mobbing behavior to counter threats to the colony (Tinbergen 1963; Nisbet 1975; Roberts 1996). Therefore, we hypothesized that if the focal species perceived the auditory or visual stimuli of aircraft, vehicles, or pedestrians as threatening, then alarm behaviors, such as erect posture or flushing, would result. Specifically, we predicted that colonial waterbirds might incubate less during an event, particularly in response to pedestrians (Erwin 1989; Henson and Grant 1991; Rodgers and Smith 1995) and to loud, low-altitude aircraft that combined auditory and visual stimuli (Owens 1977; Ward et al. 1988; Brown 1990; Brown 2001; Rojek et al. 2007).

There was little evidence that Core MOA overflights had a negative effect on nesting colonial waterbirds. However, while colonies were concentrated at the southwest and northeast ends of the island, Core MOA overflights during the 2010 and 2011 nesting seasons were dispersed throughout North Core Banks, and many were therefore not audible from nesting areas. Moreover, although the proposed floor for tactical flight speed through the Core MOA was 900 m, most USMC overflights traversed the Core MOA at considerably higher altitudes.

The focal species were also exposed to a variety of non-Core MOA fixed-and-rotary-wing military aircraft from USMC, U.S. Coast Guard, U.S. Air Force, and U.S. Navy installations, in addition to private and commercial civilian aircraft of all types. Audible commercial air traffic consisted of single-engine Cessnas (tour planes) and helicopters, and private air traffic consisted of single or twin-engine fixed-and rotary-wing aircraft. There was no indication that the focal species responded differently to these events than they did to Core MOA events.

We rarely observed alert behaviors by colonial waterbirds in our study; a finding contrary to what Brown (1990) reported for the crested tern (*Thalasseus bergii*) in Australia. Brown (1990) observed increased alert behaviors in response to increased exposure to simulated aircraft noise (a novel stimulus). This may be due to the fact that aircraft and humans were not novel stimuli to colonial waterbirds at CALO (Cape Lookout National Seashore 2006), and birds may have habituated to these events prior to this study. It also is possible that crested terns inherently respond differently to aircraft noise than the species we studied, or that simulated aircraft noise invokes different responses than actual overflights.

Contrary to our expectations, least terns increased the proportion of time spent incubating after the loudest 10% of Core MOA overflights. However, this difference was driven by two

individuals that were absent for most of the ‘pre’ samples for unknown reasons. Moreover, the mean difference in proportion of time spent incubating for the 10% loudest overflights was only 0.09, and this difference was between ‘pre’ and ‘post’ samples only. This suggests that even if the loudest Core MOA overflights affected incubation behavior, then 1) the effect size was minimal, and 2) the effect was not likely to impact demographic rates, particularly as the effect was not towards less time incubating during an overflight, but towards more time incubating after an overflight.

With the exception of CRW aircraft passing directly above least tern colonies, we did not observe a reduced proportion of time spent incubating by the focal species during overflights. This may be explained by a reluctance of birds to leave the nest during and after loud auditory stimuli of unknown origin. When perceived visual threats, e.g. gulls (*Larus* spp.) and researchers, entered colonies, birds initially flushed from their nests and mobbed the intruder, but resumed incubation when the intruder moved to a tolerable distance that varied by colony and disturbance type. For tactical speed Core MOA aircraft, we hypothesized that the associated visual stimulus, if one existed, was less intense than the suite of other human and natural disturbances common at CALO. Therefore, flushing from nests in response to loud but relatively distant events would yield no fitness benefits to individual birds. Instead, remaining vigilant at the nest during and after an unseen auditory stimulus, while leaving the nest less frequently to forage, accept food from provisioning mates, or shift posture, may be advantageous until a ‘fight or flight’ response is appropriate.

There was a non-significant effect of reduced time spent incubating by least terns during CRW overflights. On several occasions, we observed widespread, although brief, flushing responses to low-flying CRWs directly above waterbird colonies. Minor alterations in aircraft

flight path, e.g. flying over the beach or ocean as opposed to directly over the island, would likely moderate any behavioral responses of colonial waterbirds induced by visual and/or auditory cues associated with low-flying rotary aircraft (Miller 1994).

While our inference on the effects of Core MOA overflights on common terns, gull-billed terns, and black skimmers was limited due to the smaller numbers of nests for these species at CALO, we did not detect any trends in incubation behavior ‘pre’, ‘during’, or ‘post’ Core MOA overflights that would suggest that these species respond differently than least terns, for which our sample size was robust. However, we caution that most of the noise events we studied were below the MaxLEQ thresholds of behavioral response identified in many other studies. A literature review of wildlife responses to low-altitude aircraft reported an approximate response threshold of 90-115 dBA MaxLEQ (Efroymsen and Suter 2001 *in* Barber et al. 2011), while we only observed 2 noise events of this magnitude: an experimental Core MOA overflight, at 91.8 dBA (Table 2a,b), and a CRW at low altitude flying directly above the colony, at 90.3 dBA. These 2 events exposed a total of 8 least tern nests, and in only 1 case, for the CRW overflight, did a bird incubate for less time during the event compared to before or after the event (percent time incubating for this bird was 87% ‘pre,’ 0% ‘during,’ and 78% ‘post’ overflight).

Least terns responded most to pedestrians compared to all other event types, aircraft included. While we did not test the effects of within-colony activity by NPS staff and researchers on nesting bird behavior in our analyses of pedestrian events, we assumed that research and monitoring activities were more intrusive than (public) pedestrian traffic occurring exterior to posted closures surrounding colonies. However, we regularly observed birds of each focal species incubating eggs while we conducted surveys only meters away from their nests. This behavior was more typical when we remained within colonies for extended periods—

suggesting real-time habituation to researchers—and when nest density of the colony or sub-colony was high—suggesting that nesting birds farther from human intruders relinquished anti-predator defenses to individuals with whom the perceived threat was greatest (i.e. closest). By contrast, it was difficult to observe least terns at close range in sparser colonies without eliciting anti-predator behaviors. We hypothesize that this relationship between colony density and habituation to human presence would be similar for non-researcher activities exterior to colonies, although any effects of other human events were likely minimized by the 50 m buffers positioned around nesting areas by NPS staff.

There were no instances of reduced time spent incubating by the focal species during vehicle exposures, although least terns nesting < 100 m from the beach-front intertidal zone (and therefore closer to vehicle traffic) incubated significantly more on average during ORV events than before these events. However, while statistically significant, the effect size was small; we observed only a 0.03 increase in proportion of time spent incubating in the ‘during’ versus the ‘pre’ sample. Similarly, black skimmers appeared to incubate significantly less for ‘post’ ATV event samples, although the significance of this finding was due to the small sample size and erratic behavior of 1 individual.

A general pattern across all focal species was that the return interval to incubate after an absence was relatively short. If we assume that flushing frequency increases due to human activity, then the fact that most ‘during’ and ‘post’ samples were relatively similar to ‘pre’ samples suggests that nesting birds were not absent for extended periods of time during or after events, and that many never flushed at all. Therefore, if transient human events of all types were found to influence nesting bird behavior only minimally, or, in some cases, not at all, then it is unlikely that these events would produce demographic effects to CALO nesting waterbird

populations. Rather, the most likely human threat to nesting waterbirds at CALO is from vehicle traffic when adults nest unnoticed outside of posted areas, or when chicks venture outside of colonies into ORV/ATV zones. On several occasions, we observed least tern chicks in tire tracks on the front beach, presumably using the depressions as cover.

The greatest threats to colonial waterbirds at CALO were predation and flooding (Hillman et al. *in prep*, see Ch. 3 of this thesis), which is true for many beach-nesting birds (Erwin and Smith 1985; Brunton 1997; O'Connell and Beck 2003; Cohen et al. 2009; Ray 2011; DeRose-Wilson et al. *in prep*). Predators, primarily raccoons and to a lesser extent feral cats (*Felis catus*), gull-billed terns, common terns, ruddy turnstones (*Arenaria interpres*), ghost crabs (*Ocyropsis spp.*), and great-horned owls (*Bubo virginianus*), were the main causes of nest failure (Hillman et al. *in prep*, see Ch. 3 of this thesis). Across both study years and for all focal species, > 50% of all camera-nests with known fates were depredated; > 35% flooded; and < 15% hatched. There was no evidence that overflights or human recreation contributed to nest failures either directly or indirectly, particularly as nocturnal predators were the primary driver of nest failure and > 90% of all known depredation events occurred at night when the Core MOA was inactive, non-Core MOA overflights were rare, and few recreationists were observed.

We caution that our results are applicable to the active nesting period in the reproductive cycle. Because our behavioral sampling design required a remote camera focused on an incubating adult, conducting behavioral observations before or after the nesting period was outside the scope of this study. Therefore, we did not document the effects of overflights or human recreation on pre-or-post-laying birds, although some species may be more sensitive to disturbance outside of the egg-laying period (Awbrey and Hunsaker 1997; Rojet et al. 2007; Burger et al. 2010).



## MANAGEMENT IMPLICATIONS

Military overflights, in the patterns of time, location, altitude, and frequency observed during this study, did not pose a threat to nesting colonial waterbirds at CALO. While our sample size for low-altitude overflights (i.e. near 900 m AGL) was low, the data suggest that even a substantial increase in low altitude overflights would be unlikely to cause a demographic response in the focal species. Additionally, NPS beach management practices, namely the 50-m buffer between the colony edge and symbolic fencing to exclude pedestrians and vehicles, appeared to adequately protect colonial waterbirds from any demographic effects of human recreation.

While we did not calculate minimum flush distances of colonial waterbirds to specific human events in this study, we did observe what appeared to be habituation to even very close transient human events (i.e. passing ATVs and ORVs). However, when visitors exited vehicles, least terns spent significantly less time incubating. While our sample sizes for the remaining focal species were lower, there was no indication that these species respond differently than least terns. If substantial changes occurred in the patterns of Core MOA operations, or if significant changes in human-use patterns occurred such that birds were exposed to a greater frequency or intensity of overflights or human recreation, additional studies aimed at understanding the effects of the new use patterns should be considered.

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## TABLES AND FIGURES

**Table 1.** Military overflights through the Core Military Operations Area (Core MOA) over Cape Lookout National Seashore, North Carolina, 2010-2011: ‘Reported’ – total overflights for which the U.S. Marine Corps provided data; ‘nesting season’ – overflights during the colonial waterbird nesting season; ‘audible’ – overflights audible from the study site while digital audio recorders and cameras were deployed; ‘sequences’ – uniquely identifiable singular overflights, simultaneous overflights, or non-independent overflights in rapid succession; ‘sequences < 3,000 m’ – overflight sequences between 900 m and 3,000 m above ground level, which corresponds to the reduced Core MOA floor for tactical flight speed between these two altitudes.

<b>Year</b>	<b>Reported</b>	<b>Nesting Season</b>	<b>Audible</b>	<b>Sequences</b>	<b>Sequences &lt; 3,000 m</b>
2010	255	138	34	21	2
2011	120	111	43	19	10
<b>Total</b>	<b>375</b>	<b>249</b>	<b>77</b>	<b>40</b>	<b>12</b>

**Table 2.** Descriptive statistics of military overflights through the Core Military Operations Area (Core MOA) over Cape Lookout National Seashore (CALO), North Carolina, including fixed- and-rotary-wing overflights with associated climatic variables, from April-August 2010-2011. Audio data were recorded from Samson Zoom H2 Digital Audio Recorders (DAR) at North Core Banks, CALO, and post-processed using Larson Davis 831 Sound Level Meters, Audio2NV SPL software, and Acoustic Monitoring Toolbox (Natural Sounds Program, National Park Service, Fort Collins, CO). All overflights are represented irrespective of active camera-nest monitoring.

a. All overflights ( $n = 80$ )

	<b>Median</b>	<b>Mean</b>	<b>SE</b>	<b>Low</b>	<b>High</b>
Aircraft Altitude (m) <sup>a</sup>	3,947	3,291	178.5	335	5,334
CPA to DAR (m) <sup>b</sup>	2,600	5,001	598.6	3.0	20,001
Aircraft Speed (kt) <sup>a</sup>	365	325	16.3	33	550
Audibility (sec) <sup>c</sup>	77	89	5.6	27	262
MaxLEQ (dBA) <sup>d</sup>	65.0	65.5	0.93	49.8	91.8
SEL (dBA) <sup>e</sup>	77.6	77.8	0.77	59.5	99.1
SEL over ambient (dBA) <sup>e,f</sup>	5.8	7.5	0.73	-1.5	29.1
Wind Speed (m/s) <sup>g</sup>	5.70	5.42	0.21	1.5	11.0
Temperature (°C) <sup>g</sup>	25.7	25.0	0.31	19	30.2

b. Overflights < 3,000 m ( $n = 29$ )

	<b>Median</b>	<b>Mean</b>	<b>SE</b>	<b>Low</b>	<b>High</b>
Aircraft Altitude (m) <sup>a</sup>	1,280	1,366	115.9	335	2,896
CPA to DAR (m) <sup>b</sup>	1,999	4,714	1,105	60	19,295
Aircraft Speed (kt) <sup>a</sup>	190	251.9	29.6	39	550
Audibility (sec) <sup>c</sup>	71	97	13.0	27	262
MaxLEQ (dBA) <sup>d</sup>	65.3	67.7	2.2	49.8	91.8
SEL (dBA) <sup>e</sup>	77.6	78.9	1.8	59.5	99.1
SEL over ambient (dBA) <sup>e,f</sup>	9.0	11.4	1.55	0.70	29.1
Wind Speed (m/s) <sup>g</sup>	5.1	5.1	0.36	2.1	11.0
Temperature (°C) <sup>g</sup>	27.1	26.2	0.38	21.7	28.6

<sup>a</sup> Data provided by U.S. Marine Corps Air Station (MCAS) Cherry Point Range Control

<sup>b</sup> Estimated CPA (Closest Point of Approach) from DAR to overflight track based on ingress/egress coordinates provided by MCAS Cherry Point

<sup>c</sup> Total time that overflights were above ambient sound levels based on visual analysis of one-third octave band spectrograms

<sup>d</sup> Maximum equivalent 1-s average sound level (peak 1-s amplitude)

<sup>e</sup> Sound Exposure Level (total sound energy over a specified interval)

<sup>f</sup> Difference between SEL of overflight and SEL of equal interval ending 10 s prior to overflight

<sup>g</sup> Data downloaded from National Climate Data Center, Cape Lookout Station

c. Mean audio metrics of 19 low-and-high-altitude Core MOA overflights at or above tactical speed (250 kt) with closest points of approach < 0.97 km from digital audio recorders (turbofan aircraft only).

<b>Altitude of Core MOA</b>		<b>Mean</b>	<b>Mean</b>	<b>Mean</b>	<b>Mean Diff. SEL</b>
<b>Overflight (m)</b>	<b><i>n</i></b>	<b>Audibility<sup>a</sup> (SE)</b>	<b>MaxLEQ<sup>b</sup> (SE)</b>	<b>SEL<sup>c</sup> (SE)</b>	<b>from Ambient<sup>d</sup> (SE)</b>
900 – 3,000 <sup>e</sup>	8	64 (14.8)	79.7 (2.5)	88.3 (2.07)	18.6 (2.53)
≥ 3,000 <sup>f</sup>	11	81 (13.3)	65.1 (1.5)	78.2 (1.51)	6.2 (0.96)

<sup>a</sup>Total number of seconds for which overflight was above ambient

<sup>b</sup>A-weighted maximum equivalent 1-s average sound level (MaxLEQ) of time period for which overflight was above ambient

<sup>c</sup>A-weighted Sound Exposure Level (SEL) of total time for which overflight was above ambient

<sup>d</sup>A-weighted SEL of difference between overflight and ambient of an equal time period immediately before onset of audibility

<sup>e</sup>Experimental ( $n = 5$ ) and other ( $n = 3$ ) Core MOA overflights < 3,000 m above ground level flown at tactical speed that were within 0.97 km of closest approach distance to audio recorder. MCAS Cherry Point Range control arranged experimentally-flown overflights in July and August 2011 to more accurately expose nests to overflights at the proposed Core MOA floor of 900 m

<sup>f</sup>Core MOA overflights ≥ 3,000 m, the existing floor for tactical flight speed, within 0.97 km of closest approach distance to audio recorder



**Table 3.** a) Models explaining variation in received Sound Exposure Levels (SEL) of 70 Core Military Operations Area (Core MOA) fixed-wing overflights using generalized linear models (proc GENMOD, SAS Institute, Cary, NC) and Akaike weights ( $w$ ). Rotary-wing (CH-53) and turboprop (C-130) aircraft were excluded from the analysis. b) Relative importance of each variable in models of received SEL.

a. Models explaining received SEL

<b>Model</b>	<b>-2(L)</b>	<b>K</b>	<b>AICc</b>	<b><math>\Delta</math>AICc</b>	<b>RL</b>	<b><math>w</math></b>
Alt <sup>a</sup> CPA <sup>b</sup> Alt*CPA WndSpd <sup>c</sup> WndDir <sup>c</sup>	414.2	7	430.0	0.0	1.0	0.40
Alt CPA Alt*CPA WndSpd	418.0	5	431.4	1.4	0.5	0.20
Alt CPA Alt*CPA WndSpd WndDir WndSpd*WndDir	413.6	9	431.9	1.9	0.4	0.15
Alt CPA Alt*CPA WndSpd WndDir WndSpd*WndDir Temp <sup>c</sup>	411.1	10	432.1	2.1	0.3	0.14
Alt CPA Alt*CPA WndDir	420.3	6	433.7	3.7	0.2	0.06
Alt CPA Alt*CPA	424.0	4	434.9	4.9	0.1	0.03
Global	404.2	16	439.9	9.9	0.0	0.00
Alt CPA Alt*CPA WndDir Temp Colony <sup>d</sup>	414.6	13	444.1	14.1	0.0	0.00
Alt CPA Alt*CPA Temp Colony	418.7	11	445.2	15.2	0.0	0.00
Alt CPA	447.2	3	455.8	25.8	0.0	0.00
Alt CPA WndSpd	446.6	4	457.5	27.5	0.0	0.00
Alt	451.9	2	458.3	28.3	0.0	0.00
Alt WndSpd	451.9	3	460.5	30.5	0.0	0.00
Alt WndSpd WndDir WndSpd*WndDir	450.1	7	463.5	33.5	0.0	0.00
CPA	457.7	2	464.1	34.1	0.0	0.00
CPA WndSpd	457.2	3	465.8	35.8	0.0	0.00
CPA WndSpd WndDir WndSpd*WndDir	453.5	7	466.8	36.8	0.0	0.00

b. Relative importance of each variable in models of received SEL (see Table 3a)

<b>Variable</b>	<b>Sum of Akaike weights (<math>\Sigma w</math>)</b>
Altitude <sup>a</sup>	1.00
CPA <sup>b</sup>	1.00
Altitude*CPA	1.00
Wind Speed <sup>c</sup>	0.89
Wind Direction <sup>c</sup>	0.75
Wind Speed*Wind Direction	0.29
Temperature <sup>c</sup>	0.14
Colony <sup>d</sup>	0.00

<sup>a</sup> Aircraft altitude within the Core MOA.

<sup>b</sup> Closest point of approach (CPA) from overflight track to Digital Audio Recorder (DAR)

<sup>c</sup> Direction of prevailing wind (0, 1): 0 - prevailing wind within 180° of the direction from DAR to CPA of Core MOA aircraft (i.e., wind “pushes” sound away from DAR); 1 - prevailing wind within 180° of the direction from CPA of Core MOA aircraft to DAR (hourly data downloaded from National Climate Data Center, National Oceanic and Atmospheric Administration, Cape Lookout Station).

<sup>d</sup> Colony in which audio recorder was positioned; used as a random effect in the model.

**Table 4.** Mean proportion of time spent incubating by least terns (*Sternula antillarum*, Table 4a), common terns (*Sterna hirundo*, Table 4b), gull-billed terns (*Gelochelidon nilotica*, Table 4c), and black skimmers (*Rynchops niger*, Table 4d) ‘pre’, ‘during’, and ‘post’: overflights through the Core Military Operations Area (Core MOA); non-Core MOA military fixed-wing overflights; civilian fixed-wing overflights; military and civilian rotary-wing overflights; off-road and all-terrain vehicle events; and pedestrian events, with relevant data subsets by Sound Exposure Level (SEL) and distance from nest at North Core Banks, Cape Lookout National Seashore, North Carolina, April-August 2010-2011.

