ABSTRACT

BORNEMAN, TRACY ELIZABETH. Effects of Human Activity on American Oystercatchers (*Haematopus palliatus*) Breeding at Cape Lookout National Seashore, North Carolina. (Under the direction of Dr. Theodore R. Simons).

As human populations and associated development increase, human-wildlife conflicts are occurring with greater frequency. How human activity affects wildlife, particularly those species whose populations are declining and are of concern, is of great interest to ecologists, land managers, and natural resource policymakers. The American Oystercatcher (*Haematopus palliatus*), a species of federal and state management concern, nests on coastal beaches where they are subject to various forms of anthropogenic disturbance. In this study, I assessed the effects of a variety of human activities on nesting American Oystercatchers at Cape Lookout National Seashore, North Carolina.

Human activities that may disturb nesting birds at Cape Lookout National Seashore include aircraft overflights, off-road vehicles, and park visitors. A recent lowering of the minimum altitude at which high-speed military aircraft can fly through the airspace (Core MOA) above Cape Lookout National Seashore provided an opportunity to study the effects of these overflights on nesting birds. I used three metrics to assess the effects of human activity on nesting American Oystercatchers: behavior, physiology, and reproductive success. I expanded on-going monitoring of American Oystercatchers at Cape Lookout National Seashore by supplementing visual observations with continuous 24-hour video, audio, and heart rate recording at nests during the nest incubation period. Audio recorders monitored ambient sound levels and noise events; video recorders monitored oystercatcher incubating behavior, beach activity, and nest fate; and microphones embedded in artificial eggs monitored the heart rates of incubating birds.

I quantified the behavioral responses of oystercatchers as the proportion of incidents they were on versus off their nests before and during human activity events, the number of times oystercatchers departed from their nests each day, and the percent of the day oystercatchers were at and attending their nests. Oystercatchers were equally likely to be observed on their nests before and during most types of aircraft fly-overs, except for military fixed-wing flights for which they were on their nests more during than before the flights. Oystercatchers were on their nests less often during all types of off-road vehicle and pedestrian events than before those events occurred. I found no association between the altitude of Core MOA flights and the behavior of incubating birds. Oystercatchers were more likely to be off their nests during the passage of off-road vehicles and pedestrians when nests were located in open sand areas. Average daily nest attendance was higher for successful nests than for failed nests. I found no significant correlation between the number of human activity events per day and the percent of the day oystercatchers were at and attending their nests. The number of ATVs driving by nests each day was weakly associated with the total number of times oystercatchers left their nests per day.

High-speed, low-altitude Core MOA flights were the only human activity to significantly increase average heart rates of incubating oystercatchers. The biological significance of this increase (13 beats/minute) is unknown.

Reproductive success of American Oystercatchers on North Core Banks during the two seasons of this study were comparable to, or higher than, past reproductive success on the island and at other nesting sites in North Carolina. The average number of off-road vehicle events per day was correlated to reductions in daily survival rates and success of nests.

Current levels of aircraft overflights, including high-speed, low-altitude Core MOA flights, are unlikely to affect nesting success during the incubation period. In contrast, off-road vehicles appear to affect both the incubation behavior and nest hatching success of American Oystercatchers.

Effects of Human Activity on American Oystercatchers (*Haematopus palliatus*) Breeding at Cape Lookout National Seashore, North Carolina

by
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DEDICATION

To Eli, without whom I would have never completed (or survived) this research and thesis, for his unwavering support, interest, dedication, and ingenuity.

And, to the American Oystercatchers; I hope my work will contribute to ensuring your future.

BIOGRAPHY

I grew up in Maryland, spending a huge majority of my time outside, where my curiosity, my imagination, my mind, and my dreams could flow. It was in nature where I felt I was truly experiencing the world and life. I found peace, excitement, and wisdom among the wild like I found nowhere else. There were so many fascinating things in nature and a world of it I longed to experience, so I had (and still have) difficulty in pinpointing exactly which direction of learning to pursue. I finally decided to attend Salisbury University where I received a Bachelor of Science in Biology in 2002, spending a semester abroad studying Wildlife Management in Kenya along the way. After graduating, I left Maryland following an insatiable wanderlust. I traveled frequently throughout the United States after completion of my undergraduate degree, gaining diverse experience in a variety of biological and outdoor-related jobs. What wonderful adventures. An array of wildlife research technician positions led me to pursue my own research for a Master of Science in Zoology here at North Carolina State University. I was so fortunate to conduct my research in a spectacular location, Cape Lookout National Seashore, on an amazing bird, American Oystercatchers, and through an advantageous program, the North Carolina Cooperative Fish and Wildlife Research Unit at NC State University. My time in Raleigh also marked another major life milestone; I married my life adventures mate, Eli.

As my studies for my Master's degree have kept me stationary for a few years, I am feeling the restlessness of my wandering legs; I plan to roam a bit and experience more of what the world has to offer. So many ecosystems, landscapes, and species to explore…

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First and foremost, many, many, many thanks to Eli Rose for assistance in all aspects of the project including countless hours spent designing and developing equipment; assisting in the field; collecting, organizing, processing, and reviewing digital recordings; assisting in devising the sampling design; overall study insight and support; and being a general foundation through this whole process.

I thank my advisor, Dr. Ted Simons, for this opportunity, and for all his support, continual cheerleading, sound advice, and eternal patience. And, to my lab-mate, office-mate, and room-mate, Jessica Stocking, so many thanks for, well, *everything.* We experienced and learned so much together.

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None of my time here at NC State and with the Coop Unit would have been possible without Wendy Moore and her limitless knowledge of government and university administrative processes. I am so grateful for all she did for me and her guidance through much paperwork. The same is true of Meredith Henry and Susan Marschalk, whom I thank for their continual guidance on navigating graduate student procedures.

I'd also like to acknowledge the American Oystercatcher Working Group, a partnership of representatives from States within the oystercatcher's breeding range along the Atlantic and Gulf of Mexico coasts of the United States. This group is a fantastic example of what is achievable by strong, wide-range collaborations in understanding and conserving a species. Its members have been extremely supportive throughout my graduate career, and I have learned so much from them. I'm so thankful for all my interactions with this group.

And last but never least, so many thanks to my parents and siblings, particularly during exhausted, overwhelmed, and sometimes tearful phone calls and visits, for their untiring belief in me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

Introduction

Interactions between humans and wildlife are closely linked to human population growth and urbanization, particularly in the coastal zone (Vitousek et al. 1997, Crosset et al. 2004). An often overlooked form of human activity, anthropogenic noise, is a potentially serious form of wildlife disturbance. Wildlife perceive, interpret, and utilize many natural sounds in their environment, however human-generated noise is often more pervasive and louder than natural sounds (Patricelli and Blickley 2006, Popper and Hastings 2009). Understanding and managing the effects of noise is complex because noise can travel great distances and it easily crosses management boundaries, such as those around natural areas like parks and wildlife refuges. Fewer and fewer natural areas today are free of substantial human-created noise (Berger et al. 2003).

Aircraft are a significant source of anthropogenic noise, particularly in military operations areas (MOAs) (Pepper et al. 2003). One such MOA, Core Banks Military Operations Area (Core MOA), is located directly over Cape Lookout National Seashore (Cape Lookout), a unit of the National Park Service, on the central coast of North Carolina (Figure 1.1 and Figure 1.2). The Core MOA airspace is controlled by the United States Marine Corps through the Marine Corps Air Station in Cherry Point, NC. In the past, the minimum altitude for high-speed tactical speed operations (aircraft flying >250 knots) in the Core MOA was 10,000 feet, however the United States Marine Corps desired to lower the restriction to 3,000 feet during the months of May to July. In 2009, the National Park Service and the U.S. Marine Corps agreed to experimentally lower the altitude to 3,000 feet for the purposes of research to evaluate the possible effects of an increase in the speed of military overflights at low altitudes over Cape Lookout on birds breeding in the park. The National Park Service is charged with protecting birds under the Migratory Bird Treaty Act. National Park Service Management Policy 4.4.2.3: Management of Threatened or Endangered Plants and Animals states, "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" (National Park Service 2006). Several protected bird species breed at Cape Lookout including American Oystercatchers, Least Terns, Common Terns, Black Skimmers, and Wilson's Plovers, which are all listed as Species of Special Concern in North Carolina, as well as Gull-billed Terns, which are listed as threatened (North Carolina Wildlife Resources Commission 2008). Along with their inherent importance for protection as declining species, shorebirds may also be useful as indicators of environmental and ecosystem health (Piersma and Lindstrom 2004). The National Park Service must also comply with other federal mandates such as the National Environmental Policy Act (NEPA) and the National Parks Overflight Act (Public Law 100-91), which required an assessment of minimum altitudes for aircraft flying over National Park System lands.

A review of overflight effects on National Parks by the National Park Service found wildlife behavioral responses such as alert posture; alarm and panic; escape tactics such as flushing, swimming, and diving; altered movement patterns; and abandonment of noise-disturbed habitat (National Park Service 1994). Other responses to overflight noise included decreased foraging success and decreased ability to respond to predators (National Park Service 1994). Stalmaster and Kaiser (1997) found military helicopter overflights caused increased flushing rates in Bald Eagles, and they recommended restricting these activities in eagle foraging areas. Similar recommendations were adopted for Spotted Owl nesting areas (Delaney et al. 1999). In contrast, low-level F-16 military overflights were found to have no effect on wading bird colony size, establishment, or reproductive success. Some birds showed higher frequencies of alert postures, but many often showed no response (Black et al. 1984). Similarly, nesting Osprey did not respond to low-flying CF-18 jets (Trimper et al. 1998), and low-level aircraft overflights were found to have minimal effects on waterfowl in North Carolina (Conomy et al. 1998a).

Wildlife occasionally show an initial response to overflight noise, but then habituate to the disturbance. Red-tailed Hawks showed a stronger aversion to helicopter overflights in areas of recently introduced aircraft activity compared to areas where aircraft had been flying for decades (Andersen et al. 1989). Minimal responses to jet overflights by Peregrine Falcons and Ospreys were also thought to have been conditioned by prior exposure to jets (Ellis et al. 1991, Trimper et al. 1998). Black Ducks habituated to military jet overflights within a few days to a few weeks, but Wood Ducks did not, suggesting species-specific responses to overflight noise (Conomy et al. 1998b). Species-specific responses also occurred for Brant and Canada Geese. A greater percentage of Brant flocks (75%) reacted to overflights than Canada Geese flocks (8%) (Ward et al. 1999).

Military aircraft disturbance differs from other forms of anthropogenic wildlife disturbance because military activities may continue throughout the night (Bisson et al. 2009). Belanger and

Bedard (1990) suggested that substantial energetic consequences associated with human disturbance of Snow Geese might be offset by night time foraging. Stone-curlews concentrate their foraging at night and exhibit different behavior and habitat-preferences at different times of day (Caccamo et al. 2011). If disturbance reduces foraging efficiency or alters behavior, we might expect long term consequences for avian productivity and survival (Verhulst et al. 2001). Several studies (Efroymson and Suter 2001, Pepper et al. 2003) have concluded that further research is necessary to pinpoint and quantify the effects of aircraft noise on wildlife.

Military overflights through the Core MOA are one of many forms of human activity at Cape Lookout National Seashore. Other aircraft, both military and civilian, fly in the vicinity of the islands. The Core MOA airspace is immediately abutted to the east by tactical operation training grounds over the Atlantic Ocean. To the northwest, the Core MOA is bounded by an airspace, R5306A, which is used heavily by all divisions of the United States military. Flight altitude restrictions in the R5306A airspace are limited and I regularly saw aircraft flying rapidly at low altitudes there. Although aircraft in these adjacent airspaces do not physically penetrate the airspace directly above Cape Lookout, the sound they create is regularly heard in the Seashore. Civilian aircraft, both fixed-wing and rotary-wing aircraft, are allowed below 3,000 feet altitude, and were regularly seen flying over Cape Lookout. Although Cape Lookout is accessible only by boat, ferries provide public transport to the islands, carrying both vehicles and pedestrians. Open-beach driving is allowed and fishing and pedestrian beach-combing are popular. Ground-based recreational activities and non-Core MOA flights are also potentially important sources of disturbance for birds breeding at Cape Lookout.

My research focused on the effects of the Core MOA overflights and other human activity at Cape Lookout on American Oystercatchers. Simultaneously with my study, collaborators at Virginia Tech conducted similar studies on the other state-listed breeding birds (Wilson's Plovers, Least Terns, Common Terns, Gull-billed Terns, and Black Skimmers) at Cape Lookout. Researchers at North Carolina State University have studied American Oystercatcher populations on the Outer Banks continuously for the past 16 years. This research has documented a variety of factors affecting the distribution, abundance, and demographics of oystercatcher populations in North Carolina. The goal of this study is to integrate new information on the effects of aircraft overflights and other forms of human activity with existing knowledge about factors affecting breeding American Oystercatcher populations. As manifestation of effects may be complex (Kight and Swaddle 2011), I applied three metrics: changes in behavior, physiology, and reproductive success, to assess the effects of human activity on American Oystercatchers. Research was focused mainly on the incubation period of the breeding cycle; however, data from the brood-rearing stage was also included to assess effects on reproductive success.

STUDY AREA

I conducted my field research on North Core Banks, Cape Lookout National Seashore, on the central coast of North Carolina (Figure 1.2). Cape Lookout National Seashore extends approximately 90 kilometers (56 miles) from Beaufort to Ocracoke Inlets and consists of three major barrier islands: North Core Banks, South Core Banks, and Shackleford Banks (Appendix A). It is part of the southern Outer Banks of North Carolina and separates Core Sound to the west from the Atlantic Ocean to the east.

North Core Banks is the northern-most island in Cape Lookout National Seashore. It is almost entirely encompassed by the Core MOA. Just under 37 kilometers (23 miles) in length, the narrow island is characterized by open beach habitats backed by dunes or sand “flats.” These sand flats can extend across the width of the island from the ocean to Core Sound, or occur as corridors of bare sand between the outer beach and the primary dunes. Grasses, shrub thickets, and occasional areas of low trees are found between the primary dunes and Core Sound. North Core Banks is accessible only by boat with public transport consisting of a vehicular and pedestrian ferry near the southern end of the island and a pedestrian-only ferry at the northern tip of the island. The full length of the island is accessible for driving, and commercial ATV tours are offered at an historic, uninhabited village, Portsmouth Village, on the north tip of the island as well as the beaches bordering the northern tip of the island. However, vehicle activity is concentrated on the southern portion of the island, and pedestrian traffic is heavier on the northern tip. Most vehicle traffic is concentrated on the outer beach, but an unpaved road behind the primary dunes that extends from island mile 4 to island mile 6, and again from mile 7 to mile 18.5, provides vehicle access during periods of high tides or beach closures. The National Park Service extended this road prior to the 2011 bird breeding season to include a section from island mile 19.3 to mile 20.9. Nevertheless, the island is mostly undeveloped and natural habitats predominate, making it an important breeding location for shorebirds, sea turtles, and other wildlife.

In August of 2011, Hurricane Irene reopened an inlet on the southern end of North Core Banks around island mile 19. This separated the southern three miles of the island, creating Middle Core Banks, which was inaccessible to vehicles. Middle Core Banks was still accessible by boat, so continued to have pedestrian activity.

STUDY SPECIES

American Oystercatchers (*Haematopus palliatus*) are a common breeding shorebird on the Outer Banks of North Carolina. They are restricted to coastal habitats, breeding from Maine to Florida on the Atlantic coast and along the Gulf of Mexico of eastern North America (American Oystercatcher Working Group et al. 2012). North Carolina is an important breeding area for American Oystercatchers and Cape Lookout supports high productivity in the state (Simons and Stocking 2011). Birds arrive at Cape Lookout, form pairs, and establish breeding territories in early April. Pairs are highly territorial; territorial displaying and conflicts with neighboring pairs and transient oystercatchers are common. American Oystercatchers also exhibit strong nest site fidelity, frequently returning to the same territory year after year (Schulte 2012). Most nests at Cape Lookout are found on the open beach or adjacent primary dunes, but oystercatchers also nest on over-wash flats, sound-side marshes, and dredge spoil islands. Clutches of one to four eggs are incubated by both adults for an average of 27 days until hatching. Pairs may attempt multiple clutches in a single breeding season if their nests are destroyed before chicks hatch. The semi-precocial chicks leave the nest shortly after hatching, but they rely almost completely on their parents for food and protection until they fledge about 35 days after hatching. Once fledged, chicks remain with their parents for at least two months, and in some cases after their migration to the wintering grounds, depending on the adults heavily for food (American Oystercatcher Working Group et al. 2012).

The American Oystercatcher is listed as a “species of high concern” by the U.S. Shorebird Conservation Plan. This designation is for species whose populations “are known or thought to be declining, and have some other known or potential threat” (Brown et al., 2001). Oystercatchers are considered a “bird of conservation concern”, as well as a management “focal species” by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 2004). The National Fish and Wildlife Foundation designated the American Oystercatcher as a “Coastal Keystone Species” because they are sensitive to many factors affecting coastal environments (American Oystercatcher Working Group and National Fish and Wildlife Foundation 2008). The Foundation sponsored a range wide conservation initiative for the species that began in 2008. Although American Oystercatcher populations are expanding at the northern and southern portion of their range, populations in the center of the range, including the Outer Banks, may be declining (Davis et al. 2001). In North Carolina it is considered a "species of special concern", (North Carolina Wildlife Resources Commission 2008).

Annual monitoring of American Oystercatcher breeding activities at Cape Lookout National Seashore began in 1995 (Altman 2011) by a graduate student at Duke University who reported low reproductive success (Novick 1996). North Carolina State University researchers and National Park Service personnel have continued oystercatcher research and monitoring since 1997.

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TABLES AND FIGURES

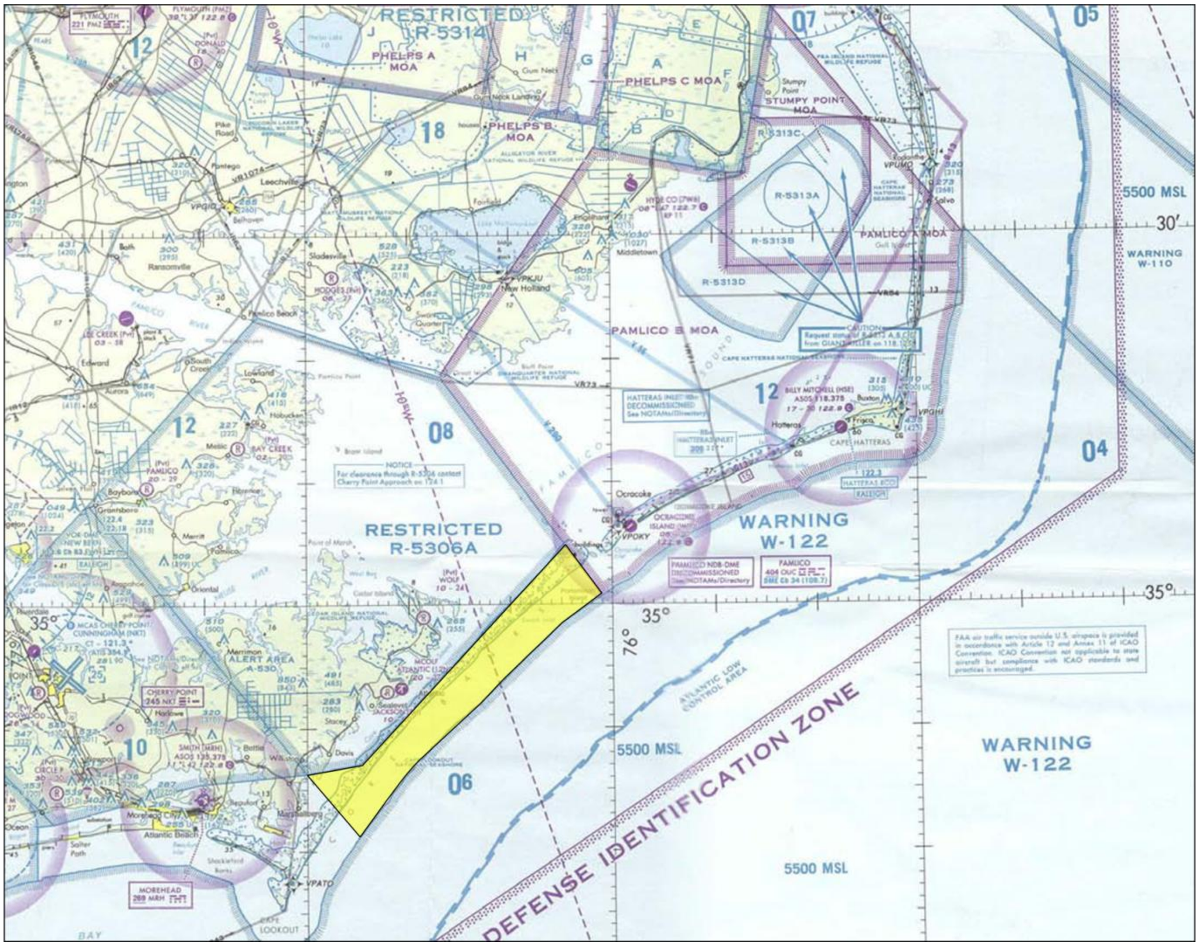

Figure 1.1. Core Banks Military Operations Area (Core MOA) airspace (in yellow) over Cape Lookout National Seashore, NC and adjacent operations area airspaces. Map courtesy of the United States Marine Corps, Marine Corps Air Station, Cherry Point, NC.

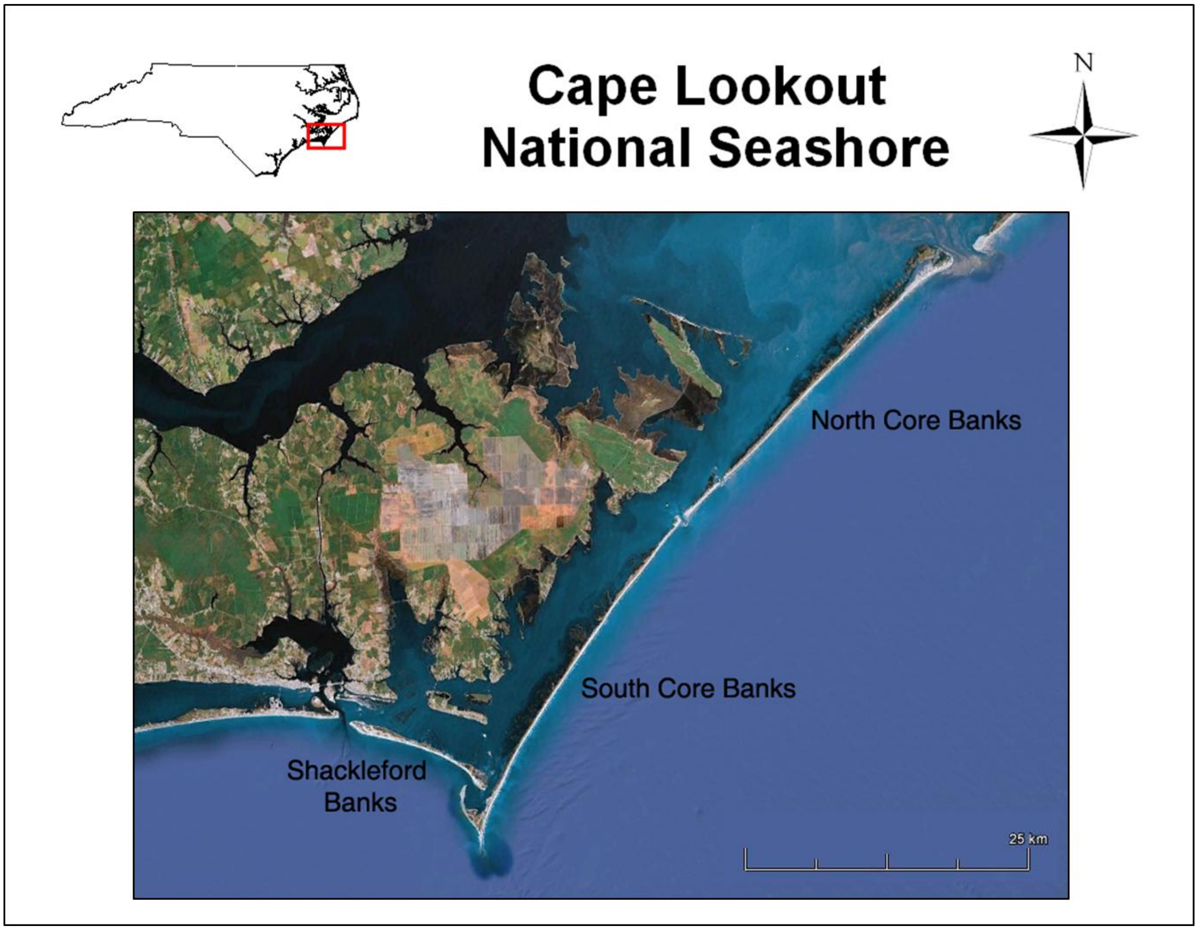

Figure 1.2. Location map and aerial photo of the study site, North Core Banks, the northern most island of Cape Lookout National Seashore, North Carolina.

