ABSTRACT

TARR, NATHAN MOLONEY. Fall Migration and Vehicle Disturbance of Shorebirds at South Core Banks, North Carolina. (Under the direction of committee chair Theodore R. Simons).

Anthropogenic disturbance has been implicated as a factor related to declines in shorebird populations because shorebirds depend upon coastal stopover sites where human recreation is concentrated for resting and refueling between long, energetically-expensive migration flights. We examined the use of South Core Banks, a barrier island on North Carolina's Outer Banks, by migrating shorebirds and recreationists during fall and measured the effects of vehicle disturbance on shorebird behavior and habitat use. To describe spatial, temporal, and tidal patterns in shorebird and vehicle abundance, we performed weekly surveys of birds and vehicles from all-terrain vehicles, recording the species, numbers, and microhabitat locations (i.e. surf, swash zone, dry sand, and wet sand) of all individuals within half-mile ocean beach segments. We summarized survey data by week, tide, beach section, and daylight hour in order to identify patterns in abundance. Shorebird densities on South Core Banks were similar to those reported for other sites on the Outer Banks, and their numbers decreased slightly throughout the season, but peaked several times. Gull and vehicle numbers increased throughout the fall while tern numbers decreased. As a group, shorebirds were more or less evenly distributed along the southeast facing beach, but individual shorebird species showed unique spatial patterns in abundance. Several species, including Sanderlings (*Calidris alba*), Black-bellied Plovers (*Pluvialis squatarola*), Semipalmated Plovers (*Charadrius semipalmatus*), Red Knots (*Calidris canutus*), and Ruddy Turnstones (*Arenaria interpres*), were more abundant on the ocean beach during high tide than during low tide. They used a sand spit and a portion of the ocean beach on the southern half of the island as roosting sites at high tide. Shorebirds were abundant in areas where vehicle abundance was also relatively high, but their distribution among microhabitats was opposite that of vehicles; vehicles were primarily located on dry sand while shorebirds were typically found in the swash zone and wet sand microhabitats.

Many environmental, habitat, and biological factors influence the distributions of nonbreeding shorebird, and they are often confounded. To examine whether or not vehicle disturbance is one of these factors, we employed a before-after-control-impact (BACI) experimental study design that isolated disturbance effects from spatial or temporal differences among sites. We manipulated disturbance levels within beach closures using paired control and impact plots and measured bird abundance and Sanderling behavior during before and after periods on both control and impact plots. Control plots were closed to vehicles during both the before and after periods. Treatment plots were closed to vehicles during the before period but subjected to a fixed level of vehicle disturbance during the after period. Differences in shorebird abundance and behavior between paired control and treatment plots provided an estimate of vehicle disturbance effects. We found that disturbance has a negative effect on site use by shorebirds, all birds, and Black-bellied Plovers. The two most abundant species of shorebird at our study sites, Sanderlings and Willets (*Catoptrophorus semipalmatus*), did not show a significant decrease in abundance in response to disturbance, but disturbance influenced Sanderling activity by decreasing the proportion of time that they spent roosting and increasing the proportion of time that they spent active. Microhabitat use shifted towards the swash zone when disturbance was introduced. We conclude that vehicle disturbance influences shorebirds' use of ocean beach habitat for roosting during the nonbreeding season and that experimental BACI study designs provide a practical tool for measuring the effects of disturbance on wildlife without the confounding that affects purely observational approaches.

Fall Migration and Vehicle Disturbance of Shorebirds at South Core Banks, North Carolina.

by
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DEDICATION

To Krystal Black for her love, support, and patience, and to my great grandparents, T.J. and Betty Beck. Though I never met them, their appreciation for wildlife has permeated generations and provided me happiness.

BIOGRAPHY

I was raised in Charlotte, NC, where I enjoyed spending time outside and developed a fondness for animals. While an undergraduate at Guilford College, I became increasingly interested in environmental issues and North Carolina’s flora and fauna. Soon after graduating, I decided to pursue a career that combined my appreciation for birds and my desire to promote wildlife conservation. I alternated between working in natural foods stores and on research projects through North Carolina State University until I was accepted as a graduate student in the USGS North Carolina Cooperative Fish and Wildlife Research Unit.

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Many people have helped me get to this point. Without their generosity and support, I wouldn’t be doing something that I enjoy so much. My wife, Krystal Black, has been supportive during hard times, picked up my slack, and paid the bills. My mother and father, Brian and Kathleen, have given me encouragement and positive thoughts. My grandparents, Stan, Elsa, and Norman, have been endlessly enthusiastic about my endeavors.

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TABLE OF CONTENTS

List of Tables vii
List of Figures viii
I. Shorebirds and anthropogenic disturbance 1
  Literature Cited 8
II. Spatial and temporal patterns in the distributions of birds and recreationists at South Core Banks, North Carolina during the fall 12
  Abstract 12
  Introduction 13
  Methods 14
  Results 20
  Temporal Patterns 23
  Spatial Patterns 25
  Discussion 30
  Literature Cited 36
III. A before-after-control-impact study of disturbance effects on nonbreeding shorebirds 133
  Abstract 133
  Introduction 134
  Methods 136
  Plot Surveys 140
  Behavioral Observations 141
  Statistical Analysis 141
  Results 143
  Discussion 146
  Assessment of the BACI Study Design 148
  Literature Cited 152

LIST OF TABLES

Table 2.1 Species list for the ocean beach of South Core Banks, North Carolina 121

Table 2.2 Count data from complete island surveys 125

Table 2.3 Shorebird densities at six sites on North Carolina’s Outer Banks 132

Table 3.1 Average disturbance effects on bird abundance 166

Table 3.2 Average disturbance effects on the proportions of birds in beach microhabitats 167

Table 3.3 Number of Sanderling behavioral observations at each plot during before and after time periods 168

Table 3.4 Average disturbance effects on Sanderling behavior 169

LIST OF FIGURES

Figure 2.1 Map of South Core Banks, North Carolina 38

Figure 2.2 The number of surveys of beach segments for each year and tide 39

Figure 2.3 The number of surveys of beach segments for each week 40

Figure 2.4 The number of surveys of beach segments for each daylight hour 41

Figure 2.5 Total number of surveys for each daylight hour 42

Figure 2.6 The abundance of gulls, shorebirds, terns, and pelicaniformes for each week 43

Figure 2.7 The abundance of Black-bellied Plovers, Sanderlings, and Willets for each week 44

Figure 2.8 The abundance of American Oystercatchers, Piping Plovers, Red Knots, and Wilson's Plovers for each week 45

Figure 2.9 The abundance of Dunlins, Ruddy Turnstones, and Semipalmated Plovers for each week 46

Figure 2.10 The abundance of Merlins and Peregrine Falcons for each week 47

Figure 2.11 The abundance of pedestrians and vehicles for each week 48

Figure 2.12 The abundance of ATVs, ORVs, moving vehicles, and stationary vehicles for each week 49

Figure 2.13 The abundance of moving people and stationary people for each week 50

Figure 2.14 Average gull, shorebird, tern, and vehicle abundance for each daylight hour 51

Figure 2.15 Average Black-bellied Plover, Sanderling, and Willet abundance for each daylight hour 52

Figure 2.16 Average American Oystercatcher, Piping Plover, Red Knot, and Wilson's Plover abundance for each daylight hour 53

Figure 2.17 Average Ruddy Turnstone and Semipalmated Plover abundance for each daylight hour 54

Figure 2.18 Average moving ATV, moving ORV, stationary ATV, and stationary ORV abundance for each daylight hour 55

Figure 2.19 Average shorebird abundance at beach segments 56

Figure 2.20 Average low and high tide shorebird abundance at beach segments 57

Figure 2.21 Average rising and high tide shorebird abundance at beach segments 58

Figure 2.22 Average high tide shorebird abundance at beach segments for each year 59

Figure 2.23 Average Sanderling abundance at beach segments 60

Figure 2.24 Average rising and high tide Sanderling abundance at beach segments 61

Figure 2.25 Average low and high tide Sanderling abundance at beach segments 62

Figure 2.26 Average high tide Sanderling abundance at beach segments for each year 63

Figure 2.27 Average Willet abundance at beach segments 64

Figure 2.28 Average rising and high tide Willet abundance at beach segments 65

Figure 2.29 Average high tide Willet abundance at beach segments for each year 66

Figure 2.30 Average Black-bellied Plover abundance at beach segments 67

Figure 2.31 Average low and high tide Black-bellied Plover abundance at beach segments 68

Figure 2.32 Average rising and high tide Black-bellied Plover abundance at beach segments 69

Figure 2.33 Average high tide Black-bellied Plover abundance at beach segments for each year 70

Figure 2.34 Average Semipalmated Plover abundance at beach segments 71

Figure 2.35 Average low and high tide Semipalmated Plover abundance at beach segments 72

Figure 2.36 Average rising and high tide Semipalmated Plover abundance at beach segments 73

Figure 2.37 Average Ruddy Turnstone abundance at beach segments 74

Figure 2.38 Average low and high tide Ruddy Turnstone abundance at beach segments 75

Figure 2.39 Average rising and high tide Ruddy Turnstone abundance at beach segments 76

Figure 2.40 Average high tide Ruddy Turnstone abundance at beach segments for each year 77

Figure 2.41 Average American Oystercatcher abundance at beach segments 78

Figure 2.42 Average rising and high tide American Oystercatcher abundance at beach segments 79

Figure 2.43 Average Red Knot abundance at beach segments 80

Figure 2.44 Average low and high tide Red Knot abundance at beach segments 81

Figure 2.45 Average rising and high tide Red Knot abundance at beach segments....82

Figure 2.46 Average Piping Plover abundance at beach segments....83

Figure 2.47 Average low and high tide Piping Plover abundance at beach segments....84

Figure 2.48 Average rising and high tide Piping Plover abundance at beach segments....85

Figure 2.49 Average gull abundance at beach segments....86

Figure 2.50 Average rising and high tide gull abundance at beach segments....87

Figure 2.51 Average high tide gull abundance at beach segments for each year....88

Figure 2.52 Average tern abundance at beach segments....89

Figure 2.53 Average low and high tide tern abundance at beach segments....90

Figure 2.54 Average rising and high tide tern abundance at beach segments....91

Figure 2.55 Average high tide tern abundance at beach segments for each year....92

Figure 2.56 Average pelicaniforme abundance at beach segments....93

Figure 2.57 Average rising and high tide pelicaniforme abundance at beach segments....94

Figure 2.58 Average high tide pelicaniforme abundance at beach segments for each year....95

Figure 2.59 Average vehicle abundance at beach segments....96

Figure 2.60 Average low and high tide vehicle abundance at beach segments....97

Figure 2.61 Average rising and high tide vehicle abundance at beach segments........98

Figure 2.62 Average high tide vehicle abundance at beach segments for each year........99

Figure 2.63 Average ATV abundance at beach segments........100

Figure 2.64 Average moving vehicle abundance at beach segments........101

Figure 2.65 Average low and high tide moving vehicle abundance at beach segments........102

Figure 2.66 Average rising and high tide moving vehicles abundance at beach segments........103

Figure 2.67 Average high tide moving vehicle abundance at beach segments for each year........104

Figure 2.68 Average pedestrian abundance at beach segments........105

Figure 2.69 The proportions of total shorebird detections from beach microhabitats during high and rising tide........106

Figure 2.70 The proportions of total Black-bellied Plover detections from beach microhabitats during high and rising tide........107

Figure 2.71 The proportions of total Semipalmated Plover detections from beach microhabitats during high and rising tide........108

Figure 2.72 The proportions of total Piping Plover detections from beach microhabitats during high and rising tide........109

Figure 2.73 The proportions of total Red Knot detections from beach microhabitats during high and rising tide........110

Figure 2.74 The proportions of total American Oystercatcher detections from beach microhabitats during high and rising tide........111

Figure 2.75 The proportions of total Sanderling detections from beach microhabitats during high and rising tide........112

Figure 2.76 The proportions of total Willet detections from beach microhabitats during high and rising tide 113

Figure 2.77 The proportions of total Ruddy Turnstone detections from beach microhabitats during high and rising tide 114

Figure 2.78 The proportions of total gull detections from beach microhabitats during high and rising tide 115

Figure 2.79 The proportions of total terns detections from beach microhabitats during high and rising tide 116

Figure 2.80 The proportions of total pelicaniforme detections from beach microhabitats during high and rising tide 117

Figure 2.81 The proportions of total moving vehicle detections from beach microhabitats during high and rising tide 118

Figure 2.82 The proportions of total stationary vehicle detections from beach microhabitats during high and rising tide 119

Figure 2.83 The proportions of total pedestrian detections from beach microhabitats during high and rising tide 120

Figure 3.1 Study sites at South Core Banks, North Carolina 158

Figure 3.2 Average shorebird abundance at beach segments where we placed study plots. 159

Figure 3.3 Average Sanderling abundance at beach segments where we placed study plots. 160

Figure 3.4 Average Willet abundance at beach segments where we placed study plots. 161

Figure 3.5 Average Black-bellied Plover abundance at beach segments where we placed study plots. 162

Figure 3.6 Indices of total vehicle and moving vehicle abundance on the ocean beaches of South Core Banks for 12 weeks during the fall. 163

Figure 3.7 Average moving vehicle numbers at beach segments on the southeast-facing ocean beach of South Core Banks. 164

Figure 3.8 Average count of shorebirds during plot surveys 165

CHAPTER 1

Shorebirds and Anthropogenic Disturbance

Anthropogenic disturbance is a category of human activities, either intentional or unintentional, that elicit responses by wildlife (Morton 1996, Walker et al. 2005). It can also be thought of as the combination of a stimulus and response, where stimuli include a variety of activities such as nature watching, photography, hiking, and off-road vehicle (ORV) driving (Knight and Cole 1991). Wildlife responses can include changes in behavior, physiology, distribution, or reproduction, and they are influenced by the type, timing, location, frequency, and predictability of human activities (Knight and Cole 1991). Human disturbance of wildlife is a topic that has received considerable attention during the last half century as human recreation levels have increased in parks and refuges, and wildlife managers and conservationists have sought to understand its effects (Cole and Knight 1991, Hill et al. 1997).

Wildlife managers seek to understand disturbance so that they can balance the costs of human disturbance to wildlife with the benefits that recreation provides in educating the public, generating support for conservation, and increasing awareness of conservation issues (Cole and Knight 1991, Gill 2007, Sutherland 2007). By identifying the causes and effects of disturbance, managers can focus their efforts and resources on activities that are the most detrimental and maintain activities that contribute to both human recreation and conservation (Gutzwiller 1991). In this chapter, we provide an overview of sources and effects of disturbance, wildlife responses, and the methods used to study shorebird disturbance.

The severity, type, and frequency of disturbance can directly influence a species' response (Knight and Cole 1991, McGowan and Simons 2006, Taylor et al. 2007), but other factors, such as species-specific tolerances, temporal differences, flocking, pre-disturbance behavior, landscape, and intraspecific differences, such as age, can act indirectly (Knight and Cole 1991, Morton 1996).

Responses to disturbance are often classified as behavioral, distributional, physiological, or reproductive. Behavioral responses include specific behaviors, such as fleeing, or changes in the frequency of a specific behavior and they can be viewed as reflecting a tradeoff between perceived risk and the opportunity cost of responding (Stillman and Goss-Custard 2002, Pomeroy 2006). Short-term behavioral responses could turn into long-term effects on individuals. These effects include; decreased productivity, reductions in physical condition and survival, changes in habitat use, and subsequent changes in feeding ecology (Knight and Cole 1991). The cost of a behavioral response is influenced by the timing, frequency, and type of stimuli (Cole and Knight 1991, Burger 1995), but it is also influenced by the individual's nutritional condition, the availability of resources, and other factors (Gill et al. 2001a, Stillman and Goss-Custard 2002, Beale and Monaghan 2004, Stillman et al. 2007). This complexity makes behavioral responses difficult to interpret (Gill et al. 2001b).

Disturbance can cause birds to alter their use of habitats (distributional responses). Distributional responses can be spatial (Pfister et al. 1992) or temporal (Burger and Gochfeld 1991b). Either way, they result in changes in a habitat's functional availability, quality, or carrying capacity for a species (Morton 1996, Hill et al. 1997). As with behavioral responses, it is often difficult to interpret the costs of distributional responses on populations (Gill et al. 2001b).

Physiological responses can occur even when behavioral responses are not apparent (Morton 1996, Bouton et al. 2005, Walker et al. 2005). They include changes in metabolism and heart rate, thermal relationships, nutrition, endocrine and immune system responses. Physiological responses are presumably more directly tied to the survival and fecundity of individuals than behavioral responses, and they are, therefore, likely to serve as better measures of disturbance consequences. Physiological responses are difficult to measure in the field because it is difficult to obtain the baseline information required for comparisons and to understand the mechanisms by which responses are connected to demographic rates (Chabot 1991, Wikelski and Cooke 2006).

Reproductive responses include nest abandonment, reduced egg laying, reduced hatching success, lower energy acquisition in young, and chick mortality (Tremblay and Ellison 1979, Piatt et al. 1990, Knight and Cole 1991, Lafferty et al. 2006). These responses are sometimes the direct result of behavioral responses by parents or young (Lafferty et al. 2006, McGowan and Simons 2006). They are directly connected to population size.

The ultimate goal of disturbance research is often to identify population level effects to improve the management of human-wildlife interactions. A variety of research approaches have been used to understand disturbance effects (Hill et al. 1997, Gill 2007). Morton (1996) identified seven approaches to studying disturbance: flush response, behavioral and energetic changes measured in the field with time budgets, distribution and displacement studies using observations or telemetry, physiological responses (i.e. heart rate) measured in the field and laboratory, simulation models that investigate population level effects, inferences from studies involving unintentional disturbance (i.e. researcher visits to nests), and inferences from studies with intentional disturbance treatments. Gill (2007) identified three approaches used in studies of disturbance effects on patterns of resource use: site-based, demographic, and population level perspectives. These three approaches focus on changes in site use, changes in fecundity or survival, and density-dependent processes that occur due to shifts in habitat use.

Most disturbance research is based on observational field studies that identify correlations between disturbance and one of the responses discussed above. Experimental studies provide more useful information because they can identify cause and effect relationships and because in observational studies disturbance is often confounded with other factors (Gutzwiller 1991). Gutzwiller (1991) identified several important biological issues that make disturbance studies difficult. First, the effect of disturbance may not be evident immediately. If the response occurs later in a species life cycle, then longer studies are needed to accurately assess an impact (Gutzwiller 1991, Walker et al. 2005). Second, it is important to identify the levels of disturbance that exceed an animal's tolerance (Morton 1996). Tolerance is the level of activity that an individual is willing to withstand without responding (Walker et al. 2005). Third, habituation may occur at different levels (location, timing, spatial scale, frequency, periodicity, and duration) of disturbance. Experiments should, therefore, include treatments of various levels (Gutzwiller 1991, Knight and Cole 1991). Predictable, benign activities may eventually fail to elicit a behavioral response even if they occur at high levels (Gutzwiller 1991, Knight and Cole 1991). Fourth, it is important to consider the spatial scale of disturbance. Disturbance could have negative effects on a species when it encompasses entire home ranges, territories, or other areas exclusively used for a behavior or resource. Therefore, the size of experimental units would, ideally, match the size of areas used for response activities (Gutzwiller 1991). Fifth, subtle characteristics of disturbance may have the capacity to influence the disturbance response, thus increasing the variability of the response and decreasing the statistical power of the experiment. Adhering to a strict, consistent protocol and randomizing observers and other aspects of the study that may increase variability can help avoid bias due to subtle stimuli (Gutzwiller 1991). Sixth, predators could be influenced by disturbance resulting in lower predation rates in disturbed areas. More research is needed to understand the interaction between predation and disturbance (Sutherland 2007), but predation can influence habitat use and foraging behavior in shorebirds (Pomeroy 2006). Seventh, attempting to simultaneously study both the process and pattern of disturbance may compromise the interpretability of study results (Gutzwiller 1991). For example, capturing and banding birds to find out how their use of a site is affected by disturbance would preclude the ability to simultaneously and accurately measure disturbance effects on the overall abundance of the species at that site. Eighth, past events and local and regional processes may influence current experiments (Gutzwiller 1991). It is possible for disturbance effects to carryover into study sites from nearby or recent disturbances, and responses to disturbance at experimental units are partly shaped by processes, such as predation or density dependence, that can manifest at a larger scale.

Gutzwiller (1991) also identified some important statistical challenges to disturbance studies. One challenge is that experimental units in field studies often vary due to different habitat characteristics and environmental factors can cause variability in the response. For example, McGowan et al. (2002) found that the response of wintering Red Knots to disturbance increased with wind speed and temperature. The use of covariates is one approach to isolating treatment effects, and randomization can sometimes decrease the need for using covariates (Gutzwiller 1991).

Despite the biological and statistical challenges involved in disturbance research, several studies have found evidence of disturbance effects on birds. Thomas et al. (2003) found that increased human presence caused migrating Sanderlings to spend less time foraging. Burger (1991) obtained similar results for wintering Sanderlings, noting an inverse relationship between daytime disturbance and time spent foraging at night (Burger and Gochfeld 1991a).

Disturbance can influence distributional patterns in bird abundance and habitat use. Morton (1996) analyzed biweekly counts of bird and human activities on the ocean beach at Assateague Island National Seashore during the winter and found that disturbance was negatively correlated with Sanderling abundance. Sanderlings were less abundant on weekends on the south end of the island where vehicles were allowed. Pfister et al. (1992) found that human disturbance on front beaches caused migrating Sanderlings and Black-bellied Plovers to shift their activity to back-beach habitats. Wintering Snowy Plovers (*Charadrius alexandrinus*) at Devereux Slough in Santa Barbara, California avoided trail heads where humans and dogs were abundant (Lafferty 2001). Klein et al. (1995) found that some migrant waders were more likely to avoid roads as traffic increased. Wintering Black-tailed Godwits (*Limosa limosa*) changed the timing of their use of feeding sites in response to disturbance, but the ability of the habitat to support godwits was not affected by disturbance (Gill et al. 2001a). When a pedestrian trail that introduced disturbance to Finney et al.'s (2005) study area was redesigned to constrain human activity, Golden Plovers (*Pluvialis apricaria*) spent their time closer to the trail.

Disturbance can have physiological effects such as elevated energy expenditure, elevated hormone levels, and other responses. Fleeing responses in wildlife are known to increase heart rate, cardiac output, and blood sugar (Gabrielsen and Smith 1995). Breeding Chinstrap penguins (*Pygoscelis antarcticus*) in Antarctica that were captured and handled for 30 seconds showed an increase in stomach temperature of 2°C that lasted for two to three hours and was accompanied by an increase in energy expenditure (Gabrielsen and Smith 1995). Magellanic penguin (*Spheniscus magellicanicus)* nestlings in Argentina that were exposed to ecotourism had elevated corticosterone levels while the adults did not. Elevated corticosterone levels early in life can have significant negative effects on an individual when it is older (Walker et al. 2005).

Disturbance can negatively influence breeding productivity in several ways. It can deter birds from establishing or maintaining nests. Tremblay and Ellison (1979) compared reproductive success in nesting colonies of Black-crowned Night Herons (*Nycticorax nycticorax*) subjected to various frequencies of researcher visits and found that colonies with elevated visitation levels had lower reproductive success due to less egg laying and increased nest abandonment. Lafferty et al. (2006) documented that once a section of beach was closed to pedestrians, Snowy Plovers began to use it as a nesting site. Least Auklets (*Aethia pusilla*) in lower disturbance sites had a higher hatching success, and Crested Auklets (*Aethia cristatella*) in high disturbance areas abandoned nests (Piatt et al. 1990). Pierce and Simons (1986) compared reproductive success in Tufted Puffin (*Fratercula cirrhata*) breeding colonies with low, moderate, and heavy investigator disturbance rates, and found higher rates of nest abandonment, longer incubation periods, and decreased chick growth and survival in heavily disturbed areas. Chicks from disturbed nests were lighter and had shorter wings at fledging than chicks from undisturbed nests. Bouton et al. (2005) found that Wood Storks (*Mycteria Americana*) nesting in an area with boat disturbance fledged fewer young than storks in an area without disturbance due to lower hatching success and chick survival. Ruhlen et al. (2003) found that Snowy Plover chick loss was three times greater on weekends and holidays than on weekdays. Although their study design didn't address the cause of chick death, they suggested that disturbance may cause a shift in parental behavior that leads to less care of chicks and subsequent mortality. McGowan and Simons (2006) tested the hypothesis that disturbance increased American Oystercatcher (*Haematopus palliatus*) parental activity during incubation and found that disturbance was correlated with a high rates of adult movement to and from nest during incubation. Nests with a higher number of parental trips had a lower probability of daily nest survival.

Despite the extensive body of research aimed at understanding the consequences of anthropogenic disturbance, there are still many unanswered questions. Gaps in knowledge involve difficulties in identifying and measuring the correct responses to disturbance in order to assess population level consequences, and measuring the effects of disturbance on individual fitness (Chabot 1991, Knight and Cole 1991, Sutherland 2007). Answering these questions will require a greater understanding of connections between behavior, physiology, reproduction, and disturbance and developing study designs that can isolate responses to disturbance from responses to environmental, biological, and habitat factors.

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Chapter 2

Spatial and Temporal Patterns in the Distributions of Birds and Recreationists at South Core Banks, North Carolina During the Fall

ABSTRACT

We describe the autumnal shorebird community, as well as human recreation, on the ocean beach of South Core Banks, North Carolina, an Atlantic Coast barrier island within Cape Lookout National Seashore. We conducted weekly surveys of birds and vehicles from ATVs, recording the species, numbers, and microhabitat locations (i.e. surf, swash zone, dry sand, wet sand) of all birds within half-mile segments of ocean beach. We summarized survey data by week, tide, segment, and daylight hour in order to describe the spatial, temporal, and tidal patterns in bird and human abundance. Shorebird densities on South Core Banks were similar to those reported for other sites on North Carolina's Outer Banks. Total shorebird numbers were fairly consistent across hours and most segments of the island, while individual shorebird species showed unique spatial and temporal patterns in abundance. Shorebird numbers on South Core Banks decreased slightly throughout the season, but peaked several times. We found that shorebirds' use of the ocean beach and its microhabitats is related to tide levels, and we identified two shorebird roosting sites. Bird distributions overlapped considerably with those of recreationists, but segregation may have occurred at the microhabitat scale.

INTRODUCTION

Many shorebird species make long, biannual migrations between breeding and wintering grounds, and these migrations are often punctuated by stops for resting and refueling (Gill and Handel 1990, Skagen 2006). Several species, including Ruddy Turnstones (*Arenaria interpres*), Sanderlings (*Calidris alba*), Black-bellied Plovers (*Pluvialis squatarola*), and Red Knots (*Calidris canutus*), have shown evidence of population declines in recent years (Bart et al. 2007), prompting attempts to identify the habitats on which they depend and challenges they face during migrations. Anthropogenic disturbance is one potentially harmful factor present at many stopover sites that may have negative impacts on shorebirds (Gill 2007).

Dinsmore et al. (1998) identified the Outer Banks of North Carolina as an important stopover habitat for shorebirds using the Atlantic flyway. Compared to other areas on the Atlantic and Gulf Coasts where extensive shorebird surveys have been conducted, the Outer Banks were relatively important to Sanderlings, Whimbrels (*Numenius phaeopus*), and Piping Plovers (*Charadrius melodus*), with Sanderlings more common on the Outer Banks than at other sites on the Atlantic Coast (Dinsmore et al. 1998). Shorebird abundance peaks twice per year on the Atlantic Coast, once in spring and once in fall (Morton 1996). Shorebird numbers during fall migration are larger than during spring (Dinsmore et al. 1998). Populations of at least one species, the Sanderling, returns to sites used during previous migrations and remains within relatively small areas (<10 km segments of beach) during stopovers (Dinsmore et al. 1998).

South Core Banks lies just south of the southernmost sites on the Outer Banks that Dinsmore et al. (1998) examined, and it was not included in their surveys. We conducted weekly counts of birds and vehicles on South Core Banks to describe patterns in bird and human abundance on its ocean beaches. Our objectives were to identify spatial and temporal patterns in the use of ocean beach habitats by shorebirds and to compare shorebird abundance on South Core Banks to the sites examined by Dinsmore et al. (1998). We also wanted to compare patterns in the abundance of humans and shorebirds and look for evidence of tide and time of day effects on their use of ocean beach habitats. Through this study, we hope to provide a context for the management of nonbreeding shorebirds on South Core Banks as well as for studies of their habitat use during fall migration and research on their relationships with human activity.

METHODS

Cape Lookout National Seashore (CALO) is located on North Carolina's Outer Banks between Ocracoke Island and Bogue Banks. South Core Banks is a barrier island with 41 km of ocean beach between miles 23 and 47.5 of Cape Lookout National Seashore (Fig. 2.1). The ocean beach stretching from mile marker 23 to 44 faces southeast and is relatively straight, has relatively consistent structure, and a low profile. The ocean beach between miles 44 and 47.5 faces west and has two distinctive features. Cape Lookout Point (the point) is a sand peninsula that fluctuated from 0.2 to 0.5 mi in length due to tide levels and the movement of sand during storms. The Power Squadron Spit is a northeast-pointing, sand peninsula with a very low profile that changes shape and area within and between years and tide levels. A camp with rental cabins is located near mile marker 30, and an historic lighthouse is located near mile marker 41.

South Core Banks is a popular destination for anglers who drive on ocean beaches between miles 23 and 46, on a back road that runs behind the primary dunes from mile 24 to 44, and on several paths (ramps) that connect the two. The Power Squadron Spit, a portion of Cape Lookout Point (point closure), the area between miles 41 and 42.5 remain closed to public vehicles for bird protection.

Other sections of beach are temporarily closed to public vehicles for sea turtle and bird nest management each spring, summer, and early fall. National Park Service staff regularly drives all-terrain vehicles through all closures. Beach closures are established with rope fences at the closures' edges that stretch from the high tide line to the dunes. Signs advertise that the closures protect bird or turtle nests.

We counted birds, vehicles, and pedestrians on South Core Banks' ocean beaches from ATVs during fall 2005, 2006, and 2007. We conducted surveys approximately twice per week between 26 September and 15 November 2005, 10 September and 5 November 2006, and 23 August and 22 October 2007. We defined weeks as the seven day periods beginning on 23 August, 30 August, 6 September, 13 September, 20 September, 27 September, 4 October, 11 October, 18 October, 25 October, 1 November, and 8 November. We attempted to survey the entire island once per week at both high and low tides during fall 2005 and high and rising tides during fall 2006 and 2007. We defined high tide as the 4 h period centered at peak high tide, low tide as the 4 h period centered at peak low tide, and rising tide as the 4 h period beginning at peak low tide. We were often unable to cover the entire island during surveys due to adverse weather or logistical constraints, so we often surveyed the island in sections over several days.

We divided the ocean beach into 51 half-mile segments, which we treated as sampling units. These segments were placed so that their northernmost edge corresponded with half-mile increments of the mile marker system used by CALO, and they were named after the increment that their northern border corresponded with. Their eastern border was the surf, and their western border was the primary dune line. While the lengths of segments (their northern to southern edge) were constant, their width (the distance from the dune to the surf) varied with tide levels and wave height. Three segments had dimensions and structures that were anomalous to the other segments. The point was triangular in shape with ocean beach on two of its three sides, giving it twice as much beach per mile as the other segments. Its length and area varied with weather and tide and its northwestern edge abutted the edges of two beach segments and the point closure. The point closure was a triangular area between segments 43.5, 44, and the point, that included areas of dry sand, several small dunes, and, occasionally, a tidal pool. We did not survey the point closure in 2005. Segment 47 was located at the tip of the Power Squadron Spit. It was usually 0.5 mi long and triangular, but its very low profile meant that its exact shape, area, and dimensions varied greatly with changes in winds, tides, and swells. In general, the area of segment 47 was larger than that of the other segments.

We performed surveys by driving an ATV through segments at a speed of 5-15 mph and recording all birds, vehicles, pedestrians and dogs on the beach, in the surf within 100 m of the shore, and flying above the surf or beach. We identified all individuals to the species level, except when it was not possible, in which case we used the names “shorebird,” “gull,” “tern,” or “songbird.” Table 2.1 lists which species were included in each of these categories. Prior to 27 October 2005, no gulls or terns were identified to the species level. We recorded unidentified shorebirds as “peep” when we could not determine whether they were Semipalmated Sandpipers (*Calidris pusilla*), Least Sandpipers (*Calidris minutilla*), or Western Sandpipers (*Calidris mauri*), and we used “dowitcher” for Short-billed and Long-billed Dowitchers (*Limnodromus spp*). We use the name “off-road vehicle” (ORV) to refer to pickup trucks, jeeps, sport utility vehicles, and modified recreational vehicles and ATV to refer to four-wheelers.

We drove in a straight line through linear segments and usually surveyed adjacent segments consecutively. When surveying the point, we traveled along one swash zone to the tip and along the other swash zone when returning, making sure not to double count birds between the two swash zones. When surveying the point closure, we traveled on the outside edges until all birds within the closure had been counted. When surveying segment 47, we simply made an attempt to cover all areas of the segment and count all birds exactly once. During all surveys, we made a concerted effort not to double count birds that moved ahead of us as we traveled through plots. We alternated the direction of travel through segments each week. Observers took as much time as they needed to count all individuals in each segment.

We recorded the microhabitat locations of individuals at the time of first detection. Microhabitat categories were defined as: surf, which extended from 100 m offshore to the water's edge; swash zone, the area where waves washed onto the beach; wet sand, areas above the water's edge that were still wet from previous tide levels; and dry sand, the area between the upper reaches of the wet sand and the dune line. During the 2005 season, we did not distinguish between the swash zone and wet sand. Birds frequently flushed as we approached, but we recorded their location prior to their movement.

We believe that our counts provided good estimates of true bird abundance in segments because most segments were relatively narrow, we were able to see all portions of the beach, and the movement of birds in response to the ATV aided identification and counting. Inaccuracies in our counts do, however, exist because observers likely missed some birds that were roosting in tire tracks or other depressions in the sand and missed birds that flushed at long distances from the ATV. Some birds were probably double-counted as they moved in response to the ATV, but observers avoided double counting birds by stopping as little as possible, only traveling in a straight line, and only counting birds in front of or beside them. We estimated the size of large flocks by counting by 10's or 100's, likely causing measurement error to increase with flock size. These errors were probably most frequent at segment 47 because it was non-linear in shape, large, and often contained large roosting flocks.

We looked for patterns in bird abundance and human recreation by summarizing counts by species, week, daylight hour, segment, tide, year and microhabitat. We generated a list of species that use the ocean beaches of South Core Banks during fall by listing all species detected during surveys or otherwise observed on the ocean beach. We also calculated the number of surveys with at least one individual detected and the total number of detections from all surveys for each species to identify common and abundant species. Flyover detections were excluded from this summary.

Although our surveys were not designed to provide accurate estimates of population sizes on South Core Banks, we generated rough estimates by summing all detections for day-tide combinations when we surveyed every segment on the island. We refer to these summed counts as complete surveys. Complete surveys were performed at low tide on 9 October 2005, high and rising tide on 20 October 2006, rising tide on 25 October 2006, high and rising tide on 3 November 2006, high tide on 11 September 2007, high tide on 4 October 2007, rising tide on 12 October 2007, and rising tide on 19 October 2007. On two occasions, high tide of 11 October 2006 and high tide of 12 October 2007, we were able to survey all segments except for those in vehicle exclosures. We report the total vehicle counts from these occasions because all segments that were open to public vehicles were surveyed. Flyover detections of birds were included in this summary. Some segments were surveyed twice during these periods, so we randomly selected one for inclusion by flipping a coin. We calculated shorebird densities on the beach to compare with densities reported by Dinsmore et al. (1998) for other sites on the Outer Banks. We calculated densities (birds/km) by dividing the average number of individuals counted during complete surveys by the length of South Core Banks' ocean beaches (41 km).

We examined temporal patterns in abundance over the fall season by plotting an index of island abundance over time for each species. To calculate the index of island abundance, we summed the means from all segments. We removed flyovers from this analysis because we suspected that the detectability of birds in the air was less than that of birds on the ground or in the surf and that the removal of flyover detections would, therefore, decrease the heterogeneity associated with our indices. Detections from all other microhabitats were initially summed to give the total abundance for each survey by species. Surveys from all tides, years, observers, and weeks were included.

We examined abundance relative to time of day by calculating the mean number of individuals per survey for each daylight hour (6:00 to 19:00 EST). We eventually omitted hours 6:00 and 19:00 because their sample sizes were very small compared to those of other hours. We also excluded flyover detections for this summary but included data from all other microhabitats, calculating the total abundance of each species for each survey first. All tides, observers, years, and weeks were included.

To describe spatial patterns in abundance over the island, we calculated the average abundance of each species at each segment. Flyovers were excluded from calculations and counts from all other microhabitats were first summed to give the total abundance for each survey by species. Data from surveys for all years, observers, tides, and weeks were used. We then separated data by tide and year combinations and again calculated means for each segment to look for differences in spatial patterns between years and tides. We performed paired *t*-tests on high and rising tide means to assess any differences in abundance between tide levels. We compared low tide and high tide distributions in 2005, and we compared rising tide and high tide distributions using 2006 and 2007 data. We compared high tide distributions from 2005, 2006, and 2007 because high tide was the only level that we consistently surveyed each year (we sampled low tide in 2005 and rising tide in 2006 and 2007). We did not, however, perform statistical tests on the means from the three years because year effects would have been confounded with week effects, since there was little overlap between the 2005 and 2007 survey seasons.

Lastly, we examined patterns in microhabitat use by comparing the proportions of total detections that were from each microhabitat during high and rising tide. We did not include 2005 data in this analysis because observers did not distinguish between the swash zone and wet sand microhabitats in 2005.

RESULTS

We performed a total of 2,316 segment surveys. These surveys were relatively well distributed among segments, years, and tides, but not among weeks and daylight hours. Each segment was surveyed between 40 and 50 times (mean = 45.41) with the exception of the point closure, which was surveyed 32 times. Segments between 38.5 and 40.5 were surveyed slightly fewer times than other segments (Fig. 2.2). The total number of surveys per year was similar for all segments except for the point closure, which was never surveyed during 2005. Segments were, on average, surveyed fewer times during 2005 than during 2006 and 2007 (2005 mean = 11.65, 2006 mean = 16.51, 2007 mean = 17.25). The number of surveys per tide level was also similar for all segments except that segment 40 was surveyed only 3 times during low tide in 2005 (mean = 5.41 surveys per segment). The number of surveys performed per week was relatively similar among segments but not among weeks (Fig. 2.3). Our 2005, 2006, and 2007 field seasons spanned different time periods, but all included the entire month of October. This is reflected in the relatively large sample size for weeks during October compared with those of late August, early September, and early November. The number of surveys performed per daylight hour was not consistent across segments (Fig. 2.4). A more general comparison of surveys per time of day with morning defined as before 10:59, midday defined as between 11:00 and 15:59, and evening defined as after 16:00 shows better evenness in the number of surveys performed among different times of the day. In general, however, large proportions of the total number of surveys were from between 8:00 and 10:00 and 13:00 and 16:00 and very few surveys were performed after 17:00 (Fig. 2.5). This distribution is in part due to the fact that day length decreased throughout our field seasons.

The average survey length was 5.73 min (SD = 3.22, max = 37 min, n = 2,200), excluding segment 47 (mean = 23.73 min, SD = 17.344, max = 85 min, n = 40), the point (mean = 11.61 min, SD = 6.14, max = 39 min, n = 44) and the point closure (mean = 11.84 min, SD = 6.95, max = 31 min, n = 32).

We observed 54 bird species from 17 families on the ocean beach (Table 2.1), including 21 species of shorebirds, 6 species of gulls, and 9 species of terns. Sanderlings, Willets (*Catoptrophorus semipalmatus*), Great Black-backed Gulls (*Larus marinus*), Herring Gulls (*Larus argentatus*), and Black-bellied Plovers were the species most frequently present during surveys. They were detected during 1,937, 1,104, 959, 925, and 885 surveys respectively. Sanderlings also had the largest number of total detections (40,807), followed by Laughing Gulls *Larus atricilla* (11,237), Great Black-backed Gulls (10,662), Herring Gulls (10,040), and Willets (8,025). Our complete surveys show that total abundance on the ocean beach varied greatly for many species (Table 2.2). Total shorebird numbers ranged between 145 and 1,984 individuals. American Oystercatcher (*Haematopus palliates*) numbers were between 3 and 18 individuals, Black-bellied Plover numbers ranged between 8 and 293, and Ruddy Turnstone numbers were between 5 and 74. Dunlin (*Calidris alpina*) and Sanderling numbers were highest on 3 November 2006 (163 and 1,475 individuals, respectively) and had minimum counts of zero and 59, respectively. Willet numbers were between 28 and 389, and the maximum number of Red Knots counted during a complete survey was 17.

Gull abundance totals from complete surveys ranged between 172 and 4,692 individuals. Great Black-backed Gull numbers were between 35 and 629, Herring Gull numbers were between 46 and 1,395, Laughing Gull numbers were between 76 and 1,125, Lesser Black-backed Gull (*Larus fuscus*) numbers were between 2 and 62, and Ring-billed Gull (*Larus delawarensis*) numbers were between 5 and 2,181.

Tern numbers from complete surveys ranged between 23 and 1,226. The maximum counts of individuals on the island's ocean beaches during any one complete survey were 95 for Caspian Terns (*Sterna caspia*), 416 for Forster's Terns (*Sterna forsteri*), 237 for Royal Terns (*Sterna maxima*), and 500 for Sandwich Terns (*Sterna sandvicensis*). The maximum counts were from high tide surveys.

On two days, we surveyed the entire island during both high and rising tides (20 October and 3 November 2006). On 3 November 2006 the numbers of all shorebirds, gulls, and terns on the ocean beaches were either higher or equal to their numbers at rising tide. A complete count on 20 October 2006 also showed greater numbers at high tide than rising tide for Black-bellied Plovers, Piping Plovers, Red Knots, Ruddy Turnstones, Sanderlings, Semipalmated Plovers (*Charadrius semipalmatus*), Willets, Great Black-backed Gulls, Herring Gulls, Laughing Gulls, Lesser Black-backed Gulls, Caspian Terns, Forster's Terns, Royal Terns, and Sandwich Terns.

The largest number of vehicles (ATVs and ORVs summed) we counted during a complete survey was 149 on 12 October 2007 and the lowest number was 10 on 11 September 2006. ATV numbers ranged between 4 and 30, and ORV numbers ranged between 6 and 119. Boats were occasionally within 100 m of the swash zone, and the most we counted in a complete survey was 49. Pedestrian numbers were highest at 240 people on 12 October 2007.

Total shorebird densities on South Core Banks were similar to those reported by Dinsmore et al. (1998) for Ocracoke Island but they were only 50% of those reported for North Core Banks and 25% of densities at North Beach (the 25km of beach between the Rodanthe, NC pier and 1 km north of Buxton, NC, Table 2.3). Black-bellied Plover, Piping Plover, American Oystercatcher, Whimbrel, and Ruddy Turnstone densities were similar to those of other sites on the Outer Banks. Willet density was smaller than at all other sites, and North Beach had a density three times that of South Core Banks. Red Knot density was similar to that of all other sites except North Core Banks, which had six times the number of Red Knots. Sanderlings density (individuals per km) at South Core Banks was similar to Ocracoke, less than at North Core, and much less than at North Beach (Table 2.3).

Temporal patterns

Our index of shorebird numbers showed a slight decreasing trend throughout the season with peaks during the end of August, middle of September, and second and fourth weeks in October (Fig 2.6). Sanderling numbers peaked at the same times as overall shorebird numbers, but their numbers were largest during the end of October (Fig. 2.7). Willet and Black-bellied Plover numbers were also variable throughout the season, but both showed a decreasing trend over the fall (Fig 2.7). Willets were most abundant during the third week of September and Black-bellied Plovers were most abundant during the first week of September. American Oystercatcher abundance decreased throughout the season and was near zero by the beginning of November (Fig 2.8). The abundance of Red Knots and Piping Plovers was highly variable, and our largest estimate of Red Knot abundance was during the week of 8 November. Wilson's Plover (*Charadrius wilsonia*) numbers were highest in August and decreased to near zero during September (Fig 2.8). Dunlin arrived during the first week of October and peaked during the first week in November (Fig. 2.9). The numbers of Semipalmated Plovers on the South Core's beaches were highly variable, but they seemed to decrease overall throughout the season. No individuals were counted in the second week of November (Fig 2.9). Ruddy Turnstone numbers were greatest at the end of August. They decreased until 27 September, then increased, and remained relatively constant.

Our index of gull abundance on South Core Banks showed that numbers increased throughout the season with a sharp rise during the end of October (Fig. 2.6). Tern abundance was variable throughout the fall but declined abruptly at the end of September (Fig 2.6). All weeks prior to 27 September had larger numbers of terns than did weeks after 27 September. The numbers of pelicaniformes (Brown

Pelicans (*Pelecanus occidentalis*) and Double-crested Cormorants (*Phalacrocorax auritus*) stayed constant until a slight increase during the first week of November (Fig. 2.10). Peregrine Falcon (*Falco peregrinus*) abundance was largest in October and began increasing during the middle of September. We detected Merlins (*Falco columbarius*) between the weeks of 6 September and 1 November.

Pedestrian and vehicle numbers showed similar patterns after the first week in September (Fig. 2.11). Prior to September, vehicle numbers increased while pedestrian numbers decreased. After the week of 6 September, both tended to increase in abundance. There were peaks in both the number of vehicles and pedestrians during the weeks of 27 September and 1 November. The numbers of ATVs and moving vehicles (moving ATVs or ORVs) were very similar, and the two followed the same temporal pattern (Fig. 2.12). Likewise, the numbers and trends of ORVs and stationary vehicles (parked ATVs or ORVs) were similar. A very small proportion of the people we recorded were moving (i.e. running or walking), and their numbers were close to zero by the week of 6 September (Fig. 2.13).

The average numbers of shorebirds and vehicles counted during surveys was consistent across daylight hours (Fig. 2.14). Average gull and tern counts per survey followed similar patterns across daylight hours with a peak at 12:00 (Fig. 2.14). Gull numbers increased during the afternoon, while tern numbers decreased. The means of Sanderlings counted per segment survey during the morning and afternoon hours were larger than those from midday (Fig. 2.15). Willet, Black-bellied Plover, Wilson's Plover, and Ruddy Turnstone counts were all consistent among daylight hours (Figs. 2.16 and 2.17). Semipalmated Plover counts were higher at 12:00 and 13:00 than at other times of the day (Fig. 2.17). The means of American Oystercatcher counts were lower during midday than during morning and afternoon (Fig. 2.16). Piping Plover abundance was highest between 11:00 and 13:00 (Fig. 2.16).

The abundance of moving ATVs and ORVs did not vary among daylight hours, but the numbers of stationary ATVs and ORVs showed peaks at 12:00 and 16:00 (Fig. 2.18).

Spatial patterns

Shorebird abundance was relatively even across segments with the exceptions of low abundance between miles 44 and 46.5 and high abundance at segments 47 (mean = 17.85, SE = 3.80) and 30 (mean = 38.49, SE = 5.34, Fig 2.19). 2006 and 2007 data indicate that high tide abundance was greater than rising tide abundance (difference in means = 13.08, two-tailed t = 3.48, df = 50, P = 0.001), especially for segments between miles 36 and 42 and at segments 46 and 47 (Fig 2.20). 2005 data showed a similar pattern with high tide means being greater than low tide means for segments between miles 36.5 and 40.5, at segment 47, and at the point (Fig. 2.21). The patterns of abundance among segments at high tide were similar across years except for higher means at segments 24, 24.5, 29.5, and 30 in 2006 (Fig. 2.22).

The distribution of Sanderlings was similar to that of total shorebird abundance (Fig. 2.23). On average, there were more than 10 individuals in segments between miles 23 and 44 and fewer than 10 between miles 44 and 47 and at the point closure. Mean Sanderling abundance was largest at cape point (mean = 39.77, SE = 4.67) and segments 30 (mean = 38.49, SE = 5.34) and 39.5 (mean = 25.05, SE = 4.61). Abundance at high tide was greater than at rising tide (difference in means = 6.84, two-tailed t = 5.89, df = 50, P < 0.0001), especially between miles 23 and 30.5, between miles 36 and the point, and at segment 47 (Fig. 2.24). Differences between high and low tide are not apparent from 2005 data (Fig 2.25), and the high tide distribution of Sanderlings appeared similar across years (Fig 2.26).

Willets were common in all segments but were primarily distributed away from the inlets (Fig. 2.27). They were most abundant between miles 27 and 44 with peaks at segments 40.5 (mean = 6.45, SE = 1.71) and 29.5 (mean = 7.04, SE =

1.37). Their numbers did not appear to vary with tide level (difference in rising and high tide means = 0.32, two-tailed *t* = 1.45, df = 50, P = 0.077, Fig. 2.28). Mean high tide abundance was lowest in 2005 for many segments (Fig. 2.29).

The average number of Black-bellied Plovers was between two and seven at most segments. We identified three distinct areas with relatively high abundance; mile 23, segments between miles 33.5 and 41, and segments at the Power Squadron Spit (Fig. 2.30). Segments 47 and 37.5 had the most Black-bellied Plovers (mean = 6.38, SE = 4.63 and mean = 3.76, SE = 1.87, respectively). Abundance was greater at high tide than at rising tide in each of these three areas (Fig. 2.31), as well as for all segments (difference in means = 2.13, two-tailed *t* = 4.57, df = 50, P < 0.0001). The area between miles 33.5 and 41 also supported more birds at high tides than during rising tides, but this pattern was not apparent from 2005 data (Figs. 2.32 and 2.33).