**a. Least Tern**

Event Type	No. Colonies <sup>a</sup>	No. Flights <sup>a</sup>	No. Blocks <sup>a</sup>	Mean Proportion Time Incubating <sup>b</sup>			MRBP <sup>c</sup>	
				Pre	During	Post	<i>S</i>	<i>p</i>
All Core MOA overflights	6	38	65	0.90	0.91	0.92	-0.24	0.32
Core MOA overflights ≥ 3,000 m	4	27	43	0.91	0.91	0.91	0.79	0.78
Core MOA overflights < 3,000 m	6	10	21	0.88	0.91	0.94	-1.09	0.13
Core MOA overflights in top 25% of SEL	6	17	24	0.85	0.88	0.90	-1.83	0.06
Core MOA overflights in top 10% of SEL	<b>4</b>	<b>8</b>	<b>14</b>	<b>0.84<sup>A</sup></b>	<b>0.87<sup>AB</sup></b>	<b>0.93<sup>B</sup></b>	<b>-3.15</b>	<b>0.01</b>
All Non-Core MOA Military Fixed Wing overflights	6	37	68	0.91	0.90	0.90	0.49	0.62
Non-Core MOA Military Fixed Wing overflights in top 25% of SEL	5	11	17	0.95	0.93	0.95	0.09	0.45
All Civilian Fixed Wing overflights	6	16	34	0.89	0.90	0.89	0.86	0.82

All Military Rotary-Wing overflights	7	43	101	0.90	0.90	0.90	0.29	0.52
Military Rotary Wing overflights in top 25% of SEL	5	17	25	0.84	0.87	0.86	0.36	0.55
All Civilian Rotary Wing overflights	5	19	57	0.88	0.86	0.91	-0.68	0.20
Civilian Rotary Wing overflights in top 25% of SEL	4	6	13	0.86	0.80	0.85	0.80	0.78
Off-Road Vehicle			96	0.95	0.96	0.94	-1.45	0.09
Off-Road Vehicles with nests located < 100 m from beach front			<b>24</b>	<b>0.95<sup>A</sup></b>	<b>0.98<sup>B</sup></b>	<b>0.97<sup>AB</sup></b>	<b>-2.14</b>	<b>0.04</b>
All-Terrain Vehicle			87	0.91	0.89	0.94	-0.83	0.17
All-Terrain Vehicles with nests located < 100 m from beach front			22	0.90	0.89	0.96	-0.91	0.16
Pedestrians			<b>24</b>	<b>0.91</b>	<b>0.79</b>	†	<b>-2.2</b>	<b>0.04</b>

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† Post-samples for pedestrian events were omitted, as pedestrians often remained within view of cameras for extended periods

**b. Common Tern**

Event Type	No. Colonies <sup>a</sup>	No. Flights <sup>a</sup>	No. Blocks <sup>a</sup>	Mean Proportion Time Incubating <sup>b</sup>			MRBP <sup>c</sup>	
				Pre	During	Post	<i>S</i>	<i>p</i>
All Core MOA overflights	3	14	15	0.94	0.93	0.94	0.85	0.81
All Non-Core MOA Military Fixed Wing overflights	1	2	2	0.97	1.00	0.97	0.71	0.74
All Military Rotary Wing overflights	3	5	6	0.99	0.92	0.92	-1.41	0.09
All Civilian Rotary Wing overflights	2	8	10	0.96	0.97	0.97	0.50	0.62
Off-Road Vehicle			3	0.89	0.95	0.96	-1.30	0.10
All-Terrain Vehicle			4	0.98	1.00	1.00	-1.41	0.09

**c. Gull-billed Tern**

Event Type	No. Colonies <sup>a</sup>	No. Flights <sup>a</sup>	No. Blocks <sup>a</sup>	Mean Proportion Time Incubating <sup>b</sup>			MRBP <sup>c</sup>	
				Pre	During	Post	<i>S</i>	<i>p</i>
All Core MOA Overflights	1	3	3	1.00	1.00	1.00	1.80	1.00
All Rotary Wing Overflights	2	4	4	0.63	0.65	0.97	0.17	0.49

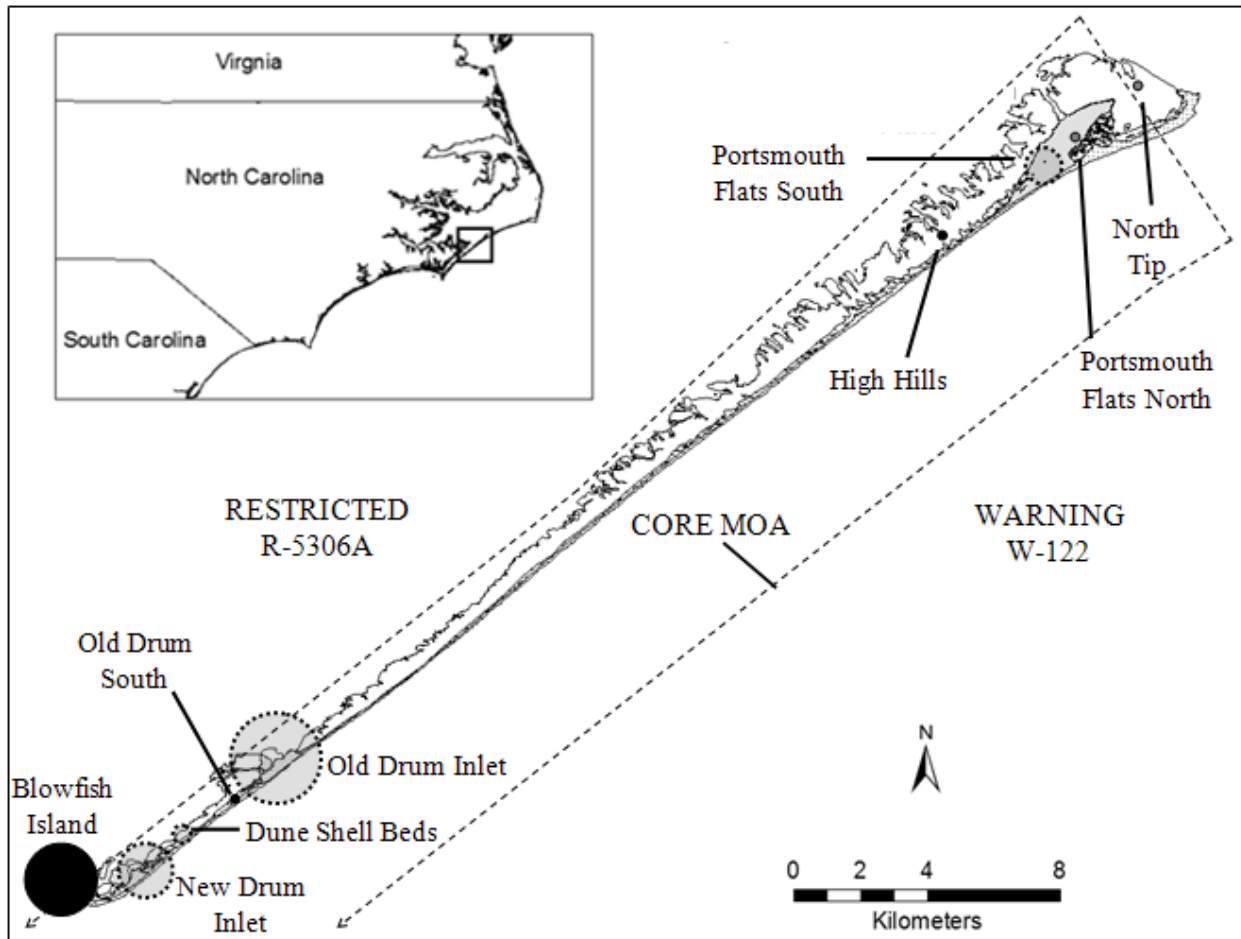
**d. Black Skimmer**

Event Type	No. Colonies <sup>a</sup>	No. Flights <sup>a</sup>	No. Blocks <sup>a</sup>	Mean Proportion Time Incubating <sup>b</sup>			MRBP <sup>c</sup>	
				Pre	During	Post	<i>S</i>	<i>p</i>
All Core MOA Overflights	2	2	3	1.00	1.00	1.00	1.80	1.00
All Non-Core MOA Military Fixed Wing Overflights	2	4	5	0.96	0.99	1.00	0.05	0.44
All Military Rotary-Wing Overflights	2	9	12	0.87	0.86	0.88	0.39	0.62
All Civilian Rotary Wing Overflights	1	3	3	0.87	1.00	1.00	-1.41	0.09
Off-Road Vehicle			6	1.00	1.00	1.00	1.80	1.00
All-Terrain Vehicle			<b>5</b>	<b>1.00<sup>AB</sup></b>	<b>1.00<sup>AB</sup></b>	<b>0.85<sup>AB</sup></b>	<b>-2.05</b>	<b>0.04</b>
Pedestrian			6	0.86	0.99	1.00	0.33	0.57

<sup>a</sup> Samples for overflight analyses were averaged across all nests within a colony for each overflight sequence (see Table 1), such that a block for the MRBP analyses of overflight responses was the mean response of all nests within a colony per overflight sequence. Samples for off-road vehicles, all-terrain vehicles, and pedestrians were blocked only by nest, as one nest was sampled within a colony for each unique event and assumed to be independent.

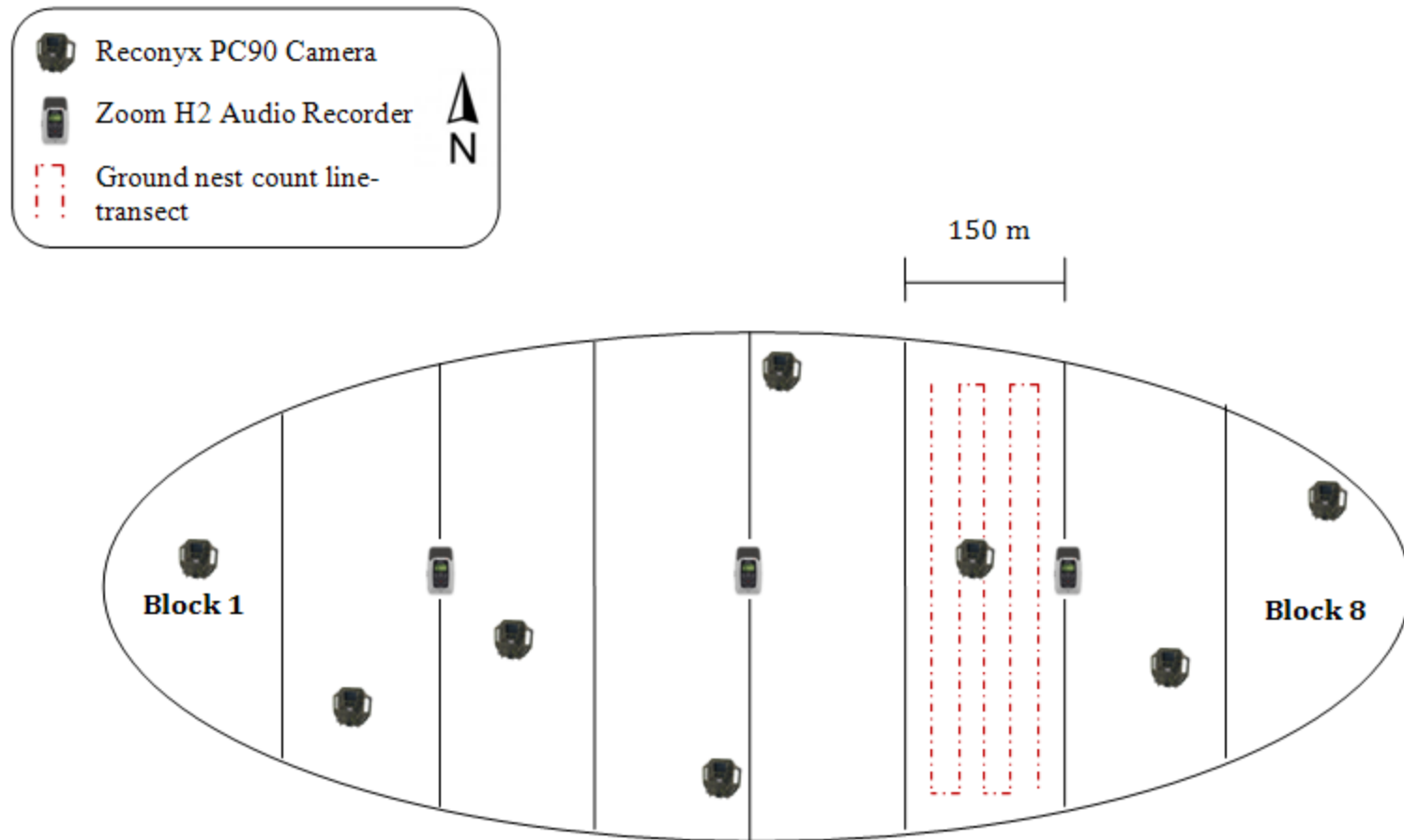
<sup>b</sup> Mean proportion of time incubating, defined as sitting on or shading eggs or chicks, was calculated as the number of frames incubating per total number of frames. ‘Pre’ and ‘post’ samples were always 5-min in length, while the ‘during’ sample was variable in length as determined by the exposure period (# seconds) of the nest (or colony) to the event.

<sup>c</sup> Results of Multiresponse Blocked Permutation Procedure comparison of mean proportion time incubating among ‘pre’, ‘during’, and ‘post’-event samples, where *S* = Pearson Type III test statistic and *p* = significance value of the test (*alpha* = 0.05). Means with different capital letters are significantly different.

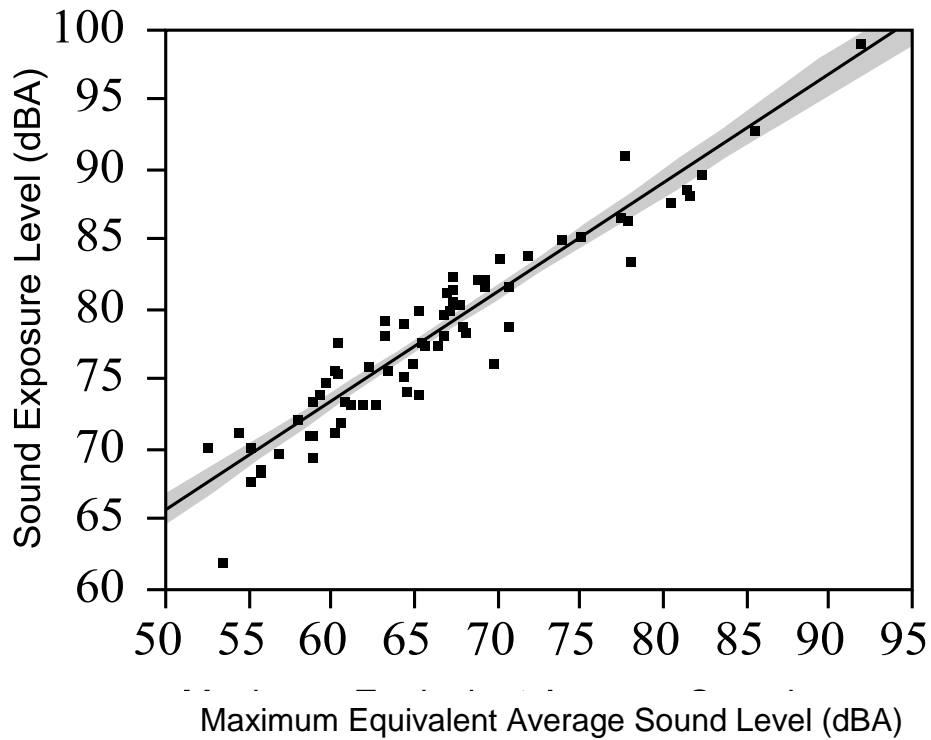


**Figure 1.** North Core Banks, Cape Lookout National Seashore (CALO), North Carolina, 2010-2011. Marine Corps Air Station Cherry Point, in cooperation with the Federal Aviation Administration, manages special-use airspaces near Cape Lookout National Seashore, including the Core Military Operations Area (Core MOA) and adjacent Restricted R-5306A and Warning W-122 Areas. The Core MOA, outlined by the dashed polygon, extends southwest of North Core Banks and terminates over South Core Banks (not pictured); R-5306A is to the west and W-122 to the east. Waterbird colonies are denoted as follows: shaded circles - active in 2010 only (North Tip, Portsmouth Flats North); black circles - active in 2011 only (Blowfish Island, Old Drum South, High Hills); transparent circles with dotted line - active in 2010 and 2011 (Portsmouth Flats South, Old Drum Inlet, Dune Shell Beds, New Drum Inlet): smallest circle - < 10 nests at peak colony incubating adult count; largest circle - > 350 nests at peak colony incubating adult count. Mixed-species colonies occurred only at Blowfish Island, New Drum Inlet, and Old Drum Inlet.

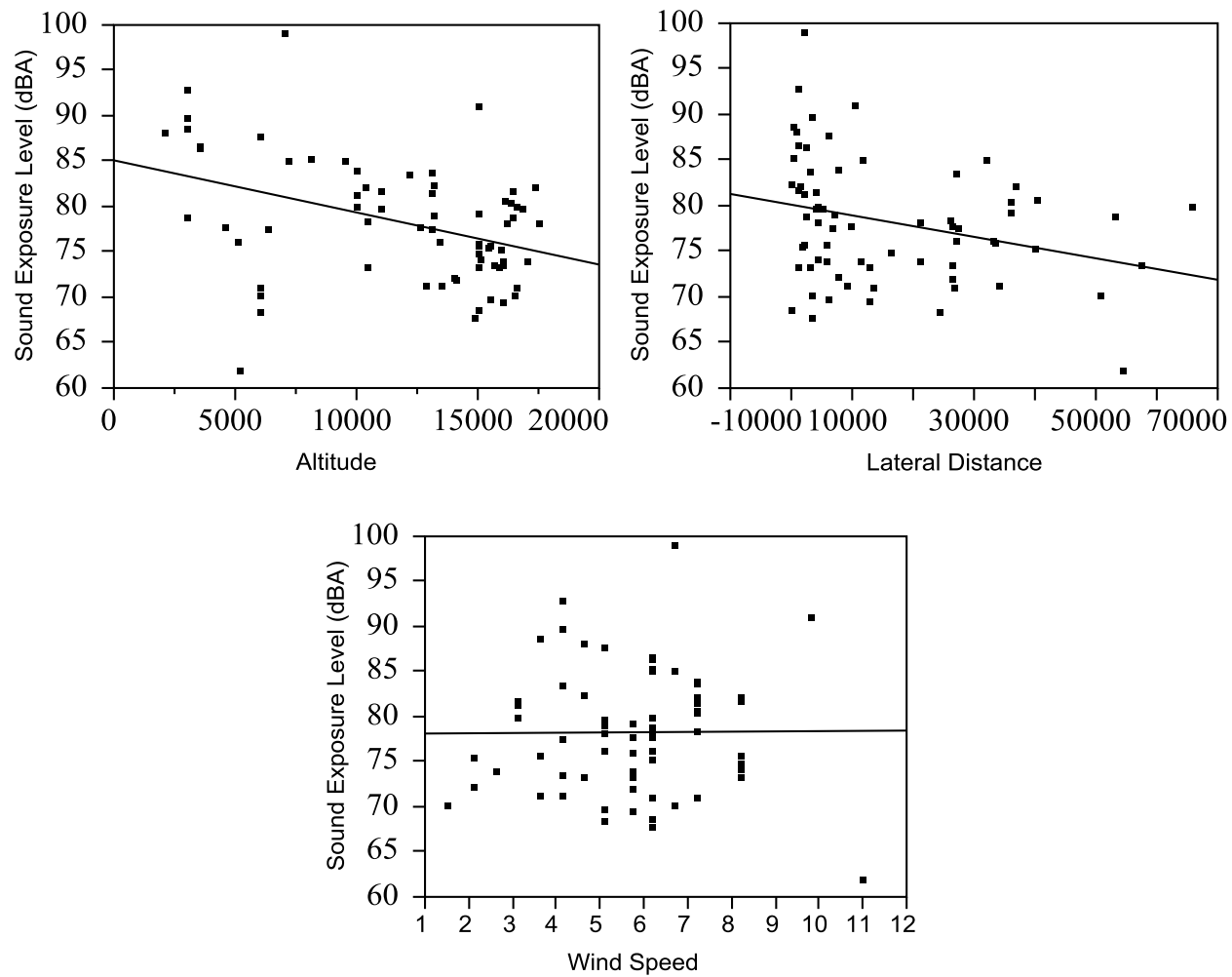




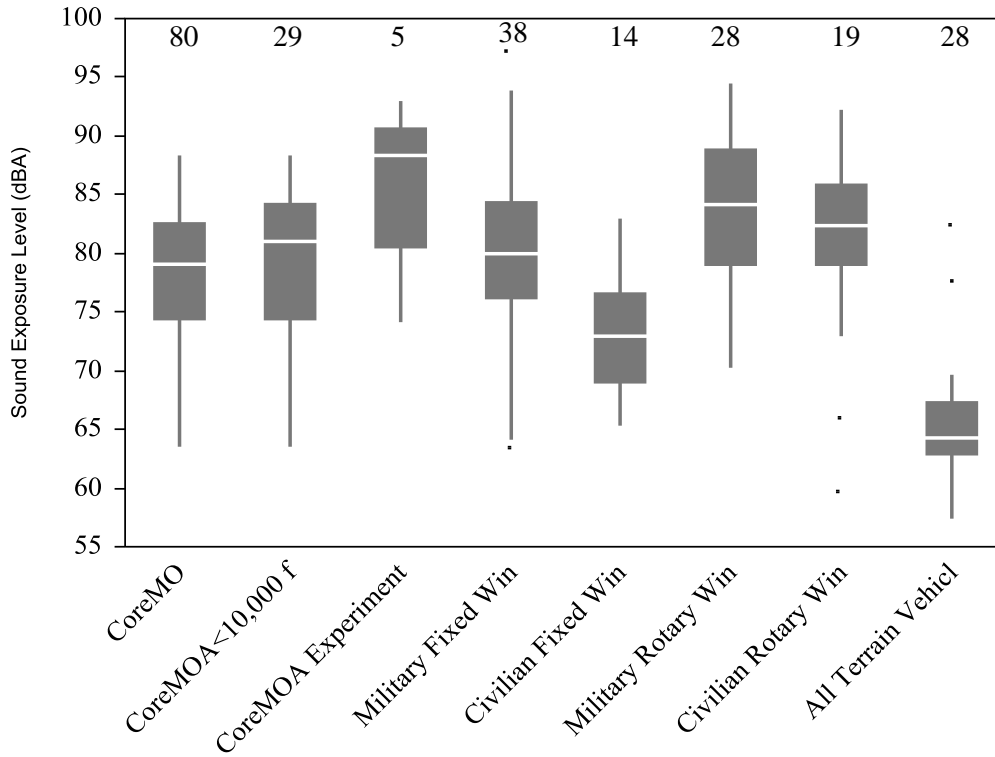
**Figure 2.** Schematic of a typical waterbird colony at Cape Lookout National Seashore, North Carolina. We deployed remote cameras at individual nests and audio recorders at 300 m intervals from April-August, 2010-2011. We randomly selected a nest within each block for camera placement and re-deployed cameras on additional random nests in each block as previous nests hatched or failed.