CHAPTER 2

Effects of Human Activity on the Behavior of Nesting American Oystercatchers

ABSTRACT

How human activity affects wildlife, particularly those species whose populations are declining and are of concern, is of great interest to ecologists, land managers, and natural resource policymakers. The American Oystercatcher (*Haematopus palliatus*), a species of federal and state management concern, nests on coastal beaches where they are subject to various forms of anthropogenic disturbance. In this study, I assessed the effects of a variety of human activities on nesting American Oystercatchers at Cape Lookout National Seashore, North Carolina using continuous video and audio recordings during the incubation period. Observations of military and civilian aircraft, passenger vehicles, all-terrain vehicles, utility-terrain vehicles, and pedestrian activity in the vicinity of nests were recorded an average of 34±2 times per day. Oystercatchers were on their nests about the same amount of time before and during most types of aircraft overflights, except for military fixed-wing flights for which they were on their nests more during than before the flights. Oystercatchers were on their nests significantly less during all types of off-road vehicle and pedestrian events than control periods before events. I found evidence that nesting habitat influenced the behavioral responses of oystercatchers to human activity, as oystercatchers were more likely to be off their nests during ground-based human activity (off-road vehicles and pedestrians) when nests were located in open sand areas. I found no significant correlation between the number of human activity events per day and the percent of the day oystercatchers were at and attending their nests. The number of ATVs driving by nests each day was weakly associated with the total number of times oystercatchers left their nests per day. American Oystercatchers appear to respond differently to different types of human activity. They have either habituated to the presence of aircraft in their nesting environment, or view overflights as less of a threat than vehicles and pedestrians.

INTRODUCTION

Concerns about human activity disturbing wildlife are at the forefront of biodiversity conservation (Gill 2007, Sutherland 2007). Human activity may be classified as a disturbance if it changes wildlife activity patterns (Bowles 1995). Human activity has been shown in studies on many different wildlife species to have a variety of effects. A meta-analysis of ungulates found they flee anthropogenic disturbance, reacting at greater distances to human pedestrians than to aircraft, terrestrial vehicles, or anthropogenic noise (Stankowich 2008). Borgmann (2011) calculated 86% of reviewed studies found human activity disturbed waterbirds. The waterbirds stopped feeding, vocalized, took flight, abandoned the site, and had decreased reproductive success. Penguins also alter foraging and behavior in the presence of humans (Carney and Sydeman 1999). In general, bird behavioral responses to human disturbance include flushing, increased vigilance and anti-predator behavior, decreased resting, vocalizing, decreased foraging rates, interspecific attacks, and site abandonment (Robert and Ralph 1975, Anderson and Keith 1980, Burger 1981, Safina and Burger 1983, Rodgers and Smith 1995, Conomy et al. 1998b, Carney and Sydeman 1999, Lafferty 2001, Verhulst et al. 2001, Villiers et al. 2005, Fernandez-Juricic et al. 2007, Tarr et al. 2010).

Disturbance combined with the high energy demands of migration and reproduction can be particularly costly for birds. Altered behaviors can lead to decreased fitness, such as was the case of deliberately-flushed geese which gained less body fat on migratory feeding grounds and had decreased reproductive output than geese undisturbed by humans (Madsen 1995). Deliberately-flushed European Oystercatchers attended their nests less during times of human disturbance (Verhulst et al. 2001), which can lead to higher incidence of egg loss (Robert and Ralph 1975, Tremblay and Ellison 1979) presumably from predation and decreased egg viability due to environmental exposure. Disturbance may also cause reductions in clutch size (Samraoui et al. 2012) and nest abandonment (Safina and Burger 1983, Tremblay and Ellison 1979). Nesting success may decrease with higher levels of human disturbance (Safina and Burger 1983, Westmoreland and Best 1985, Tremblay and Ellison 1979).

However, responses to disturbance vary considerably among species. Although Greater Prairie-Chickens were flushed repeatedly by researchers monitoring their nests, Westemeier et al. (1998) found no correlation between researcher disturbance and levels of nest success, nest abandonment or embryonic loss. Similarly, Black Oystercatcher productivity was not decreased by low levels of human recreation (Morse et al. 2006). In studies of direct comparisons of responses by related species, a greater percentage of Brant flocks (75%) reacted to aircraft overflights than flocks of Canada Geese (8%) (Ward et al. 1999), Black Ducks habituated to aircraft while Wood Ducks did not (Conomy et al. 1998b), three species of ducks (Ruddy ducks, Northern Shovelers, and Bufflehead) were undisturbed by hikers while three other species (Greater and Lesser Scaup and Canvasbacks) decreased in abundance (White 2009), and different species of wading birds flushed at varying distances to vehicle passage (Stolen 2003).

Understanding the potential effects of anthropogenic disturbance is particularly relevant for species of conservation concern, such as the American Oystercatcher. Terrestrial human recreational activity has been associated with changes in incubation behavior and nest site selection, nest failure, and chick mortality of American Oystercatchers (Novick 1996, Davis 1999, McGowan and Simons 2006, Sabine et al. 2008, Schulte 2012). American Oystercatchers are particularly vulnerable to disturbance associated with human recreational use of beaches because they incubate their eggs for at least 27 days in nests on the open beach (American Oystercatcher Working Group et al. 2012). Prior research at Cape Lookout National Seashore found that vehicles, pedestrians, and occasionally low-flying aircraft influenced nesting behavior (McGowan and Simons 2006). In this study, I used long-term continuous video and audio recording at American Oystercatcher nests to measure changes in oystercatcher incubation patterns associated with multiple types of human activity in the vicinity of nests at North Core Banks, Cape Lookout National Seashore.

METHODS

Field Methods

I conducted surveys of American Oystercatchers and their nests on North Core Banks at Cape Lookout National Seashore during the oystercatcher breeding season from early April to early August in 2010 and 2011. I attempted to locate every oystercatcher nest on the island. I classified nests by habitat as either open sand or dune nests. Open sand habitats included the open beach and sand flats where the terrain was flat and open with minimal vegetation. Dune habitats were areas of varying and elevated terrain and vegetation.

Video and Audio Monitoring at Nests

I monitored the incubation behavior of American Oystercatchers and human activity in the vicinity of their nests during the 2010 and 2011 breeding seasons with continuous digital video and audio recording. I was unable to monitor all American Oystercatcher nests with recording equipment and therefore used a stratified sampling scheme in which I randomly selected breeding pairs for monitoring from strata determined by location along the length of the island, location relative to the primary dunes, and vehicle closure status.

Video cameras continuously monitored incubating oystercatcher behavior and the nest vicinity for human activity, 24 hours a day. The video recordings also provided information about nest predation events, incubation rates, and interspecific and intraspecific interactions. The video monitoring system was comprised of an outdoor, closed-circuit security camera with infrared-capability, a digital video recorder, two 12V 35 amp-hour AGM sealed lead acid batteries, and a voltage regulator (Figure 2.1). All components were housed in a 5-gallon plastic bucket with a waterproof lid for protection, weatherproofing, and transportability. I outfitted some of the cameras with 16mm zoom lenses so I could place them farther from nests. The remainder of the cameras used their original 4 mm wide-angle lenses. I built 35 video camera units, 20 with zoom lenses that were used for recording nests, and 15 with wide-angle lenses for recording human activity on the beach. I deployed between 10 and 15 cameras at any given time throughout the 2010 and 2011 breeding seasons. Camera units were replaced in the field with a fresh unit every seven days to download recorded video and replace batteries, which minimized the disturbance of nesting birds. Most monitoring equipment exchanges were completed in less than 20 minutes. I positioned video cameras approximately 15 feet from incubating birds with the adjacent beach habitat in the field of view so that I could identify as many sources of human activity and potential disturbance (off-road vehicles, pedestrians, pets, predators, etc.) as possible. If the location of the nest did not provide a clear view of the beach and the nest, I placed a second video recorder adjacent to the nest at a location where the beach was visible. Due to differences in the landscape around nests, the total area surveyed by video recordings varied among nests

Audio recorders monitored ambient sound levels and noise events at selected American Oystercatcher nests (Figure 2.2). I selected nests for audio monitoring in the manner described above for video monitoring, such that all nests monitored with video equipment were also monitored with audio equipment. I placed Samson Zoom H2 digital audio recorders (Samson Technologies Corp., Hauppauge, NY) within a windscreen mounted approximately 1.5 meters above the ground. An atomic clock wristwatch synchronized the start/stop times of recordings. Ambient sound was recorded continuously at nests until the nest either failed or hatched. These recordings provided a record of both natural and anthropogenic sounds in the immediate vicinity of nesting American Oystercatchers. I replaced audio recorders in the field every 3-4 days to download recorded audio and replace batteries. I calibrated the Zoom HR recordings using a highly sensitive and accurate Larson Davis 831 sound level meter to ensure the accuracy of my sound level measurements. The National Park Service Natural Sounds and Night Skies Division processed the calibration data as described by Mennitt and Fristrup (2012).

Island-wide Sound Monitoring

I monitored the island-wide ambient sound environment to provide context for my measurements at oystercatcher nests (Pater et al. 2009). Ambient sound data were collected from a linear array of audio recorders placed every two miles along the length of North Core Banks following protocols established by the Natural Sounds and Night Skies Division of the National Park Service (Figure 2.2). Sound recordings were made over three 5-7 day periods once each in May, June, and July 2010 to provide baseline measurements of summer ambient sound levels on North Core Banks.

Vehicle Closures

The National Park Service managed vehicle activity on North Core Banks to prevent destruction of nests and reduce disturbance to breeding shorebirds. Nests in vehicle traffic areas were posted with signs inhibiting vehicle activity. In 2011, the National Park Service expanded their management practices, closing additional sections of the beach to vehicles by rerouting traffic to a primitive road behind the dunes. These management practices allowed me to monitor nests in areas without beach driving. For my analyses, I identified four classifications of vehicle management used in 2011. Full closures were large areas closed to protect nesting terns and Piping Plovers; vehicles were excluded inside the closure but they could drive along parts of the perimeter. Vehicles were not managed (no closure) at nests located in dune or other habitats away from approved vehicle routes. Ramp closures rerouted vehicles around active nests on the oceanfront beach to the interior primitive road behind the dunes. Drive-through closures prevented vehicles from stopping in the vicinity of nests, but allowed driving by the nests. As the National Park Service adapts their vehicle management to changing conditions during the breeding season, I assigned these classifications to nests on a daily basis. I incorporated vehicle closure type into my analyses of aircraft overflights to control for the potentially confounding effect of variations in vehicle activity.

Video and Audio Analyses

Video/Audio Recordings Processing and Behavior and Activity Sampling

The United States Marine Corps, Cherry Point Naval Air Station provided information on timing, location, speed, and altitude of military overflights through the Core MOA airspace above Cape Lookout National Seashore. I used this information with the time stamps on the audio and video recordings to identify the Core MOA flights on the recordings and assess them independently from other types of aircraft.

I collected approximately 48,000 hours of video and audio recordings during the 2010 and 2011 breeding seasons. Analyses were conducted by reviewing all video and audio recordings collected during known Core MOA overflights. In addition, starting on the day following the deployment of recording equipment at a nest (i.e., the first full 24-hour day of recording), I reviewed all video and audio recording files within a 24-hour period from every fourth day of monitoring. From these sub samples, I noted every occasion when an oystercatcher left or returned to its nest, every incident of human activity (either heard on the audio recordings, seen on the video recordings, or both), and the behavior of the incubating oystercatcher before and during the human activity events. A human activity "event" was defined as the time at which an incident of human activity could first be seen or heard on the recordings to the time it was no longer visible or heard. I observed whether or not oystercatchers were on and attending their nests both during and 20 minutes before human activity events. I classified an oystercatcher as on the nest if it was sitting on or standing over the eggs at the "peak" time of the human activity event (i.e. the time of the highest sound level during an event or the time when the human stimulus was closest to the nest). I compared this to presence/absence of an oystercatcher on the nest exactly 20 minutes before the peak time of the event.

I used motion detection software developed by Syed Hussain, a North Carolina State University Ph.D. candidate in electrical and computer engineering, to automate the process of detecting activity at oystercatcher nests on the video recordings. The software processed the original video recordings and extracted frames in which oystercatchers moved to or from their nest, as well as any activity of humans or other animals within the field of view. Reviewing the extracted still frame images greatly decreased the time required to review the videos. In cases where the motion-detected images produced ambiguous results, I watched the full video recording to document activity at the nest. I compared samples of video reviewed by human observation versus the motion detection software and determined the software had a very high detection rate of events when visibility at the nest was good (26 of 28 events seen on the video during a 6-hour sample were detected by the motion detection software). However, event detection by the motion detection software was less reliable when conditions were foggy (9 of 49 events seen on the video during a 6-hour sample were detected by the motion detection software). Therefore, I reviewed the full video recordings whenever fog was present.

I processed the audio data using two software programs, Audio2NVSPL and Acoustic Monitoring Toolbox (v1.3877), developed and provided by the Natural Sounds and Night Skies Division of the National Park Service (Joyce 2009). This software allowed me to review the audio recordings in one hour segments summarized visually as spectrograms rather than listening to the full audio recordings in real-time (Figure 2.3). Noise events appeared on the spectrogram as blotches of color. I listened to the segment of the audio recording containing the noise events, using both auditory and visual clues to identify the source of the noise. When human activity was identified, I used the software to calculate sound level values for each human noise event.

I measured sound levels using two metrics, maximum L_{EQ} (MaxLEQ) and Sound Exposure Level (SEL), to assess oystercatcher responses to individual aircraft and vehicle noise events (Pater et al. 2009). LEQ is the equivalent average sound level over a specified time period, in my case for one second. Therefore, MaxLEQ is the maximum LEQ recorded at one second intervals for the duration of the noise event. SEL represents the total noise energy produced from a single noise event. It takes into account sound levels measured at multiple frequencies over the duration of the event. MaxLEQ and SEL are quantified in decibels (dB), which for this study are A-weighted (dBA) to take into account the presumed frequency hearing range of the American Oystercatcher (Meyer 1986, Conomy et al. 1998a, Beason 2004). I measured sound levels for observed human activities at oystercatcher nests, both to compare the sound levels of different types of human activity and to compare anthropogenic sound to ambient sound. Ambient sound levels were randomly sampled from the array of audio recorders distributed every two miles across North Core Banks with samples taken at times when no human activity was evident on the recordings.

I also compared sound levels during human activity events to ambient levels of similar duration 20 minutes before human activity events occurred by calculating the average change in sound levels from 20 minutes before to during human activity events. This provided a more direct measure of how human activity was altering the sound environment (Pater et al. 2009). For comparison, I calculated how ambient sound environments may change naturally over a similar 20 minute interval but without human influence. Ambient sound “events” were randomly sampled from an array of audio recorders distributed every two miles across North Core Banks with samples taken at times when no human activity was evident on the recordings. The duration chosen for sampling ambient sound “events” was 51 seconds, which was the average duration of human activity events.

Island-wide Sound Monitoring

The island-wide array of audio recorders generated a total of 3,924 hours of audio recordings; 1,327 hours were recorded in May, 1,506 hours in June, and 1,092 hours in July. I processed and reviewed the recordings using the same software and metrics described above for audio recordings at nests. Ambient sound levels were measured at high and low tide on every day of recording at every recording location. Samples included all ambient sounds recorded on the island at the time of sampling including: weather, human activity, wildlife, etc. Along with tide height, I also used National Oceanic and Atmospheric Administration weather archives of historical ocean surf swell height and wind speed levels at nearby Ocracoke Island to investigate the effects of environmental variables in explaining natural variations in the ambient sound environment of North Core Banks during the periods of island-wide ambient sound recording.

Statistical Analysis

All statistical analyses were conducted in R (R Development Core Team 2011), applying a significance level of 0.05.

Island-wide Sound Monitoring

I compared the effects of environmental conditions on ambient sound levels on the island using multiple linear regression and Welch’s two-sample t-tests to account for potential unequal sample variances.

Video and Audio Monitoring at Nests

I compared the hatching success ratio of nests monitored with video and audio recording equipment to the hatching success ratio of nests that were not recorded using a chi-squared test.

Anthropogenic Activity

I compared sound levels of aircraft to off-road vehicles using a Welch's two-sample t-test. I compared the change in sound levels from 20 minutes before to during human activity to the change in ambient sound levels for a similar 20 minute interval using indicator variables for each human activity type using an Analysis of Variance.

Behavioral Response

To compare the distributions of on/off nest behavior before and during human activity events, I used McNemar's chi-squared tests for paired data. Each human activity type was assessed individually. I conducted further analyses to assess if other variables were interacting with or confounding the behavioral response of oystercatchers to the human activities. Restricting my analysis to only human activity events where an oystercatcher was on the nest 20 minutes before the events occurred, and taking into account potential response variation among the breeding pairs of oystercatchers, I conducted an analysis using a generalized linear mixed model (mixed effects logistic regression). In this model, human activity type and nesting habitat type were fixed effects, and nest (breeding pair) was a random effect. The model also estimated a possible interaction between human activity type and habitat type. Because I was specifically interested in flights through the Core MOA, I conducted another analysis using the model described above, but with human activity type reclassified to include only two categories: 1) Core MOA flights and 2) all other human activity types. In this analysis, the interaction between human activity type and habitat type was not significant, so was excluded from the model. I also used a mixed effects logistic regression model to compare the effects of the Core MOA flight altitudes on the behavioral responses of oystercatchers. This analysis included only Core MOA flights. The model included altitude as a categorical fixed effect (low versus high altitude), habitat type as a fixed effect, and nest (breeding pair) as a random effect. High altitude flights were defined as those 10,000 feet and above; low-altitude flights were below 10,000 feet. The interaction between altitude and habitat was not significant, so was excluded from the model.

I compared the daily nest attendance of hatched nests to failed nests using a Welch's t-test to account for the possibility of unequal variance between samples. To determine if the amount of human activity around nests affected nest attendance, I tested how the daily amount of human activity affected daily nest attendance using simple and multiple linear regression models. Because nest attendance was estimated as the proportion of the day oystercatchers spent on their nests, I used an arcsine square root transformation, which is a common variance-stabilizing transformation for proportional data. I also tested for a relationship between the amount of daily human activity and the number of times oystercatchers departed from their nests each day using simple and multiple linear regression.

I analyzed differences in the behavior of oystercatchers nesting in different types of vehicle closures using analysis of variance.

RESULTS

Island-wide Sound Monitoring

I estimated an ambient average MaxLEQ level of 55.7±0.7 dBA and an average SEL of 67.9±0.1 dBA across the island (n = 55). Average ambient sound levels (both MaxLEQ and SEL values) on the island were significantly higher at high tide than low tide (Table 2.1). Ambient sound levels on the island were significantly correlated to ocean tide height and surf swell, however wind speed did not appear to explain variations in sound levels (Table 2.1). Weekdays (Monday through Friday) had significantly louder average ambient sounds levels (MaxLEQ = 60.3±0.3 dBA, SEL = 83.5±0.2 dBA) than weekends (Saturday and Sunday; MaxLEQ = 57.2±0.6 dBA, SEL = 80.1±0.3 dBA) (MaxLEQ: $t = 4.619$, $p < 0.0001$; SEL: $t = 8.727$, $p < 0.0001$).

An example of sound attenuation from a low-altitude Core MOA overflight is summarized in Figure 2.5. The overflight occurred on 21 June 2010 at an altitude of 5,200 feet. I recorded the overflight on the audio recorder nearest the flight path (island mile 13) from 09:43:21 to 09:44:44. Peak sound levels were measured at this audio recorder (72.5 dBA) at 09:43:48. I then measured sound levels at the same time from recorders located along the length of the island. Overall, sound levels decreased rapidly as distance from the flight path increased.

Video and Audio Monitoring at Nests

I monitored 62 nests (55% of 112 total nests; 33 in 2010 and 29 in 2011) laid by 47 breeding pairs of oystercatchers with video and audio recording equipment. Of the 62 nests recorded, 24 successfully hatched and 38 failed. A higher proportion of nests with recording equipment successfully hatched young (0.39) than nests without recording equipment (0.18) (χ^2 = 4.759, p = 0.029).

Anthropogenic Activity

The US Marine Corps reported 245 flights through the Core MOA from 7 March - 12 August 2010 (Figure 2.4). Of these, 105 flights occurred during the nesting period of American Oystercatchers (21 April – 31 July 2010), 24 of which were below an altitude of 10,000 feet. Suitable data were available for analysis of 21 of the 24 low-altitude flights. In 2011, the US Marine Corps reported 116 flights through the Core MOA from 14 April - 27 July 2011 (Figure 2.4). Of these, 114 occurred during the nesting period of American Oystercatchers (14 April – 4 July 2011), 35 of which were below an altitude of 10,000 feet. Suitable data were available for analysis of 12 of the 35 low-altitude flights. Fifteen low-altitude flights could not be analyzed because they occurred at the end of the oystercatcher nesting season when only one nest remained. This nest had inviable eggs and therefore was not suitable for an analysis of incubation behavior. Eight low-altitude flights were not analyzed due to equipment malfunction or logistical complications in maintaining or deploying recording equipment. The 33 usable low-altitude flights (below 10,000 feet) flown through the Core MOA over both years provided 114 opportunities to assess changes in oystercatcher behavior associated with the overflights.

Anthropogenic activities recorded in the nesting environment included; Core MOA overflights (military aircraft corresponding with reported flights through the Core MOA), other military fixed-wing aircraft (military aircraft not reported as flying through the Core MOA), civilian fixed-wing aircraft, rotary-wing aircraft (I could not differentiate military from civilian rotary-wing aircraft), passenger vehicles, all-terrain vehicles (ATVs; single passenger), utility-terrain vehicles (UTVs; all-terrain vehicles with two passengers side-by-side), and pedestrians (Figure 2.6). Flights through the Core MOA were recorded much less frequently than other types of human activity. Other military fixed-wing aircraft, ATVs, and passenger vehicles were the most frequently recorded human activity types with passenger vehicles by far the most common human activity occurring around nests. I recorded an average of 34±2 human activity events at nests each day (averaged over 51 video-monitored nests in 2010 and 2011).

