

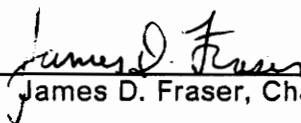
**PIPING PLOVER BREEDING BIOLOGY, FORAGING ECOLOGY AND
BEHAVIOR ON ASSATEAGUE ISLAND NATIONAL SEASHORE, MARYLAND**

by

John P. Loegering

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Master of Science
in
Fisheries and Wildlife Sciences

APPROVED:


James D. Fraser, Chairman


Roy L. Kirkpatrick


Curtis S. Adkisson

March, 1992

Blacksburg, Virginia

LD
5655
V855
1992
L633
c.2

**PIPING PLOVER BREEDING BIOLOGY, FORAGING ECOLOGY AND
BEHAVIOR ON ASSATEAGUE ISLAND NATIONAL SEASHORE, MARYLAND**

by

John P. Loegering

James D. Fraser, Chairman

Fisheries and Wildlife Sciences

(ABSTRACT)

We studied piping plovers (*Charadrius melodus* Ord) on Assateague Island National Seashore, Maryland, during the 1988-1990 breeding seasons. The estimated breeding population declined from 25 pairs in 1988 to 14 pairs in 1990. Nest predation by red foxes (*Vulpes vulpes*) was high. Predator exclosures constructed around individual nests did not increase nest survival. Chick survival was higher in bay beach and island interior brood-rearing habitats than on the ocean beach. Our evidence supports the hypothesis that the availability of adequate food is driving the differences in survival observed among brood-rearing habitats. Chicks raised on the bay beach or island interior weighed more, had higher foraging rates, and spent a greater proportion of their time foraging than chicks reared on the ocean beach. Indices of invertebrate prey abundance indicated that insects were more abundant on the bay beach and island interior than on the ocean beach. Disturbance did not differ among brood-rearing habitats. Human disturbance was higher in 1990 than in previous years. Overall productivity was 0.71 chicks fledged/breeding pair, well below our estimate of the productivity needed to deter a population decline. Management efforts should focus on reducing nest predation and maintaining overwash access paths to high quality brood-rearing habitat.

Acknowledgements

I am profoundly grateful to my advisor, James Fraser, for his advice, assistance, and friendship. I will always carry the sense of professionalism and dedication that he displayed and represented. I feel fortunate to have been able to work with an advisor who excelled as both mentor and friend. I would also like to thank committee members Drs. Roy Kirkpatrick, whose commitment to good science and fine art is appreciated, and Curtis Adkisson. Their many helpful comments greatly improved this study.

I thank the many people who assisted me in the field. Arlene Blumton, Kathleen and Mike Finnegan, and Susie Mersmann began field work in 1988, before I arrived. Laura Weber-Peacock, Kathy Anderson, Susie Leslie, and Lisa Loegering are commended for cheerfully facing early wake-up calls, long days, scorching heat, dehydration, and the nearly unbearable flies and mosquitoes.

A special thanks goes to the personnel of Assateague Island National Seashore who provided us with housing and over-sand transportation. We greatly appreciated the efforts of Gordon Olson, Jack Kumer, Elaine Furbish, Gary Ludwig, Jeff Chynoweth, the law enforcement staff, and the many others who assisted with many aspects of the field research.

I also would like to thank L. Weber, Renee Speenburgh, Brian Clark, and L. Loegering for processing the many invertebrate samples. Their patience spared me this tedious task, for which I am grateful.

I am thankful that L. Loegering did the majority of the data entry. Her accuracy proved to be head and shoulders above all others. I also thank K. Anderson for volunteering for this less-than-enjoyable experience.

I gratefully thank J. McConnaughey, S. Coutu-Wrenn, S. Haig, and M. Brown who sighted color-banded birds and passed the locations on to me.

I would like to thank the National Park Service, especially Paul Buckley and John Karish, and the Chesapeake Bay and Endangered Species Fund of the Maryland Department of Natural Resources, Natural Heritage Division and Rodney Bartgis for providing financial support for this project.

I feel fortunate to have had the opportunity to know the faculty at Virginia Tech. I found our conversations stimulating and helpful.

I also thank the many fellow graduate students who kept me laughing through it all. Special thanks go to the members of the 1988 cohort, especially officemates Eric Schrading, Marty O'Connell, Kelly Meyer, and Steven Sumithran. Fridays and defenses will never be the same.

I am also indebted to M. Patterson. This study was based on his findings and he played a substantial role in its initiation. Thank you.

I would also like to thank Drs. G. Allen and M. Ryan for my first taste of field experience. They sparked an interest that has continued to consume me. I also recognize the many individuals who have contributed to my development, especially Drs. W. Bleier, M. Butler, G. Clamby, J. Grier, and G. Nuechterlein.

My deepest thanks go to my father, who instilled in me the importance of education and value in sharing that knowledge with others.

Finally, I am grateful for the love and encouragement of Lisa Loegering. In addition to being involved in nearly every aspect of the project, she has been at my side and always there when I needed her. I couldn't imagine doing it without her.

Table of Contents

INTRODUCTION 1

OBJECTIVES 3

STUDY AREA 3

 Human Activity 4

 Tides 5

 Methods for Location Assignment 6

 Weather 6

Chapter 1. SURVEYS OF FORAGING HABITAT BEFORE NESTING 8

METHODS 9

RESULTS 12

 Habitat Selection 12

 Detection and Reaction Distances 14

DISCUSSION 15

 Habitat Selection 15

 Detection and Reaction Distances 16

 Biases and Observer Effort 17

SUMMARY 19

Chapter 2. PIPING PLOVER BREEDING BIOLOGY 20

METHODS 22

Nest Searches 22

 Predator Exclosures 24

 Flush Distances 26

Estimating Nest Success 27

Chick Survival 28

RESULTS 29

Population Estimate 29

 Flush Distances 29

Nest Success 30

 Predator Exclosures 31

Chick Survival 32

 Reproductive Success 32

DISCUSSION 34

 Flush Distances 36

Nest Success 40

 Predation 43

 Predator Exclosures 48

 Fox depredation of exclosed nests 51

Chick Survival 55

 Chick Weight, Survival, and Energy Demands 56

 Reproductive Success 58

SUMMARY 61

Chapter 3. COMPARING BROOD FORAGING HABITAT 62

METHODS 64

Determining Brood Foraging Habitat 64

Behavioral Observations 65

 Foraging Behavior 65

 Time Budgets 67

Prey Sampling 67

 Terrestrial Arthropods 68

Substrate Invertebrates	69
Monitoring Human Use and Predator Abundance	70
Disturbance-predation Transects	70
RESULTS	72
Brood Movements	72
Behavioral Observations	72
Foraging Behavior	72
Time Budgets	74
Disturbance and Foraging Observations	74
Disturbance and Time Budgets	75
Human disturbance	75
Disturbance during behavioral observations	76
Behavioral Observations	77
Relative Prey Abundance	80
Terrestrial Arthropods	80
Substrate Invertebrates	81
Monitoring Human Use and Predator Abundance	82
Disturbance-predation Transects	83
DISCUSSION	85
Behavioral Observations	85
Foraging Behavior	85
Time Budgets	90
Disturbance	92
Disturbance and Behavioral Observations	92
Human disturbance	93
Human Use and Disturbance	95
Invertebrate Prey	95
Monitoring Human Use and Predator Abundance	97

Disturbance-predation Transects	97
SUMMARY	99
 Chapter 4. SURVIVAL AND POPULATION MODELS	100
METHODS	101
Survival Rates	101
Population Model	103
RESULTS	104
Survival Rates	104
Population Model	104
DISCUSSION	106
Survival Rates	106
Population Model	108
SUMMARY	110
 CONCLUSIONS	111
Factors Limiting Productivity	111
The Importance of Natural Storm Events	113
 MANAGEMENT RECOMMENDATIONS	114
Maintain Overwash Paths	114
Monitor Human Activity	115
Reduce Nest Predation	116
Predator Exclosures as a Management Tool	117
 LITERATURE CITED	119
TABLES	132

FIGURES	194
Appendix A. Methods for Location Assignment	208
Appendix B. Long vs. short behavioral observations.	210
Appendix C. Behavioral observation biases	212
Appendix D. Effects of disturbance source on behavioral observations	214
Appendix E. Piping plovers banded on AINS	223
Appendix F. Piping plover breeding histories	228
Appendix G. Scientific names of selected species	235
Appendix H. Piping Plover Morphometrics	237
METHODS	237
RESULTS	240
DISCUSSION	241
Appendix I. Piping Plover Leg Injuries	243
DISCUSSION	244
Appendix J. Migration and Winter Sightings	246
DISCUSSION	246
Vita	248

List of Tables

Table 1. Definitions of terms used.	133
Table 2. Habitat type codes used in location identification on Assateague Island National Seashore.	135
Table 3. Climatological data for April - August, 1988-1990 on Assateague Island National Seashore.	136
Table 4. The number of piping plovers observed in different habitat types during foraging habitat surveys on Assateague Island National Seashore, Maryland, 1990.	137
Table 5. Observer effort and piping plovers observed during foraging habitat surveys on Assateague Island National Seashore.	138
Table 6. Number of piping plovers observed during foraging habitat surveys on the northern 8 km of Assateague Island National Seashore.	140
Table 7. Number of piping plovers observed at three times of day during foraging habitat surveys on the northern 8 km of Assateague Island National Seashore.	141
Table 8. Number of piping plovers observed at mid-tide rising and midtide falling during foraging habitat surveys on Assateague Island National Seashore.	142
Table 9. Distances at which piping plovers were detected and reacted to an observer's approach during foraging habitat surveys on Assateague Island National Seashore.	143
Table 10. General statistics for piping plovers on Assateague Island National Seashore, 1972-1990.	144
Table 11. Observer effort while searching for piping plover nests on Assateague Island National Seashore.	145
Table 12. Distances at which piping plovers flushed from their nest as an observer approached on Assateague Island National Seashore.	146
Table 13. Fate of 81 piping plover nests on Assateague Island National Seashore, 1988-1990.	147
Table 14. Fate of 284 eggs from 81 piping plover nests on Assateague Island National Seashore, 1988-1990.	148
Table 15. Cause of loss for 124 piping plover eggs with identifiable causes on Assateague Island National Seashore, 1988-1990.	149