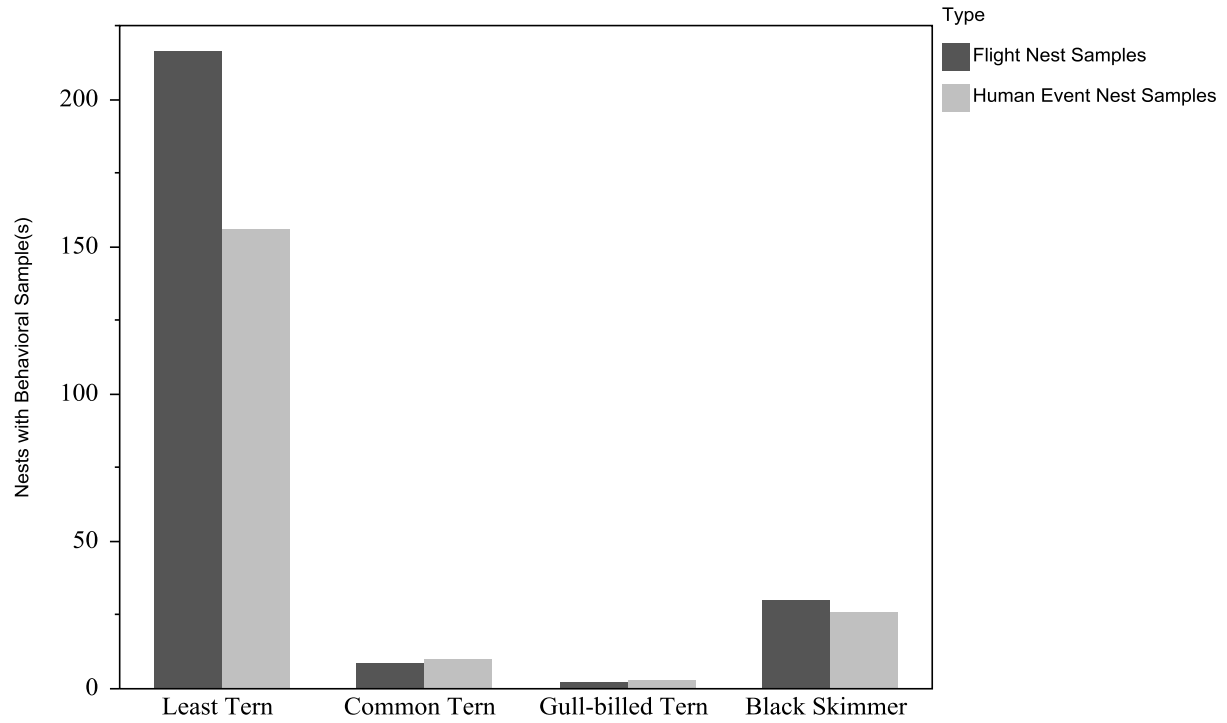
**Figure 3.** There was a strong positive relationship between Sound Exposure Level (SEL) and Maximum 1-s Average Equivalent Sound Level (MaxLEQ) for military overflights through the Core Military Operations Area ( $r^2 = 0.90$ ,  $n = 70$  overflights,  $RMSE = 2.11$ ,  $p < 0.001$ ,  $SEL = 26.8 + 0.78 * MaxLEQ$ ). The shaded region shows the bounds of the 95% confidence intervals on the regression line.



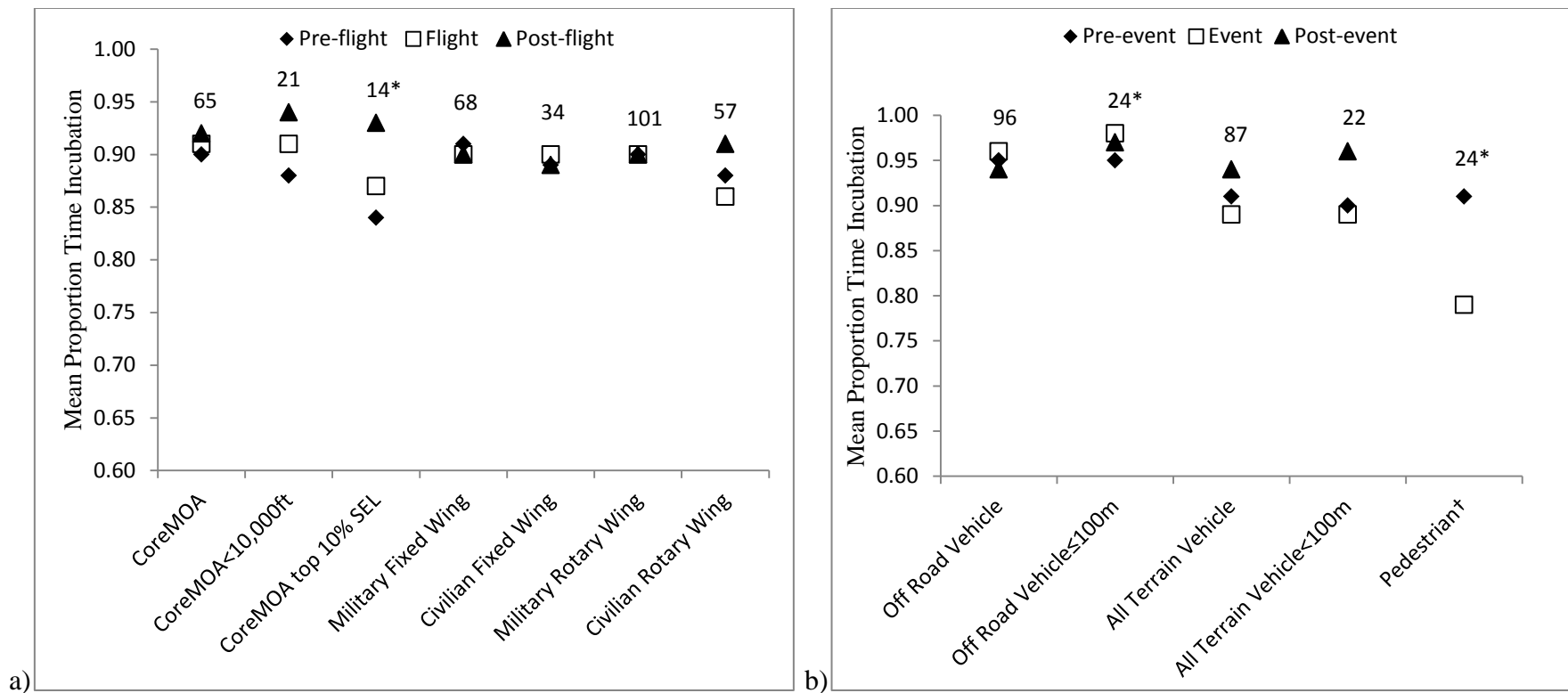
**Figure 4.** Sound Exposure Levels of overflights through the Core Military Operations Area ( $n = 70$ ) as related to altitude, lateral distance (i.e., Closest Point of Approach), and wind speed on North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011.



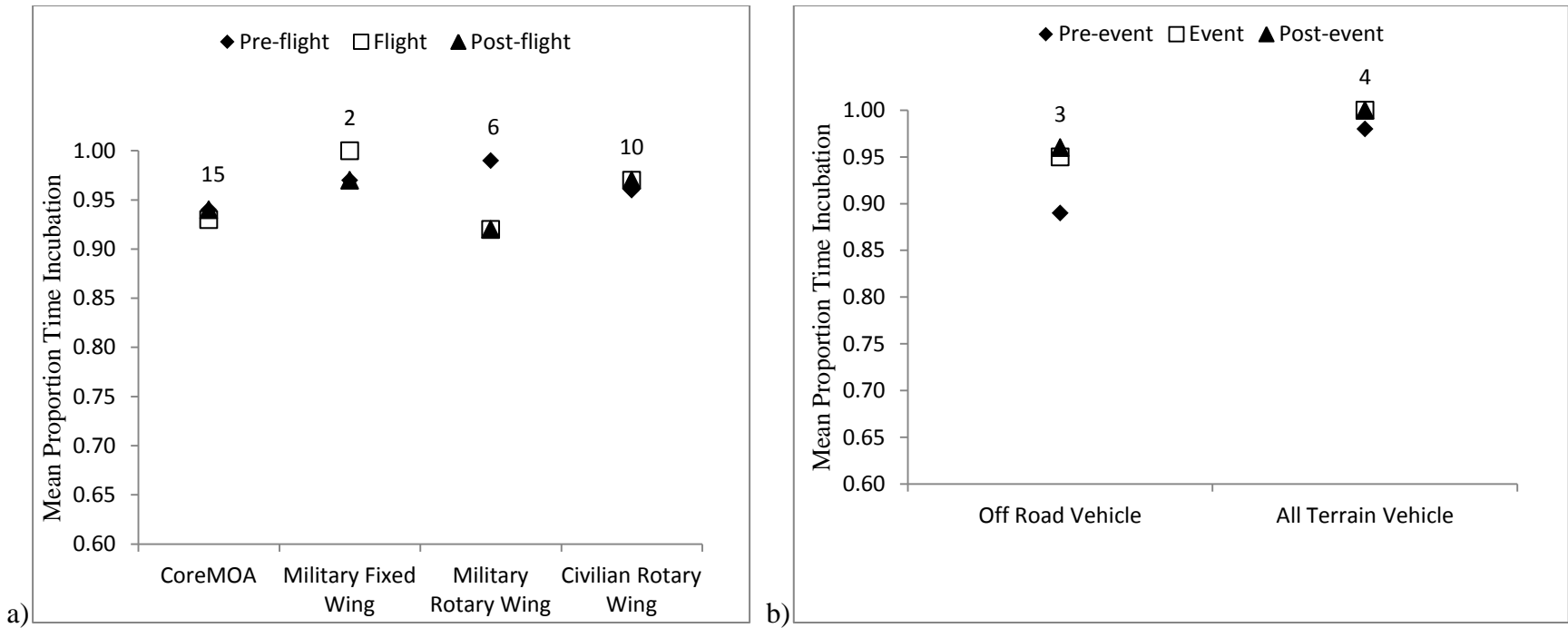
**Figure 5.** Sound Exposure Levels (SEL) of overflights through the Core Military Operations Area (Core MOA), non-Core MOA overflights, and all-terrain vehicles (sample sizes above box plots) recorded from digital audio recorders in waterbird colonies at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011. ‘Core MOA experimental’ denotes the 5 overflights flown from July-August 2011 by Marine Corps Air Station Cherry Point conducted near the 900 m Core MOA floor and within 0.97 km of closest point of approach to colonies. Audio data was calibrated using Larson Davis 831 Sound Level Meters and post-processed using Audio2NVSPL and Acoustic Monitoring Toolbox software programs (Natural Sounds Program, National Park Service).



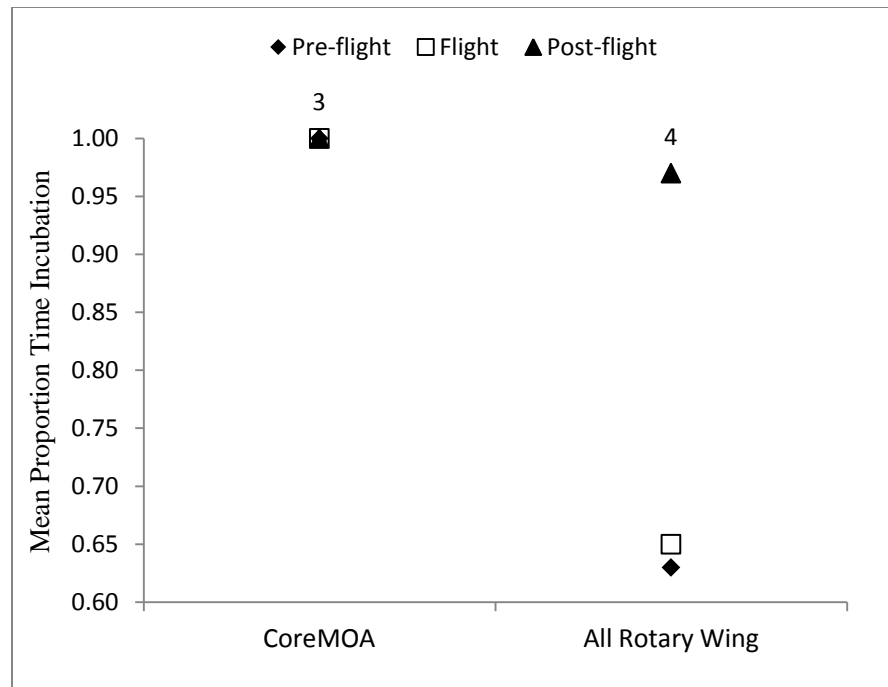
**Figure 6.** The number of nests for each colonial waterbird species from which behavior was sampled in response to all overflights (dark gray) and to other human events (off-road vehicles, all-terrain vehicles, and pedestrians, light grey).



**Figure 7.** Mean proportion of time spent incubating by least terns ‘pre’, ‘during’, and ‘post’ a) overflights and b) other human events at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011 (sample sizes above symbols). \*Indicates  $p < 0.05$  for Multi-Response Blocked Permutation (MRBP) test between ‘pre’, ‘during’ or ‘post’ samples.

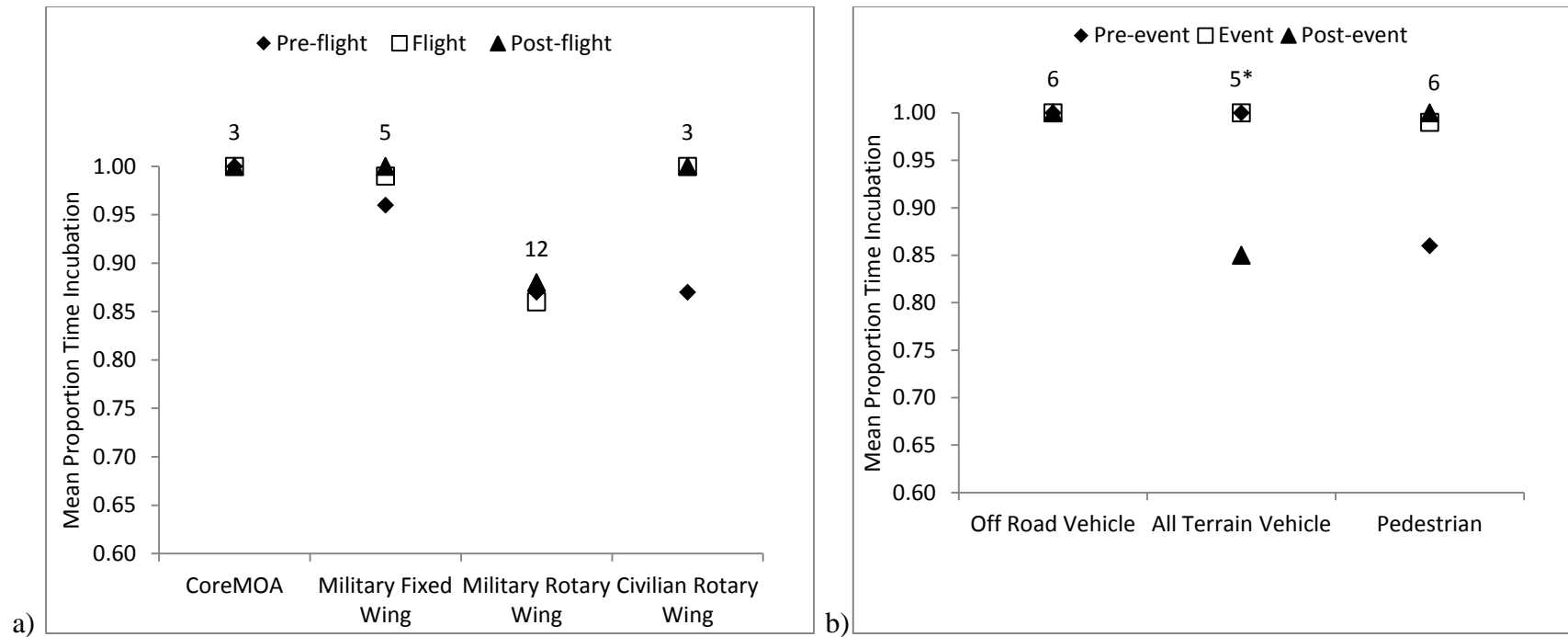


**Figure 8.** Mean proportion of time spent incubating by common terns ‘pre’, ‘during’, and ‘post’ a) overflights and b) other human events at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011 (sample sizes above symbols).



**Figure 9.** Mean proportion of time spent incubating by gull-billed terns ‘pre’, ‘during’, and ‘post’ Core MOA and rotary wing overflights at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011 (sample sizes above symbols).





**Figure 10.** Mean proportion of time spent incubating by black skimmers ‘pre’, ‘during’, and ‘post’ a) overflights and b) other human events at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010-2011 (sample sizes above symbols). \*Indicates  $p < 0.05$  for Multi-Response Blocked Permutation (MRBP) test between ‘pre’, ‘during’ and ‘post’ samples.

### **Chapter 3 - Effects of Camera Monitoring on Least Tern Nest Success at Cape Lookout National Seashore, North Carolina**

**ABSTRACT** The Least Tern (*Sternula antillarum*), a ground-nesting colonial waterbird, is noted for high rates of nest failure due to predation and flooding. However, without the ability to continuously monitor nests, specific nest fates are either unknown or estimated based on evidence found around the nest site. While remote cameras can reduce this uncertainty, their presence near a nest may have unintended consequences. We deployed Reconyx PC90 auto-triggered cameras at a random sample of Least Tern nests at Cape Lookout National Seashore (CALO), North Carolina in 2011 to identify nest predators, quantify predation rates, and assess our accuracy at estimating nest ages and nest fates based on field-collected data alone. We also tested for camera-monitoring effects on daily nest survival rates of Least Terns. Raccoons (*Procyon lotor*) were the primary nest predator species at CALO, accounting for 79% of all depredation events. Estimating nest fate from evidence found around the nest site overestimated hatching success by 31% and increased rates of unknown nest fate by 75%. Daily survival rates for nests with and without cameras were 79% and 85%, respectively. While cameras effectively reduced bias in determining nest fates, they substantially increased nest failure rates. We hypothesize that raccoons routinely investigated cameras placed near nests, which increased the probability that a nest would be located and depredated. While cameras are an effective nest-monitoring tool in other study systems, additional research is needed at CALO and at similar areas that experience intense mesocarnivore predation on ground-nesting birds to mitigate adverse camera-monitoring effects.

**KEY WORDS** camera effects, camera traps, Least Terns, nest success, nest survival, predation

Reliably documenting nest success or failure has long been a challenge to those interested in the factors driving avian demographic rates. As it is rare to directly observe the causes of nest failure in the field, many studies estimate nest fate based on physical evidence (e.g. tracks, shell fragments, flood waters) observed around the nest site during routine monitoring (Mayfield 1975; Mabee et al. 2006; Pietz et al. 2012). However, relying on post-failure physical evidence alone may be inaccurate if the assumptions about signs of predators, weather, or flooding are incorrect (Lariviere 1999; Williams and Bohall Wood 2002). For example, many nest predators either do not leave human-identifiable sign around the nest site, or their sign is erased by wind or rain. A recent camera-trapping study of Wilson's Plovers (*Charadrius wilsonia*) documented multiple predator species, some of which left tracks and some of which did not, visiting a single nest during a single night (Ray 2011). These challenges either produce results with limited utility if a nest is assumed depredated but the predator species is unknown, or they may lead to spurious results if a nest fate was categorized differently from the actual outcome. In an effort to address these concerns, biologists have increasingly relied on remote video or camera-monitoring systems to provide comprehensive data on nesting birds, hatchlings, and the type and frequency of their interactions with predators and other causes of nest failure (Ribic et al. 2012).

While cameras provide a unique opportunity to attain high-quality, detailed data on nesting birds, studies have suggested that the presence of a camera at a nest may alter nest survival (Herranz et al. 2002), but the directionality of the effects on survival is varied. Cameras may increase nest abandonment (Pietz et al. 2012), reduce nest predation if predators avoid cameras (Thompson et al. 1999; Herranz et al. 2002; Sequin et al. 2003; Richardson et al. 2009), increase nest predation if predators are attracted to cameras (Cartar and Montgomerie 1985; Renfrew and Ribic 2003), or have no measurable effects (Pietz and Granfors 2000; Coates et al.