Semipalmated Plover distributions were similar to those of Black-bellied Plovers. Their numbers were very low in most segments (less than one), and three distinct areas had relatively high abundance; the areas between miles 23 and 26, between miles 34 and 41, and at segments 46, 46.5, and 47 (Fig. 2.34). Semipalmated Plover numbers were largest in segments 47 and 46.5 (mean = 35.55, SE = 12.14, and mean = 2.74, SE = 1.72, respectively). They used these areas almost exclusively during high tide (Figs. 2.35 and 2.36). We did not find a statistically significant overall difference between high and rising tide means, but this was likely due to large variance (difference between means = 2.38, two-tailed *t* = 1.48, df = 50, P = 0.15).

Ruddy Turnstones were most abundant south of mile 35 and at the northernmost 3 mi portion of the island (Fig. 2.37). Of these areas, the point (mean = 4.14, SE = 0.90) and segment 41.5 (mean = 1.83, SE = 0.46) had the highest abundance. High tide means were greater than rising tide means for segments between miles 37.5 and 46 (Fig. 2.38), and there was a statistically significant difference in the high and rising tide means of all segments (difference = 0.42, two-tailed *t* = 3.43, df = 50, P = 0.001). In 2005, there was an area on the southern half of the island for which high tide means were greater than low tide means (between miles 35.5 and 42.5), but there was also an area on the northern half of the island, between miles 23 and 30, with higher abundance at low tide (Fig. 2.39). High tide distributions appeared similar among all three years (Fig. 2.40).

Unlike Ruddy Turnstones, American Oystercatchers were primarily distributed along the northern half of South Core Banks, between miles 25.5 and 28.5 (Fig. 2.41). They were most abundant at segment 27 (mean = 1.17, SE = 0.36) followed by segments 25.5 (mean = 0.69, SE = 0.23), 28 (mean = 0.68, SE = 0.19), and 28.5 (mean = 0.65, SE = 0.21). The patterns of abundance at high and rising tide both resembled the pattern of overall abundance and their means were not different (two tailed *t* = 0.20, df = 50, P = 0.84, Fig. 2.42).

We observed Red Knots at most segments on the island, but average counts were generally small. Only one segment, segment 23, had a mean greater than one (mean = 1.08, SE = 0.52, Fig. 2.43). High tide abundance was greater than low tide abundance at segments between miles 23 and 25 and between 27.5 and 29 during 2005 (Fig. 2.44). 2006 and 2007 data, however, suggest that abundance at high tide was not greater than at rising tide (difference in means = 0.25, two-tailed *t* = 0.46, df = 50, P = 0.65, Fig. 2.45).

We primarily encountered Piping Plovers at the northern and southern ends of the island, and they were most abundant at segments 46.5 (mean = 0.67, SE = 0.53), and 47 (mean = 2.36, SE = 0.69), which make up the Power Squadron Spit (Fig. 2.46). Mean abundance for these segments was larger at high tides than at low or rising tides (Figs. 2.47 and 2.48).

We only detected Wilson's Plovers at segments 39.5, 40.5, 46.5, and 47. All encounters with this species, with the exception of one, were at high tide.

Gulls were common throughout the ocean beaches of South Core Banks, but we identified three distinct peaks in their distribution across segments (Fig. 2.49). One, their numbers were relatively high around segment 29.5 (mean = 100.77, SE = 15.78). Two, they were abundant at the point (mean = 70.30, SE = 16.64) and segment 44 (mean = 105.47, SE = 34.49). Three, they were abundant in the segments that make up the Power Squadron Spit (segment 47 mean = 228.85, SE = 93.49, max = 3,631). Their distribution did not appear to vary by tide (difference in high and rising tide means = 2.70, two-tailed *t* = 0.69, df = 50, P = 0.50, Fig. 2.50) but high tide means were lowest during 2007 (Fig. 2.51).

The spatial distribution of terns was similar to that of gulls with peaks at segment 47 (mean = 144.60, SE = 38.87) and around the point closure (closure mean = 46.63, SE = 26.97; point mean = 42.20, SE = 16.23; segment 44 mean = 84.26, SE = 31.57, Fig. 2.52). The area between miles 28 and 31.5 also had relatively large numbers of terns. Tern numbers were only larger at high tide than low or rising tide at segment 47 (difference in high and rising tide means for all segments = 3.01, two-tailed *t* = 0.85, df = 50, P = 0.40, Figs. 2.53 and 2.54). The high tide distribution of terns did not appear to vary over years, except that numbers were low at segment 44 during 2007 compared to numbers from 2006 and 2007 (Fig. 2.55).

We counted pelicaniformes in most segments, and their numbers were highest at segment 47 (mean = 31.58, SE = 6.24, Fig. 2.56). For both high and rising tide, they were more abundant at segment 47 (high tide mean = 33.57, SE = 9.90, rising tide mean = 14.07, SE = 33.57, Fig. 2.57). Their distribution at high tide was consistent across years (Fig. 2.58).

The relative abundance of all vehicles (ORV and ATV numbers combined) among beach segments was representative of that of ORVs and stationary vehicles. Vehicle numbers were largest at the point (mean = 12.98, SE = 1.49) and segments 43.5 (mean = 7.09, SE = 1.06), 23 (mean = 4.16, 0.68), 35.5 (mean = 3.13, SE = 0.61), and 30.5 (mean = 3.04, SE = 0.58, Fig 2.59). The largest numbers of vehicles counted during one segment survey were 43 vehicles at segment 44, 38 vehicles at the point, and 30 vehicles at segment 34.5. The patterns of abundance across segments were similar at all tides and years, with the exception of lower abundance at some segments between miles 34 and 39 during the 2007 season (Figs 2.60, 2.61, and 2.62). The distribution of ATVs was similar to that of all vehicles but with smaller average abundance at each segment (Fig. 2.63)

Average counts of moving vehicles for all but one segment, the point (mean = 1.02, SE = 0.19), were less than one (Fig. 2.64). Moving vehicles were also abundant at segment 44 (mean = 0.72, SE = 0.34) and between miles 30 and 34.5 where means ranged between 0.56 and 0.68. The maximum number of vehicles counted in one survey was 14 at segment 44, followed by 10 vehicles at segment 44.5, and 9 vehicles at segment 30.5. Spatial patterns in abundance appeared similar across tide levels and years (Figs. 2.65, 2.66, and 2.67).

Pedestrians were distributed similar to vehicles except for in the area between miles 41 and 42.5, where pedestrian abundance was relatively high and vehicle abundance was relatively low (Figs. 2.59 and 2.68). The segments with the highest mean pedestrian abundance were the point (mean = 19.68, SE = 2.59), segment 43.5 (mean = 8.56, SE = 1.59), and segment 23 (mean = 5.63, SE = 1.07).

We found differences in microhabitat use between high and rising tides for some species of shorebirds. We counted more shorebirds during high tide surveys than during rising tide surveys, and shorebirds were more frequently encountered in dry sand microhabitats at high tide than during rising tides (Fig. 2.69). For all shorebird species except for Willets and American Oystercatchers, we recorded more individuals at high tides than at rising tides. Black-bellied Plovers, Semipalmated Plovers, and Piping Plovers showed similar differences in microhabitat use between high and rising tide (Figs. 2.70, 2.71, and 2.72). They used the swash zone very little at high tide and shifted from the dry sand to the swash zone during rising tides. Red Knots were in all three microhabitat types during high tides, however we only observed one individual in the dry sand during rising tide surveys (Fig. 2.73). American Oystercatchers were most common in the swash zone during rising tides but their distribution shifted toward dry areas at high tide so that more individuals were in the dry sand at high tide than rising tide (Fig. 2.74). Sanderling, Willet, and Ruddy Turnstone numbers were lower in the dry sand than in the swash zone or wet sand during both tide levels (Figs. 2.75, 2.76, and 2.77). They did, however, increase their use of the dry sand microhabitat and decrease their use of the swash zone during high tide.

We counted similar numbers of gulls during high and rising tides. The proportions of individuals in the surf and swash zone were similar across tide levels, but there were slightly more in the dry sand and fewer in the wet sand during rising tides than high tides (Fig. 2.78). Terns were distributed evenly between the dry and wet sand during high tide but a small proportion of individuals used the swash zone during rising tides (Fig. 2.79). The proportions of Brown Pelicans and Double-crested Cormorants using the dry sand and swash zones were similar between tides but during rising tides, fewer individuals were in the wet sand and more were in the surf (Fig. 2.80).

Moving and stationary vehicles were concentrated in the dry sand portions of beach segments during high and rising tides, but both were more abundant on wet sand during rising tides (Figs. 2.81 and 2.82). Pedestrians were also observed in the dry sand more than in the other locations (Fig. 2.83). They did not appear to shift their distribution on the beach with changes in tide level.

DISCUSSION

The ocean beach of South Core Bank is used by a variety of shorebird, gull, and tern species between the end of August and middle of November. Shorebird numbers are similar to those reported at other sites on the Outer Banks (Table 2.3), and they show distinct patterns in abundance over time and space that overlap with those of human activity in the park.

The patterns in total abundance within the fall differed between the species and groups that we examined, and they were consistent with ones reported by Dinsmore et al. (1998) for other sites on the Outer Banks. We identified six general patterns. The numbers of terns, Black-bellied Plovers, Willets, American Oystercatchers, Wilson's Plovers, and Semipalmated Plovers generally declined throughout the fall (Figs. 2.7-2.9). This group includes species that breed at CALO (American Oystercatcher, Wilson's Plover, Willet, and tern species). Gulls, pelicaniformes, and Dunlins showed increases in abundance as the season progressed (Figs. 2.6 and 2.7). Total shorebird and Sanderling numbers exhibited a variable pattern that suggests pulses in migration (Fig. 2.6 and 2.7). Ruddy Turnstone numbers were fairly constant as the season progressed, but temporarily declined during the end of September (Fig. 2.9). Red Knots and Piping Plovers showed a fifth pattern, which was one of sporadic peaks throughout the season with periods of absence and no clear general increasing or decreasing trend (Fig. 2.8). We speculate that this is a result of small local population sizes and inconsistent detections. When detected, Red Knots were usually in small flocks. Piping Plovers seemed to use the ocean beach inconsistently. Merlin and Peregrine Falcon numbers clearly showed an increase followed by a decrease, whereby their numbers increased from zero, peaked, and decreased back to zero within the season (Fig. 2.10).

Shorebirds, as a whole, were evenly distributed among segments between miles 23 and 44 (Fig. 2.19), but the spatial distributions of individual species were unique. Black-bellied Plovers and Semipalmated Plovers were relatively abundant in the same areas; the spit, the northern end of the island, and a section of beach between miles 33.5 and 41 (Figs. 2.30 and 2.34). They were both more abundant at high tide in these areas (Figs. 2.32 and 2.36). Willets were distributed in an "M" shape with smaller numbers at the northern and southern tips of the island and in the middle

(Fig. 2.27). Sanderlings were more evenly distributed across the island than other shorebirds, but still had relatively low numbers between the point and the Power Squadron Spit (Fig. 2.23). Ruddy Turnstones were concentrated on the southern half of the island, and they were relatively abundant between 33.5 and 41, along with Black-bellied and Semipalmated Plovers (Fig. 2.37). American Oystercatchers were concentrated in the northern half of the island. We observed the largest flocks of oystercatchers at segments between miles 25 and 29 (Fig. 2.41). During 2007, our field season was early enough that some adults and juveniles were still on breeding territories between miles 35 and 41. Piping Plover numbers were largest at the Power Squadron Spit and near Ophelia Inlet (Fig. 2.46). They were rarely or never present at segments between miles 25.5 and 42.5. Red Knots were most abundant at the northern tip of the island and were encountered infrequently at various other segments along the island (Fig. 2.43).

Overall, there were several regions on the South Core Banks with notable bird communities. The northernmost 3 mi of the island supported large numbers of gulls, Black-bellied Plovers, Ruddy Turnstones, Red Knots, and Piping Plovers relative to other areas of the island's ocean beaches. The beach between this region and the Great Island Cabin Area, at mile 30, was used relatively little by all species except for Willets and American Oystercatchers. The beach adjacent to the Great Island Cabin Area frequently hosted large, mixed-species flocks of gulls, terns, and various shorebirds, usually Sanderlings, Willets, Black-bellied Plovers, and Ruddy Turnstones. The beach between miles 33.5 and 41 had large numbers of Black-bellied Plovers, Semipalmated Plovers, Sanderlings, and Ruddy Turnstones compared to other areas, except for those near inlets. The area composed of segments 43.5, 44, the point, and the point closure was frequently used as a roosting site by terns and gulls. Shallow pools were occasionally located in the point closure and we observed several shorebird species, including Least Sandpipers, Pectoral Sandpipers (*Calidris melanotos*), Greater Yellowlegs (*Tringa melanoleuca*) and Lesser Yellowlegs (*Tringa flavipes*), along their edges. The beach between miles 44.5 and 46 had the smallest numbers of shorebirds of any portion of the island. Only two species, Piping Plovers and Ruddy Turnstones, were abundant in this area relative to other areas. The Power Squadron Spit was characterized by a large diversity and abundance of birds. We regularly observed large flocks of gulls, terns, pelicaniformes, and shorebird species roosting at high tides, as well as plovers and sandpipers foraging there during low tides.

Tide influenced the abundance of some shorebirds on the ocean beaches. Overall shorebird numbers on the ocean beach, as well as those of Sanderlings, Black-bellied Plovers, and Ruddy Turnstones were greater at high tides than during rising tides tide. We did not find a statistically significant difference between Semipalmated Plover, Willet, American Oystercatcher, Red Knot, and Piping Plover numbers at high and rising tide, but there was some evidence that Semipalmated Plovers, Red Knots, and Piping Plovers were more abundant in some areas at high tide (Figs. 2.35, 2.36, 2.44, 2.45, 2.47, 2.48). In general, the segments comprising the Power Squadron Spit and segments between miles 35 and 41 supported more birds during high tide than during low tide levels. Terns and pelicaniformes were more abundant during high tide at segment 47. We did not identify any areas where shorebird abundance was greater during low tides than during high tides.

Many of the same shorebird species for which tide appeared to influence abundance used dry sand microhabitats more during high tides than during rising tides (Fig. 2.36). This preference was most pronounced for Black-bellied Plovers, Semipalmated Plovers, Red Knots, Piping Plovers, and American Oystercatchers (Figs. 2.70 – 2.74). The proportions of detections in the dry sand was greater during high tide than during rising tide for Sanderlings, Ruddy Turnstones, and Willets, but these differences were not as large as for other species (Figs. 2.75 – 2.77). The greater abundance, greater use of dry sand at high tide, and the infrequency of encounters with shorebirds foraging in the dry sand microhabitat lead us to conclude that some shorebirds use South Core Banks' ocean beach as a roosting site during high tide.

Our data show that total shorebird abundance was similar among daylight hours but that hourly patterns existed for some species. Sanderlings were most abundant in the morning and afternoon (Fig. 2.15). American Oystercatcher, Red Knot, Piping Plover, and Semipalmated Plover numbers varied with daylight hour, but the variation in abundance within some hours was very large and, therefore, no clear patterns were distinguishable (Figs. 2.16 and 2.17). The abundance of four shorebird species, Ruddy Turnstones, Black-bellied Plovers, Willets, and Wilson's Plovers appeared constant throughout the day (Figs. 2.15 – 2.17). Gull and tern numbers followed the same pattern of increasing until noon and then decreasing until 14:00, when their patterns diverged (Fig. 2.14).

In general, the numbers of people and vehicles on South Core Banks' ocean beach increased throughout the fall, and after 6 September visitor abundance corresponded closely with vehicle abundance (Fig. 2.11). The total number of vehicles present on the beaches was relatively constant across daylight hours, but the number of stationary vehicles peaked at noon and 16:00 (Fig. 2.14). Most vehicles on the beach were stationary ORVs, and they were not evenly dispersed along the beach (Fig. 2.59). The distribution of ATVs and ORVs were similar except that ATV numbers were smaller (Figs. 2.59 and 2.63). Vehicle users favored the southern end of the island, including the area between the point and mile 46, segments near mile 35.5, segments near the Great Island Cabin Area, and the northernmost tip of the island. Vehicles were relatively sparse on the beach between miles 29 and 23.5. The distribution of moving vehicles did not follow that of stationary ones, and they were most abundant on the beach between miles 30 and 33.5 and at the segments near the point (Fig. 2.64). Vehicles were mostly located on dry sand, but a small proportion was in the wet sand microhabitat (Figs. 2.81 and 2.82).

We found considerable overlap in the distributions of birds and recreationists on South Core Banks. The numbers of visitors and vehicles on the island increased throughout the season while Willets, Sanderlings, and Black-bellied Plovers remained abundant (Figs. 2.7 and 2.11). Tern numbers generally declined as vehicle numbers increased, but terns remained present throughout the season (Fig. 2.6). Gull numbers increased almost in unison with visitor numbers (Figs. 2.6 and 2.11).

Our descriptions of the spatial distribution of birds among segments show little evidence of segregation between birds and vehicles. In fact, visitors, vehicles, and some bird species were abundant in the same places at the same times. Gull numbers were largest in areas with high visitor abundance, and shorebirds were relatively common on the beach adjacent to the Great Island Cabin Area (mile 30, Figs. 2.49 and 2.59). There is, however, a possibility that segregation occurred within our segments. Shorebird species that were common on the beaches (i.e. Willets, Ruddy Turnstones, and Sanderlings) were primarily found in the swash zone, while vehicles were usually located in the dry sand (Figs. 2.75 – 2.77). We also observed roosting flocks of terns at cape point that were within the same beach segment as vehicles, but positioned away from them.

Although our surveys provided a large data set that was useful for describing patterns in shorebird, pedestrian, and vehicle abundance, we recognize several important limitations in our data. Dinsmore et al. (1998) reported that the largest numbers of shorebirds were on the Outer Banks during July and August. We detected large numbers of Semipalmated Plovers and Black-bellied Plovers early on, which suggests that a late summer peak is likely at South Core Banks. We did not survey in these months, so we did not sample the complete migration season. Nevertheless, we sampled a large portion of fall migration.

Our sampling effort was fairly well distributed among high and low tides, years, and segments, but not weeks or daylight hours (Figs. 2.2 – 2.4). Our description is most appropriate for the months of September and October because that is when we did most of our surveys. Surveys from August were all from 2007 and surveys from November were mostly from 2005, so differences in the distribution of birds among years are confounded with differences among weeks.

Most of the species that we examined use habitats other than the ocean beach, such as mudflats and sound-side beaches. Our total counts from complete surveys and our island abundance indices are, therefore, a larger proportion of the true island abundance for species that primarily use ocean beaches. Finally, many shorebirds are known to be active both diurnally and nocturnally (Burger 1984, Burger and Gochfeld 1991b), but we were only able to survey during daylight. There may be patterns of habitat use related to daylight that we were unable to identify.

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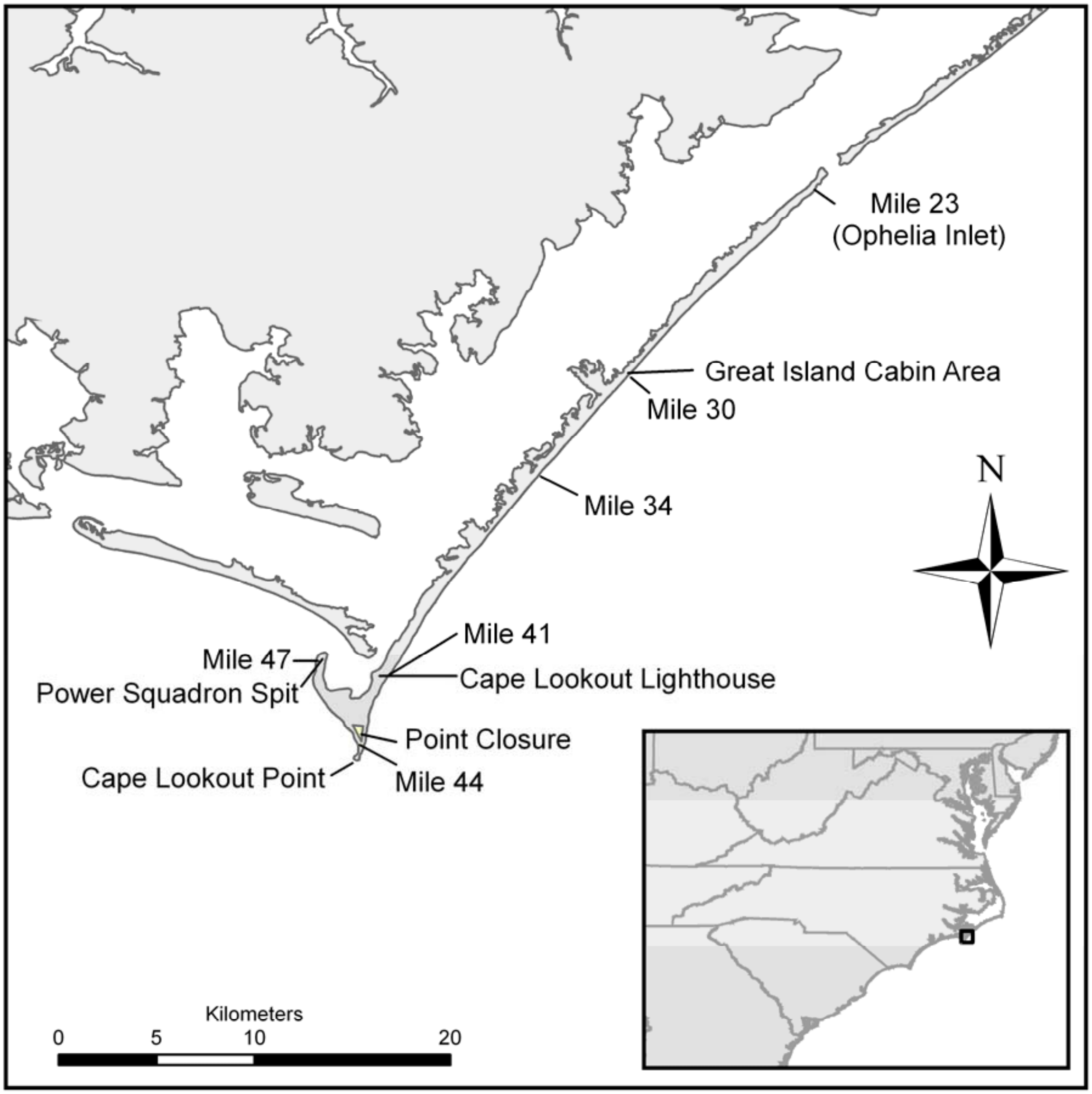

Figure 2.1. Map of South Core Banks, NC. The miles that are labeled correspond with Cape Lookout National Seashore's (CALO) mile marker system. A new inlet was created at mile 23 during Hurricane Ophelia in September 2005.

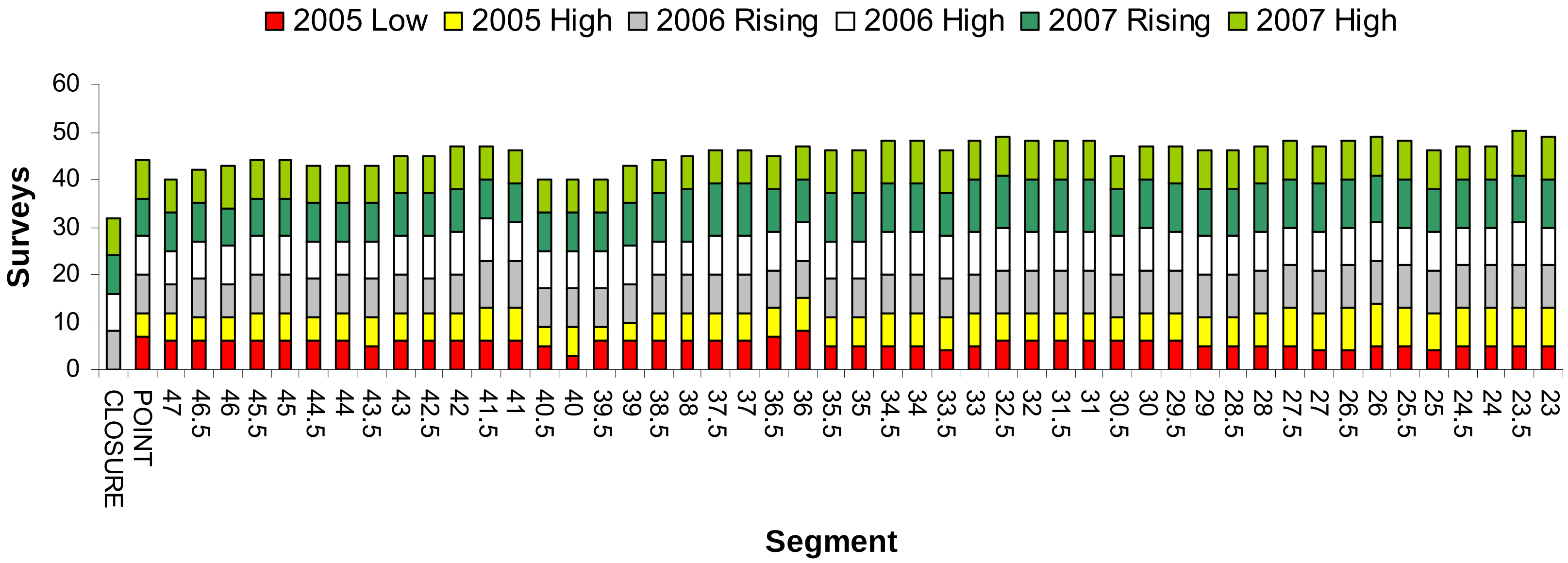

Figure 2.2. The number of surveys performed at beach segments on South Core Banks, NC for each year and tide. Segment names denote where the segment's northern edge falls within Cape Lookout National Seashore's mile marker system. Low tide was from 2 h before until 2 h after peak low tide. Rising tide was from peak low tide to 4 h after peak low tide. High tide was from 2 h before until 2 h after peak high tide.

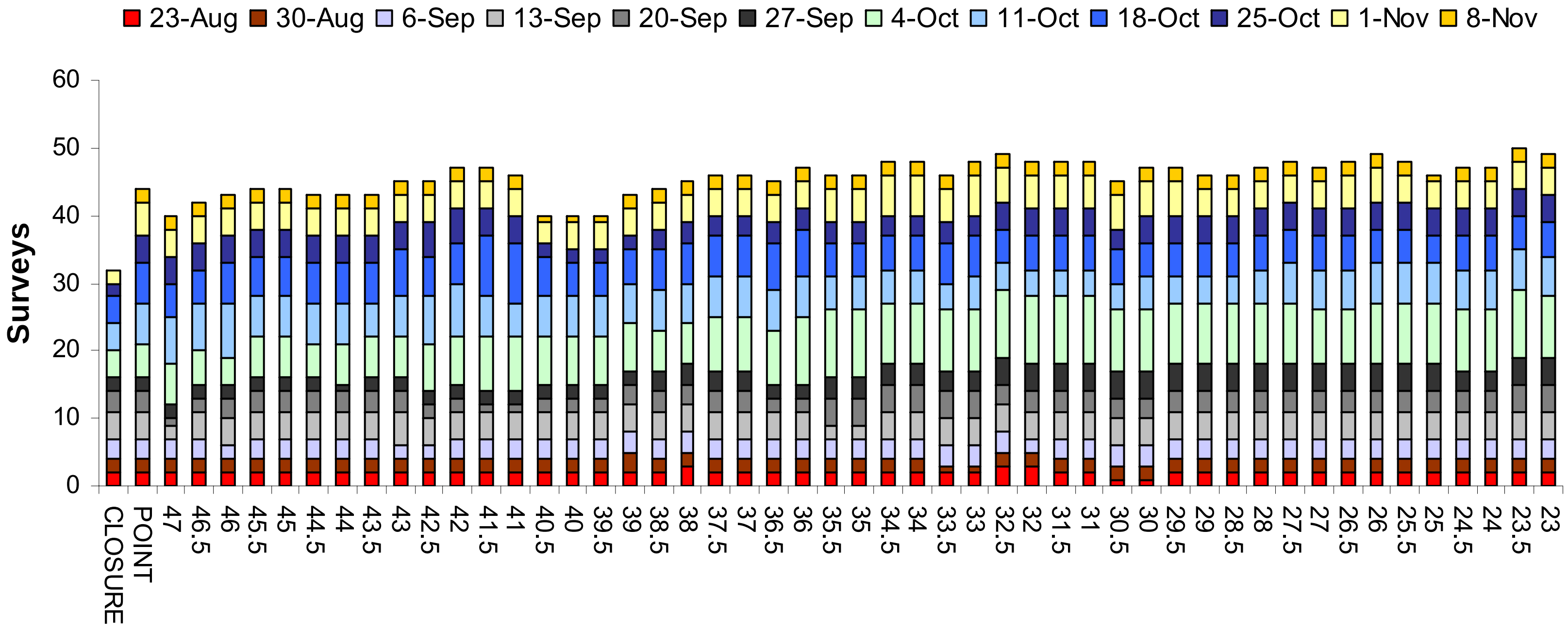

Figure 2.3. The number of surveys performed at beach segments on South Core Banks, NC for each week. Weeks in the same month are colored with shades of the same color (August – Red, September – black/gray, October – blue/green, November – yellow/orange). Weeks were named after the date of the first day of the week. Segment names denote where the segment's northern edge falls within Cape Lookout National Seashore's mile marker system.

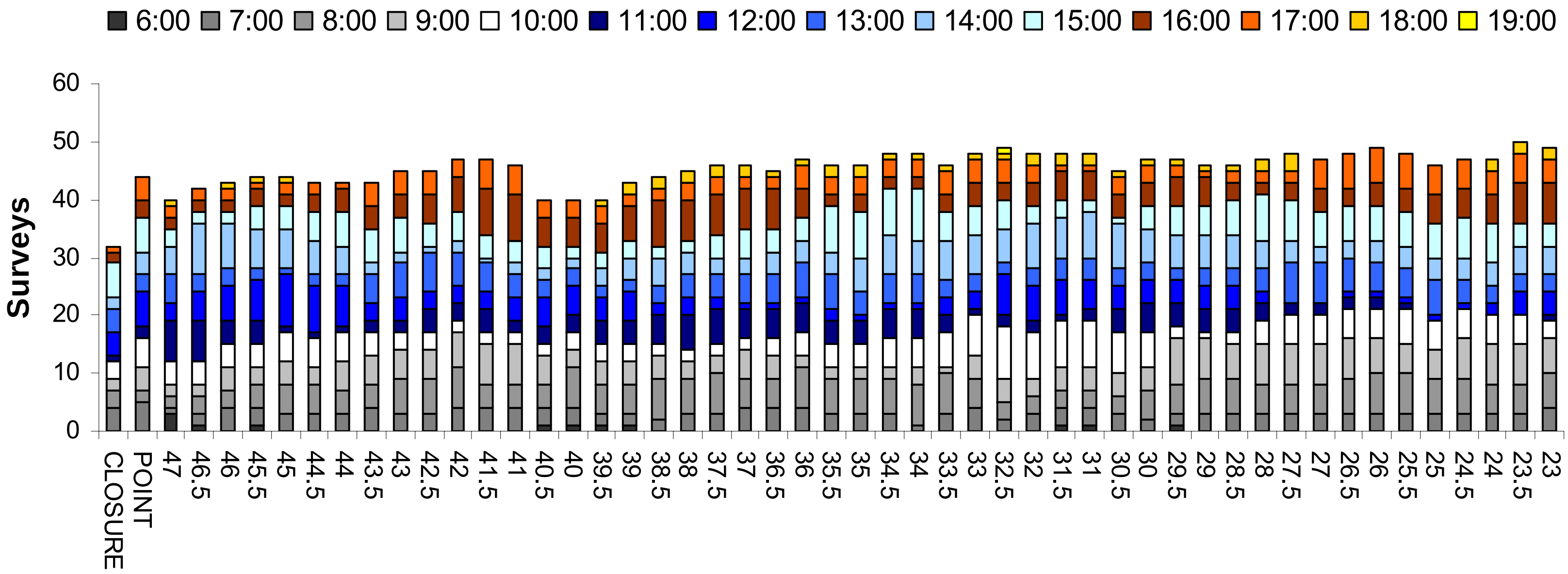

Figure 2.4. The number of surveys performed at beach segments on South Core Banks, NC for each daylight hour EST. Hours during the morning are shades of grey, hours at midday are shades of blue, and hours during the evening are shades of red or yellow. Segment names denote where the segment's northern edge falls within Cape Lookout National Seashore's mile marker system.

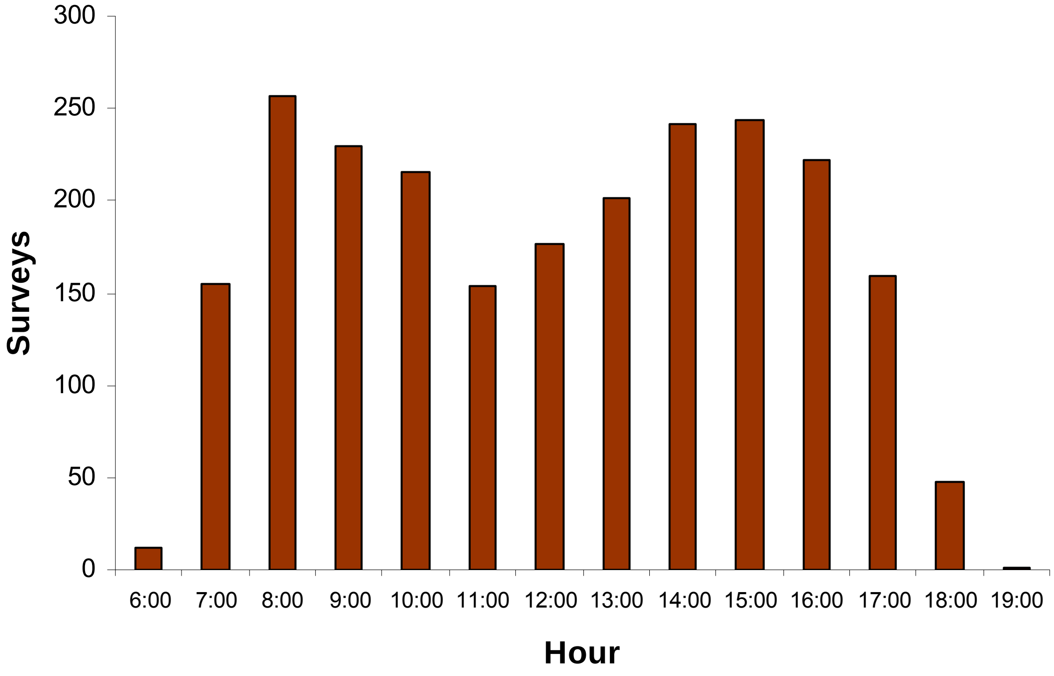

Figure 2.5. Sample size of surveys for each daylight hour EST. Surveys were assigned to hour bins based on their start time.

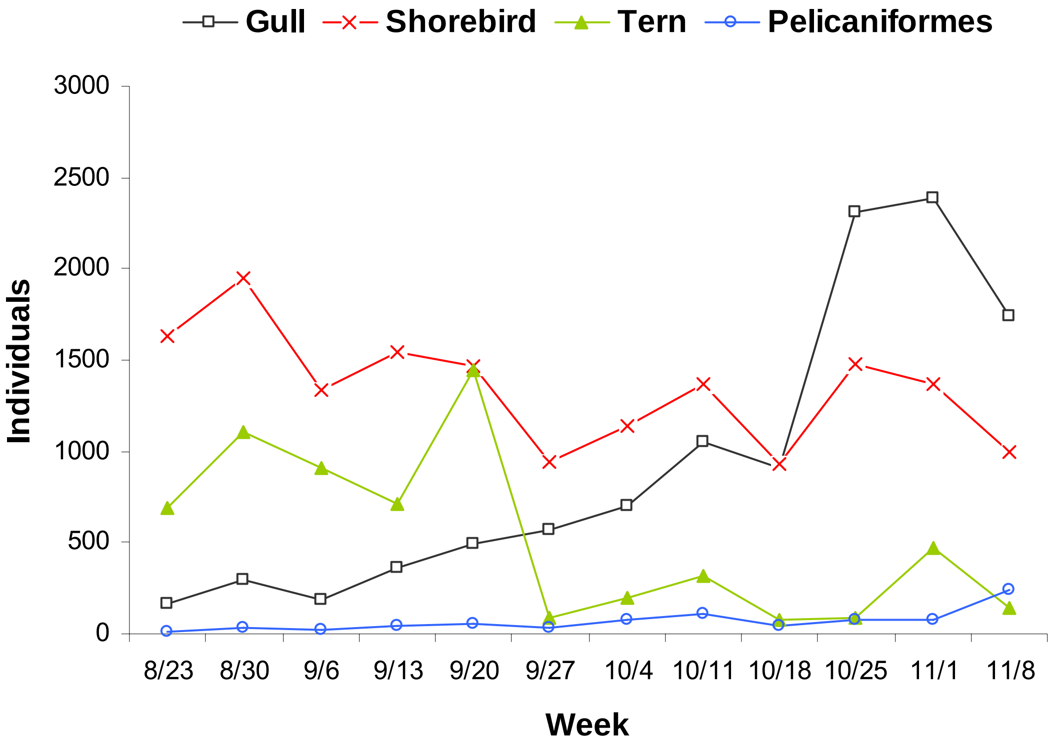

Figure 2.6. The abundance of gulls, shorebirds, terns, and pelicaniformes (Brown Pelicans, Double-crested Cormorants) at South Core Banks, North Carolina during fall weeks. We used the sum of average abundance from all beach segments as an index of abundance on the whole island for each week. Data from 2005, 2006, and 2007 were included, detections of flying birds were excluded, and one site, a vehicle exclosure at the upper beach at cape point, was never surveyed during the week of 8 November. Dates on the x-axis are the first day of the week.

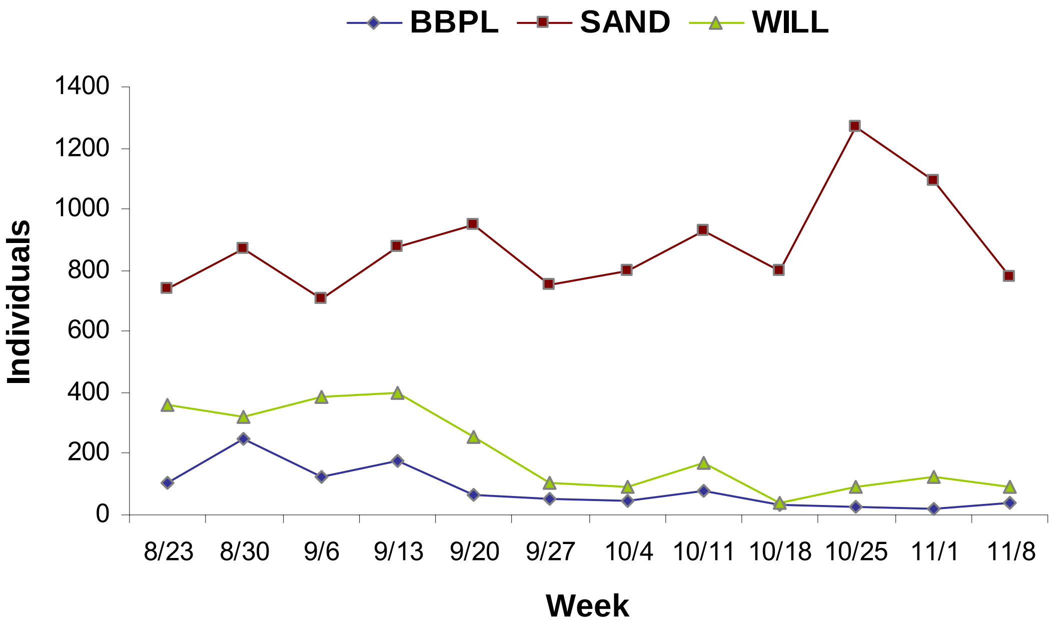

Figure 2.7. The abundance of Black-bellied Plovers (BBPL), Sanderlings (SAND), and Willets (WILL) at South Core Banks, North Carolina during fall weeks. We used the sum of average abundance from all beach segments as an index of abundance on the whole island for each week. Data from 2005, 2006, and 2007 were included, detections of flying birds were excluded, and one site, a vehicle exclosure at the upper beach at cape point, was never surveyed during the week of 8 November. Dates on the x-axis are the first day of the week.

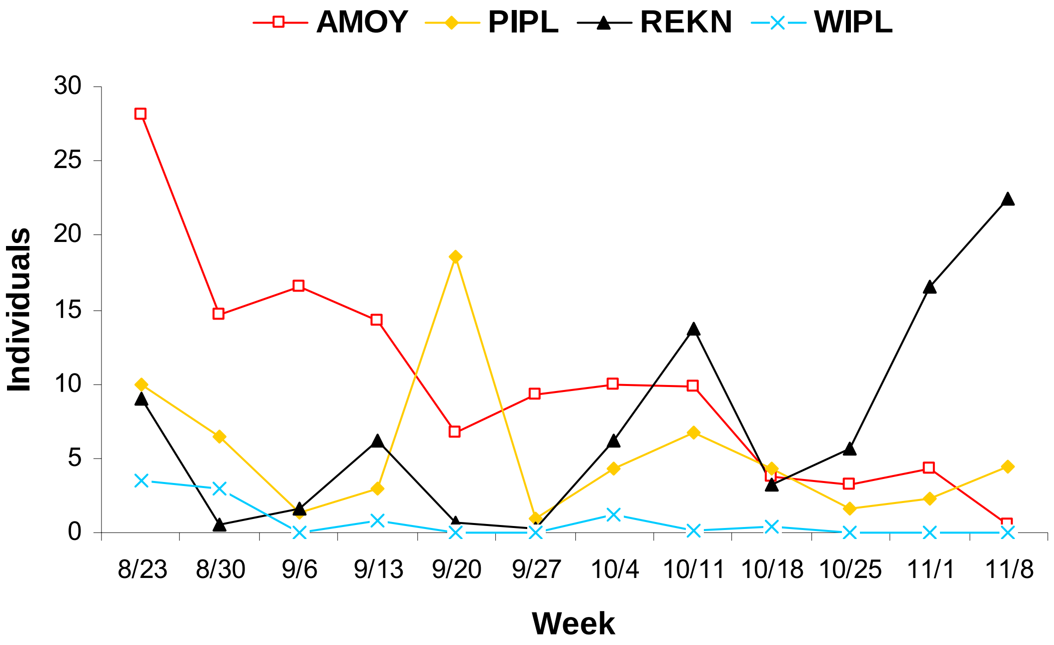

Figure 2.8. The abundance of American Oystercatchers (AMOY), Piping Plovers (PIPL), Red Knots (REKN), and Wilson's Plovers (WIPL) at South Core Banks, North Carolina during fall weeks. We used the sum of average abundance from all beach segments as an index of abundance on the whole island for each week. Data from 2005, 2006, and 2007 were included, detections of flying birds were excluded, and one site, a vehicle exclosure at the upper beach at cape point, was never surveyed during the week of 8 November. Dates on the x-axis are the first day of the week.

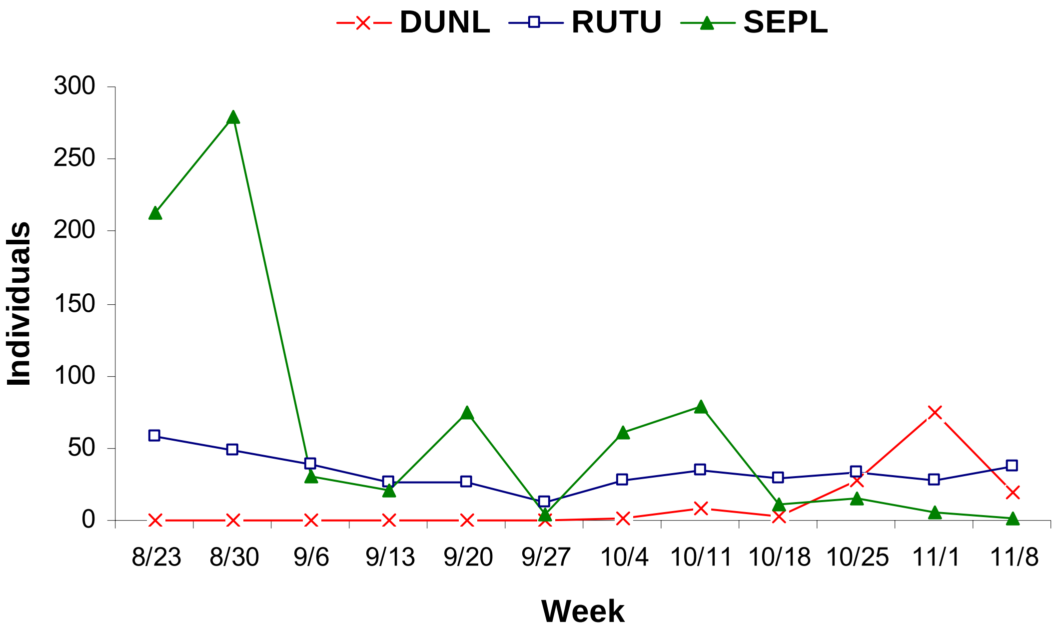

Figure 2.9. The abundance of Dunlins (DUNL), Ruddy Turnstones (RUTU), and Semipalmated Plovers (SEPL) at South Core Banks, North Carolina during fall weeks. We used the sum of average abundance from all beach segments as an index of abundance on the whole island for each week. Data from 2005, 2006, and 2007 were included, detections of flying birds were excluded, and one site, a vehicle exclosure at the upper beach at cape point, was never surveyed during the week of 8 November. Dates on the x-axis are the first day of the week.

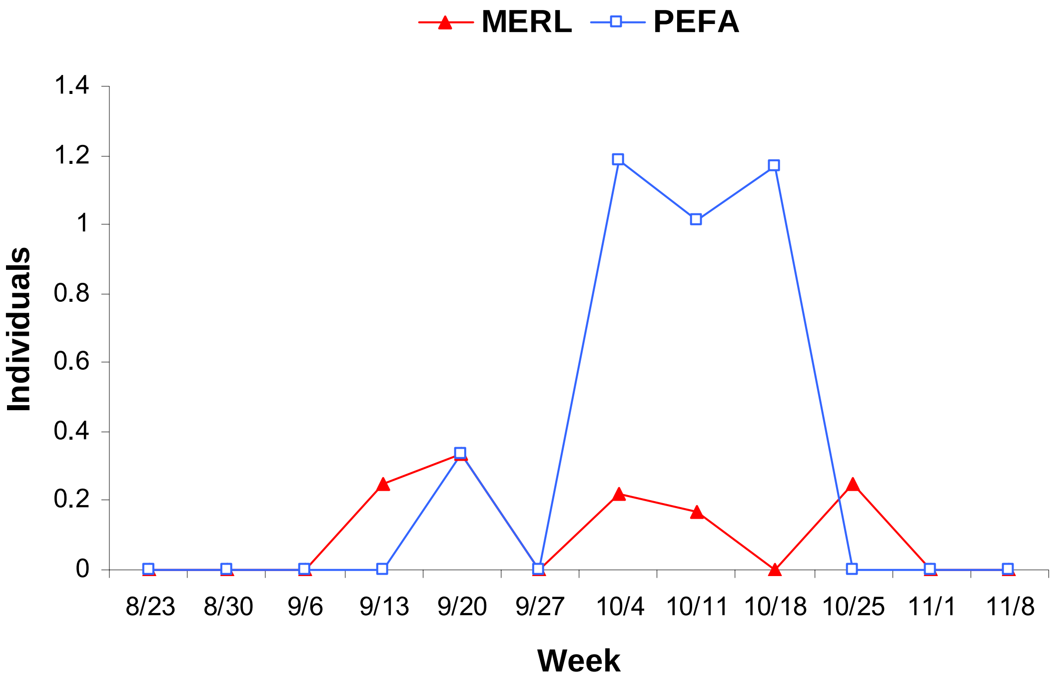

Figure 2.10. The abundance of Merlins (MERL) and Peregrine Falcons (PEFA) at South Core Banks, North Carolina during fall weeks. We used the sum of average abundance from all beach segments as an index of abundance on the whole island for each week. Data from 2005, 2006, and 2007 were included, detections of flying birds were excluded, and one site, a vehicle exclosure at the upper beach at cape point, was never surveyed during the week of 8 November. Dates on the x-axis are the first day of the week.