I measured sound levels for all human activity events. As I found a strong positive correlation between the SEL and MaxLEQ values I recorded for sound events (n = 3977, R^2 = 0.88, p

< 0.001), I conducted further analyses using only SEL values. Ambient SELs averaged 70.34±0.62 dBA ($n = 55$) (Figure 2.7). Aircraft (all types of aircraft included) had significantly louder average SELs than off-road vehicles (all types of off-road vehicles included) (Aircraft: mean = 73.87±0.16 dBA, $n = 2420$; ORV: mean = 67.85±0.17 dBA, $n = 3585$; $t = 25.812$; $p < 0.0001$). Low-altitude Core MOA flights had the highest average SEL at 82.22±0.88 dBA with a maximum of 99.60 dBA ($n = 110$) (Figure 2.7). The average SEL before and after the flights was 68.0±0.49 and 68.49±0.62 dBA, respectively (Figure 2.8). Low-altitude flights were audible in the recordings for an average of 67.82±4.45 seconds.

Low-altitude Core MOA flights produced the greatest average change in sound levels from before to during the event (14.22±0.84 dBA). The average change in SEL for low-altitude Core MOA flights, 14.22±0.84 dBA, was significantly higher than the average change in ambient SEL, -0.05±0.13 dBA (Table 2.2, Figure 2.9). All other human activity types, except for UTVs, also had significantly greater average changes in sound levels from before to during the activity when compared to changes in ambient sound levels (Table 2.2, Figure 2.9).

Behavioral Responses

Oystercatchers were on their nests about the same amount of time before and during most types of aircraft fly-overs, including all flights through the Core MOA (low-altitude Core MOA flight: $n = 101$, $\chi^2 = 0.063$, $p = 0.803$; high-altitude Core MOA flight: $n = 166$, $\chi^2=0.281$, $p = 0.596$; civilian fixed-wing: $n = 492$, $\chi^2 = 0.096$, $p = 0.757$; rotary-wing: $n = 135$, $\chi^2 = 0$, $p = 1$) (Figure 2.10). Oystercatchers were on their nests significantly more during military fixed-wing flights than before the flights ($n = 1474$, $\chi^2 = 5.306$, $p = 0.021$). Oystercatchers were on their nests significantly less during all types of off-road vehicle and pedestrian events than they were before those events occurred (passenger vehicle: $n = 2101$, $\chi^2 = 91.88$, $p < 0.001$; ATV: $n = 1109$, $\chi^2 = 517.5$, $p < 0.001$; UTV: $n = 211$, $\chi^2 = 34.46$, $p < 0.001$; pedestrian: $n = 154$, $\chi^2 = 21.73$, $p < 0.001$) (Figure 2.10). It took oystercatchers an average of 9.75±0.35 minutes ($n = 1638$ events occurring at 52 nests) to return to their nests following human activity events during which they were not on their nests. The longest return time following a human activity event was 59.78 minutes (after passage of a passenger vehicle), but 75% of oystercatchers returned to their nests within 8.83 minutes following a human activity event (Figure 2.11).

The type of human activity had a strong effect on the probability that an incubating oystercatcher was off its nest during human activity events (n = 5203 observations from 53 nests, $p <$ 0.001) (Figure 2.12). Oystercatchers were more likely to be off their nests during off-road vehicle and pedestrian events than during aircraft events. Oystercatchers had the highest probability of being off their nests during ATV events and the lowest probability of being off their nests during MOA flights (all altitudes combined). Nesting habitat also appeared to influence oystercatcher behavioral responses to human activity. An interaction between these two predictor variables suggests that oystercatchers nesting in open sand and dune habitats react differently to different types of human activity. Oystercatchers were more likely to be off their nests during the passage of off-road vehicles and pedestrians when nests were located in open sand areas than they were when nests were located in dune habitats (Figure 2.12). The probability of an oystercatcher being off its nest during aircraft activity varied by aircraft type and nesting habitat (Figure 2.12). I compared flights through the Core MOA to all other human activity types combined into a single category and compared the behavior of oystercatchers during the Core MOA flights to behavior during all non-Core MOA activity types. The probability of oystercatchers being off their nests during Core MOA flights was significantly less than during all non-Core MOA human activities (n = 5203 observations from 53 nests, z = 5.962, $p <$ 0.001). The altitude of the flights through the Core MOA (low versus high) had no significant effect on the probability that oystercatchers were off their nests during the flights (n = 227 observations from 42 nests, z = 0.200, p = 0.841).

Daily nest attendance (the percentage of each 24-hour period of each day oystercatchers were sitting on or standing over their nests) averaged 88.2±0.7% (21.2±0.2 hours) of the day (n = 230 days from 55 nests) (Figure 2.13). Nests that successfully hatched had higher average daily nest attendance (89.7±1.0%; n = 23) than nests that failed (81.7±2.5%, n = 32), (t = 2.972, df = 40.894, p = 0.005), (Figure 2.14). I found no relationship between the average number of all human activity events per day and the average daily nest attendance (n = 55 nests, R^2 = 0.013, F = 0.633, p = 0.43). I also found no relationship between the number of human activity events in a given day and the daily nest attendance for that day (n = 175 days, R^2 = 0.040, F = 0.111, p = 0.739). Daily nest attendance was not related to the number of off-road vehicle events in a day (n = 175, R^2 = 0.002, F = 0.349, p = 0.555), or to the number of Core MOA flights daily (n = 175, $R^2 <$ 0.001, $F <$ 0.001, p = 1). Of all human activity types, only rotary-wing aircraft showed a negative correlation between the number of daily human events and daily nest attendance, although it explained only 2.9% of the variation in attendance, which I deemed biologically insignificant (n = 175, R^2 = 0.029, F = 5.347, p = 0.022).

I found a positive relationship between the total number of all human activity events occurring around a nest in a day and the number of times the oystercatchers departed from their nest that day, although the number of human events explained only 3.7% of the variation in oystercatcher departures so I did not deem it to be biologically significant (n = 173 days, $R^2 = 0.037$, $F = 6.525$, $p = 0.012$). However, when each human activity type was assessed individually, only the daily number of ATVs was positively related to the daily number of departures from the nest, explaining 8.7% of the variation in departures ($n = 173$, $R^2 = 0.087$, $F = 16.34$, $p < 0.001$).

Closure type had no effect on the daily nest attendance of oystercatcher pairs (Means±SE: None = 89.9±2.8% (n = 7), Full = 88.5±1.5% (n = 21), Drive-through = 91.2±1.9% (n = 27), Ramp=86.4±1.5% (n = 44); $F = 2.274$; $p = 0.085$) or the daily number of departures from the nest (Means±SE: None = 22.9±1.3 (n = 7), Full = 27.2±1.6 (n = 21), Drive-through = 29.1±1.1 (n = 27), Ramp = 28.9±1.5 (n = 44); $F = 1.403$; $p = 0.247$). There was no effect of closure type on the average proportion of observations per day of oystercatchers off their nests during aircraft overflights of any type (Table 2.3).

DISCUSSION

Human activity has clear effects on the sound environment of Cape Lookout National Seashore. Low-altitude Core MOA flights increased sound exposure levels (SEL) above ambient by an average of 14.22±3.96 dBA, and rotary wing aircraft increased them 8.39±0.76 dBA. Similar increases in environmental sound levels were reported for helicopter overflights in a study of King Penguins (Hughes et al. 2008). It is important to note that the decibel scale is not linear, but log-based. A ten decibel increase in sound levels is perceived by the average human as a doubling of sound intensity (Sataloff and Sataloff 2006), so the 14 dBA increase caused by the low-altitude Core MOA flights would be perceived by humans as more than twice as loud as the ambient environment.

I did not detect significant behavioral responses of American Oystercatchers to most aircraft, including high-speed low-altitude flights through the Core MOA airspace above North Core Banks. It appears American Oystercatchers either view aircraft as a minimal threat, or they have habituated to the presence of aircraft in their nesting environment. A similar lack of behavioral response, perhaps due to habituation, was noted in studies of raptors (Andersen et al. 1989, Ellis et al. 1991, Trimper et al. 1998), ducks (Conomy et al. 1998b), and penguins (Hughes et al. 2008).

Oystercatchers may have been on their nests more during non-MOA military fixed-wing flights as a freeze response to evade detection during the flights, or this result may indicate a response of birds to activities occurring before the flights that were not evident from my video or audio monitoring. Prior research at Cape Lookout National Seashore noted low-flying aircraft occasionally influenced oystercatcher incubation behavior (McGowan and Simons 2006). However, many aircraft flights in the nesting environment may not have been accounted for in this study because it used short-interval video recordings without audio, which may have missed non-visible overflights.

I did observe oystercatcher behavioral responses to all types of off-road vehicle and pedestrian activity. Previous research has noted that shorebirds respond differently to different types of human activity (Burger 1981, Sabine et al. 2008). Although off-road vehicle and pedestrian activity has been occurring in the nesting environment of the oystercatchers for many years, and some habituation may have occurred, off-road vehicles and pedestrians presumably represent a greater threat to incubating birds than aircraft. ATV activity, in particular, elicited a strong behavioral response from oystercatchers, with oystercatchers on their nest only about 30% of the time when ATVs drove past their nests. McGowan and Simons (2006) also found ATV traffic affected incubation behavior of American Oystercatchers along North Carolina coasts. The strong response of oystercatchers to ATVs may be an association between ATVs and the activity of researchers, because research activities on North Core Banks are conducted mainly from ATVs. Therefore, this finding may not be applicable to locations outside of North Core Banks where oystercatcher monitoring and research is not conducted on ATVs. American Oystercatchers at Cumberland Island National Seashore, Georgia responded to pedestrians much as they did in North Carolina, but showed a weaker response to vehicles and ATVs (Sabine et al. 2008). However, it is also likely that smaller, faster, and louder ATVs, with more visible human drivers, are perceived by birds as a greater threat than other types of vehicles. Tarr et al. (2010) found that ATVs altered wintering shorebird behavior and habitat use at Cape Lookout National Seashore even though the birds in his study were not regularly approached by ATVs. Oystercatchers nesting in open beach areas responded more strongly to off-road vehicle activity, presumably because they are more exposed with much greater visibility than oystercatchers nesting in more sheltered dune habitats.

The behavioral response of birds to off-road vehicles and pedestrians may explain some of the variation in the nesting success of American Oystercatchers. McGowan and Simons (2006) found evidence that vehicles and pedestrians influenced incubation behavior of American Oystercatchers and altered incubation behavior affected daily nest survival. Unattended eggs are likely more vulnerable to predators, such as ghost crabs and avian predators, and they are subject to temperature fluctuations that may harm the developing embryo (Anderson and Keith 1980, Robert and Ralph 1975). Although I found nest attendance influenced hatching success of American Oystercatcher nests, I did not find human activity affected oystercatcher nest attendance. Oystercatchers rely on their inconspicuous nest scrapes and cryptically-colored eggs to avoid detection by predators (Colwell et al. 2011, Lee et al. 2010). Higher rates of movement to and from a nest may attract predators or allow predators to locate nests more easily (Martin et al. 2000). Although I found oystercatchers were often off their nests during vehicle and pedestrian events, I found minimal evidence that human activity affected the total number of times oystercatchers left their nests in a day, suggesting oystercatchers move to and from their nests frequently during the day regardless of human activity.

My analysis of the behavior of oystercatchers in different types of vehicle closures was constrained by small sample sizes. Only nine nests in drive-through closures, 14 nests in ramp closures, seven nests in full closures, and two nests in no closure were available for this analysis. Furthermore, the location of nests within closures was not standardized, so the distance to and visibility of vehicles from nests most likely played a role in the response of oystercatchers. Finally, some ramp and full vehicle closures had occasional vehicle traffic because National Park Service staff and researchers continued to access closed areas with off-road vehicles to conduct research, monitoring, and management duties. Future research on the effects of vehicles would benefit from the establishment of complete vehicle closures for the duration of the incubation period, as well as larger closed areas to decrease visibility of vehicle activity beyond the boundaries of the closures.

I found no evidence, based on observations of banded individuals, that birds abandoned active breeding territories in areas of off-road vehicle use. However, I did document several oystercatcher pairs from failed nests outside of vehicle closures that re-nested within vehicle closures.

American Oystercatchers appear to respond differently to different types of human activity. While aircraft overflights elicited minimal behavior responses by the oystercatchers, I found a strong behavioral response to vehicles and pedestrians.

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TABLES AND FIGURES

Table 2.1. Effect of tide, surf swell, and wind speed on ambient sound levels at North Core Banks, Cape Lookout National Seashore, NC. Sound levels (dBA) were measured with Samson Zoom H2 Digital Audio Recorders from a week each in May, June, and July 2010. Sound levels are reported using two metrics, maximum L_{EQ}, the maximum equivalent average sound level recorded at one second intervals for the duration of the noise event, and Sound Exposure Level, which represents the total noise energy produced from a single noise event. Environmental data were obtained from the National Oceanic and Atmospheric Administration weather archives for nearby Ocracoke.

a. Welch's two-sample t-test comparing low and high tide sound levels individually

			Maximum L_{eq}			**Sound Exposure Level**		
		n	***mean±SE (dBA)***	***t***	***p-value***	***mean±SE (dBA)***	***t***	***p-value***
Tide	High	407	59.9±0.4	1.966	0.0498	83.1±0.3	3.483	0.0005
	Low	396	58.8±0.4			81.8±0.3		

b. Multiple linear regression comparing all environmental variables simultaneously.

	Maximum L_{eq}			**Sound Exposure Level**		
	Estimate±SE	***t***	***p-value***	***Estimate±SE***	***t***	***p-value***
(Intercept)	52.79±0.78	67.4	<0.0001	75.44±0.47	162.2	<0.0001
Tide (low)	-1.27±0.53	-2.4	0.0172	-1.55±0.31	-4.9	<0.0001
Surf Swell	6.38±0.69	9.3	<0.0001	6.99±0.41	17.1	<0.0001
Wind Speed	0.04±0.11	0.4	0.7188	0.03±0.07	0.5	0.603
	n=607, R^2=0.166			*n=607, R^2=0.405,*		

Table 2.2. Average change in sound levels from 20 minutes before to during various human activities recorded at American Oystercatcher nests at North Core Banks, Cape Lookout National Seashore, NC. Sound levels were measured with Samson Zoom H2 Digital Audio Recorders. Sound levels are reported as A-weighted Sound Exposure Level (dBA), which represents the total noise energy produced from a single noise event. Ambient sound levels were randomly sampled from an array of audio recorders distributed every two miles across North Core Banks with samples taken at times when no human activity was heard. The duration chosen for sampling ambient sound levels is 51 seconds, which is the average duration of human activity events. Core MOA flights were military aircraft corresponding with reported flights through the Core military operations area (Core MOA) above Cape Lookout National Seashore, NC, while military fixed-wing aircraft were other military aircraft not reported as flying through the Core MOA. ATVs were single-passenger all-terrain vehicles while UTVs were side-by-side utility-terrain vehicles.

Human Activity Type	*mean±SE (dBA)*	*F*	*n*	*p-value*
Core MOA Flight (Low-altitude)	14.22±3.96	567.5	110	<0.0001*
Core MOA Flight (High-altitude)	3.96±0.27	4.1	173	0.0433*
Military Fixed-Wing	4.59±0.14	199.8	1447	<0.0001*
Civilian Fixed-Wing	3.56±0.20	43.0	483	<0.0001*
Rotary-Wing	8.39±0.76	259.5	131	<0.0001*
Passenger Vehicle	1.05±0.13	5.1	589	0.0235*
ATV	1.80±0.12	5.6	776	0.0177*
UTV	1.27±0.21	3.0	145	0.0810
Ambient	-0.05±0.13		55	

**significant at p<0.05*

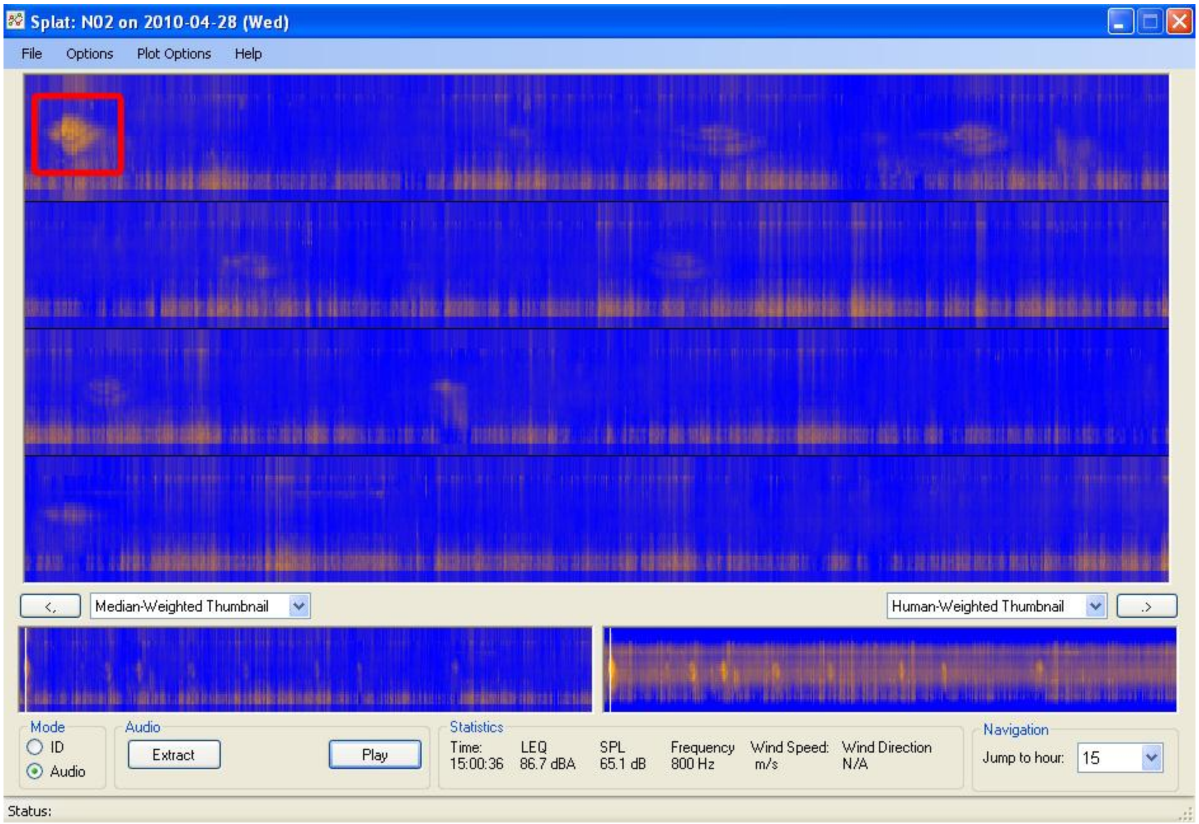
Table 2.3. Analysis of variance of the effect of vehicle closures on the proportion of observations per day of American Oystercatchers not on their nests during aircraft overflights. Vehicle closures were active vehicle management by the National Park Service at North Core Banks, Cape Lookout National Seashore, NC around shorebird breeding areas. Core MOA flights were military aircraft corresponding with reported flights through the military operations area (Core MOA) above Cape Lookout National Seashore, NC, while military fixed-wing aircraft were other military aircraft not reported as flying through the Core MOA.

Human Activity Type	*Overall F*	*Overall p-value*	*Closure Type*[*]	*Average Proportion ± SE*	*n*
Core MOA Flight	1.215	0.315	None	0±0	4
			Full	0.05±0.03	11
			Drive-through	0.19±0.08	21
			Ramp	0.07±0.06	16
Military Fixed-Wing	0.185	0.906	None	0.07±0.07	5
			Full	0.12±0.04	13
			Drive-through	0.13±0.06	18
			Ramp	0.10±0.03	33
Civilian Fixed-Wing	1.043	0.379	None	0.15±0.07	6
			Full	0.04±0.02	18
			Drive-through	0.13±0.04	16
			Ramp	0.13±0.04	35
Rotary-wing	2.269	0.105	None	0.50±0.50	2
			Full	0.0083±0.0083	10
			Drive-through	0±0	3
			Ramp	0.13±0.08	14

[*] *Vehicle closures types included in this analysis: (1) None - nests without closures were located in habitats away from approved vehicle routes with minimal management. (2) Full closures were large areas closed to protect nesting shorebirds and colonies; vehicles were excluded inside the closure but they could drive along parts of the perimeter. (3) Vehicle drive-through closures prevented vehicles from stopping in the vicinity of nests, but allowed driving by the nests. (4) Ramp closures required vehicle traffic to detour to the sand road behind the dunes.*

Figure 2.1. Video recording equipment used to monitor incubating American Oystercatchers and surrounding beach activity. The recording system consisted of a camera, digital video recorder, and batteries encased in a white 5-gallon plastic bucket (left). A camera unit deployed at an active oystercatcher nest at North Core Banks, Cape Lookout National Seashore, NC (right).

Figure 2.2. An audio recorder at mile marker nine on North Core Banks at Cape Lookout National Seashore, NC. The microphone/digital recorder (inset) is surrounded by a windscreen and suspended one meter above the ground. The white plastic bucket holds batteries that allow the recorder to run continuously for up to two weeks. An array of recorders distributed every two miles along the length of the island provided baseline ambient sound levels on the island. I also placed these recorders near American Oystercatcher nests to monitor sounds in the nesting environment.


Splat: N02 on 2010-04-28 (Wed)

○ ID
● Audio

Time: 15:00:36
LEQ 86.7 dBA
SPL 65.1 dB
Frequency 800 Hz
Wind Speed: m/s
Wind Direction N/A

Jump to hour: 15

Figure 2.3. Acoustic Monitoring Toolbox (AMT) audio analysis software. Audio recordings can be viewed visually as a spectrogram. Pictured above is a one-hour segment (shown as four consecutive 15 minute blocks) of an audio recording. A military fixed-wing flight recorded at North Core Banks, Cape Lookout National Seashore, NC is highlighted by the red box.