2008; McKinnon and Bêty 2009) on nest survival. A meta-analysis of camera-monitoring effects on birds found that while most authors reported no significant differences between nest predation rates with and without cameras, on average, the presence of cameras tended to increase nest survival (Richardson et al. 2009); the authors proposed that neophobia of predators to cameras was the mechanism by which this pattern was driven. Due to the inconclusive nature of the literature, nest survival studies should attempt to document the effects, if any, that investigator activity has in the study system, whether related to deploying cameras or otherwise monitoring nests.

The mechanisms by which investigator effects, including but not limited to the use of cameras, may occur are site and context-dependent. Direct effects of investigator activity may include nest abandonment due to frequent monitoring visits (Safina & Burger 1983) or adverse reactions by nesting birds in response to foreign objects placed at the nest site (e.g., cameras, flagging, stakes; Thompson et al. 1999; Stake and Cimprich 2003; Pietz et al. 2012). Investigators may also inadvertently damage nests, eggs, or chicks by mishandling or crushing them. Indirect investigator effects may include an increase in the types and frequency of aggressive behaviors by nesting birds that lead to egg or chick casualties; this is particularly true in colonial species (Burger 1981). Moreover, nesting birds that flush with greater frequency when approached by investigators may increase the likelihood of nest failure by 1) providing cues to predators on the location of the nest, 2) leaving nests unguarded and therefore exposed to predators, or 3) exposing chicks or eggs to adverse environmental conditions (Major 1990; Tulp et al. 2000). Deploying cameras and/or other visual markers may reduce nest concealment and/or provide scent or visual trails to predators, thereby increasing the probability that a monitored or marked nest is depredated compared to that of a non-monitored nest (Skutch 1966;

Major 1990). Conversely, investigator activity may reduce nest predation if predators actively avoid human-visited sites or objects placed by humans (MacIvor et al. 1990). Therefore, while deploying a camera or other object near a nest may increase the probability of nest detection by a predator, it may also reduce predation by deterring other would-be predators from the site or by reducing the need for frequent nest-monitoring visits by investigators.

Some studies have suggested that birds nesting in open habitats, such as beaches or grasslands, may be particularly susceptible to supplementary investigator-induced predation due to the relative ease with which visually-oriented predators can locate the nests visited and/or marked by humans (Galbraith 1987; Gotmark 1992; Smith et al. 2007). If we assume that investigator-placed objects at nest sites are also easy for predators to detect, and if predators become conditioned to associate these objects with prey, then objects, such as cameras, may increase predation rates of these nests (Murphy et al. 2003).

In this study, we asked whether deploying cameras at the nests of Least Terns (*Sternula antillarum*), a colonial ground-nesting species that nests in open habitats, increased our accuracy at determining nest fate as compared to nest visit data alone. As determining if a nest has failed or succeeded from field-visits depends on estimating hatch date from egg-float data (Hays & LeCroy 1977), and assuming that nests that disappear before the estimated hatch date have failed, we also deployed cameras at nests to assess the accuracy of egg-float data for estimating hatch date. Lastly, we assessed if cameras affected Least Tern nest success and daily nest survival rates.

## STUDY AREA

We conducted our study at North Core Banks, Cape Lookout National Seashore (CALO), North Carolina (34° 52' 54.37" N, 76° 16' 46.92" W, Fig. 1). North Core Banks is a 37 km barrier island that marks the northernmost end of the 3-island chain forming CALO.

## METHODS

We searched for Least Tern nests from May – July of 2011 at all active waterbird colonies on North Core Banks. We attempted to locate every nest at the smaller colonies (i.e., colonies with fewer than about 40 nests) by scanning for incubating adults from the perimeter and/or by conducting ground nest counts within the colony. At the larger colonies, we sampled nests by establishing a series of evenly-spaced parallel transect lines, beginning from a randomly selected starting point such that each colony had a minimum of 7 transects and 8 blocks ranging from 150 – 250 m in width (Figure 2). We randomly selected 1 nest per block to monitor with an auto-triggered camera (see below) and used transect sampling to locate and monitor additional nests without cameras. We marked all nests with global positioning systems (Oregon 450, Garmin International Inc., Olathe, KS) and tongue depressors placed 1 m due south of the nest cup, and floated eggs in water to estimate nest age (Hays & LeCroy 1977).

We deployed covert infrared cameras (Reconyx PC90, Reconyx, Inc., Holmen, WI) 2 m from a randomly selected sample of Least Tern nests throughout the nesting season to confirm nest fates and to monitor behavior for concurrent study objectives (see Ch 2). We encased cameras in wood housing painted to mimic the color of the sand. We set cameras on time lapse to capture one frame every 5 s for 24 hr/day. Cameras were powered by deep-cycle sealed lead-acid batteries (TD22-12, Tempest Batteries, San Jose, CA) which we placed in watertight containers and buried behind the camera. After initial camera deployments, we observed nests

from > 100 m outside of the colony boundary to ensure that the adult returned to incubate; if it did not, we removed the camera after 30 min of inactivity. We visited nests with and without cameras with the same frequency, twice-weekly, to field-record signs of hatching, predation, abandonment, or flooding, and to swap batteries and memory cards at camera-nests. We compared field-collected nest fate data with camera data to assess our accuracy at determining nest fates based on field-collected data alone.

We evaluated the accuracy of our nest age estimates by comparing known hatch dates with estimated hatch dates derived from egg-float data on the same nests using Wilcoxon rank-sum tests (the data did not meet assumptions of normality for parametric tests). We considered a hatch date known if we observed eggs hatching from the camera footage or if we observed at least one freshly hatched chick in the nest cup during a visit, and the chick was known to be the first (or only) of the clutch to have hatched.

Using a combination of estimated hatch date data and field-recorded nest-visit data, we categorized nest fates as follows: hatched or likely hatched (chicks or pipped eggs in nest), depredated (estimated hatch date was > 3 days from survey date, eggs were missing, and predator sign was found in vicinity of nest), unknown failure (nest was not due to hatch for > 3 days from survey date, eggs were missing, and there were either conflicting signs or no signs of nest fate), abandoned (eggs remained but nest showed no signs of incubation activity), flooded (signs of recent overwash of the nest), or unknown (eggs were due to hatch within 3 days of nest visit and there were no signs of nest fate). We then reviewed camera footage and again characterized nest fate according to the criteria above to test the field-accuracy of estimating nest fates. Observers reviewing camera footage were unaware of field-recorded data.

We used the logistic exposure method (Shaffer 2004), as coded for Proc NLMIXED (SAS Institute, Cary, NC), to compare daily nest survival rates of camera-nests versus non-camera nests. As hatch date data derived from camera-nests were more precise than those of non-camera nests, we considered nests successful if they were actively being incubated and had  $\geq 1$  egg or chick within 3 days of the estimated hatch date. This 6-day interval around the estimated hatch date was based on our twice-weekly survey frequency and accounted for the potential error associated with egg-floating. We omitted nests from the analysis when it was not possible to determine whether they were active or inactive within 3 days of the estimated hatch date. Additional logistic exposure model parameters included colony as a random effect and the estimated day of year that a nest was initiated and clutch size as fixed effects. We controlled for the effect of Blowfish Island because it was a sandbar separated from North Core Banks and was thus exposed to considerably lower predation rates compared to the other colonies.

## RESULTS

We studied 7 waterbird colonies at North Core Banks, CALO in 2011 (Fig. 1). We deployed cameras at 163 individual Least Tern nests and monitored an additional 522 Least Tern nests without cameras throughout the nesting season. Least Terns nested on open, sandy beaches, overwash flats, and interdune areas.

Camera data confirmed 6 nest predator species of Least Tern eggs and chicks, including raccoon (*Procyon lotor*), Gull-billed Tern (*Gelochelidon nilotica*), ghost crab (*Ocypode* sp.), Common Tern (*Sterna hirundo*), domestic cat (*Felis catus*), and Great-horned Owl (*Bubo virginianus*); raccoons accounted for 79% of all confirmed predation events. Fifteen percent of all camera-nests hatched at least 1 egg, 67% were depredated, 4% were abandoned, 2% flooded, 9% failed for unknown reasons (i.e., equipment malfunctioned and eggs were missing > 3 days



before the estimated hatch date), and 2% were unknown (i.e., equipment malfunctioned within 3 days of the estimated hatch date). Five nesting birds did not return to incubate within 30 min of deploying cameras, although each resumed incubating within 5 min after cameras were removed; 2 nests were abandoned within 1 day of camera deployment. Five nests successfully hatched chicks but the chick(s) and/or remaining egg(s) were depredated at the nest site within 24 hr of hatching. We observed multiple predator species consuming eggs and/or chicks, or multiple causes of nest failure, at camera-nests on 6 occasions.

We documented known (e.g., depredated by raccoon) or partially-known (e.g., unknown failure) nest fates for 160, or 98%, of camera-monitored nests, and verified precise nest fates (i.e., confirmed hatched, flooded, abandoned, or depredated by a known species) for 134, or 82%, of camera-monitored nests. By contrast, we documented known or partially-known nest fates for 482 (92%) of nests without cameras, and were confident in precise nest fates (e.g., a nest had missing eggs and raccoon tracks that led to the nest bowl > 3 days before the estimated hatch date) for only 160, or 31%, of nests without cameras. Using data from evidence found around the nest site overestimated hatching success by 31% and increased rates of unknown nest fate by 75% (Table 1).

Of all camera and non-camera nests confirmed to have hatched ( $n = 127$ ), there were 26 for which actual hatch dates were precisely known. In comparing the estimated versus actual hatch dates from these 26 nests, we underestimated actual hatch dates for 73% of nests by an average (SE in parentheses) of 2.0 (0.28) days; overestimated actual hatch dates for 15% of nests by an average of 1.3 (0.25) days; and were accurate for 12% of estimated hatch dates. The overall absolute value of the average difference between egg-float-estimated versus confirmed

hatch dates was 1.9 days (0.25), although even given this, actual hatch dates were not significantly different from estimated hatch dates (Wilcoxon  $Z = -0.61$ ,  $P = 0.54$ ).

The top-ranked nest survival model included colony as a random effect with camera presence and clutch size as fixed effects (Tables 2, 3). Cameras at a nest decreased daily nest survival and a larger clutch size increased daily nest survival. The average (SE) daily nest survival rate across all colonies was 0.79 (0.08) for camera-monitored nests and 0.85 (0.06) for nests without cameras. Period survival over the 21-day Least Tern incubation period for nests with and without cameras was 0.7% and 3.3%, respectively. Conversely, average daily nest survival at the Blowfish Island colony was 0.94 for camera-monitored nests and 0.97 for nests without cameras, with associated period survival rates of 29% and 55%, respectively.

## DISCUSSION

Similar to earlier studies (Trevor et al. 1991; Lariviere 1999; Williams and Bohall Wood 2002; White et al. 2010), we found that estimating nest fate from physical signs around a nest site is subject to error. Misclassifications of nest fate in our study could bias our understanding of the factors affecting Least Tern nest success, depending on the cause of those inaccurate estimates. In most cases of such misclassifications in our study, the nests were expected to hatch between visits based on egg float data and no signs of flooding or predation were recorded at the nest site; however, examination of the camera data confirmed that these were depredated.

Conversely, at least 7% of nests hatched  $\geq 1$  day earlier than expected based on egg-float data, but were field-recorded as potentially-depredated based on predator sign observed around the nest site; camera data subsequently revealed that these 7% of nests were in fact successful (i.e., hatched at least 1 egg), here resulting in an underestimate of nest success. If we assume that nest fate bias of non-camera nests occurred at similar rates to that of camera-nests, then the

number of inaccurate nest fates combined with unknown nest fates would be 1/3 of all nests lacking cameras; again if trends are similar to camera-monitored nest, we expect that in many cases more nests were classified as successful when in fact they failed.

For example, one nest that we categorized as ‘unknown’ in the field was confirmed by camera data to have hatched 1 chick, which was then depredated by a Great-horned Owl (*Bubo virginianus*) 9 min post-hatch. The parents subsequently abandoned the nest for 21 hr and returned to incubate the remaining (unviable) egg until 13 days after the estimated hatch date, at which time the nest flooded. Although camera data revealed this to be a successful nest, we coded it as ‘unknown’ in the field because no sign of hatching or predation was evident and the nest was within 3 days of the estimated hatch date (the egg actually hatched 2 days after the estimated hatch date). Depending on the timing of the nest visit, and the criteria for ascribing nest fate, this nest could have correctly been categorized as hatched, depredated, abandoned, unviable, or flooded.

We found that estimating hatch dates by floating Least Tern eggs using the methods of Hays and LeCroy (1977) provided reliable estimates to within an average of 1.9 days, but given the range, we recommend that managers consider egg-float estimates as accurate within no fewer than 3 days of the estimated hatch date. Given this, and given our twice-weekly survey frequency, it would not be appropriate to model nest survival based on criteria where a nest was considered successful only if chicks were found in the nest (as this was relatively rare) or if it was active to within 0 — 2 days of the estimated hatch date. By analyzing nest survival where a nest was considered successful if it was active within 3 days of the expected hatch date, we reduced the potential biases associated with 1) the higher precision of nest fate data for camera-nests versus non camera-nests and 2) estimating nest fates based on imprecise egg-float data.

Our estimated daily nest survival of camera and non-camera-nests was low compared to other Least Tern studies. Lombard et al. (2009) reported daily nest survival rates ranging from 0.91 - 0.97 for Least Terns in the U.S. Virgin Islands, and Bomberger Brown et al. (2011) reported daily nest survival rates of 0.97 - 0.99 for Least Terns in Nebraska, versus the 0.79 - 0.85 observed in this study. However, direct comparability of our findings to these studies is difficult as our methods for defining a successful versus a failed nest were dissimilar from other studies. First, our nest visit return interval, which averaged 4 days but was as many as 6 days when sites were inaccessible due to weather, was longer than other studies. Second, we used multiple methods (cameras vs. field visits) to estimate nest fate, which varied in accuracy as discussed above, whereas other studies have only used field-visit data which we found tended to overestimate nest success. Therefore, we do not recommend directly comparing our nest survival estimates to previous published estimates unless the data were collected in the same manner.

Period survival of camera-nests was nearly 5 times less than that of non-camera-nests. We hypothesize that this difference was driven by raccoon predation. Cameras may have increased nest detection and predation by providing visual cues to raccoons as they foraged through colonies. For example, the colony at Blowfish Island was located on a sandbar separated from North Core Banks by a 50 m-wide channel, which greatly reduced raccoon activity at that site (only 1 confirmed nest predation by raccoon out of 273 total nests monitored at Blowfish Island). Average daily nest survival rates at this colony were higher than at any other, and the difference between daily nest survival for nests with and without cameras was also the smallest. Our observations support the hypothesis that raccoons frequently inspected cameras, as camera data and field-observations confirmed that raccoons routinely investigated cameras and other beach debris; their tracks showed clear patterns of seeking prominent features

over the otherwise flat and open colonies. Therefore, placing cameras at Least Tern nests may have increased the probability that raccoons ventured towards cameras and subsequently located nests. We cannot rule out that raccoons and other predators may have also cued in on investigator activities or sign unrelated to deploying cameras at nest sites, including human footprints and/or scent trails that led to nests or the tongue depressors that we used to mark all nests. We could not compare nest survival rates of nests with differential human visitation because we visited all nests with the same frequency. Additional research is needed to examine the specific mechanisms by which predators modify their search behaviors based on human activity.

Although we cannot discount the possibility that raccoons learned to associate cameras with a prey source, the fact that the date of nest initiation term was not present in our top model suggests that such learning by raccoons over the course of the nesting season was not prevalent. While date of nest initiation was in our second-best model, its inclusion did not reduce model deviance and thus we considered it an uninformative parameter with no ecological effect (Arnold 2010).

On average, cameras reduced daily nest survival by 6%, while larger clutch sizes increased daily nest survival. In the latter case, we speculate that Least Terns with 2 - 4 eggs versus 1 egg were more invested in parental care, including anti-predator defenses, and less inclined to abandon nests. Similarly, a larger clutch size may reduce the probability that a nest will fail due to one or more eggs being unviable.

We conclude that estimating Least Tern nest fate at CALO without the use of remote monitoring devices may substantially bias results, in general resulting in an overestimation of nest success and a misclassification in causes of nest failure. However, we also note that

cameras decreased daily nest survival rates by increasing raccoon predation at camera-nests. Our camera systems measured about 45 cm tall x 30 cm long x 15 cm wide and we placed cameras no further than 2 m from nests due to limitations in focal length and nocturnal infrared illumination. However, if cameras were less obvious, e.g., if they were smaller or could be positioned further from nests, their effects on nest survival may be reduced. The effects of cameras may also differ depending on whether the dominant nest predators locate nests by visual or other cues.

Investigators and managers must weigh the benefits of increased accuracy in determining nest fate provided by camera data with the potential costs of decreased nest survival when deciding whether to use cameras in research and monitoring activities. If the reduction in nest survival rates due to cameras is tolerable under given conservation objectives, the benefits of cameras may outweigh the risks as camera-effects can be explicitly included in models of population dynamics (Rotella et al. 2000). Conversely, unknown bias in nest fate is more difficult to incorporate. However, given the substantial reduction in daily nest survival of nests with cameras compared to nests without cameras at CALO, we do not recommend the continued use of our camera methods in this study system.

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TABLES AND FIGURES

**Table 1.** Differences between field-estimated nest fates and remote camera-confirmed nest fates for 163 Least Tern nests at Cape Lookout National Seashore, North Carolina in 2011.

<b>Nest fate</b>	<b>Field-estimated</b>	<b>Camera-confirmed</b>	<b>%Change from field-estimated to camera-confirmed</b>
Hatched	36	25	-31
Depredated	106	109	16
Abandoned	4	7	75
Flooded	2	4	-100
Unknown failure	3	15	400
Unknown	12	3	-75

**Table 2.** Models of the factors affecting survival of camera- and non-camera-monitored Least Tern nests at Cape Lookout National Seashore, North Carolina, May-August 2011.

<b>Model</b>	<b>-2(L)<sup>a</sup></b>	<b>K<sup>b</sup></b>	<b>AICc<sup>c</sup></b>	<b>ΔAIC<sup>d</sup></b>	<b>w<sub>i</sub><sup>e</sup></b>
Colony <sup>f</sup> camera clutch_size	1328.6	4	1336.6	0.0	0.63
Colony camera clutch_size initiation_date	1327.7	5	1337.8	1.2	0.35
Colony egg	1339.0	3	1345.0	8.4	0.01
Colony egg initiate	1337.1	4	1345.1	8.5	0.01
Colony camera	1402.8	3	1408.8	72.2	0.00
Camera clutch_size initiation_date	1745.9	4	1753.9	417.3	0.00

<sup>a</sup> Log-likelihood

<sup>b</sup> Number of parameters in model

<sup>c</sup> Aikake's information criterion corrected for small sample sizes

<sup>d</sup> Change in AICc from top model

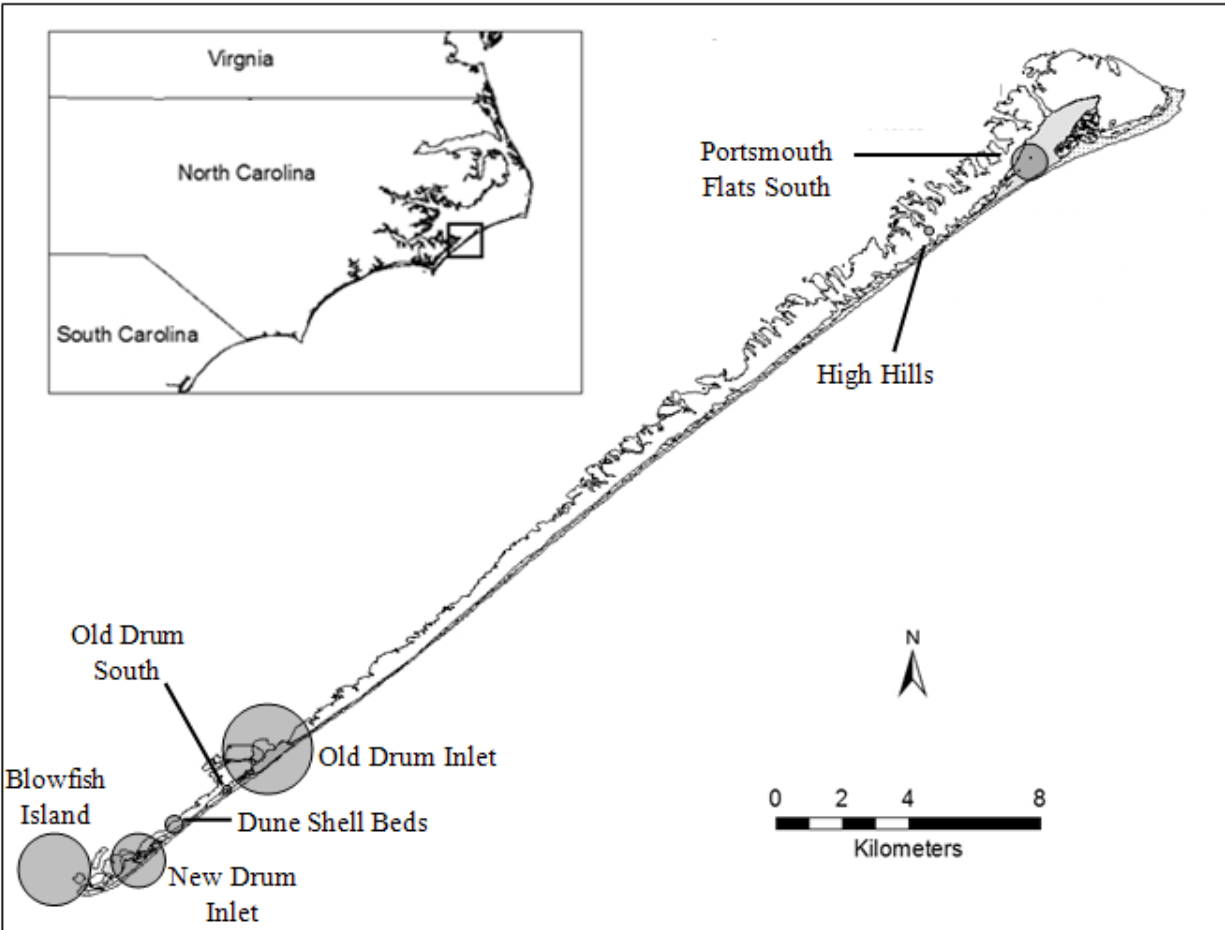
<sup>e</sup> AICc weights

<sup>f</sup> Model parameters include Colony, Camera, Clutch-size, and Initiation date