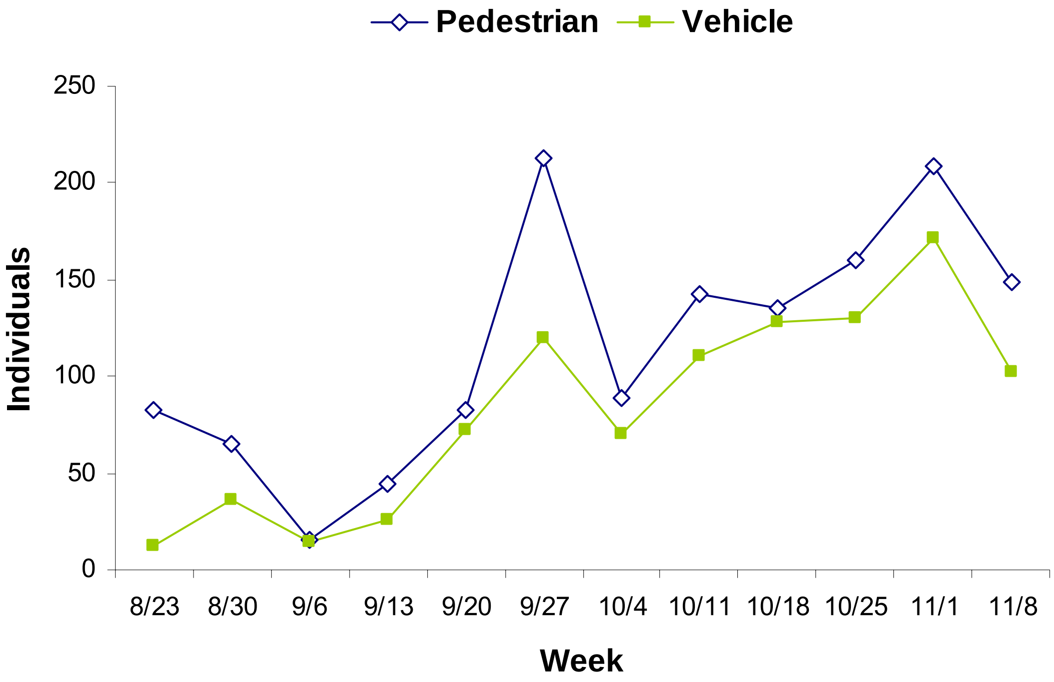

Figure 2.11. The abundance of pedestrians (moving or stationary) and all vehicles (moving or stationary ORVs or ATVs) at South Core Banks, North Carolina during fall weeks. We used the sum of average abundance from all beach segments as an index of abundance on the whole island for each week. Data from 2005, 2006, and 2007 were included. One site, a vehicle exclosure at the upper beach at cape point, was never surveyed during the week of 8 November. Dates on the x-axis are the first day of the week.

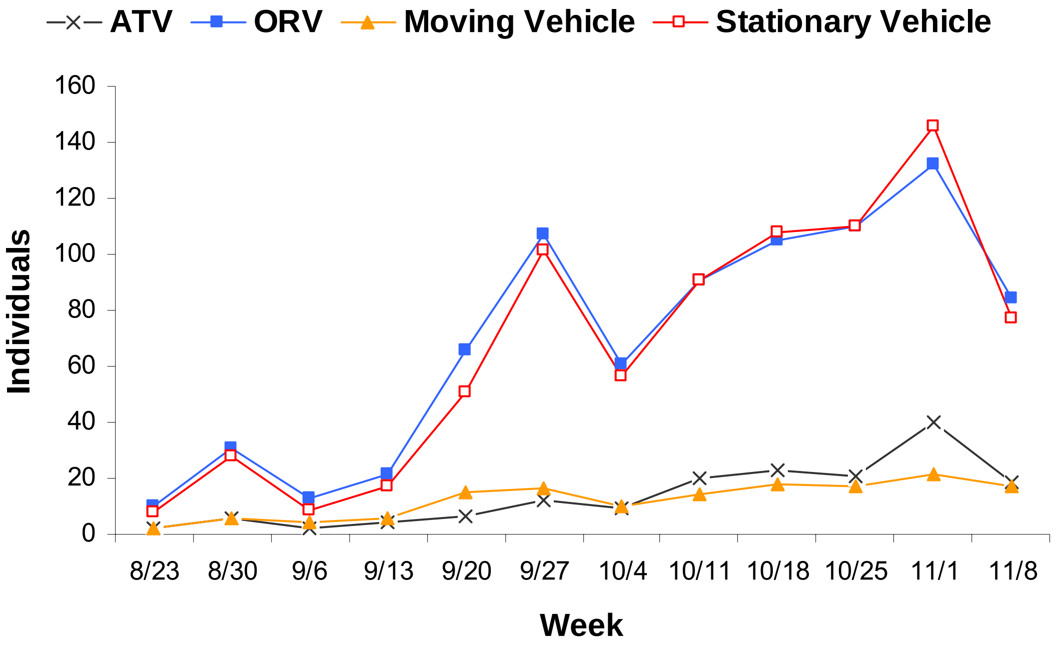

Figure 2.12. The abundance of ATVs (moving or stationary), ORVs (moving or statrionary), moving vehicles (moving ATVs or ORVs), and stationary vehicles (stationary ATVs or ORVs) at South Core Banks, North Carolina for fall weeks. We used the sum of average abundance from all beach segments as an index of abundance on the whole island for each week. Data from 2005, 2006, and 2007 were included. Dates on the x-axis are the first day of the week.

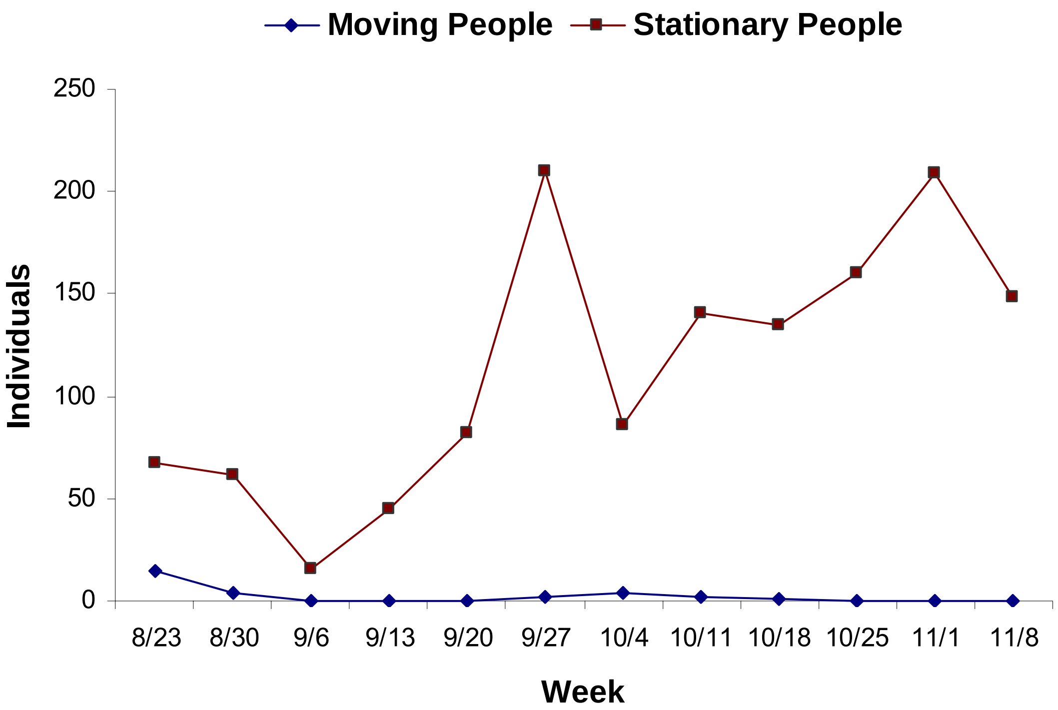

Figure 2.13. The abundance of moving people (runners, joggers, and walkers) and stationary people at South Core Banks, North Carolina for fall weeks. We used the sum of average abundance from all beach segments as an index of abundance on the whole island for each week. Data from 2005, 2006, and 2007 were included. One site, a vehicle exclosure at the upper beach at cape point, was never surveyed during the week of 8 November. Dates on the x-axis are the first day of the week.

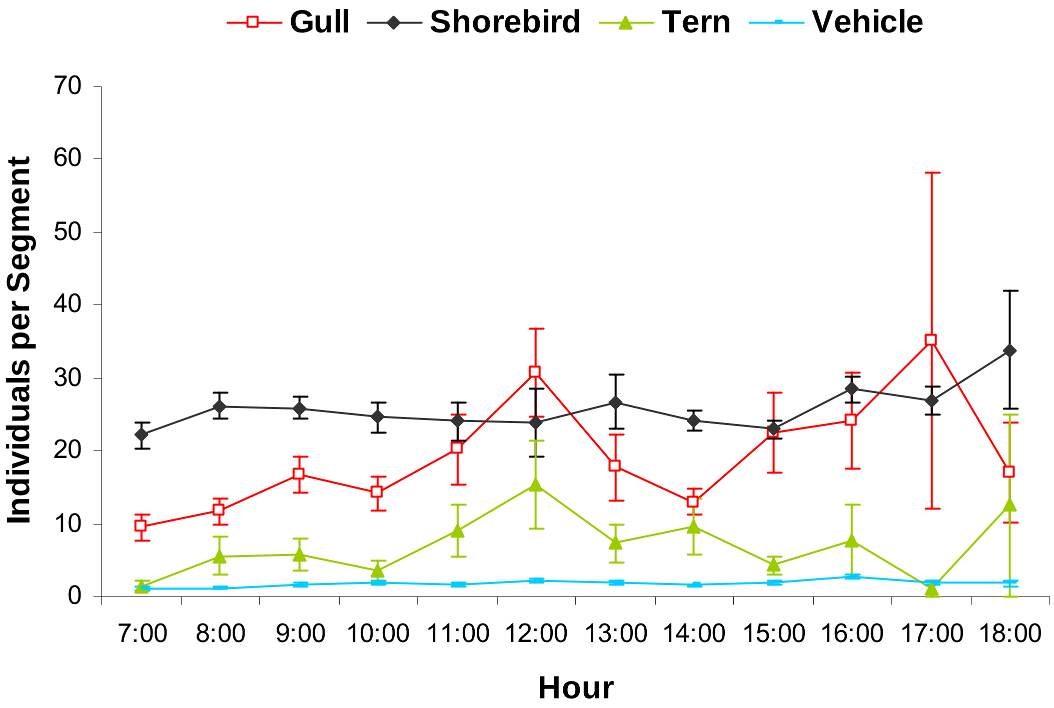

Figure 2.14. The average number of gulls, shorebirds, terns and vehicles (ORVs and ATVs combined) counted per segment survey for each daylight hour EST. Surveys from all tide levels, segments, years, dates, and observers were included, but we excluded detections of flying birds from this summary. Error bars represent one standard error, and 6:00 and 19:00 left out due to small sample sizes.

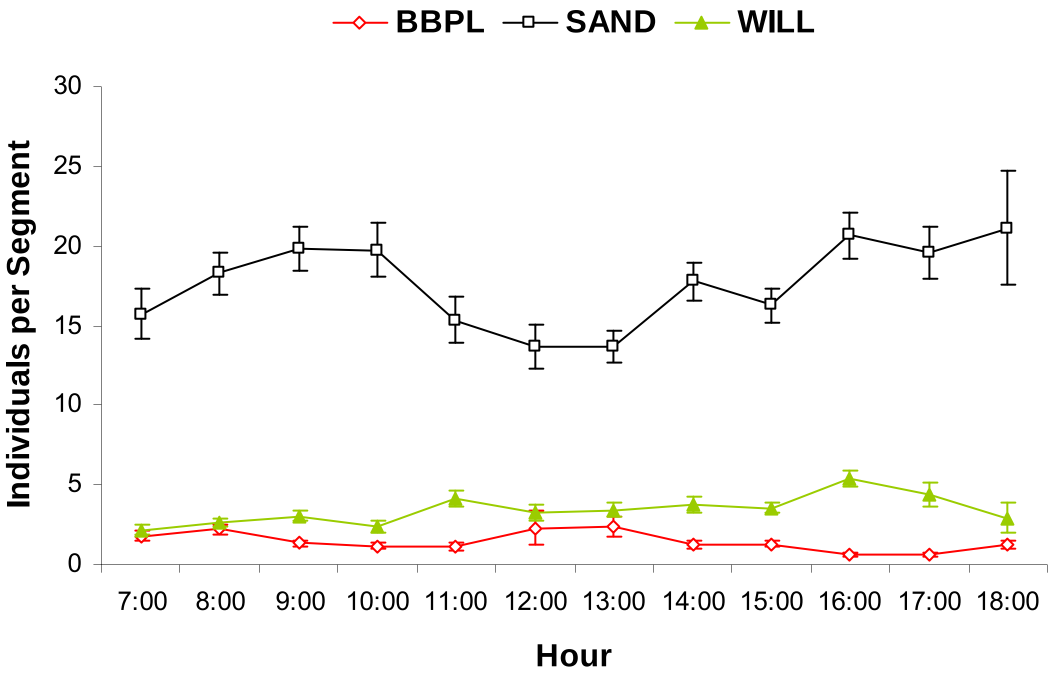

Figure 2.15. The average number of Black-bellied Plovers (BBPL), Sanderlings (SAND), and Willets (WILL) counted per segment survey for each daylight hour EST. Surveys from all tide levels, segments, years, dates, and observers were included, but we excluded detections of flying birds from this summary. Error bars represent one standard error, and 6:00 and 19:00 left out due to small sample sizes.

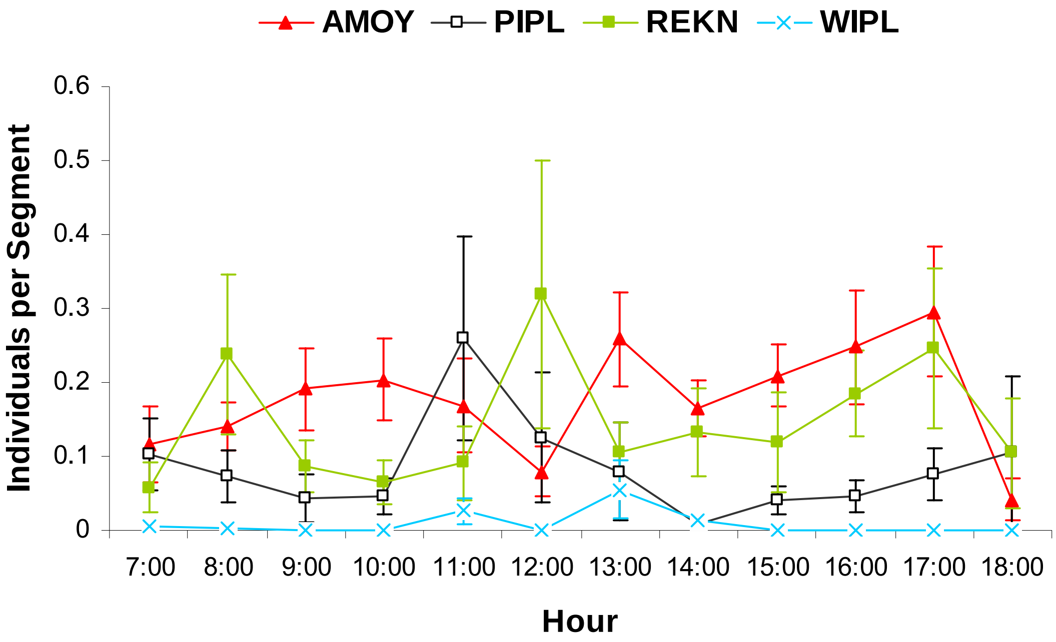

Figure 2.16. The average number of American Oystercatchers (AMOY), Piping Plovers (PIPL), Red Knots (REKN), and Wilson's Plovers (WIPL) counted per segment survey for each daylight hour EST. Surveys from all tide levels, segments, years, dates, and observers were included, but we excluded detections of flying birds from this summary. Error bars represent one standard error, and 6:00 and 19:00 left out due to small sample sizes.

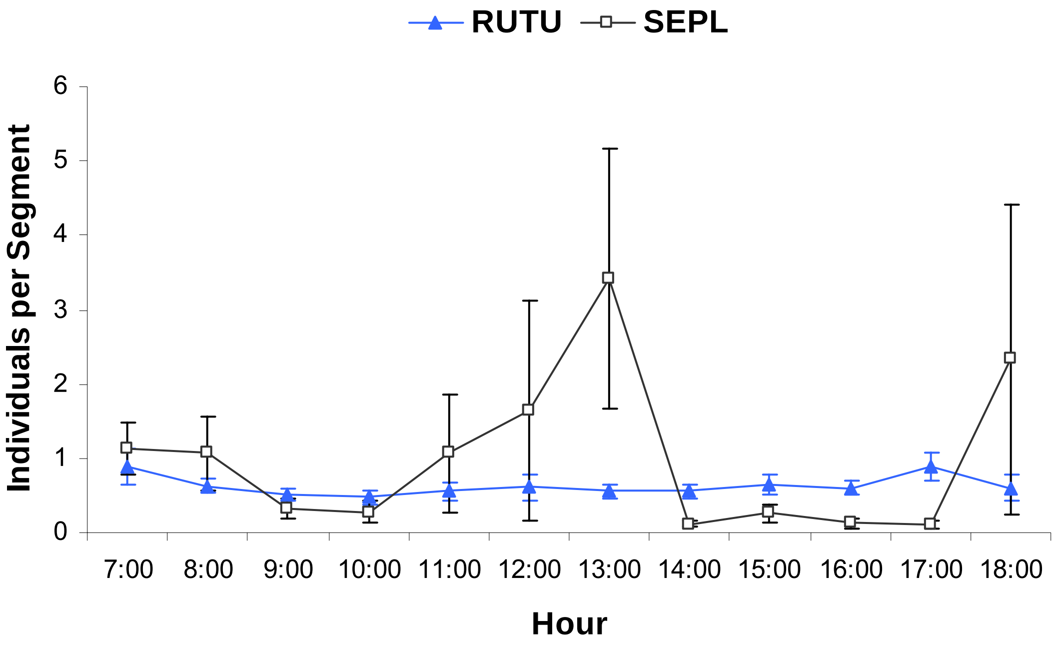

Figure 2.17. The average number of Ruddy Turnstones (RUTU) and Semipalmated Plovers (SEPL) counted per segment survey for each daylight hour EST. Surveys from all tide levels, segments, years, dates, and observers were included, but we excluded detections of flying birds from this summary. Error bars represent one standard error, and 6:00 and 19:00 left out due to small sample sizes.

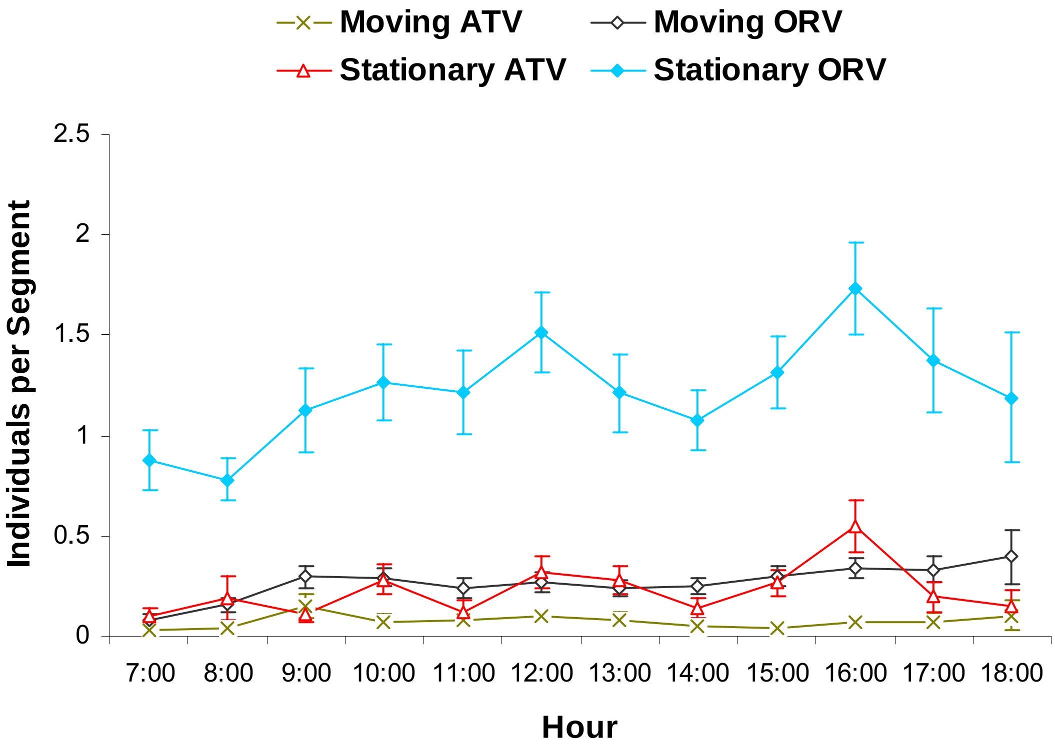

Figure 2.18. The average number of moving ATVs, stationary ATVs, moving ORVs, and stationary ORVs counted per segment survey for each daylight hour EST. Surveys from all tide levels, segments, years, dates, and observers were included, but we excluded detections of flying birds from this summary. Error bars represent one standard error, and 6:00 and 19:00 left out due to small sample sizes.

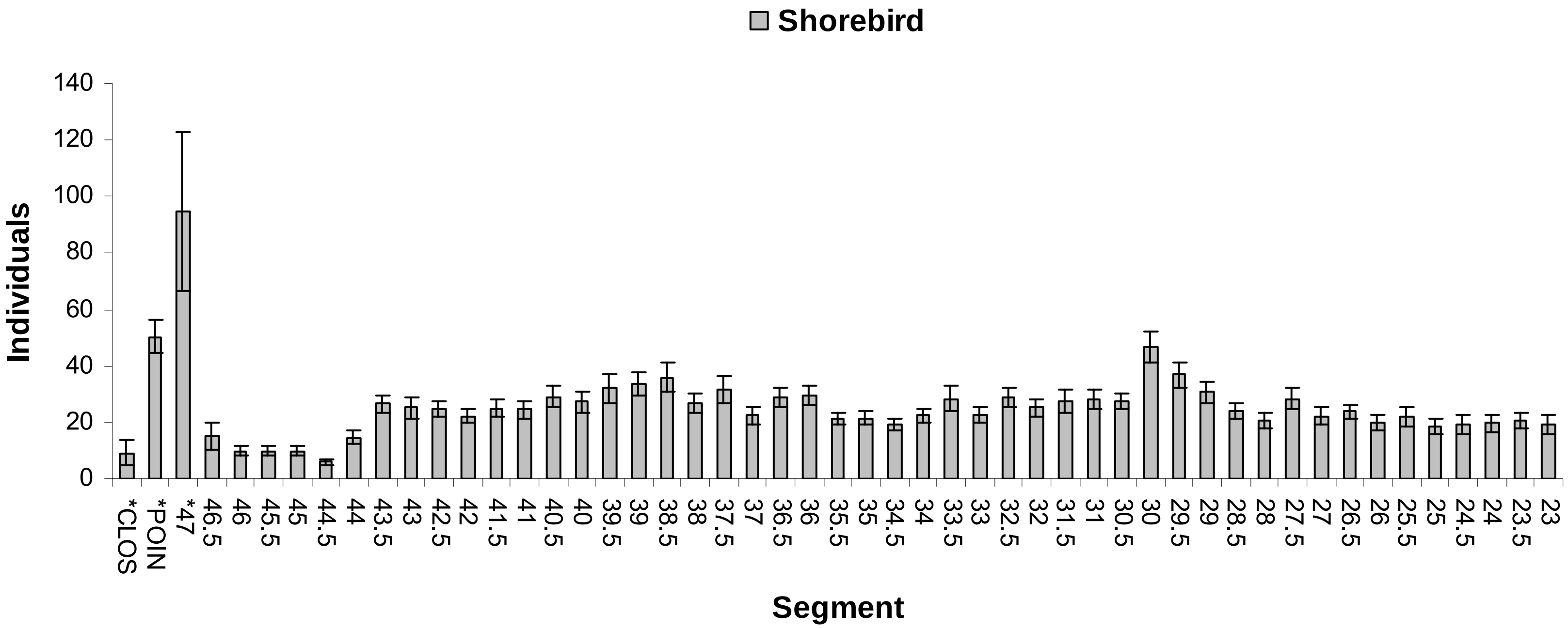

Figure 2.19. Average shorebird abundance at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

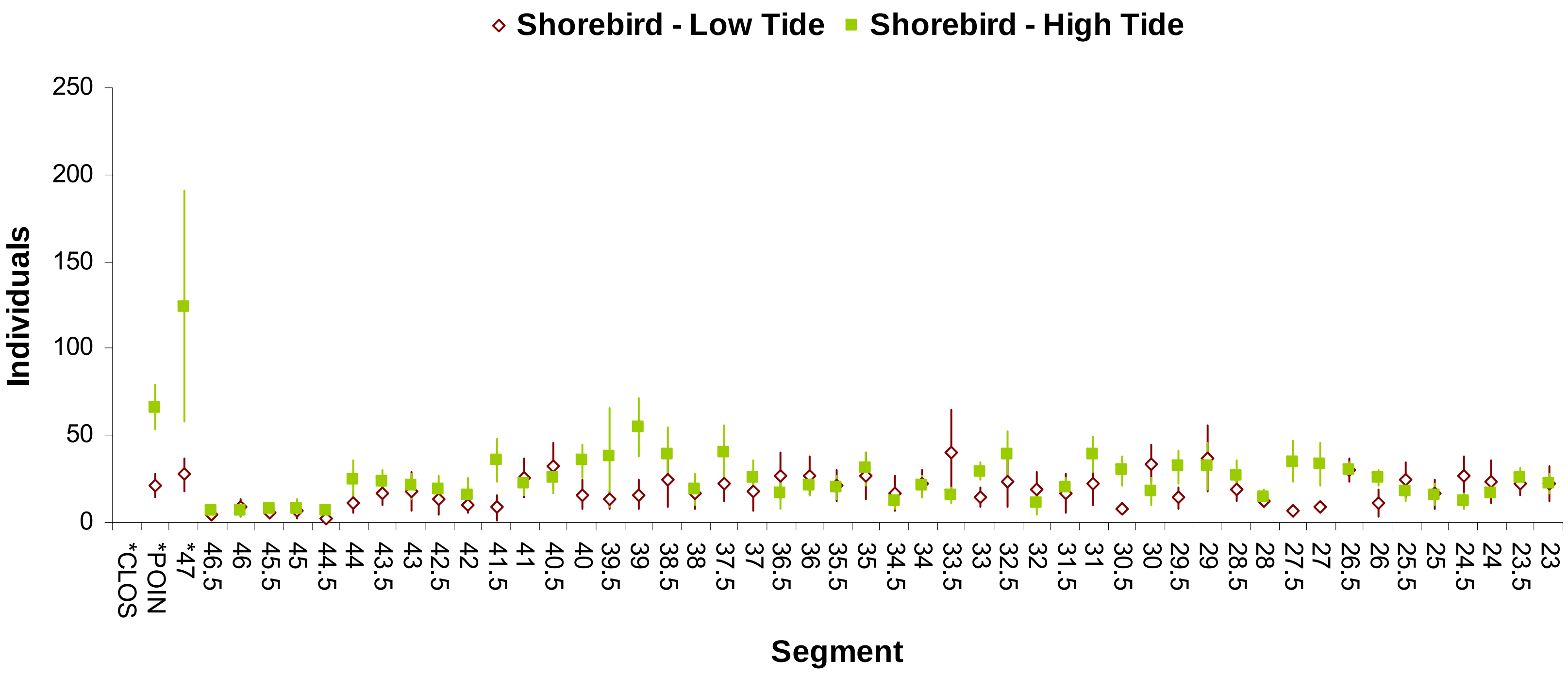

Figure 2.20. Average shorebird abundance with standard error bars for beach segments on South Core Banks, NC during high and rising tide levels in 2006 and 2007. Rising tide surveys were within 4 h after peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.

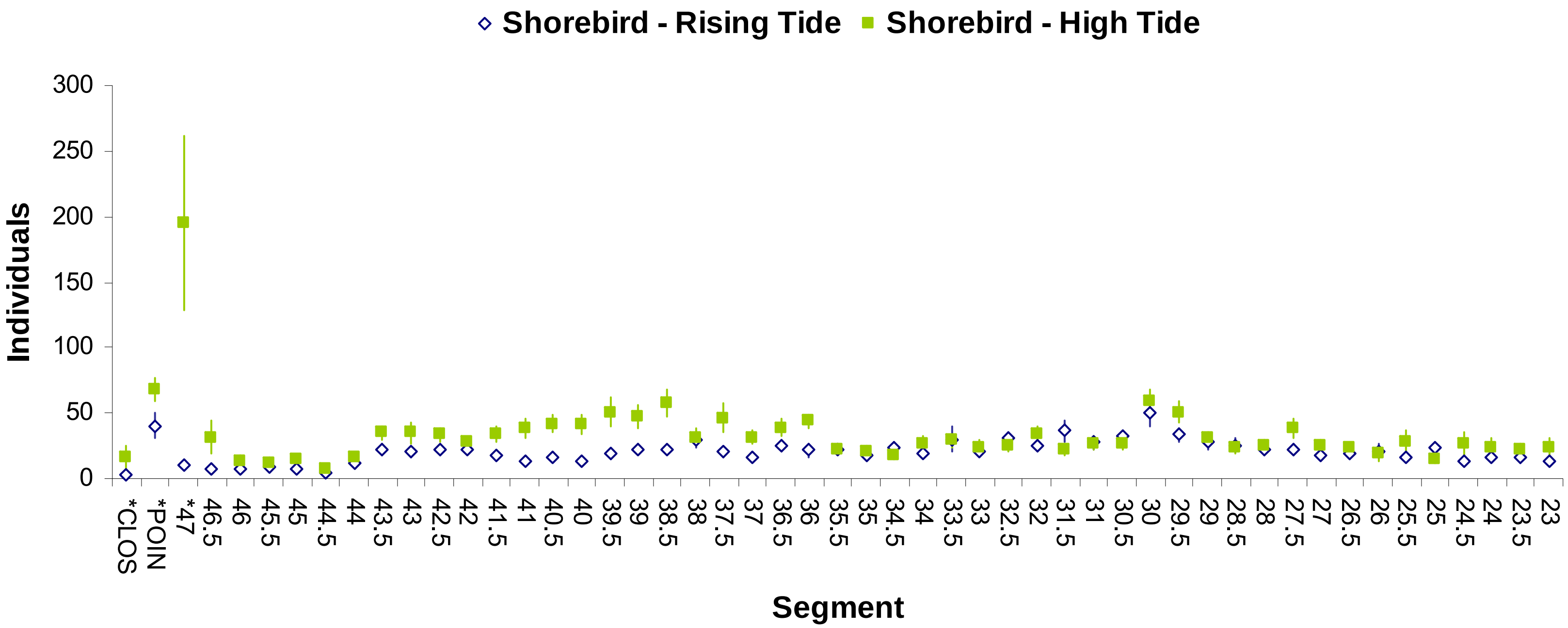

Figure 2.21. Average shorebird abundance at beach segments on South Core Banks, NC during low and high tide levels in 2005. Lines illustrate the standard error bars. Low tide surveys were within 2 h of peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.

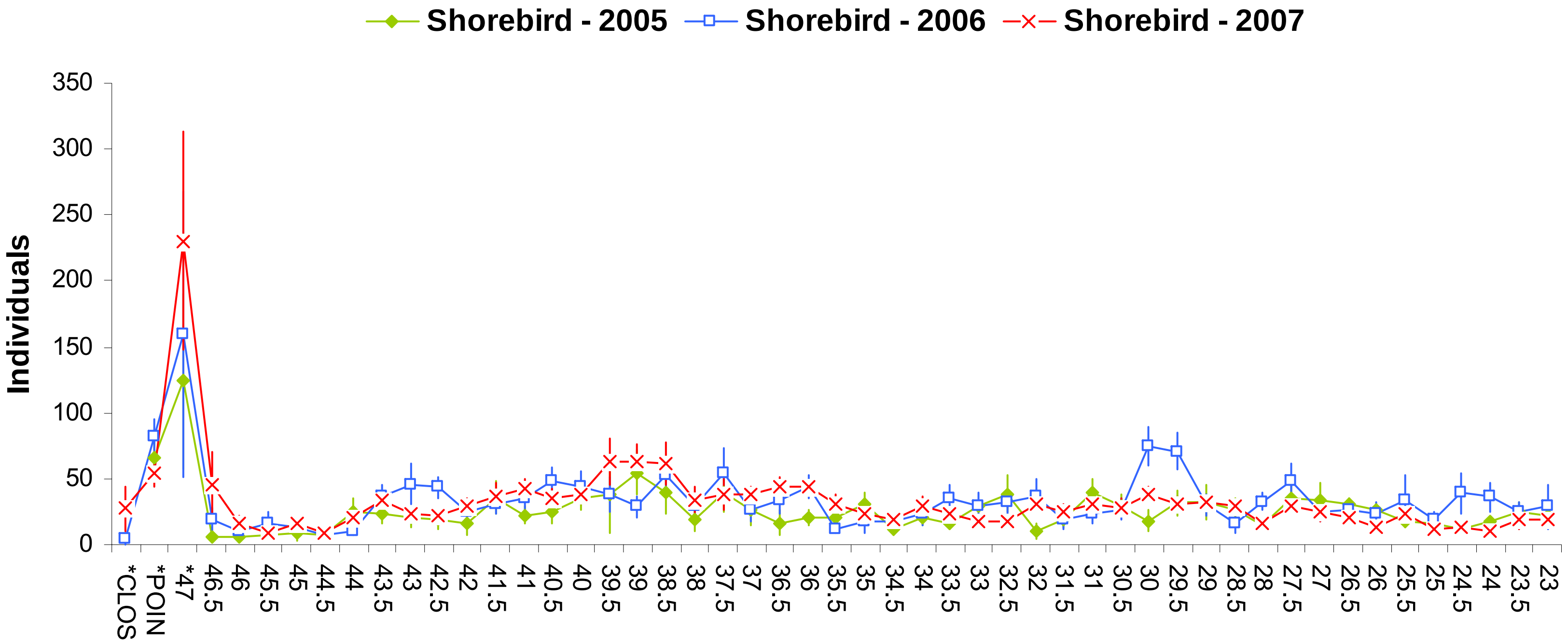

Figure 2.22. Average shorebird abundance at high tide from 2005, 2006, and 2007 for beach segments on South Core Banks, NC. Lines represent one standard error. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.
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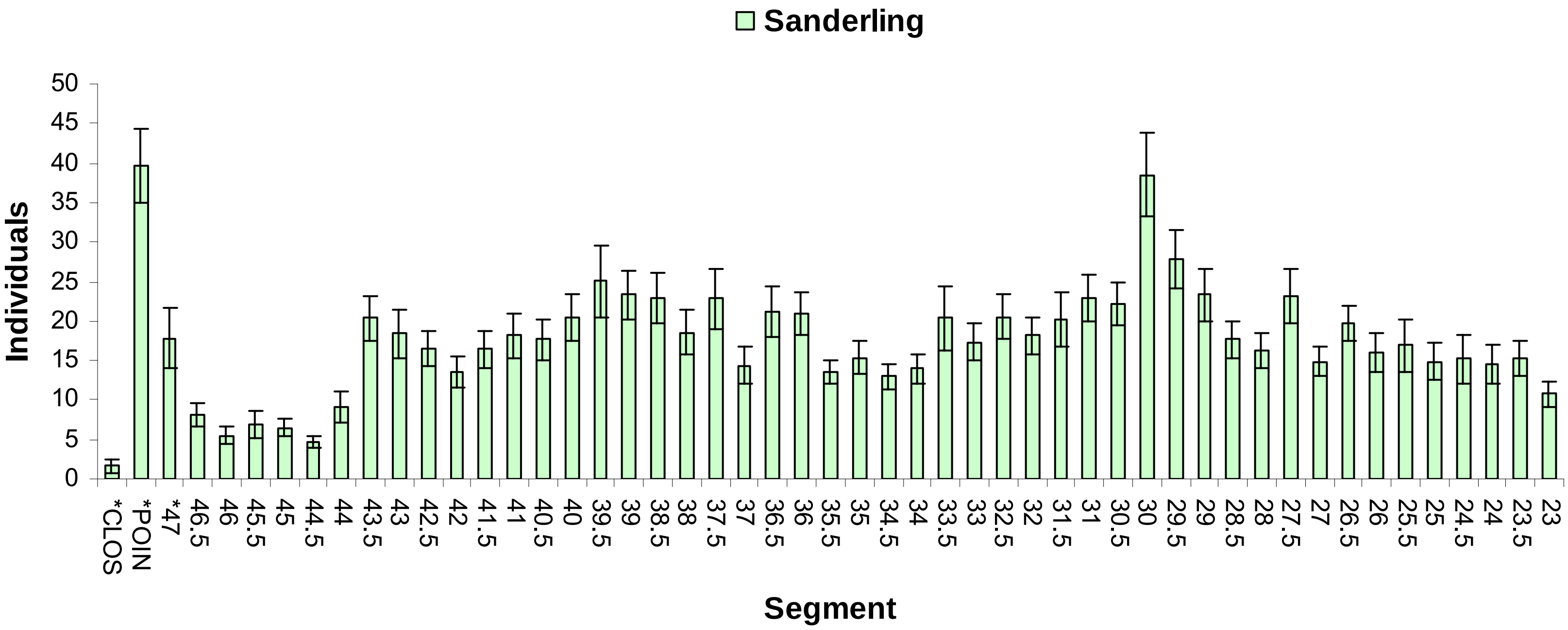

Figure 2.23. Average Sanderling abundance at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

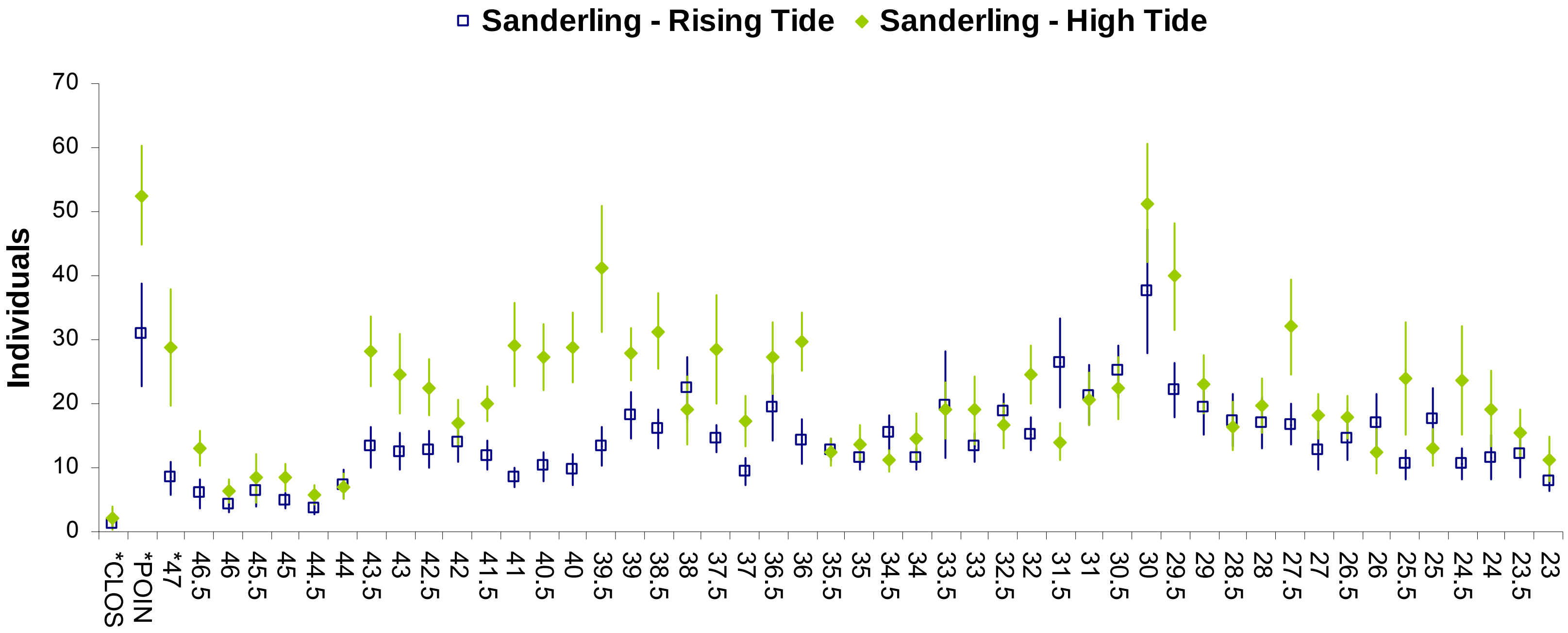

Figure 2.24. Average Sanderling abundance at beach segments during high and rising tide levels. Data from 2006 and 2007 were used in this summary, and lines illustrate the standard errors. Rising tide surveys were within 4 h after peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

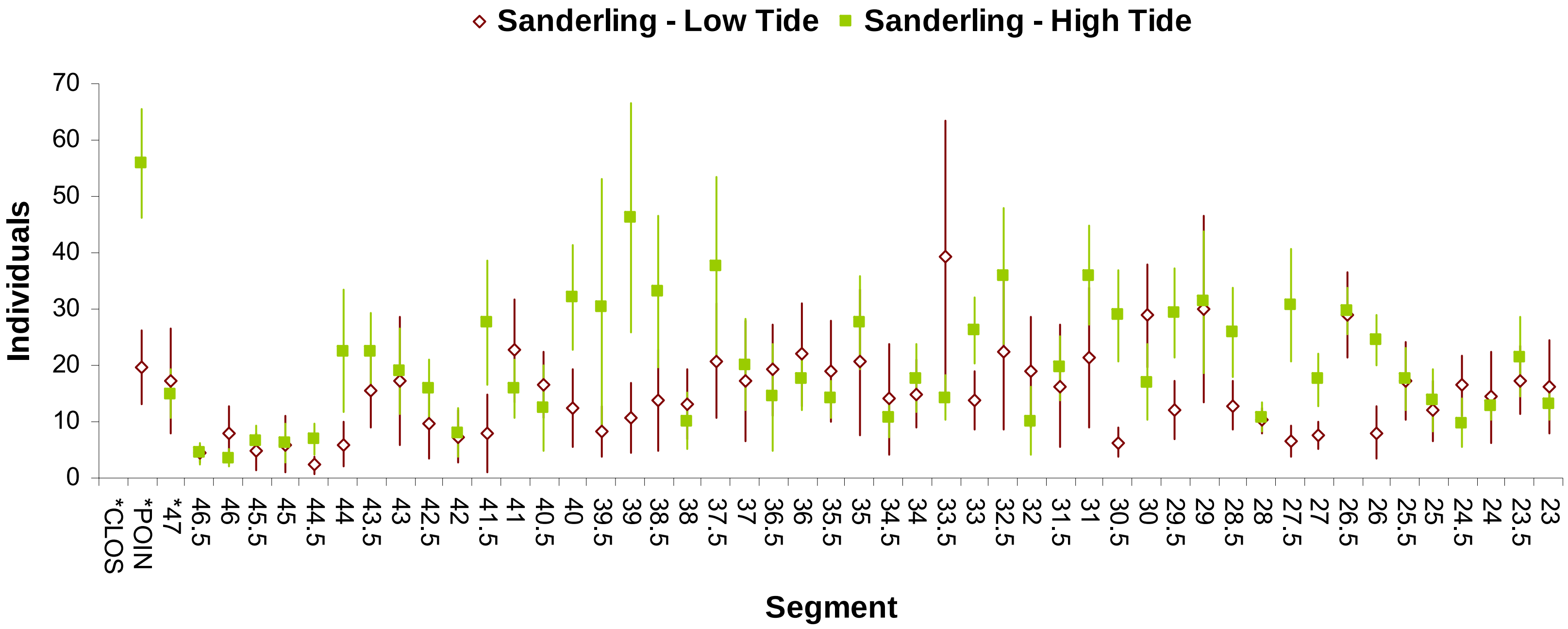

Figure 2.25. Average Sanderling abundance at beach segments during low and high tide levels. Data from 2005 were used in this summary, and lines illustrate the standard errors. Low tide surveys were within 2 h of peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

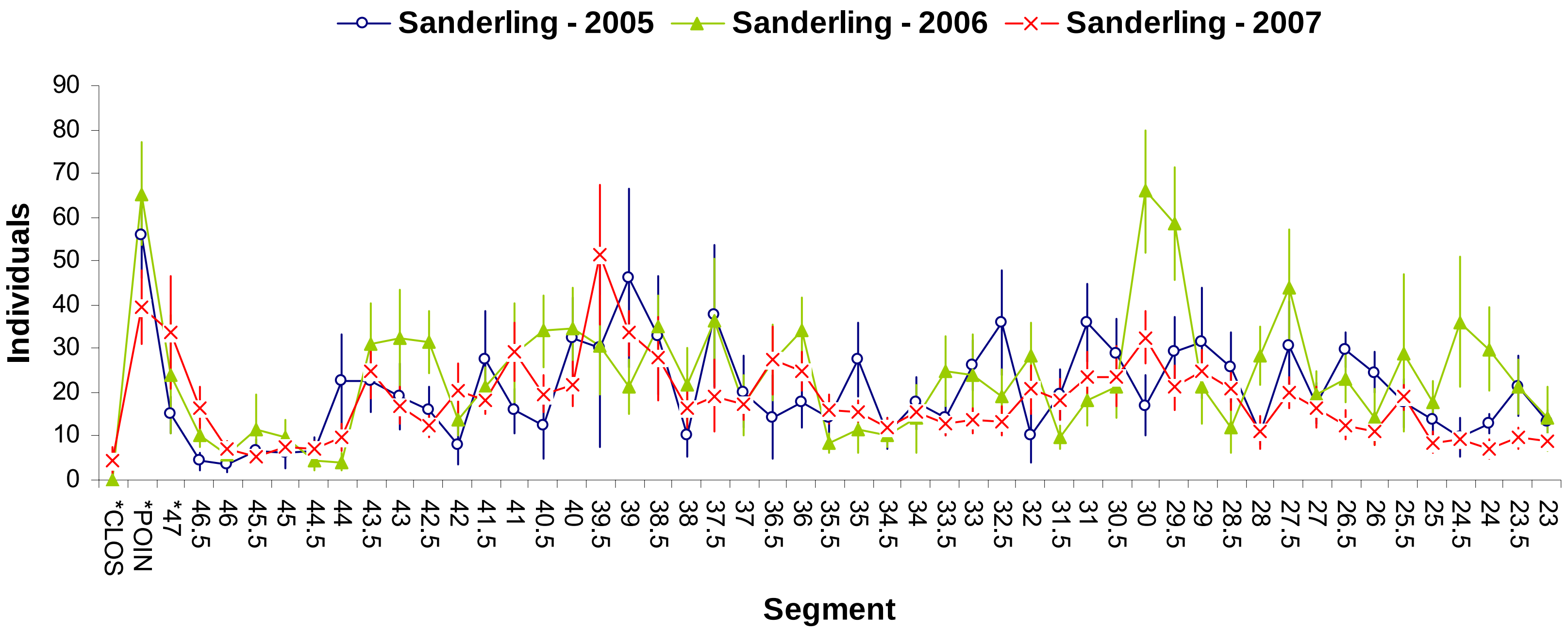

Figure 2.26. Average Sanderling abundance at high tide from 2005, 2006, and 2007 for beach segments on South Core Banks, NC. Lines represent one standard error. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.