Table 16. Clutch size of 68 complete piping plover clutches on Assateague Island National Seashore, 1988-1990.	150
Table 17. Characteristics of piping plover nest sites on Assateague Island National Seashore, 1988-1990.	151
Table 18. Daily survival rates of piping plover nests on Assateague Island National Seashore, 1988-1990.	152
Table 19. Daily survival rates of piping plover nests with and without predator exclosures on Assateague Island National Seashore, 1988-1990.	153
Table 20. Predator exclosure construction times and return times for adults resuming incubation on Assateague Island National Seashore, 1988-1990.	154
Table 21. Daily survival rates of piping plover chicks on Assateague Island National Seashore, 1988-1990.	155
Table 22. Mass of piping plover chicks 4-5 days old reared in different habitats on Assateague Island National Seashore, 1988-1990.	156
Table 23. Morphometric measurements of piping plovers chicks 4-5 days old surviving to fledging and those that did not on Assateague Island National Seashore, 1988-1990.	157
Table 24. Chick survival in different brood-rearing habitats on Assateague Island National Seashore, 1988-1990.	158
Table 25. Piping plover behaviors used in the analysis on Assateague Island National Seashore, 1988-1990.	159
Table 26. Distance from the nest that piping plover broods moved following hatching on Assateague Island National Seashore, 1988-1990.	160
Table 27. Foraging rates (attempts/minute) of piping plover chicks and adults on Assateague Island National Seashore, 1988-1990.	161
Table 28. Different foraging attempts used by piping plovers to capture prey on Assateague Island National Seashore, 1988-1990.	162
Table 29. Mean time (%) spent in various behavioral categories in different habitats by piping plovers on Assateague Island National Seashore, 1988-1990.	163
Table 30. Total foraging rates (attempts/minute) of disturbed and undisturbed piping plover chicks and adults on Assateague Island National Seashore, 1988-1990.	164

Table 31. Mean time (%) spent engaged in different behaviors in disturbed and undisturbed piping plovers on Assateague Island National Seashore, 1988-1990.	165
Table 32. Total foraging rates (attempts/minute) of human disturbed and undisturbed piping plovers on Assateague Island National Seashore, 1988-1990.	167
Table 33. Mean time (%) engaged in different behaviors of undisturbed and human disturbed piping plovers on Assateague Island National Seashore, 1988-1990.	168
Table 34. Mean time (%) disturbed during behavioral observations that differed among years on Assateague Island National Seashore, 1988-1990. ...	170
Table 35. Sources of disturbance during behavioral observations on Assateague Island National Seashore, 1988-1990.	171
Table 36. Proportion of time (%) piping plovers were disturbed by various sources during behavioral observations on Assateague Island National Seashore, 1988-1990.	172
Table 37. Arthropod abundance indices on Assateague Island National Seashore, 1988-1990.	173
Table 38. Composition of terrestrial arthropod samples on Assateague Island National Seashore, 1988-1990.	174
Table 39. Sweep net insect counts on Assateague Island National Seashore, 1988-1990.	175
Table 40. Substrate invertebrates on Assateague Island National Seashore, 1988-1990.	176
Table 41. Ocean beach substrate invertebrates taken from the wet and saturated intertidal zone on Assateague Island National Seashore, 1988-1990. ..	180
Table 42. Animal trails from random and brood-rearing territory transects on Assateague Island National Seashore, 1988-1990.	181
Table 43. Animal trails differing between random and brood-rearing territory transects on Assateague Island National Seashore, 1988-1990.	182
Table 44. Number of piping plovers banded on Assateague Island National Seashore, Maryland, 1987-1989 and resighted the following year. ...	183
Table 45. Input variables and values used for population modeling of plovers on Assateague Island National Seashore.	184
Table 46. Survival estimates for piping plovers banded on Assateague Island National Seashore, 1988-1990.	185

Table 47. Piping plovers color-banded on Assateague Island National Seashore, 1987-1990 and sighted elsewhere.	186
Table 48. Reproductive success necessary to maintain stationary piping plover populations on Assateague Island National Seashore.	187
Table 49. Annual piping plover survival estimates based on resightings.	188
Table 50. Color band combinations of piping plovers sighted on Assateague Island National Seashore, 1988-1990, but banded elsewhere.	189
Table 51. Morphometric measurements of adult piping plovers on Assateague Island National Seashore, 1988-1990.	190
Table 52. Categorical data collected while banding adult piping plovers on Assateague Island National Seashore, 1988-1990.	191
Table 53. Morphometric measurements of piping plovers chicks 4-5 days old on Assateague Island National Seashore, 1988-1990.	192
Table 54. Injured piping plovers observed on Assateague Island National Seashore, 1988-1990.	193

List of Illustrations

Figure 1.	Piping plover nesting areas and types of recreational access on Assateague Island.	195
Figure 2.	Northern 8 km of Assateague Island National Seashore.	196
Figure 3.	Habitat units used for location assignment on Assateague Island National Seashore.	197
Figure 4.	Distances (m) of human tracks we observed when we approached active piping plover nests.	198
Figure 5.	Distances (m) that we observed humans from active piping plover nests during nest checks.	199
Figure 6.	Daily piping plover chick loss on Assateague Island National Seashore.	200
Figure 7.	Conceptual model relating the time required to elicit flushing and the distance between human and plover.	201
Figure 8.	Foraging rate of 3-10 day-old piping plover chicks on the bay beach, island interior, and ocean beach.	202
Figure 9.	Arthropods captured, by date, on the bay beach, island interior, and ocean beach.	203
Figure 10.	Arthropods captured at different tidal levels on the bay beach, island interior, and ocean beach.	204
Figure 11.	Human contacts with piping plover broods on Assateague Island National Seashore, Maryland, 1988-1990.	205
Figure 12.	Human contacts within 5 m of piping plover broods on Assateague Island National Seashore, Maryland, 1988-1990.	206
Figure 13.	Predicted population trends on Assateague Island National Seashore, given different annual adult survival.	207

INTRODUCTION

The piping plover (*Charadrius melodus* Ord) is a small shorebird endemic to North America. Its breeding distribution is limited to three geographical regions: the Atlantic Coast from Newfoundland south to North Carolina, the Great Lakes, and the northern Great Plains. Populations winter in the Bahamas and the West Indies, and along the shores of the southern Atlantic Coast and the Gulf of Mexico, (Bent 1929, Sidle 1985, Haig and Oring 1985, 1988c). In 1973, because of a decline in the breeding population, the species was placed on the Audubon Society's Blue List (Arbib 1972-1979, Tate 1981, Tate and Tate 1982, Tate 1986). In 1986, it was protected under the Endangered Species Act, and classified as endangered in the Great Lakes region and threatened throughout the rest of its range (Sidle 1985). The population decline has been attributed to loss of breeding habitat and poor reproductive success (Dyer et al. 1988). Predation, human disturbance, and habitat loss from beach development and stabilization are thought to be responsible for the decline (Wilcox 1959, Arbib 1976, Via 1979, Cairns and McLaren 1980, Raithel 1983, Flemming et al. 1988, Williams et al. 1988, Patterson et al. 1991). Reproductive success has been low in some cases even when human disturbance was minimal. The reasons for low reproduction are poorly understood, but nest predation (Haig 1985, Ailes 1988, Cross 1989, MacIvor

1990, Patterson et al. 1991) and low chick survival (Cairns 1977, Flemming 1984, Patterson et al. 1991) are thought to play a role.

Assateague Island National Seashore (AINS) is the northern portion of a barrier island off the coast of Maryland. Patterson (1988, pers. commun.) and this study observed plovers rearing their broods in three types of habitat: the bay beach, the island interior along the margin of the vegetation, and the ocean beach. Patterson et al. (1991) reported that survival rates of chicks raised on the ocean beach were significantly lower than those of chicks raised on the bay beach. There are (at least) 3 hypothetical explanations for this difference: 1) differential predation pressures may lead to higher survival rates on bay beaches, 2) higher disturbance rates on ocean beaches may result in more time spent vigilant or crouching and less time spent foraging, leading to lower survival, and 3) poor food supplies on the ocean beach may result in the starvation or weakening of young, leading to lower survival (Patterson et al. 1991). The goal of this study was to evaluate these hypotheses on Assateague Island National Seashore, with special focus on the food availability hypothesis. Additionally, we continued to provide baseline population monitoring on Assateague Island National Seashore.

OBJECTIVES

My objectives were to 1) estimate the population size and the number of breeding pairs on the Maryland portion of Assateague Island, 2) estimate reproductive success, both with and without predator exclosures, 3) identify and evaluate factors limiting piping plover productivity, 4) examine the importance of foraging habitat, 5) estimate survival rates of banded plovers, 6) use these survival estimates to model the population, and 7) estimate the reproductive output needed for a stable population.

STUDY AREA

Assateague Island is a 59-km-long barrier island off the coasts of Maryland and Virginia. The Virginia portion is Chincoteague National Wildlife Refuge (NWR), administrated by the U. S. Fish and Wildlife Service (USFWS). The Maryland portion of the island is administered by the National Park Service (NPS) as Assateague Island National Seashore (AINS). The NPS also oversees recreational use on Chincoteague NWR. My work was restricted to the Maryland portion of the island.

Patterson et al. (1991) found piping plover breeding distribution on Assateague Island to be restricted to 3 distinct areas; the hook, the wild beach/wash flats, and the

northern 8 km of the island (Figure 1). The first two areas are on Chincoteague NWR while the third made up the majority of my study area.

The northern portion of AINS has a relatively wide, flat beach and few small (≤ 1 m high) broken dunes. Open beach width (berm, See Table 1 for definitions) ranged from 140 to 380 meters, but the island is less than 300 m wide in some places (Patterson 1988). Large flat areas are occasionally overwashed by winter storms, creating vegetation-free pathways that piping plover broods use when moving from the ocean side to the bay side of the island. The only large dune system in the northern 8 km is restricted to the northernmost 1 km and the elevation seldom exceeds 3 meters. These dunes are composed of dredge spoil material deposited by the U. S. Army Corps of Engineers in 1962 (Buckley and Psuty 1986).

Ocean beach vegetation is nonexistent. Sand, shells, pebbles, and very small cobble make up the wide ocean beach, which can extend nearly to Sinepuxent Bay at times. Salt meadows, marshes and mud flats are common bay side features. Shrubby vegetation regularly grows along the bay side water's edge (Figure 2).

Human Activity

Human activity was concentrated south of the study area on AINS. State and federal campgrounds operated throughout the breeding season. Off-Road-Vehicle (ORV) use was restricted to the southern 20 km of the National Seashore (Maryland) at a maximum density of 12 vehicles per 1.6 km of beach. The northern 8 km of AINS

was restricted to foot or boat access only, with the exception of Park Service and research vehicles (Figure 1). A hike-in campground was located approximately 700 m north of the southern study area boundary (Figure 2) and received frequent use (0-20 campers/night during June-August).

Tides

I calculated the 1988 - 1990 tides for the northern end of Assateague Island National Seashore (U. S. Department of Commerce 1988a, 1989a, 1990a), using the Ocean City (Isle of Wight Bay) adjustments for the tabled Sandy Hook values. I used these corrections as they provided the closest estimate to tidal fluctuations on the bay side of the northern 8 km of the island. Calculated high tides lagged 11 minutes, at most, behind actual ocean beach high tides. Tides on the Off Road Vehicle (ORV) section of the island lag approximately 15 minutes behind the tabled tides for the north end (extrapolated from U. S. Dept. of Commerce 1988a, 1989a, 1990a).