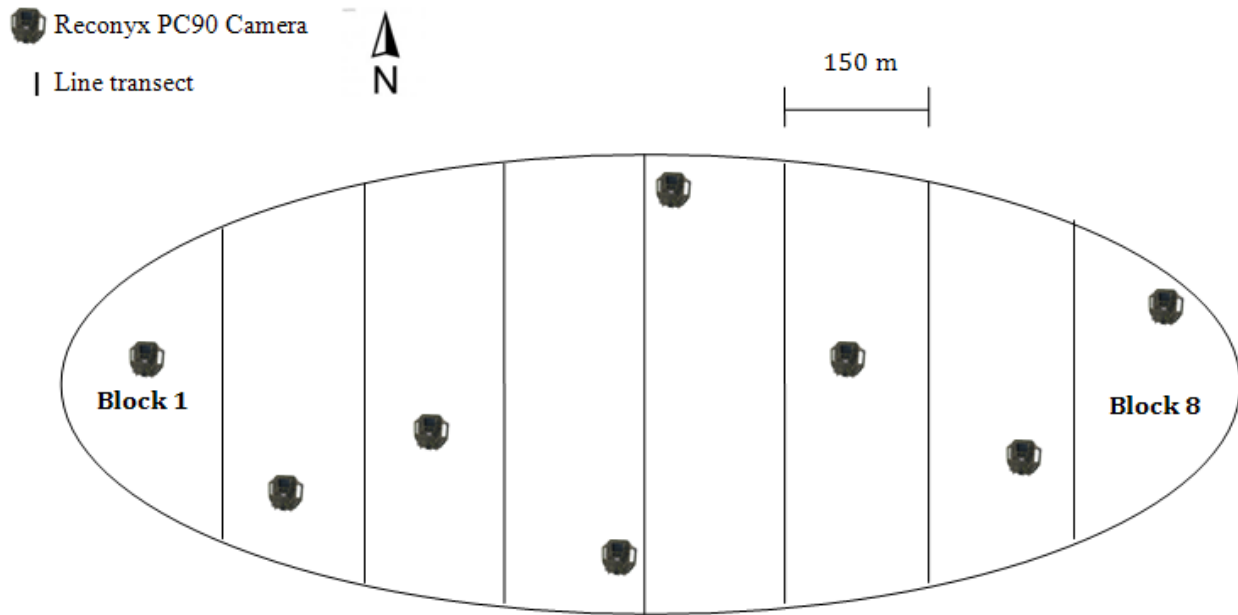
**Table 3.** Parameter estimates from top-ranked model of the factors affecting survival of Least Tern nests from May-August 2011 at Cape Lookout National Seashore, NC.

<b>Model term<sup>a</sup></b>	<b>Estimate</b>	<b>SE</b>	<b>DF</b>	<b>Log Odds</b>	<b>Lower</b>	<b>Upper</b>
Intercept	-0.18	0.45	7	0.83	-1.36	0.99
Camera	-0.41	0.13	7	0.66	-0.71	-0.11
Clutch_Size	0.95	0.11	7	2.60	0.69	1.22
SD_Colony	1.46	0.95	7	4.32	-0.77	3.70

<sup>a</sup> Model parameters include Colony, Camera, Clutch-size, and Initiation date.



**Figure 1.** We studied nest fates and daily nest survival rates of Least Terns at 7 colonies on North Core Banks, Cape Lookout National Seashore (CALO), North Carolina in 2011. Colony size is denoted as follows: Smallest circle - < 10 nests at peak colony incubating adult count; largest circle - > 350 nests at peak colony incubating adult count. Mixed-species colonies occurred only at Blowfish Island, New Drum Inlet, and Old Drum Inlet.



**Figure 2.** Schematic of the layout of camera, block, and transect line placement in a waterbird colony at Cape Lookout National Seashore, North Carolina. We deployed remote cameras at individual nests selected randomly within each block to study nest fates in May-July 2011. We also sampled nests along transect lines to estimate nest fate and nest survival of nests lacking cameras. Block width was 150 m at smaller or more vegetated colonies and up to 250 m at large, open colonies.

## **Chapter 4 - Assessing Bias and Variation in Survey Methods and the Window Census**

### **Protocol for Least Terns**

**ABSTRACT** Common methods to estimate the number of nests and the size of the breeding population at least tern colonies include direct colony walk-through counts of nests ('ground nest counts') and indirect counts of incubating adults performed from the colony perimeter ('incubating adult counts'). The accuracy, bias, and variance of different methods, and the comparability of data from repeated surveys versus once-annual window censuses, are poorly understood. Our objectives were to 1) assess the accuracy, potential bias, and variation of the more rapid incubating adult counts as compared to the time-intensive ground nest counts, and 2) assess the accuracy of a once-annual window census in capturing peak nesting abundance. We studied 9 least tern colonies at Cape Lookout National Seashore (CALO), North Carolina from April-August 2010 - 2012. In 2010, we conducted concurrent ground nest counts and incubating adult counts every 4-5 days in a 0.30 - 0.75 ha section of each colony from initiation (28-April) until all nests hatched or failed (13-17 July); in 2011, we conducted twice-weekly incubating adult counts at all colonies; and in 2012, we conducted 3 weekly incubating adult counts only during the regional census window. We deployed time-lapse cameras at a random sample of 156 nests to assess if the proportion of time spent incubating varied by colony, time of day, or time of season. We explored inter-observer variability in incubating adult counts, differences in estimates between incubating adult counts and ground nest counts, and variation between the numbers of nests recorded during the window census period and the observed nesting peak. We analyzed observer and survey agreement with concordance correlation coefficients and the proportion of time spent incubating with generalized linear mixed models. Concordance correlation coefficients for all comparisons were  $> 97\%$ , indicating substantial agreement

between observers, survey methods, and time of day or season that surveys took place. On average, least terns incubated for 94% of the time, irrespective of colony, nesting stage, month, or time of day. While the CALO nesting peak occurred within the annual least tern window census period in 2010 to 2012, abundance estimates varied by as much as 39% within the window. We recommend conducting incubating adult counts to estimate nest and breeding population abundance of least terns when vegetation or dunes do not obstruct colony viewing area from the perimeter. As estimates from incubating adult counts and ground nest counts were highly correlated, and ground nest counts took > 90% more time and were more disruptive to nesting birds, incubating adult counts are a useful tool for managers to track seasonal nest abundance. Incubating adult counts should be performed at least twice during the window census period, with the maximum count being reported as peak nest abundance at a given site.

**KEY WORDS** ground nest counts, incubating adult counts, least tern, North Carolina, *Sternula antillarum*, survey methods, window census.

Wildlife managers use a variety of survey methods to estimate nest numbers and breeding population abundance of the least tern (*Sternula antillarum*), a migratory ground-nesting colonial waterbird that is federally endangered (California subspecies, *S. a. browni*, and Interior subspecies, *S. a. athalassos*,) and state-listed (Eastern subspecies, *S. a. antillarum*) throughout its North American breeding range. Common survey methods include colony walk-through counts of active nests (ground nest counts), colony perimeter scans of incubating adults (incubating adult counts), total counts of adults at a site, and flock estimates of flushed birds. While some management agencies perform one or more of these methods several times throughout a nesting season, others do so only once every 1-3 years (U.S. Fish and Wildlife Service 2012). Moreover,



survey methods are inconsistent within and among management agencies, colonies, and years due to variation in colony locations, accessibility, spatial extent, nest density, vegetation, topography, and available personnel resources, each of which determines survey type and frequency. As a result, managers are uncertain whether to trust and/or extrapolate least tern nest counts on local and regional levels due to a lack of information regarding bias and variance within and between survey methods conducted at different times throughout the breeding season (Savereno 1992; Leucke 2010).

Of the four survey methods listed above, incubating adult counts and ground nest counts are most often used to estimate least tern nest and breeding population abundances (Marschalek 2010; U.S. Fish and Wildlife Service [USFWS] 2012; K. O'Brien, USFWS, pers. comm.). While assumptions are frequently made about the validity of incubating adult and ground nest counts, these assumptions are rarely challenged despite our recognition that multiple types of error may be associated with each method and with bird population estimates in general. First, nest and/or population estimates may be inaccurate if the estimate differs from the true value. Second, nest and/or population estimates may be biased when inaccurate estimates systematically miss the truth in a given direction. Lastly, population estimates may have high variance, or lack of precision over repeated samples (Thompson 2002).

Assuming that active nests (i.e., nests with  $\geq 1$  egg) are detectable, ground nest counts of least terns are potentially more accurate, and less biased, than incubating adult counts, at estimating nest abundance and breeding population size. Because the presence of a visible incubating adult at the nest is not required for ground nest counts, these surveys are not as likely to be influenced by topography, time of season, time of day, nesting stage, weather, colony disturbance, or behaviors of non-breeding birds within the colony. However, these factors may

influence the accuracy of an incubating adult count (Erwin 1979; Lott 2006). For example, if fewer adults incubate eggs during the cooler morning and evening hours—at which time tending to chicks and eggs is not as critical as doing so during mid-afternoon sun and heat (Grant 1982; Mayer et al. 2009)—then an incubating adult count performed during these times would underestimate nest numbers and breeding population size.

Variance, the third type of error, can be assessed and accounted for in all survey methods by comparing multiple counts conducted at the same area within a short time period using the same method or by comparing simultaneous counts by multiple observers.

While ground nest counts are the most exhaustive method and are generally perceived as the most accurate, least biased, and most precise as described above, they are also time-intensive and require prolonged periods of colony disturbance (Steinkamp 2003). Incubating adult counts, while relatively quick and disturbance-free to nesting birds, are regarded as less accurate and precise than ground nest counts, particularly with respect to least terns and other species with complex colony dynamics (Savereno 1992; Leucke 2010).

While estimating nest abundance and breeding season population size within a colony is difficult at any given point in space and time due to the potential bias and variance in survey methods, additional complexities are introduced when the goal is to estimate abundance at a spatial scale larger than a single colony. Managers must account for confounding behaviors, such as asynchronous nest initiation, multiple nesting waves due to failed early nesters and later migrants to the study site, the presence of non-breeders within a colony, and inter-regional, within-season movements by adults (Massey and Atwood 1981; Steinkamp et al. 2003; Gregory et al. 2004). Lott (2006) recommended that counts of least terns take place when the maximum numbers of adults are incubating eggs, as breeding populations are most stable, inter-colony

movements by adults are minimal, and individuals counted should consist of breeding birds and not migrants. Unfortunately, it is impossible to know until after the nesting season is complete when these criteria will be met.

In an attempt to meet some of these recommendations and to survey least terns in a coordinated manner, managers from throughout the U.S. least tern breeding range conduct annual window censuses within a discrete time period to 1) provide an index of the breeding population size for long-term population trend analyses, 2) document the distribution of nesting areas, and 3) describe the types of habitats used for nesting (Lott 2006; U.S. Fish and Wildlife Service 2012). The following are untested assumptions with respect to the ground nest count and incubating adult count surveys used in these window censuses: 1) equal detection probabilities among different observers, habitats, and breeding stages, 2) a one-to-one nest-to-incubating adult ratio, 3) a two-to-one breeding pair-to-incubating adult ratio, 4) “closed” colonies (i.e., no immigration or emigration of adults during the survey period), 5) numerical agreement between different survey methods, and 6) the predetermined window census period, on average, accurately reflects peak nest abundance for each region, recognizing that peak nest abundance does not equal total nest abundance but rather is an index to breeding population size. On the U.S. Atlantic coast, where our study was conducted, window censuses were performed any time between 5-20 June from Delaware to North Carolina and between 5-30 June from New Jersey to Maine prior to 2012; the current window was shifted 5 d earlier in the southern region to better reflect estimated regional nesting peaks (U.S. Fish and Wildlife Service 2012). The goal of confining surveys to a two-week window is to reduce some count error associated with regional movements of breeding birds within a nesting season, and the variable start dates accommodate for differential peak nesting dates between northern and southern regions.

Our overarching objective was to compare common techniques for, and the timing of, least tern surveys of nest and breeding population abundances to provide guidance for managers charged with assessing this species' breeding population trends within and across sites and years. First, we recognized that if the sources of bias and variance in incubating adult counts, as compared to ground nest counts, could be understood and minimized, then managers would likely use the more rapid incubating adult counts for breeding season population estimates of least terns. Therefore, we studied 1) the agreement between incubating adult counts conducted by multiple observers to assess variance, 2) the effects of time of day and season on incubation behavior to test whether these variables introduce bias or variation in incubating adult counts, and 3) the agreement between rapid incubating adult counts and time-intensive ground nest counts using a double sampling approach to assess bias (Bart and Earnst 2002; Thompson 2002). Second, we evaluated the accuracy of the June window census period at Cape Lookout National Seashore (CALO), North Carolina by assessing whether the predetermined time interval captured peak nesting abundance of least terns over 3 breeding seasons from May-July 2010-2012.

## STUDY AREA

We conducted our study at CALO (34° 52' 54.37" N, 76° 16' 46.92" W) from May-August 2010-2012 (Fig. 1). CALO is located between Ocracoke and Atlantic Beach, NC, USA and is part of the barrier island ecosystem that extends along much of the Atlantic seaboard from Massachusetts to Florida. CALO consists of 12,000 ha of land and water and is managed by the National Park Service (NPS). The islands routinely change in shape and number due to wind, waves, and currents. During our study, CALO consisted of 3 - 4 islands: Shackleford Banks, South Core Banks, Middle Core Banks, and North Core Banks, collectively spanning 90 km of ocean shoreline and averaging about 800 m in width (Cape Lookout National Seashore 2008).

Habitat included sandy beaches, vegetated dunes, shrub thickets, salt marshes, and maritime forest. We conducted our study on the 37-km long North Core Banks and/or Middle Core Banks, depending on the year and location of the inlets.

## METHODS

### **Field Methods**

We delineated potential least tern colony boundaries based on prior years' nesting sites using information provided by the NPS. We marked boundaries with wooden stakes and flagging placed on existing NPS signage before eggs were laid in late April 2010 - 2012. We demarcated colonies every 150-250 m into North-South rectangular blocks that varied in width depending on how topography affected the visibility of incubating birds from the perimeter (Fig. 2). We selected one survey block per colony in which to conduct ground nest counts concurrently with incubating adult counts for our first set of objectives. We conducted incubating adult counts in each block to achieve colony-wide nest estimates for our second objective. Effective survey area of blocks ranged from approximately 0.30 ha at the smaller, vegetated colonies to 0.75 ha at the largest, most open colony.

We conducted incubating adult counts and ground nest counts concurrently at three colonies, one block per colony, twice-weekly in 2010. We began the first incubating adult count at sunrise. Two observers scanned independently at the same time and location and counted the number of apparently-incubating adults within a predefined area delineated by boundary markers that were visible through 20-60 x 80 mm spotting scopes (Bushnell Corporation, Overland Park, KS). We repeated incubating adult counts 2-5 hr later following a ground nest count within the same block. Where necessary, we used mobile 2-m high viewing platforms to perform incubating adult counts at expansive colonies and those where topography or vegetation

obscured viewing distant nests. We recorded the number of incubating adults, courting pairs, chicks, and fledglings by species. We examined the behavior of each apparently-incubating adult to assess whether it was incubating or shading eggs, brooding chicks, or resting/not incubating eggs (Appendix D). We repeated surveys as needed when birds within the survey block flushed.

High nest densities within most survey blocks prevented mapping each nest by hand while performing incubating adult counts; thus we were not able to compare individual nests missed by one observer with those recorded by both observers to evaluate observer-specific detection probabilities (Green et al. 2008). We report unadjusted estimates of nest numbers derived from each method, with the assumptions that ground nest counts best reflected true nest abundance and that measurement error from repeated surveys was independent.

We typically conducted ground nest counts with two observers, but used up to five observers where nest abundance and density of the focal block was high ( $\geq 200$  total nests or about 1 nest  $5/m^2$ ). We walked slowly, 5-10 m apart (e.g., 5 m at vegetated colonies and those with shell substrate, which increased egg crypsis and the difficulty in locating nests, and up to 10 m when focal blocks were flat, open and sandy) and scanned on either side of the transects. We marked nests with global positioning systems (Oregon 450, Garmin International Inc., Olathe, KS) and tongue depressors to prevent double-counting and repeated transects in this manner until we reached the end of the survey block.

We deployed infrared cameras (Reconyx PC90, Reconyx, Inc., Holmen, WI) set to 5 s time lapse for 24 hr/day at least tern nests to determine temporal patterns in incubation behavior. We used a stratified random sampling design such that each block contained 1 randomly-placed camera-monitored nest. We encased cameras in camouflaged wood housing and placed them 2

m from active nests. We connected each camera to 1 external 12-volt sealed lead acid battery (TD 22-12, Tempest Batteries, San Jose, CA). We buried the battery and cables in the sand and revisited camera-monitored nests twice-weekly to check nests and swap memory cards and batteries.

We recorded the number of frames in which the focal bird was not actively incubating eggs for four 5-min, 60-frame samples per day. We selected one sample at random in each of four time periods: 0000-0200, 0600-0800, 1200-1400, and 1800-2000. We defined ‘incubate’ as any bird that was directly above eggs in a given camera frame, whether sitting on top of a nest or indirectly shading it (Appendix D, Figure D1). We defined the response variable as the proportion of time a bird was incubating.

We chose a random start date constrained within the first week of nesting (i.e., the first week of May) with which to begin behavioral sampling of incubating least terns, and we sampled nests systematically every 8 days thereafter. We sampled camera-monitored nests from all colonies throughout North Core Banks and grouped sampling dates into 5 periods: 04 and 12 May, 20 and 28 May, 05 and 13 June, 21 and 29 June, and 07 and 15 July.

To evaluate the accuracy of the least tern window census at North Core Banks, and to estimate seasonal nest abundance and island-wide nesting peaks, we conducted twice-monthly incubating adult counts in all blocks throughout each colony in 2010 and twice-weekly incubating adult counts, again in all blocks throughout each colony, in 2011, from May-July. In 2012, we conducted only 3 island-wide incubating adult counts: one each at the beginning, middle, and end of the newly-revised 1-15 June census window.

## **Analyses**

We used concordance correlation coefficients ( $\rho_c$ , Lin 1989, 2002) to measure the level of agreement, and paired  $t$ -tests to compare means, between 1) incubating adult counts and

ground nest counts conducted within the same survey block, 2) incubating adult counts performed by two independent observers, and 3) mean incubating adult counts in the morning versus afternoon. Unlike the Pearson correlation coefficient, which measures the precision of a linear relationship, the concordance correlation coefficient includes components of both precision and accuracy (Barnhart et al. 2002; Lin 2002). We used repeated measures logistic regression (Proc GLIMMIX, SAS Institute, Cary, NC) to analyze the proportion of time that least terns incubated by time of day and season, and included unique nest identifiers as a random effect (i.e., the repeated term). We used the logit link function and a binary response distribution where '1' indicated that a bird incubated for all 60 frames sampled over a 5-min period and '0' indicated that a bird incubated for < 60 frames in a 5-min period. We used this sampling scheme because it was congruent with other objectives and it adequately captured even short bouts (1 camera frame) away from the nest.

## RESULTS

### **Assessing survey bias and variation**

We studied least terns which nested in 4 monospecific colonies and 2 mixed-species colonies with Black Skimmers (*Rynchops niger*), Common Terns (*Sterna hirundo*), and Gull-billed Terns (*Gelochelidon nilotica*) in 2010; in 4 monospecific colonies and 3 mixed-species colonies in 2011; and in 7 monospecific colonies and 2 mixed-species colonies in 2012 (Fig. 1). Colony habitat consisted of expansive sand flats (created either by overwash or by the natural closing of inlets), inter-dune shell beds, and small island sandbars. Total colony area ranged from approximately 0.30 ha to 85 ha. Observer-averaged peak incubating adult counts per colony ranged from 2-481 in 2010; 5-306 in 2011; and 4-341 in 2012.



We conducted ground nest counts concurrently with incubating adult counts at 3 colonies in 2010 (New Drum Inlet, Old Drum Inlet, and Portsmouth Flats South, Fig. 1); > 90% of all known nests in 2010 on North Core Banks occurred at these three colonies. The remaining 3 colonies in 2010 either had too few nests to adequately compare methods (North Tip and Portsmouth Flats North,  $n = 2$  nests for each) or were too vegetated and topographically diverse to perform accurate perimeter scans from elevated or non-elevated positions (Dune Shell Beds,  $n = 26$  nests, Fig. 1).