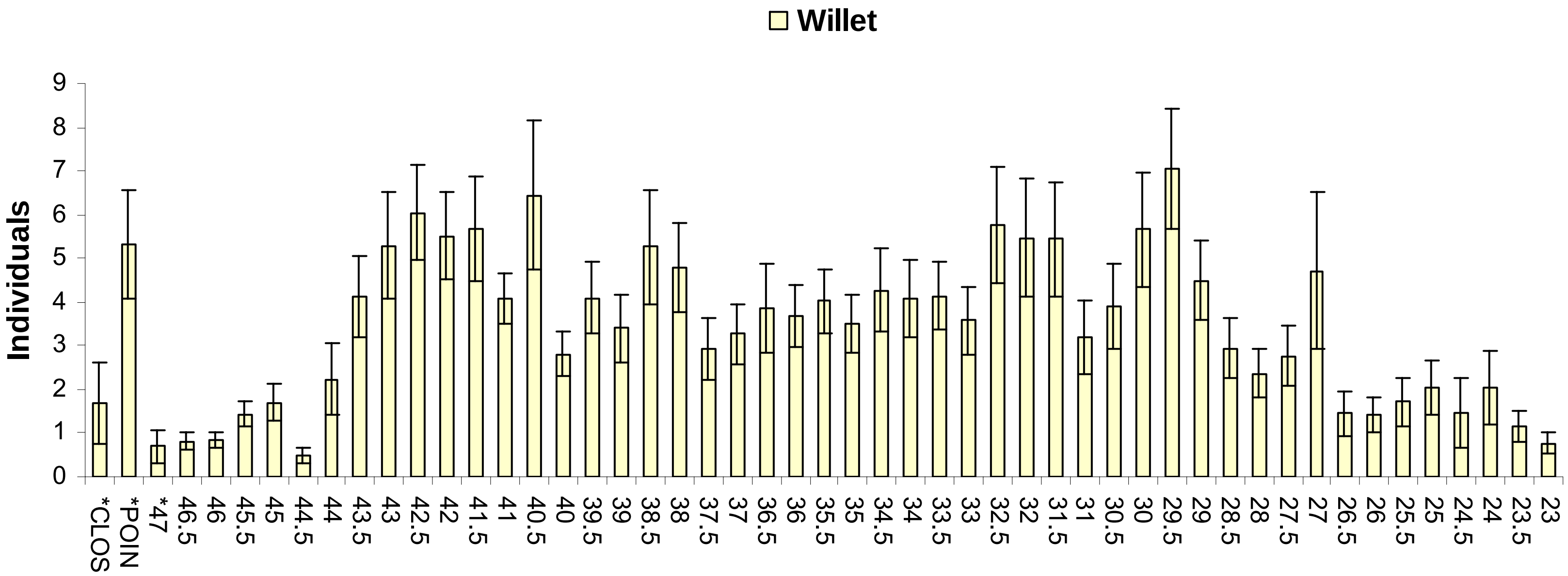

Figure 2.27. Average Willet abundance at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

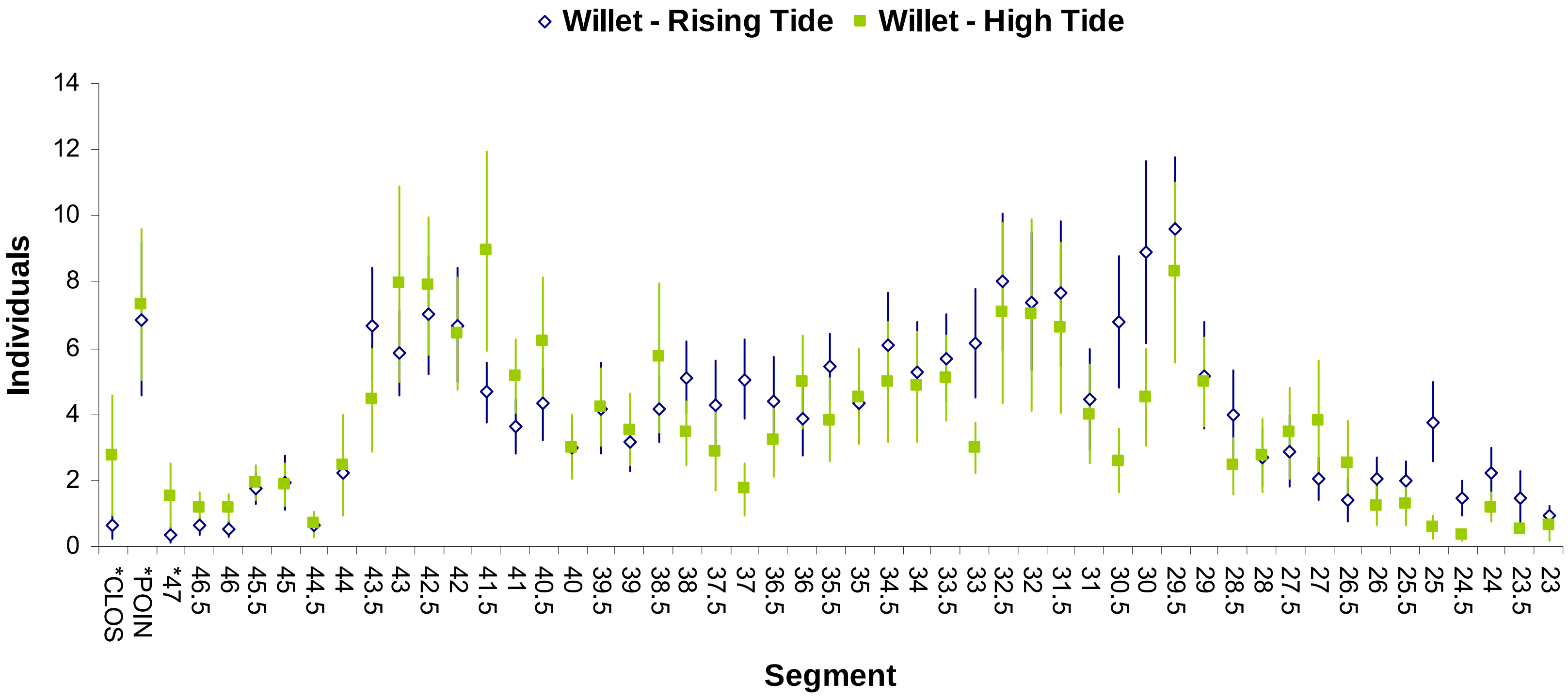

Figure 2.28. Average Willet abundance at beach segments during high and rising tide levels. Data from 2006 and 2007 were used in this summary, and lines illustrate the standard errors. Rising tide surveys were within 4 h after peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

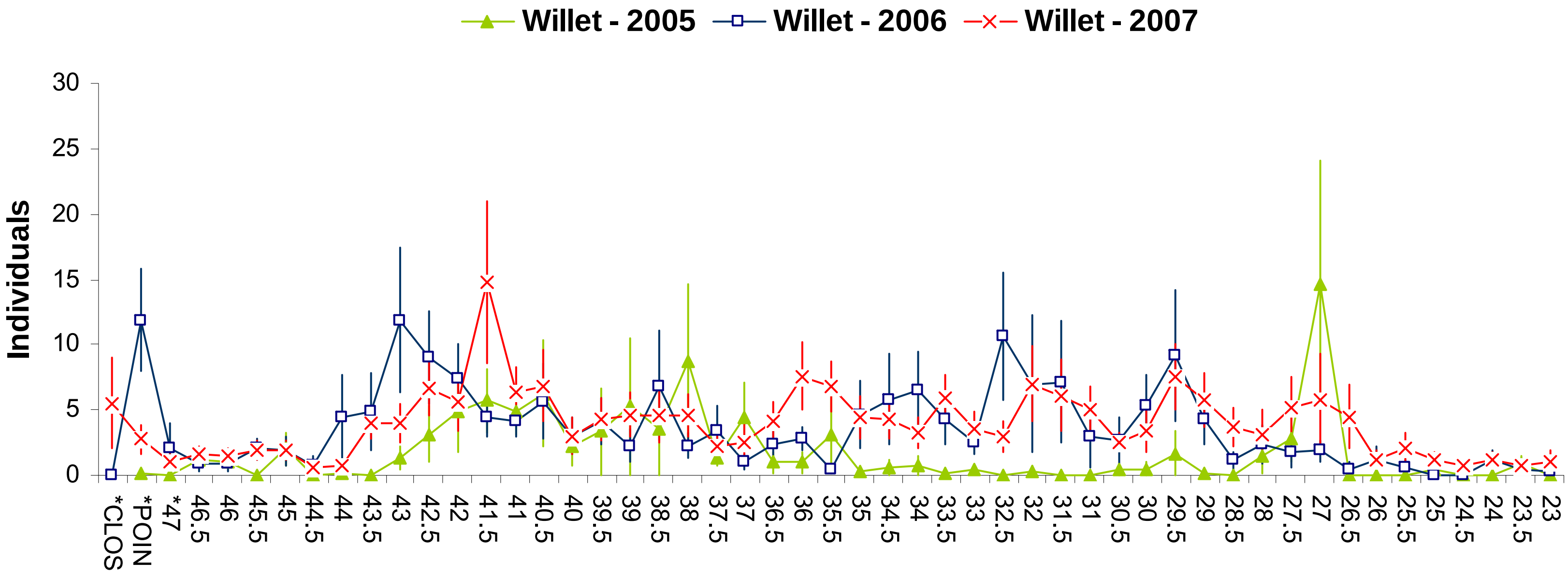

Figure 2.29. Average Willet abundance at high tide from 2005, 2006, and 2007 for beach segments on South Core Banks, NC. Lines represent one standard error. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.

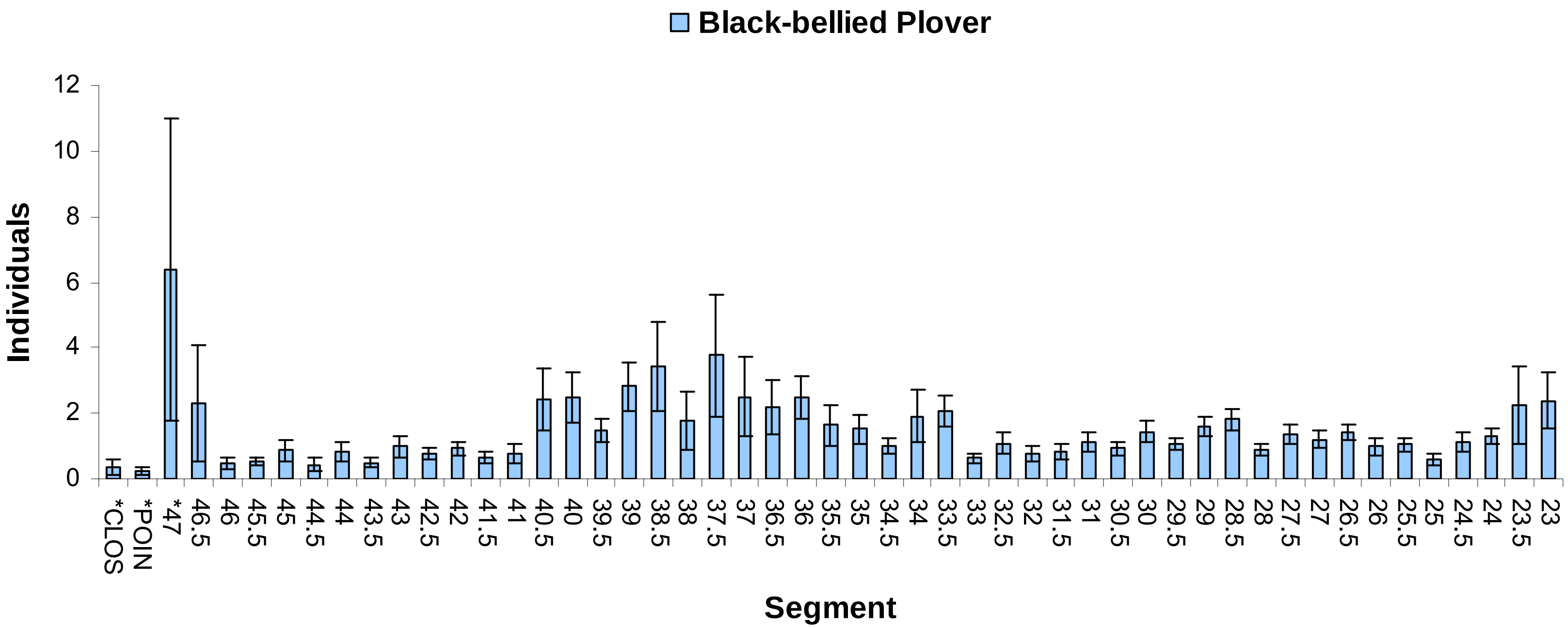

Figure 2.30. Average Black-bellied Plover abundance at beach segments on South Core Banks, NC with standard error bars. We named segments after their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

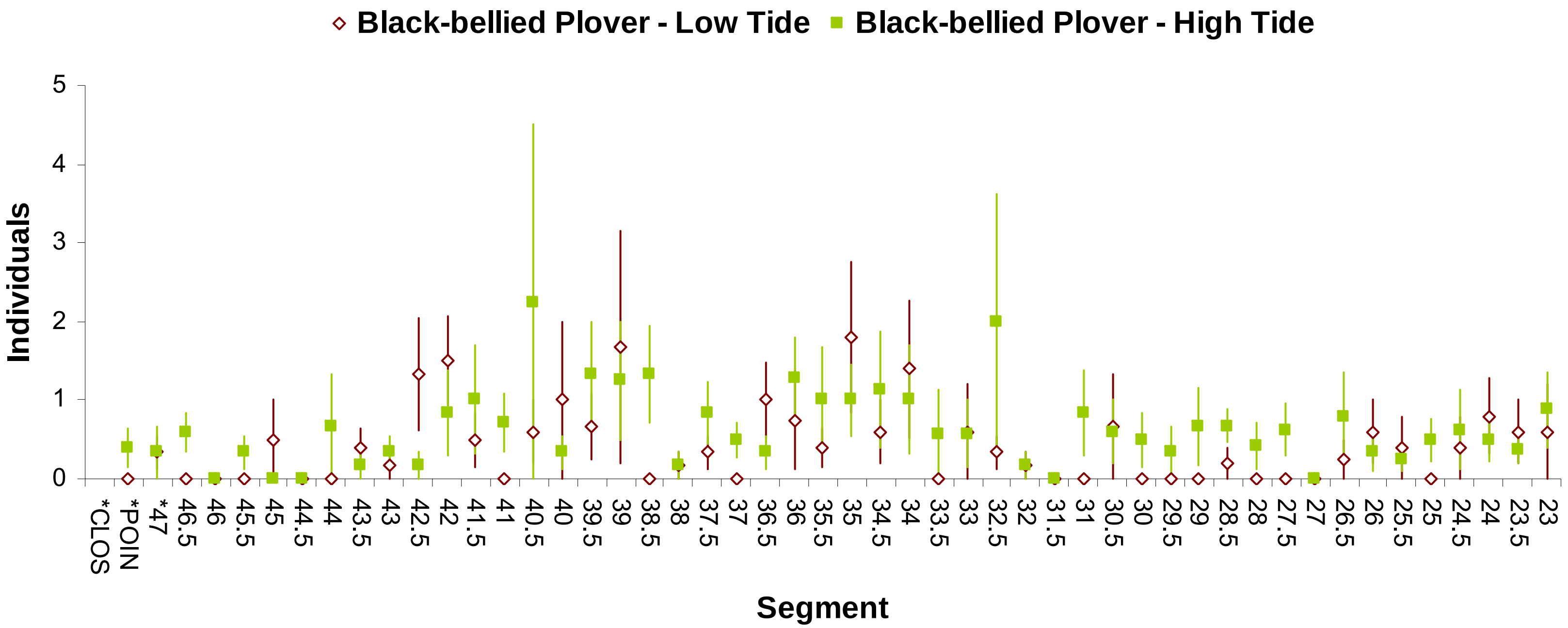

Figure 2.31. Average Black-bellied Plover abundance at beach segments during low and high tide levels. Data from 2005 were used in this summary, and lines illustrate the standard errors. Low tide surveys were within 2 h of peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

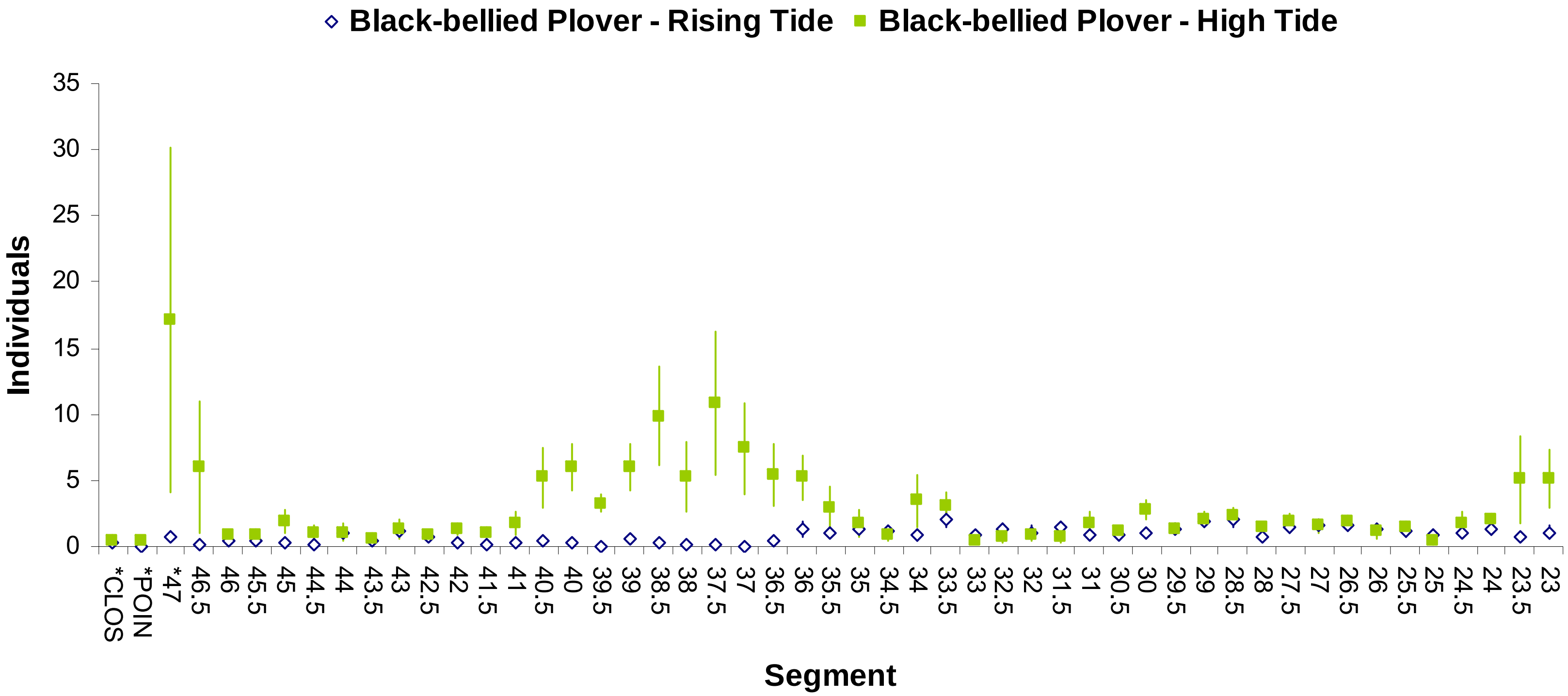

Figure 2.32. Average Black-bellied Plover abundance at beach segments during high and rising tide levels. Data from 2006 and 2007 were used in this summary, and lines illustrate the standard errors. Rising tide surveys were within 4 h after peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

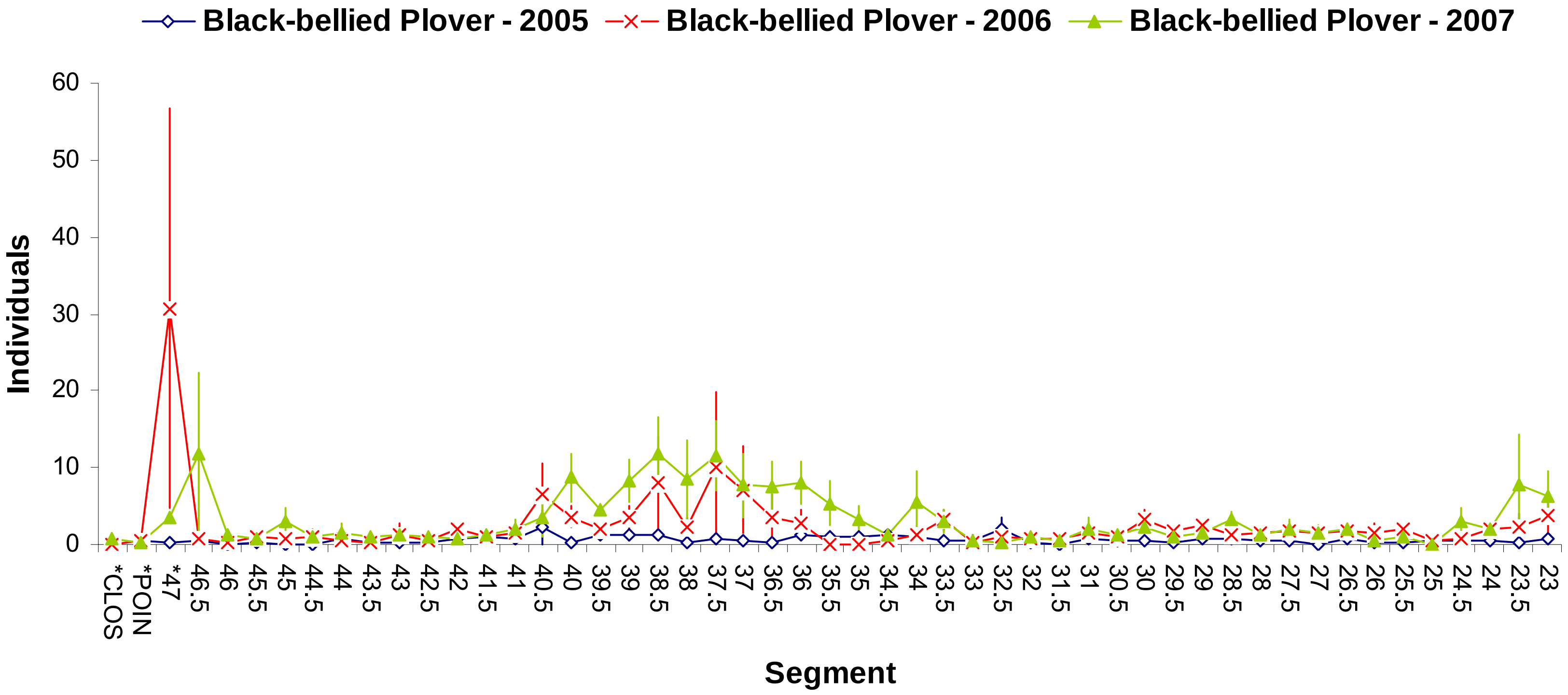

Figure 2.33. Average Black-bellied Plover abundance at high tide from 2005, 2006, and 2007 for beach segments on South Core Banks, NC. Lines represent one standard error. Segments 47, POINT, and CLOSURE had different dimensions and beach structure than other segments.

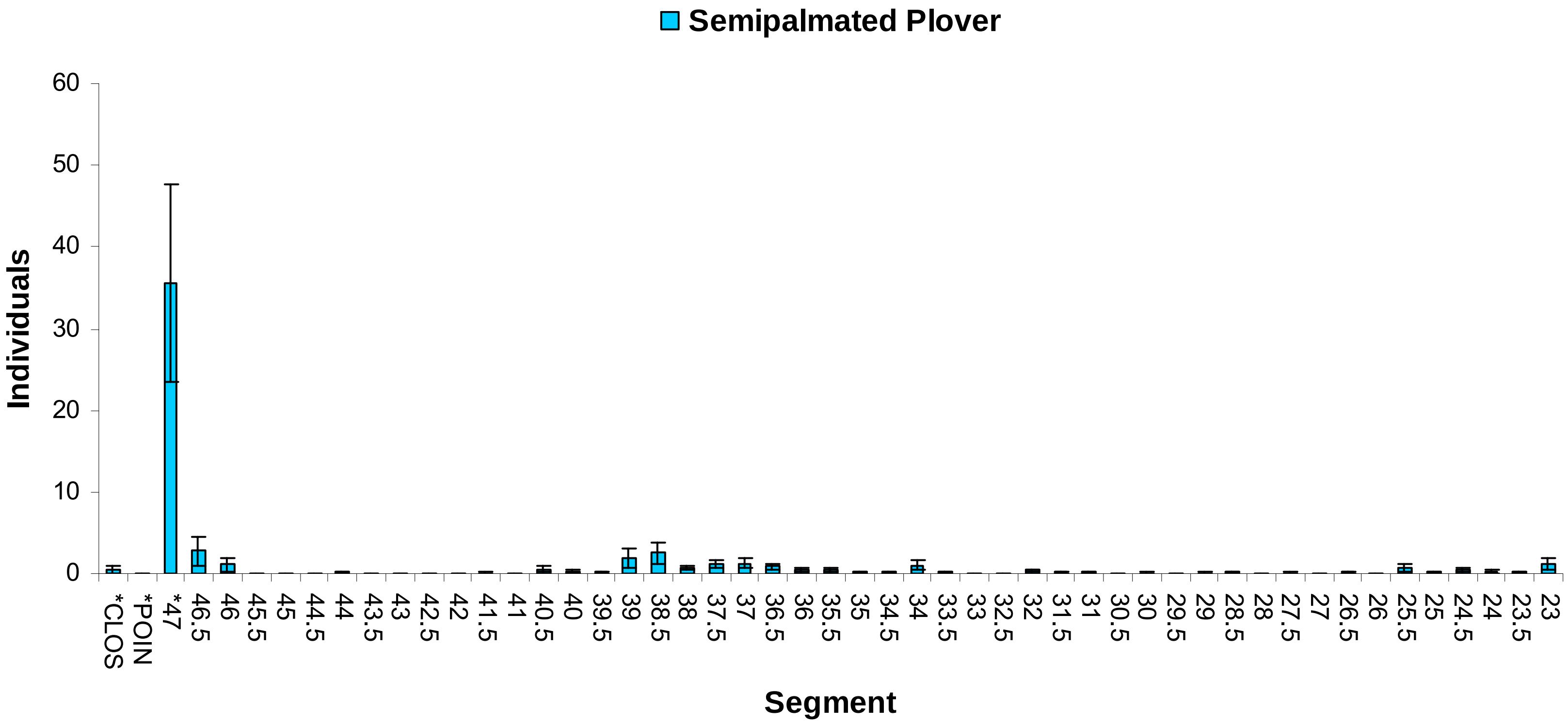

Figure 2.34. Average Semipalmated Plover abundance at beach segments on South Core Banks, NC with standard error bars. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.

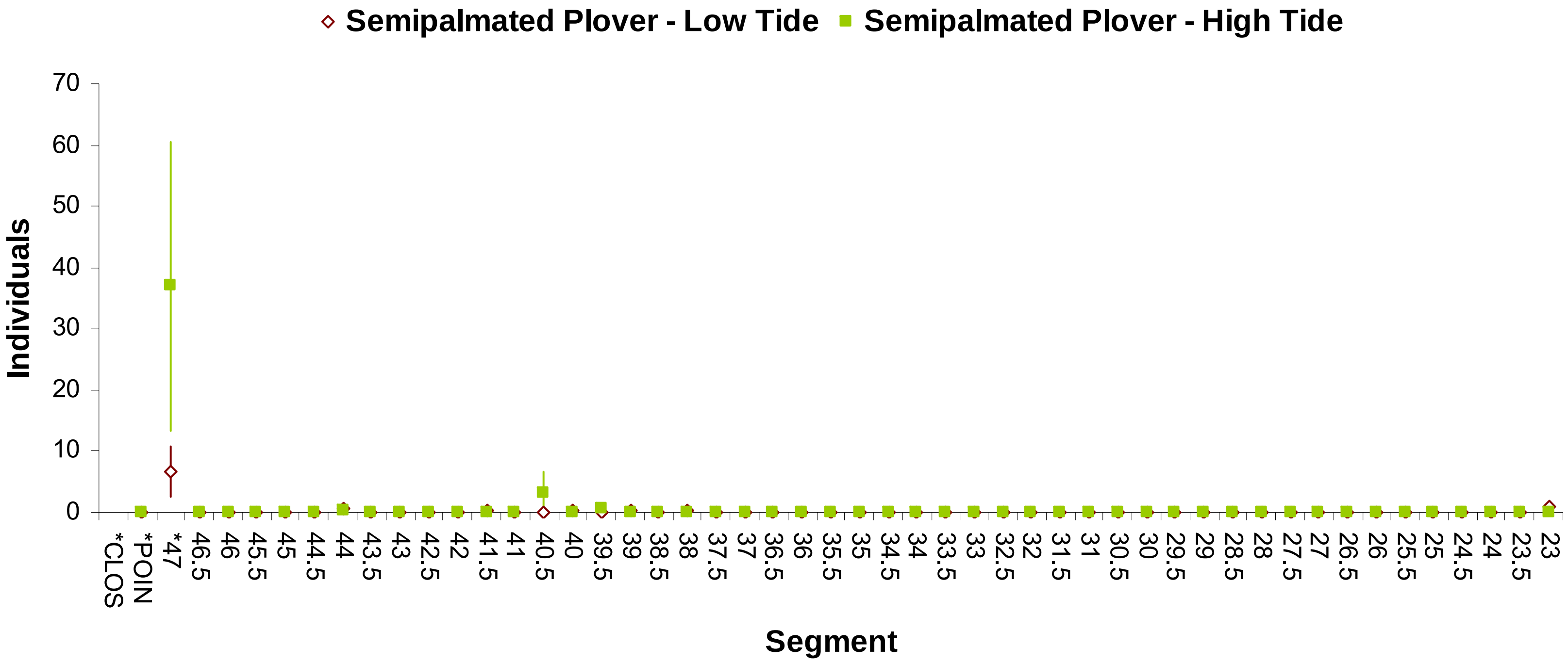

Figure 2.35. Average Semipalmated Plover abundance at beach segments during low and high tide levels. Data from 2005 were used in this summary, and lines illustrate the standard errors. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

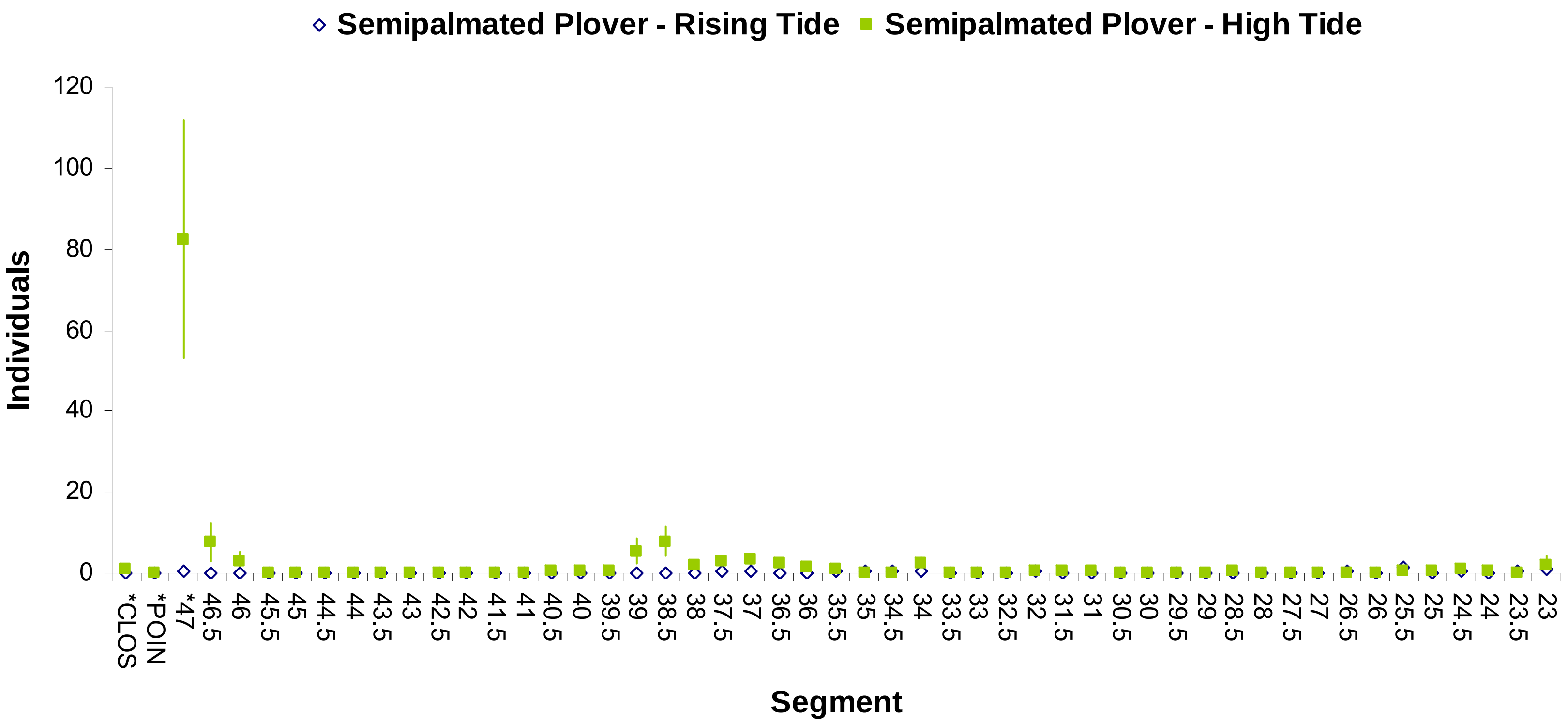

Figure 2.36. Average Semipalmated Plover abundance at beach segments during high and rising tide levels. Data from 2006 and 2007 were used in this summary, and lines illustrate the standard errors. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

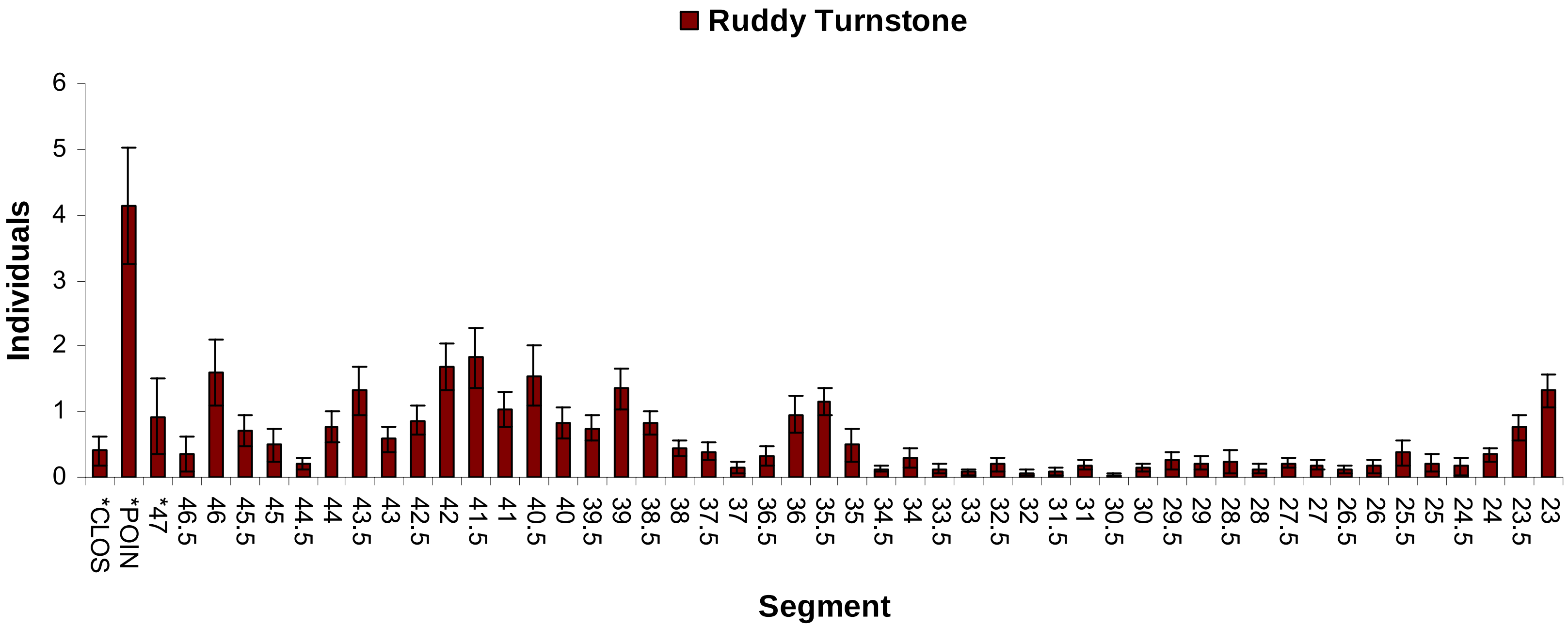

Figure 2.37. Average Ruddy Turnstones abundance at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

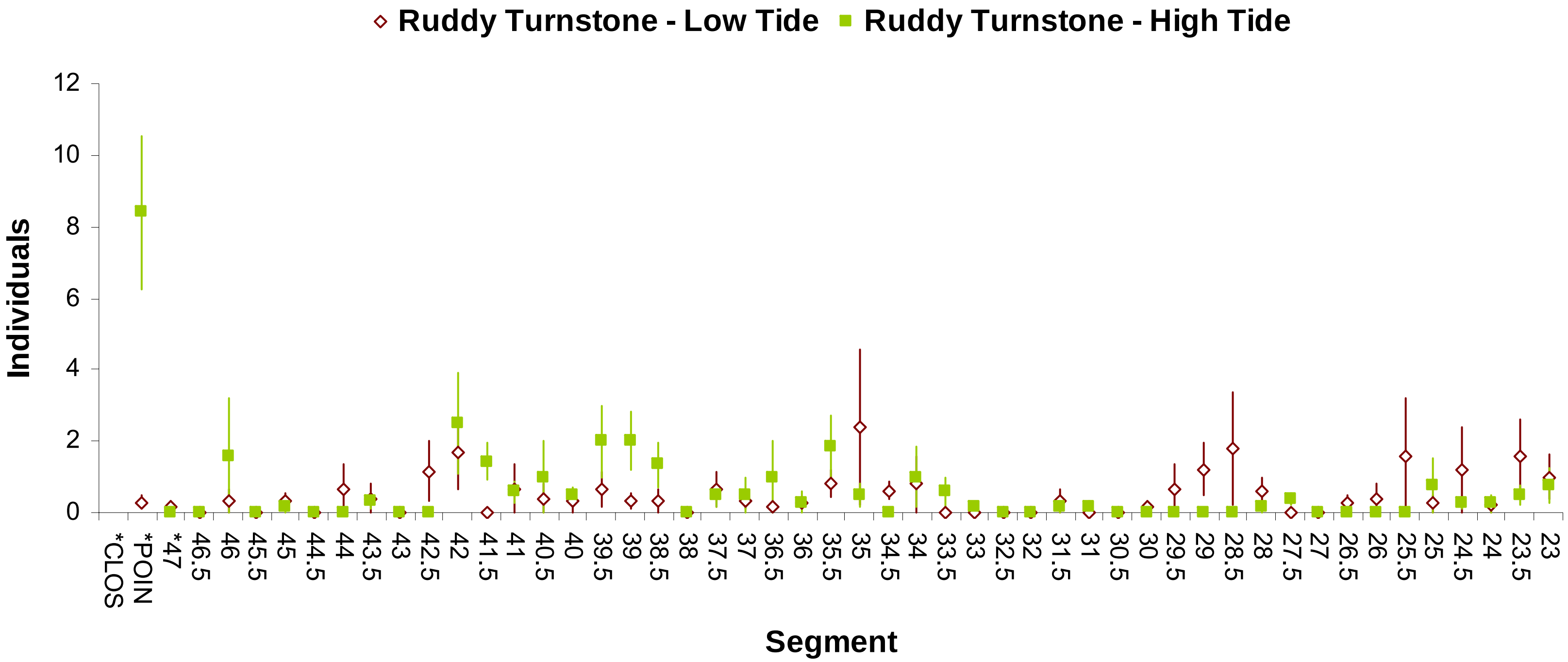

Figure 2.38. Average Ruddy Turnstone abundance at beach segments during low and high tide levels. Data from 2005 were used in this summary, and lines illustrate the standard errors. Low tide surveys were within 2 h of peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

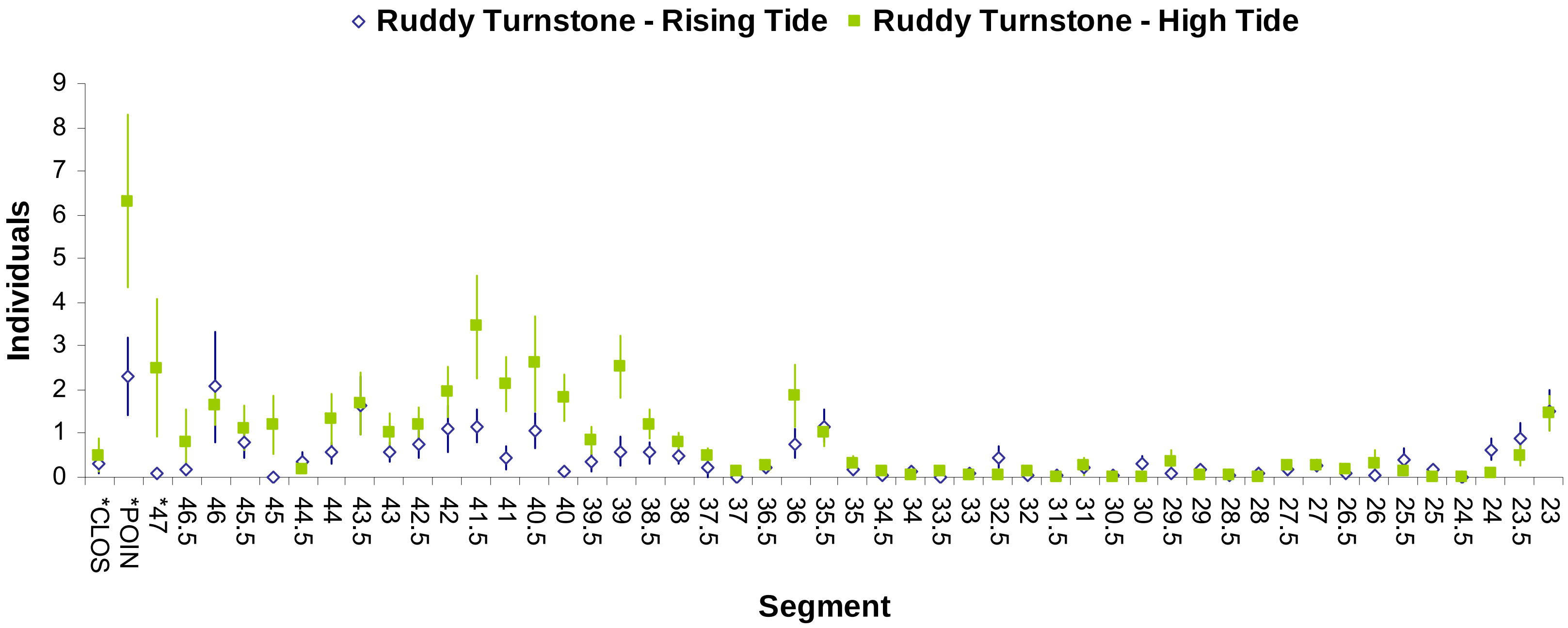

Figure 2.39. Average Ruddy Turnstone abundance at beach segments during high and rising tide levels. Data from 2006 and 2007 were used in this summary, and lines illustrate the standard errors. Rising tide surveys were within 4 h after peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

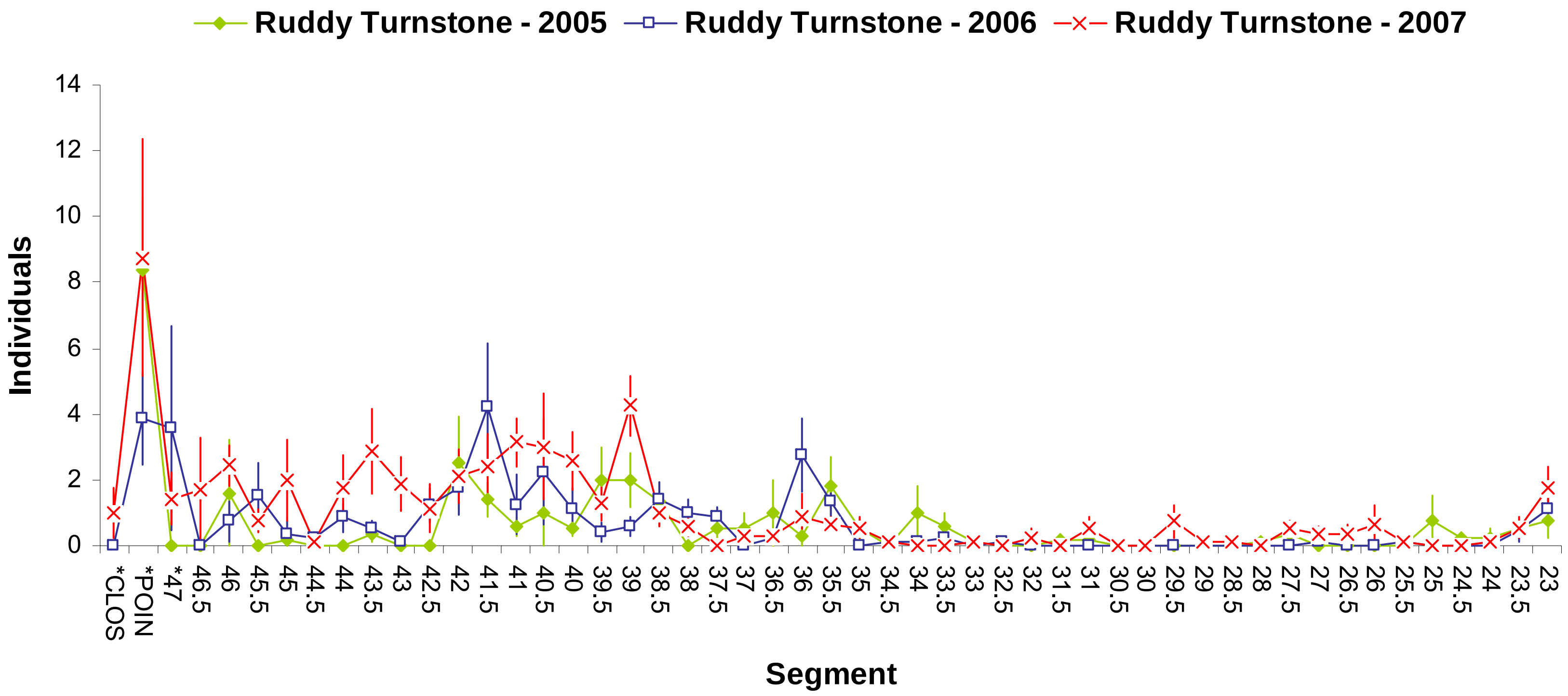

Figure 2.40. Average Ruddy Turnstone abundance at high tide from 2005, 2006, and 2007 for beach segments on South Core Banks, NC. Lines represent one standard error. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.