Maximum tidal range was 0.57 meters during neap tides and 1.43 m during spring tides. Actual tidal ranges and heights observed, however, occasionally varied from the tabled values because of local weather patterns (mostly wind; Defant 1958, pers. obs.).

Methods for Location Assignment

To keep track of effort expended in various areas, I divided the northern 8 km of the island into 16 habitat blocks. Each block was 500 meters north to south and extended over the width of the island. Each block was further divided into five 100-m strips (Figure 3). Locations in each parallel band were identified further by the habitat type of each location (Ocean tidal zone, berm, mud flat, etc., Table 2). I divided the ORV zone, located south of the NPS developed zone, in a similar manner. See Appendix A for more details.

I clustered habitat blocks into 3 groups: the northern section of the northern 8 km (blocks 1-8), the southern section of the northern 8 km (blocks 9-16) and the ORV section (blocks 21-33). This was necessary because only one section could be practically surveyed during a given day for some surveys. I will refer to these 3 sections throughout.

Weather

Weather data were collected by NPS personnel at the AINS campground ranger station (U. S. Dept. Commerce 1988b, 1989b, 1990b). Average daily temperatures ranged from 7.9 °C to 25.0 °C. Temperatures were relatively cool in March and April, rose dramatically in May, and stabilized by June. June, July and August all had

mean daily temperatures above 20 °C. Monthly rainfall during the course of the study ranged from 2.7 cm to 16.9 cm (Table 3).

Chapter 1. SURVEYS OF FORAGING HABITAT

BEFORE NESTING

Piping plovers arrive on the breeding grounds more than a month prior to nest initiation (Patterson 1988, pers. obs.). During this period, plovers initiate courtship, territory selection, and foraging in preparation for the breeding season (Cairns 1982, Ricklefs 1974). In 1990, we attempted to assess the use of tidal foraging areas by plovers prior to the initiation of nesting to accomplish a number of objectives. We hoped to determine how important these habitats are to foraging plovers. Additionally, we hoped to locate concentrations of plovers to assist future researchers in locating birds prior to breeding. Intensive surveys also provided us with opportunities to locate color-banded birds returning to the island to breed as these returns were the basis of our survival estimates. Preferred foraging habitats need to be conserved as they are important to plovers as they prepare to breed.

METHODS

I conducted 9 surveys from 3-19 April, 1990 to determine foraging areas used by plovers before nesting. Sampling was conducted at combinations of 3 times of day and 3 tidal levels, one survey for each combination (Latin square design). Morning, mid-day, and evening surveys were centered on 0800, 1200, and 1600 hours, respectively. High, low, and mid-tide surveys were centered on tabled high tide, low tide, and a midpoint between the extremes. I accomplished this by starting 1-1.5 hours before the appropriate tidal level (a survey was completed in approx. 2.5-3 hours). Two mid-tide rising (0800 and 1600 hours) and one mid-tide falling (1200 hours) surveys were completed. I recorded the time spent in each habitat unit as a measure of observer effort.

I observed birds with binoculars or a 15-45x spotting scope. To avoid recording positions of birds that were affected by my presence, I recorded only the first location obtained for each bird. I traversed areas on foot, sampling all intertidal habitat. I surveyed the shoreline by walking a complete loop. I walked the bay side shoreline, crossed the island, and walked the ocean beach returning to the point of origin, or visa versa. The direction of the loop (clockwise/counter-clockwise) and the starting point (north or south end of the survey section) were chosen randomly. I recorded the time in and out of each habitat block.

The northern section (habitat blocks 1-8) and the southern section (habitat blocks 9-16) were surveyed on consecutive days. Only one section could be practically searched given time of day and tidal constraints. The section searched first (northern vs. southern) was determined randomly. I surveyed the ocean beach from a transect between and parallel to the highest water mark (spring tide) and the most recent high tide mark. In this way, I could observe birds foraging low on the beach, as well as those roosting above the high tide line. I made no effort to locate birds more than 5 m inland of the spring tide mark. I stopped every 60-70 meters to scan the beach ahead with binoculars. Tidal level, estimated wind speed and direction, temperature, and cloud cover were recorded for each observation. When possible, I recorded the distance at which I first observed the birds (detection distance) and the distance at which they appeared to be reacting to me (reaction distance). I defined "reacting" as alarm calling or stopping their current behavior and walking/running to avoid me.

Available foraging habitat was determined using aerial photographs and observations in the field. Shoreline distances were measured with a planimeter on maps digitized from 1988 aerial photographs. I measured mud flats' perimeters at low tide. All ocean beach and berm areas were considered available. Bay beach areas were considered unavailable if <0.5 m of beach was present. Unavailable shoreline, such as where saltmarsh extended to the bay and no beach was present, was excluded from our shoreline distance measures. I categorized plover sightings into 4 habitat types: ocean tidal zone, berm, bay beach and mud flats (Table 1).

I compared the number of plovers observed in each habitat type with the expected number of plovers based on the proportion of all available habitat in each type (chi-square goodness-of-fit). Following the rejection of the null hypothesis, I compared the proportion of plovers observed in each habitat and the proportion of available habitat to determine if any habitats were selected or avoided (Neu et al. 1974). Similarly, I determined if plovers were distributed evenly among the 16 habitat blocks, as would be predicted by the available habitat, with a goodness-of-fit test. I was unable to compare use and availability within each block using Neu et al. (1974) because the large number of blocks exceeded the authors' recommended maximum.

I analyzed the total number of plovers observed, and the plovers observed / kilometer of available habitat, on the bay side and ocean side during a given survey loop. Wilcoxon Rank Sum tests were used to test differences in the number of birds observed between the two beaches (bay vs. ocean) and mid-tide rising vs. mid-tide falling. I used the Kruskal-Wallis test to test time of day and tidal effects on the plovers observed. I also examined time of day and tidal effects on the number of plovers observed / km of available habitat simultaneously using 2-way ANOVA.

RESULTS

Habitat Selection

Plovers were not distributed uniformly among habitats ($\chi^2 = 114$, 3 df, $P < 0.001$). I observed plovers on bay side mud flats more frequently than expected ($P < 0.05$, Table 4) and less frequently than expected on the berm or ocean tidal zone ($P < 0.05$). Plovers used the bay beach in proportion to its availability ($0.1 > P > 0.05$).

Plovers were not distributed uniformly among all habitat blocks ($\chi^2 = 51.8$, 15 df, $P < 0.001$). Bay side blocks 3, 8, and 12 contained twice as many observations as other blocks and 58% of all bay side plover observations. Habitat blocks 5, 11, and 13 on the ocean side likewise contained greater numbers than other blocks and 56% of all ocean side observations (Table 5).

Overall, I observed plovers on the bay side more frequently than on the ocean side (Wilcoxon Rank Sum, $n = 18$, $Z = 2.8$, $P = 0.006$ and $n = 18$, $Z = 3.2$, $P = 0.001$ for the number of plovers and plovers/km respectively, Table 6). However, at high tide there was no difference between bay side and ocean side plover observations.

On the bay side, I observed an average of 1.17 plovers during high tide, 5.67 plovers during mid-tide and 5.83 plovers during low tide (Kruskal-Wallis, $P = 0.005$).

On the ocean side, I observed 2.0, 1.3, and 1.17 plovers at high, low and mid-tide, respectively ($P = 0.926$, Table 6). Fewer plovers were observed on the bay side at high tide than at mid- or low tides (Wilcoxon Rank Sum, $n = 6$, $Z = 2.8$, $P = 0.005$ and $n = 6$, $Z = 2.6$, $P = 0.010$ respectively).

Plovers observed per kilometer of beach showed similar trends (Table 6). On the bay side, I observed fewer plovers/km at high tide than at mid- or low tides (Wilcoxon Rank Sum, $n = 6$, $Z = 2.8$, $P = 0.005$ and $n = 6$, $Z = 2.8$, $P = 0.005$). In contrast, there were no differences among tidal levels on the ocean beach (Kruskal-Wallis $\chi^2 = 0.16$, $P = 0.924$).

Similarly, tidal level and time of day affected plovers observed / km on the bay side (2-way ANOVA $F = 6.2$, 17 df, $P = 0.0052$). Tidal level was responsible for a significant portion of the observed differences ($P = 0.0013$) while time of day did not contribute significantly ($P = 0.46$). On the bay side, I observed fewer plovers / km at high tide than at mid or low tide (Duncans multiple range test $P = 0.05$). On the ocean side, tidal and time of day effects were not significant (2-way ANOVA $F = 0.71$, 17 df, $P = 0.60$).

I observed greater numbers of plovers on the bay side during mid- and low tides than on the ocean side (Wilcoxon Rank Sum $n = 18$, $Z = 2.6$, $P = 0.009$ and $n = 18$, $Z = 2.6$, $P = 0.010$). Plovers/km also were greater on the bay side than on the ocean side during mid- and low tide (Wilcoxon Rank Sum, $n = 18$, $Z = 2.7$, $P = 0.008$ and $n = 18$, $Z = 2.8$, $P = 0.005$).

Time of day did not affect the number of plover observations (Table 7). Mid-tide falling and mid-tide rising surveys also did not differ (Table 8).

Detection and Reaction Distances

Detection and reaction distances were available for a limited number of observations (Table 9). Detection and reaction distances were no different between beaches (Wilcoxon Rank Sum, $Z = 1.2$, $P = 0.223$ and $Z = 1.3$, $P = 0.211$, for the bay and ocean beaches respectively). The difference of the two (detection - reaction) also showed no difference (Wilcoxon Rank Sum, $Z = 0.41$, $P = 0.683$). The variance between bay side and ocean side distances did not differ (Moses Rank-like test, $P > 0.5$ for detection, reaction, and the difference), although high variances and a small sample size appeared to hamper this analysis.

DISCUSSION

Habitat Selection

Piping plover distribution is not uniform before breeding. At this time, plovers favor large mud flats for foraging areas. As a result, I observed plovers more frequently in bay side habitats than in other areas during lower tidal levels. The most frequently used bay side habitat blocks contain both mud flats and bay side beaches. Habitat blocks with frequent ocean side use did not have these bay side features. During the breeding season on Plymouth Beach, Massachusetts, Brown (1986) found more plovers at low tide using the inner beach (similar to our bay beach) than on the outer beach, but, as in this study, found approximately equal numbers on either beach at high tide. Burger et al. (1977) observed high shorebird use of mud flats and sand flats during lower tidal levels as well, especially during the hour following low tide. On the wintering areas, Haig and Oring (1985) observed plovers using sand flats more than adjacent coastal beaches on 27 sites along the Gulf Coast. Johnson (1987) and Johnson and Baldassarre (1988) also noted plovers more frequently used mud flats at lower tidal levels than outer ocean beaches during winter.

Nichols (1941) described plovers feeding on the ocean beach on Long Island, N.Y.; however, the availability of bay side beaches and mud flats or the search effort expended in these habitats are unknown. Burger (1977) observed plovers in New Jersey frequently on the ocean beach and inner beach foraging mainly in the wet sand zone (Table 1); however, observations in mud flat habitats were not frequent enough to be included in the analysis.