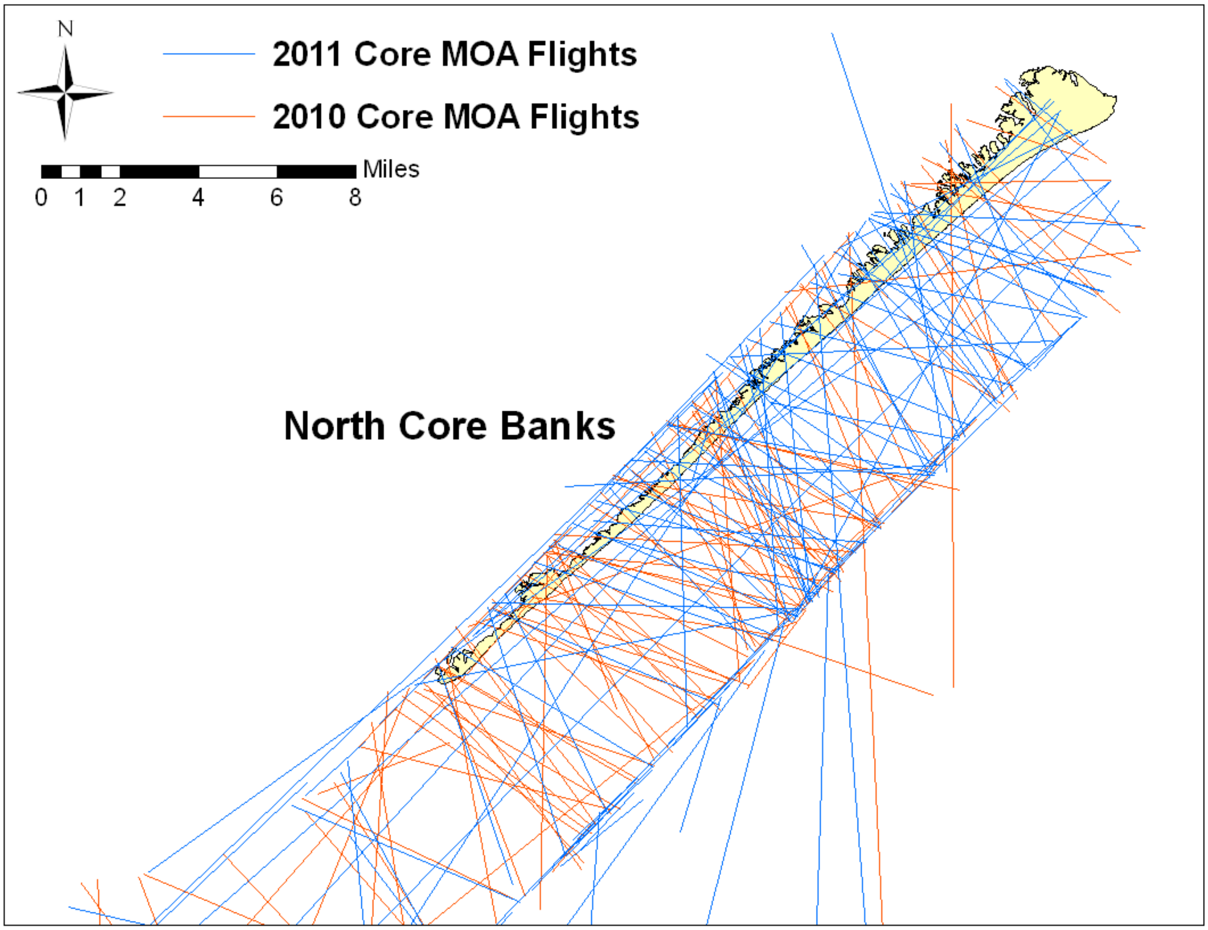


Figure 2.4. Map of military flight paths through the military operations area (Core MOA) airspace above North Core Banks, Cape Lookout National Seashore, NC in 2010 and 2011.

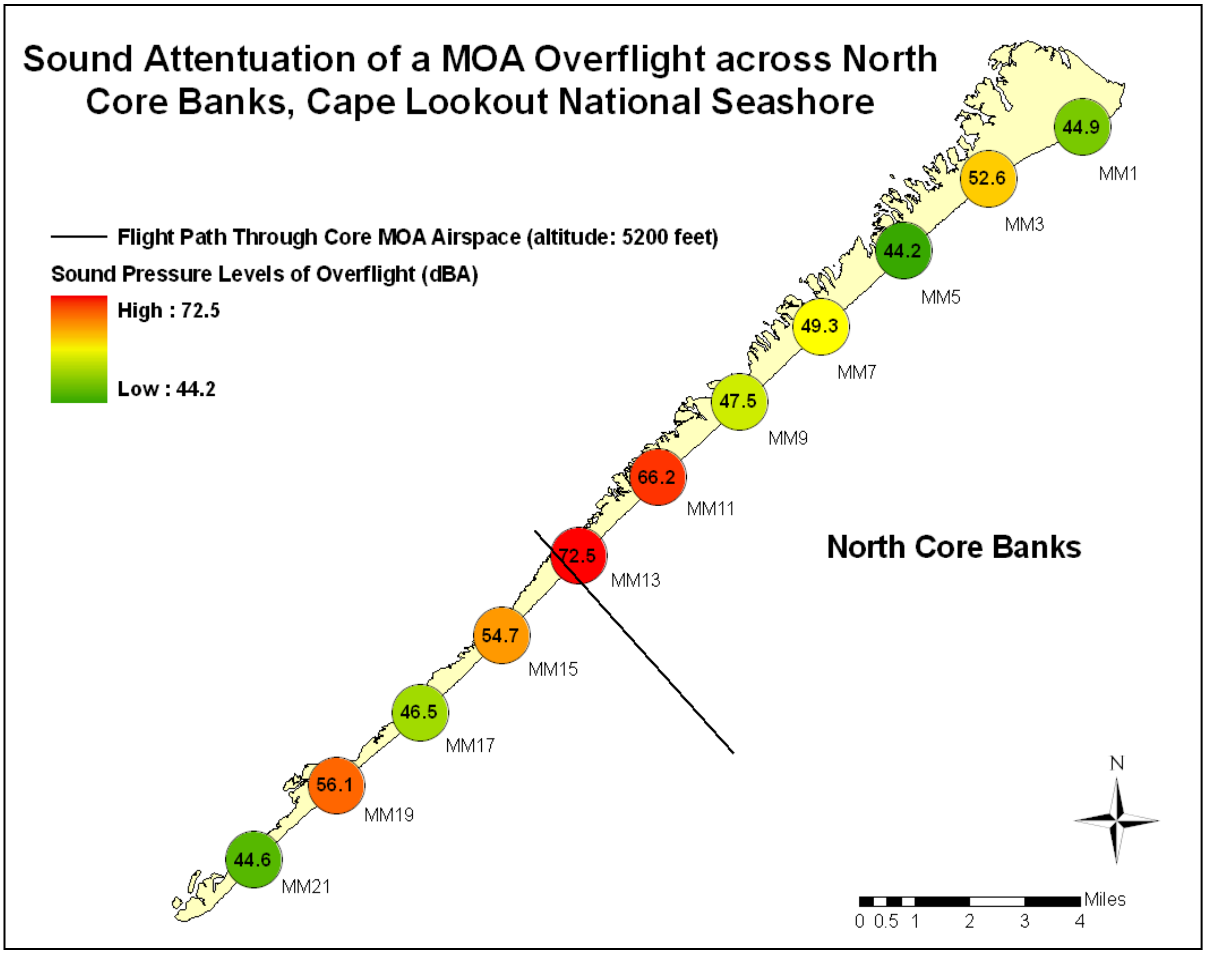


Figure 2.5. Instantaneous island-wide sound levels on North Core Banks, Cape Lookout National Seashore, NC during a flight through the military operations area (Core MOA) airspace above the island. The overflight occurred on 21 June 2010, and sound level measurements were taken at 09:43:48. Sound levels were calculated from recordings generated by audio recorders placed at mile markers (MM) every two miles across the length of the island.

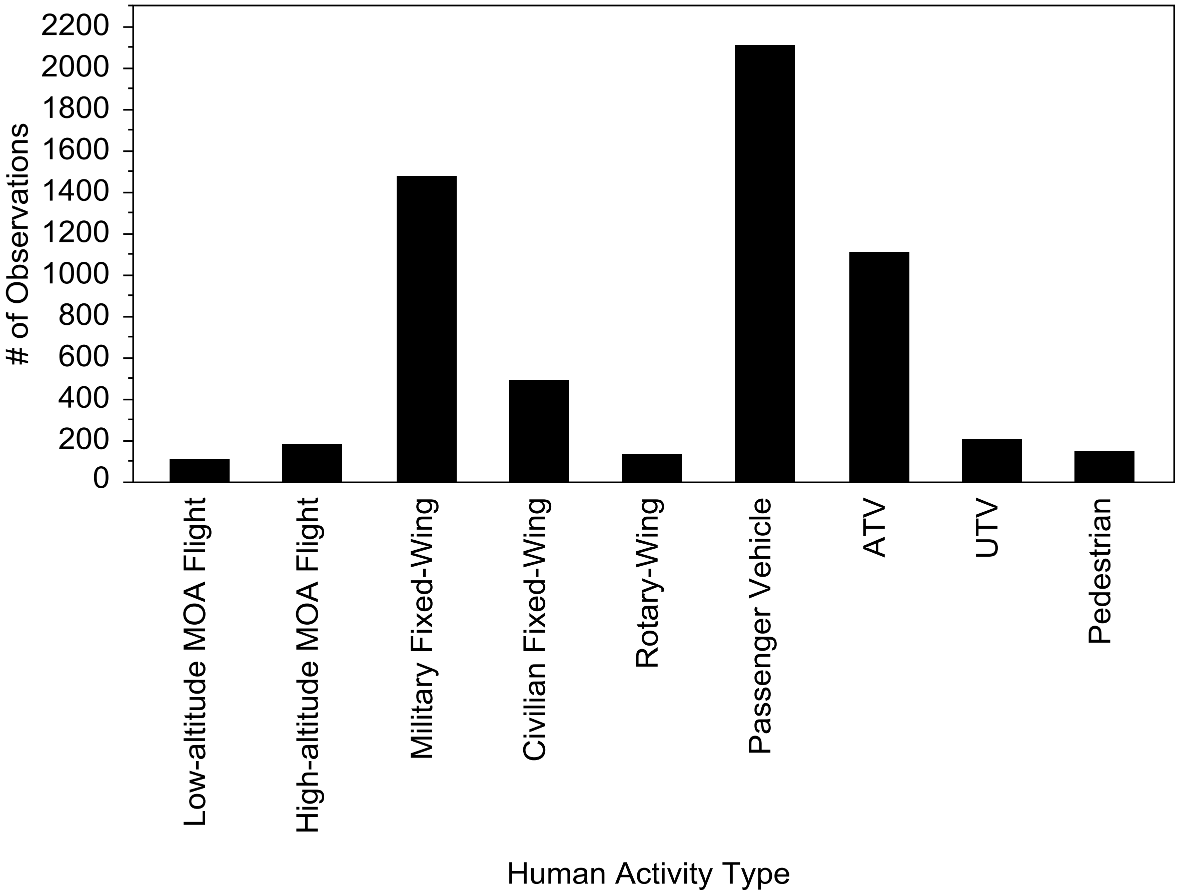


Figure 2.6. Human activities recorded near American Oystercatcher nests by video and audio monitoring equipment on North Core Banks, Cape Lookout National Seashore, NC. The plot is a tally of all incidents of each human activity type observed on video and audio recordings from 177 recording days from 56 nests monitored in 2010 and 2011. The plot shows relative abundance of each human activity category. MOA flights were military aircraft corresponding with reported flights through the military operations area (Core MOA) above Cape Lookout National Seashore, NC, while military fixed-wing aircraft were other military aircraft not reported as flying through the Core MOA. ATVs were single-passenger all-terrain vehicles while UTVs were side-by-side utility-terrain vehicles.

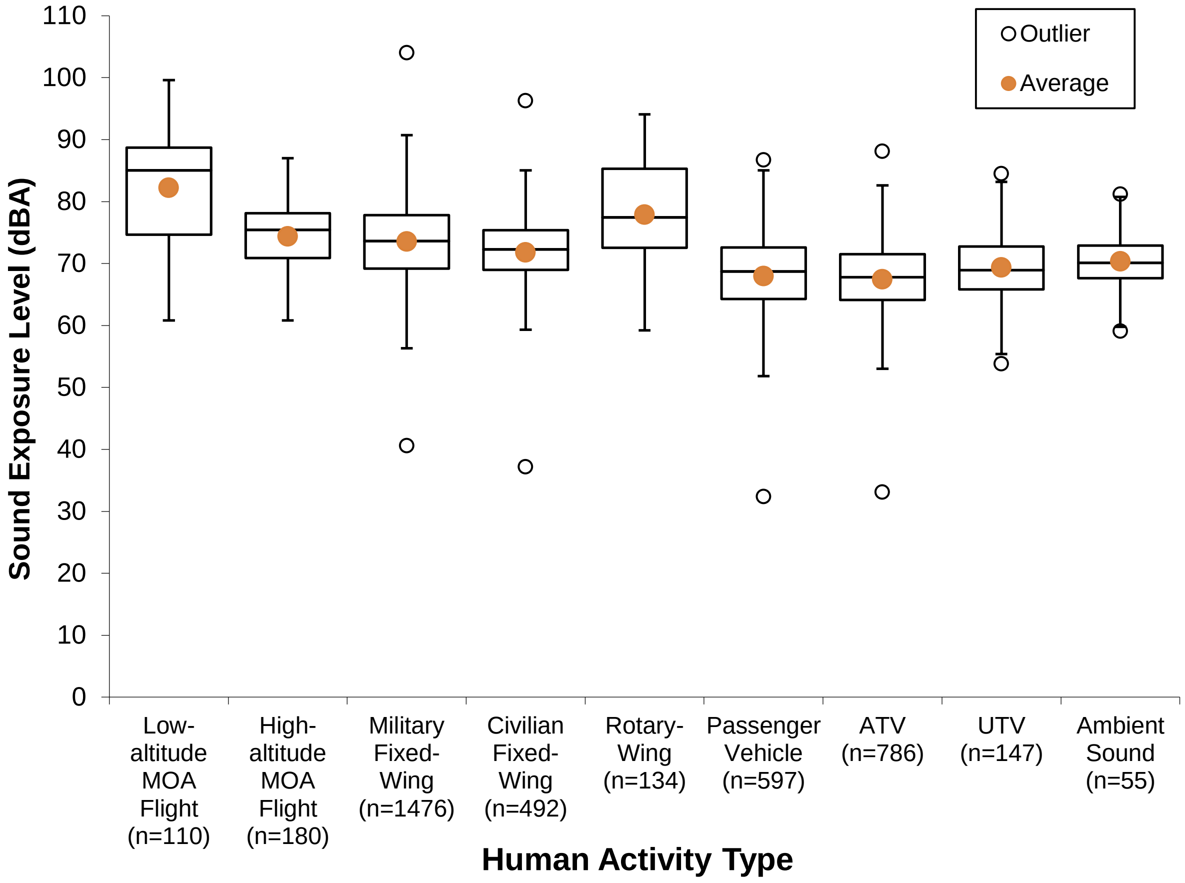


Figure 2.7. Sound levels, reported as Sound Exposure Levels (dBA), of various human activities recorded at American Oystercatcher nests on North Core Banks, Cape Lookout National Seashore, NC. Ambient sound levels were randomly sampled from an array of audio recorders distributed every two miles across North Core Banks with samples taken at times when no human activity was evident on the recordings. Sound Exposure Levels represent the total noise energy produced from a single event. They take into account A-weighted sound pressure levels measured at multiple frequencies over the duration of the event. MOA flights were military aircraft corresponding with reported flights through the military operations area (Core MOA) above Cape Lookout National Seashore, NC, while military fixed-wing aircraft were other military aircraft not reported as flying through the Core MOA. ATVs were single-passenger all-terrain vehicles while UTVs were side-by-side utility-terrain vehicles.

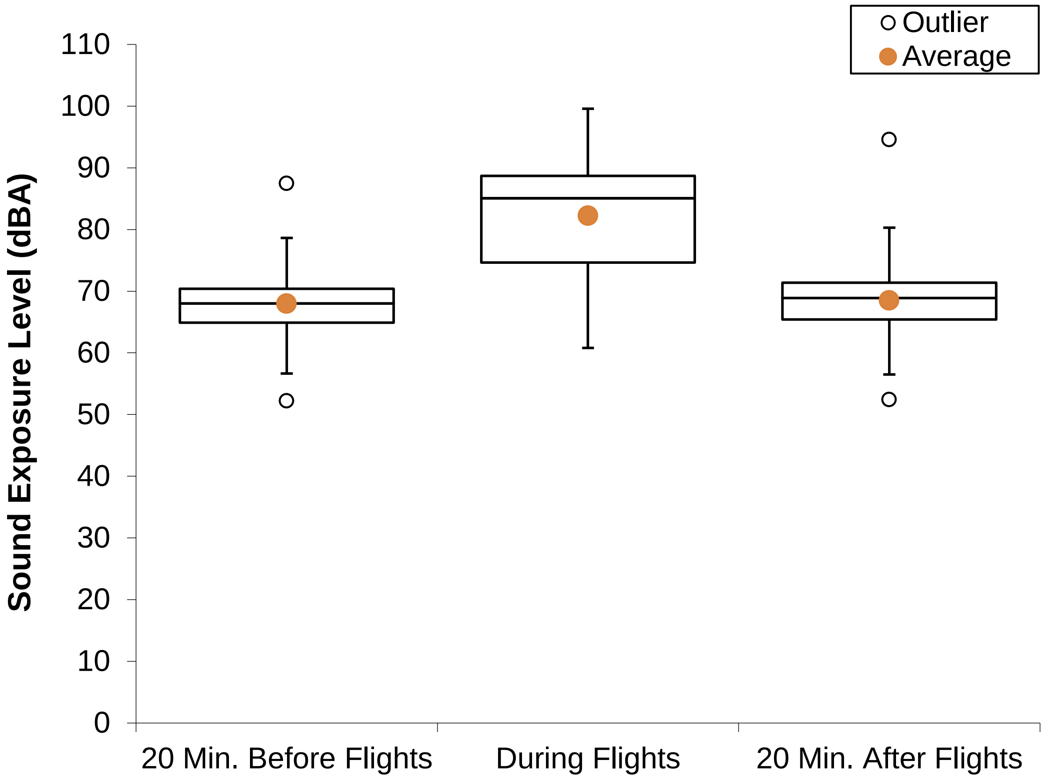


Figure 2.8. Sound levels recorded on North Core Banks, Cape Lookout National Seashore, NC before, during, and after low-altitude (<10,000 feet) overflights through the military operations area (Core MOA) airspace above the island (n=110). Sound levels are measured by A-weighted Sound Exposure Level (dBA), which is the total noise energy produced over the duration of a single noise event. Sound Exposure Levels before and after flights are calculated using the same sample duration as the flights.

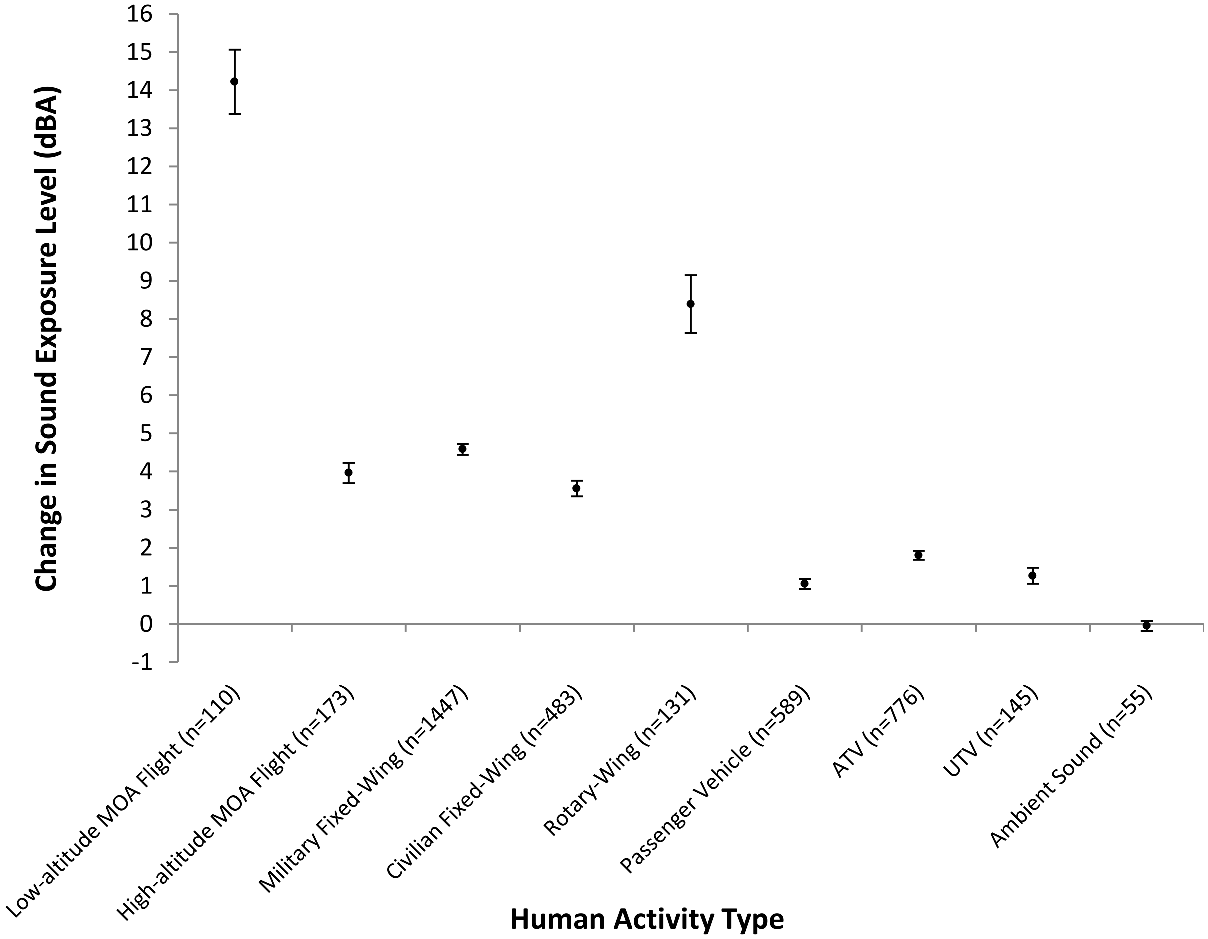


Figure 2.9. Average (±SE) change in sound levels, measured by A-weighted Sound Exposure Level (dBA), from 20 minutes before to during various human activities. Sound Exposure Level is the total noise energy produced over the duration of a single noise event. Samples 20 minutes before human activity events have the same duration as the corresponding sample during human activity events. Ambient sound "events" were randomly sampled from an array of audio recorders distributed every two miles across North Core Banks with samples taken at times when no human activity was evident on recordings. Similar to human activity events, the average change in ambient sound levels is calculated from 20 minutes before to during a randomly chosen sample. The duration chosen for sampling ambient sound "events" is 51 seconds, which is the average duration of human activity events. MOA flights were military aircraft corresponding with reported flights through the military operations area (Core MOA) above Cape Lookout National Seashore, NC, while military fixed-wing aircraft were other military aircraft not reported as flying through the Core MOA. ATVs were single-passenger all-terrain vehicles while UTVs were side-by-side utility-terrain vehicles.