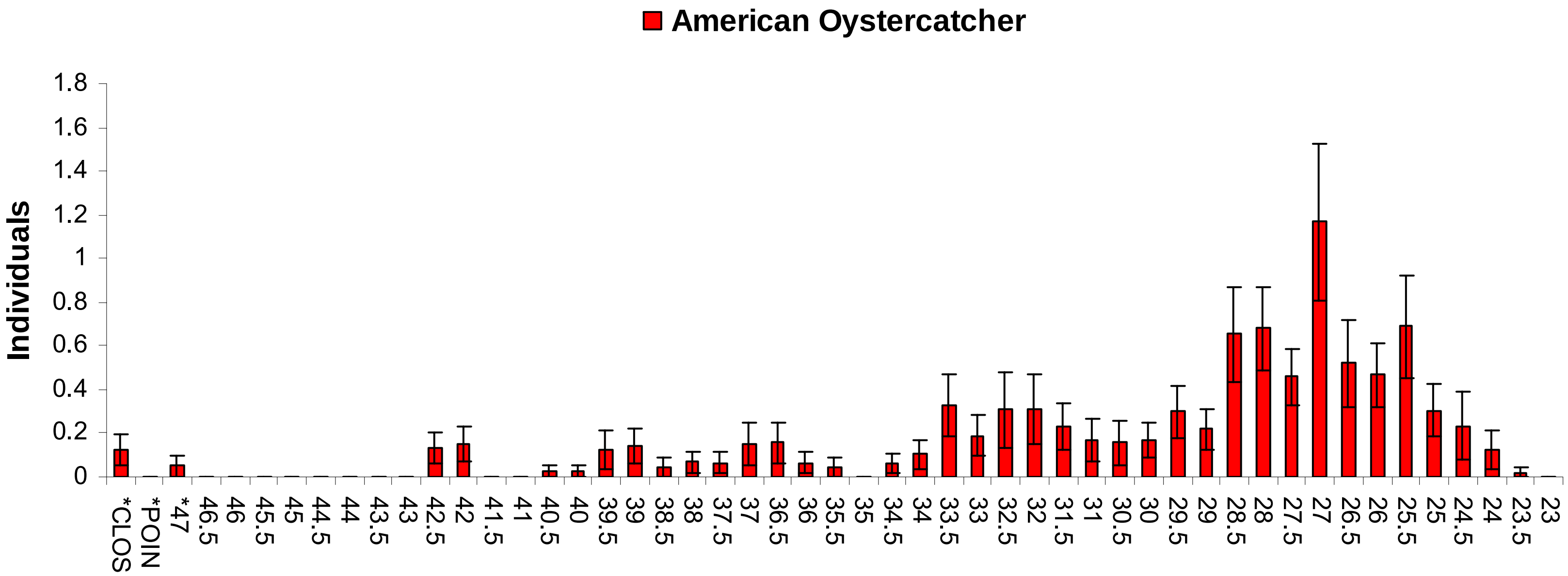

Figure 2.41. Average American Oystercatcher abundance at beach segments on South Core Banks, NC with standard error bars. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

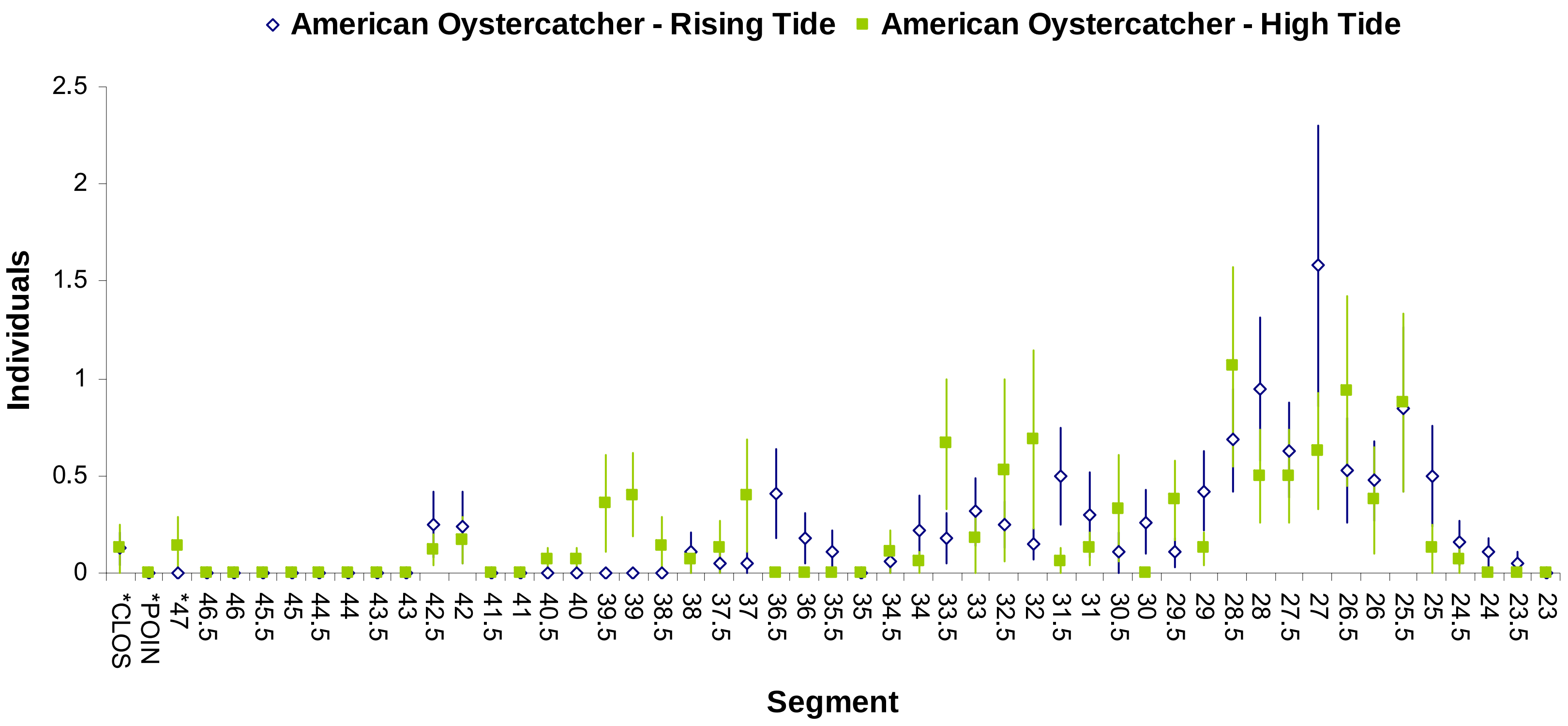

Figure 2.42. Average American Oystercatcher abundance at beach segments during high and rising tide levels. Data from 2006 and 2007 were used in this summary, and lines illustrate the standard errors. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

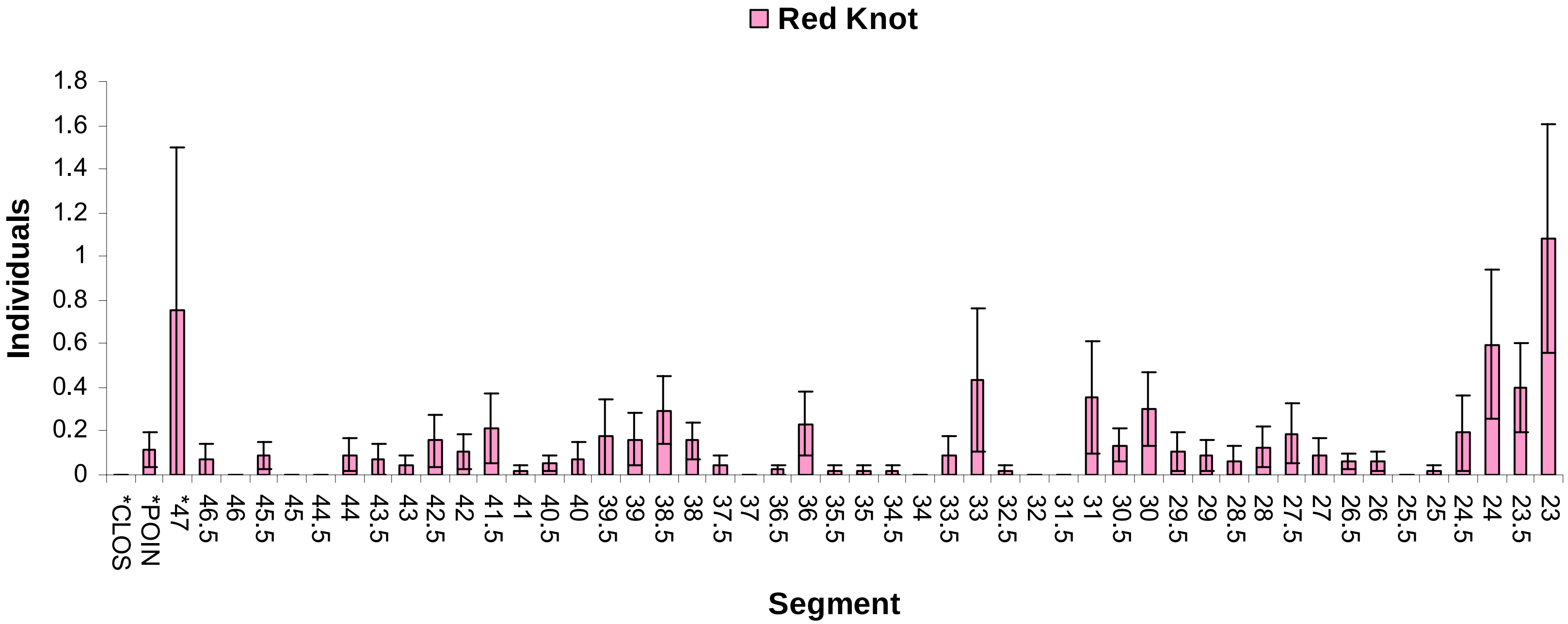

Figure 2.43. Average Red Knot abundance at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

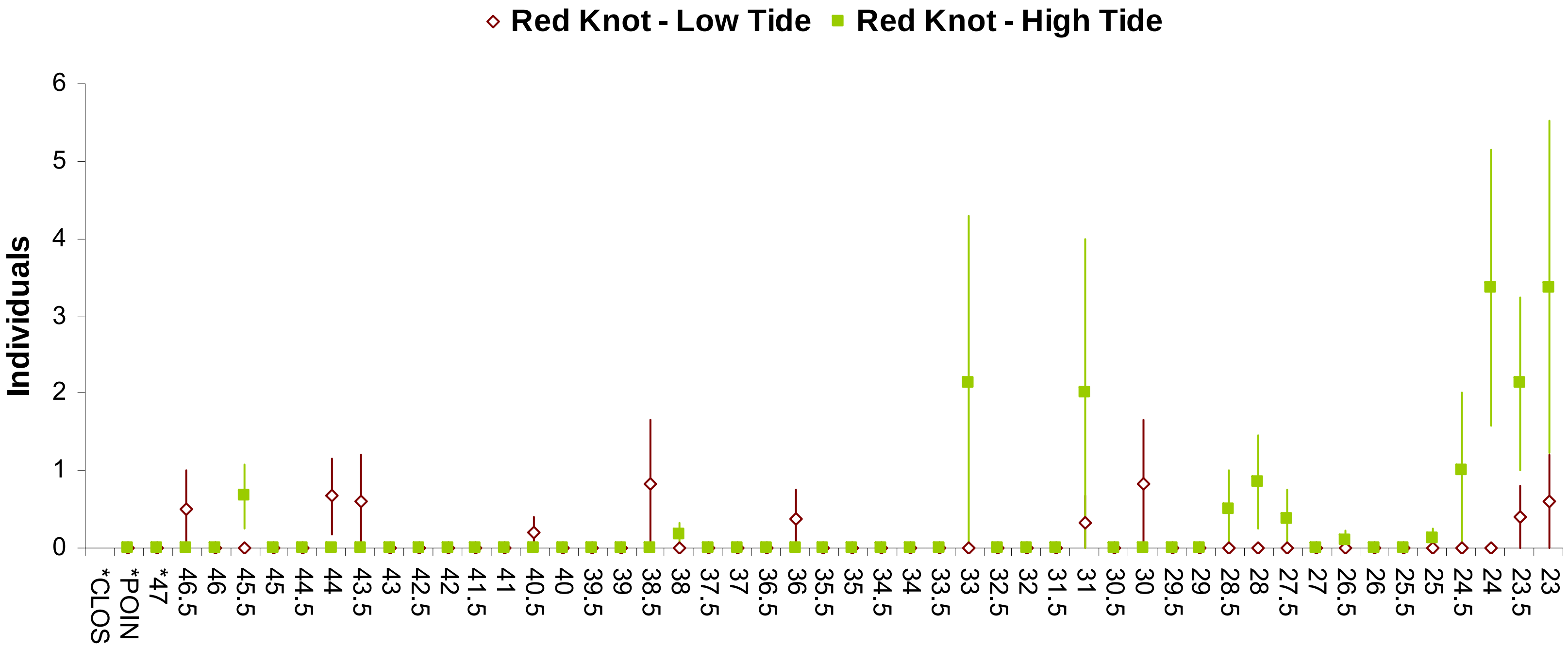

Figure 2.44. Average Red Knot abundance at beach segments during low and high tide levels. Data from 2005 were used in this summary, and lines illustrate the standard errors. Low tide surveys were within 2 h of peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

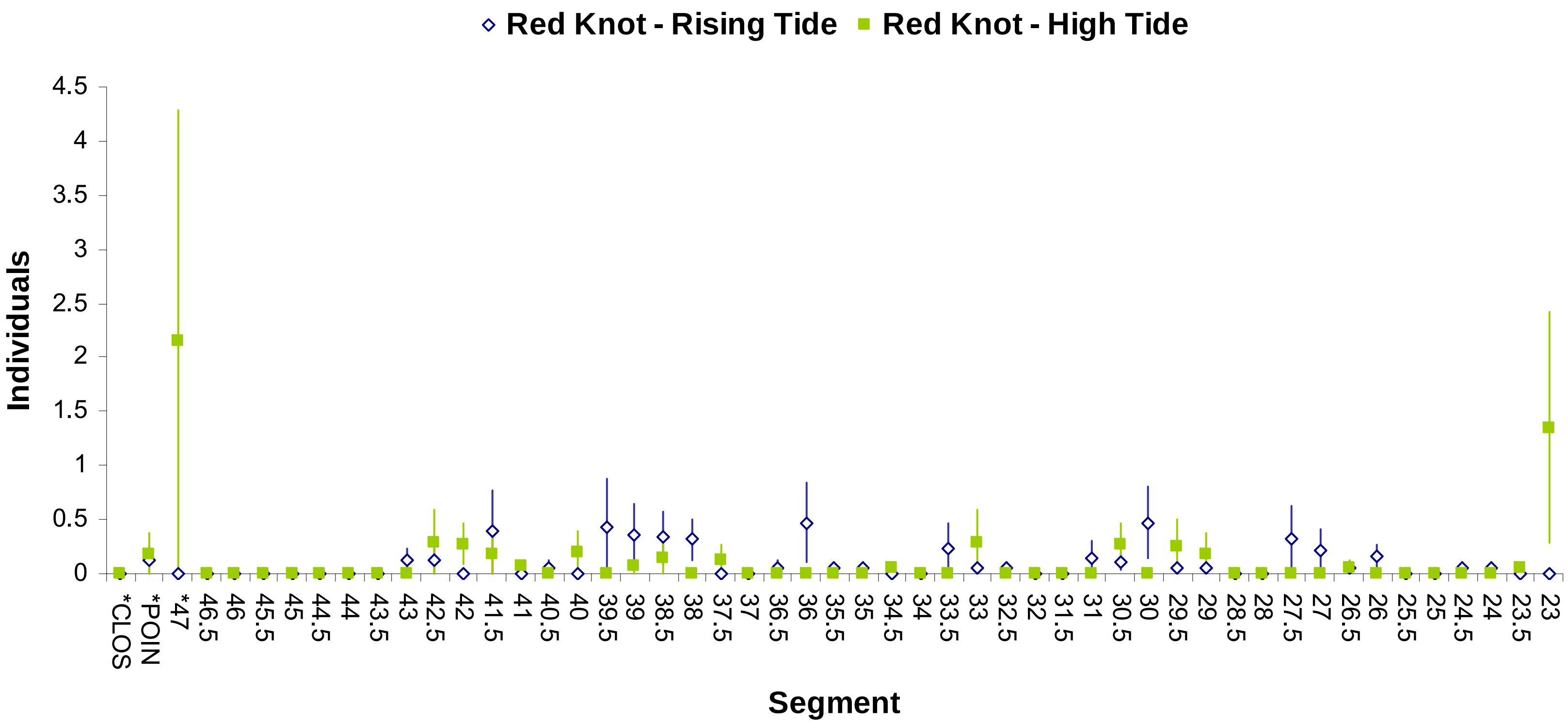

Figure 2.45. Average Red Knot abundance at beach segments during high and rising tide levels. Data from 2006 and 2007 were used in this summary, and lines illustrate the standard errors. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

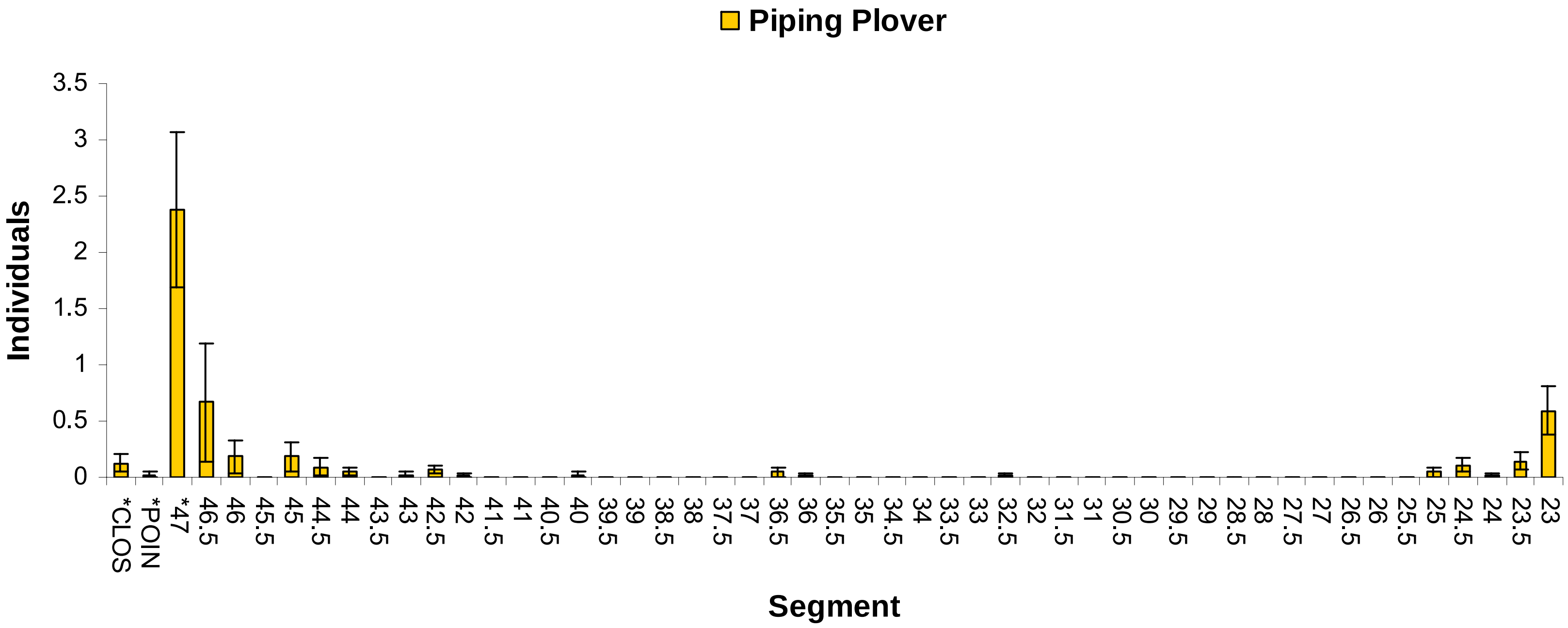

Figure 2.46. Average Piping Plover abundance at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

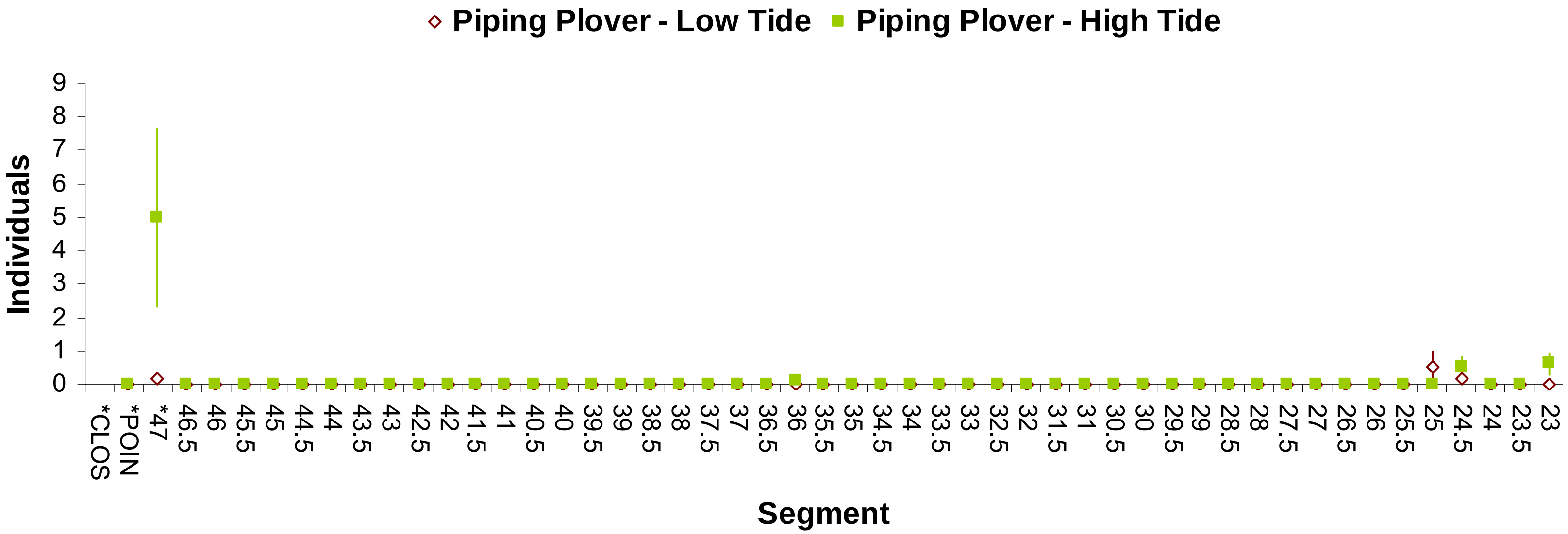

Figure 2.47. Average Piping Plover abundance at beach segments during low and high tide levels. Data from 2005 were used in this summary, and lines illustrate the standard errors. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

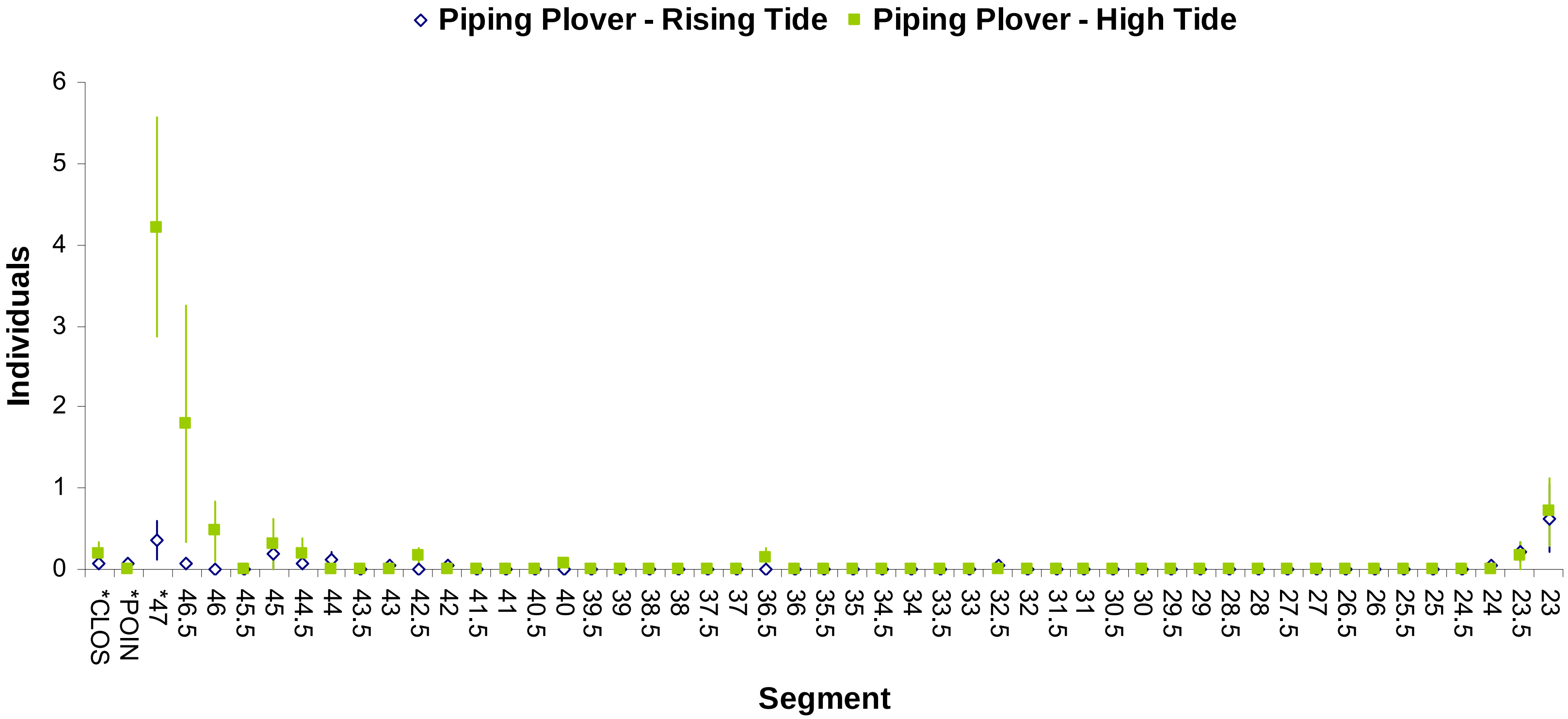

Figure 2.48. Average Piping Plover abundance at beach segments during high and rising tide levels. Data from 2006 and 2007 were used in this summary, and lines illustrate the standard errors. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

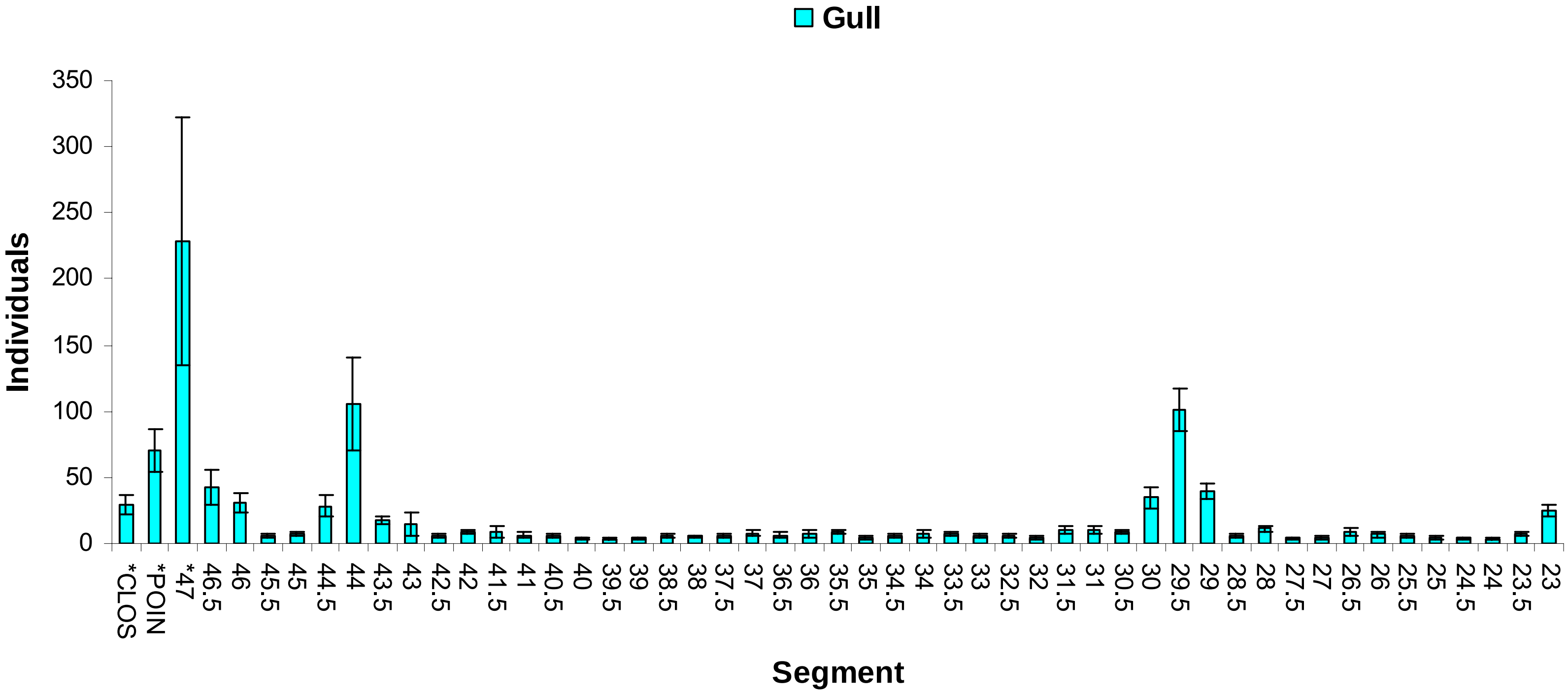

Figure 2.49. Average gull abundance at beach segments on South Core Banks, NC with standard error bars. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

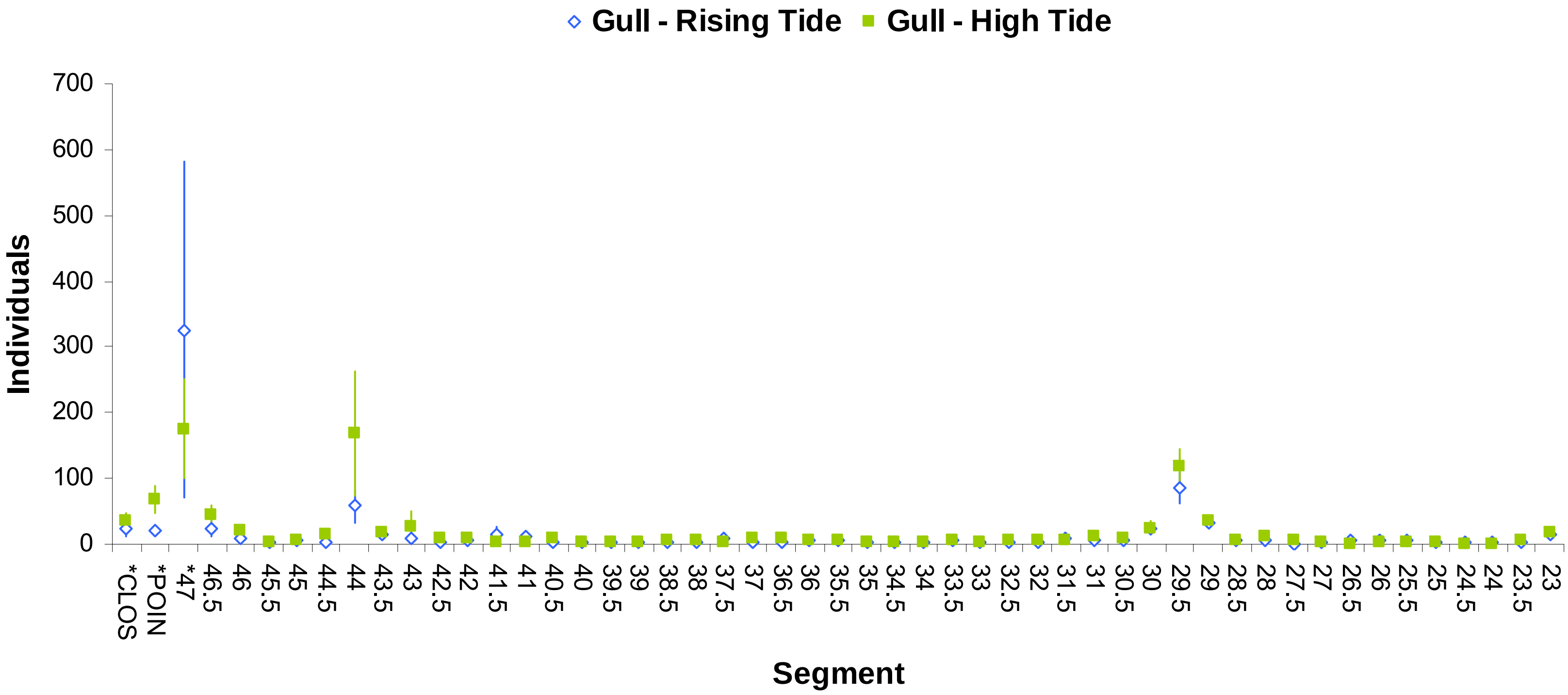

Figure 2.50. Average gull abundance at beach segments during high and rising tide levels. Data from 2006 and 2007 were used in this summary, and lines illustrate the standard errors. Rising tide surveys were within 4 h after peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

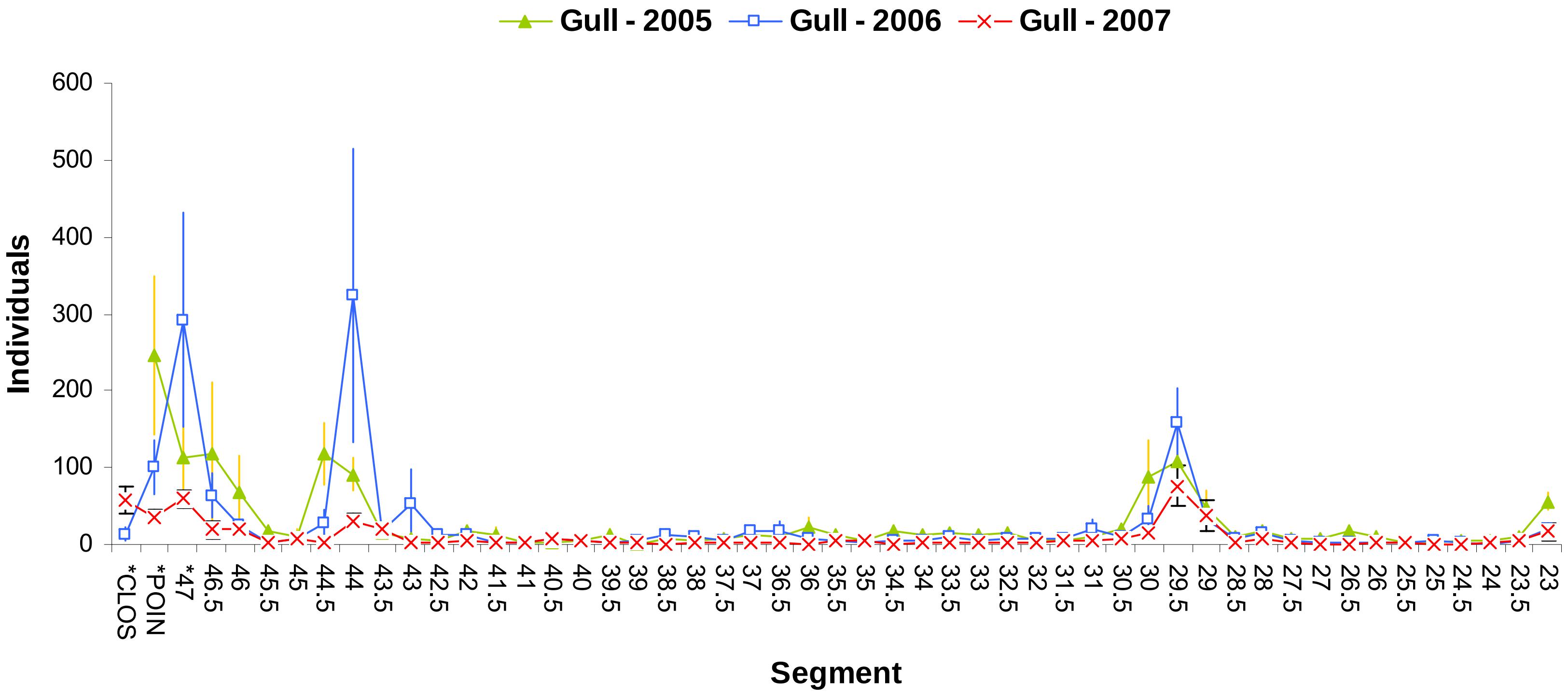

Figure 2.51. Average gull abundance at high tide from 2005, 2006, and 2007 for beach segments on South Core Banks, NC. Lines represent one standard error. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.

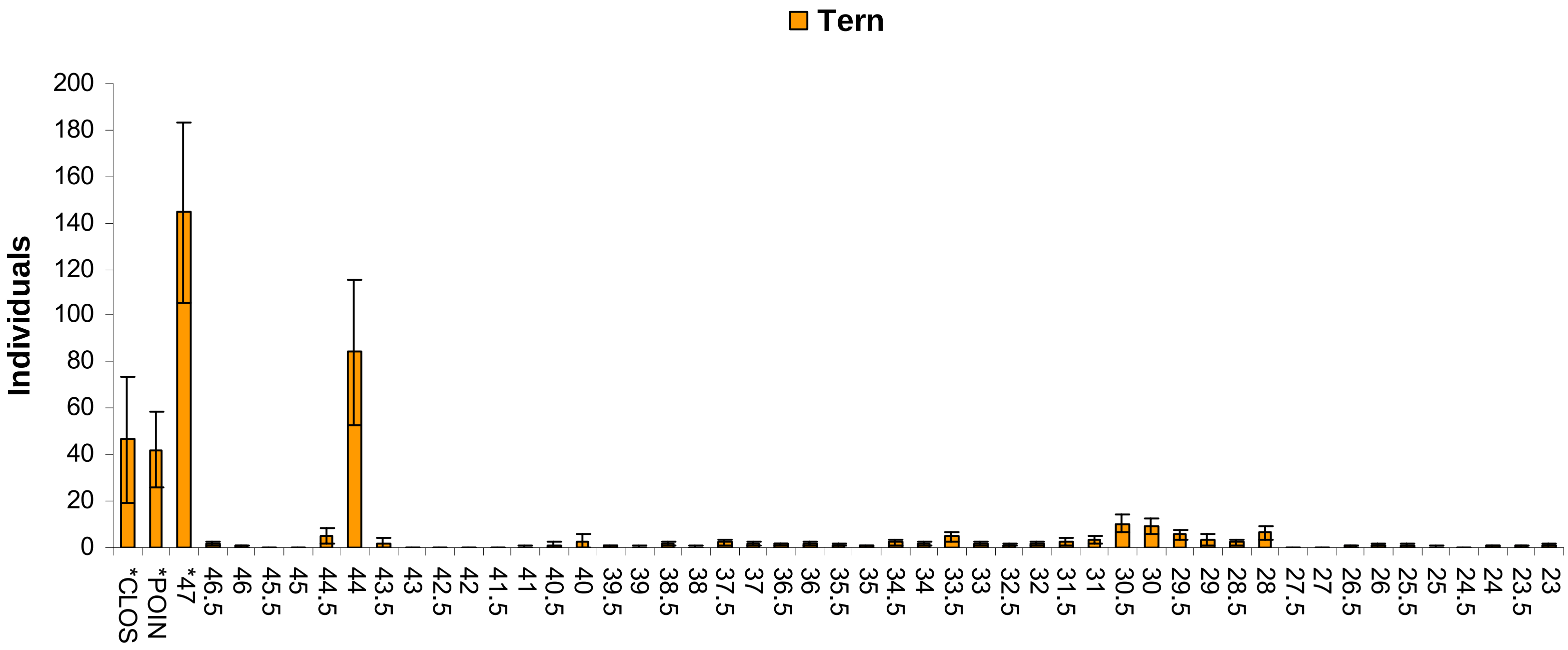

Figure 2.52. Average tern abundance at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

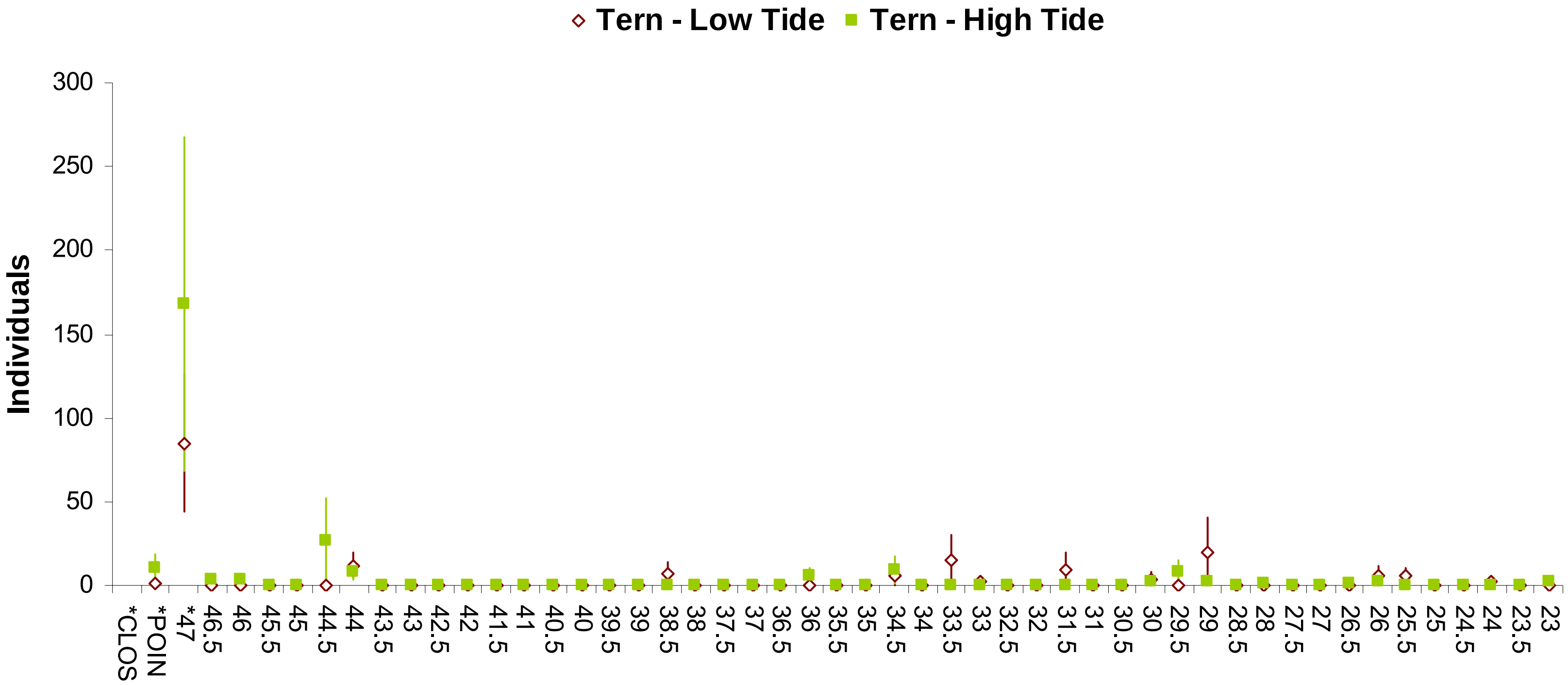

Figure 2.53. Average tern abundance at beach segments during low and high tide levels. Data from 2005 were used in this summary and lines illustrate the standard errors. Rising tide surveys were within 2 h of peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

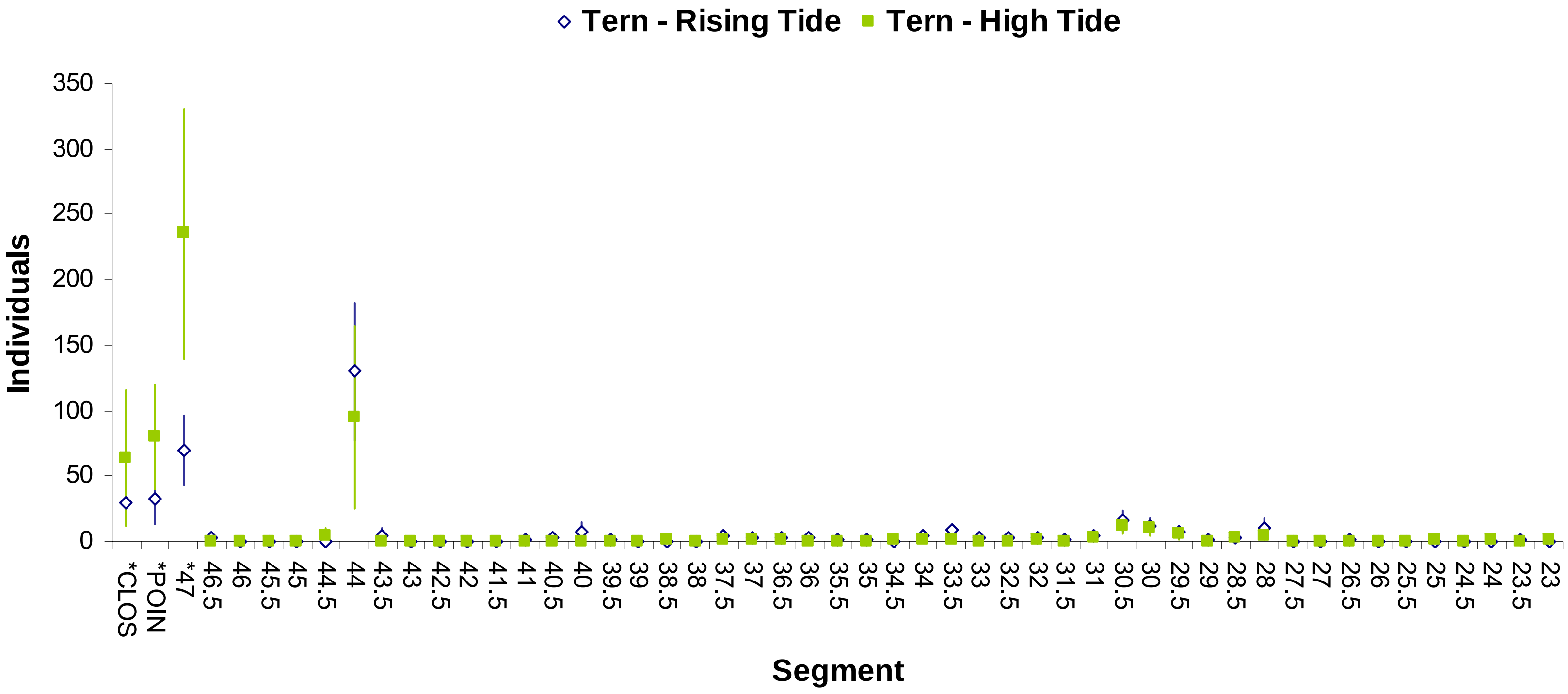

Figure 2.54. Average tern abundance at beach segments during high and rising tide levels. Data from 2006 and 2007 were used in this summary, and lines illustrate the standard errors. Rising tide surveys were within 4 h after peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

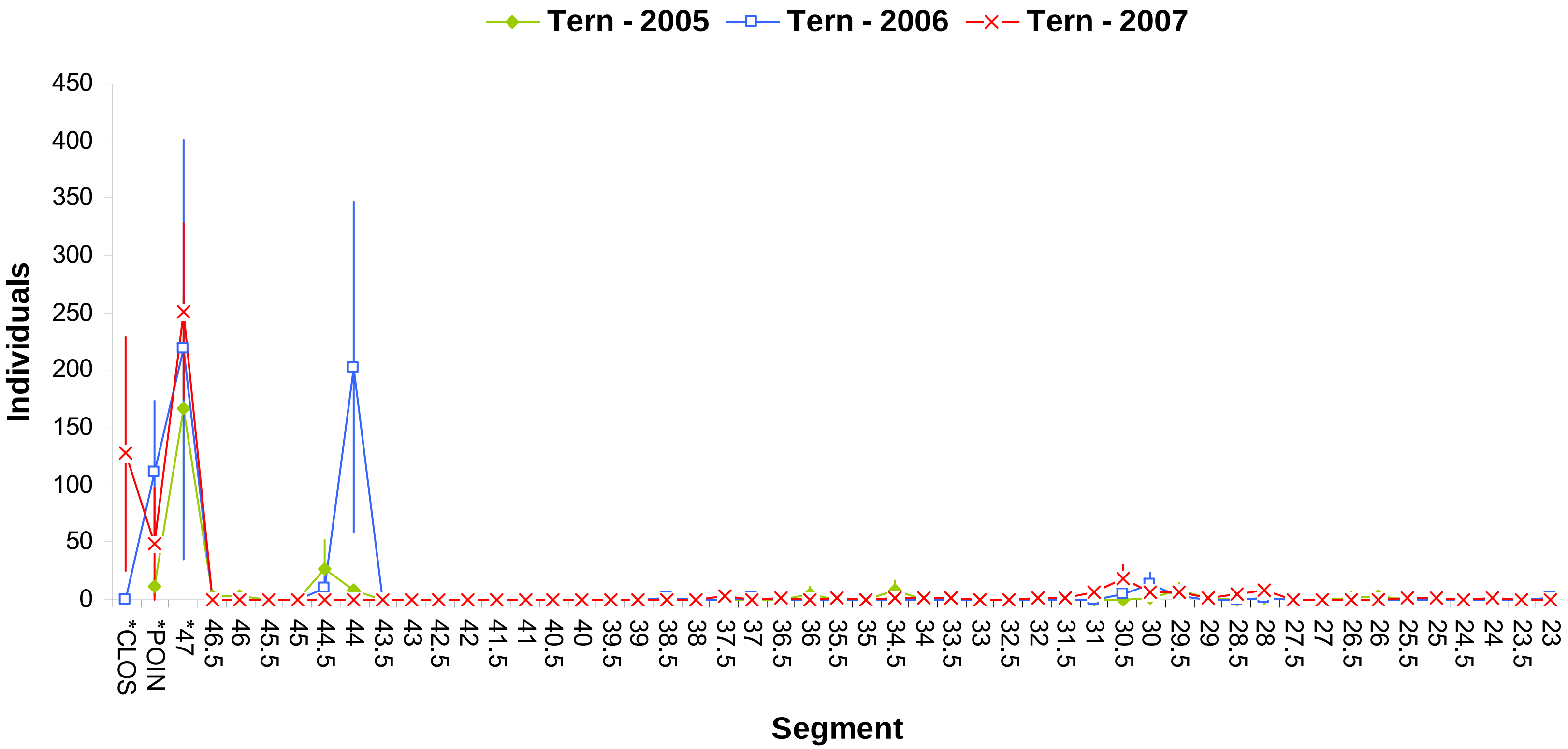

Figure 2.55. Average tern abundance at high tide from 2005, 2006, and 2007 for beach segments on South Core Banks, NC. Lines represent one standard error. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.