Mud flats are selected by plovers as a foraging site prior to breeding. Maintaining these sites may be important to plovers, given their energetic needs prior to breeding. Activities that would increase disturbance or mud flat destruction clearly should be avoided. Because most mud flats extend from the island toward the active channel into Sinepuxent Bay, the impacts of boat activity need to be addressed. Increased boating activity may accelerate the erosion of mud flats and bay side beaches (Maryland Dept. of Natural Resources 1981). The impacts on the infauna (animals in the substrate) clearly need further investigation, not only with respect to plovers, but with all shorebirds in mind, as these areas are frequently used by migrants.

Detection and Reaction Distances

Detection and reaction distances did not differ between the bay side and ocean side but sample sizes were small. The difference between detection and reaction distances provides a measure of an observer's ability to detect plovers before they

react to his or her presence. On bay side surveys, this difference was limited because of the irregular shoreline. I believe that the counts, however, were not affected because of a surprise factor. When rounding a point, I quickly scanned the bay beach ahead to detect plovers before they had a chance to react. On the ocean side, my ability to see plovers may have been limited by beach slope and the occasionally undulating surface of the intertidal zone. Ocean side reaction and detection distances may be underestimated here because I did not observe birds before they reacted to my presence in 3 of 6 instances. This only happened 1 of 7 times on the bay side.

Biases and Observer Effort

Although I believe the observed differences between bay beach and ocean beach plover counts exist, I recognize a number of potential sources of bias which could lead to underestimating ocean side plover counts. On the ocean side, the observer is visible from greater distances. Plover visibility is lower on the ocean side because plovers blend in well with the mottled white sands of the ocean beach, and bay side substrates tend to be darker in color and more contrasting to a plover. A larger sample and 2 observers would be an improvement for future surveys.

I considered using the time spent in each habitat block as a measure of observer effort to correct bird counts for disproportionate habitat block sizes. I believe that birds observed/km of shoreline, however, is a better correction factor for several

reasons. I believe I expended the same effort searching for plovers in each habitat block. I walked at the same rate and stopped at approximately the same intervals. I attempted to scan all areas ahead for the same amount of time. Time, however, was directly related to the number of plovers observed. Because the color band combinations of returning birds was important for our estimates of annual survival, I would often sit for many minutes attempting to read a band combination. Frequently, I would sit recording band combinations for periods exceeding the usual survey time. Also, high water conditions on some high tide bay side surveys resulted in disproportionately greater amount of time spent in those areas. Numerous guts, cuts and small creeks could not be crossed as readily at extremely high tides as they could at lower tidal levels. These areas had to be crossed further inland.

SUMMARY

Before nesting, plovers use mud flats and bay side beaches to a greater extent than ocean side beaches, especially at lower tidal levels. Efforts to locate color-banded birds returning to breed should focus on these habitats at lower tides to be most effective. Protection of bay side beaches and mud flats from excessive disturbance, destruction, or alteration is important to plovers prior to breeding and to other shorebirds during migration.

Chapter 2. PIPING PLOVER BREEDING BIOLOGY

The piping plover is endemic to central and eastern North America. Although nearly extirpated by shooting in the late 1800's, populations began to recover following the passage of protective legislation (Bent 1929). More recent population declines have been attributed to reproductive failure, among other factors (Sidle 1985, Haig and Oring 1985, Dyer et al. 1988). Factors limiting reproductive success include egg and chick losses from predation, recreational disturbance, and habitat destruction (beach development, dune stabilization; Wilcox 1959, Arbib 1976, Sanderson 1977, Via 1979, Cairns and McLaren 1980, Raithel 1983, Haig and Oring 1985, Williams et al. 1988, Goldin et al. 1988).

Assateague Island National Seashore supports 100% of the known piping plover breeding population in Maryland (Hecht 1988, 1989, 1990). Past reproductive success has been limited by nest predation and low chick survival. Red foxes (*Vulpes vulpes*) were responsible for 71% (n = 17) of nest predations on AINS in 1986-1987 (Patterson et al. 1991). In 1986-87, chick survival on AINS was 54% but varied from 19% to 69% among different brood-rearing habitats. Broods reared on the ocean beach had the lowest survival (19%) while broods reared on the bay beach had the highest survival (69%, Patterson 1988).

The Atlantic Coast piping plover recovery plan calls for an increase in the breeding population as a primary objective as well as annual monitoring (Dyer et al. 1988). In addition, the marked differences in chick survival among different brood-rearing habitats in 1986-87 warranted further investigation. To assist in these recovery goals, my objectives were to 1) document the breeding population size on AINS, 2) provide basic population monitoring, 3) calculate daily nest and chick survival rates, 4) investigate the utility of predator exclosures as a management tool to boost hatching success, 5) document nest predation sources, and 6) formulate management recommendations for the AINS plover population.

METHODS

Nest Searches

After the first nest scrapes (Table 1) were observed (~15 April each year), we searched potential nesting areas for nests during all hours of the day, but avoided periods of excessive heat or inclement weather to protect the eggs. We conducted most surveys in the morning because search conditions generally were best then. We surveyed the ocean beach using a transect parallel to the ocean between the high tide line and the foredune. We used transects that were approximately 70-m wide. We searched wide stretches of beach using more than one parallel transect. Additionally, we searched separately areas with small dunes and gaps in the dune line caused by overwashing winter or storm tides. We discovered nests by patiently watching as flushed birds returned to their nests. Nests also were found by following plover tracks in areas frequented by plovers. On discovery, we approached each nest close enough to determine the number of eggs (approximately 5-10 m). We marked nest locations subtly to prevent observer-induced predation or disturbance. We placed common beach debris (e.g. tires, driftwood, pier and shipwreck debris,

etc.) no closer than 10 m from the nest. No markers were used that might serve as a perch or visual cue for possible avian predators (Picozzi 1975, Strang 1980). As in foraging habitat searches, we recorded the time spent in each area.

Piping plovers in Maryland have nested in the same areas since at least 1985 (Hoffman 1985, Patterson 1988). We searched these areas at least once every 7 days (more often when possible). We surveyed the ORV section three times in 1988 and 1990, and twice in 1989 between mid-April and the first week in July. Patterson (1988) found only 1 occurrence of nest initiation after 5 July on AINS; therefore, all nest surveys were discontinued after the second week in July.

Nest search surveys were the basis for our breeding population estimate. Our estimate is based on the assumptions that 1) we found all nests and/or broods and 2) we identified all renesting attempts correctly. To accomplish this, we recorded the location of each bird observed. Through time, we were able to recognize areas where nests were likely to occur by the pattern of observations, and we monitored these areas closely. Because we were able to identify individual birds (via unique color-band combinations), we were able to determine if the same birds were observed together in the same area on more than one search. Each year we assumed we located all nesting attempts. This is not unlikely as we spent considerable time searching for nests. Renesting attempts were identified by either the presence of a banded bird (from a previously failed nest, $n = 15$) or by considering the location of the previously failed nest and the interval between failure and renest when the birds were not banded ($n = 6$). Piping plovers frequently renest following

an unsuccessful nesting attempt (Wilcox 1959, Cairns 1977, Whyte 1985, Haig 1987, MacIvor 1990), usually in 6-10 days (Haig and Oring 1988b, Patterson 1988). These assumptions were realistic as one (11 pairs) or both (41 pairs) birds were recognizable (color-banded) in 88% of first nesting attempts (59 breeding pairs) in 1988-1990. Four of the 6 nests that we classified as renests when neither plover was banded were within 300 m of the previously failed nest and were initiated within 8-10 days after the first nest was lost. We conservatively considered the other 2 nests as renests, even though 20 days elapsed between the loss of the first nest and the initiation of the second nest.

Nest surveys also yielded information on nest initiation and clutch completion necessary for estimating nest survival. Nest site characteristics were recorded. A permanent record of nest locations, plotted on aerial photographs, also was compiled. These data, in turn, were incorporated into a GIS database.

Predator Exclosures

Predator exclosures were square-shaped with rounded corners and sides that bowed slightly out (intermediate between a square and a circle). Exclosures were ~2.2 m on each side. We constructed predator exclosures from the following materials: 1 - 91-cm x 10-m galvanized welded wire with 5-cm x 10-cm mesh, 4 - 122-cm x 2.5-cm x 2.5-cm wooden tomato stakes, brass hog rings, garden ties

(plastic-coated twist ties), and monofilament fishing line (4.5-27.2 kg (10-60 lb.) test strength).

We used two-person crews to erect exclosures in the following manner. The tomato stakes were driven into the sand around the nest to a height at least 10 cm below the top edge of the finished exclosure, reducing the chance they would be used as a perch site. We then encircled the 4 stakes with the welded wire and buried the bottom wire to a depth of 10 cm. In hard sand, we dug a narrow trench to simplify burial. We clamped the two ends together with the hog rings and secured the welded wire to the stakes with the garden ties. Early in 1988, we did not use tops, but after nests were predated by birds, we strung monofilament line in parallel strips 10 cm apart across the top. We used monofilament line ranging from 4.5 to 27.2 kg (10-60 lb.) test strength. This design is similar to that used by MacIvor (1990).

In 1988, we erected predator exclosures around one half of the nests in each of two categories: those with access to the bay beach and those without such access. Status was assigned in order of finding. Pairs with nests within 500 meters (measured parallel to the wrack line [Table 1]) of an unobstructed pathway from the ocean (nesting) beach to the bay were considered to have access to the bay beach. We considered pathways unobstructed if they were free of shrubs for a width greater than 3 meters and free of dense (≥ 200 stems / m²) grasses and forbes for a width of 1.5 meters or more. These subjective criteria were determined following observations in 1988 and seemed reasonable as this was the smallest opening we

observed chicks moving through. As nests were discovered, every other one was assigned to an exclosed status.

In 1989, we split the nests into two categories as we did in 1988: those with access to the bay beach and those without. For those with access to the bay beach, we fenced one half of all nesting sites (areas presumably used by 1 pair of plovers) while the other half received no predator exclosures. In the interest of boosting success of nests far from bay access paths, we exclosed all nests. In 1990, we constructed exclosures at all nests (with the exception of 1 nest lost to fox predation very quickly).

Flush Distances

We noted the distance at which an incubating adult flushed from the nest as we approached the nest to trap the adults or construct an exclosure. In 1988 and 1989, flush distances were not a primary objective and were collected when we approached nests for other reasons. In 1988-1989, we noticed that birds flushed soon after we left the vehicle, suggesting that we had been able to approach the nest closer in the vehicle than would have been possible on foot. In 1990, recognizing this potential negative bias, we approached nests on foot from greater starting distances to more accurately record incubating plover's response (flush) to a human on foot. We calculated a mean value for each nest to satisfy the statistical assumption of independence (nests were approached 1-6 times, $\bar{x} = 2.25$, $SE = 0.23$, $n = 43$ nests).

Kruskal-Wallis and Wilcoxon Rank Sum tests were used to compare the flush distances among years.