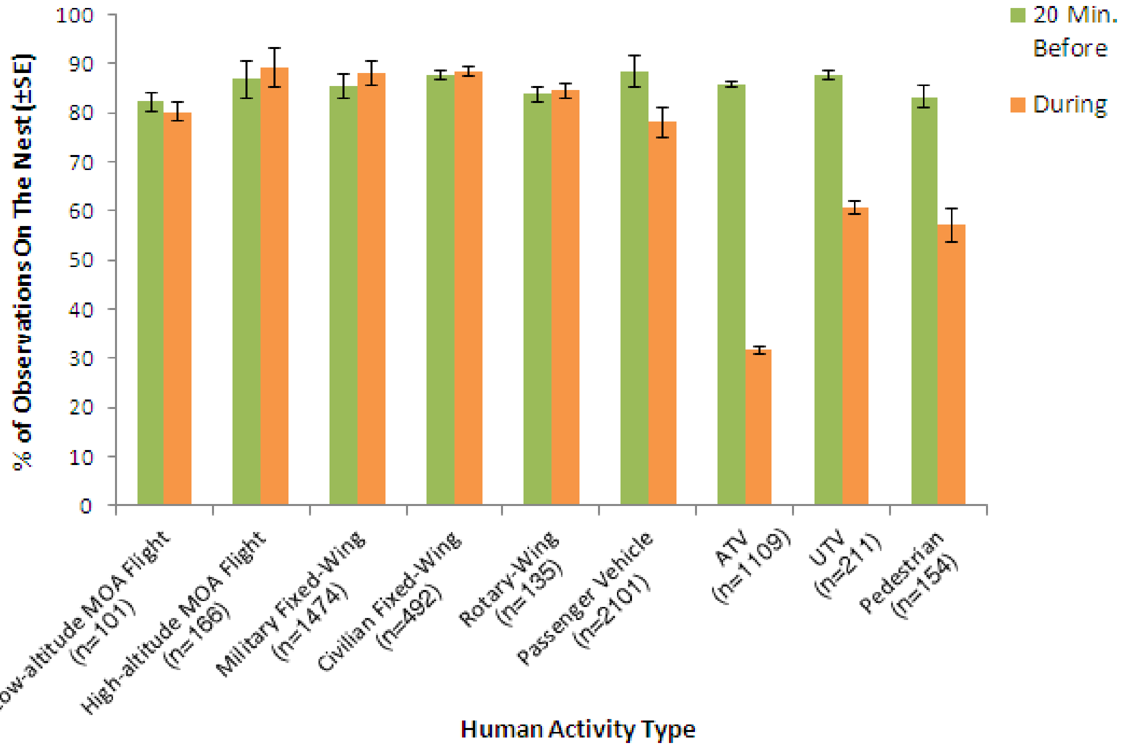


Figure 2.10. The percentage of observations (±SE represented by the black ticks on the tops of percentage bars) of American Oystercatchers on their nests during human activities and 20 minutes before those incidents of human activity occurred at North Core Banks, Cape Lookout National Seashore, NC. Sample sizes include all compiled observations of these human activities on recordings from 56 audio/video-monitored nests. MOA flights were military aircraft corresponding with reported flights through the military operations area (Core MOA) above Cape Lookout National Seashore, NC, while military fixed-wing aircraft were other military aircraft not reported as flying through the Core MOA. ATVs were single-passenger all-terrain vehicles while UTVs were side-by-side utility-terrain vehicles.

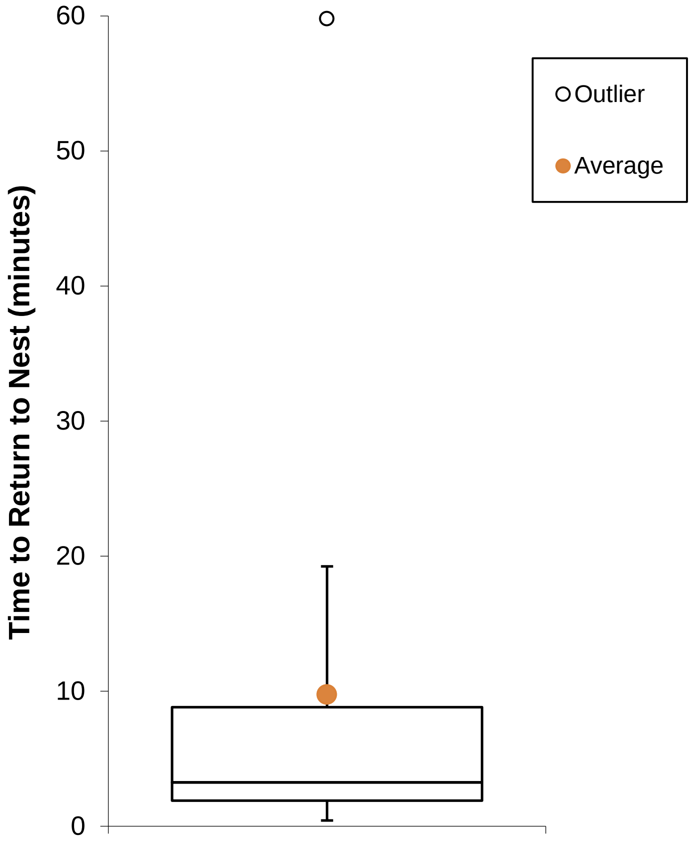


Figure 2.11. Return time for American Oystercatchers that left their nests during human activity events at North Core Banks, Cape Lookout National Seashore, NC (n=1638 events occurring at 52 nests).

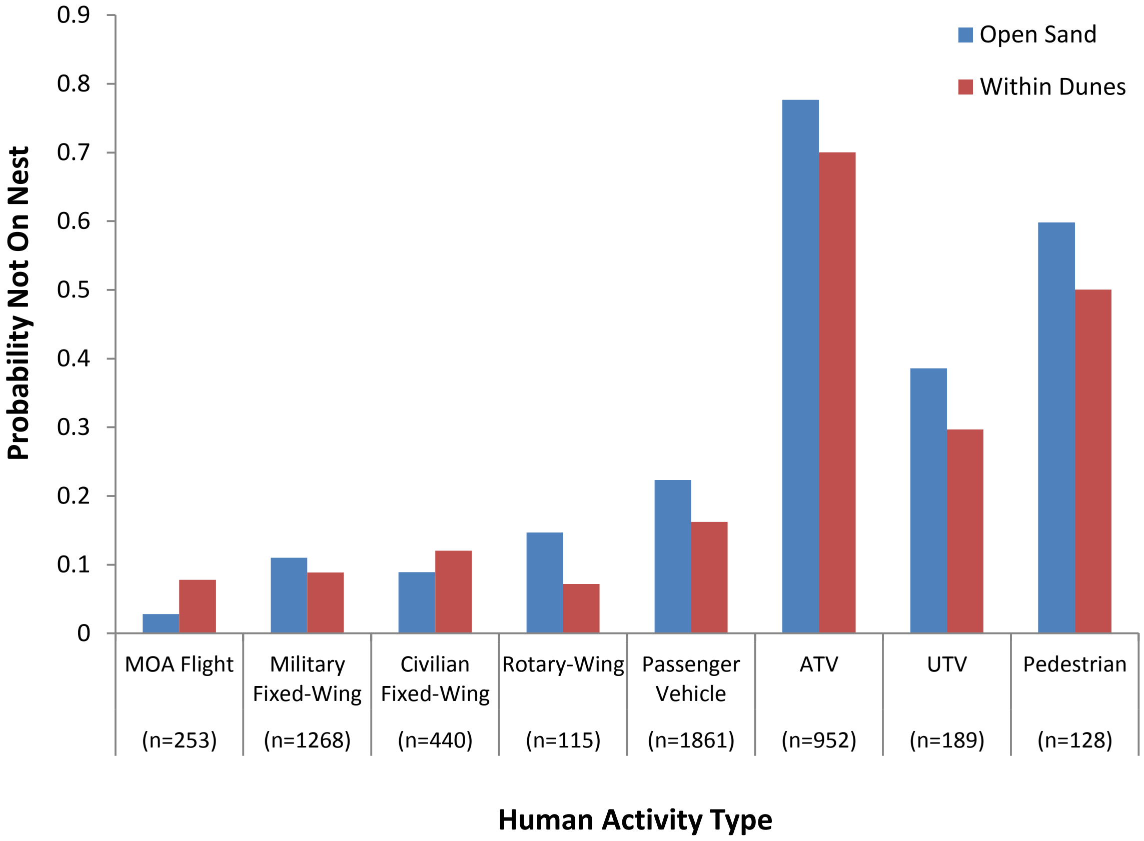


Figure 2.12. Probability that oystercatchers were not on their nest during various types of human activity in open sand and dune nesting habitats at North Core Banks, Cape Lookout National Seashore, NC. Open sand areas are habitat such as the open beach and sand flats in which visibility is high, while dune habitats are located within large dunes with more limited visibility. MOA flights were military aircraft corresponding with reported flights through the military operations area (Core MOA) above Cape Lookout National Seashore, NC, while military fixed-wing aircraft were other military aircraft not reported as flying through the Core MOA. ATVs were single-passenger all-terrain vehicles while UTVs were side-by-side utility-terrain vehicles.

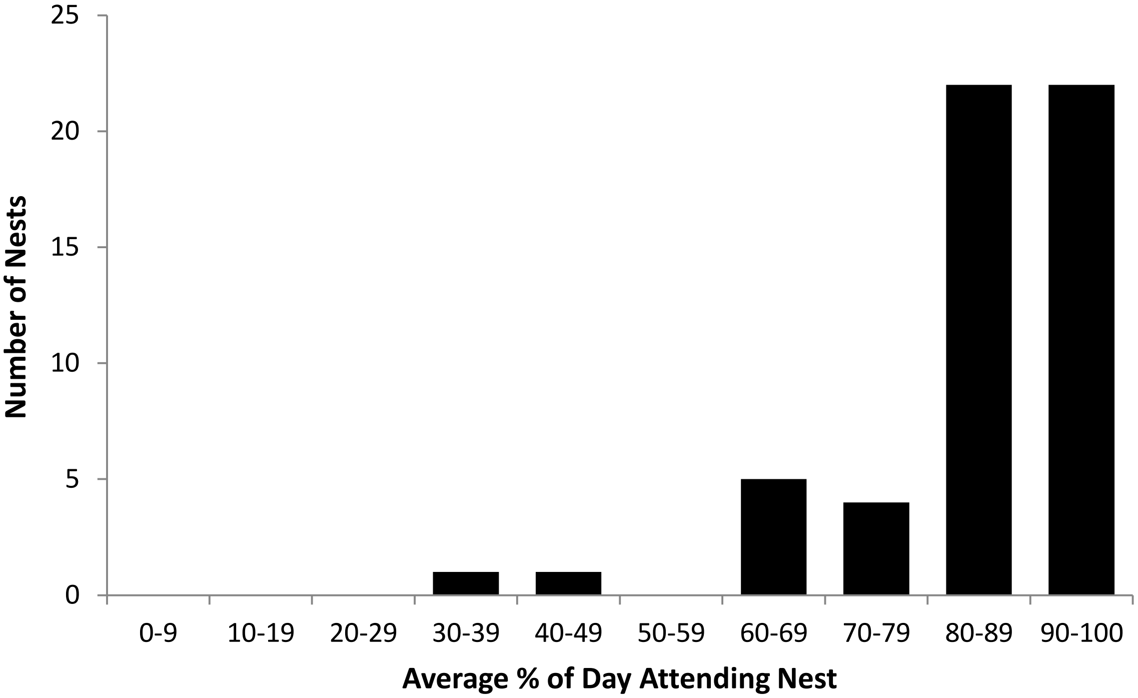


Figure 2.13. Frequency distribution of average daily nest attendance of video-monitored American Oystercatcher nests (n=55) at North Core Banks, Cape Lookout National Seashore, NC. Daily nest attendance is determined by the percent of a 24-hour period the birds spend at their nests either incubating or shading the eggs.

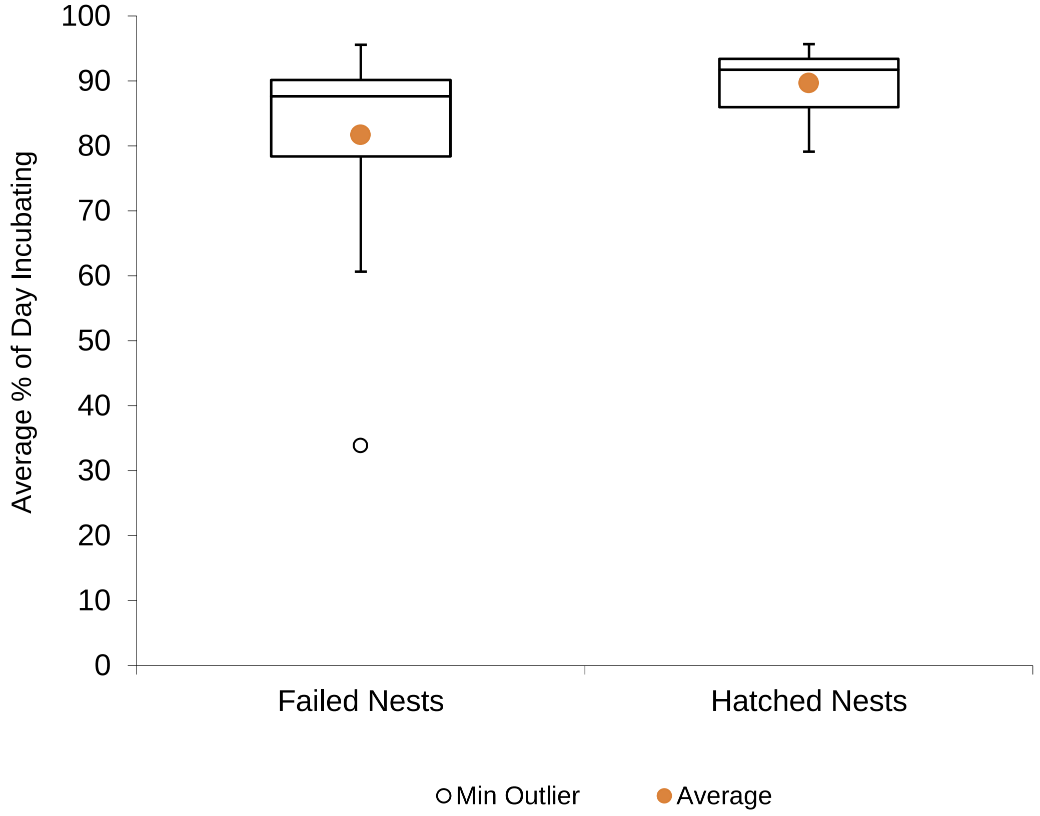


Figure 2.14. Average daily nest attendance of video-monitored American Oystercatcher nests which failed to hatch (81.7±2.5%, n=32) and nests which successfully hatched (89.7±1.0%; n=23) at North Core Banks, Cape Lookout National Seashore, NC.

CHAPTER 3

Effects of Human Activity on the Physiology of Nesting American Oystercatchers

ABSTRACT

An organism's heart rate is a commonly used indicator of physiological stress to environmental stimuli. I used heart rate to monitor the physiological response of American Oystercatchers (*Haematopus palliatus*) to human activity in their nesting environment. I placed artificial eggs with embedded microphones in 42 oystercatcher nests in 2010 and 2011, which recorded the heart rate of incubating oystercatchers continuously until nests hatched or failed. I compared heart rates to continuous video and audio recording at nests to determine the physiological response of birds to various types of human activity. I observed military and civilian aircraft, passenger vehicles, all-terrain vehicles, utility-terrain vehicles, and pedestrians around nests. With the exception of high-speed low-altitude military overflights, I found little evidence that oystercatcher heart rates were influenced by most types of human activity. The low-altitude flights were the only human activity to significantly increase average heart rates of incubating oystercatchers (from 161±4 beats/minute 20 minutes before the flights to 174±5 beats/minute during the flights). However, although statistically significant, I do not consider the increase in heart rate during high-speed, low-altitude military overflights to be of biological significance because this difference appears well within the range of variation for resting heart rate of this species.

INTRODUCTION

The effect of human activity on wildlife populations is a topic of great interest to ecologists, land managers, and policymakers (Boyle and Samson 1985, Sutherland et al. 2006, Sutherland 2007, Fleishman et al. 2011). Although research often focuses on behavioral responses of wildlife to human activity, the lack of a behavioral response does not imply a lack of disturbance (Wilson et al. 1991, Nimon et al. 1996). Human disturbance can produce a variety of physiological responses that may reduce the fitness of individual birds by reducing fecundity and survival (Wingfield and Sapolsky

2003). Hormonal and other physiological changes caused by stress may also directly suppress reproduction (Wingfield and Sapolsky 2003).

I examined physiological responses to human activity by measuring the heart rates of incubating birds. Heart rate monitoring is being used with greater frequency as a measure of disturbance (Hüppop and Hagen 1990, Wilson et al. 1991, Nimon et al. 1995, Nimon et al. 1996, Weisenberger et al. 1996, Harms et al. 1997, Giese et al. 1999, Bisson et al. 2009). Weisenberger and others (1996) found that simulated aircraft noise caused heart rates to increase in desert ungulates. Although Adelie penguins showed both behavior responses and increased heart rates in response to approaching helicopters, their response to approaching humans was limited to increasing heart rate until very close proximity (Wilson et al. 1991). Heart rate responses to human disturbance for Gentoo Penguins were more ambiguous (Nimon et al. 1995, Culik and Wilson 1995). European Oystercatchers exhibited increased heart rate during human disturbance (Hüppop and Hagen 1990). Simulated jet noise initially increased heart rate of Black Ducks, but the response rapidly declined as exposure continued with no effect on overall daily heart rate suggesting no net energetic cost to the ducks (Harms et al. 1997). White-eyed vireos exhibited a similar pattern, initially increasing their heart rate in response to human disturbance, but with little evidence of long-term effects on energy expenditure (Bisson et al. 2009).

Monitoring avian heart rates often requires stressful captures and the use of externally mounted or internally implanted monitoring devices (Culik 1992, Harms et al. 1997, Bisson et al. 2009). I adapted a non-invasive method for recording the heart rates of breeding birds using small microphones mounted in false eggs (Nimon et al. 1996, Arnold et al. 2011). I placed these devices in American Oystercatcher nests at Cape Lookout National Seashore, North Carolina to monitor the heart rate of the incubating oystercatchers in response to human activity.

METHODS

Field Methods

Anthropogenic Activity and Behavior Monitoring at Nests

I monitored the incubation behavior of American Oystercatchers and human activity in the vicinity of their nests during the 2010 and 2011 breeding seasons with continuous digital video and audio recording. I was unable to monitor all American Oystercatcher nests with recording equipment and therefore used a stratified sampling scheme in which I randomly selected breeding pairs for monitoring from strata determined by location along the length of the island, location relative to the primary dunes, and vehicle closure status. I recorded continually 24 hours per day at selected nests until the nest either failed or hatched. Video cameras monitored the incubating oystercatcher's behavior, as well as the surrounding beach for human activity, and audio recordings provided a record of both natural and anthropogenic sounds in the immediate vicinity of the oystercatcher nests. Due to differences in the landscape around nests, the total area surveyed by video recordings varied among nests. Video recordings also provided information about nest predation, incubation rates, and interspecific interactions.

I classified nests by habitat as either open sand or dune nests. Open sand habitats included the open beach and sand flats where the terrain was flat and open with minimal vegetation. Dune habitats were areas of varying and elevated terrain and vegetation.

Heart Rate Monitoring at Nests

I recorded the heart rates of incubating oystercatchers using miniature microphones implanted in artificial eggs that were added to a clutch for the duration of nest survival. This allowed me to make continuous audio recordings of the incubating oystercatcher's heart rate. This minimally invasive design has been used previously with terns and gulls (Arnold et al. 2011), but for much shorter monitoring intervals. I constructed my heart rate sensors by drilling a hole in a plastic egg and mounting a small microphone flush with the surface of the shell (Figure 3.1). A wire lead attached to the microphone allowed me to connect the sensor to an external digital audio recorder. The plastic eggs and microphones were then covered with either a balloon or Parafilm™ (I found balloons were the superior membrane for producing good heart rate recordings) to protect and conceal the microphone. The covering was painted to resemble an American Oystercatcher egg. I assembled 20 artificial egg monitors, placing one egg in a nest for heart rate monitoring. Once I began heart rate monitoring at a nest, I continued monitoring continuously 24 hours per day for the duration of the incubation period. Artificial eggs were checked every few days and periodically replaced as their outer membrane deteriorated. I adapted the same Zoom H2 digital audio recorders used for ambient noise monitoring to record heart rates. I placed the recorder and battery in a plastic bucket buried approximately 30 feet from the nest. I also buried the wire connecting the artificial egg to the recorder. During the 2010 breeding season, I buried the initial length of the cord straight down about six inches below the artificial egg to tether the egg in place. I hoped this would help maintain the proper orientation of the microphone beneath the incubating bird while allowing some manipulation of the egg. However, I found this method allowed too much movement of the egg causing the microphone to become misaligned and unable to record the heartbeat. Therefore, during the 2011 breeding season, I attached a 6-inch screw to the wire slightly below the artificial egg, and secured this screw in the sand below the nest. This more rigid configuration continuously maintained the correct orientation of the microphone increasing the consistency and quality of heart rate recordings. On occasion, the artificial egg became separated from the rest of the clutch due to the activity of the incubating adults. If this occurred, I moved the artificial egg a few inches to the new nest location.

In 2011, I made additional modifications to improve the heart rate recordings. I tested a new artificial egg design with two microphones embedded in the egg instead of one, with the objective of increasing the chances a microphone would pick up the heartbeat if the position of the egg shifted beneath the incubating bird. I also adjusted and changed the artificial eggs in the nests more frequently to reduce the deterioration of recording quality over time that I observed in 2010. Nevertheless, I did not see improved performance in eggs with two microphones. However, anchoring the artificial egg with a nail and placing fresh artificial egg monitors more frequently increased the number and quality of the recordings. With increased effort and alterations in the design of the heart rate monitors, I was able to double heart rate recording hours in 2011.

Although I was initially concerned that the artificial eggs might disturb incubating birds, I saw little indication of this problem. In fact, on several occasions following destruction of the clutch by a nest predator, adults returned to their nests and continued to incubate the remaining artificial egg until I removed it. I checked nests with heart rate monitoring equipment daily. I did not add an artificial egg to the single nest with a four-egg clutch, because four eggs is the maximum number of eggs oystercatchers are known to incubate.

Analysis of Heart Rate Recordings

I collected approximately 48,000 hours of video and audio recordings and 12,000 hours of heart rate recordings during the 2010 and 2011 breeding seasons. The United States Marine Corps, Cherry Point Naval Air Station provided information on timing, location, speed, and altitude of military overflights through the Core MOA airspace above Cape Lookout National Seashore. I used this information with the time stamps on the audio and video recordings to identify the Core MOA flights on the recordings and assess them independently from other types of aircraft. Analyses were conducted by reviewing all video, audio, and heart rate recordings collected during known Core MOA overflights. In addition, starting on the day following the deployment of recording equipment at a nest (i.e., the first full 24-hour day of recording), I reviewed all video and audio recording files within a 24-hour period from every fourth day of monitoring. From these sub samples, I noted every occasion when an oystercatcher left or returned to its nest, every incident of human activity (either heard on the audio recordings, seen on the video recordings, or both), and the behavior of the incubating oystercatcher before and during the human activity events. A human activity “event” was defined as the time at which an incident of human activity could first be seen or heard on the recordings to the time it was no longer visible or heard. Anthropogenic activities recorded in the nesting environment included; Core MOA overflights (military aircraft corresponding with reported flights through the Core MOA), other military fixed-wing aircraft (military aircraft not reported as flying through the Core MOA), civilian fixed-wing aircraft, rotary-wing aircraft (I could not differentiate military from civilian rotary-wing aircraft), passenger vehicles, all-terrain vehicles (ATVs; single passenger), utility-terrain vehicles (UTVs; all-terrain vehicles with two passengers side-by-side), and pedestrians. If an oystercatcher was on the nest during a human activity event, I reviewed the heart rate recording corresponding to that incident and calculated heart rate before, during and after as many human activity events as possible. Despite more and better heart rate recordings in 2011, it was impossible to calculate heart rates during some events due to poor recordings.

I used Adobe® Audition® audio-editing software (Adobe Systems Incorporated) to analyze heart rate recordings. I counted the heart beats as I heard them in the recording, and compared those counts to the number of spikes on the visual waveform produced in Adobe® Audition® (Figure 3.2). When necessary, I slowed the playback speed of rapid heart rate recordings to facilitate these analyses. I took 10-second samples of heart rate at the peak of events (either the loudest point of the event on the audio recordings or when the human activity stimulus was closest to the nest in the video recordings) and extrapolated those samples to beats per minute by multiplying the sampled heart rate by six. Heart rate was measured in a similar manner exactly 20 minutes before the peak time of an event as a control.