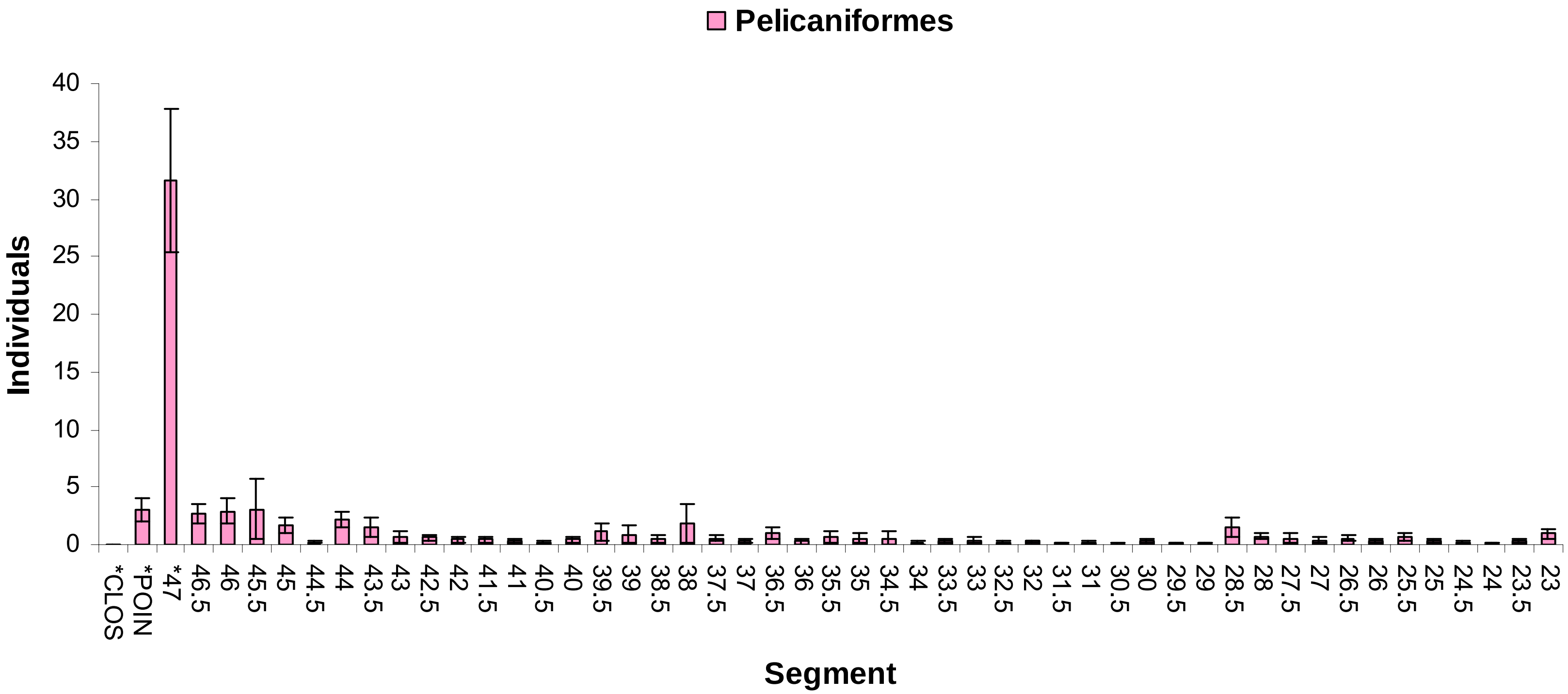

Figure 2.56. Average abundance of Brown Pelicans and Double-crested Cormorants (pelicaniformes) at beach segments on South Core Banks, NC with standard error bars. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

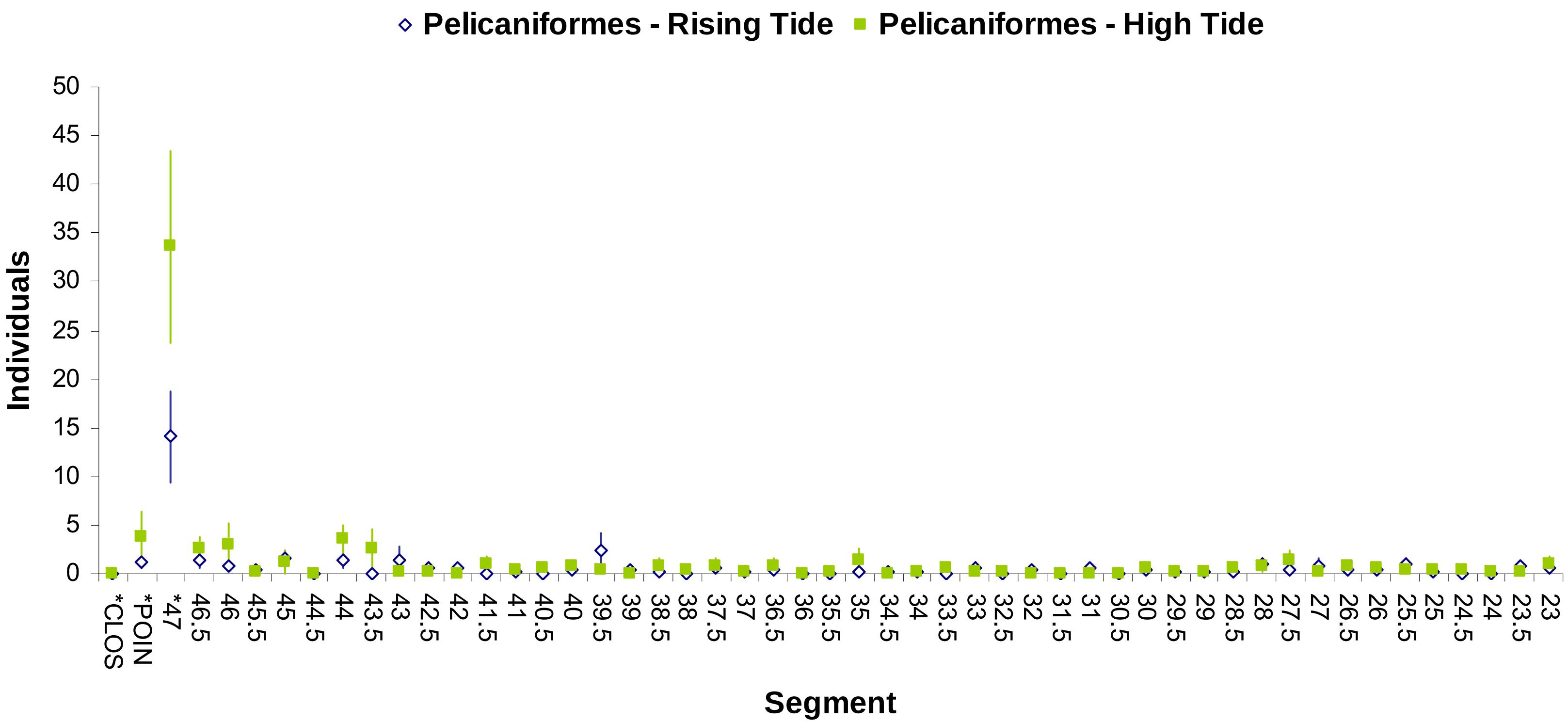

Figure 2.57. Average abundance of Brown Pelicans and Double-crested Cormorants (pelicaniformes) at segments during high and rising tides. Data from 2006 and 2007 were used, and lines illustrate the standard errors. Rising tide surveys were within 4 h after peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

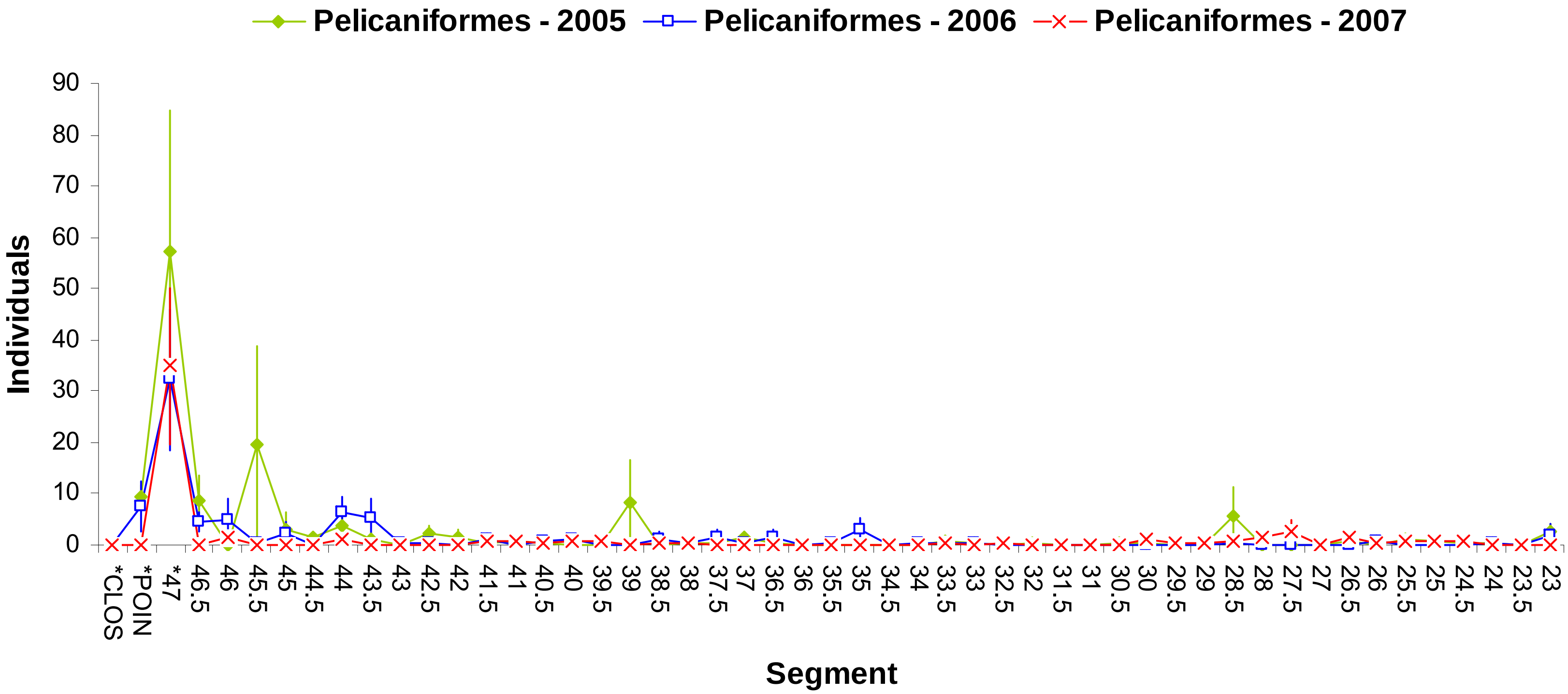

Figure 2.58. Average Brown Pelican and Double-crested Cormorant (pelicaniformes) abundance at high tide from 2005, 2006, and 2007 for beach segments on South Core Banks, NC. Lines represent one standard error. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.

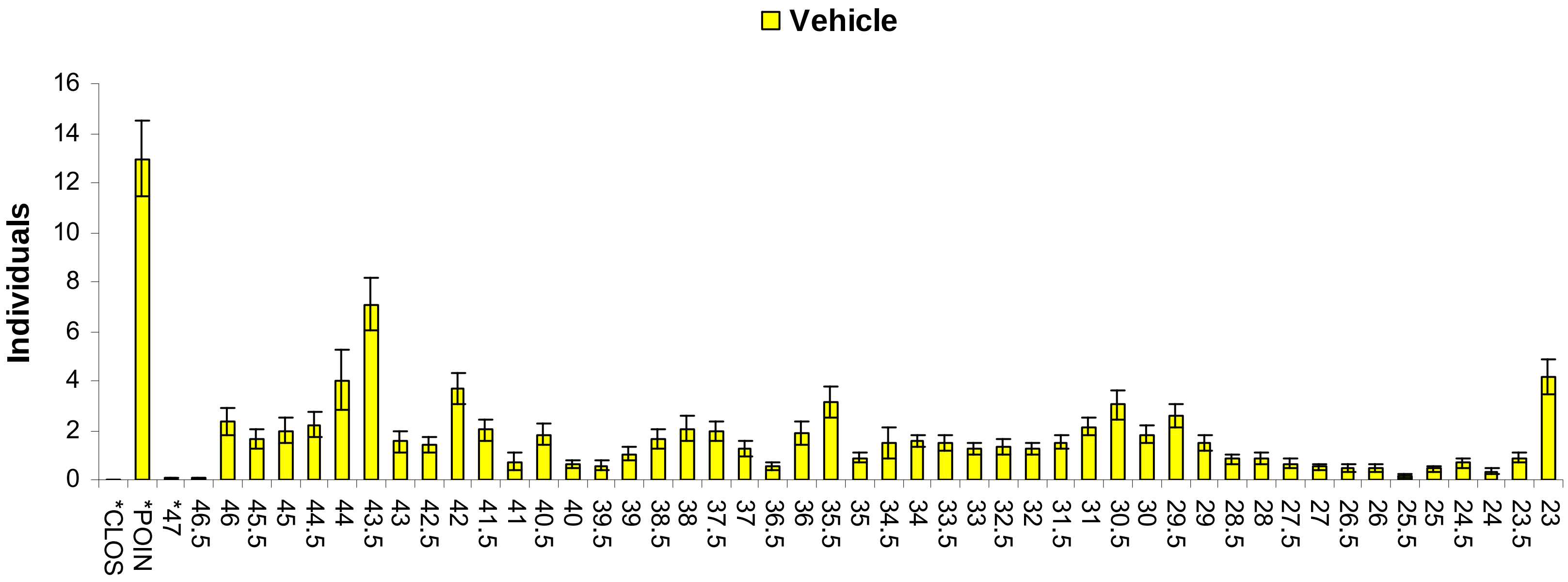

Figure 2.59. Average vehicle (ORVs and ATVs) abundance at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segments 46.5, 47, and POIN were closed to vehicles. POINT varied from 0.2 to 0.5 mi long.

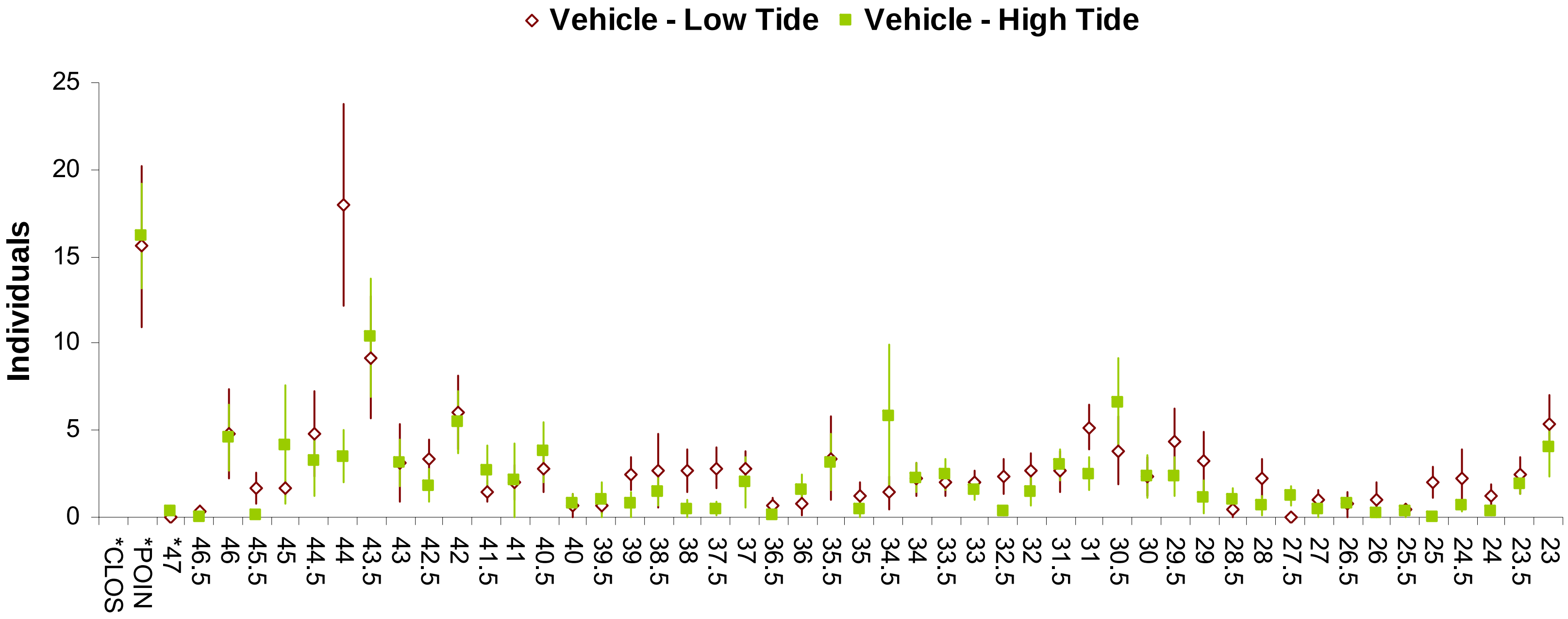

Figure 2.60. Average abundance of vehicles (ORVs and ATVs) at segments during low and high tides. Data from 2005 were used and lines illustrate the standard errors. Rising tide surveys were within 2 h of peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 46.5, 47, and POIN were closed to vehicles. POINT varied from 0.2 to 0.5 mi long.

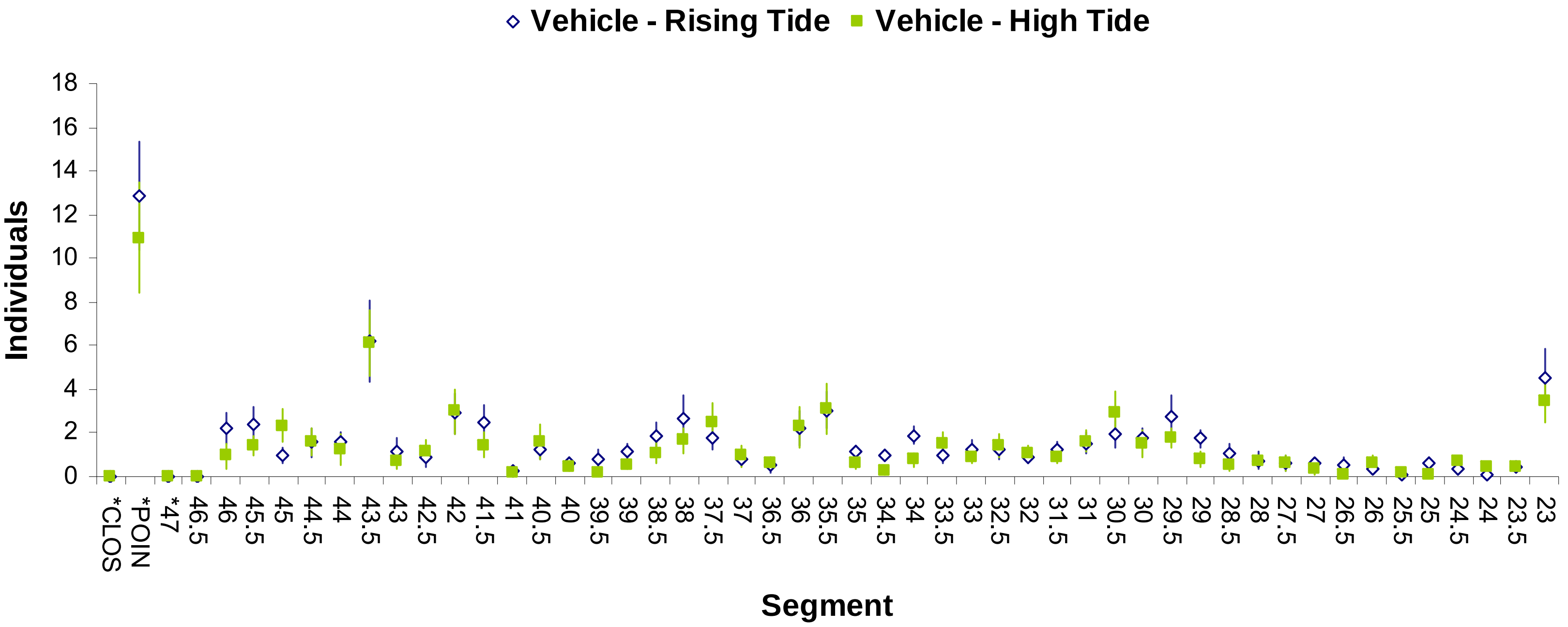

Figure 2.61. Average abundance of vehicles (ORVs and ATVs) at segments during high and rising tides. Data from 2006 and 2007 were used, and lines illustrate the standard errors. Rising tide surveys were within 4 h after peak low tide, and high tide surveys were within 2 h of peak high tide. Segments 46.5, 47, and POIN were closed to vehicles. POINT varied from 0.2 to 0.5 mi long. Segments 47, POINT, and CLOSURE had different dimensions and beach structure than other segments.

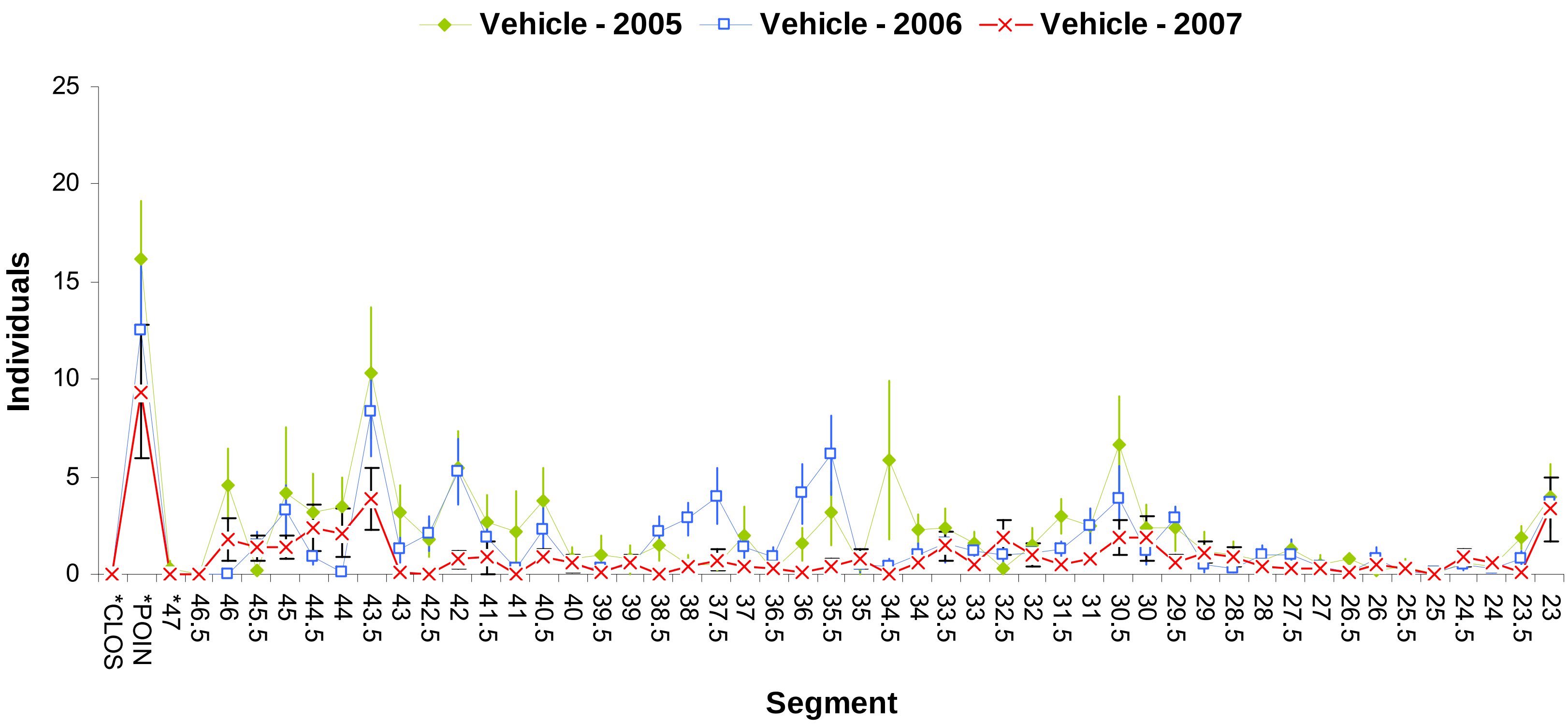

Figure 2.62. Average vehicle abundance at high tide from 2005, 2006, and 2007 for beach segments on South Core Banks, NC. Lines represent one standard error. Segments 46.5, 47, and POIN were closed to vehicles. POINT varied from 0.2 to 0.5 mi long. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments.

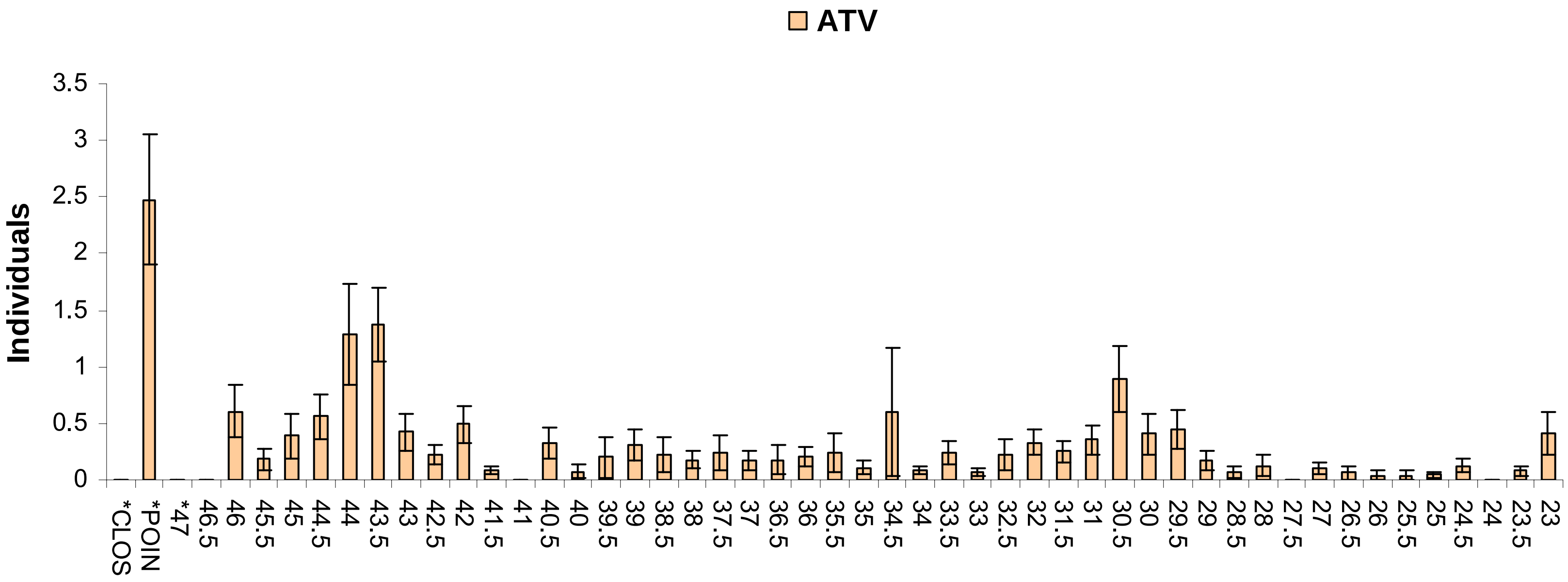

Figure 2.63. Average all-terrain vehicle (ATV) abundance at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segments 46.5, 47, and POIN were closed to vehicles. POINT varied from 0.2 to 0.5 mi long.

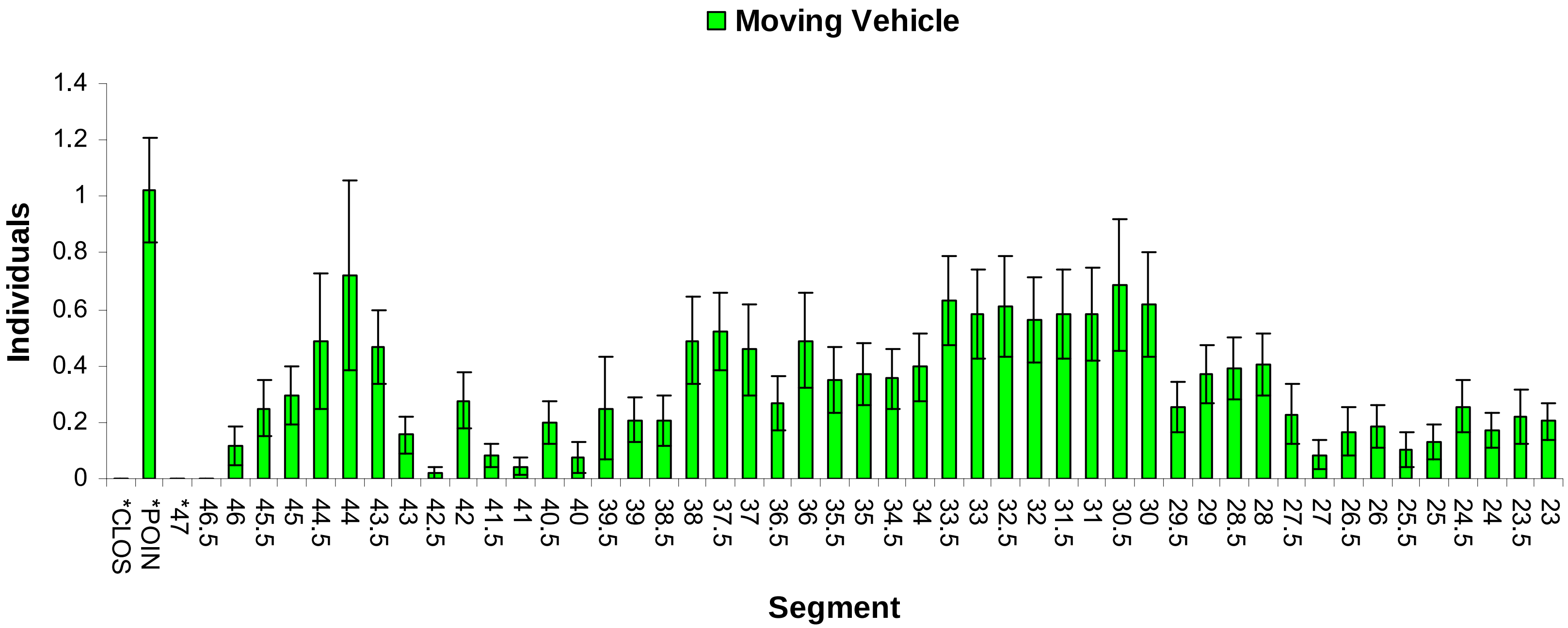

Figure 2.64. Average abundance of moving vehicles (ATVs and ORVs) at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segments 46.5, 47, and POIN were closed to vehicles. POINT varied from 0.2 to 0.5 mi long.

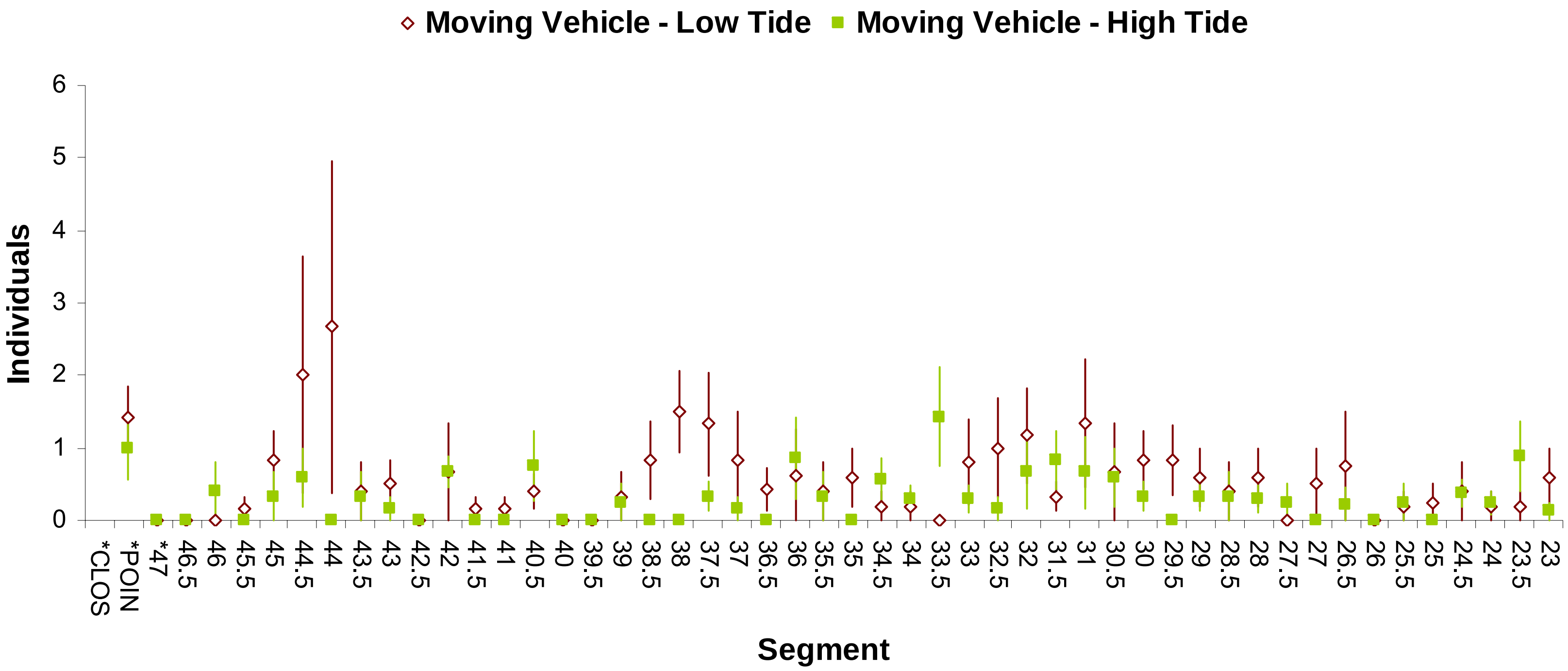

Figure 2.65. Average abundance of moving vehicles (ORVs and ATVs) at segments during low and high tides. We used data from 2005, and lines illustrate the standard error. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

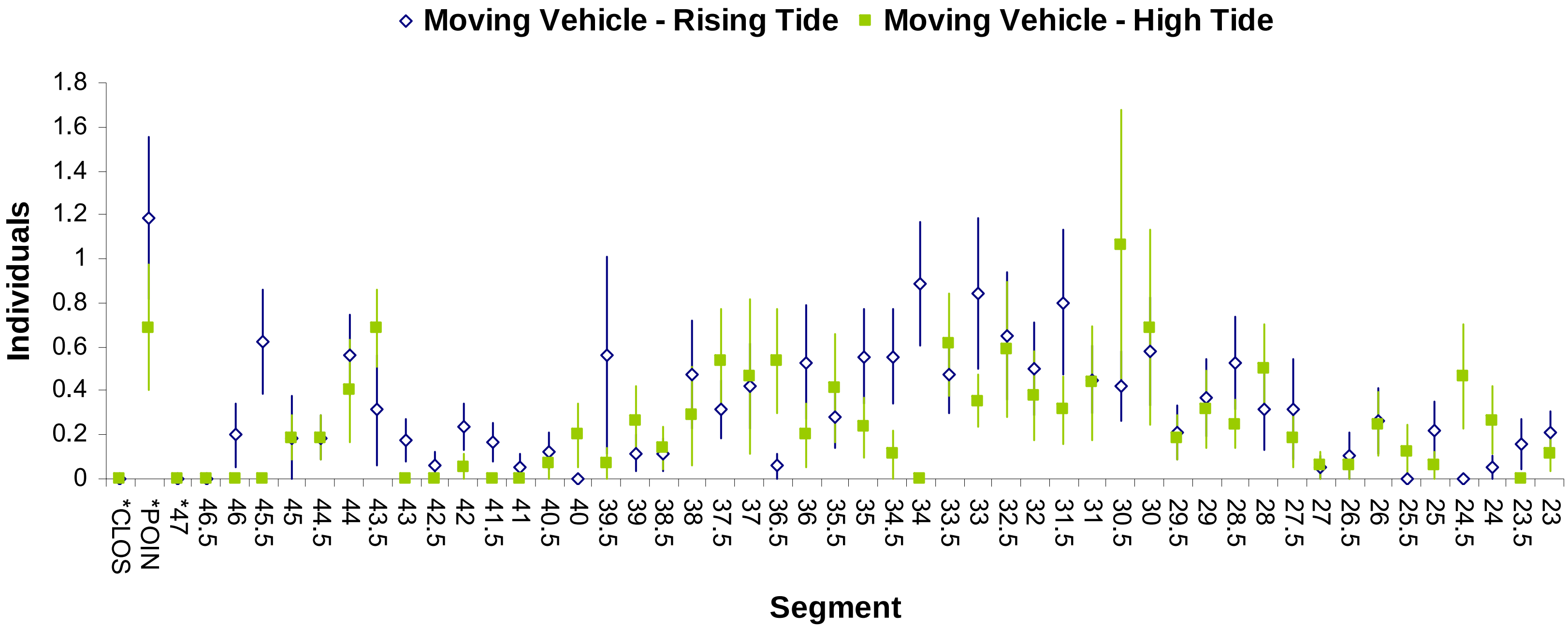

Figure 2.66. Average abundance of moving vehicles (ORVs and ATVs) at segments during rising and high tides. We used data from 2006 and 2007, and lines illustrate the standard error. Segments 47, POINT (Cape Lookout Point), and CLOSURE had different dimensions and beach structure than other segments.

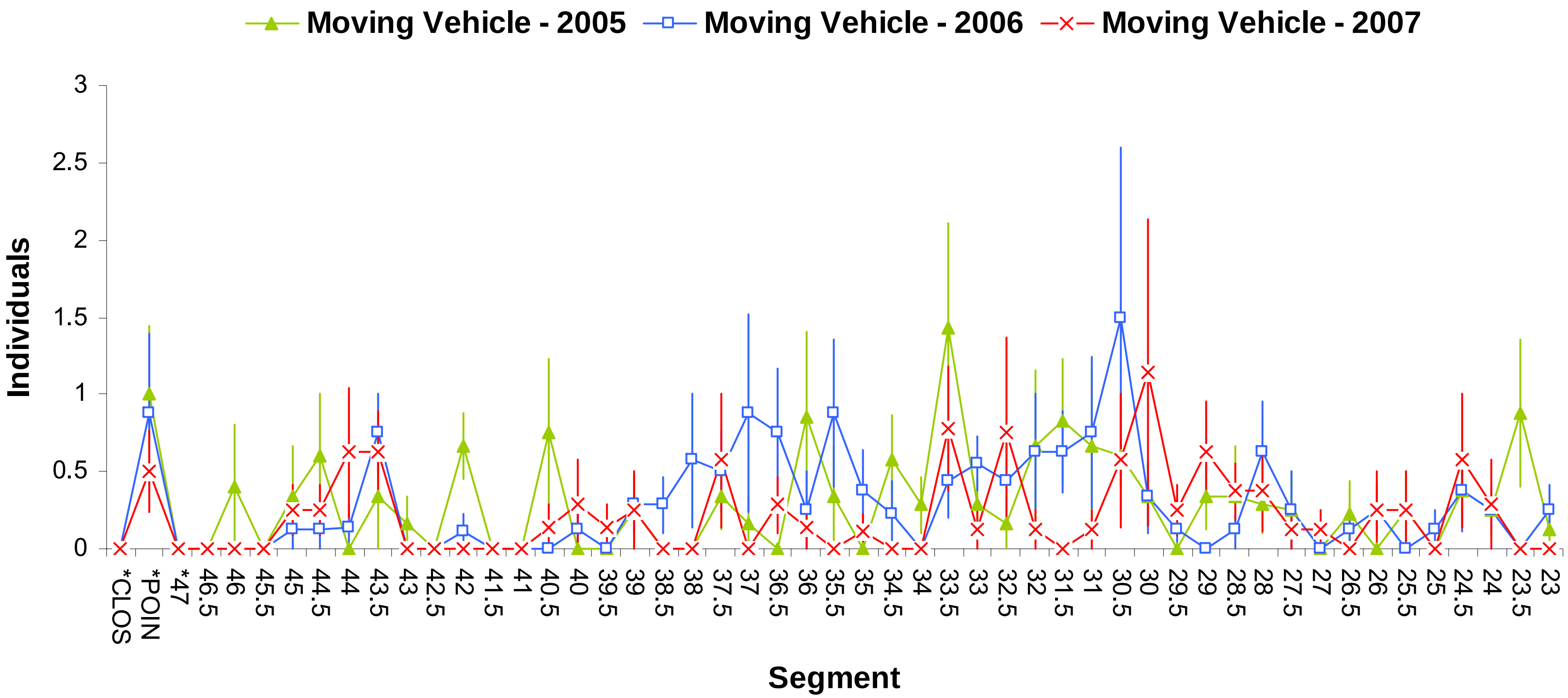

Figure 2.67. Average moving vehicle (ATVs and ORVs) counts at high tide from 2005, 2006, and 2007 for beach segments on South Core Banks, NC. Lines represent one standard error. Segments 46.5, 47, and POIN were closed to vehicles. Segments 47, POINT, and CLOSURE had different dimensions and beach structure than other segments.

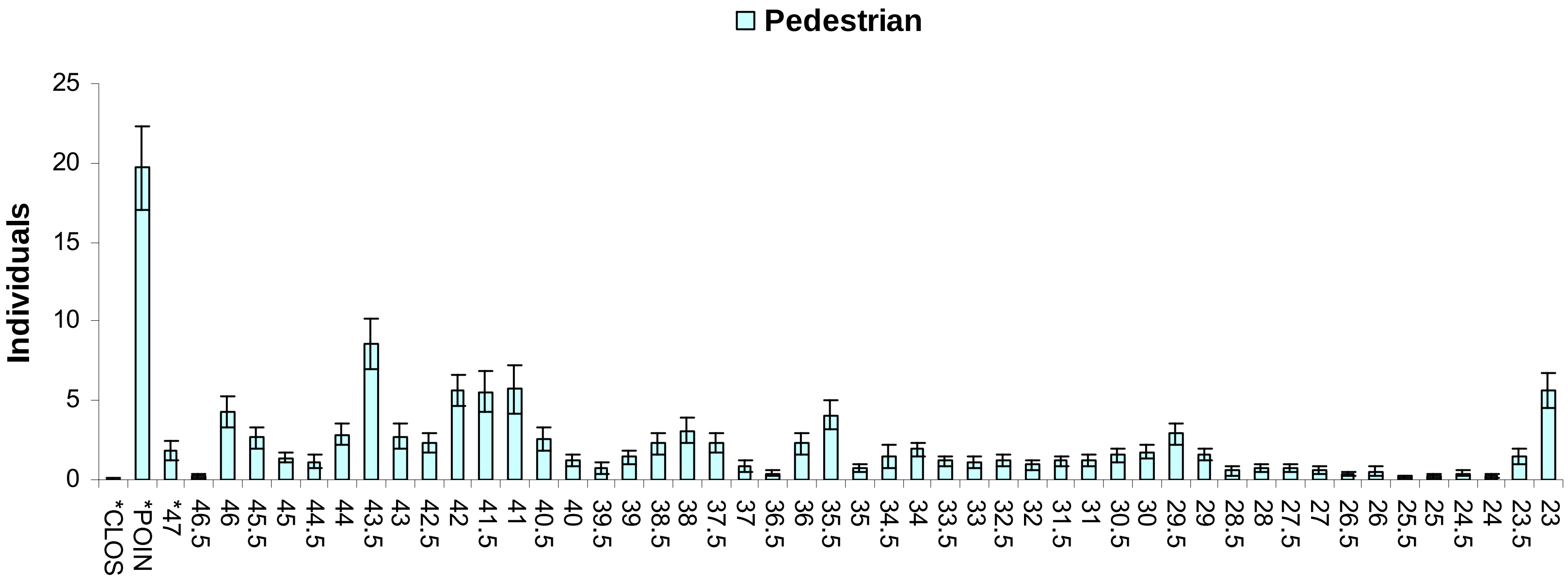

Figure 2.68. Average pedestrian abundance at beach segments on South Core Banks, NC with standard error bars. Segments were named by their northern edge's location in CALO's mile marker system. Segments 47, POINT (Cape Lookout Point), and CLOSURE (a vehicle exclosure on the back beach at Cape Lookout Point) had different dimensions and beach structure than other segments. Segment 47 was a large sand spit, POINT varied from 0.2 to 0.5 mi long with swash zones on two sides, and CLOSURE contained dry sand, some small dunes, and pools but no swash zone.