We conducted sequential incubating adult counts and ground nest counts on 32 days from 11 May - 14 July 2010. We used natural log transformations on the count data to meet assumptions of normality. We removed three outliers due to inclement weather that reduced visibility and resulted in lower than expected incubating adult counts. We removed two sampling occasions in early July, when [presumably migrating] birds in non-breeding plumage inundated focal blocks and caused repeated flushing behaviors of nesting and non-nesting birds.

We found no differences in incubating adult counts between observers ( $\rho c = 0.98$ ,  $p = 0.74$  for morning counts;  $\rho c = 0.97$ ,  $p = 0.98$  for afternoon counts, Table 1) nor between observer-averaged incubating adults counts in the morning versus afternoon ( $\rho c = 0.97$ ,  $p = 0.73$ , Table 1).

We sampled 74 camera-monitored nests in 2010 and 82 nests in 2011 and extracted 760 5-min behavioral samples from these nests. Least terns incubated in all 60 frames for 77% of all samples. For samples where least terns were not incubating in  $\geq 1$  camera frame ( $n = 177$ ), the average proportion of time spent incubating was 0.66. Birds were entirely absent from a nest in only 25 out of 760 samples; only 6 (i.e., < 1%) of which occurred outside of the 0000-0200

(nocturnal) sampling interval, when incubating adult counts would not be possible without night vision scopes.

There was an effect of time of day ( $F_{3,586} = 3.08, p = 0.03$ ) on the proportion of time spent incubating by least terns, but no effect of time of season ( $F_{4,586} = 1.78, p = 0.13$ ) nor of the interaction term of season by time of day ( $F_{12,586} = 1.76, p = 0.05$ , ratio of the generalized chi-square to degrees of freedom = 0.97). Least terns incubated less during the 0000-0200 nocturnal interval as compared to all other intervals ( $p < 0.05$  between 0000-0200 and each diurnal interval, Fig. 3). The mean proportion of time spent incubating across survey weeks was 0.94 (SE = 0.01) for the 3 diurnal sampling intervals and 0.88 (SE = 0.02) for the 0000-0200 sampling interval. We did not include temperature as a model term because it was highly correlated with time of day and time of season, and our management recommendations are based on these temporal variables as they provide easier guidelines when selecting an appropriate survey time.

We averaged the morning incubating adult counts between observers and compared these estimates with ground nest counts conducted on the same day. We found a high level of agreement and no difference between mean incubating adult counts and ground nest counts ( $\rho c = 0.98, p = 0.59$ , Table 1). The averaged morning incubating adult counts ( $n = 29$ ) 1) were greater than ground nest counts 31% of the time by an average (SE) of 1.7 (0.54) nests, 2) precisely agreed with ground nest counts 17% of the time, and 3) underestimated ground nest counts 52% of the time by an average (SE) of 8.1 (3.3) nests.

Ground nest counts in Old Drum Inlet, the densest-nesting colony at the 2010 nesting peak, averaged 141 min and ranged from 54-270 min for two observers to cover a 3.5 ha block. By comparison, incubating adult counts at the same block averaged 10 min and ranged from 5-23 min for two observers scanning simultaneously.

## Window census evaluation

There were two least tern nesting peaks in 2010 and 2011: the first, in mid-late May of both years, was characterized by relatively few nests spread throughout more colonies, while the second, in mid-June of both years, was characterized by a net increase in nests with nesting localized at one colony (Fig. 4a,b). While most failed early-nesters from the 2 largest colonies in 2010 re-nested at an existing colony (Old Drum Inlet), failed early-nesters in 2011 nested at a newly established colony (Blowfish Island, confirmed by band-resight data, Hillman et al. *in prep.*), a 1.3 ha sandbar separated from North Core Banks by a 50 m channel. In 2010 and 2011, Old Drum Inlet and Blowfish Island colonies, respectively, contained > 70% of all nests on North Core Banks during the mid-June peak.

In all 3 years, peak nest abundance was captured within the regional window census period at North Core Banks (Fig. 4c).

## DISCUSSION

Observers were well-trained at distinguishing least tern incubating behaviors and postures, thus incubating adult counts were an acceptable method for estimating least tern nest abundance at CALO when topographical features within a colony did not significantly limit viewing area from the perimeter. While 1–4 m-high dunes at one colony (Dune Shell Beds) limited the utility of incubating adult counts, and a 20 m<sup>2</sup> vegetated section within the survey block at another colony (Old Drum Inlet) likely caused us to miss some incubating adults at the nesting peak, ground nest counts and incubating adult counts were still highly correlated, irrespective of time of day, time of season, or observer.

Our findings contrast with other studies that reported significantly lower detectability from rapid survey methods compared to more intensive methods (Savereno 1992; Bart and

Earnst 2002; Green et al. 2008; Luecke Flaherty 2010). For example, Savereno (1992) and Luecke Flaherty (2010) each reported that incubating adult counts systematically underestimated least tern nest abundance. Differences between abundance estimates by these methods, when they did occur, were small and not in a predictable direction. We suspect that our results differed from the above-mentioned studies because 1) the CALO colonies that we studied were generally more open and less vegetated, particularly in comparison to those studied by Luecke Flaherty (2010) in Massachusetts, affording us a better opportunity to view incubating adults from the perimeter, 2) our use of a 2 m-high mobile viewing platform allowed us to scan effectively over vegetation, small dune systems, and over long distances, 3) we conducted incubating adult counts only at one manageable section at a time in each colony as opposed to the entire colony from a single vantage point, and we moved systematically between sections within a colony when whole-colony counts were needed, and 4) we used spotting scopes capable of 60x magnification to differentiate incubating adults from resting or non-breeding birds within the colony (Appendix D), whereas previous studies used binoculars and/or lower-magnification spotting scopes. Given that our incubating adult counts and ground nest counts were highly correlated, with no consistent or significant differences between estimates, we did not apply a correction factor to the more rapid incubating adult counts based on the more intensive ground nest counts, as recommended in other studies (Bart and Earnst 2002; Luecke Flaherty 2010).

We hypothesize that incubating adult counts and ground nest counts were congruent because least terns were almost always incubating eggs during the daylight hours; thus there was typically a bird at the nest to be detected during a colony perimeter scan. We found no effect of time of day or date in the proportion of time spent incubating, further suggesting that diurnal incubating adult counts should provide similar results to ground nest counts, in that an active nest

was highly likely to have an incubating adult present to be detected. We do not think that it is necessary to correct for the approximately 6% of the time that birds were not incubating, because the data were sampled from camera snapshots, some of which likely consisted of birds that left the field of view for brief periods (e.g., just longer than the 5 s interval between frames). Because we often observed each individual bird's behavior for > 5 s during incubating adult counts, particularly for non-incubating birds within the colony, we were more likely to count birds as incubating if they were absent from the nest for a brief period than we would if we solely used the camera data.

Least terns incubated nests less from 0000-0200 compared to the diurnal sampling intervals. Previous studies have similarly reported that both least terns and common terns (*Sterna hirundo*) may leave nests unattended for varying lengths of time at night (Marshall 1942; Nisbet and Welton 1984; Shealer and Kress 1991; Wendeln and Becker 1999; Perkins 2004; Norwood 2011). We hypothesize that this pattern may be due to increased nocturnal predator activity at CALO. Absences may either be a direct behavioral response to an observed predator within the colony, as hypothesized by Perkins (2004) for least terns in Maine, or an evolutionary strategy to reduce the likelihood of detection by nocturnal predators such as raccoons (*Procyon lotor*): the leading cause of nest failure during our study (Hillman et al. *in prep*, see Ch. 3). If we assume that an incubating least tern is easier to detect than a nest without an incubating bird, and if environmental conditions are appropriate (e.g., ambient temperature is near internal body temperature and there is relatively little wind), then there may be a fitness benefit to leaving nests unattended, particularly as avian embryos can tolerate reduced temperatures related to absence of the incubating adult (Webb 1987). Anecdotally, we did observe a high number of

loafing adults exterior to colonies at night; although it was not clear whether these were breeding or non-breeding birds.

While the least tern nesting peak at North Core Banks occurred within the established census window in all three years of our study, there was considerable variation in nest abundance within this 15 day window. For example, if a once-annual window census was conducted around the 5 or 20 June extremes of the census window in 2011, then actual peak nest abundance would have been underestimated by 39% for a 5-7 June survey and by 22% for an 18-20 June survey. Therefore, we recommend conducting  $> 1$  survey of all colonies at a site within the census window, each spanning as few days as possible, and reporting the largest count as the peak seasonal nesting estimate. Ideally, managers would conduct up to 3 weekly surveys during the census window to better assess inter-regional and inter-annual abundance trends, with additional twice-monthly surveys outside of the window to estimate and refine seasonal trends in peak nesting abundance by colony and by region.

Given the personnel resources required to conduct multiple surveys as opposed to 1 annual survey, and the strong relationship between the survey methods we studied, agencies that currently conduct 1 ground nest count within a breeding season might consider switching to multiple incubating adult counts when topographical features permit. In addition to providing more accurate estimates of peak nesting abundance, more frequent surveys would allow managers to refine regional estimates of tern nesting phenology to address the accuracy of the current window census periods of 1-15 June from Delaware south and 5-30 June from New Jersey north on the U.S. Atlantic Coast. At CALO, the first least tern eggs typically are laid in late April to early May, and the first eggs hatch around the 3<sup>rd</sup> week of May (assuming a 21-day average incubation period, Thompson et al. 1997). In the absence of extensive re-nesting due to

failed first nests, peak nesting at CALO would theoretically occur just after the earliest few eggs hatch, from about late May to early June—as opposed to the observed mid-June peaks in 2010 and 2011—because newly-arrived birds continue to nest for the 3-week period when chicks are not yet present. As eggs hatch, those nests become unavailable to count after about 1 – 3 days, at which time broods leave the nest site.

A late May or early June nesting peak may have occurred in 2010, earlier than the window census period. In this year, we conducted twice-monthly incubating adult counts around the 1<sup>st</sup> and 15<sup>th</sup> of each month, and a flood destroyed > 90% of all known nests on 25 May, 5 days prior to the planned 30 May survey. As we estimated nearly 400 nests during the 15-16 May island-wide count, and nesting was anecdotally observed to increase substantially between this and the 25 May flood, it is likely that nest abundance approached or even surpassed the observed mid-June peak of 540 nests if a 30 May survey was conducted without a prior flood. Although not as pronounced, this pattern was also true in 2011. By contrast, in 2012, when there were no major floods and thus less re-nesting, the peak count date was earlier (7-8 June). Observations are needed across a greater time and spatial extent to more fully understand expected versus actual peak nesting dates and the probability of capturing these peaks in the set window census period per region. Future studies should also assess within-season turnover rates of breeding birds to understand the agreement between peak nesting estimates and total population counts.

## MANAGEMENT IMPLICATIONS

We recommend performing incubating adult counts to assess trends in population abundance at all colonies where this method is feasible. Where vegetation, dunes, and/or an expansive nesting area prevents viewing the entire colony from one vantage point, we recommend delineating

manageable sections of the colony with natural and/or observer-placed survey markers and summing counts from each section, using elevated platforms if appropriate. Some colonies may require a combination of methods if scanning is not practicable at certain portions but may be at others. For highly vegetated colonies or those with varied topography throughout the nesting area, ground nest counts may remain the only realistic means by which to estimate breeding effort. Given that nest attendance was high in the morning, afternoon, and evening, managers can elect to conduct incubating adult counts based on logistics, weather conditions, or other factors, as opposed to a predetermined time of day or season.

A minimum of 2 nest abundance surveys should be conducted during the regional 2 wk window census period for least terns, with the highest count reported as the nesting peak. However, if only one survey is possible due to personnel constraints and/or colony accessibility, it should be performed earlier in the window if widespread nest loss (e.g., large-scale flooding) is not observed in mid May or early June and later in the window if it is. Future studies should also assess methods to combine estimates of nest abundance with productivity and survival data. Least terns are a long-lived species (record longevity is 24 years, Klimkiewicz and Futcher 1989), thus current abundance estimates of nesting adults alone should not be used to understand population dynamics.

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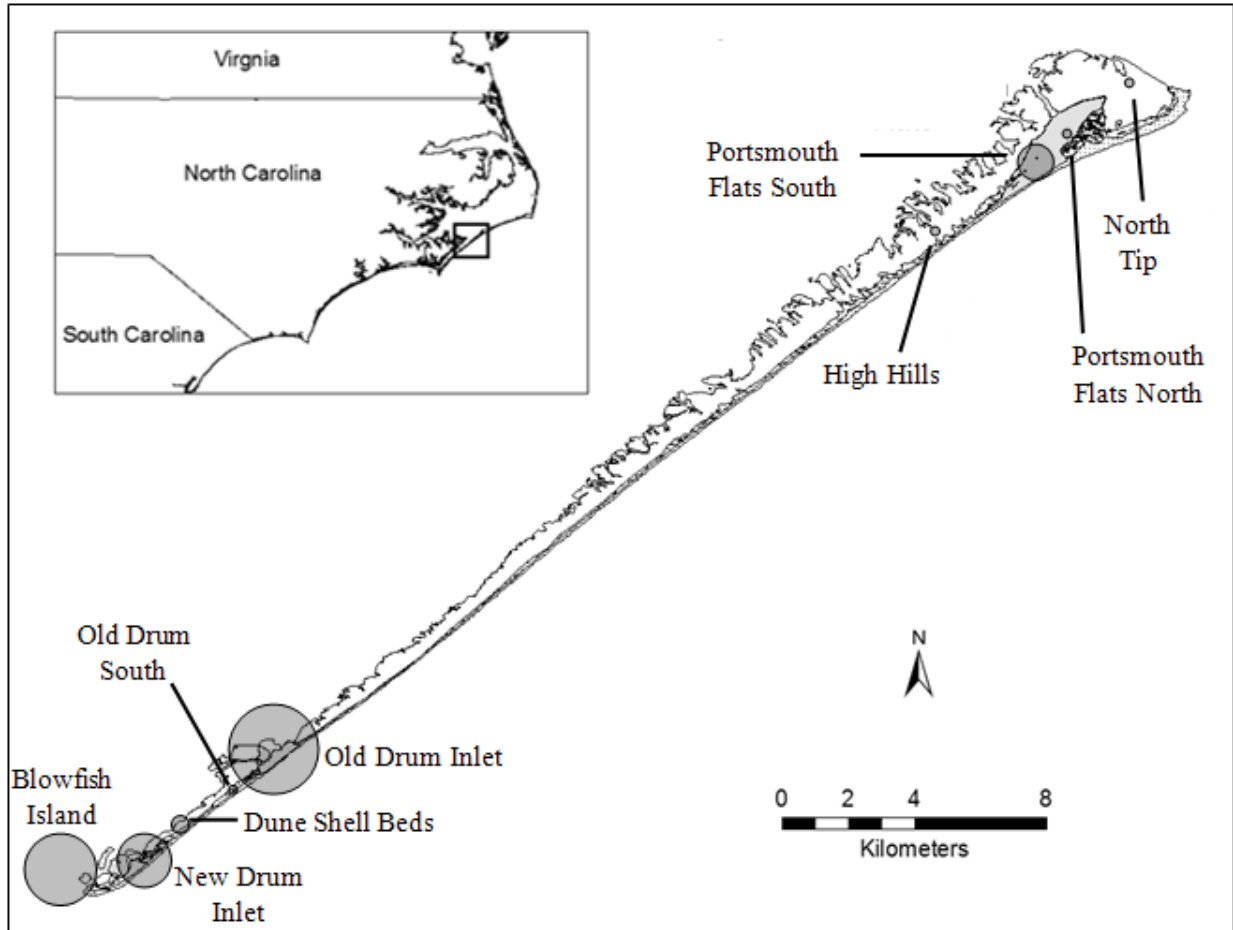
TABLES AND FIGURES

**Table 1.** Sample size, covariance, concordance correlation coefficients, and 95% confidence intervals of: 1) inter-observer variability by time of day for least tern incubating adult counts, and 2) sequential ground nest counts and. morning and afternoon incubating adult counts at North Core Banks, Cape Lookout National Seashore, North Carolina, 2010.

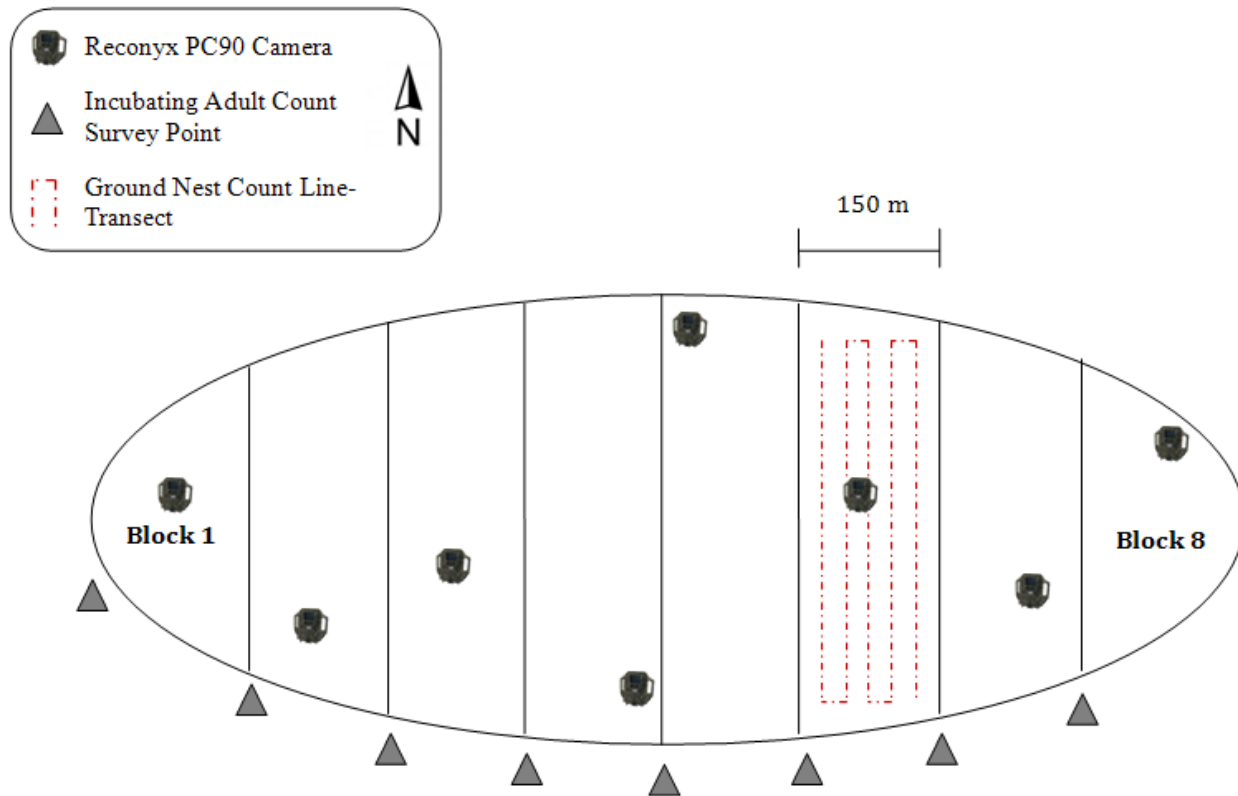
<b>Counts Compared</b>	<i>n</i>	<i>cov</i>	$\rho_c$	<b>Lower 95%</b>	<b>Upper 95%</b>
Observer 1 vs observer 2 morning IAC <sup>1</sup>	29	1.78	0.98	0.95	0.99
Observer 1 vs observer 2 afternoon IAC	27	1.84	0.97	0.94	0.99
Observer-averaged morning vs afternoon IAC	27	1.72	0.97	0.93	0.99
GNC <sup>2</sup> vs. observer-averaged morning IAC	29	2.00	0.98	0.95	0.99
GNC vs observer-averaged afternoon IAC	27	1.92	0.97	0.94	0.99

<sup>1</sup> Incubating Adult Count: Perimeter scan of the colony to estimate the number of incubating adults

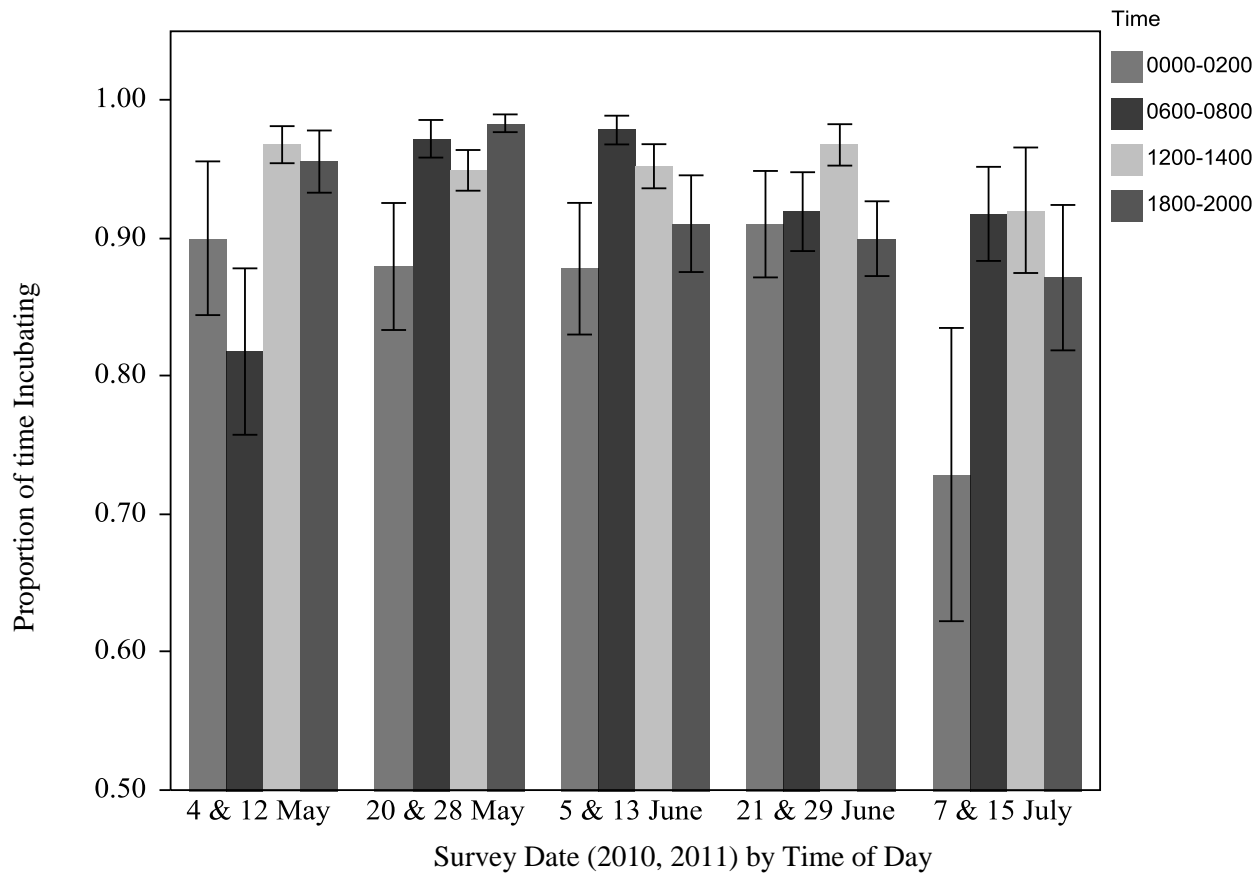
<sup>2</sup> Ground Nest Count: Direct count of nests via a colony walk-through



**Figure 1.** We estimated least tern nest abundance at 9 colonies on North Core Banks, Cape Lookout National Seashore (CALO), North Carolina in 2010-2012. Waterbird colonies are denoted as follows: Smallest circle - < 10 nests at peak colony incubating adult count; largest circle - > 350 nests at peak colony incubating adult count. Mixed-species colonies occurred only at Blowfish Island, New Drum Inlet, and Old Drum Inlet.