If necessary, I used Adobe® Audition® to review video, audio, and heart rate files simultaneously. Concurrent viewing and listening allowed me to align the three recordings with a high degree of temporal accuracy, not achievable by the timestamp on the recordings alone.

Statistical Analysis

Heart Rate Monitoring

I compared hatching success ratios of nests with and without heart rate monitors using a chi-squared test.

Physiological Response

All statistical analyses were conducted in R (R Development Core Team 2011), applying a significance level of 0.05. Initially, I pooled heart rate samples from all pairs of oystercatchers for a general analysis of their physiological response to human activity. I compared heart rate samples before and during human activity using paired t-tests, hypothesizing that heart rate during human activity would be higher than the baseline heart rate 20 minutes before incidents of human activity. Responses to each type of human activity were also assessed individually. I also compared heart rate samples after human activity to heart rate samples before and during human activity using paired t-tests, hypothesizing that heart rate 20 minutes after human activity events would be lower than heart rate during human activity and the same as baseline heart rate 20 minutes before human activity. I compared sound levels and oystercatcher heart rate during human activity using simple linear regression.

To take into account potential response variation among breeding pairs of oystercatchers, and to assess other potential explanatory variables, I also conducted an analysis using a linear mixed model (linear mixed effects model). In this model, human activity type, nesting habitat type, the mean number of human activity events per day, and the day in the incubation period of the nest were fixed effects, and nest (breeding pair) was a random effect. In preliminary analyses, interactions between variables were not significant, so I did not include them in my final model. Because I was specifically interested in flights through the Core MOA, I conducted another analysis using the same model described above, but with human activity type reclassified into only two categories: 1) Core MOA flights and 2) all other human activity types. Again, interactions were not significant, so were excluded from the model. I also used a mixed effects linear regression model to compare the effects of Core MOA flight altitudes on the heart rate responses of oystercatchers. This analysis included only Core MOA flights. The model included altitude as a categorical fixed effect (low versus high altitude), nesting habitat type, the mean number of human activity events per day, and the day in the incubation period of the nest as fixed effects, and nest (breeding pair) as a random effect. High altitude flights were defined as those 10,000 feet and above; low-altitude flights were below 10,000 feet. Interactions were not significant, so were excluded from the model.

RESULTS

Heart Rate Monitoring

I monitored 42 nests (38% of 112 total nests; 18 in 2010 and 24 in 2011) laid by 36 breeding pairs of oystercatchers with heart rate monitoring artificial eggs. I collected approximately 12,000 hours of heart rate recordings (~4,000 hours in 2010 and ~8,000 hours in 2011). Of the 42 nests with heart rate monitors, 15 successfully hatched and 27 failed. The proportion of successfully hatched heart-rate-monitored nests (0.36) was not significantly different than nests that were not monitored (0.26) ($\chi^2 = 0.828$, $p = 0.363$).

Physiological Response

Heart rate samples came from all 36 oystercatcher pairs with heart rate monitoring in 2010 and 2011. I calculated a “resting” heart rate of American Oystercatchers by opportunistically sampling heart rate of incubating oystercatchers which had their bills tucked under a wing, a common resting posture in birds, when I heard and saw no evidence of human activity on the video and audio recordings. Resting heart rate of incubating oystercatchers ranged from 126-288 beats/minute with an average of 189±6 beats/minute ($n = 35$ samples from 18 pairs).

Baseline heart rate samples 20 minutes before human activity events ranged from 108-342 beats/minute (*n* = 662), while heart rate samples during human activity ranged from 114-336 beats/minute (*n* = 662). The average heart rate of incubating oystercatchers during human activity events for all activity types combined (186±1 beats/minute) was not significantly higher than the baseline heart rate from birds 20 minutes before the human activity events occurred (184±1 beats/minute), (paired $t = 1.39$, df = 530 ($n = 531$), $p = 0.918$). Heart rate 20 minutes after human activity events ranged from 108-366 beats/minute (*n* = 475). The average heart rate 20 minutes after human activity events for all activity types combined (186±2 beats/minute) did not differ significantly from the baseline 20 minutes before human activity events (188±2 beats/minute), (paired $t = 1.29$, df = 474 ($n = 475$), $p = 0.901$) or the average during human activity events (186±2 beats/minute), ($t = 0.20$, df = 474 ($n = 475$), $p = 0.839$).

However, the heart rate of oystercatchers 20 minutes before low-altitude Core MOA flights (161±4 beats/minute) was significantly less than the heart rate during the flights (174±5 beats/minute) (Table 3.1, Figure 3.3). Average heart rates before events were not significantly different than during the events for all other types of human activity (Table 3.1, Figure 3.3). I found no correlation between sound levels and oystercatcher heart rate during human activity events (MaxLEQ: $R^2 = 0.001$, $p = 0.253$; SEL: $R^2 = 0.005$, $p = 0.070$). The noise of rotary-wing aircraft and low-altitude Core MOA flights occasionally drowned out the sound of the heart beats on the recordings making it impossible to calculate a heart rate during those events.

I postulated that other variables may have been affecting the physiological response such as the habitat of the nesting environment, the daily amount of human activity occurring around a nest, and the stage of the incubation period in which the event occurred. Restricting my analysis to only human activity events where an oystercatcher was on the nest 20 minutes before the events occurred, and taking into account the potential for variation among the responses of individual pairs of oystercatchers, I did not find evidence to suggest that nesting habitat, mean number of events per day, day of incubation, or type of human activity had an effect on oystercatcher heart rate ($n = 410$ observations from 26 nests; Habitat: $F = 2.01$, $p = 0.173$; Mean # Events: $F = 0.73$, $p = 0.401$; Incubation Day: $F = 1.67$, $p = 0.200$; Event Type: $F = 1.17$, $p = 0.319$). Comparing flights through the Core MOA (all altitudes) to all other human activity types combined I found that the average heart rate during Core MOA flights (174.6±4.2 beats/minute) was not significantly different from the average heart rate of oystercatchers during non-Core MOA human activities (187.8±1.8 beats/minute) ($n = 410$ observations from 26 nests, $F = 0.03$, $p = 0.858$). I did find a significant effect of the altitude of Core MOA flights on the heart rate of incubating oystercatchers. Average heart rates of incubating birds were 27.7 beats per minute higher during low altitude flights than they were during high altitude flights (*n* = 34 observations from 14 nests, *F* = 6.18, *p* = 0.040).

DISCUSSION

The heart rates of incubating oystercatchers were not influenced by most types of human activity, perhaps because they had habituated to these activities. Habituation was noted as a potential reason for minimal behavioral responses of several raptor species to low-level jet overflights (Ellis et al. 1991, Trimper et al. 1998). Physiological response may show similar patterns of habituation as well. Harms and others (1997) suggested habituation as the explanation for declines in heart rate responses of Black Ducks to continued exposure to aircraft noise.

However, the recent reduction in the minimum altitude of high-speed Core MOA flights may make them a relatively novel event for birds nesting on North Core Banks. I did find evidence that the heart rate of incubating American Oystercatchers increased during high-speed low-altitude Core MOA flights. Low-altitude flights may also be more visible than high-altitude flights and the visual stimulus of the jet combined with higher sound levels during low-altitude flights may represent a stronger threat to incubating oystercatchers than other forms of human activity. This effect may be true for rotary-wing aircraft as well, as they too had high sound levels and were seen flying at low altitudes, however the noise of rotary aircraft often obscured the heartbeat of the incubating oystercatchers in my recordings, so sample sizes for these aircraft were insufficient for analysis. Physiology changes, such as increased heart rate, often reflect higher stress levels and higher energetic costs which may be detrimental to reproduction (Wingfield and Sapolsky 2003). Although I did occasionally observe individual cases of elevated heart rates in response to other forms of human activity, low-altitude Core MOA flights were the only type of human activity that significantly increased the heart rate of incubating oystercatchers. However, although statistically significant, it is not clear that this increase is biologically significant. I found, on average, that heart rate was 13 beats per minute higher during low-altitude Core MOA flights than baseline rates 20 minutes before. And, average heart rate during low-altitude flights was 27.7 beats per minute higher than during high-altitude flights. A short-term (50 hours) study of a single pair of European Oystercatchers, a species very similar to American Oystercatchers, found a range of 16 beats per minute (152-168 beats/minute) in the baseline heart rate of the pair as they incubated their nest (Hüppop and Hagen 1990). Given that resting heart rates for American Oystercatchers varied over a range of 162 beats per minute (126-288 beats/minute), it is unlikely that the increase in heart rate during low-altitude Core MOA flights is biologically significant. Furthermore, the infrequency of these low-altitude flights, 24 in 2010 and 35 in 2011 during the 3-month oystercatcher nesting seasons, suggests they would have a negligible physiological cost and minimal biological significance to nesting oystercatchers.

It is clear that American Oystercatchers respond to aircraft, vehicles, and humans in different ways. Birds showed elevated heart rates in response to low-altitude Core MOA flights but they seldom left their nests (Results, Chapter 2). In contrast, birds frequently responded to off-road vehicles and pedestrians by leaving their nests, but when remaining on their nests during these human activity types did not show elevated heart rates. I suspect that birds detect vehicles and pedestrians visually at greater distances and either have elevated heart rate immediately prior to departing their nests or depart before their heart rates are elevated. Birds that are habituated to these activities may remain on their nests and not show elevated heart rates.

I did occasionally record very brief increases in heart rate at the beginning of vehicle and pedestrian events. These quickly subsided, presumably after the birds assessed the source of the event. To further evaluate this phenomena, I sub-sampled a small number (n=93) of human activity events continuously from five minutes prior to the event to five minutes after the event, taking 20-second samples of heart rate every minute and found no indication of bias in my sampling protocol. Nevertheless, I found considerable fluctuation in the baseline heart rate 20-minutes before human activity was well as in the resting heart rates of incubating oystercatchers during periods with no evidence of human activity. These variations may reflect unaccounted for differences among individual oystercatchers, variations in ambient temperature and associated thermoregulatory demands, or they may indicate a response of birds to activities that were not evident from my video or audio monitoring. Although perhaps not sensitive enough to discriminate among more subtle responses, I believe my heart rate sampling protocol was proficient for detecting strong consistent responses to human activities. American Oystercatchers which remain on their nests during human activity at Cape Lookout National Seashore do not exhibit strong heart rate responses.

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TABLES AND FIGURES

Table 3.1. Incubating American Oystercatcher heart rates (beats per minute) before and during different types of human activity in the vicinity of their nests. Core MOA flights were military aircraft corresponding with reported flights through the military operations area (Core MOA) above Cape Lookout National Seashore, NC, while military fixed-wing aircraft were other military aircraft not reported as flying through the Core MOA. ATVs were single-passenger all-terrain vehicles while UTVs were side-by-side utility-terrain vehicles.

Human Activity Type	*HR Before mean±SE (bpm)*	*HR During mean±SE (bpm)*	*paired t*	*df*	*n*	*p-value*
Core MOA Flight (Low-altitude)	161±4	174±5	-2.044	26	27	0.0256*
Core MOA Flight (High-altitude)	187±10	176±9	1.290	12	13	0.2215
Military Fixed-Wing	189±2	186±3	1.356	161	162	0.1771
Civilian Fixed-Wing	183±4	180±3	1.307	88	89	0.1948
Rotary-Wing	175±7	182±11	-0.888	14	15	0.3893
Passenger Vehicle	188±2	187±2	0.601	257	258	0.5485
ATV	191±5	189±5	0.382	54	55	0.7038
UTV	208±8	196±7	1.790	22	23	0.0873
Pedestrian	207±9	200±9	0.462	16	17	0.6501

**significant at $p<0.05$*

Figure 3.1. A plastic egg with an embedded microphone (left). Once covered and painted to resemble real American Oystercatcher eggs, the sensors were added to an active nest and used to record the heart rate of incubating American Oystercatchers (right). The red arrow indicates the artificial egg in the nest. The microphone is visible as a white spot on the upper surface of the egg.

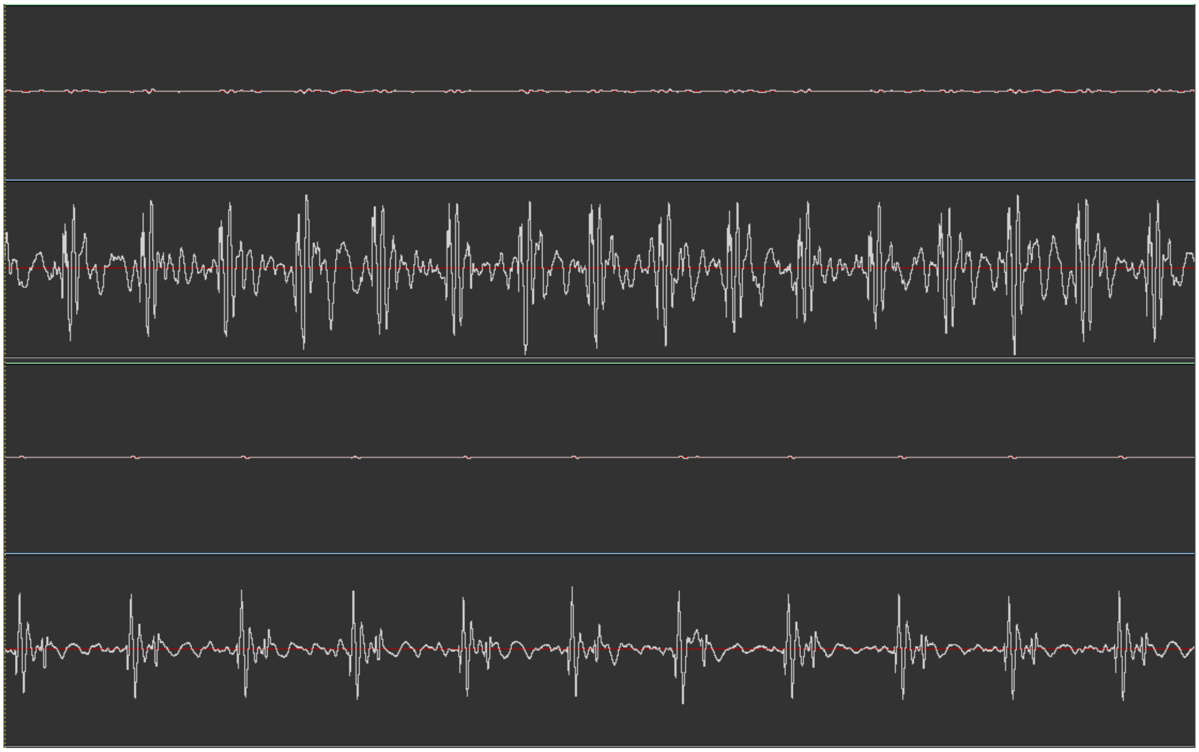

Figure 3.2. Ten-second clips from audio recordings of American Oystercatcher heart beats viewed as waveforms in Adobe® Audition® audio-editing software (Adobe Systems Incorporated). The top heart rate waveform is from an incubating American Oystercatcher and corresponds to a heart rate of 228 beats/minute. The bottom waveform is from an incubating American Oystercatcher and corresponds to a heart rate of 168 beats/minute.

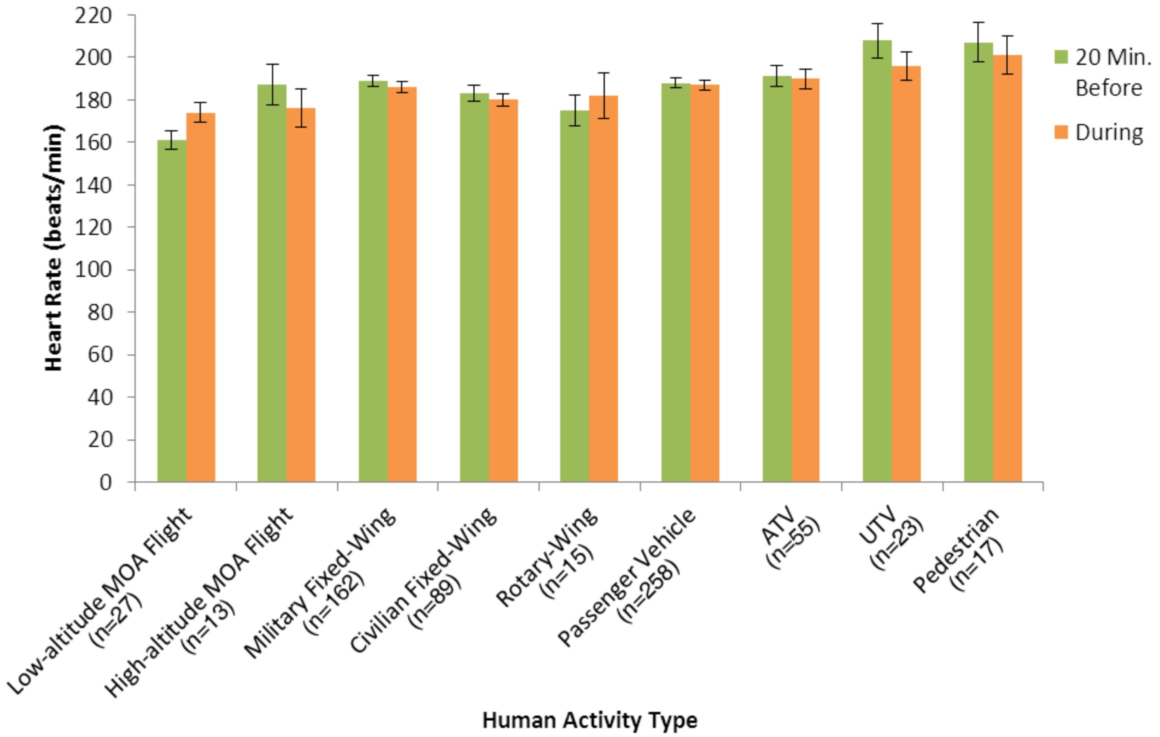

Figure 3.3. Average (±SE) heart rate of American Oystercatchers before and during human activities. Samples include all 42 oystercatcher pairs monitored for heart rate in 2010 and 2011. MOA flights were military aircraft corresponding with reported flights through the military operations area (Core MOA) above Cape Lookout National Seashore, NC, while military fixed-wing aircraft were other military aircraft not reported as flying through the Core MOA. Low-altitude Core MOA flights were the only human activity type for which oystercatchers had higher average heart rate during than before the activity. ATVs were single-passenger all-terrain vehicles while UTVs were side-by-side utility-terrain vehicles.

CHAPTER 4

Effects of Human Activity on the Annual Reproductive Success of American Oystercatchers

ABSTRACT

Many shorebird species have declining populations, with human disturbance implicated as a factor contributing to this trend. This study assessed the effects of human activity on the reproductive success of the American Oystercatcher (*Haematopus palliatus*), a nesting shorebird of conservation concern on the Outer Banks of North Carolina. The research supplemented long-term monitoring of American Oystercatcher productivity that has continued since 1995 at Cape Lookout National Seashore in North Carolina, with 24-hour video and audio monitoring at 62 nests in 2010 and 2011. Average nest survival and productivity (chicks fledged per pair) were relatively high (0.340±0.041 and 0.617±0.133, respectively) suggesting that experimental low-altitude overflights through the airspace over Cape Lookout, as well as recording equipment at nests, had little effect on reproductive success. I assessed incubation behavior, human activity, vehicle management practices, and habitat effects on daily nest survival rates and nest success using multiple logistic regression models, logistic exposure models, and AIC. I found that daily numbers of off-road vehicles was the only variable consistently associated with significant reductions in nest success and daily survival.

INTRODUCTION

Research and surveys have noted reductions in many shorebird populations (Flemming et al. 1988, Howe et al. 1989, Clark et al. 1993, Donaldson et al. 2000, Brown et al. 2001). Human use and disturbance is one factor believed to strongly contribute to these population declines. Human use has been found to cause bird mortality, to decrease the amount of suitable nesting habitat, to displace birds, and to alter bird breeding activity leading to reduced reproductive success (Carney and Sydeman 1999, Brown et al. 2001). For example, increased human access decreased the numbers of Dunlin on Delaware Bay beaches in New Jersey (Clark et al. 1993). Low use of New Jersey beaches by Common Terns, Least Terns, Black Skimmers, and Herring Gulls for breeding was attributed to heavy human development and use (Erwin 1980). Human activity decreased nesting success of Herring Gulls (Hunt 1972) and Black Skimmers (Safina and Burger 1983). Black skimmers also had reduced fledging success correlated to higher levels of disturbance and abandoned heavily disturbed breeding areas (Safina and Burger 1983). Human recreation increased chick loss for Snowy Plovers in northern California (Ruhlen et al. 2003), while Snowy Plovers moved into areas newly protected from humans in Santa Barbara, California and initiated highly successful breeding (Lafferty et al. 2006). Human activity has also been found to have detrimental effects on the reproductive success of non-shorebird species including Brown Pelicans (Anderson and Keith 1980), Black-crowned Night Herons (Tremblay and Ellison 1979), Mourning Doves (Westmoreland and Best 1985), Great Tits (Halfwerk et al. 2011), and Adelie Penguins (Giese 1996).

The American Oystercatcher is a beach-nesting shorebird strongly tied to coastal habitats along the Atlantic and Gulf coasts of the United States (American Oystercatcher Working Group et al. 2012). Population declines (Mawhinney and Bennedict 1999, Nol et al. 2000, Davis et al. 2001) lead to listing the species as a “species of high priority” in the United States Shorebird Conservation Plan (Brown et al. 2001). In North Carolina, it is considered a “species of special concern” (North Carolina Wildlife Resources Commission 2008). Early monitoring of American Oystercatchers in North Carolina suggested a link between low nesting success and human activity (Novick 1996). Favored human recreational areas on open beaches adjacent to the ocean are also prime nesting habitat for American Oystercatchers. Human activity on these beaches can destroy nests or flush incubating oystercatchers from nests leaving the nests more susceptible to predation and unprotected from temperature fluctuations (Sabine et al. 2008). Human activity was associated with increased egg and chick loss of a similar species, African Black Oystercatchers (Tjorve and Underhill 2008) and it may have played a significant role in the extinction of the Canarian Black Oystercatcher (Hockey 1987). This study assessed the effects of various human activities on the reproductive success of American Oystercatchers on the Outer Banks of North Carolina. The research supplemented long-term monitoring of American Oystercatcher productivity that has continued since 1995 at Cape Lookout National Seashore in North Carolina, with 24-hour video and audio monitoring of nests.

METHODS

Productivity Monitoring

I conducted surveys of American Oystercatchers on North Core Banks at Cape Lookout National Seashore during the oystercatcher breeding season from early April to early August in 2010 and 2011. Birds were located by driving the length of the island. I identified birds exhibiting breeding or territorial behaviors, and then located nests by observing the birds, following their tracks, or systematically searching areas of suspected breeding activity. I attempted to locate every oystercatcher nest on the island during the breeding seasons in both 2010 and 2011.