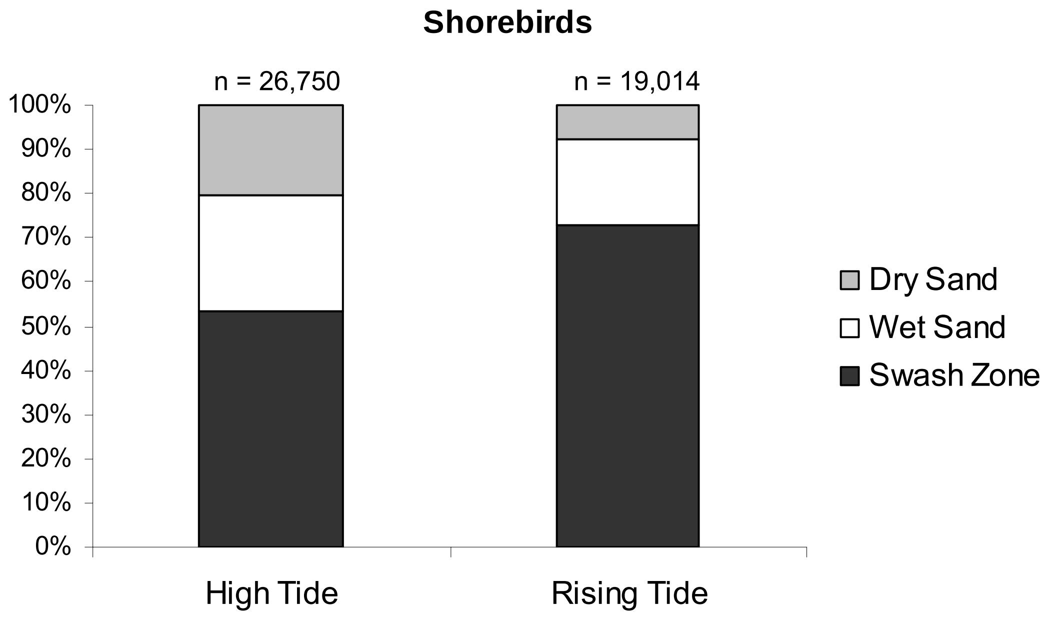

Figure 2.69. The proportions of total shorebird detections that were from dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

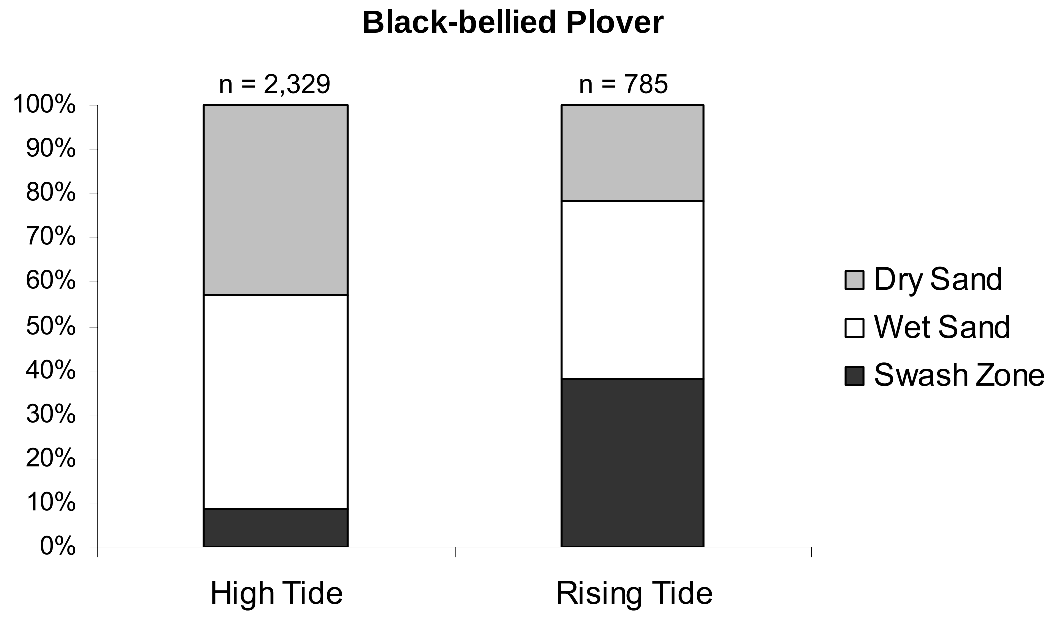

Figure 2.70. The proportions of total Black-bellied Plover detections that were from dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

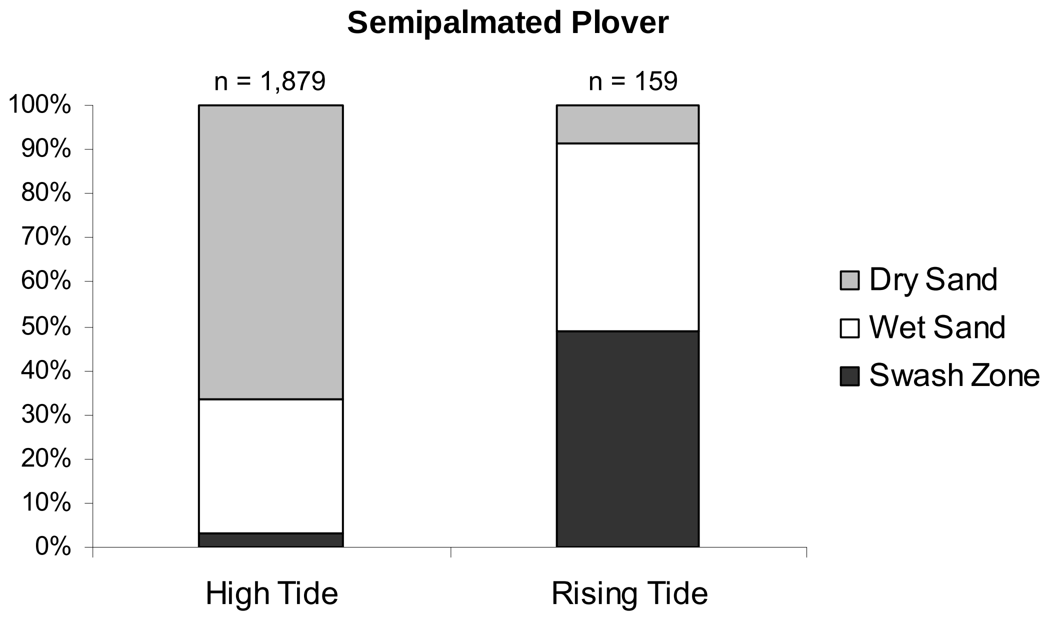

Figure 2.71. The proportions of total Semipalmated Plover detections that were from dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

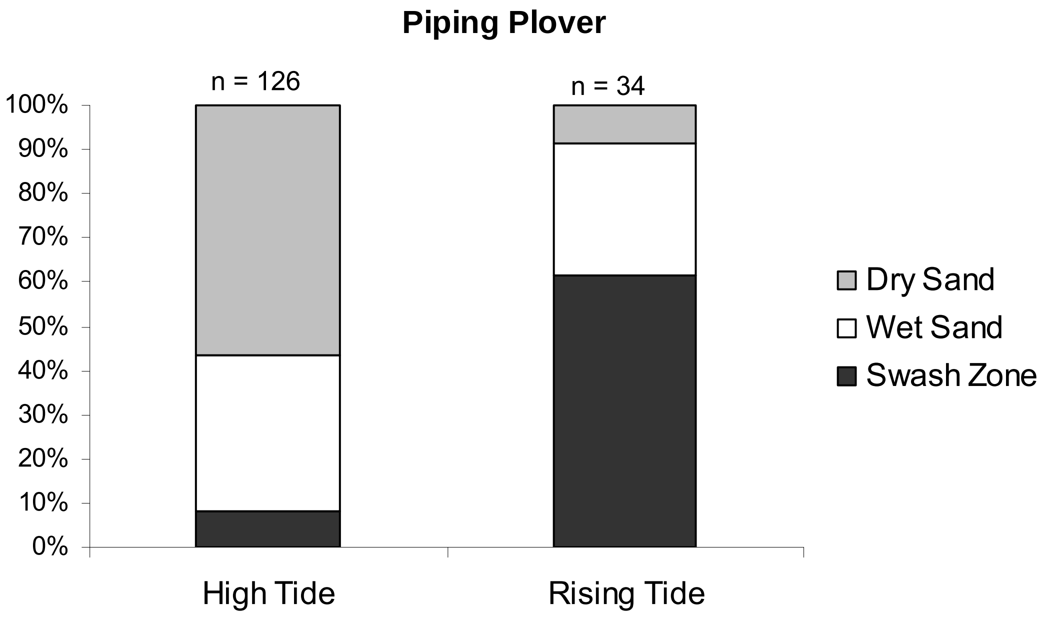

Figure 2.72. The proportions of total Piping Plover detections that were from dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

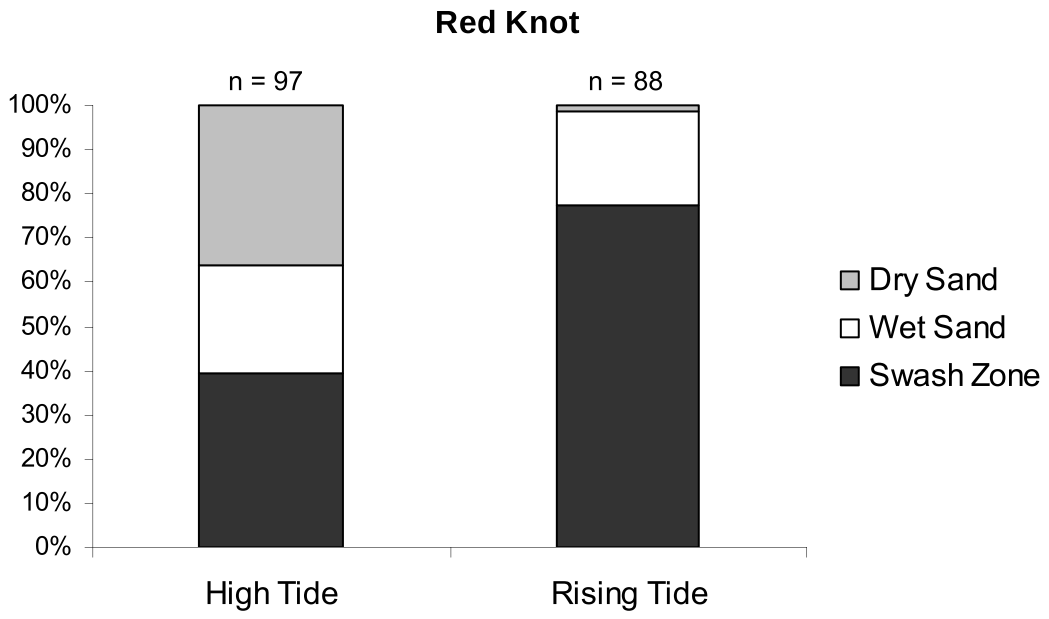

Figure 2.73. The proportions of total Red Knot detections that were from dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

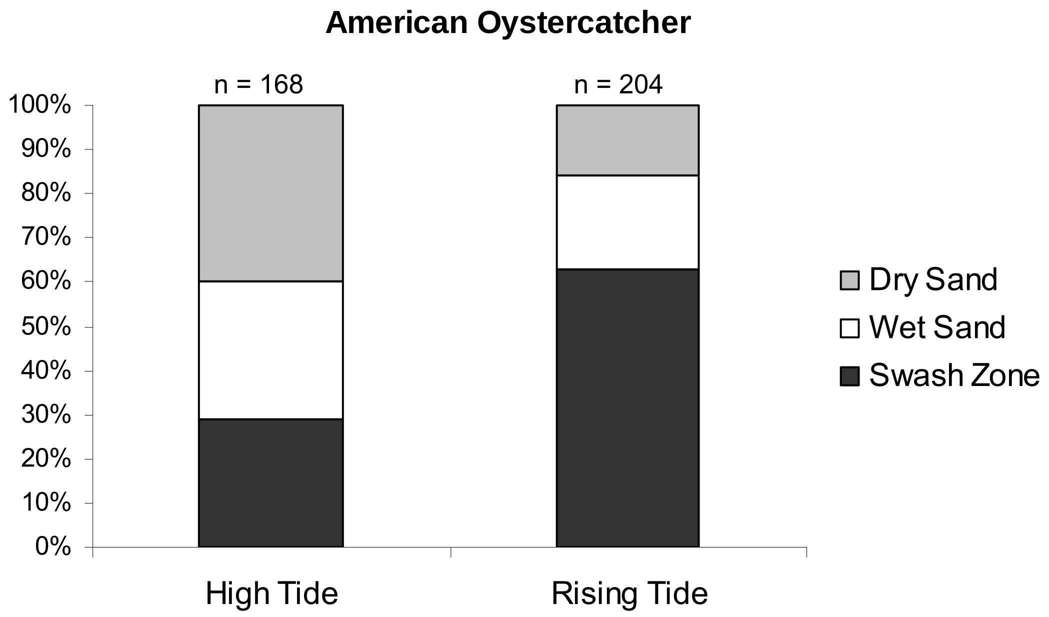

Figure 2.74. The proportions of total American Oystercatcher detections that were from dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

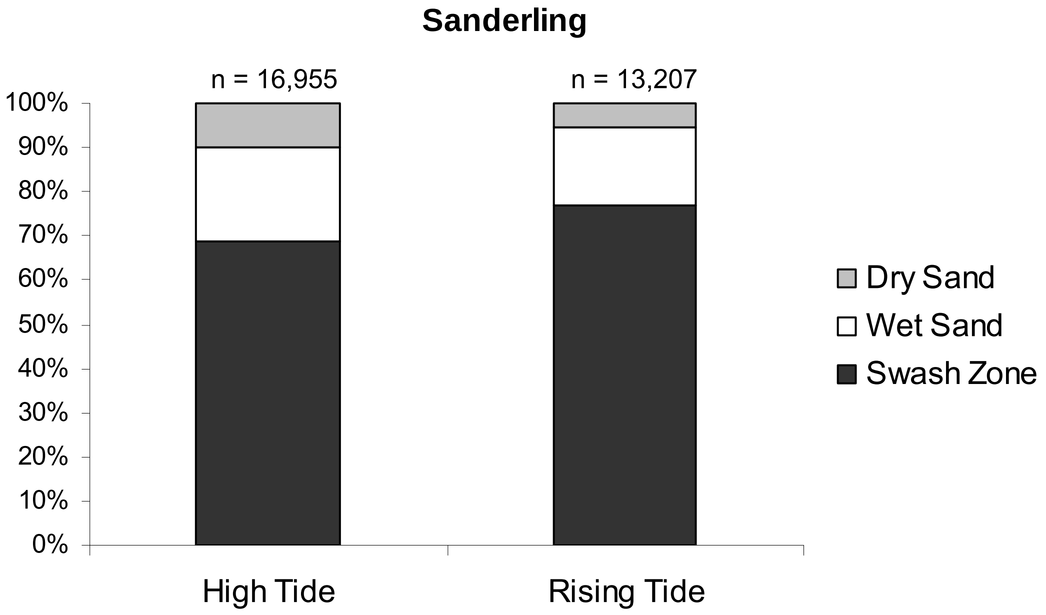

Figure 2.75. The proportions of total Sanderling detections that were from dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

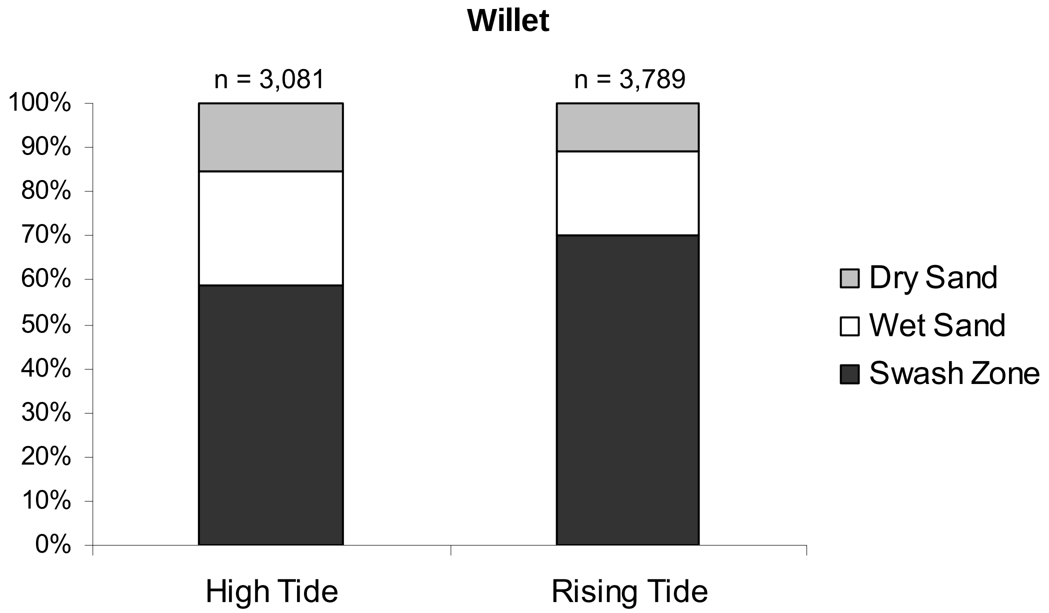

Figure 2.76. The proportions of total Willet detections that were from dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

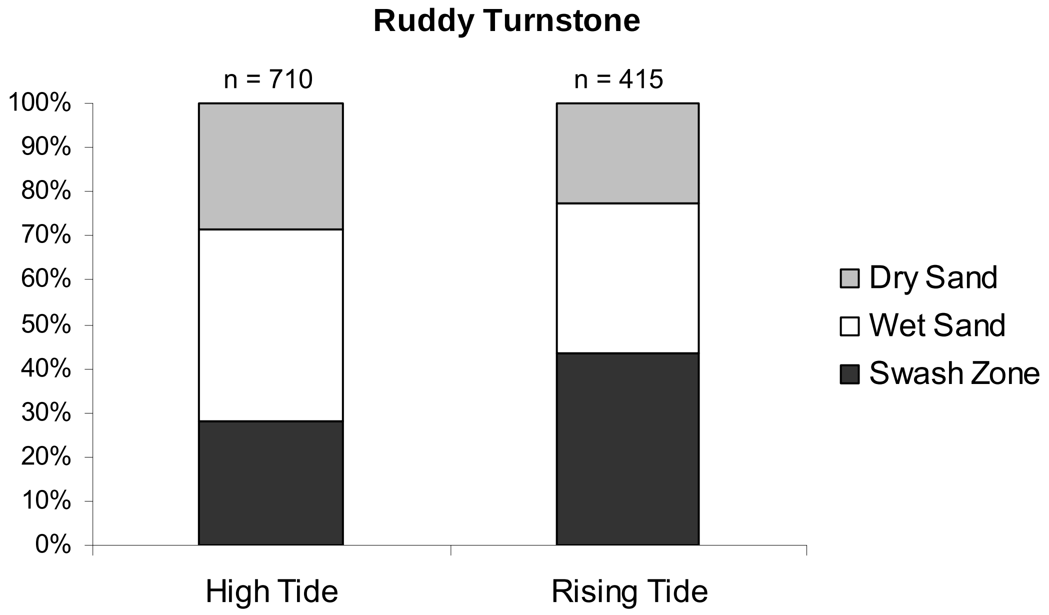

Figure 2.77. The proportions of total Ruddy Turnstone detections that were from dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

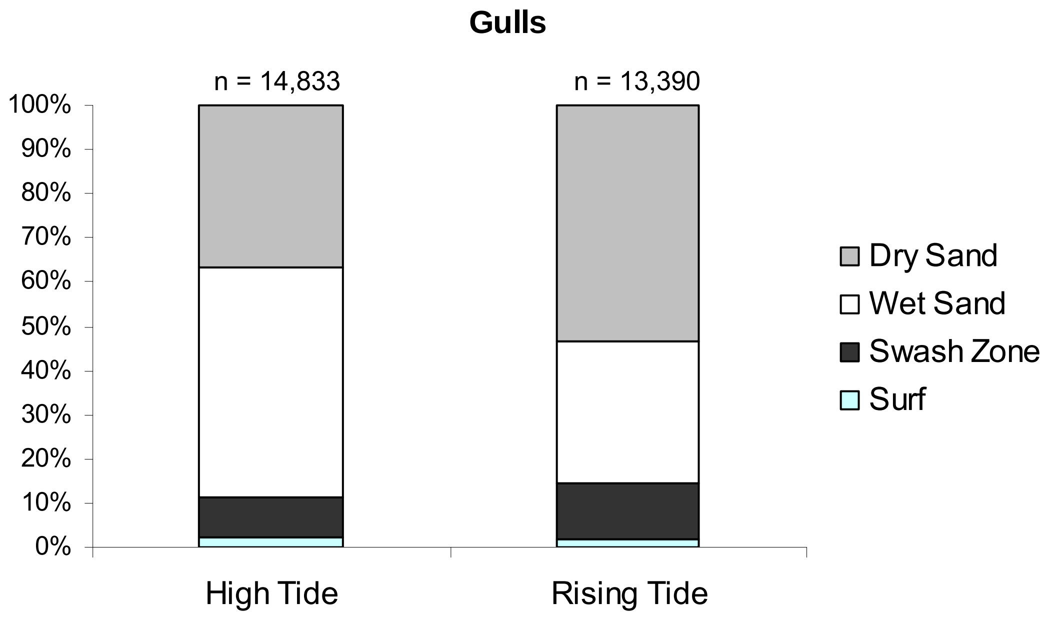

Figure 2.78. The proportions of total gull detections that were from dry sand, wet sand, swash zone, and surf microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

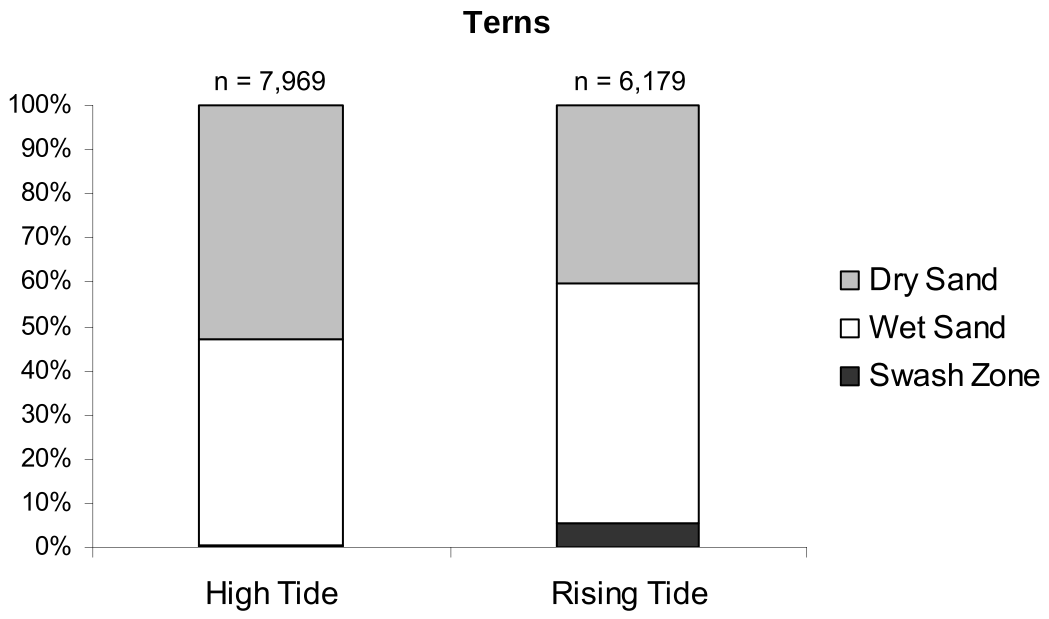

Figure 2.79. The proportions of total tern detections that were from dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

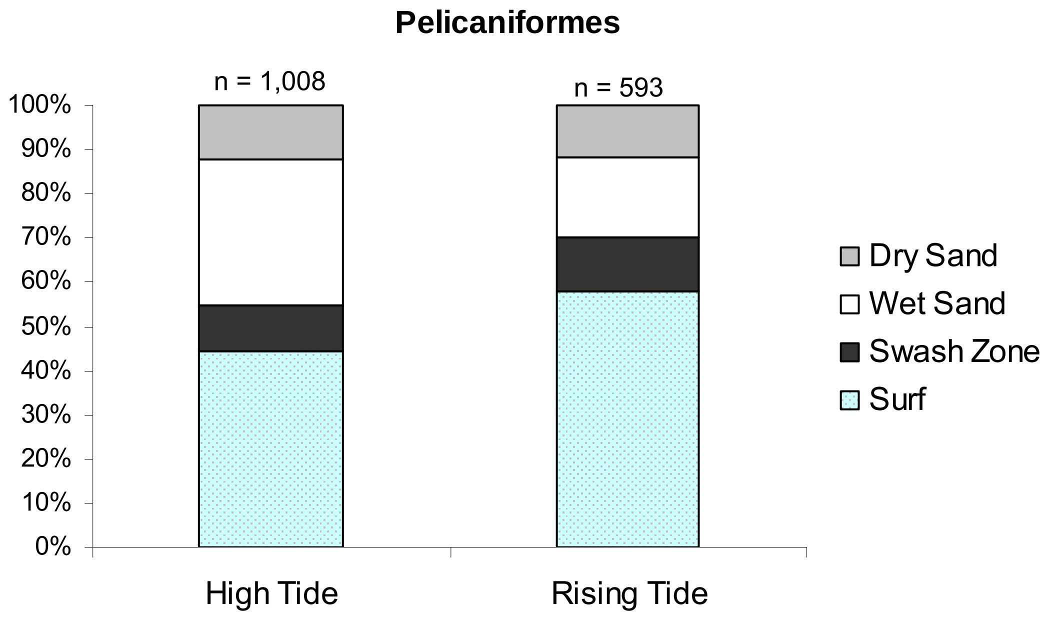

Figure 2.80. The proportions of total Brown Pelican and Double-crested Cormorant (pelicanidae) detections that were from dry sand, wet sand, swash zone, and surf microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

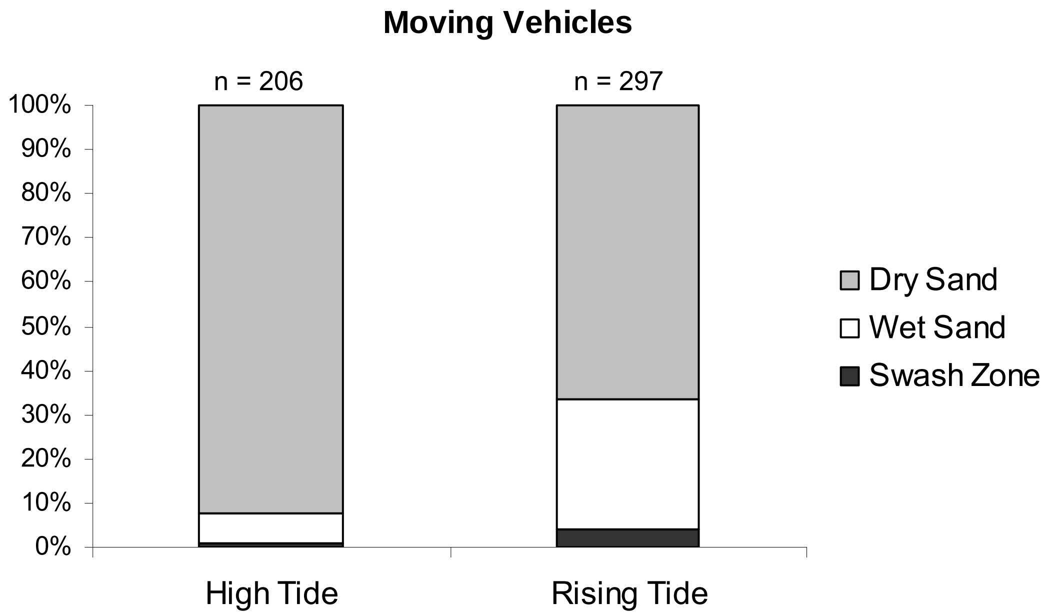

Figure 2.81. The proportions of total moving vehicles (moving ATVs or ORVs) detected that were in dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

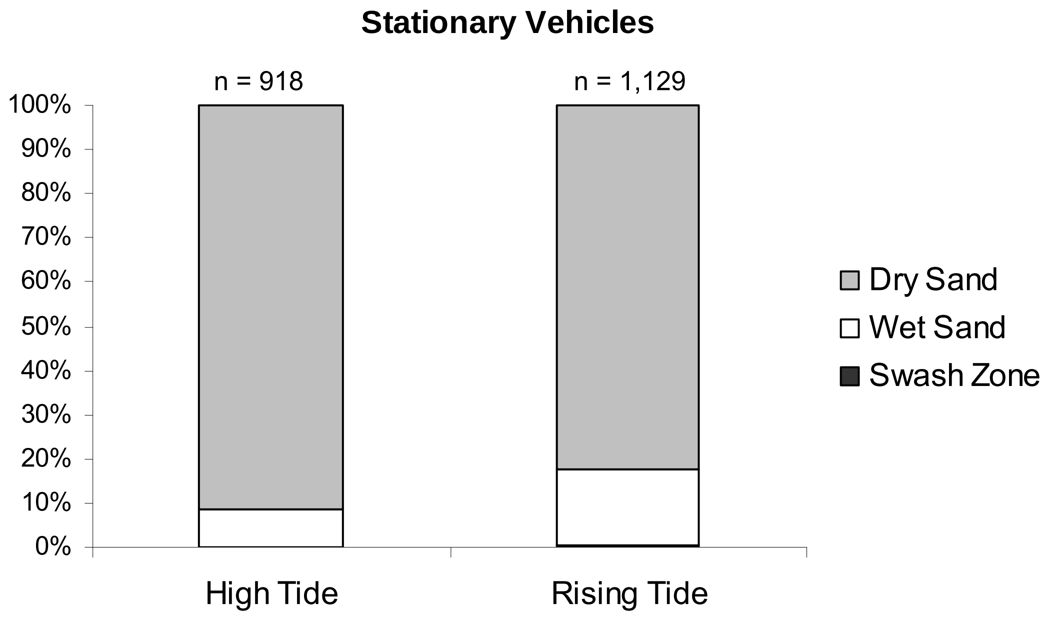

Figure 2.82. The proportions of total stationary vehicles (moving ATVs or ORVs) detected that were in dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

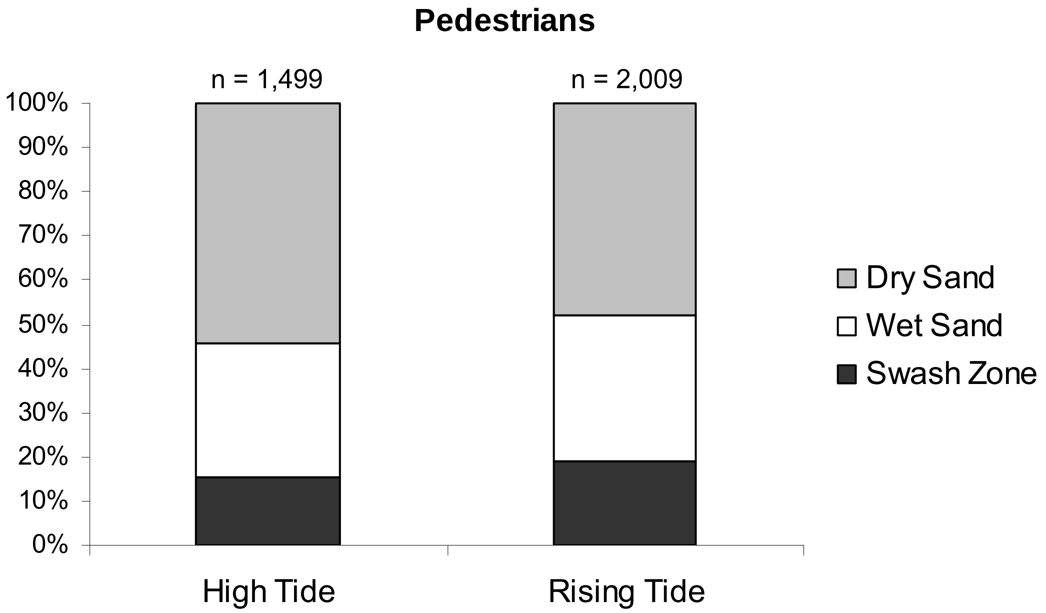

Figure 2.83. The proportions of pedestrians detected that were in dry sand, wet sand, and swash zone microhabitats at high and rising tide levels. Data from 2006 and 2007 were included in this summary.

Table 2.1. A list of species detected during surveys of ocean beach and surf (flyovers were excluded) at South Core Banks, North Carolina during fall 2005, 2006, and 2007. We performed 2,316 surveys at 51 half mile beach segments.

Species	Scientific name	Surveys where present	Total detections
Podicipedidae			
Horned Grebe	*Podiceps auritus*	2	3
Gaviidae			
Common Loon	*Gavia immer*	6	8
Pelecanidae			
Brown Pelican	*Pelecanus occidentalis*	292	2,736
Phalacrocoracidae			
Double-crested Cormorant	*Phalacrocorax auritus*	51	208
Sulidae			
Northern Gannet	*Morus bassanus*	1	1
Ardeidae			
Great Blue Heron	*Ardea herodias*	7	7
Snowy Egret	*Egretta thula*	16	1
Black-crowned Night-Heron*	*Nycticorax nycticorax*	0	0
Threskiornithidae			
White Ibis	*Eudocimus albus*	1	1
Anatidae			
Blue-winged Teal	*Anas discors*	1	1

Table 2.1 Continued

Species	Scientific name	Surveys where present	Total detections
Accipitridae			
Osprey	*Pandion haliaetus*	4	4
Falconidae			
Merlin	*Falco columbarius*	5	6
American Kestrel	*Falco sparverius*	1	1
Peregrine Falcon	*Falco peregrinus*	20	21
Charadriidae			
Black-bellied Plover	*Pluvialis squatarola*	885	3,434
Piping Plover	*Charadrius melodus*	60	204
Semipalmated Plover	*Charadrius semipalmatus*	176	2,329
Wilson's Plover	*Charadrius wilsonia*	9	26
Killdeer	*Charadrius vociferus*	5	8
Haematopodidae			
American Oystercatcher	*Haematopus palliatus*	186	431
Scolopacidae			
Greater Yellowlegs	*Tringa melanoleuca*	1	1
Lesser Yellowlegs	*Tringa flavipes*	1	2
Willet	*Catoptrophorus semipalmatus*	1,104	8,025
Whimbrel	*Numenius phaeopus*	21	34
Marbled Godwit	*Limosa fedoa*	1	1

Table 2.1 Continued

Species	Scientific name	Surveys where present	Total detections
Ruddy Turnstone	*Arenaria interpres*	525	1,438
Red Knot	*Calidris canutus*	91	341
Sanderling	*Calidris alba*	1,937	40,807
Dunlin	*Calidris alpina*	119	567
Pectoral Sandpiper	*Calidris melanotos*	3	16
White-rumped Sandpiper	*Calidris fuscicollis*	1	1
Western Sandpiper	*Calidris mauri*	23	468
Semipalmated Sandpiper	*Calidris pusilla*	6	7
Least Sandpiper	*Calidris minutilla*	9	148
Short-billed Dowitcher**	*Limnodromus griseus*	59	236
Laridae			
Bonaparte's Gull	*Larus philadelphia*	3	3
Laughing Gull	*Larus atricilla*	685	11,237
Ring-billed Gull	*Larus delawarensis*	452	4,381
Herring Gull	*Larus argentatus*	925	10,040
Lesser Black-backed Gull	*Larus fuscus*	107	319
Great Black-backed Gull	*Larus marinus*	959	10,662
Caspian Tern	*Sterna caspia*	89	910
Royal Tern	*Sterna maxima*	128	4,590
Sandwich Tern	*Sterna sandvicensis*	141	3,941
Common Tern	*Sterna hirundo*	69	1,730

Table 2.1 Continued

Species	Scientific name	Surveys where present	Total detections
Forster's Tern	*Sterna forsteri*	117	1,526
Least Tern	*Sterna antillarum*	32	104
Gull-billed Tern*	*Sterna nilotica*	0	0
Black Tern	*Chlidonias niger*	26	210
Black Skimmer	*Rynchops niger*	1	17
Columbidae			
Mourning Dove	*Zenaida macroura*	2	3
Hirundinidae			
Barn Swallow	*Hirundo rustica*	4	81
Icteridae			
Common Grackle	*Quiscalus quiscula*	3	20
Boat-tailed Grackle	*Quiscalus major*	22	38

*Species observed on the beach but not during surveys

**We did not attempt to identify Long-billed Dowitchers (*Limnodromus scolopaceus*).

Table 2.2. Total number of individuals counted at South Core Banks on days when we surveyed all beach segments during low (L), rising (R), or high (H) tide. Flyovers are included in this summary. “Peep” denotes unidentified small sandpipers such as Western Sandpipers, Least Sandpipers, or Semipalmated Sandpipers. Only vehicle counts are reported for 11 October 2006 and 12 October 2007 because extreme high tides blocked vehicle access to some beach segments. On 9 October 2005, the observers did not identify gulls and terns to the species level. Instead, they simply recorded them as “gull species” or “tern species”.

Year	2005	2006						2007				
Date	9 Oct	11 Oct	20 Oct		25 Oct	3 Nov		11 Sep	4 Oct	12 Oct		19 Oct
Tide	L	H	H	R	R	H	R	H	H	H	R	R
Pelicaniformes	27		74	77	208	99	169	42	138		138	31
Brown Pelican	27		67	64	201	98	55	42	137		136	28
Double-crested Cormorant	0		7	13	7	1	114	0	1		2	3
Shorebirds	1,284		1,331	145	1,499	1,984	1,340	1,691	1,468		1,431	655
American Oystercatcher	13		4	8	5	5	6	18	8		8	3
Black-bellied Plover	24		79	9	37	27	8	293	99		52	20
Dowitcher species	0		0	0	0	0	1	8	0		3	0

Table 2.2 Continued

Year	2005	2006						2007				
Date	9 Oct	11 Oct	20 Oct		25 Oct	3 Nov		11 Sep	4 Oct	12 Oct		19 Oct
Tide	L	H	H	R	R	H	R	H	H	H	R	R
Dunlin	0		3	4	43	156	163	0	2		3	0
Killdeer	0		0	0	0	1	0	0	0		0	0
Least Sandpiper	0		0	0	0	0	0	4	7		0	0
Marbled Godwit	0		0	0	0	0	0	0	1		0	0
Pectoral Sandpiper	0		0	0	1	0	0	0	0		0	0
Piping Plover	0		6	0	5	7	0	3	1		5	0
Red Knot	7		6	1	17	8	7	11	2		0	1
Ruddy Turnstone	37		31	5	40	53	12	74	51		47	25
Sanderling	788		1,120	59	1,060	1,475	1,045	800	937		948	573
Semipalmated Plover	4		25	13	33	0	2	84	125		0	3
Semipalmated Sandpiper	0		0	0	2	0	0	0	1		0	0

Table 2.2 Continued

Year	2005	2006						2007					
Date	9 Oct	11 Oct	20 Oct		25 Oct	3 Nov		11 Sep	4 Oct	12 Oct		19 Oct
Tide	L	H	H	R	R	H	R	H	H	H	R	R
Spotted Sandpiper	0		0	0	0	0	0	1	0		0	0
Western Sandpiper	0		0	0	1	0	2	10	128		0	0
Whimbrel	0		1	0	0	0	0	11	0		0	0
Willet	389		56	46	172	236	87	335	71		365	28
Wilson's Plover	0		0	0	0	0	0	2	7		0	0
"Peep"	0		0	0	0	0	2	24	1		0	2
Semipalmated Plover or "peep"	7		0	0	0	0	0	0	0		0	0
Unidentified shorebird	15		0	0	83	16	5	13	27		0	0
Gulls	752		1,131	692	4,692	3,929	2,110	172	788		812	569
Bonaparte's Gull	0		0	0	0	2	0	0	0		0	0
Great Black-backed Gull	0		320	258	526	629	284	35	304		302	183

Table 2.2 Continued

Year	2005	2006						2007				
Date	9 Oct	11 Oct	20 Oct		25 Oct	3 Nov		11 Sep	4 Oct	12 Oct		19 Oct
Tide	L	H	H	R	R	H	R	H	H	H	R	R
Herring Gull	0		341	178	1,257	1,395	492	46	278		265	196
Laughing Gull	0		193	86	643	1,125	208	76	157		168	168
Lesser Black-backed Gull	0		14	3	5	62	2	3	16		5	2
Ring-billed Gull	0		79	118	2,181	181	172	5	10		14	10
Unidentified Gull	752		184	49	80	535	952	7	23		58	10
Terns	3		228	34	133	1,226	757	533	262		190	23
Black Tern	0		0	0	0	0	0	19	0		1	0
Caspian Tern	0		8	1	2	41	0	9	95		37	7
Common Tern	0		0	0	0	0	0	30	0		0	0
Forster's Tern	0		54	6	8	416	71	13	10		95	6
Least Tern	0		0	0	0	0	0	5	0		0	0

Table 2.2 Continued

Year	2005	2006						2007				
Date	9 Oct	11 Oct	20 Oct		25 Oct	3 Nov		11 Sep	4 Oct	12 Oct		19 Oct
Tide	L	H	H	R	R	H	R	H	H	H	R	R
Royal Tern	0		3	3	22	100	52	237	79		6	2
Sandwich Tern	0		23	1	32	500	139	91	61		3	0
Unidentified tern	3		140	23	69	169	495	129	17		48	8
Miscellaneous sp.	5		10	3	4	3	1	10	1		6	6
Barn Swallow	0		0	0	0	0	0	5	0		0	0
Blue-winged Teal	0		0	0	0	0	0	0	0		1	0
Boat-tailed Grackle	0		5	0	2	1	0	0	1		2	1
Common Loon	0		0	0	1	0	0	0	0		1	0
Duck species	0		0	0	0	0	0	3	0		0	0
Great Blue Heron	0		0	1	0	0	0	0	0		1	1
Unidentified heron	0		0	1	0	0	0	0	0		0	0
Horned Grebe	0		0	0	0	2	0	0	0		0	0

Table 2.2 Continued

Year	2005	2006						2007				
Date	9 Oct	11 Oct	20 Oct		25 Oct	3 Nov		11 Sep	4 Oct	12 Oct		19 Oct
Tide	L	H	H	R	R	H	R	H	H	H	R	R
Northern Gannet	0		0	0	0	0	1	0	0		0	0
Osprey	1		1	0	0	0	0	1	0		0	0
Peregrine Falcon	3		4	1	0	0	0	0	0		1	4
Snowy Egret	1		0	0	1	0	0	1	0		0	0
All vehicles	82	91	105	129	132	122	127	10	47	69	149	103
ATV	19	10	17	15	22	25	26	4	4	4	30	8
Stationary ATV	15	10	14	9	18	22	20	0	1	3	21	7
Moving ATV	4	0	3	6	4	3	6	4	3	1	9	1
ORV (non-ATV)	63	81	88	114	110	97	101	6	43	65	119	95
Stationary ORV	51	71	83	93	96	80	87	4	35	56	105	71
Moving ORV	12	10	5	21	14	17	14	2	8	9	14	24

Table 2.2 Continued

Year	2005	2006						2007				
Date	9 Oct	11 Oct	20 Oct		25 Oct	3 Nov		11 Sep	4 Oct	12 Oct		19 Oct
Tide	L	H	H	R	R	H	R	H	H	H	R	R
All boats	0		0	4	11	3	4	0	1		3	49
Stationary boat	0		0	4	4	3	4	0	1		2	2
Moving boat	0		0	0	7	0	0	0	0		1	47
All pedestrians	63		85	140	172	174	178	7	73		240	94
Stationary pedestrian	63		85	138	172	174	178	7	69		228	89
Moving pedestrian	0		0	2	0	0	0	0	4		12	5
All dogs	0		0	0	1	4	0	0	0		2	1
Dog on a leash	0		0	0	1	2	0	0	0		2	1
Unleashed dog	0		0	0	0	2	0	0	0		0	0

Table 2.3. Shorebird densities (birds/km) at six sites on North Carolina's Outer Banks. All data except for South Core Banks are from Dinsmore et al. (1998). We calculated birds/km by dividing the average number of individuals counted during complete surveys by the length of South Core Banks' ocean beaches (41 km).

	Bodie Island	North Beach	South Beach	Ocracoke	North Core Banks	South Core Banks
All shorebirds	88	117	41	36	56	31
Black-bellied Plover	2	4	2	1	3	2
Piping Plover	<l	<l	<l	<l	<l	<1
American Oystercatcher	1	<l	1	<l	1	<1
Willet	6	12	6	9	9	4
Whimbrel	1	2	<1	<1	<1	<1
Ruddy Turnstone	1	2	2	<1	<1	1
Red Knot	1	<l	<l	1	6	<1
Sanderling	76	97	28	22	34	21

CHAPTER 3

A Before-After-Control-Impact Study of Disturbance Effects on Nonbreeding Shorebirds

ABSTRACT

We examined whether the abundance, habitat use, and behavior of migrating shorebirds differed at sites with and without vehicle disturbance. We employed a before-after-control-impact (BACI) experimental study design to isolate treatment effects (vehicle disturbance) from spatial or temporal differences among our study sites. We manipulated disturbance levels within beach closures at South Core Banks, Cape Lookout National Seashore, North Carolina using paired control and impact plots. We measured bird abundance and Sanderling (*Calidris alba*) behavior during before and after periods on both control and impact plots. Control plots were closed to vehicles during both the before and after periods. Treatment plots were closed to vehicles during the before period but subjected to a fixed level of vehicle disturbance during the after period. Differences in shorebird abundance and behavior between paired control and treatment plots provided an estimate of vehicle disturbance effects. We found that vehicle disturbance decreased shorebird abundance and altered shorebird habitat use on treatment plots and decreased the amount of time Sanderlings spent roosting and resting. We believe that experimental BACI study designs provide a practical tool for measuring the effects of disturbance on wildlife without the confounding that affects purely observational approaches.

INTRODUCTION

Many species of shorebirds embark on long, energetically expensive migrations. Stopover sites provide an opportunity for individuals to rest and rebuild the energy stores necessary for migration and survival on their breeding or wintering grounds. North Carolina's Outer Banks include stopover sites that are used by a variety of shorebird species during fall and spring migration (Dinsmore et al. 1998). Many of theses sites are also open to off-road vehicles, which have become popular for human recreational activities, such as camping and fishing. Nonbreeding shorebirds are frequently observed flushing in response to vehicles, a behavior that reflects a tradeoff between avoiding a perceived risk and other requirements such as foraging or roosting (Gill and Sutherland 2000). If flushing in response to human activity increases a bird's overall energy expenditure, then disturbance could have indirect population level consequences via reductions in body condition and other traits associated with fitness (Gill and Sutherland 2000). Declines in the numbers of shorebirds using Atlantic stopover sites (Howe et al. 1989, Bart et al. 2007), coupled with increases in recreational activity have raised concerns about the effects of disturbance on coastal bird populations.

Site-based disturbance studies have provided evidence that the abundance, distribution, and behavior of nonbreeding shorebirds are influenced by human activity. Morton (1996) found that the abundance of wintering Sanderlings (*Calidris alba*) at Assateague Island National Seashore was influenced by human activity. Sanderlings were 14% more likely to occur at beaches without human activity, and Sanderling abundance was 2.4 times higher on plots without human activity. Barbee et al. (1994) found that spring and fall shorebird numbers were larger in areas without disturbance on North Carolina's outer banks. Pfister et al. (1992) found that Short-billed Dowitcher (*Limnodromus griseus*) and Sanderling abundance was negatively correlated with vehicle counts. They also found that roosting site selection by nonbreeding Sanderlings, Semipalmated Sandpipers (*Calidris pusilla*), Black-bellied Plovers (*Pluvialis squatarola*), and Ruddy Turnstones (*Arenaria interpres*) was correlated with disturbance levels. Peters and Otis (2007) found that human activity (boat traffic) influenced roost site selection by Red Knots (*Calidris canutus*). Disturbance has also been correlated with behavioral changes such as increases in vigilance, flying and preening, and decreases in walking, running, and roosting by Sanderlings (Morton 1996). Barbee et al. (1994) found that nonbreeding shorebirds spent less time roosting in areas with human activity than in areas closed to vehicles. Some studies have found a negative correlation between human activity and time spent foraging by nonbreeding Sanderlings (Burger and Gochfeld 1991b, Thomas et al. 2003) while others have found time spent foraging to be unaffected by human activity levels (Barbee et al. 1994, Morton 1996). This difference may reflect different methodologies because Thomas et al. (2003) and Burger and Gochfeld (1991) only sampled foraging birds, while Barbee et al. (1994) and Morton (1996) sampled all birds in their study plots.

Site-based disturbance studies such as these are strictly observational. They identify correlations between disturbance and changes in behavior, distribution, or abundance. Observational studies are often used to study disturbance (Hill et al. 1997) because they are convenient and inexpensive, but results are often difficult to interpret because the effects of disturbance are confounded by variations in environmental or habitat factors that are unrelated to disturbance (Cole and Knight 1991, Gutzwiller 1991, Sutherland 2007, Neuman et al. 2008). This is especially problematic for studies on nonbreeding shorebirds because their behavior is sensitive to many factors that are highly dynamic, such as weather, time of day, and tide levels (Burger et al. 1977, Morton 1996, Beauchamp 2006). For example, Morton (1996) found that Sanderling abundance, human activity, and prey densities covaried temporally, probably in response to temperature. Predation risk is a particularly important factor to consider in disturbance studies because many animals respond similarly to human disturbance and predation-risk (Frid and Dill 2002, Peters and Otis 2005, Yasue 2006). Peters and Otis (2005) found that vigilance behaviors in nonbreeding American Oystercatchers (*Haematopus palliatus*) increased with predator numbers, but that human activity levels covaried with changes in predator numbers. Gutzwiller (1991) and others have advocated the use of experimental studies, especially ones that compare control and treatment areas or before and after impact measures, because of their ability to isolate disturbance effects and demonstrate causal relationships (Walters and Holling 1990, Cole and Knight 1991, Gutzwiller 1991, Knight and Cole 1991, Hill et al. 1997, Sutherland 2007). Experiments are generally only affordable or practical at spatial scales that encompass a small fraction of the populations of interest (Gill et al. 2001b, Sutherland 2007), but they may be feasible for site-based studies in refuges, parks, or other places where human activity or other disturbance factors can be manipulated (Gutzwiller 1991).

We used a before-after-control-impact (BACI) study design to determine how vehicle disturbance affects the abundance, distribution, and activity budgets of nonbreeding shorebirds at a fall migration stopover site; South Core Banks, Cape Lookout National Seashore, North Carolina. The study design allowed us to isolate treatment effects (a controlled level of vehicle disturbance) from spatial or temporal differences among our study sites. This separation would not have been feasible using an observational approach.

METHODS

South Core Banks is one of several barriers islands that comprise Cape Lookout National Seashore, North Carolina (Fig. 3.1). Approximately 41 km in length, the ocean beach faces southeast and is relatively straight with homogeneous structure. The remainder of the island faces west and has two distinctive features.

Cape Lookout Point is a 0.31 km southeast facing sand peninsula that is occasionally inundated on high tides, and the Power Squadron Spit is a flat northeast facing peninsula of sand. South Core Banks is a popular fall surf-fishing location and fisherman are allowed to drive on the ocean beach from mile marker 23 to 46, on a back road that runs behind the dune line from mile marker 24 to 44, and on several access ramps that connect the two areas. Segments of beach between ramps are sometimes closed to public traffic to protect sea turtle nests during the summer and early fall. The Power Squadron Spit and a portion of Cape Lookout Point are closed to public vehicles year round to protect nesting and wintering birds. Beach segments are closed by the establishment of rope fences that run from the high tide line to the dunes, and signs that delineate bird and turtle nesting closures. A variety of shorebird species including Sanderlings, Black-bellied Plovers, Willets (*Catoptrophorus semipalmatus*), Red Knots, Ruddy Turnstones, and Piping Plovers (*Charadrius melodus*) use South Core Banks as a migratory stopover site (Chapter 2). Shorebird numbers on the Outer Banks peak between August and November (Dinsmore et al. 1998), and overnight visitor numbers at South Core Banks peak in October (Chapter 2, National Park Service 2007).

We conducted a BACI study (Stewart-Oaten et al. 1986, Stewart-Oaten and Bence 2001) with replication in areas closed to public vehicles where we could manipulate vehicle disturbance levels and measure responses in shorebird distribution, abundance, and behavior. During the periods 9 September - 5 November 2006 and 29 August - 22 October 2007, we sampled paired control and impact plots (n = 17 pairs) for four days, sampling on consecutive days whenever possible. Both the control and impact plots from each pair remained free of vehicle traffic during the first two days of sampling. We then introduced a vehicle disturbance treatment to the impact plot during the third and fourth days of sampling. Differences in shorebird diversity, abundance, and behavior over time between control and impact plots provided estimates of disturbance effects at each pair of plots. The BACI design is useful because it controls for environmental factors that affect both plots equally (i.e. temperature and wind) as well as controlling for habitat variability, such as beach structure, and associated factors, such as prey abundance, that can vary spatially or temporally among plots. This is possible because BACI studies test for relative differences between paired plots over the pre and post-impact periods, rather than simply measuring the absolute differences between pairs of plots, or the absolute changes at impact plots.

Plot locations were distributed throughout the southeast facing beach and were located in areas with shorebird abundance that was indicative of South Core Banks' southeast facing ocean beach (Figs. 3.1 – 3.5). Plot locations were not randomly selected because placement was restricted by sea turtle nest sites and it was only practical to establish closures adjacent to vehicle access ramps. Early in the season we used closures that were established primarily to protect sea turtle nests, but later in the season, as sea turtle nests hatched or failed, we established closures for the exclusive use of our study. This lack of randomization in our selection of experimental units disqualifies our design as a true experiment (Ott and Longnecker 2001), but it did not preclude our ability to conduct an experimental manipulation and make inferences about the effects of a controlled variable (Hurlbert 1984, Williams et al. 2002). Vehicle exclosures were created by routing vehicle traffic to the back-dune road using closure signs and rope barriers that stretched from the dunes to the high tide line. Closures were established at least 24 h prior to sampling and 48 h or more when possible. We placed plots at least 100 m from closure fences to avoid influences from vehicles outside the closures and at least 200 m from each other to avoid influencing the control plot with the disturbance treatment. Observers were unable to see more than 150 m in either direction, even when standing on top of the primary dunes. Therefore, plots were comprised of 300 m long segments of beach that extended from the dune line 100 m into the surf zone. The distance from the dune line to the water's edge ranged from 23 m to 77 m (mean = 49 m, SD = 12 m).

In an analysis of biweekly survey data from Assateague Island National Seashore, Morton (1996) found that negative correlations between Sanderling and vehicle counts were strongest on his small (161 m) plots. This suggests that our plot size was optimal for capturing disturbance effects on Sanderlings. In most cases we randomly assigned plots as control or impact plots, but in six cases plots containing active sea turtle nests were designated control plots to comply with the park's sea turtle management policy of excluding vehicles in the vicinity of active sea turtle nests.

Vehicles and pedestrians were excluded from our sampling areas with a few exceptions. Park staff drove all-terrain vehicles (ATVs) through six of the plot pairs once per day to monitor sea turtle nests, but this occurred outside of our sampling periods. In at least eight instances, we observed vehicles driving through our plots and one of these was at a time when there were no birds present in either plot. In these situations, the vehicles moved straight through both plots without stopping and were, therefore, unlikely to affect the relationship between the plots or our results.

Our experimental vehicle disturbance treatment involved driving an ATV on a variable, winding route through the impact plot at speeds of 15 to 20 mph every 10 min during the sampling period. Drivers made an effort to approach and flush all birds in the plot, but on a few occasions, high lunar tides created wide swash zones and large puddles on the ocean beach. Under these conditions, we were not able to approach all birds in the plot with the ATV. The disturbance treatment was initiated on the plot immediately following the second sampling period, or 22 h before the third sampling period. We attempted to simulate high levels of beach traffic based on an assessment of traffic levels conducted during a pilot field season.