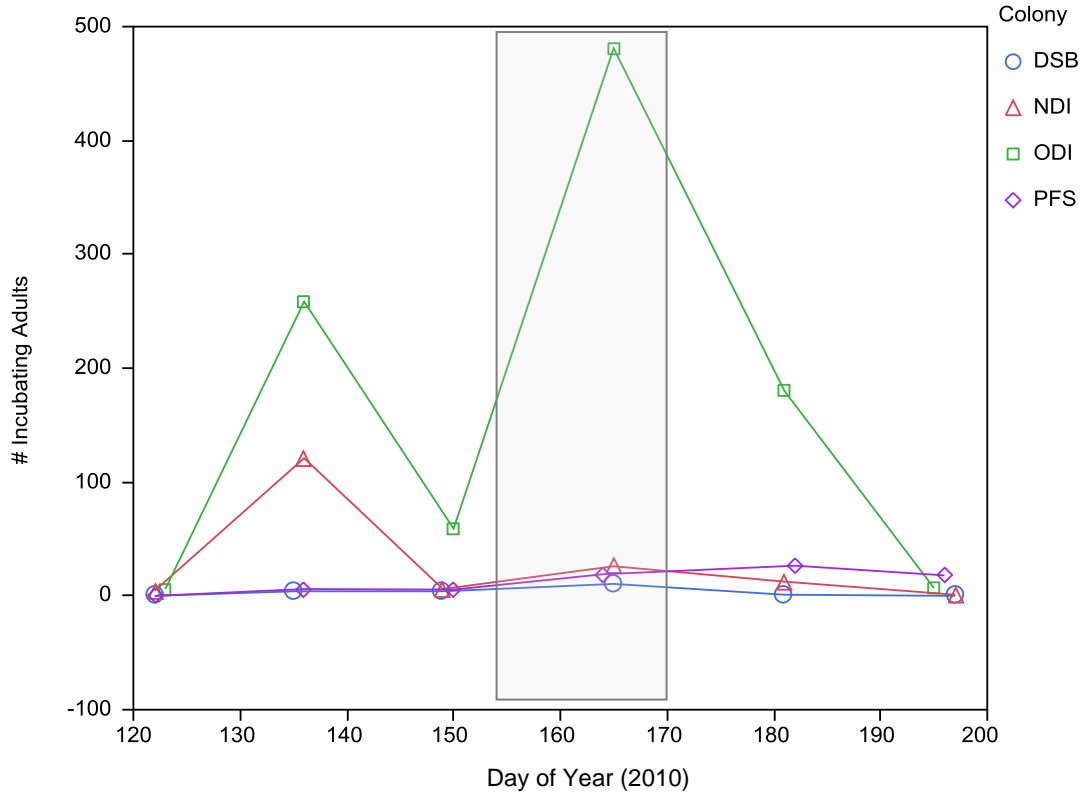


**Figure 2.** Schematic of a waterbird colony at Cape Lookout National Seashore, North Carolina. We deployed remote cameras at individual nests selected randomly within each block to quantify incubation behavior from April-August, 2010-2011. We summed incubating adult counts from each block to estimate nest abundance over the course of the season, and validated the accuracy of incubating adult counts by conducting intensive ground-nest counts at one block for direct comparisons between methods. Block width was 150 m at smaller or more vegetated colonies and up to 250 m at large, open colonies.

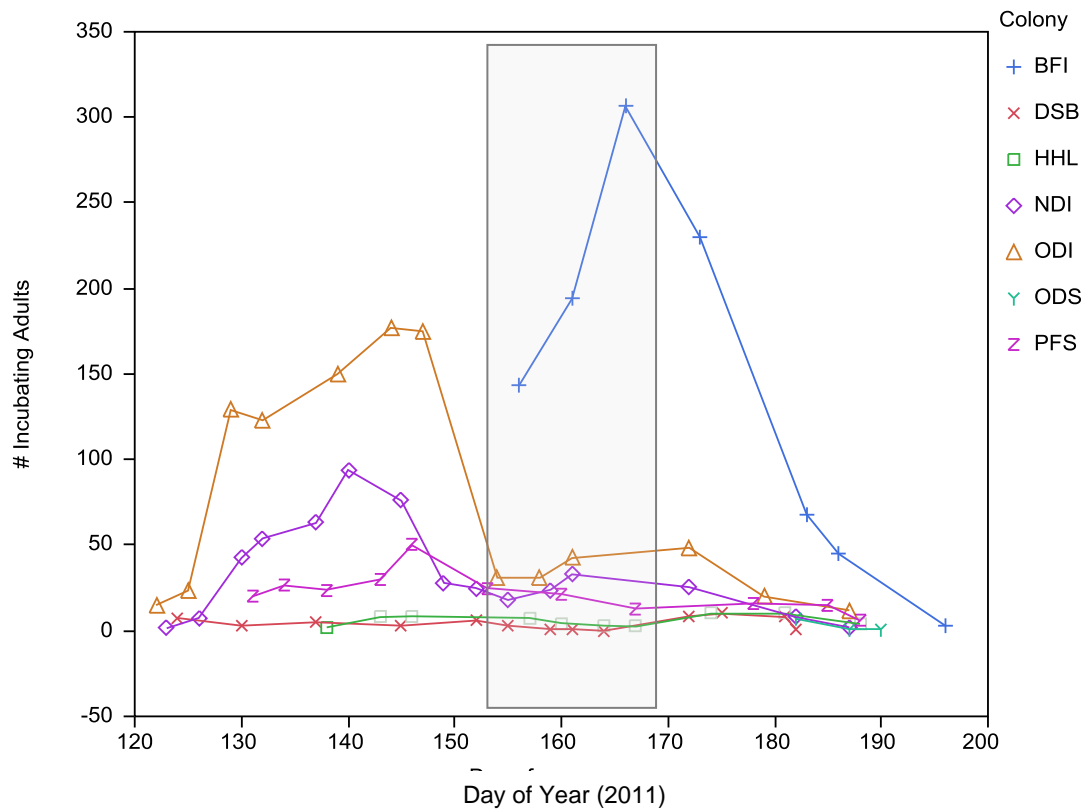


**Figure 3.** The mean proportion of time spent incubating by least terns, with standard error bars, by sampling period and time of day from a random sample of 156 camera-monitored nests from May - July, 2010-2011, North Core Banks, North Carolina.

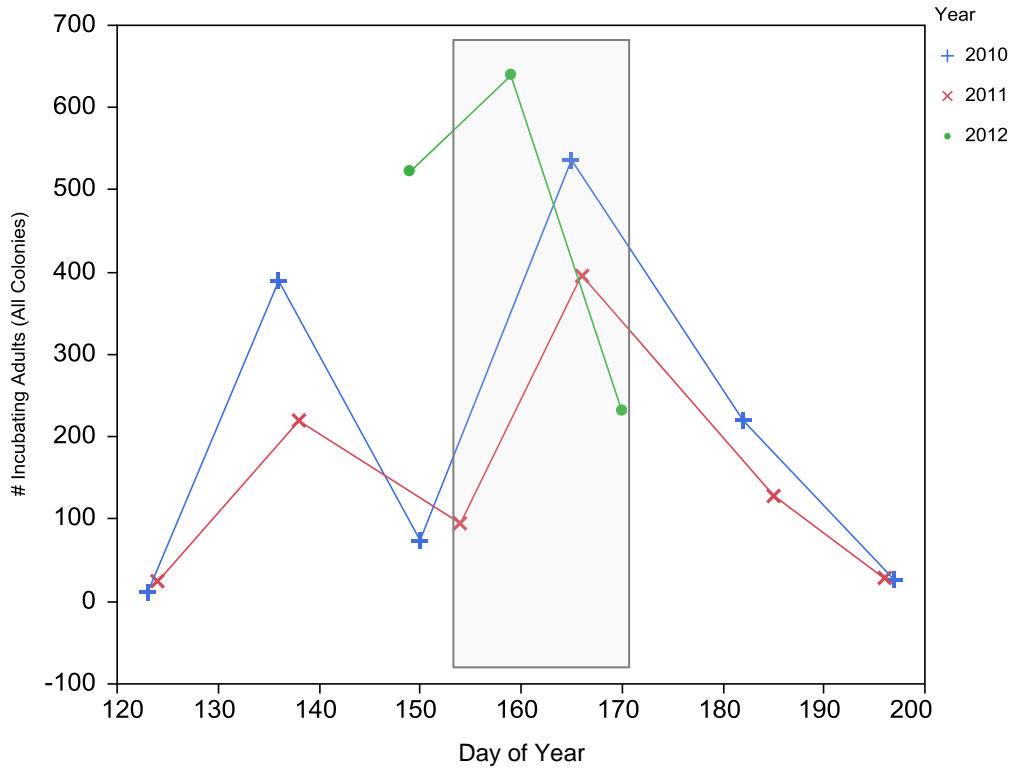




**a)**



**b)**



c)

**Figure 4.** Least tern incubating adult counts, North Core Banks, Cape Lookout National Seashore, North Carolina: a) 2010 bi-weekly counts by colony, b) 2011 twice-weekly counts by colony, and c) 2010 -2012 island-wide bi-weekly counts for all colonies combined. Shaded rectangles denote the 5-20 June annual window census period. Colony codes: BFI – Blowfish Island, DSB – Dune Shell Beds, NDI – New Drum Inlet, HHL – High Hills, ODI – Old Drum Inlet, ODS – Old Drum South, PFS – Portsmouth Flats South.

## **Chapter 5 – Conclusion: Recommendations for Management and Future Studies of Colonial Waterbirds at Cape Lookout National Seashore**

In this final chapter, I summarize key management recommendations and suggest future research needs resulting from each objective of my study.

*Objective 1:* To determine if military overflights through the Core MOA changed the behavior of nesting colonial waterbirds, and to place any responses associated with military overflights in the context of other natural and human disturbances common to CALO.

U.S. Marine Corps (USMC) overflights, in the patterns observed during the 2010 and 2011 nesting seasons, did not affect the behavior or demographics of colonial waterbirds at Cape Lookout National Seashore (CALO). While military overflights at tactical speeds near the 900 m Core MOA floor were louder than any other type of overflight, there was no evidence that nesting birds altered incubation behavior as a result of these novel stimuli. I hypothesize that nesting colonial waterbirds at CALO did not perceive low-altitude tactical speed overflights differently than the higher-altitude tactical speed overflights to which they had been regularly exposed before my study. Colonial waterbirds either 1) habituated to the types of overflights observed in this study quickly such that I was not able to detect changes in behavior or 2) never perceived overflights as threatening, even when as novel stimuli. Given these findings, future changes in Core MOA operational patterns, e.g. an increase in the frequency of tactical-speed flights near the Core MOA floor, would be unlikely to generate adverse impacts to nesting colonial waterbirds. However, if substantial changes in received sound levels or visual signals occurred, including a further reduction in tactical-speed aircraft altitude, the introduction of a novel type of aircraft to the Core MOA, or a change in training patterns to include supersonic overflights or close-proximity live-fire exercises, then additional studies should be considered.

Evidence that military and civilian fixed and rotary-wing overflights did not impact colonial waterbird demographic rates at CALO was two-fold: 1) overflights did not affect incubation behavior and therefore did not increase exposure of eggs or chicks to adverse environmental conditions or to predation, and 2) overflights generally occurred only during the daylight hours while most nest losses resulted from nocturnal raccoon predation when the Core MOA was inactive and few civilian aircraft traversed CALO. The primary driver of colonial waterbird demography at CALO in 2010 and 2011 was raccoon predation and the secondary driver was flooding, each of which showed no relationship to aircraft activity.

Despite National Park Service (NPS) management policies that prohibit public access within 50 m of waterbird colonies, pedestrian traffic altered incubation rates of least terns during my study. However, the mean decrease in the percentage of time that least terns incubated during a pedestrian event compared to the control period was small (only 12%). This reduction in incubation rate is qualified by my field observations that flushed birds frequently returned to incubate in a short period of time (i.e., within 1 min, and often while pedestrians were still in view of the nest), and that many birds did not flush at all during pedestrian events. However, as with overflights, pedestrians were/are a regular occurrence in this study system, and nesting birds have likely habituated to their presence. Moreover, while I did not evaluate flush distances in this study, I suspect that pedestrians closer to colonies had a greater impact on nesting bird behaviors than those further away. As the NPS maintains a 50 m posted human buffer around all active colonies, pedestrian events at close range seldom occurred in this study. Therefore, NPS management policies likely minimized nesting bird responses to human recreation at CALO, and as a result, I found no evidence that pedestrian traffic or other human recreation events impacted colonial waterbird demographic rates. I recommend continuation of the 50 m buffer around

colonial waterbird nesting areas to minimize the effects of human recreation on avian behavior and demography.

*Objective 2:* To understand the colony dynamics and demographic parameters of the focal species, including researcher-induced effects on nest survival.

As raccoon predation accounted for over half of all known nest failures at CALO, followed by flooding, policies targeting raccoon management would be most effective at increasing colonial waterbird nest success. The extent to which raccoons impacted waterbirds at North Core Banks was not known prior to this study, and without the use of night-vision auto-triggered cameras, this information would be difficult if not impossible to collect in an accurate and systematic manner. However, cameras also increased the probability that raccoons detected and depredated nests, which further reduced least tern nest survival for camera-monitored nests; the average daily nest survival rate for nests with cameras was 0.79 compared to 0.85 for nests without cameras.

Given the importance of monitoring nests via remote cameras to accurately identify nest fates, additional studies that assess less intrusive methods to monitor least tern nests are warranted. For example, if a smaller camera with a longer focal length is placed further from a nest, it may be less obvious to raccoons or to other predators that may use these objects as visual cues. Conversely, there may be no camera impacts in other systems where raccoons are not the dominant nest predator species. While it is critical to attain unbiased estimates of nest survival, which can be accomplished via camera-monitoring, it is also important for scientific and ethical considerations to simultaneously address the relative impacts that cameras may have on the study system.

*Objective 3:* To evaluate the bias and variance of two commonly used techniques to estimate least tern nest abundance.

Incubating adult counts were an effective method by which to estimate breeding least tern peak nest abundance with accuracy and precision, and took considerably less effort to complete compared to ground nest counts. Managers should evaluate each colony independently when deciding which type of survey to conduct. Incubating adult counts are of high value at flat, open colonies, and ground nest counts should be considered at vegetated or topographically diverse colonies, or at vegetated sub-sections of larger colonies. While the two-week window count period accurately captured the nesting peaks at North Core Banks in 2010 and 2011, nest abundance varied by as much as 39% within this window. Therefore, when possible, > 1 count should be performed within the window, of which the highest should be reported as the state-wide nesting peak. Future studies should assess within-season turnover rates of breeding birds to understand the agreement between peak nesting estimates and total breeding population counts.

## Appendix A

**Table A1.** Study species: My study focused on 4 migratory colonial waterbird species that nested at Cape Lookout National Seashore (CALO), North Carolina, in 2010 and 2011: a) least terns (*Sternula antillarum*), b) common terns (*Sterna hirundo*), c) gull-billed terns (*Gelochelidon nilotica*), and d) black skimmers (*Rynchops niger*).

### a) Least tern

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There are 3 subspecies of least tern (Fig. A1) that breed in North America: 1) the California subspecies (*S.a. browni*), listed as endangered under the U.S. Endangered Species Act, 2) the Interior subspecies (*S.a. athalassos*), which breeds along the major interior river systems and along the Gulf of Mexico, also federally-endangered, and 3) the Atlantic-coast subspecies (*S.a. antillarum*), which breeds from Maine to Florida and is state-listed as either rare, special concern, threatened, or endangered in every Atlantic-coast state (least terns are listed as ‘special concern’ in North Carolina, which is my study area, NC Wildlife Resources Commission [NCWRC], 2008). Least terns are generally piscivorous and plunge-dive for prey during daylight hours, typically in sound or inlet water bodies in North Carolina, although their varied diet also consists of small crustaceans and insects (Thompson et al. 1997). On North Core Banks at CALO, least tern nesting begins late April to early May and continues until early August. Nesting occurs in open or sparsely vegetated beach habitats, and the locations, nest density, and number of nests per colony varies widely among colonies and within and among years. Least terns formed both mixed-species colonies and monospecific colonies at North Core Banks. All colonies occurred within 12 km of the southwestern and northeastern inlets of North Core Banks during my study in 2010-2011.

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#### b) Common tern

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Common terns (Fig. A1) breed on the Atlantic Coast from North Carolina, U.S.A. to the Canadian Maritime Provinces, in the Great Lakes states and provinces, and along lakes and river systems of the Northern Great Plains and Prairie Canada (Nisbet 2002). In North Carolina, common terns are listed as a species of special concern (NCWRC 2008). Common terns are piscivorous and plunge-dive for fish and small crustaceans. On North Core Banks, CALO they nest in mixed-species colonies that include least terns, gull-billed terns, and black skimmers. These mixed-species colonies formed only at the southwest end of North Core Banks in both study years; at New Drum Inlet and Old Drum Inlet in 2010 and at New Drum Inlet, Old Drum Inlet, and Blowfish Island in 2011. Common terns generally nested in sparsely-vegetated beach habitat at North Core Banks, and preferred more vegetation and diverse topography around nest sites than did least terns. Nesting occurred from mid to late May through July in 2010 and 2011.

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#### c) Gull-billed tern

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Gull-billed terns (Fig. A1) breed in coastal areas in isolated pockets from North Carolina south to Florida, throughout the Gulf of Mexico, and along the eastern shore of the Gulf of California in Mexico (Molina et al. 2009). In North Carolina, the species is listed as threatened (NCWRC 2008). Whereas the other focal species are mainly piscivorous, Gull-billed terns have a broader diet and will hawk for insects, plunge-dive for fish, and depredate eggs of other beach-nesting waterbirds (Hillman, pers. obs.). Gull-billed terns nested in the same colonies as least terns, common terns, and black skimmers at North Core Banks, from mid-May through July, in 2010 and 2011.