Nests in vehicle traffic areas were posted with signs by National Park Service personnel to inhibit human and vehicle activity in the immediate vicinity of the nest, and to prevent nests from being run over. Nests on the open beach were provided additional protection in the form of a drive-through-only corridor that extended 300 feet on either side of the nest. The National Park Service also completely closes areas of high shorebird and tern breeding to vehicles and pedestrians. In 2011, the National Park Service closed additional sections of the beach to vehicles by rerouting traffic to a primitive road behind the dunes, which allowed me to monitor nests in areas without beach driving. These different management practices allow the National Park Service to adapt their vehicle management to changing conditions during the breeding season. I identified five classifications of vehicle management used in 2010 and 2011 for my analyses. Full closures were large areas closed to protect nesting terns and Piping Plovers; vehicles were excluded inside the closure but they could drive along parts of the perimeter. Nest-only closures were small areas posted with signs along a 15-foot radius around the nest. Vehicles were not managed (no closure) at nests located in dune or other habitats away from approved vehicle routes. Ramp closures rerouted vehicles around active nests on the oceanfront beach to the interior primitive road behind the dunes. Drive-through closures prevented vehicles from stopping in the vicinity of nests, but allowed driving by the nests.

I also classified nests by habitat as either open sand or dune nests. Open sand habitats included the open beach and sand flats where the terrain was flat and open with minimal vegetation and visibility was high. Dune habitats were areas of varying and elevated terrain and vegetation with limited visibility.

I monitored nests to estimate the distribution, abundance, productivity, survival, and incubation behavior of oystercatchers and to determine levels of human activity in the nesting environment. Nest monitoring was conducted by direct observation every 1-3 days and with continuous audio and video recording (as described in Chapter 2) until the eggs hatched or the nest failed. If a nest failed, I determined the cause of nest failure from evidence at the nest site or by reviewing the nest monitoring video.

The National Park Service also established vehicle closures for all breeding oystercatcher pairs with chicks by rerouting traffic along the primitive road behind the primary dunes. Areas lacking a primitive road were posted with signs to reduce the vehicle speed limit and warn vehicle operators of the presence of chicks. I located and observed chicks every 1-2 days after hatching to determine chick survival and fledging dates.

Banding

I banded a total of 42 American Oystercatchers for future identification; three adults and 14 chicks in 2010, and one adult and 24 chicks in 2011. Banding is ongoing on North Core Banks, with several hundred oystercatchers banded at Cape Lookout National Seashore over 10 years prior to this study, so I did not put extensive effort into banding adults as many were banded previously. However, I attempted to band every chick that survived to 25 days of age (the age at which the legs of most chicks are large enough to accommodate a band). I used both U.S. Geological Survey metal bands and large alphanumeric color bands engraved with unique codes for each bird. Alphanumeric bands are readable with binoculars and spotting scopes at distances of up to 100 m. I resighted banded birds throughout the study to document movement patterns, habitat use, and survival. Adults were captured using an American oystercatcher decoy, recorded American Oystercatcher vocalizations, and a “Whoosh Net” (Figure 4.1). I captured chicks by hand, or with light hand nets.

Statistical Analyses

I used Program MARK (White and Burnham 1999) to estimate nest and chick survival and Program CONTRAST (Hines and Sauer 1989) to compare productivity estimates.

I compared hatching success ratios of nests with and without equipment using a chi-squared test. I included variables for oystercatcher behavioral responses, human activity, vehicle closure type, and habitat type in multiple logistic regression models to assess the effect of these covariates on nest success.

Daily nest survival rates and the effects of covariates were assessed with a logistic exposure model in the software, R (R Development Core Team 2011). The logistic exposure model accounts for biases associated with variations in the age of discovery and exposure periods of nests, heterogeneity in daily survival rates among nests, and allows for the inclusion of explanatory variables (Shaffer 2004, Shaffer and Thompson 2007). The effect of monitoring equipment at a nest on daily nest survival and hatching success was assessed apart from other nest covariates as data for other covariates were collected using the monitoring equipment making them fully dependent.

I used a significance level of 0.05, and odds ratios with 95% confidence intervals to assess the magnitude of the effect of any significant explanatory variable. I compared competing candidate models containing combinations of explanatory variables using Akaike's information criterion.

RESULTS

I observed 68 adult American Oystercatchers on North Core Banks (approximately two oystercatchers/kilometer) during the 2010 breeding season. Of these, 31 pairs made 58 nesting attempts (Table 4.1). The first nest was found on 21 April 2010 and the last nest failed on 31 July 2010. Thirty chicks hatched from 15 nests, and 15 of those chicks survived to fledging.

During the 2011 breeding season, I observed 68 adult American Oystercatchers on North Core Banks (approximately two oystercatchers/kilometer). Of these, 32 pairs made 54 nesting attempts (Table 4.1). The first nest was found on 14 April 2011 and the last nest failed on 14 July 2011. Thirty-seven chicks hatched from 18 nests, and 24 of those chicks survived to fledging.

Nest survival was 0.259±0.059 in 2010 and 0.333±0.064 in 2011, increasing from 0.175±0.060 in the year prior to the study (2009) (Table 4.1, Appendix 1). Nest survival continued to increase the year after the study (0.346±0.093 in 2012). Chick survival on North Core Banks was lower in 2010 (0.500±0.091) than in 2009 (0.533±0.129), but increased to 0.649±0.078 chicks fledged per chicks hatched in 2011, then dropping only a small amount to 0.636±0.111 in 2012. Breeding productivity (chicks fledged per breeding pair) was 0.484±0.089 in 2010 increasing to 0.750±0.149 in 2011 and 0.933±0.284 in 2012, all of which were higher than productivity in 2009 (0.276±0.121). Average nest survival during study years (0.340±0.041, 2010-2011) was higher than nest survival in pre-study years for which we have data (0.280±0.059, 1999-2009), although the averages were not significantly different ($\chi^2 = 1.597$, df = 1, $p = 0.206$) (Figure 4.4). Average productivity during study years (0.617±0.133, 2010-2011) was significantly higher than productivity in pre-study years for which I have data (0.345±0.022, 1998-2009) (χ^2 = 6.495, df = 1, *p* = 0.011) (Figure 4.5). Nest survival, chick survival, and productivity in study seasons were comparable to or higher than overall levels in North Carolina from 1995-2012 (Table 4.1, Appendix 1). I also calculated daily nest survival rates (n=112) using a logistic exposure model (Shaffer 2004). The overall daily survival rate for all nests was 0.966±0.004.

Nests in both study breeding seasons (2010 and 2011) were distributed across the length of the island in open beach, inter-dune, and sand flat habitats (Figure 4.2). A nest-free area on the southern half of the island is centered around a small area of development and concentrated human activity. Almost one third (28.57%) of nests attempted in both years successfully hatched chicks (Figure 4.3). Predation was by far the greatest cause of nest failure (41.96% of total nests). Environmental elements, such as wind and storm overwash were responsible for failure of 10.71% of nests and 7.14% of nests were abandoned. I was unable to determine the causes of nest failure for 11.61% of the nests. Video recording at the nests increased my knowledge of the causes of nest failure from 52% historically (*n* = 1172 nests from 1999-2008) (Schulte 2012) to 88% in this study (*n* = 112 nests from 2010-2011).

Of the 62 nests (33 in 2010 and 29 in 2011) monitored with video and audio equipment throughout the incubation period, 24 nests successfully hatched chicks and 38 failed. Hatching success at nests with recording equipment (0.39) was significantly higher than hatching success at nests without recording equipment (0.18) (χ^2 = 4.759, *p* = 0.029). The presence of recording equipment was also significantly associated with increased daily nest survival (Estimate±SE = 0.564±0.235, *z* = 2.40, *p* = 0.016). The odds of daily nest survival were 1.76 (95% C.I.: [1.12, 2.77]) times greater for nests with recording equipment, than those without.

I then assessed the effects on hatching success and daily nest survival (*n* = 48 nests) of other covariates including: the average number of aircraft events per day, the average number of off-road vehicle events per day, the vehicle closure type (type of management of human activity around nests), the average number of times oystercatchers left their nests per day, the average daily nest attendance, and nest habitat type. The average number of off-road vehicle events per day was the only variable significantly correlated to decreased daily nest survival (Table 4.2) and hatching success (Table 4.3), given the presence of the other variables. For every increase in average off-road vehicle numbers per day, the odds of a nest surviving each day decreased 6% (odds ratio = 0.94, 95% C.I.: [0.90, 0.98]) and the odds of successful hatching of a nest decreased by 12% (odds ratio = 0.88, 95% C.I.: [0.76, 0.97]).

The best-fitting logistic exposure model (from a set of candidate models including combinations of the above variables) assessing effects on daily nest survival included the average number of off-road vehicles per day, the type of vehicle closure, and daily nest attendance, although differences in AIC values among models were minimal (Table 4.4). When I reran the analysis including only variables from the top model, off-road vehicle numbers had a significant effect (Estimate(SE) = -0.05(0.02), $z = -3.013$, $p = 0.003$), decreasing the odds of nest success by 6% (odds ratio = 0.94, 95% C.I.: [0.91, 0.98]). Only one type of vehicle closure, no closure, had a significant effect (Estimate(SE) = -1.35(0.63), $z = -2.14$, $p = 0.032$), decreasing the odds of nest success by 75% (odds ratio = 0.25, 95% C.I.: [0.07, 0.90]) compared to nests in full closures. Nest attendance did not significantly affect nest success (Estimate(SE) = 0.03(0.02), $z = 1.50$, $p = 0.134$). The best-fitting regression model assessing effects on hatching success contained only the average number of off-road vehicles per day, although differences in AIC values among models were minimal (Table 4.5). When I reran the analysis including only variables from the top model, the average number of off-road vehicles per day was negatively correlated with hatching success (Estimate(SE) = -0.13(0.05), $z = -2.82$, $p = 0.005$), decreasing the odds of hatching by 12% (odds ratio = 0.88, 95% C.I.: [0.79, 0.95]).

Records of the timing of placement and removal of vehicle closures in 2011 allowed me to estimate the proportion of the incubation period that a nest was protected by a vehicle closure. I added this covariate to my regression and logistic exposure models analyzing the 2011 nests ($n = 25$). Again, the average number of off-road vehicle events per day was significantly correlated to decreased daily nest survival and hatching success, but in this analysis, I also found a significant positive correlation between the average number of aircraft overflights and daily nest survival (Table 4.6) and hatching success (Table 4.7). Every increase in the average number of off-road vehicles per day produced an 8% decrease in the odds of daily nest survival (odds ratio = 0.92, 95% C.I.: [0.86, 0.96] and a 34% decrease in the odds of hatching success (odds ratio = 0.66, 95% C.I.: [0.40, 0.93]). The odds of nests surviving each day increased by 10% (odds ratio = 1.10, 95% C.I.: [1.01, 1.21]) and the odds of successful hatching of nests increased by 34% (odds ratio = 1.34, 95% C.I.: [1.07, 1.89]) for every one flight increase in aircraft overflights per day.

The best-fitting logistic exposure model assessing effects on daily nest survival did not contain average number of aircraft overflights. It included only the average number of off-road vehicle events per day and nest habitat type (Table 4.8). As with prior model comparisons, AIC values did not differ greatly among the models. When I reran the analysis only including variables included in the top model, only the average number of off-road vehicle events per day had a significant effect (Estimate(SE) = -0.06(0.03), $z = -2.195$, $p = 0.028$), decreasing the odds of success by 6% (odds ratio = 0.94, 95% C.I.:[0.90, 0.99]). The effect of habitat was not significant (Estimate(SE) = -1.07(0.63), $z = -1.71$, $p = 0.088$). The best-fitting regression model assessing effects on hatching success contained the average number of aircraft overflights, the average number of off-road vehicle events per day, and nest habitat type (Table 4.9). Again, AIC values did not differ greatly among the models. When I reran the regression including only variables from the top model, none of the variables had a statistically significant association with hatching success (Vehicles: Estimate(SE) = -0.15(0.09), $z = -1.69$, $p = 0.090$; Aircraft: Estimate(SE) = 0.09(0.06), $z = 1.60$, $p = 0.109$; Habitat: Estimate(SE) = -2.98(1.58), $z = -1.89$, $p = 0.059$).

DISCUSSION

Reproductive success of American Oystercatchers on North Core Banks during the two seasons of this study were comparable to, or in many cases higher than, past reproductive success on the island for the 12 years (1998-2009) prior to this research (Appendix B). This is true when compared to historical statewide data for North Carolina as well (Stocking 2012). Research in other states has documented observed nest survival ranging from 0.038 in New Jersey in 2005 and 2006 to 0.46 in Georgia in 2004 (American Oystercatcher Working Group et al. 2012). A similar study of video-monitored American Oystercatcher nests at Cumberland Island National Seashore in Georgia, had an equivalent rate of nest predation (40.63%, Sabine et al. 2006).

The average number of off-road vehicles driving by nests per day showed a significant negative correlation with nesting success in almost every analysis. McGowan and Simons (2006) found a relationship between ATV traffic and changes in incubation behavior of American Oystercatchers and suggested that variations in nest attendance associated with ATV traffic might explain variations in nesting success. I did not find a strong correlation between behavior of incubating oystercatchers and metrics of nesting success, so cannot identify a clear mechanism to explain the relationship between vehicle traffic and nest survival. Nest attendance was included as a variable affecting daily survival rates of nests in the best-supported model for 2010 and 2011 nests, however its effect was not statistically significant. A comparison of the average daily nest attendance for hatched versus failed nests (Chapter 2) did suggest nest attendance was higher for successful nests (t = 2.972, df = 40.894, p = 0.0049), but it did not point to a strong relationship between daily nest attendance and the number of off-road vehicle events in a day (n = 175, R^2 = -0.004, F = 0.349, p = 0.555); Chapter 2).

Although the number of off-road vehicles is correlated with nesting success, I saw no indication that breeding pairs abandoned their territories following nest failure. I frequently saw the same individually marked oystercatchers nesting in the same location from year to year. The high nest site fidelity of American Oystercatchers could be problematic in areas of high human activity. Sutherland (2007) described these sites as ecological traps; habitats that seem ideal when oystercatchers are selecting breeding sites but prove to be of low quality later in the breeding season, hindering reproductive success. It is noteworthy that almost no oystercatchers nested within two miles of the island’s permanent lodging facilities during this study. This area experiences heavier human activity and vehicle traffic than other parts of the island. In 2012, a single pair including one individual that was banded as a chick three years earlier attempted to breed near the developed area, and fledged three chicks. However, one chick was later found dead on the primitive interior road apparently hit by a vehicle. Determining the population-level effects of human disturbance, particularly in long-lived species with highly variable annual productivity such as American Oystercatchers, will take years of carefully monitoring rates of fecundity and survival in this population.

I am at a loss to explain why the average number of aircraft overflights per day showed a positive relationship with both nesting success and daily survival rates in 2011. I found little evidence that oystercatchers left their nests during aircraft overflights (Chapter 2). Prior studies found no correlation between military overflights and reproductive success. Breeding Mexican Spotted Owls subjected to experimental helicopter flights had similar nesting success and fledging success to owls not subjected to the overflights (Delaney et al. 1999). Black and others (1984) found no correlation between low-level military flights and the reproductive success of five wading bird species (Great Egrets, Snowy Egrets, Tricolored Herons, Little Blue Herons, and Cattle Egrets).

I was also somewhat surprised to find a positive association between the presence of recording equipment and nest success and daily survival. Reproductive success at the video monitored nests was high compared to levels prior to this study as well. I observed several instances of raccoons investigating video cameras without detecting the adjacent nests. Most of these nests survived to successfully hatch. It is possible that these novel features distracted predators away from nearby nests.

I was unable to assess the effects of pedestrians on the nesting success of American Oystercatchers due to small sample sizes. A comparable study in Georgia at Cumberland Island National Seashore found pedestrians walking frequently near nests disrupted American Oystercatcher incubation activities and caused nest failure (Sabine et al. 2006). Pedestrian activity (researchers checking nests) also flushed Eurasian Oystercatchers off their nests, but did not increase egg loss (Verboven et al. 2001). I believe the current low levels of pedestrian activity at North Core Banks have minimal reproductive consequences for nesting American Oystercatchers.

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TABLES AND FIGURES

Table 4.1. American Oystercatcher reproductive success at North Core Banks, Cape Lookout National Seashore, NC during study years and the year prior to the study, and historically for North Carolina.

	North Core Banks				North Carolina State Summary (1995-2012)
		Study Seasons			
	2009	**2010**	**2011**	2012[a]	
Breeding Pairs	29	**31**	**32**	15	1689
Nests	40	**58**	**54**	26	2633
Average Clutch Size	-	**2.38**	**2.5**	-	-
Average Nesting Attempt/Pair	-	**1.87**	**1.69**	-	-
Nests Hatched	7	**15**	**18**	9	863
Eggs (Chicks) Hatched	-	**30**	**37**	-	-
Nest Survival Observed (SE)[b]	0.175 (0.060)	**0.259 (0.059)**	**0.333 (0.064)**	0.346 (0.093)	0.328 (0.009)
Nest Survival Adjusted (SE)[c]	0.188 (0.056)	**0.299 (0.056)**	**0.381 (0.061)**	0.351 (0.092)	0.331 (0.010)
Chicks Fledged	8	**15**	**24**	14	710
Chick Survival (SE)[d]	0.533 (0.129)	**0.500 (0.091)**	**0.649 (0.078)**	0.636 (0.111)	0.480 (0.013)
Productivity (SE)[e]	0.276 (0.121)	**0.484 (0.089)**	**0.750 (0.149)**	0.933 (0.284)	0.399 (0.018)

[a] *A hurricane in August 2011 opened an inlet that separated the southern three miles of North Core Banks creating a distinct second island, Middle Core Banks. Data from only North Core Banks was reported for 2012 as Middle Core Banks had unique factors affecting reproductive success metrics, which would not be comparable to previous years.*

[b] *Observed nest survival = nests hatched/total nests*

[c] *Adjusted nest survival is calculated using Program MARK.*

[d] *Chick survival = chicks fledged/chicks hatched*

[e] *Productivity = chicks fledged/breeding pairs*

Table 4.2. Logistic exposure model of factors affecting the daily survival rate of American Oystercatcher nests at North Core Banks, Cape Lookout National Seashore, NC in 2010 and 2011 (n=48).

Explanatory Variable	*Estimate (SE)*	*z*	*p-value*	*Odds Ratio*[a] *($e^{Estimate}$)*	*95% C.I. for Odds Ratio*
Intercept	0.800 (2.627)	0.304	0.761		
Avg. Daily Aircraft Events	0.013 (0.020)	0.660	0.509		
Avg. Daily Vehicle Events	-0.063 (0.021)	-2.941	0.003*	0.939	0.902, 0.982
Vehicle Closure[b]					
Nest-only	14.810 (929.137)	0.016	0.987		
None	-1.373 (0.875)	-1.570	0.116		
Drive-through	0.104 (0.847)	0.123	0.902		
Ramp	-0.345 (0.575)	-0.601	0.548		
Avg. Daily Oystercatcher Departures	0.043 (0.055)	0.777	0.437		
Avg. Daily Nest Attendance	0.038 (0.023)	1.653	0.098		
Habitat[c]					
Within Dunes	-0.236 (0.740)	-0.319	0.750		

[*] *significant according to a significance level of $p<0.05$*

[a] *Odds ratios were only calculated for variables which were significant*

[b] *Vehicle closures were active vehicle management by the National Park Service around shorebird breeding areas. Types included in this analysis: (1) Full closures were large areas closed to protect nesting shorebirds and colonies; vehicles were excluded inside the closure but they could drive along parts of the perimeter. (2) None - nests without closures were located in habitats away from approved vehicle routes with minimal management. (3) Vehicle drive-through closures prevented vehicles from stopping in the vicinity of nests, but allowed driving by the nests. (4) Ramp closures required vehicle traffic to detour to the sand road behind the dunes.*

[c] *Nest habitats were generally classified as open sand or within dunes. Open sand habitats included the open beach and sand flats where the terrain was flat and open with minimal vegetation and visibility was high. Dune habitats were areas of varying and elevated terrain and vegetation with limited visibility.*

Table 4.3. Logistic regression analysis of factors associated with American Oystercatcher nesting success at North Core Banks, Cape Lookout National Seashore, NC in 2010 and 2011 (n=48).

Explanatory Variable	*Estimate (SE)*	*z*	*p-value*	*Odds Ratio[a] ($e^{Estimate}$)*	*95% C.I. for odds ratio*
Intercept	-10.467 (9.035)	-1.158	0.247		
Avg. Daily Aircraft Events	0.076 (0.054)	1.409	0.159		
Avg. Daily Vehicle Events	-0.132 (0.062)	-2.116	0.034*	0.877	0.757, 0.970
Vehicle Closure[b]					
Nest-only	18.144(2164.6)	0.008	0.993		
None	-2.468 (1.583)	-1.559	0.119		
Drive-through	-0.173 (1.238)	-0.140	0.889		
Ramp	0.158 (1.114)	0.142	0.887		
Avg. Daily Oystercatcher Departures	0.091 (0.094)	0.971	0.332		
Avg. Daily Nest Attendance	0.099 (0.078)	1.277	0.201		
Habitat[c]					
Within Dunes	-0.311 (1.304)	-0.239	0.811		

**significant according to a significance level of $p<0.05$*

[a] Odds ratios were only calculated for variables which were significant

[b] Vehicle closures were active vehicle management by the National Park Service around shorebird breeding areas. Types included in this analysis: (1) Full closures were large areas closed to protect nesting shorebirds and colonies; vehicles were excluded inside the closure but they could drive along parts of the perimeter. This closure type was used as the baseline for analysis, so does not appear in the analysis output above. (2) Nest-only closures were small closed areas extending only in a 15-foot radius from the nest. (3) None - nests without closures were located in habitats away from approved vehicle routes with minimal management. (4) Vehicle drive-through closures prevented vehicles from stopping in the vicinity of nests, but allowed driving by the nests. (5) Ramp closures required vehicle traffic to detour to the sand road behind the dunes.

[c] Nest habitats were generally classified as open sand or within dunes. Open sand habitats included the open beach and sand flats where the terrain was flat and open with minimal vegetation and visibility was high. Dune habitats were areas of varying and elevated terrain and vegetation with limited visibility.

Table 4.4. Akaike's Information Criteron (AIC) values for candidate models including potential factors affecting daily survival rate of American Oystercatcher nests at North Core Banks, Cape Lookout National Seashore, NC in 2010 and 2011 (n=48). Factors included: the average number of aircraft events per day (Aircraft), the average number of off-road vehicle events per day (ORV), the vehicle closure type (type of management of human activity around nests, Closure), the average number of times oystercatchers left their nests per day (Depart), the average daily nest attendance (Attendance), and nest habitat type (Habitat).

Model	***K***	***ΔAIC***	***AIC weight***
ORV*+Closure*+Attendance	4	0	0.51
ORV+Closure+Depart+Attendance	5	1.08	0.30
Aircraft+ORV+Closure+Depart+Attendance	6	2.68	0.13
Aircraft+ORV+Closure+Depart+Attendance+Habitat	7	4.58	0.05

**significant (significance level p<0.05) variable in the best-supported model*

Table 4.5. Akaike's Information Criteron (AIC) values for candidate models including potential factors affecting hatching success of American Oystercatcher nests at North Core Banks, Cape Lookout National Seashore, NC in 2010 and 2011 (n=48). Factors included: the average number of aircraft events per day (Aircraft), the average number of off-road vehicle events per day (ORV), the vehicle closure type (type of management of human activity around nests, Closure), the average number of times oystercatchers left their nests per day (Depart), the average daily nest attendance (Attendance), and nest habitat type (Habitat).

Model	***K***	***ΔAIC***	***AIC weight***
ORV*	2	0	0.27
ORV+Closure	3	0.44	0.21
Aircraft+ORV+Closure	4	0.64	0.19
Aircraft+ORV+Closure+Attendance	5	1.07	0.16
Aircraft+ORV+Closure+Depart+Attendance	6	1.57	0.12
Aircraft+ORV+Closure+Depart+Attendance+Habitat	7	3.51	0.05

**significant (significance level p<0.05) variable in the best-supported model*

Table 4.6. Logistic exposure model of factors affecting the daily survival rate of American Oystercatcher nests at North Core Banks, Cape Lookout National Seashore, NC in 2011 (n=25) including the percent of the incubation period the nest was protected by a closure.