We observed beach traffic at locations where we expected high traffic over two busy weekends corresponding with the beginning of the fall fishing season (23 September 2006) and a fishing tournament (29 and 30 September 2006) for comparison with our disturbance treatment level. We selected mile markers 28, 32, and 43 as sampling locations because we had previously used these sections of beach as study plots, and because we believed they were located in high traffic areas. However, beach survey data show that these dates were not during the weeks with the largest vehicle numbers and that only one observation location, mile 32, was actually in an area with relatively high vehicle traffic (Chapter 2, Figs. 3.6 and 3.7). We recorded the time, type, and location on the beach of each vehicle during a 1 h period at each location each day, which also provided us with the number of moving vehicles and time intervals between them. We completed nine 1 h sampling periods at mile markers 28 and 32 and four sampling periods at mile marker 43 for a total of 22 h and 17 min of observation.

Plot Surveys

We used scan surveys at 20 min intervals to sample bird abundance and distribution in our plots. Observers recorded all birds and assigned them to one of four habitat types within the plot. Habitat categories were defined as: surf which extended from 100 m offshore to the water's edge; swash zone, the area where waves washed onto the beach; wet sand, areas above the water's edge that were still wet from previous tide levels; and dry sand, the area between the upper reaches of the wet sand and the dune line. Black-bellied Plovers, and shorebirds in general, use dry sand microhabitat more at high tide than at low tide on South Core Banks. This shift in microhabitat use is also true for Sanderlings and Willets, although it is not as well defined (Chapter 2). We sampled plots at high or rising tide when we believed birds were most abundant on the ocean beach. The abundance of several shorebird species is greater during high tide than rising tide (Chapter 2). Burger (1984) identified a time of day effect on shorebird behavior, so we attempted to distribute our sampling effort evenly over the sampling periods. High tide sample periods began 2 h before peak tide and ended 4 h later. Rising tide sample periods began at peak low tide and ended 4 h later. With the exception of one plot that was sampled 12 times, every plot was surveyed 13 times per sampling day. In an attempt to minimize observer influences, surveys were performed from the top of a dune at the center of the plot or at the central point on the beach farthest from the waterline that still allowed a full view of the swash zone. On a few occasions, observers had to stand within 10 m of the swash zone in order to see the entire plot. We assume that the detectability for birds in plots was generally 100 percent because we chose plot dimensions based on the distance an observer could see small birds, beach widths were small, and all detections were visual.

Behavioral Observations

We sampled the behavior of randomly selected Sanderlings during the intervals between complete plot surveys. We chose Sanderlings as our focal species because they are common during fall migration (Dinsmore et al. 1998), and they have served as focal species for numerous investigations of wintering and migrating shorebird behavior (Maron and Myers 1985, Burger and Gochfeld 1991b, Dinsmore and Collazo 2003, Thomas et al. 2003). We recorded a focal bird's behavior every 10 s for 1 to 5 min using a stop watch with a repeat timer. Behavior categories recorded included: foraging, roosting, standing, walking, running, flying, preening, bathing, and pursuing conspecifics. As Sanderlings often change behaviors very quickly, and we recorded their behavior at the instant the timer sounded. This meant that birds recorded as running were, in many cases, feeding in the swash zone, but all birds recorded as feeding were actually feeding (i.e. probing, pecking, stabbing, etc.) and not running from an ATV, wave, or another bird. This definition of foraging differs from those used in some studies on disturbance and foraging Sanderlings (Burger and Gochfeld 1991b, Thomas et al. 2003).

Statistical Analysis

Depending on the normality of data, we used modified paired *t*-tests or signed rank tests to examine whether or not there was a significant treatment effect at the $\alpha = .05$ level using SAS 9.1 (SAS Institute, Cary, North Carolina, USA). This was done by averaging values of the response variable from the pre-impact samples and post-impact samples separately for each plot. We then calculated the difference between the change at the impact plot and control plot, to estimate the treatment effect for each pair of plots. This is represented by

$$D_i = (X_{IAi} - X_{IBi}) - (X_{CAi} - X_{CBi})$$

where D_i is the difference between the ith pair control and impact plot (treatment effect), X_{IA} is the average response at the impact plot after the treatment, X_{IB} is the average response at the impact plot before treatment, X_{CA} is the average response at the control plot after the treatment was applied to the impact plot, and X_{CB} is the average response at the control plot before the treatment was added to the impact plot. Calculating the difference in this way eliminates any confounding of treatment with temporal and spatial processes. We used counts from surveys as the response variable when testing for an effect on abundance, the proportion of time sampled individuals spent exhibiting a particular behavior as the response variable for an effect on activity, and the proportion of individuals in a microhabitat as the response variable when testing for an effect on distribution. During the analysis of each behavior, we removed data from pairs of plots that did not have any birds exhibiting a particular behavior during either the before or after period. The paired *t*-tests assume that D_i's are normally distributed and the signed rank tests assume that D_i's are symmetric about the median (Ott and Longnecker 2001). Both tests assume that pairs are independent. All tests on abundance effects were one-tailed, and tests on distribution effects were two-tailed. Tests on behavior effects were one-tailed, except for tests on foraging effects where we used a two-tailed test because of conflicting results from prior studies (Burger and Gochfeld 1991b, Barbee et al. 1994, Morton 1996, Thomas et al. 2003).

RESULTS

We sampled 11 pairs of plots at high tide and 6 pairs during rising tides. Shorebirds were the most abundant group of birds in plots (mean = 9.03, SE = 0.30) followed by gulls (mean = 1.36, SE = 0.23). Terns and waterbirds were present but much less abundant, averaging less than one bird per survey. Sanderlings, Willets, and Black-bellied Plovers were the most abundant shorebirds with Sanderlings (mean = 5.86, SE = 0.25) 3.5 times more abundant than Willets, the next most common shorebird (Fig. 3.8). Other shorebird species observed were American Oystercatcher, Dowitcher sp., Dunlin (*Calidris alpina*), Semipalmated Plover (*Charadrius semipalmatus*), Least Sandpiper (*Calidris minutilla*), Pectoral Sandpiper (*Calidris melanotos*), Piping Plover, Red Knot, Ruddy Turnstone, Semipalmated Sandpiper, Western Sandpiper (*Calidris mauri*), Spotted Sandpiper (*Actitis macularia*), Whimbrel (*Numenius phaeopus*), and Wilson's Plover (*Charadrius wilsonia*). The relative abundance among bird species in our plots was similar to that of the entire ocean beach between miles 23 and 44 (Chapter 2).

Responses to vehicle disturbance varied by species and group. Vehicle disturbance had a significant negative effect on the overall number of birds using experimental plots (one-tailed *t* = -2.89, df = 16, P = 0.0053). The treatment effect (mean = -7.35, SE = 2.54) due to disturbance was 70% of the average from impact plots before the treatment was introduced (Table 3.1). Pairs with an average abundance of ten or more birds in the impact plot pre-impact showed a negative treatment effect. We removed gulls, terns, and waterbirds from our analyses to measure the response of shorebirds to disturbance. We found a negative effect on abundance (mean = -4.83, SE = 2.14, one-tailed *t* = -2.26, df = 16, P = 0.019) that was 58% of the average shorebird abundance at impact plots before treatment (Table 3.1). As with our analysis of all birds combined, plot pairs with an average abundance of ten or more shorebirds in the pre-treatment impact plot showed a negative treatment response. The similarity between analyses of all birds and shorebirds was to be expected because 83% of the birds counted in plots were shorebirds. Sanderlings were the most abundant shorebird in plots. We did not detect a significant effect on their numbers (mean = -1.66, SE = 1.66, one-tailed *t* = -1.50, df = 16, P = 0.077), but all pairs with an average abundance greater than six on impact plots showed a negative treatment response. Willet abundance was not significantly affected by disturbance (mean = -1.00, SE = 0.66, one-tailed *t* = -1.45, df = 13, P = 0.086). We had zero counts at both the impact and control plots of one pair during the pre-impact period and two pairs during the post-impact period, so we excluded these pairs from analysis. Black-bellied Plover abundance was negatively affected by the disturbance treatment with only four of the 12 pairs included in the analysis showing a positive treatment effect (one-tailed S = -29, df = 11, P = 0.011). This treatment effect (mean = -2.34, SE = 1.20) was approximately two times (193%) the average count from impact plots pre-treatment (Table 3.1). However, Black-bellied Plover numbers were generally low and they were not always present on plots. We excluded five plots from analysis because there were none counted during either the before or after periods.

Birds also shifted their microhabitat associations in response to disturbance (Table 3.2). Disturbance decreased the proportion of Black-bellied Plovers using the dry sand (mean effect = -0.32, SE = 0.11, two-tailed *t* = -2.94, df = 8, P = 0.02). It shifted the distribution of Sanderlings, shorebirds, and all birds away from wet sand and into the swash zone. Disturbance increased the proportions of Sanderlings using the swash zone (mean effect = 0.13, SE = 0.047, two-tailed *t* = 2.66, df = 16, P = 0.02) and decreased the proportion using the wet sand (mean effect = -0.10, SE = 0.034, two-tailed t = -2.93, df = 16, P = 0.01). Disturbance increased the proportions of shorebirds and all birds using the swash zone (shorebirds; mean effect = 0.14, SE = 0.048, two-tailed *t* = 2.97, df = 16, P = 0.009; all birds, mean effect = 0.12, SE = 0.05, two-tailed *t* = 2.41, df = 16, P = 0.03) and decreased the proportions using the wet sand (shorebirds; mean effect = -0.10, SE = 0.039, two-tailed *t* = -2.55, df = 16, P = 0.02; all birds, mean effect = -0.16, SE = 0.043, two-tailed *t* = -3.79, df = 16, P = 0.002). We did not find significant treatment effects on the distribution of Willets on our plots.

Sanderling behavior was also affected by vehicle disturbance. We performed 1,977 behavioral observations of Sanderlings, with a mean observation length of 3 min. The average number of observations per plot pair was 116, and we performed between two and fifty-six observations per plot per time period (Table 3.3). Vehicle disturbance had a negative effect on the proportion of time Sanderlings spent roosting (mean effect = -0.082, SE = 0.043, one-tailed *t* = -1.88, df = 14, P = 0.04) and resting (mean effect = -0.071, SE = 0.037, one-tailed *t* = -1.89, df = 16, P = 0.04). Resting was defined as roosting or standing. The means of these treatment effects were 85% (roosting) and 34% (resting) of the average proportion of time spent on the behavior on impact plots during the pre-impact period (roosting; mean = 0.096, SE = 0.022, n = 17 resting; mean = 0.28, SE = 0.033, n = 17). Test statistics from an analysis of time spent foraging were not significant (mean effect = 0.022, SE = 0.031, two-tailed S = 34.5, df = 16, P = 0.11). Disturbance did, however, increase the proportion of time birds spent active, which was defined as any behavior other than roosting or standing (mean effect = 0.07, SE = 0.37, df = 16, P = 0.04). We did not find significant effects on any other behaviors (Table 3.4).

We counted 175 vehicles during traffic observations, and the average number of vehicles (average = 7.95, median = 6.50, SD = 5.86) was higher than our treatment level of 6 vehicles per h. No vehicles passed during one 1 h sampling period, and the maximum number of vehicles during one hour was 22. The average length of time between vehicles was less than our treatment interval length of 10 min (average = 5.15 min, SD = 6.37, minimum = 0 min, maximum = 32 min, median = 2 min, and n = 38 intervals). All vehicles were trucks (49%), ATVs (25%), passenger vehicles (17%), or large campers (8%). Fifty eight percent of the vehicles drove on the dry sand and 42% drove on wet sand.

DISCUSSION

Our results indicate that vehicle disturbance influences the distribution, abundance, and behavior of shorebirds on ocean beaches habitats at migratory stopover sites. The introduction of vehicle disturbance to ocean beach segments decreased the numbers of all birds and shorebirds in experimental plots, decreased their relative use of the wet sand microhabitat, and increased their use of the swash zone. These results concur with Barbee et al.'s (1994) comparison of shorebird numbers on open and closed beaches. Black-bellied Plover abundance decreased in response to disturbance and their use of dry sand habitats decreased. This finding is consistent with our observations that most Black-bellied Plovers roosted on upper beach areas and left the plots altogether when disturbed. Some individuals moved toward the water's edge in response to disturbance, but our results did not indicate displacement into wet sand and swash zone habitats. Black-bellied Plover numbers were rarely large in plots, and they were usually absent when the disturbance treatment was applied. We did not detect any disturbance effects on Willets, but we regularly observed them leaving plots in response to our ATV. We believe that our failure to detect a disturbance effect was due to highly variable counts resulting from the tendency of foraging Willets to flock and move quickly through our plots during both before and after treatment periods.

We did not find a significant effect on Sanderling abundance, but their distribution shifted from the wet sand to the swash zone and they spent less time resting and more time in active behaviors. Our results do not support Morton's (1996) findings that Sanderlings were more abundant in areas without human activity, but agree with his finding that Sanderlings roosted less in areas with disturbance.

We found evidence of intraspecific variation in Sanderlings' responses to disturbance. Although we did not mark individuals, unique patterns of molt allowed us to identify and observe individuals over the course of trials at some experimental plots. This mostly occurred during August and the first part of September when we observed individual Sanderlings defending feeding territories within the plot against small roving flocks of foraging Sanderlings (Myers et al. 1979). After we introduced disturbance, the transient individuals seemed to spend less time in the plot while the territorial birds tolerated the disturbance and maintained their feeding territories. If our observations are correct, then it would follow that measuring an overall treatment effect on abundance would be more likely for transient birds than territorial ones.

Our results concur with Morton and Barbee's conclusion that Sanderlings do not spend less time foraging in response to disturbance. We did, however, frequently see Sanderlings leave roosting sites in the dry and wet sand, move to the swash zone, and begin feeding. This behavior is reflected in our finding that their distribution shifted toward the swash zone and leads us to agree with Morton's (1996) suggestion that foraging is a manifestation of agitation. It is possible that disturbance decreases the time foraging birds spend probing, pecking, and eating (foraging as we defined it), supporting Burger and Gochfeld (1991b) and Thomas et al.'s (2003) work, while increasing the time birds spend in the swash zone foraging.

Although we demonstrated responses of shorebirds to moderate levels of disturbance, it is important to recognize that we are unable to assess the effects of these responses on individuals and populations. The connection between behavior and population level responses has rarely been demonstrated (Hill et al. 1997). Interpreting behavioral responses in terms of the costs to individuals or populations is problematic because an individual's decisions about how to respond to disturbance stimuli and their consequences depend on the context of current resources, body condition, and risks (Gill et al. 2001b, Gill 2007). Behavioral responses are not good indicators of impacts on fitness for this reason. For example, in a food supplementation experiment, Beale and Monaghan (2004) showed that Ruddy Turnstones' responses to disturbance were influenced by their body condition and birds in better condition responded more to disturbance than birds in poor condition. Bouton et al. (2005) found that Wood Storks' (*Mycteria americana*) reproductive success was negatively influenced by boat disturbance despite the lack of a noticeable behavioral response.

Changes in abundance and distribution are not reliable measures of fitness consequences either. Disturbance may influence the distribution of birds among or within habitats but not affect the numbers of individuals that a site can support because birds may compensate for habitat deterioration in one area by using other areas more heavily or returning when disturbance declines, for example by foraging at night (Burger and Gochfeld 1991b, Morton 1996, Gill et al. 2001a, Smart and Gill 2003). Similarly, interspecific variation in responses to disturbance may merely be a result of different spatial and temporal patterns of habitat use. Species that use ocean beach as well as sound-side habitat may be more likely to leave in response to disturbance than species that exist exclusively in the disturbed habitat. Our results support such a relationship because we observed gulls, terns, and Black-bellied Plovers in large numbers on sound-side beaches and sand flats but Willets and Sanderlings appeared most abundant on the ocean beach. Studies that use measures of resource use, refueling rates, body condition, or physiological stress, rather than behavior would be better for assessing disturbance impacts on individual fitness (Beale and Monaghan 2004, Lyons et al. 2008).

Assessment of the BACI study design

We believe that our study illustrates the practicality and value of BACI study designs to measure the response of wildlife to disturbance or other treatment effects when simultaneously sampling or applying a treatment to numerous replicate study sites is not feasible. One particularly useful feature of the BACI design for studies involving shorebirds is its ability to handle the dynamic environmental conditions characteristic of coastal habitats. Using control and impact plots with before and after periods allowed us to measure disturbance effects over days with different weather conditions and at sites that were similar but not identical. This design can also handle environmental conditions that affect sampling, as long as they affect both plots identically. For example, strong winds and changes in local beach topography occasionally limited visibility at some of our paired plots, but we were able to include data from these plots because the conditions were similar at both plots and we do not think they affected the relationship between them.

A common challenge when designing field experiments is to choose a treatment level that can be standardized and is heavy enough to test hypotheses while still being similar to actual levels in the system of interest (Gutzwiller 1991). Researchers could, therefore, benefit greatly from pilot studies that measure the natural patterns and levels of treatment factors and from careful selection of a treatment level. We were unable to simulate vehicle traffic patterns from unrestricted areas because they are irregular, and it was important that our treatment be standardized among treatment plots. Actual traffic levels on the National Seashore consist of a variety of vehicle types (ATV, recreational vehicle, pickup truck etc.) driven at variable frequencies and speeds, primarily in the dry sand. Our treatment was consistent, frequent, spanned all beach microhabitats, and almost always resulted in birds flushing. Our findings identify a disturbance level at which we know disturbance influences shorebirds' utilization of ocean beach habitat but it is not an assessment of the effects of actual traffic levels.

Selecting an appropriate distance between paired control and impact plots is a critical issue to consider when designing a BACI study, because plots need to be close enough together that they are similar in terms of environmental conditions and habitat characteristics (e.g. wind, prey density, predator levels) but far enough apart that they are independent in terms of the treatment effect. Plots that are too close together will violate the central assumption that the change in the relationship between the plots is a result of the treatment, and plots that are too far apart will compromise the study's ability to separate the treatment effect from responses to changes in environmental conditions. Pilot studies that assess how far treatment effects persist in space and time should be used to identify an appropriate distance between plots. We chose a between-pair distance of 200 - 300 m based on informal observations of how far birds flew when flushed and Thomas et al.'s (2003) description of minimal approach distances for nonbreeding Sanderlings (30 m), but we were often constrained by the length of beach closures. Morton reported mean flush distances in nonbreeding Sanderlings of 17.8 m and 10.8 m for pedestrians and vehicles, respectively. Despite the seemingly large distance between our plots, we observed occasional interactions between birds on treatment and control plots. On a few occasions, large flocks of Willets or Sanderlings were observed occupying both treatment and control plots simultaneously. This meant that when birds were disturbed part of the flock on the impact plot, a chain reaction occurred that eventually caused birds to leave both treatment and control plots. On several other occasions foraging birds were flushed from the impact plot into the control plot. While these cases violated the assumption that paired plots were independent, we do not believe they compromised our results because they were infrequent, and they could have resulted in increases or decreases in the number of birds on control plots.

BACI studies that are designed to measure the effects of disturbance on abundance should distribute sampling units in a way that maximizes the initial abundance of animals. In our study, plots with low abundance showed greater variation and smaller treatment effects than plots with high abundance, and all plots with high abundance showed a negative treatment effect. We believe that this is a result of greater opportunities to measure treatment effects when there are more individuals on plots. Another benefit of using plots with high before-treatment abundance is that statistical tests could be used that test hypotheses about the percent change in response to disturbance rather than just the response itself, which would address biological significance more directly than comparing treatment effects to before-treatment abundance as we have done. Such an approach would be accomplished by adding X_{IBi} to the denominator when calculating D_i's to give a new variable

$$D_i^* = \frac{(X_{IAi} - X_{IBi}) - (X_{CAi} - X_{CBi})}{X_{IBi}}$$

Using this method with small or variable before-treatment abundance would result in extreme and excessively variable D_i values and that is why it was not used here.

Finally, we recommend the use of blinds in disturbance studies because we observed that most birds avoided areas in the immediate proximity (approximately <10 m) of observers. The distance maintained by most individuals was shorter than the distance to the plot edge, so we don't think it influenced our abundance estimates. However, many American Oystercatchers, Brown Pelicans (*Pelecanus occidentalis*), and Double-crested Cormorants (*Phalacrocorax auritus*) were seen roosting on the beach outside of our plots and they often flushed at distances greater than 150 m, effectively excluding them from our study.

The BACI design allowed us to identify disturbance effects on nonbreeding shorebirds at a migration stopover site, which is a highly variable system with many environmental and habitat factors that often covary. These effects were short-term and difficult to relate to population level consequences, but the BACI design may also be useful for studies that seek to identify disturbance effects on breeding birds, which are more directly related to population sizes and individual fitness. We believe that it could be especially useful for studies of disturbance effects on parental and chick behaviors because disturbance effects would likely be measurable immediately, and other experimental designs would be difficult to use because of logistical difficulties associated with measuring behavior and applying a disturbance treatment to multiple sites at once.

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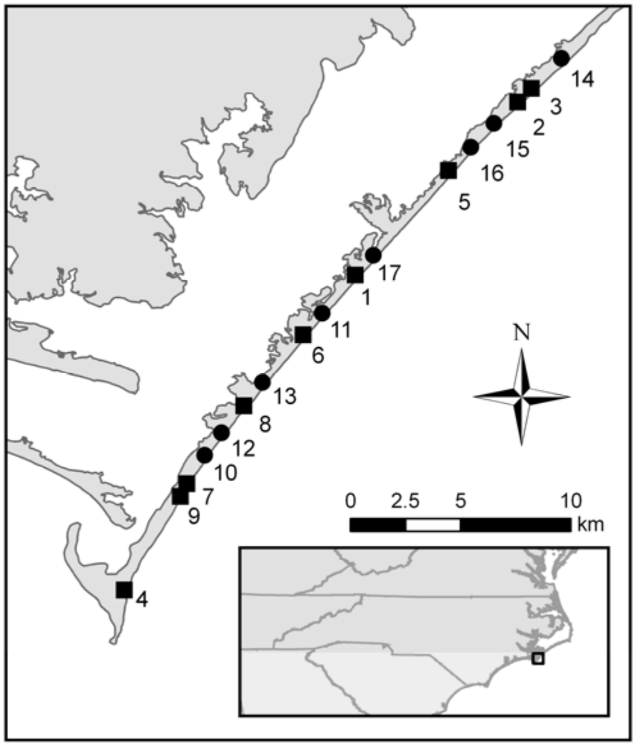

Figure 3.1. Study sites at South Core Banks, Cape Lookout National Seashore, on North Carolina's Outer Banks. Each square represents a pair of plots used in fall 2006 (n = 9) and each circle represents a pair used in fall 2007 (n = 8). Pairs are numbered in the order they were used.

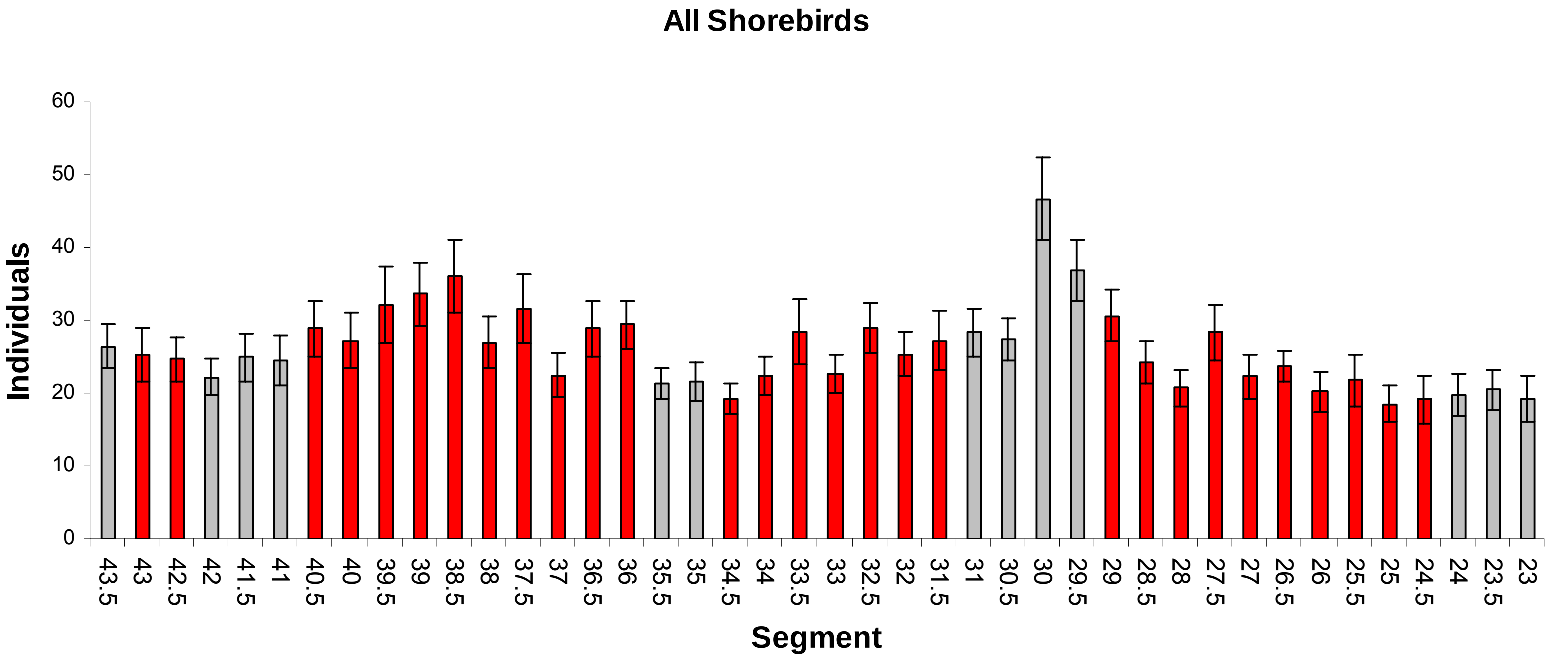

Figure 3.2. Average shorebird abundance at beach segments where we placed study plots. Segments that were used in our study are red and those that were not used, but that had beach structure similar to that of our plots, are grey. Segment numbers correspond with their position in the CALO mile marker system, in which mile numbers increase from north to south.

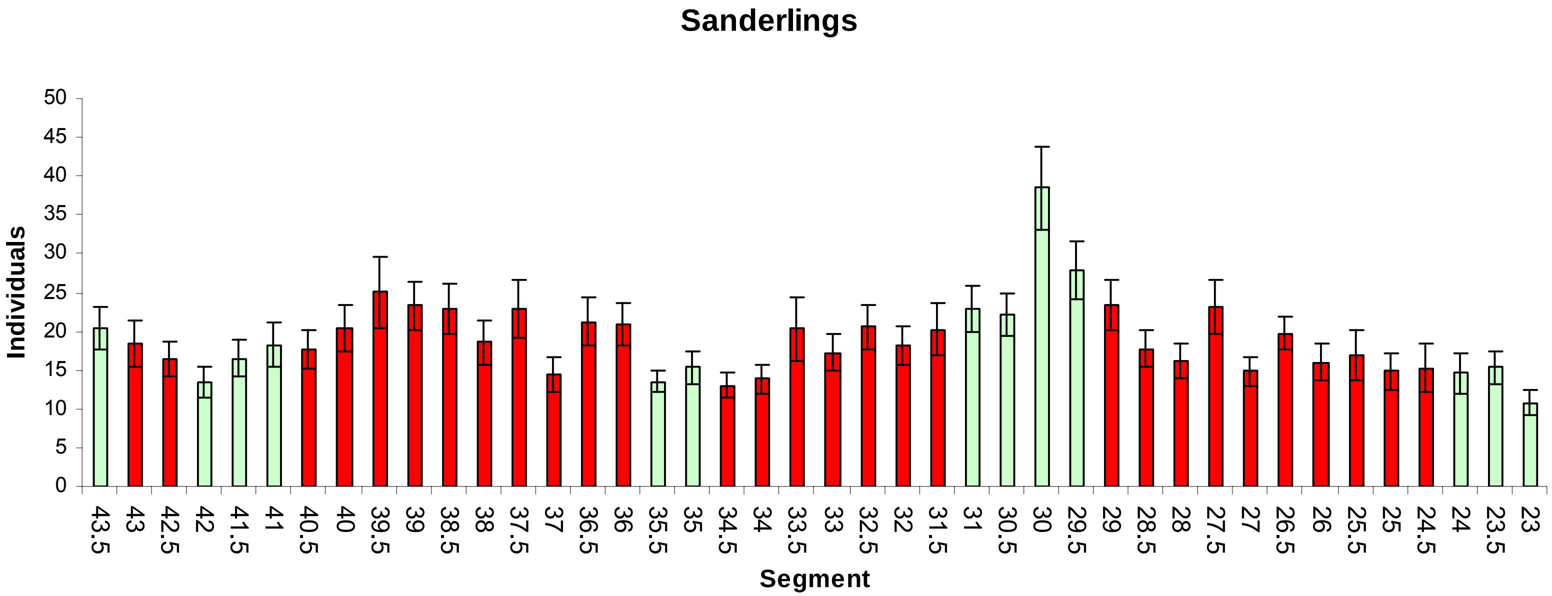

Figure 3.3. Average Sanderling abundance at beach segments where we placed study plots. Segments that were used in our study are red and those that were not used, but that had beach structure similar to that of our plots, are blue-green. Segment numbers correspond with their position in the CALO mile marker system, in which mile numbers increase from north to south.

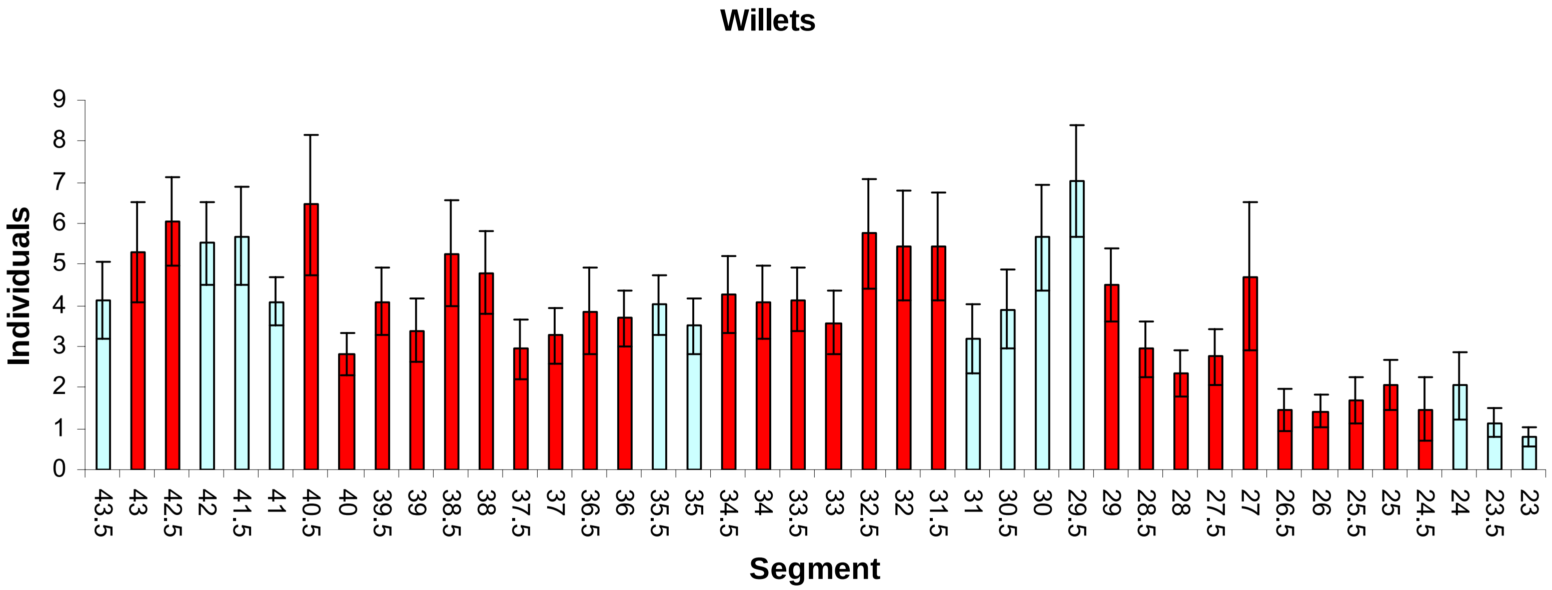

Figure 3.4. Average Willet abundance at beach segments where we placed study plots. Segments that were used in our study are red and those that were not used, but that had beach structure similar to that of our plots, are blue. Segment numbers correspond with their position in the CALO mile marker system, in which mile numbers increase from north to south.

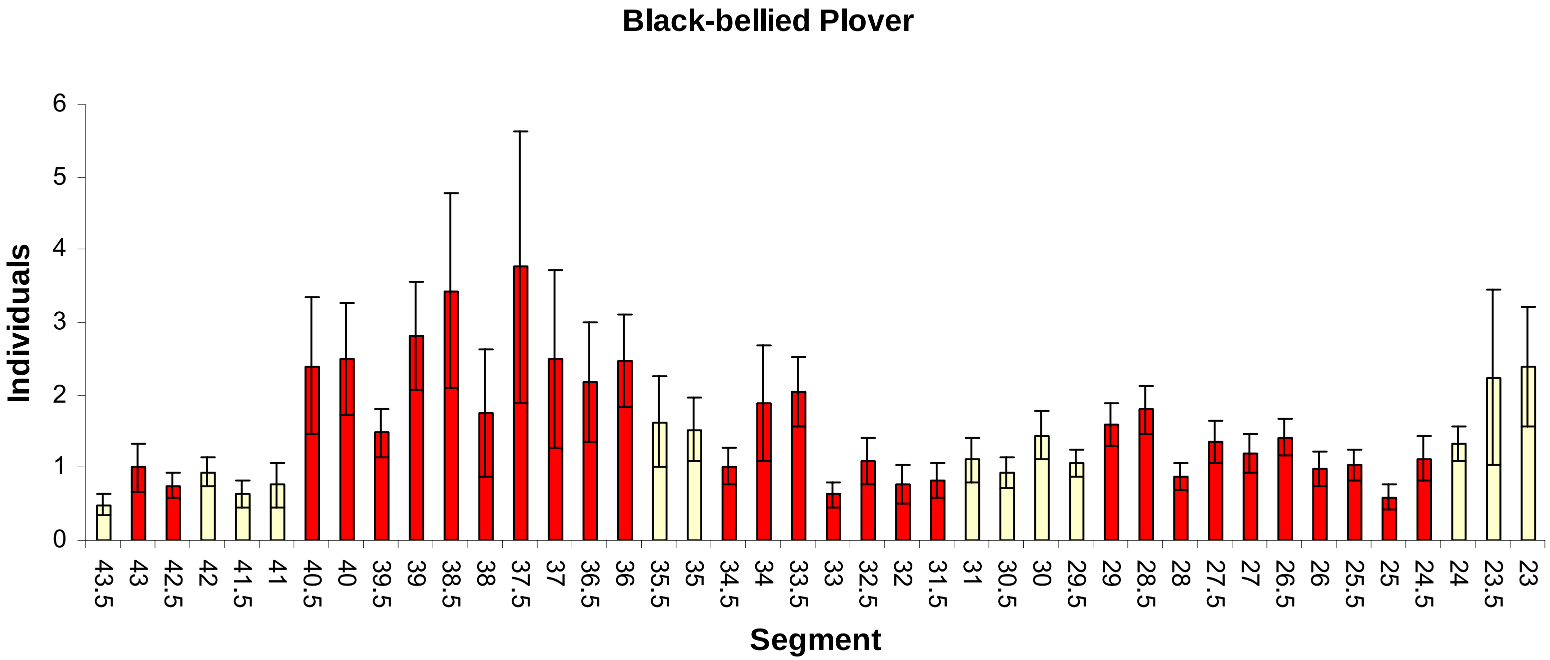

Figure 3.5. Average Black-bellied Plover abundance at beach segments where we placed study plots. Segments that were used in our study are red and those that were not used, but that had beach structure similar to that of our plots, are light yellow. Segment numbers correspond with their position in the CALO mile marker system, in which mile numbers increase from north to south.

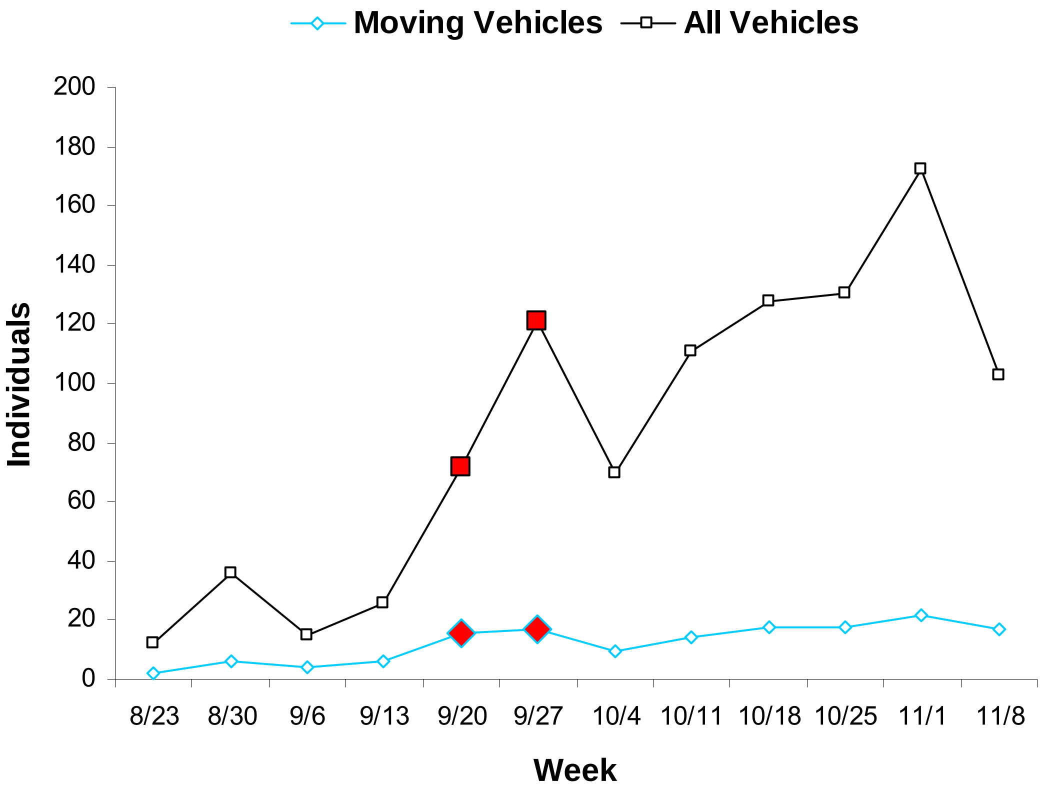

Figure 3.6. Indices of total vehicle and moving vehicle abundance on the ocean beach of South Core Banks for 12 weeks during the fall. Weeks when we performed traffic observations are highlighted with large, red marks. We calculated abundance indices by summing the means of surveys from all beach segments for each week (Chapter 2). We named weeks after their first day (month/day).

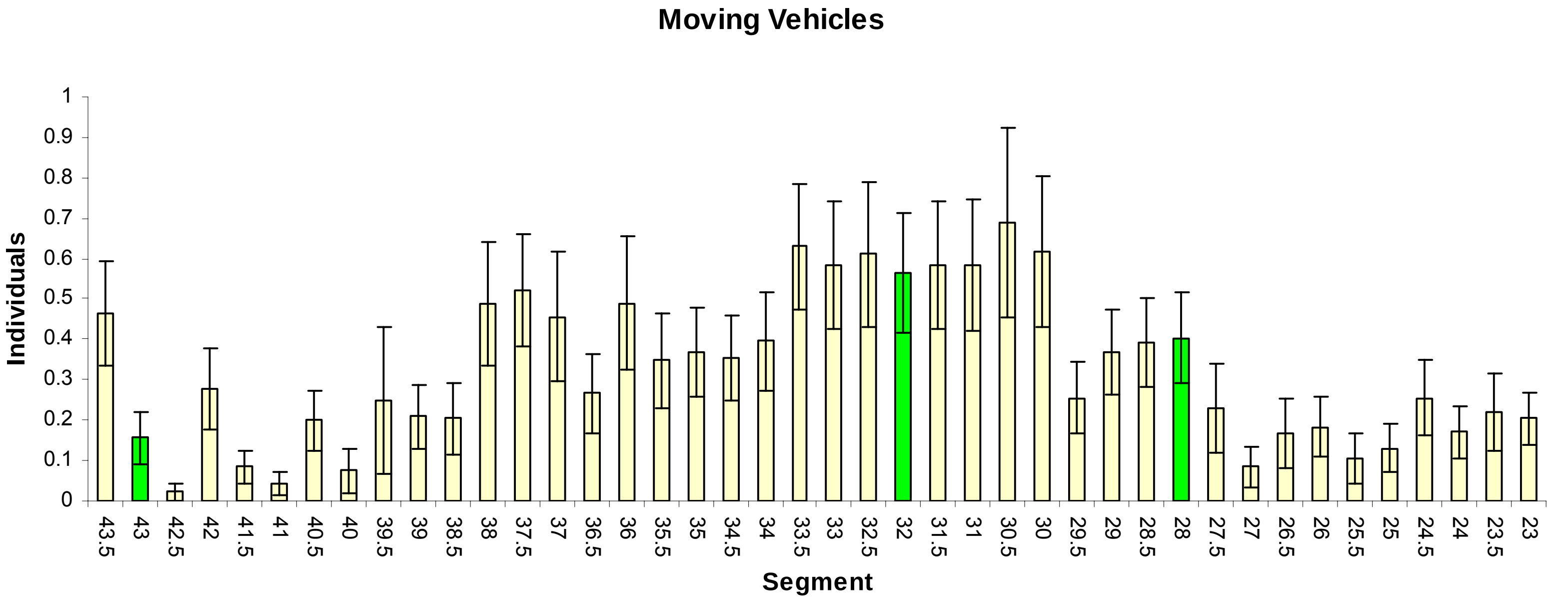

Figure 3.7. Average moving vehicle numbers at beach segments on the southeast facing ocean beach of South Core Banks. We recorded moving vehicle abundance at every segment during surveys (Chapter 2) and recorded the frequency of vehicle passes during traffic observations at three locations. Segments where we performed traffic observations are green and all other segments are beige. Error bars show one standard error, and segment numbers correspond with their position in the CALO mile marker system, in which mile numbers increase from north to south.

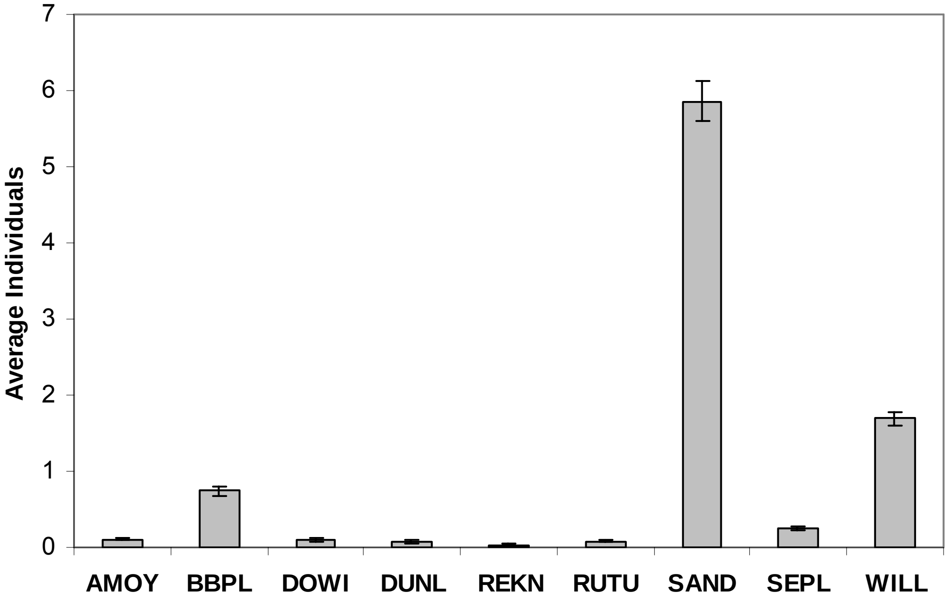

Figure 3.8. Average count of American Oystercatcher (AMOY), Black-bellied Plover (BBPL), Dowitcher species (DOWI), Dunlin (DUNL), Red Knot (REKN), Ruddy Turnstone (RUTU), Sanderling (SAND), Semipalmated Plover (SEPL), and Willet (WILL) during plot surveys (n = 1760). Error bars represent one standard error.

Table 3.1. Average disturbance effect on the numbers of all birds, shorebirds, Sanderlings, Willets, and Black-bellied Plovers with the average abundance at impact plots in the before-treatment period for comparison. All tests for significance were one-tailed.

	Disturbance Effect					Impact, Before	
	mean	SE	Test statistic	df	P	mean	SE
All birds	-7.35	2.54	*t* = -2.89	16	0.01*	10.50	2.04
Shorebirds	-4.83	2.14	*t* = -2.26	16	0.02*	8.38	1.92
Sanderlings	-1.66	1.11	*t* = -1.50	16	0.08	4.52	0.55
Willets	-1.00	0.66	*t* = -1.45	13	0.09	2.35	0.94
Black-bellied Plovers	-2.34	1.20	S = -29	11	0.01*	1.21	0.19

*P<0.05

Table 3.2. Average effects of ATV disturbance treatment on the proportion of all birds, shorebirds, Sanderlings, and Black-bellied Plovers in beach microhabitats. Averages from impact plots during the before-treatment period are shown for comparison. All tests for significance were two-tailed.

	Disturbance Effect					Impact, Before	
	Mean	SE	Test statistic	df	P	mean	SE
All birds							
Swash zone	0.12	0.05	*t* = 2.41	16	0.03*	0.52	0.04
Wet sand	-0.16	0.04	*t* = -3.79	16	<0.01*	0.27	0.03
Dry sand	-0.03	0.04	*t* = -.70	16	0.49	0.13	0.04
Surf	0.07	0.04	S = 31	16	0.12	0.08	0.03
Shorebirds							
Swash zone	0.14	0.05	*t* = 2.97	16	0.01*	0.61	0.05
Wet sand	-0.10	0.04	*t* = -2.55	16	0.02*	0.26	0.03
Dry sand	-0.04	0.05	*t* = -0.86	16	0.40	0.13	0.04
Sanderlings							
Swash zone	0.13	0.05	*t* = 2.66	16	0.02*	0.70	0.05
Wet sand	-0.10	0.03	*t* = -2.93	16	0.01*	0.23	0.04
Dry sand	-0.02	0.03	*t* = -0.68	16	0.51	0.07	0.02
Black-bellied Plovers							
Swash zone	0.02	0.12	*t* = 0.15	8	0.88	0.20	0.10
Wet sand	0.30	0.17	*t* = 1.77	8	0.12	0.42	0.11
Dry Sand	-0.32	0.11	*t* = -2.94	8	0.02*	0.37	0.11

*P<0.05

Table 3.3. Number of Sanderling behavioral observations at each plot during before and after-treatment time periods.

	Before Treatment		After Treatment		
Pair	Control Plot	Impact Plot	Control Plot	Impact Plot	Total
A	30	31	31	25	117
B	10	25	26	31	92
C	18	15	13	7	53
D	18	19	20	13	70
E	32	18	10	16	76
F	2	2	15	33	52
G	13	18	44	54	129
H	27	33	35	30	125
I	24	14	48	50	136
J	47	44	51	21	163
K	33	35	38	53	159
L	56	27	54	38	175
M	51	24	24	22	121
N	26	18	48	33	125
O	18	23	17	19	77
P	33	30	45	31	139
Q	35	41	52	40	168
Mean	28	25	34	30	116

Table 3.4. The average effect of the ATV disturbance treatment on the proportion of time Sanderlings spent on each behavior and tests for significance. One-tailed, paired *t* or signed-rank tests were used for all analyses except for foraging. We defined resting as the proportion of time spent roosting or standing and defined active as the proportion of time spent foraging, walking, running, flying, bathing, preening, or pursuing.

	Disturbance Effect					Impact, Before	
	mean	SE	Test statistic	df	P	mean	SE
Resting	-0.07	0.04	*t* = -1.89	16	0.04*	0.21	0.03
Roosting	-0.08	0.04	*t* = -1.88	14	0.04*	0.10	0.02
Standing	0.00	0.03	*t* = 0.19	16	0.43	0.13	0.01
Active	0.07	0.04	*t* = 1.87	16	0.04*	0.79	0.03
Foraging	0.02	0.03	S = 34.5	16	0.11	0.38	0.04
Walking	0.00	0.03	*t* = 0.14	16	0.45	0.15	0.02
Running	0.01	0.02	*t* = 0.41	16	0.34	0.17	0.02
Flying	0.02	0.01	*t* = 1.52	15	0.07	0.02	0.00
Bathing	-0.00	0.00	S = -7.5	9	0.25	0.00	0.00
Preening	0.02	0.03	S = 5.5	16	0.41	0.07	0.01
Pursuing	-0.00	0.00	S = -1	5	0.48	0.01	0.00

*P<0.05