Estimating Nest Success

We examined all nests daily to determine success and hatch dates. We viewed nests through a 15-45x spotting scope from distances great enough so that the birds would not be disturbed. Nest success was estimated using Mayfield's (1961, 1975) method. Comparisons were made using Hensler's (1985) techniques. I used a 34-day laying/incubation period for my calculations based on observations by Wilcox (1959), Cairns (1982), and Patterson (1988). Interval survival rates (probability that any given nest will hatch) were calculated by raising the daily survival rate to the 34th power. The micro computer program MICROMORT (Heisy and Fuller 1985) was used to calculate the daily and interval survival rates.

During daily nest checks, we recorded the locations of all people within 300 meters of the nest. Thus, a daily instantaneous sample was taken for all nests during incubation. Overall, sampling was uniform throughout the day.

Whenever we approached a nest closely, such as for banding, exclosure construction, or checking after nest failure, we briefly searched for evidence of human or predator presence within 50 m of the nest and recorded the results of that

search. When a nest failed (loss of eggs to predators, flooding, or abandonment), the area within 10 meters of the nest was searched for signs of predation.

Chick Survival

We observed broods daily for a period of at least 25 days to estimate survival to fledging. Any bird we observed at 25 days of age or older was considered fledged. Patterson (1988) observed chicks as young as 20 days old in flight. We calculated daily chick survival using MICROMORT (Heisy and Fuller 1985), as we did with nest survival.

We captured chicks at 4 days of age to individually mark them whenever possible. If we did not catch them at 4 days, we attempted to do so as soon after 4 days of age as possible. We banded and weighed the chicks. For the analysis, I included only chicks captured at 4 or 5 days of age to reduce age-related variation. With recognizable individuals, we were able to determine which chicks survived and which did not.

RESULTS

Population Estimate

We found 34, 27, and 19 nests in 1988-1990, respectively. We know of missing only one nest in 1990 when we observed chicks 1-2 days old in an area in which we suspected the presence of a nest, but could not find one. We estimated the breeding population was 25, 20 and 14 pairs in 1988, 1989, and 1990, respectively (Table 10). Observer effort expended in nest searching is shown in Table 11.

Flush Distances

Piping plovers flushed from their nests at an average distance of 78 meters (Table 12). Flush distances in 1990 were significantly greater than in 1988 or 1989 (pairwise Wilcoxon Rank Sum, $P = 0.0001$ and $P = 0.002$, respectively).

Nest Success

Thirty-two of 81 piping plover nests (40%) produced chicks (Table 13). However, 37% of the total nests were destroyed by predators. Red foxes were responsible for more known nest losses than any other factor ($\chi^2 = 36.3$, 3 df, $P < 0.0001$). Forty-four percent of the total eggs were lost to known causes (Table 14). Of these known losses, red fox (68%) and avian predators (17%) accounted for most egg loss (Table 15). Flooding, gull predation, plovers and research accidents (during trapping) also contributed to egg loss. Mean size of complete clutches was 3.79 (Table 16). Plovers placed their nests on flat portions of the beach (70%) devoid of vegetation (81%). Shell fragments lined 84% of the nests (Table 17).

Daily nest survival averaged 0.962. Daily nest survival did not differ between nests with and without access to the bay side of the island (Table 18). We also observed no difference between early nests (initiated on or before 21 May) and late nests (initiated after 21 May) or nests > 75 m from the high tide line vs. nests < 75 m to the high tide line.

When we approached nests for banding and exclosure construction ($n = 268$), we observed fox tracks < 1 m from an active nest on 2 (0.7%) occasions. Pony (*Equus caballus*)(4, 1%) and sika deer (*Cervus nippon*)(1, 0.4%) tracks also were recorded at this distance. Human track distances ranged from 1 m to 100 m ($n = 15$ occurrences (6%), Figure 4). When we observed nests from a distance ($n = 744$),

humans were observed to pass within 20 m of active nests only 3% of the time (Figure 5). Humans were not observed within 300 m during 97% of nest observations.

Predator Exclosures

Overall, predator exclosures did not significantly increase daily nest survival (Table 19). In 1988, 6 nests were lost initially because of an ineffective early design (no tops), but nest success was 100% after we added tops. In 1989, every nest exclosed hatched successfully. Foxes destroyed 8 exclosed nests in 1990.

We were able to construct predator exclosures quickly (Table 20), usually in < 20 minutes. We observed no nest abandonment ($n = 37$) because of predator exclosure construction. Ninety-two percent of birds ($n = 27$) resumed incubation in less than 10 minutes after construction. We did not observe birds resuming incubation after 10 constructions because we could not see the nest from a distance or we exclosed the nest before clutch completion and an adult was not incubating before we constructed the exclosure. In 5 instances, we trapped and banded one or both adults before exclosure construction.

Chick Survival

Chick mortality was concentrated in the first 10 days of life (Figure 6). Older chicks (11+ days of age) had significantly higher daily survival rates than younger birds (Table 21). Chicks foraging on the bay beach and island interior habitats had much higher daily survival rates than chicks foraging on the ocean beach. Additionally, chicks with access to the bay side had a higher daily survival rate than those without access (79% [n = 14] of the broods with access to the bay side moved to the bay side). Nest initiation date, however, did not affect chick survival rates.

Weights of chicks 4 and 5 days old were lowest on the ocean beach and highest on the island interior (Kruskal-Wallis $\chi^2 = 8.1$, $P = 0.018$; Table 22). Weights of chicks 4 or 5 days old surviving to fledging were higher than those not surviving (Wilcoxon Rank Sum, $Z = 2.7$, $P = 0.008$; Table 23). Culmen length of surviving chicks was longer than that of chicks that did not survive (Wilcoxon Rank Sum, $P = 0.039$).

Reproductive Success

In 1988-1990, 13, 18, and 11 chicks fledged respectively. Fledging success was higher in the bay beach and island interior habitats than on the ocean beach (χ^2 test for equality of proportion, $P < 0.0001$; Table 24). Reproductive success was 0.71

chicks fledged/breeding pair in 1988-1990. Success varied from year to year (Table 10) but did not exceed 0.90 chicks fledged/breeding pair.

DISCUSSION

Piping plovers on AINS generally nested in a shallow scrape on the wide, open beach (Patterson 1988). We observed many nests lined with shell fragments. A majority preferred areas of moderate to high numbers of shells and pebbles in the substrate (Patterson 1988, this study), which would add to the disruptive pattern used as camouflage. Eighty-one percent preferred unvegetated sites, although a few (11) nested among vegetation or in the center seaside goldenrod (*Solidago sempervirens*) clumps. These nest-site preferences are consistent with other Atlantic coast plover nesting sites (Bent 1929, Wilcox 1959, Cairns 1982, Burger 1987, MacIvor 1990).

Our population estimates of 25, 20 and 14 breeding pairs indicate a rapid decline. The 1991 population was 17 breeding pairs (MacIvor pers. commun.), suggesting there is some natural fluctuation. Estimates from 1972 and 1980, however, suggest the breeding population was twice as large as currently present. Hoffman (1985) found 18-20 pairs in 1985. Patterson (1988) searched extensively and estimated 17 and 23 breeding pairs in 1986 and 1987. While the local population has declined, the Atlantic coast population has remained stable to slightly increasing in the past few years (Hecht pers. commun.), although this may be an artifact of increased search effort. Increased concern for the species recovery by state and federal

agencies and private citizens has increased the number of surveyers searching for plovers on their breeding areas. Continued monitoring is appropriate to determine if the local population is in decline or if these fluctuations are a response to the variable nature of nesting habitat. Availability of quality nest sites may change year to year and influence local plover populations (MacIvor 1990). The absence of violent winter storms and lack of overwashing has resulted in widespread revegetation of some overwash areas on AINS (Kumer pers. commun., pers. obs). Additionally, the presence of dredge spoil dunes has provided protection against past storms and allowed vegetation to dominate the northern 1 km of the island. Although the overwash areas may not be used directly, they do provide access to quality brood foraging habitat. Cross (1987) found plovers on Metompkin Island selecting nest sites closer to open overwashes with access to the bay side mud flats. Plovers also select nest sites near tidepools that function as bay side mud or sand flats (Cross 1989). If these overwashes revegetate on AINS, nest site selection could be altered or deterred.

I predict that the AINS breeding plover population will increase in years following major storm events. Reproductive success also may increase. The most recent winter storm on January 4, 1992 provides an opportunity to test this prediction during the 1992 and 1993 breeding seasons.

Nest search effort

We were able to completely search the northern or southern sections of the northern 8 km of AINS in one day 80% of the time. The northern section took slightly

longer to search than the southern section because of beach characteristics. The northern beach is much wider in more places and required more search time. In 1990, we completed nest searching more quickly than in 1989. Our shorter search times may have been a result of our nest searching experience. By 1990, we had 2 years experience working with plovers on AINS. Additionally, fewer plovers nested in 1990, and as a result, we may have spent less time observing plovers to detect nests. Though it is conceivable that we found fewer nests in 1990 because we spent less time, I believe this to be highly unlikely. Adults on a breeding territory advertise their presence and react to observers. When birds were observed, we always attempted to locate a possible nest. In 1990, we observed fewer adults on breeding territories.

Flush Distances

Flush distances were significantly greater in 1990, compared to either of the previous two years. In fact, they were nearly double the 1988 and 1989 distances. Most 1988 and 1989 flush distances were collected during nest trapping and banding, and I believe we may have biased flush distances by approaching the nest too closely in the truck. Many birds flushed immediately as we left the truck, or while we were within a few meters of the truck. Our closer approach in the truck was necessary to assure a quick and safe retrieval of the trapped birds. Flush distance data were collected secondarily and, unfortunately, I believe this underestimates the true

flushing distance for 1988 and 1989. In 1990, we avoided close approaches and the flush distance nearly doubled. Therefore, I believe the 1990 data are more appropriate when addressing recreational disturbance of nesting piping plovers on AINS.

Flush distances may be used as an index of plover sensitivity at a particular site and to establish disturbance buffer zones around piping plover nesting areas. These data, however, may underestimate the area needed to minimize disturbance.

Flushing in response to human presence presumably is an attempt to conceal the nest location (predator avoidance) (Byrkjedal 1987). At distances greater than that required for flushing, human activity elicits greater attentiveness from incubating birds. Birds often sit more erectly and watch people more closely. Physiological and psychological responses at these agitation distances are difficult to assess but are important considerations. McGarigal et al. (1991:37-41) discuss a "Dual Disturbance Threshold Model" as it relates to human-eagle interactions that conceptually applies to human management in plover use areas. The conceptual model (Figure 7) defines an agitation zone beginning at the flush distance and extending to a distance at which human disturbance first elicits a physiological, psychological, or behavioral response. Human disturbance between the two thresholds and the time required to elicit a response appear to be related, though the exact shape of the curve is unknown. As the distance is decreased, less time is required to elicit avoidance or escape behavior. We observed a similar response from incubating piping plovers and from tending adults with broods. During a few ($n < 5$) observations of incubating birds, our

approach was noted by the incubating adult; however, it did not flush. After 5 to 10 minutes, the adult flushed from the nest and alarm called with no apparent provocation. We would suggest that our approach was not close enough to elicit immediate flushing but close enough to agitate the incubating bird to an intolerable level after a period of time.