Explanatory Variable	*Estimate (SE)*	*z*	*p-value*	*Odds Ratio*[a] *($e^{Estimate}$)*	*95% C.I. for Odds Ratio*
Intercept	-2.983 (8.357)	-0.357	0.721		
Avg. Daily Aircraft Events	0.096 (0.046)	2.074	0.038*	1.100	1.011, 1.213
Avg. Daily Vehicle Events	-0.085 (0.033)	-2599	0.009*	0.919	0.864, 0.985
Vehicle Closure[b]					
None	-1.126 (1.472)	-0.765	0.444		
Drive-through	-0.035 (1.623)	-0.022	0.983		
Ramp	1.572 (1.009)	1.558	0.119		
% Nest Closed	-0.004 (0.012)	-0.318	0.751		
Avg. Daily Oystercatcher Departures	0.052 (0.093)	0.558	0.577		
Avg. Daily Nest Attendance	0.048 (0.069)	0.700	0.484		
Habitat[c]					
Within Dunes	-0.720 (1.347)	-0.535	0.593		

**significant according to a significance level of $p<0.05$*

[a] *Odds ratios were only calculated for variables which were significant*

[b] *Vehicle closures were active vehicle management by the National Park Service around shorebird breeding areas. Types included in this analysis: (1) Full closures were large areas closed to protect nesting shorebirds and colonies; vehicles were excluded inside the closure but they could drive along parts of the perimeter. (2) None - nests without closures were located in habitats away from approved vehicle routes with minimal management. (3) Vehicle drive-through closures prevented vehicles from stopping in the vicinity of nests, but allowed driving by the nests. (4) Ramp closures required vehicle traffic to detour to the sand road behind the dunes.*

[c] *Nest habitats were generally classified as open sand or within dunes. Open sand habitats included the open beach and sand flats where the terrain was flat and open with minimal vegetation and visibility was high. Dune habitats were areas of varying and elevated terrain and vegetation with limited visibility.*

Table 4.7. Logistic regression analysis of factors associated with American Oystercatcher nesting success at North Core Banks, Cape Lookout National Seashore, NC in 2011 (n=25) including the percent of the incubation period the nest was protected by a closure.

Explanatory Variable	*Estimate (SE)*	*z*	*p-value*	*Odds Ratio*[a] *($e^{Estimate}$)*	*95% C.I. for odds ratio*
Intercept	52.210 (34.752)	1.502	0.133		
Avg. Daily Aircraft Events	0.289 (0.140)	2.063	0.039*	1.335	1.070, 1.894
Avg. Daily Vehicle Events	-0.420 (0.202)	-2.079	0.038*	0.657	0.403, 0.925
Vehicle Closure[b]					
None	-17.659 (3520.280)	-0.005	0.996		
Drive-through	-3.632 (4.221)	-0.860	0.390		
Ramp	1.833 (2.806)	0.653	0.514		
% Nest Closed	-0.074 (0.047)	-1.576	0.115		
Avg. Daily Oystercatcher Departures	-0.265 (0.210)	-1.263	0.206		
Avg. Daily Nest Attendance	-0.437 (0.284)	-1.539	0.124		
Habitat[c]					
Within Dunes	-11.108 (6.107)	-1.819	0.069		

**significant according to a significance level of $p<0.05$*

[a] Odds ratios were only calculated for variables which were significant

[b] Vehicle closures were active vehicle management by the National Park Service around shorebird breeding areas. Types included in this analysis: (1) Full closures were large areas closed to protect nesting shorebirds and colonies; vehicles were excluded inside the closure but they could drive along parts of the perimeter. (2) None - nests without closures were located in habitats away from approved vehicle routes with minimal management. (3) Vehicle drive-through closures prevented vehicles from stopping in the vicinity of nests, but allowed driving by the nests. (4) Ramp closures required vehicle traffic to detour to the sand road behind the dunes.

[c] Nest habitats were generally classified as open sand or within dunes. Open sand habitats included the open beach and sand flats where the terrain was flat and open with minimal vegetation and visibility was high. Dune habitats were areas of varying and elevated terrain and vegetation with limited visibility.

Table 4.8. Akaike's Information Criteron (AIC) values for candidate models including potential factors affecting daily survival rate of American Oystercatcher nests at North Core Banks, Cape Lookout National Seashore, NC in 2011 (n=25) including the percent of the incubation period the nest was protected by a closure. Other factors included: the average number of aircraft events per day (Aircraft), the average number of off-road vehicle events per day (ORV), the vehicle closure type (type of management of human activity around nests, Closure), the average number of times oystercatchers left their nests per day (Depart), the average daily nest attendance (Attendance), and nest habitat type (Habitat).

Model	*K*	*ΔAIC*	*AIC weight*
ORV*+Habitat	3	0	0.379
Aircraft+ORV+Habitat	4	0.02	0.375
Aircraft+ORV+%Closed+Habitat	5	1.83	0.15
Aircraft+ORV+%Closed+Attendance+Habitat	6	3.57	0.06
Aircraft+ORV+%Closed+Depart+Attendance+Habitat	7	5.50	0.02
Aircraft+ORV+Closure+%Closed+Depart+Attendance+Habitat	8	8.03	0.01

**significant (significance level p<0.05) variable in the best-supported model*

Table 4.9. Akaike's Information Criteron (AIC) values for candidate models including potential factors affecting hatching success of American Oystercatcher nests at North Core Banks, Cape Lookout National Seashore, NC in 2011 (n=25) including the percent of the incubation period the nest was protected by a closure. Other factors included: the average number of aircraft events per day (Aircraft), the average number of off-road vehicle events per day (ORV), the vehicle closure type (type of management of human activity around nests, Closure), the average number of times oystercatchers left their nests per day (Depart), the average daily nest attendance (Attendance), and nest habitat type (Habitat).

Model	*K*	*ΔAIC*	*AIC weight*
Aircraft+ORV+Habitat	4	0	0.38
Aircraft+ORV+Closure+Habitat	5	0.71	0.27
Aircraft+ORV+Closure+Depart+Habitat	6	1.71	0.16
Aircraft+ORV+Closure+%Closed+Depart+Habitat	7	2.29	0.12
Aircraft+ORV+Closure+%Closed+Depart+Attendance+Habitat	8	3.45	0.07

**significant (significance level p<0.05) variable in the best-supported model*

Figure 4.1. American Oystercatcher decoy and "Whoosh Net" used to capture adult American Oystercatchers. The decoy and recorded oystercatcher vocalizations attract territorial oystercatchers. The net, propelled by elastic cords, is triggered by a researcher hiding nearby.

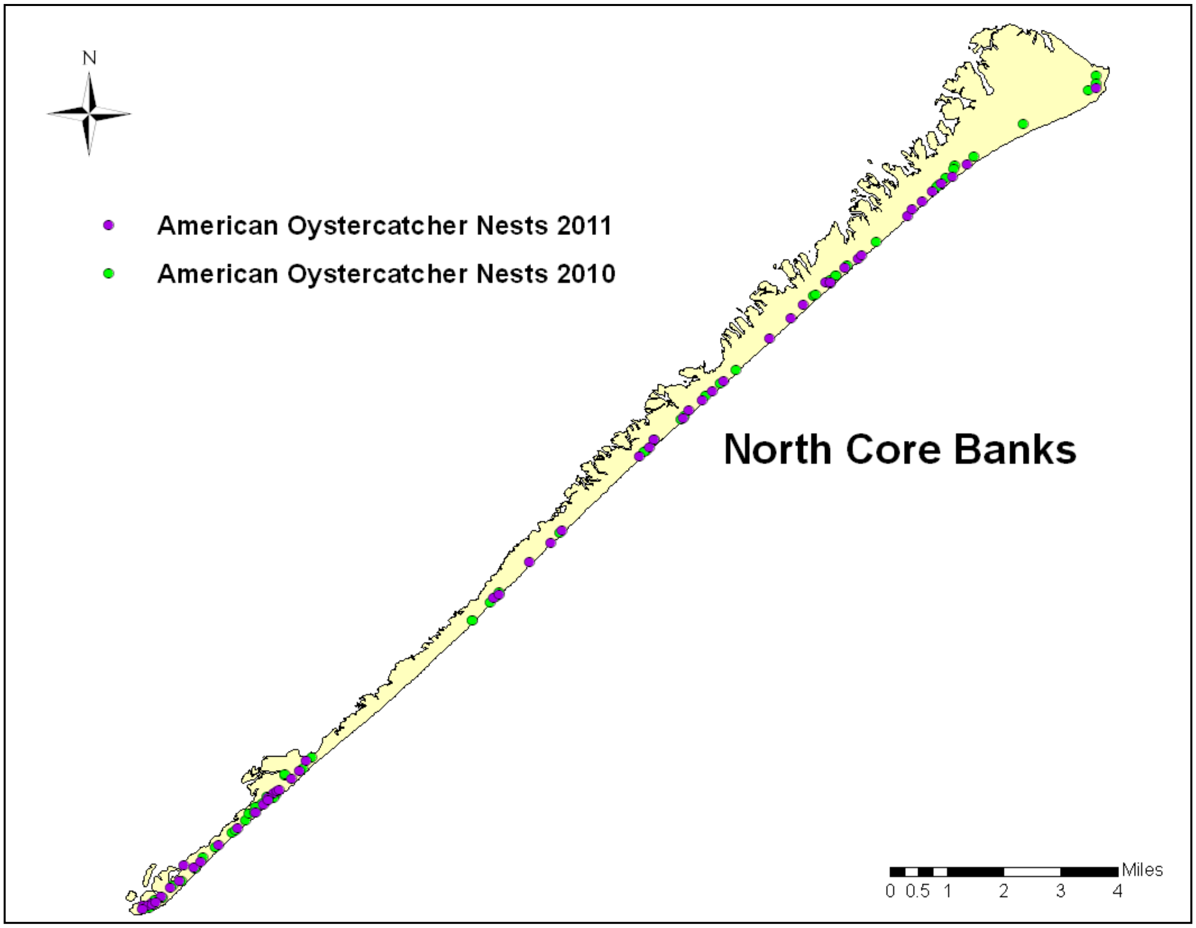

Figure 4.2. North Core Banks, Cape Lookout National Seashore, NC and locations of all 58 American Oystercatcher nests monitored in 2010 and all 54 nests monitored in 2011.

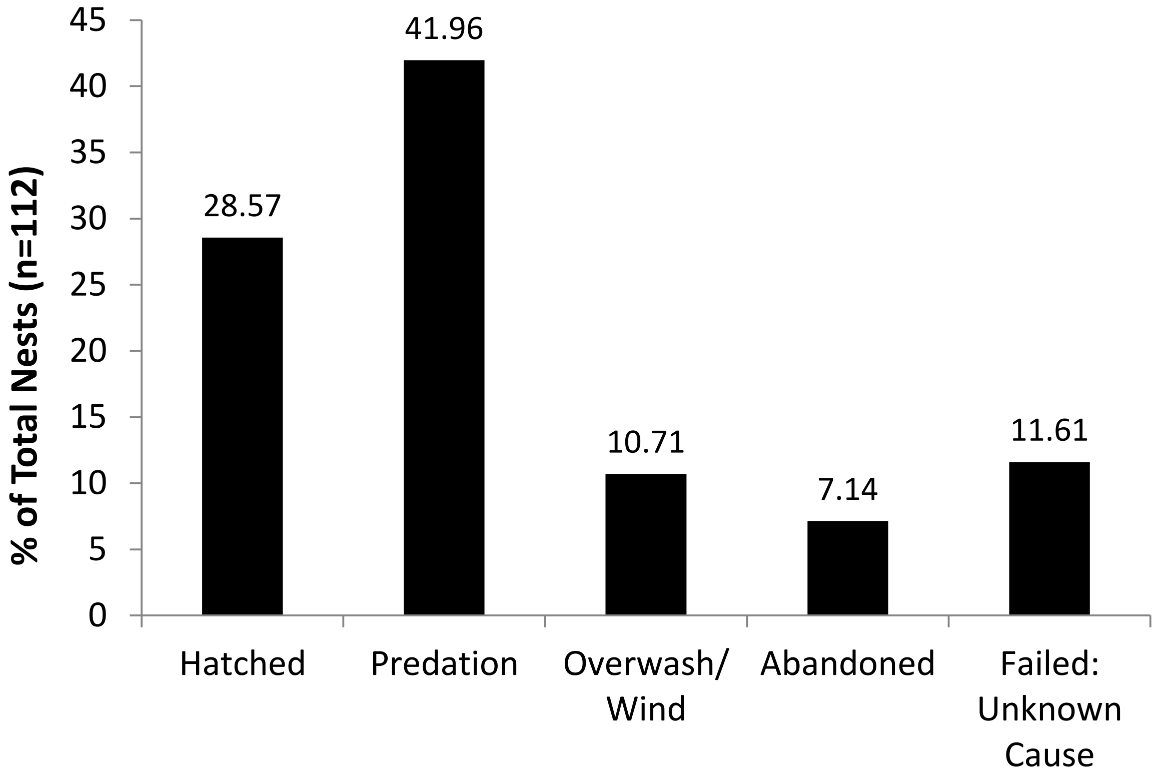

Figure 4.3. Fate of all 112 American Oystercatcher nests attempted in the 2010 and 2011 breeding seasons at North Core Banks, Cape Lookout National Seashore, NC.

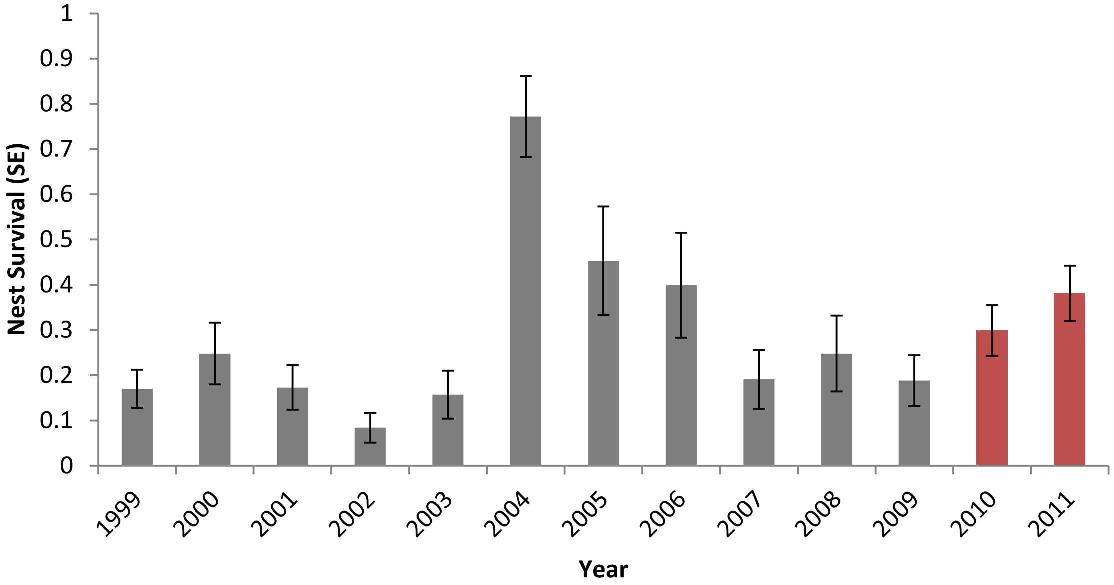

Figure 4.4. Historical nest survival rates for American Oystercatchers on North Core Banks, Cape Lookout National Seashore, NC. Nest survival was adjusted to account for nests which failed before they were found. Study seasons (2010 and 2011) are highlighted in red.

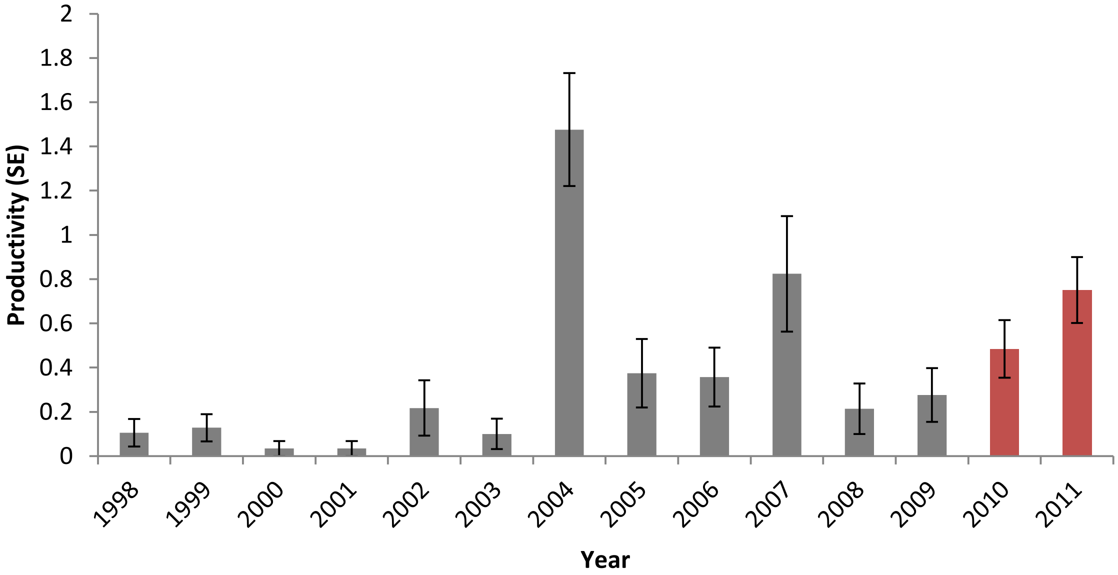

Figure 4.5. Historical productivity (chicks fledged per breeding pair) of American Oystercatchers on North Core Banks, Cape Lookout National Seashore, NC. Study seasons (2010 and 2011) are highlighted in red.

CONCLUSIONS

High speed low-altitude flights through the Core MOA airspace increased the ambient sound levels on North Core Banks, Cape Lookout National Seashore, more than any other type of human activity. However, these flights occurred less frequently than other types of human activity and did not have a significant effect on the nesting behavior nor nesting success of American Oystercatchers. Although oystercatchers had increased heart rates during low-altitude Core MOA flights, the increases do not appear to be of biological significance. I found no effects on oystercatchers from any other type of aircraft. In comparison, off-road vehicles and pedestrians elicited a significant behavioral response from oystercatchers, but I found no evidence of a physiological response. Off-road vehicles were also correlated to a decrease in nest survival and success. Aircraft does not appear to pose as great a perceived threat to incubating oystercatchers as ground-based activities. I believe that demographic effects from aircraft, including low-altitude Core MOA flights, through the nest incubation stage of breeding are unlikely under current levels of human activity at North Core Banks. However, off-road vehicles appear to be affecting both the incubation behavior and nest hatching success of American Oystercatchers.

Although most of my research was focused on the nest-incubation period, the remainder of the breeding season is no less important to the productivity of American Oystercatchers. The chick-rearing stage of oystercatcher reproduction is equally important and subject to different factors affecting productivity and survival (Schulte 2012). Effects during the nest-incubation stage of reproduction may be compounded by effects during the chick-rearing stage, which, although not the focus of this research, has been shown in past research to be strongly affected by human activity. Schulte (2012) found decreased survival of American Oystercatcher broods on the Outer Banks of North Carolina in the presence of off-road vehicles, and he also documented direct vehicle-caused mortality of chicks and differences in chick behavior inside and outside of vehicle closures.

It is difficult with long-lived species which have variable annual productivity such as American Oystercatchers (American Oystercatcher Working Group et al. 2012) to access long-term effects on population productivity. The short time-frame of this study limits its ability to produce a full understanding of effects of human activity on long-term population viability of American Oystercatchers.

LITERATURE CITED

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APPENDICES

Appendix A

National Park Service map of Cape Lookout National Seashore. Available at: http://www.nps.gov/calo/planyourvisit/upload/CALOmap1.pdf

Appendix B

American Oystercatcher productivity at North Core Banks, Cape Lookout National Seashore, NC from 1995-2012

Year and Location	Breeding pairs	Nests	Nests hatched	Nest survival observed (SE)	Nest survival adjusted (SE)	Chicks fledged	Chick Survival (SE)	Chicks fledged/ breeding pair (SE)
CAPE LOOKOUT								
North Core Banks								
1998	38	72	5	0.069 (0.030)	NA	4	NA	0.105 (0.062)
1999	39	61	11	0.177 (0.049)	0.170 (0.042)	5	0.208 (0.083)	0.128 (0.061)
2000	29	36	7	0.194 (0.066)	0.248 (0.068)	1	0.059 (0.057)	0.034 (0.034)
2001	29	53	12	0.226 (0.057)	0.173 (0.049)	1	0.091 (0.061)	0.034 (0.034)
2002	23	46	4	0.087 (0.042)	0.084 (0.033)	5	0.455 (0.150)	0.217 (0.125)
2003	20	36	7	0.194 (0.066)	0.157 (0.053)	2	0.118 (0.078)	0.100 (0.069)
2004	21	25	20	0.800 (0.080)	0.772 (0.089)	31	0.608 (0.068)	1.476 (0.255)
2005	16	20	11	0.550 (0.111)	0.453 (0.120)	6	0.286 (0.099)	0.375 (0.155)
2006	14	18	8	0.444 (0.117)	0.399 (0.116)	5	0.263 (0.101)	0.357 (0.133)
2007	17	32	8	0.250 (0.077)	0.191 (0.065)	14	0.778 (0.098)	0.824 (0.261)
2008	14	22	4	0.182 (0.082)	0.248 (0.084)	3	0.429 (0.187)	0.214 (0.114)
2009	29	40	7	0.175 (0.060)	0.188 (0.056)	8	0.533 (0.129)	0.276 (0.121)
2010	31	58	15	0.259 (0.059)	0.299 (0.056)	15	0.500 (0.091)	0.484 (0.130)
2011	32	54	18	0.333 (0.064)	0.381 (0.061)	24	0.649 (0.078)	0.750 (0.149)
2012	15	26	9	0.346 (0.093)	0.351 (0.092)	14	0.636 (0.111)	0.933 (0.284)
Middle Core Banks								
2004	5	5	4	0.800 (0.179)	NA	7	0.875 (0.117)	1.400 (0.510)
2005	7	9	5	0.556 (0.166)	0.511 (0.172)	9	0.643 (0.128)	1.286 (0.474)
2006	8	9	7	0.778 (0.139	0.745 (0.155)	8	0.500 (0.125)	1.000 (0.267)
2007	11	11	7	0.636 (0.145)	0.570 (0.160)	10	0.833 (0.108)	0.909 (0.315)
2008	6	6	4	0.667 (0.192)	NA	7	0.875 (0.117)	1.167 (0.477)
2012	13	18	7	0.389 (0.115)	0.218 (0.106)	12	0.706 (0.111)	0.923 (0.288)
Ophelia Banks								
2007	2	3	2	0.667 (0.272)	NA	3	0.750 (0.217)	1.500 (0.500)
2008	2	2	1	0.500 (0.354)	NA	0	0.000 (0.000)	0.000 (0.000)

Note: Due to natural barrier island changes and inlet closures and openings, in some years Middle Core Banks and Ophelia Banks may attach and become part of North Core Banks, and in other years they may be separate islands.