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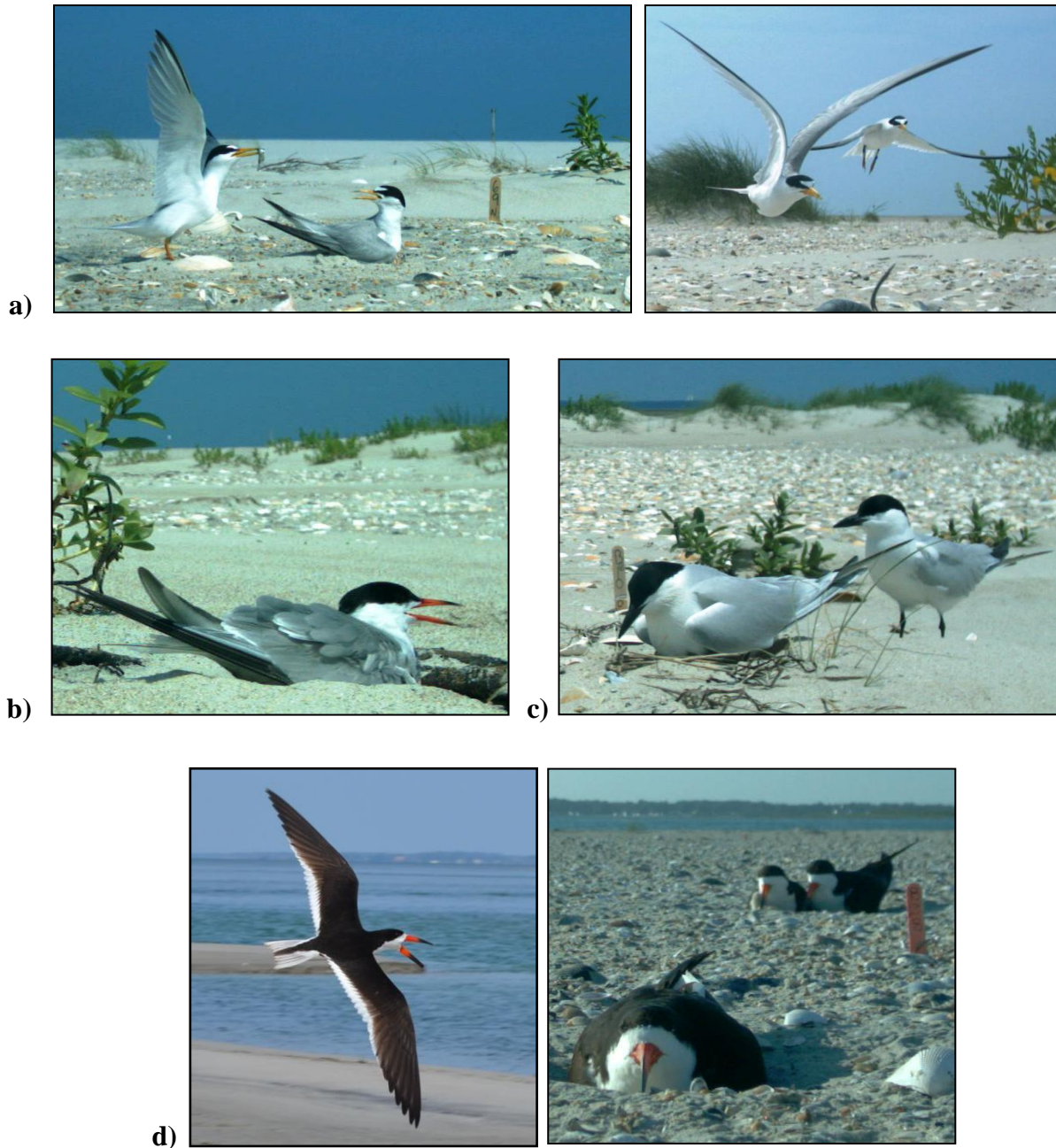


d) Black skimmer

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In the U.S., Black skimmers (Fig. A1) breed in coastal areas from Massachusetts south to Florida, throughout the Gulf of Mexico, and in isolated pockets along the Southern California coast (Gochfeld and Burger 1994). In North Carolina, black skimmers are a species of special concern (NCWRC 2008). Black skimmers are tactile foragers and skim the water's surface for fish and other marine organisms. On North Core Banks, black skimmers nested from mid to late May until early September, and formed sporadic mixed-species colonies in close association with the above-mentioned colonial species, in 2010 and 2011.

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**Figure A1.** Study species: The state-protected, beach-nesting colonial waterbird species that were the focus of my study were a) least terns (*Sternula antillarum*), b) common terns (*Sterna hirundo*), c) gull-billed terns (*Gelocheledon nilotica*), and d) black skimmers (*Rynchops niger*).

**Appendix B.** The types of stressors associated with aircraft and the habitat or animal properties likely to influence the impact of each stressor on birds (adapted from Efroymson et al. 2000).

<b>Stressor</b>	<b>Property of animal or its habitat leading to increased exposure to stressor</b>
Sound	Acute hearing Habitat in location directly below or near overflight Habitat in open area, without tree cover Activity time of animal coincides with time of overflight
Visual image of aircraft	Habitat in open area, without tree cover
Vibration	Sensory responsiveness to vibration
<b>Stressor</b>	<b>Property of animal that increases its sensitivity to stressor</b>
Sound	Lack of previous exposure to sound level associated with activity Nocturnal activity (nocturnal populations rely more on hearing than on sight to avoid predators or locate prey, Mancini et al. 1988) Reliance on auditory cues to: locate young, locate mate, avoid predators Reliance on natural sounds to provide information about landscape and wind speed Sensitivity to particular frequency range of sound Relatively high susceptibility to auditory damage
Sound & visual of aircraft	Lack of previous exposure Flocking or herding behavior (startle of a few leads to flight of many) Instinctive or learned reaction to perception of predator overhead
Visual only	Diurnal activity
Vibration	Use of vibration sensors to detect movements of predators or prey
<b>Stressor</b>	<b>Mechanism of action in response to stressor</b>
Sound	Alarm or avoidance behaviors Impaired vocal development in young due to impaired hearing

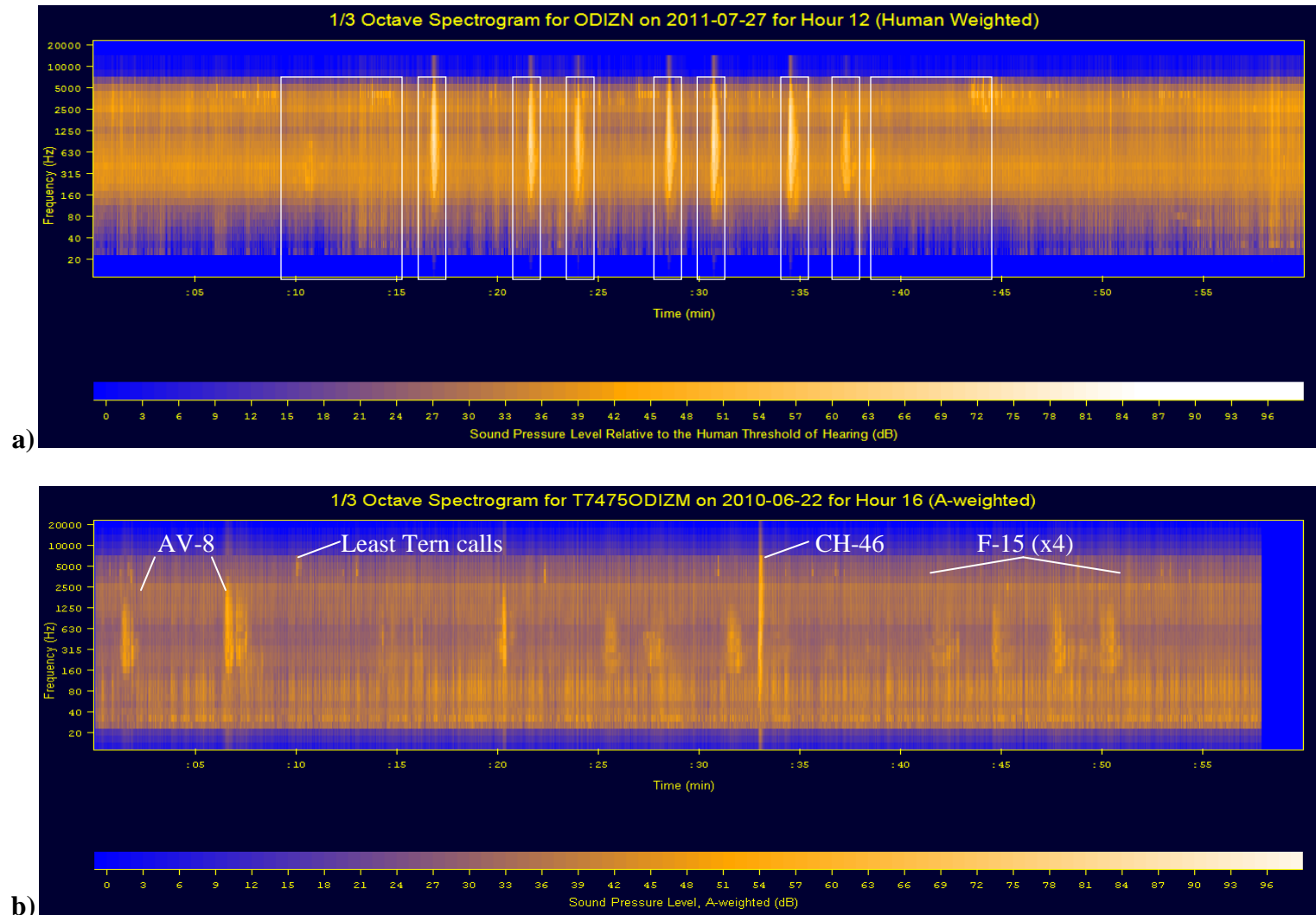
**Appendix C.** Field and laboratory methods and visual illustrations of results for the Core Military Operations Area overflight study at Cape Lookout National Seashore, North Carolina, 2010-2011.



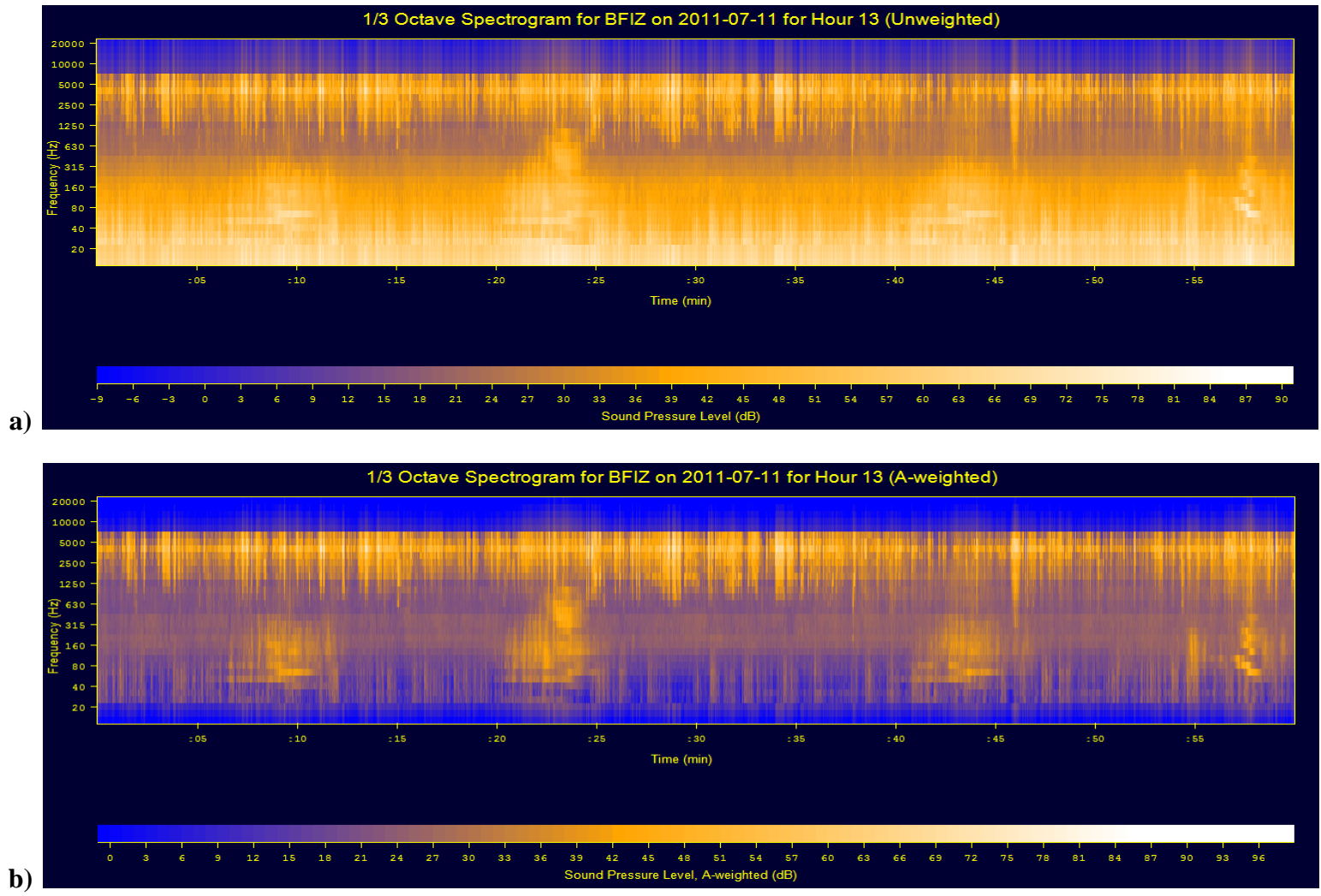
**Figure C1.** Nest-monitoring methods: a) Least tern nest in sandy substrate with coded tongue depressor 2 m south of nest and b) camera-monitored least tern adult in incubating posture.



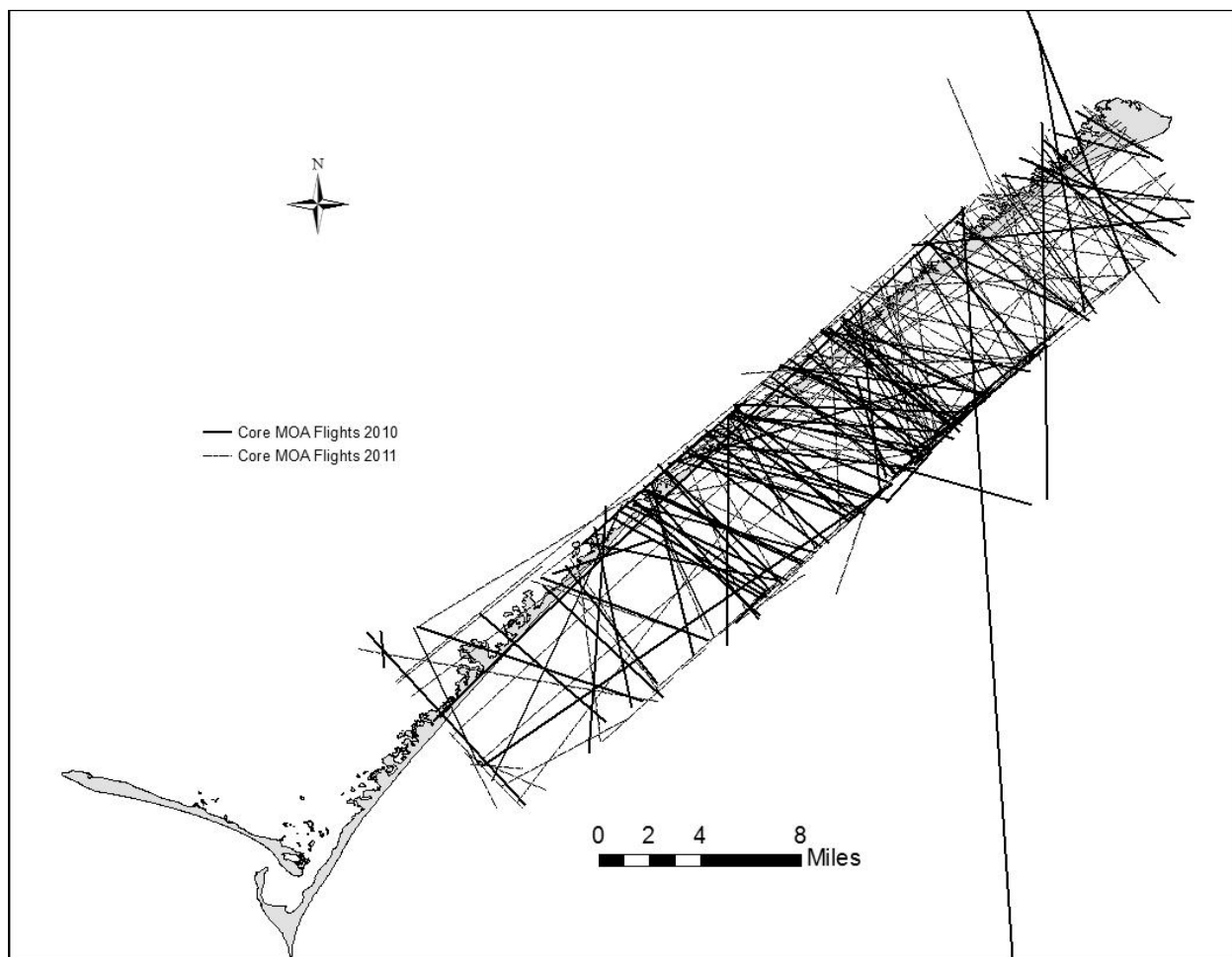
**Figure C2.** Audio-monitoring methods: Weather-proofed Zoom H2 Digital Audio Recorder connected to a 12 V sealed lead-acid battery (in bucket) with close-up of recording unit. These units recorded within-colony sound environments continuously for 24 hr/day throughout the 4-month nesting seasons in 2010-2011.



**Figure C3.** Spectrograms: a) One-third octave band spectrogram of U.S. Marine Corps (USMC) AV-8 Harrier fixed-wing aircraft flown experimentally over Cape Lookout National Seashore at 900 m, with ‘pre’, ‘during’, and ‘post’ behavioral sampling intervals (white boxes), and b) USMC AV-8 Harrier and F-15 Eagle fixed-wing aircraft of varying altitudes and closest points of approach, and one CH-46 Sea Knight rotary-wing aircraft flying 150 m (estimated) over the ocean-beach adjacent to waterbird nesting areas.



**Figure C4.** A-weighting: a) Unweighted (dB) spectrogram of U.S. Marine Corps AV-8 Harrier aircraft traversing the Core Military Operations Area over Cape Lookout National Seashore, North Carolina, and b) A-weighted (dBA) spectrogram of the same event. A-weighting is an expression of the relative loudness of sound in air as perceived by the human ear, and presumably by many avian species. A-weighting reduces amplitude in the lower frequency ranges.



**Figure C5.** Core Military Operations Area (Core MOA) overflight tracks: Lines depict all overflight paths through the Core MOA over Cape Lookout National Seashore, North Carolina. Overflight data were provided in 2010 (dark lines) and 2011 (light lines) by U.S. Marine Corps Air Station Cherry Point Range Control. A subset of these overflights was analyzed because some occurred outside of the active nesting period for colonial waterbirds and others were not audible from the study site. Lines represent estimated overflight paths and were constructed by drawing a straight line between the ingress/egress coordinates for each overflight through the Core MOA.





**Figure C6.** Human events: Incubating colonial waterbird exposure to human activities at Cape Lookout National Seashore, North Carolina: a) U.S. Marine Corps (USMC) C-130 fixed-wing aircraft, b) USMC CH-46 rotary-wing aircraft (‘Pedro’), c) civilian single-engine fixed-wing aircraft, d) civilian rotary-wing aircraft, e) pedestrians and off-road vehicles behind a mixed-species colony, f) off-road vehicle, and g) all-terrain vehicle (not pictured: turbofan fixed-wing aircraft).

**Appendix D.** Least Tern (*Sternula antillarum*) behaviors commonly observed while performing incubating adult counts from the colony perimeter.



**Figure D1.** Typical Least Tern incubating postures: a) Incubating eggs, b) shading eggs, c) incubating eggs and brooding chicks. Each of these frames represents 1 incubating adult, 1 nest, or 1 breeding pair.



**Figure D2.** Non-incubating Least Tern postures: a) Legs are visible and bird is not crouched or shading eggs (as in Fig D1b), b), adults are brooding chicks that have left the nest bowl, and c) any bird in non-breeding or subadult plumage, irrespective of its behavior.

Appendix E. Institutional Animal Care and Use Committee (IACUC) approval letter.



VirginiaTech

**Office of Research Compliance**

Institutional Animal Care and Use Committee  
2000 Kraft Drive, Suite 2000 (0497)  
Blacksburg, Virginia 24060  
540/231-2166 Fax 540/231-0959  
e-mail iacuc@vt.edu  
Website: www.aoc.vt.edu

**MEMORANDUM**

**DATE:** April 13, 2010

**TO:** Sarah Karpanty

**FROM:** Virginia Tech Institutional Animal Care and Use Committee

**IACUC NUMBER:** 10-019-FIW

**SUBJECT:** Review of Research Protocol Involving Animals Entitled **"Assessing the responses of breeding shorebirds to military jet overflights of the Core MOA at Cape Lookout National Seashore."**

The purpose of this memo is to verify that, on **April 13, 2010**, the Virginia Tech Institutional Animal Care and Use Committee (IACUC) reviewed and granted approval of the above described Protocol submission.

**Period of Protocol Approval**

This Research Protocol is approved for the following period, from **April 13, 2010 to April 12, 2013**.

All protocols must undergo continuing review on an annual basis for as long as the protocol is active, even if the protocol is only active for a portion of the first year after approval. The principal investigator must submit an annual continuing review form when notified by the IACUC Office.

If the research proposed under this protocol will continue to be conducted after the end of the three-year approval period, a new protocol must be submitted and approved prior to the three-year anniversary of the original approval date if uninterrupted work is desired to continue. The principal investigator is responsible for submitting all paperwork required to maintain IACUC approval.

**Changes to Approved Protocols**

Any changes in study personnel, animal numbers, species, procedures/treatments, or any other minor or significant change to your protocol must be submitted to the IACUC for review and approval before those changes are implemented. Failure to seek IACUC approval for amending approved protocol procedures may result in withdrawal of permission to conduct the research.

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