Nesting area buffer zones at sites with human recreational pressures should be designed so that boundaries are outside the agitation distance. Although inadequate buffers may not cause immediate flushing, flushing could be elicited by constant human activity on the buffer boundary. Given the tendency for recreationists to park their ORVs or recreate immediately adjacent to closed areas (pers. obs.), establishing boundaries outside the agitation distance is important. The type of human activity also plays a role. Motionless activities, such as sunbathing, are less disturbing than beach sports (e.g. paddleball, volleyball) or pedestrians walking or running by the nest (Brown 1986, pers. obs.). Unfortunately, we collected no data on agitation distances. I suggest the use of a minimum of 50 m as a conservative estimate of the agitation distance; however, I recognize that some fine-tuning may be necessary after additional data are collected.

Therefore, we recommend a minimum buffer zone radius of 225 m for symbolic fencing and signs to be placed around each nest on AINS. This estimate is based on the greatest mean nest flush distance (174 m) and our estimated minimal agitation distance (50 m).

Plovers on AINS appear to be more sensitive to disturbance than at other sites. Wilcox (1959) reported that plovers flushed at approximately 61 m in New York while Cairns (1982) reported mean nest flush distances of 43.1 m (5-93 m range, $n = 66$) in Nova Scotia. At study sites in New Jersey, Burger (1987) reported a mean nest flush distance of 21 meters. On Chincoteague NWR, Cross (1989) found plovers flushed at a mean distance of 47 m (5-300 m range). We observed a mean flush distance in 1990 nearly twice the distance of any other study. This may be the result of AINS historically having very low human disturbance or the extremely wide, flat beaches that allow plovers to observe an intruder's approach from a considerable distance.

Another hypothesis is that the plovers were sensitized by our research activities (nest searching, exclosure construction, banding, etc.), and therefore, flushed at greater distances. Unfortunately, we were unable to test this hypothesis because we rarely observed the birds' response to humans other than ourselves.

At sites with high human use, plovers may be habituated to human presence or more sensitive plovers may be excluded. Cairns and McLaren (1980) found plovers on remote beaches flushed from the nests at distances > 85 m whereas on high recreational use beaches, observers were able to approach as close as 3 m before the bird flushed. Plovers breeding on Long Island, New York flushed from their nests at 12-61 m (Wilcox 1959). On Breezy Point, New York, adult plovers flushed in response to approaching pedestrians or joggers at 15-20 m, though it is unclear if these birds were incubating or foraging (Goldin et al. 1988). Burger (1987) reported a mean flush distance of 21 m and implied that the study beaches experienced

frequent and extensive recreational use. Hoopes et al. (1988) observed foraging piping plover broods while collecting behavioral data from a mean distance of 43 m to "minimize or eliminate researcher disturbance." Our observation distances on AINS often exceeded 150-200 m and only approached 50 m when foraging birds moved toward a parked research vehicle that had not moved recently.

Nest Success

The probability that a nest would survive (one or more eggs hatch) on AINS was 27% during 1988-1990 using the Mayfield (1975) method. Patterson (1988) reported a 40% survival during 1986-1987. Prindiville Gaines and Ryan (1988) reported nest success rates of 41-42% in North Dakota. Few other studies have reported daily nest survival, making comparisons difficult. The lower daily nest survival on AINS in 1988-1990, compared with 1986-1987, may have been the result of the quick loss of the initial nests exclosed in 1988 and the fox depredated exclosed nests in 1990. An increasing predation pressure also may have contributed to the lower nest survival.

Apparent hatching success (no. of eggs hatched/ no. found) was 35% (n = 284), fairly low compared with other studies. Wilcox (1959) and Cairns (1982) reported high hatching successes of 92% (n = 668) on Long Island, New York and 76% (n = 201) in Nova Scotia, respectively. Goldin et al. (1988) observed 57% success (n = 44 eggs).

MacIvor (1990) was the only study that reported lower hatching success (25%, $n = 565$ eggs). She attributed the low success to predation, which is true for this study as well.

The importance of using consistent and reliable estimates of nest success, such as daily nest survival, is shown in this study. Apparent nest success (40%, Table 13), apparent egg success (35%, Table 14), and Mayfield nest success (27%, Table 18) differ considerably from each other. The frequent use of success defined as the number of eggs (or nests) hatched divided by the number found may underestimate losses (Mayfield 1975, Miller and Johnson 1978). These estimates do not incorporate the span of time observed. Nests lost in the earlier stages of incubation have a lower probability of being found and incorporated into nest success. At sites with high predation or when nests lost early could be easily missed (as with plovers), daily survival rates accurately report nest success. Nest success at study sites with catastrophic losses, such as floods, however, is best estimated using the apparent method (Johnson and Shaffer 1990), but this requires high nest detectability. Techniques for calculating nest success when nests are visited at irregular (Bart and Robson 1982) or infrequent intervals (Miller and Johnson 1978, Johnson 1979) also have been developed. Pollock and Cornelius (1988) proposed a distribution-free nest survival estimator. These techniques were not needed for our calculations because we observed nests daily (a frequent and regular interval). Calculating the probability that any given nest will hatch (the interval survival rate) from the daily survival rate is most appropriate for piping plovers.

Survival of nests with or without bits of white shell fragments as a nest scrape lining was nearly significantly different ($P = 0.077$); however, this may be misleading. Nest site information was collected after the nest hatched or during incubation (such as during banding or exclosure construction). Shell fragments appear to be added to the nest scrape during laying and incubation (Cairns 1982, pers. obs.). Nests lost very early, such as after the first or second egg, may not have had "seashell" fragments present because of the timing of the loss. Half (5) of the nests without shell fragments were lost very early, suggesting this bias.

Piping plovers have been observed to line their nest scrapes with broken pieces of white shell (as we observed), small stones, bits of slate, and driftwood (Bent 1929, Wilcox 1959, Palmer 1967, Cairns 1982, Sidle 1985, Haig and Oring 1988b), depending upon what materials are available. The exact function of a nest scrape lining is unknown, but it may facilitate water drainage away from the eggs. However, Cairns (1982) reported eggs inundated with water later hatched. A nest scrape lining also may reduce heat conductance from the sand on hot days, or help maintain a more constant incubation temperature in a cooler environment. Another possible function of a nest scrape lining may be to stabilize the sand in the nest cup and, therefore, keep the nest from collapsing when the incubating bird leaves the nest.

Human disturbance of incubating adults

Few contacts between humans and plovers were recorded. Humans were within 300 m of a nest in less than 3% of all nest observations. When we approached nests, we observed human tracks in the area 6% of the time. These data suggest that

current human use on the northern 8 km of AINS is infrequent, compared to other Atlantic Coast beaches. Goldin et al. (1988) reported plovers were disturbed by humans an average of every 2.4 minutes at Breezy Point, New York. MacIvor (1990) and Burger (1987) also reported human use on their study beaches that appears to be higher than on AINS (town beaches, condominiums adjacent to the beaches, restricting human use to travel corridors through the dunes, and the use of beach sweeping equipment and bulldozers to clean the beaches), but they did not directly quantify human use.

Although human presence near nests is infrequent, one nest apparently was abandoned because of nearby human activity in 1990. We found many human tracks and empty beverage bottles among the dunes 20-30 meters from the nest. It appeared as though the humans spent considerable time adjacent to the nest and one set of human tracks lead up to and away from the predator enclosure. The adult plovers did not return to the nest the following day.

Predation

We observed high rates of piping plover nest predation on AINS. Predators destroyed 37% of known nests and were responsible for 77% of known nest losses. Patterson (1988) found predation to be high in previous years as well (30% of known nests and 65% of known nest losses). In Massachusetts, MacIvor et al. (1990) and Rimmer and Deblinger (1990) reported 52-81% and 71% of nests lost to predators at

various beaches. Whyte (1985) also found nest predation to be high. Cairns (1982) found 35% of known eggs were lost to predators; Haig and Oring (1988b) reported that 40% of known nests were destroyed by predators. Ailes (1988) and Cross (1989) reported that predators were responsible for a majority of known nest losses on Chincoteague NWR (south end of Assateague Island), but they also have achieved some success using predator exclosures and extensive predator control.

Red foxes were responsible for 77% of total nest predations on the north end of Assateague Island, and were the sole predator in 1989 and 1990. Fox predation rates on AINS were 71% in 1986-1987 (Patterson 1988). MacIvor et al. (1990) attributed 71-100% of nest predations on Cape Cod to red foxes. Similarly, Rimmer and Deblinger (1990) reported red foxes were responsible for 47% of nest predations in Massachusetts. Although problematic in the past, red foxes were only responsible for 14% of the total loss in 1988 on Chincoteague NWR (Ailes 1988); however, extensive predator control and the use of exclosures helped reduce losses.

Observations of red fox foraging movements suggest foxes primarily are nocturnal and are not searching specifically for piping plover nests. Foxes find plover nests through systematic searches through nesting habitat or by accidental encounters on Cape Cod (MacIvor et al. 1990) and on AINS (Bashore pers. commun.).

Our initial exclosure design did not prevent high losses (6 of 7 nests) to avian predators, but we recorded only 1 instance of avian predation (gull) not associated with an exclosure. Avian predation does not appear to be a problem on AINS, yet the potential exists. Woody vegetation encroachment, such as that occurring on the

northern 1 km of the island, has recently provided nesting habitat for crows (*Corvus* spp.) and boat-tailed grackles (*Quiscalus major*) immediately adjacent to plover nesting areas. In 1988, fish crows (*C. ossifragus*) were observed regularly carrying least tern eggs from an adjacent colony to presumed nesting areas in the trees.

Although a problem in other areas, raccoons (*Procyon lotor*) do not appear to be very abundant on the northern 8 km of AINS. They are, however, present farther south on the island and have preyed on piping plover nests in Virginia (Patterson 1988). Other reported nest predators include American crows (*Corvus brachyrhynchos*), opossums (*Didelphis virginiana*), skunks (*Mephitis mephitis*), gulls (*Larus* spp.), domestic pets, grackles (*Quiscalus* spp.), Norway rats (*Rattus norvegicus*), and house mice (*Mus musculus*) (Wilcox 1959, Burger 1987, Patterson 1988, MacIvor 1990, Rimmer and Deblinger 1990).

Predation has been identified as a major limiting factor affecting Atlantic Coast piping plover populations (Dyer et al. 1988). Further investigation of piping plover productivity has confirmed the impact of predators, especially red foxes, yet little is known about predator population dynamics. Red foxes are important predators on Assateague Island and on Cape Cod, but few historical data are available. Foxes may not have been a problem in the past because they were not a natural component of barrier island systems. Rhodes (1903), Gilmore (1946), and Churcher (1959) provide convincing evidence that the foxes on the Atlantic Coast barrier islands are descendants from European stocks, placed there by fox hunters between 1650 and 1750. Colonial records show foxes were introduced into New York, Maryland, and

Virginia. Native red foxes appear to have been restricted to northern boreal forests prior to European colonization. The determination of whether these populations are native or exotic (European) is especially important when considering management options on sites administered by the National Park Service.

Although not a problem on AINS during this study, expanding gull populations could increase gull predation in the future. Recently, gull populations have been expanding their breeding ranges (Sidle 1985, Lock 1988). In addition to direct predation, gulls also may exclude plovers from nesting areas (Dyer et al. 1988). MacIvor (1990) suggested that plovers avoided nesting on Monomoy NWR because of its large gull population, even though physically suitable habitat was present. Cross (1987) thought herring gulls (*Larus argentatus*) affected nesting distribution of plovers on Metompkin Island. Gull population dynamics and the effects of human refuse deposited in coastal landfills should be addressed.

At other nesting sites, concern that humans may inadvertently attract predators to nesting areas may be warranted. Leftover or discarded food scraps, garbage, or fish entrails all could attract potential predators. On AINS, however, we found very little human refuse on the northern 8 km of the island (See Chapter 3 for details).

Other factors limiting reproductive success of plovers include coastal development. Construction projects can remove suitable nesting habitat directly (e.g. by onsite construction) or indirectly (e.g. by encouraging increased human use), forcing plovers into suboptimal habitat. Dune stabilization encourages vegetative growth, reduces overwash, forms narrower, steeper beaches (Dolan 1973, Godfrey

and Godfrey 1973), and destroys the flat beach that plovers tend to prefer (Burger 1987). Wilcox (1959) noted that plovers abandoned a site following a successful dune stabilization project. The placement of dredge spoil material also is of interest, as new nesting habitat can be created. MacIvor (1990) observed plovers nesting on dredge spoil deposits. Spoil deposition that would retard the natural scouring and overwashing of barrier beaches, however, should be discouraged. Vegetative encroachment because of a lack of overwash has forced plovers to nest elsewhere (MacIvor 1990) in Massachusetts. The northern 1 km of AINS has been protected from storm events by a spoil dune since 1962. As a result, vegetation is flourishing on the bay side of the spoil dune. Loblolly pines (*Pinus taeda*) > 5 m tall with > 25.4 cm diameter breast height (DBH), and extensive bayberry (*Myrica pensylvanica* and *M. cerifera*) thickets (> 7.5 cm DBH) are present. This unnatural encroachment on a barrier island tip has provided a refuge for potential predators, including red foxes, crows, and boat-tailed grackles. Additionally, because overwashing waves have been prevented from reaching the bay, no access paths are present. Dredge spoil deposition alters the naturally dynamic nature of barrier islands and promotes stabilization. These natural processes are vital to the maintenance of nesting habitat and provide access to the bay side of the island.

Predator Exclosures

Predator exclosures did not increase daily nest survival on AINS because a number of exclosed nests were predated. Mayer and Ryan (1991), however, increased nest survival substantially in North Dakota by fencing off entire nesting beaches. Rimmer and Deblinger (1990) used large (30-m perimeter) triangular exclosures around individual nests to significantly boost apparent hatching success to 92% in Massachusetts. MacIvor (1990) also increased apparent nest success to 77%, compared with 13% for unexclosed nests on Cape Cod. Similarly, Ailes (1988) and Cross (1989) reported 85% and 78% apparent nest success for exclosed nests compared with 27% and 35% for unexclosed nests. In the present study, all exclosed nests hatched in 1989, but in 1988 and 1990, some exclosed nests were depredated, reducing our nest success. No predators got inside predator exclosures used by Rimmer and Deblinger (1990)(n = 26). Mayer and Ryan (1991) reported several intrusions of their exclosed beaches resulting in depredations, but overall nest success remained high. Nol and Brooks (1982) did not increase killdeer (*Charadrius vociferus*) nest success with exclosures and suggested their design was too small (1-m square) because raccoons could reach through the openings and obtain the eggs. Mink (*Mustela vison*) and long-tailed weasels (*Mustela frenata*) also were not stopped by their design, although few designs would be effective against mink and weasels and still allow the incubating bird access to the nest.

The probability of an unexclosed nest hatching in 1988 was $< 40\%$ (interval survival, Table 20). In 1989-1990, this was $< 3\%$. Predation pressures were not as extreme in 1988 as they were in the 2 following years. Actual nest survival probabilities were lower than these rates suggest, as nests lost before clutch completion have been excluded from this analysis. The low probability of survival underscores the high and possibly increasing predation pressures on AINS. The higher nest survival rate in 1988 may have been a result of many factors. In 1988, least terns nested on the northern 1 km of the island, adjacent to the denning area of 1 family of foxes. Tern eggs and chicks may have supplemented the foxes diet, reducing the pressure on the plovers. The colony was decimated and terns did not return in 1989 or 1990. The mobbing behavior of the terns provided no additional protection for nesting plovers from fox predation as only one pair nested within the tern colony and it was an enclosed nest.

Local factors are important in determining the implementation of exclosures. Exclosures without tops were used in Massachusetts with no ill effect (MacIvor pers. commun.). The results of using topless exclosures on AINS were catastrophic. In 1988, six of seven topless exclosures were depredated by unidentified avian predators (we suspect grackles and/or crows). Avian predators may have investigated the sudden appearance of an unfamiliar object or perhaps used the exclosure as a perch and discovered the eggs secondarily. The remaining nest may have been protected from avian predators as it was located in a least tern (*Sterna antillarum*) colony (Burger 1987, MacIvor 1990).

In 1988 and 1989, we waited to exclose a nest until it contained a complete clutch to avoid the chances of desertion and so that we could trap and band the adults. Consequently, 17 of 81 (21%) nests were depredated before they reached a complete clutch or before we could band the adults. In 1990, we constructed exclosures as soon after finding the nest as possible. We had no problem with acceptance of the exclosures before clutch completion and recommend this period for exclosure construction. Adults incubate sporadically at this time and construction may not interrupt an incubation bout. Although others (Ailes 1988, Cross 1989, MacIvor 1990) generally have waited for clutch completion, we believe our method is prudent at sites with high predation pressure.

The time to construct an exclosure was 17.7 minutes, 10 minutes for the exclosure construction and 7 minutes for constructing the top. MacIvor (1990) reported a construction time of 10.5 minutes for a similarly designed exclosure (without a top); however, she used 3-4 people rather than 2, as we did. Plovers were away from the nest longer for our study (17.1 vs. 24.3 min.), but this is approximately the time needed to construct the top. On Chincoteague NWR, Cross (1989) constructed exclosures of similar design in 15 minutes and his total exposure time (construction time + time for the plover to return) was 29 minutes.

MacIvor (1990) observed that 2 of 16 (12.5%) piping plover pairs would not tolerate the presence of an exclosure and resumed incubation only after the exclosure was removed. Furthermore, she suggested that, for one pair, this intolerance may have been the result of banding 1 of the birds on the previous day.

We observed no such response. On 5 occasions, we trapped and banded one or both adults immediately prior to exclosure construction. Although we experienced no problem with this technique, I recommend trapping and exclosing nests on the same day be done cautiously. It took the adults longer to resume incubation following both banding and exclosure construction, compared to exclosure construction alone. Longer exposure periods could increase the risk of temperature stress on the eggs. The increased nest exposure and resume time can only be justified at sites with extremely high predation pressures.

Fox depredation of exclosed nests

The sequence of events at exclosed nests attacked by foxes suggested that the fox(es) became increasingly adept at gaining access to exclosed nests. It appears that the fox(es) responsible for the exclosure depredations learned and remembered. The fact that, in 1990, each exclosure penetrated had less digging than the previously violated exclosure, and that exclosures were ultimately entered over the top is consistent with this hypothesis. In 1989, foxes dug around 1 exclosure two days before hatch and again on hatch day, but did not get inside. On Chincoteague NWR, foxes were observed to dig around exclosures as well; however, none gained access to the nest (Ailes 1988, Cross 1989). In 1990, we observed 11 of 19 exclosures with evidence of fox activity around them. The first 4 instances all involved fox(es) digging to depths of 10-15 cm, completely encircling 3 exclosures. Fox(es) climbed over the

exclosure and depredated the nest in 2 of these first 4 instances (both were within a day or 2 of hatching). The next 2 instances had only 2 scratches in the sand outside the exclosure and also were lost to foxes. The subsequent 3 instances showed no signs of foxes digging around the exclosure and all 3 nests were eaten. The last 2 instances each had digging around all sides of the exclosure but only 1 nest was lost. In an attempt to exclude fox(es), we increased the strength of the monofilament top to 60 lb. test, and reduced the space between lines to 5 cm. We also doubled the height of two exclosures to ~1.5 m using 2 welded wire sections with 20 cm overlap. Neither new design excluded the fox. We suspect that all 8 nests depredated were the work of a single fox because all were within a single fox territory (Bashore pers. commun.).

I suspect chick communication before hatch may have drawn the fox to the nests. I examined 5 nests just prior to hatching. I could hear clicking or the chicks pecking against the shell in all cases. In 4 nests, I heard chicks peeping 3, 2, 2, and 1 days before hatching. Experimental evidence shows chicks make clicking sounds a day or two before they hatch to synchronize hatching (Vince 1966, 1969, 1972). Near the time of hatching, adults seemed to be restless and easily disturbed. The noise from the eggs, or the increased motion of the adults may have attracted predators to the nest. -

MacIvor et al. (1990) suggested red foxes on Cape Cod avoided experimental nests where human scent was applied daily (the eggs were handled). Additionally, MacIvor (1990) felt that red foxes may avoid contact with exclosures. Conversely, Nol

and Brooks (1982) thought human scent on exclosures may have attracted mammalian predators to killdeer nests. Foxes on AINS appeared to locate and destroy exclosed nests regardless of human scent.

We recommend continued use of predator exclosures. Our current design is inexpensive, quickly erected and only requires 2 people for construction. When individual foxes learn to associate exclosures with eggs, these individuals must be removed. Selective removal of problem foxes by trapping or shooting would likely be most effective just prior to the breeding season. At this time, foxes have established breeding territories (Bashore pers. commun.), and selective removal of individuals would disrupt successful fox reproduction and eliminate individuals residing near plover breeding areas.

We recognize a number of improvements to our current design. The number of stakes used should be increased to 5 (instead of 4) to make the exclosure sides more rigid and the overall shape more circular. In our previous design, the welded wire was not completely rigid between the stakes and may have allowed fox(es) to use the side of the exclosure as an incline rather than acting as a vertical barrier. Slightly taller (1.2 m) exclosures may create a better barrier to red foxes. An overall larger diameter (15 m circumference) would further separate the exclosure sides from the eggs. This might help reduce predation if sight, scent or sounds from the nest are providing cues. Tops are effective against avian, but not mammalian, predators; therefore, we recommend their continued use using 20 lb. monofilament (fishing line) with 10-cm spacing. At sites where foxes have learned to plunder enclosed nests, a

top of chicken-wire may prove effective. On AINS in 1991, initial field trials using chicken-wire as a top resulted in no loss of nests (MacIvor pers. commun.), but the sample size was small ($n < 5$). A more rigid top, however, may be more likely to injure the incubating adult if it attempts to fly from the nest. We observed 2 instances when adults were startled and flew straight up, through the monofilament top. A more rigid top would prevent this.

The recent widespread use of predator exclosures may increase hatching success, but could reduce chick survival at sites with high predation pressures. The use of predator exclosures usually boosts hatching success, putting more broods on the beach in a given year. With more broods present in a given area, the chance that a predator will encounter a brood increases. Predators (such as foxes) may come to recognize plover chicks as a food resource with an increasing frequency of encounters, and may increase their search effort in the immediate area around a plover brood once they had found a chick (Tinbergen et al. 1967). If whole broods are eaten, this could be a serious setback because plovers frequently renest after losing their nest (Wilcox 1959, Cairns 1977, Whyte 1985, Haig 1987, Patterson 1988, MacIvor 1990) but seldom renest after losing a brood (MacIvor 1990, this study). To boost reproductive success, both the egg stage and chick stage need to be protected.

Chick Survival

Seventy-five percent of chick mortality occurred within the first 6 days of life.

Chicks surviving to 10 days of age had nearly twice the probability of surviving than younger chicks. This is consistent with survival at AINS in previous years. Patterson (1988) reported that 79% of chick mortality in 1986-1987 occurred in the first 10 days. Cairns (1982) also reported that most chick mortality was concentrated in the first 10 days of life. Cross (1989) reported that 70% of chick mortality on Chincoteague NWR occurred in the first week. On Cape Cod, Massachusetts, MacIvor (1990) observed slightly lower chick mortality (59%) during this same period in 1985-1989. Flemming et al. (1988), however, found chick mortality in Nova Scotia during 1979-1983 concentrated between 10 and 17 days of age.

Specific causes of chick loss are difficult to identify. Patterson (1988) did not identify any causes of chick mortality in 44 hours of daylight brood observations on AINS. I attempted limited night observations using night-vision equipment but found the contrast between the light colored plovers and the sand was not sufficient to distinguish the plovers. Pienkowski (1982) experienced similar problems with ringed plovers (*Charadrius hiaticula*) but found a dark mud flat to have sufficient contrast.

We observed 2 instances in which we are confident in assigning the causes of loss. In 1988, we watched a brood of 2 chicks cross the beach, become disturbed, and retreat. We only saw 1 chick after this disturbance. Minutes later, we discovered a ghost crab (*Ocypoda quadrata*) feeding on a freshly eviscerated chick. The chick

was 8 days old and weighed 9 g (eviscerated). We are confident that the ghost crab caught and killed the chick. Patterson (1988) saw a ghost crab attack a newly hatched chick, but the adults quickly repelled the crab in that instance. Ailes (1988) and Cross (1989) reported that ghost crabs were responsible for a large portion of chick mortality on the Wild Beach at Chincoteague NWR, but they provided no direct observations to support this. The alternative hypothesis that chicks are limited by the availability of food resources still needs to be addressed on the Wild Beach.

In 1990, we approached an exclosed nest (previously with 4 eggs) and found only 1 egg, which was in the process of hatching. A 1-m band of fox tracks completely encircled the exclosure and there was some digging. Although we did not directly observe any foxes, the evidence suggests that any previously hatched chicks (maximum of 3) were eaten by waiting fox(es). The final chick hatched later that day, and fledged.

Other than these 2 instances, we were unable to document any causes of direct chick mortality. Patterson (1988) found a chick crushed by a vehicle in 1987. Goldin et al. (1988) found 2 dead chicks: 1 crushed by a vehicle and the other dying from unknown causes.

Chick Weight, Survival, and Energy Demands

The chick weights and survival patterns that we observed in the different habitats are consistent with the hypothesis that differing food availability is an

important determinant of the different survival patterns of plover chicks in different habitats (In Chapter 3, we will continue this discussion and provide additional evidence). In habitats without sufficient forage, chicks cannot maintain a positive energy balance, and therefore lose weight and may succumb to exposure or predation as a result of their starvation-induced weakness. For this reason, we examined the weights of chicks in different habitats. We found chicks on the bay beach and island interior were heavier than those on the ocean beach. Additionally, daily survival rates of chicks on the bay beach and island interior were substantially higher than those on the ocean beach.

Chick Weight

The fact that, at 4 to 5 days of age, the weights of chicks that ultimately survived were greater than the weights of chicks that did not survive, is consistent with our hypothesis that poor food supply contributes importantly to chick mortality on AINS. Cairns (1982) also found that chicks that did not fledge had lower body weights in the first 10 days than chicks that survived. On AINS, chicks that fledged had longer culmens than those that perished, suggesting that surviving chicks are growing, as well as gaining weight.

Chick Energetics

Upon hatching, chicks continue to draw on yolk energy reserves for the first few days; however, most species exhaust the yolk reserve in 1-4 days at a fairly even rate (Kear 1965, Ricklefs 1974, Whittow 1976, Welty 1982, O'Connor 1984). Yolk reserves provide the chick with energy during the first few days while it learns various survival skills

(e.g. foraging, predator avoidance, etc.), freeing it of the need to instantly learn how to forage effectively.

Energy demands increase soon after hatching. Basal metabolism of a typical precocial species peaks soon after hatching and can easily reach 2-3 times that of adult rates. At 10-25% of adult weight, the metabolic rate and energy demand is greatest (Ricklefs 1974:246). This corresponds to piping plover chick weights of 5-13 g -- the same range of weights we observed in chicks 4-5 days old. Precocial chicks lose weight during the first two days after hatching. Their weight stabilizes and they begin to gain weight after the third day (Soikkeli 1967, Cairns 1977, Pienkowski 1984a). Pienkowski (1984a) found that ringed plover chicks did not begin to gain weight until 2-3 days after hatching, but then gained weight steadily through fledging.

Access to food is essential for the survival of these young chicks. Their metabolic demands are increasing at a time when yolk reserves are exhausted. If food is not available, mortality rates would increase as chicks deplete their internal energy reserves.

Reproductive Success

Overall, 43% of the chicks that hatched on AINS fledged (Table 24). The variations in how fledging success is defined and reported in other studies makes comparisons difficult; therefore, I will only discuss comparable figures. MacIvor (1990) reported a mean of 61% for the beaches in her study. Patterson (1988)

reported 19-69% of chicks fledged in different brood foraging habitats. On Chincoteague NWR, Ailes (1988) found a 40% chick fledging rate.

Productivity (chicks fledged/breeding pair) is low and highly variable in North America (Haig and Oring 1985). During the course of this study, reproductive rates varied among Atlantic Coast states from a low of 0.43 (n = 14 pairs) in North Carolina in 1990 to a high of 2.38 (n = 16 pairs) in Maine in 1989 (Hecht 1988, 1989, 1990). Overall, Maryland had nearly the lowest productivity of all Atlantic Coast states and provinces in all 3 years with only North Carolina (0.59 in 1989 and 0.43 in 1990) and Delaware (0.0 in 1988) reporting lower figures. This underscores the need for efforts to boost reproductive success on AINS. The successful use of predator exclosures in 1989 increased reproductive success but not substantially. Further efforts to increase reproductive success are warranted.

The productivity on AINS is currently below levels necessary to maintain a stable population (Prindiville Gaines and Ryan 1988, Melvin et al. 1991, this study). Productivity is limited on AINS by high nest predation and the early loss of chicks. Chick loss is difficult to quantify, but predation and the availability of adequate forage (Chapter 3) impacts chick survival. MacIvor (1990) recognized the difficulty in identifying chick mortality and believed predation was responsible for a substantial portion of her losses. Wiens and Cuthbert (1984) also suggested that most chicks were lost to predators, but recognized starvation as an alternative hypothesis. Cross (1989) believed that avoiding predation was of greater importance to chicks on Chincoteague NWR than acquiring sufficient food. On Tom's Cove Hook, the south

end of Assateague Island, where broods have a choice of foraging habitats, 85% (n = 14) moved to mud flats, tidal pools or barrier flats soon after hatching, areas we recognize as higher quality foraging areas (as discussed in the following chapter) suggesting that adequate forage may not be limiting.

SUMMARY

The piping plover breeding population on AINS was 25, 20, and 14 pairs in 1988, 1989, and 1990, respectively. We found 34, 27, and 19 nests in 1988, 1989, and 1990, respectively. Incubating plovers flushed from their nests at greater distances than reported elsewhere (median = 120 meters) in 1990. To reduce disturbance to incubating adults, we recommend the use of 225 m disturbance buffers on AINS. Forty percent of the piping plover nests found hatched. The daily nest survival rate was 0.962. Nest predation was high and was primarily due to red fox. Predator exclosures did not improve overall nest survival. Six exclosed nests were lost to avian predators and 8 exclosed nests were lost to foxes.

Chick mortality was concentrated in the first 10 days of life. Chick survival on the bay beach and island interior habitats was higher than on the ocean beach. Similarly, weights of chicks raised on the bay beach and island interior were greater than those raised on the ocean beach. Surviving chicks were substantially heavier and had grown more than chicks that died. Thirteen, 18, and 11 chicks fledged in 1988-1990, respectively. Overall reproductive success was 0.71 chicks fledged / breeding pair for the study, well below the estimated levels necessary to maintain a stationary population.

Chapter 3. COMPARING BROOD FORAGING

HABITAT

In 1986-87, Patterson (1988) observed that plover chicks in broods that moved to bay beach foraging areas had a higher probability of surviving than those that were reared on the ocean beach. Plovers moved to the bay beach via vegetation-free paths created by storm wave overwashes. Large waves generated by Hurricane Gloria extensively overwashed the northern 8 km of Assateague Island in September, 1985 (U.S. Dept. of Commerce 1985), scouring numerous paths from the open beach to the bay (Bashore and Krim 1986). Hurricane Charley in August, 1986 (U.S. Dept. of Commerce 1986) maintained these paths (Patterson pers. commun.). Other portions of the northern 8 km of the island were not as extensively overwashed, and chicks hatching in these areas selected or were restricted to feed on the ocean beach. In 1988, we identified a third major habitat use area, the island interior, and incorporated it into our study design. The island interior is located along the margin of the vegetation or within sparse vegetation (Table 1).

Any of three hypotheses could explain the observed differences in chick survival between broods reared on the bay beach (high survival) and those restricted to the ocean beach (low survival, Table 24): 1) higher predation pressures on the ocean

beach could reduce survival, 2) disturbance rates could be greater on the ocean beach, resulting in plover chicks spending more time vigilant, less time feeding, and expending more energy escaping, 3) lower food availability on the ocean beach may weaken chicks and contribute to increased starvation or predation, or any combination of hypotheses (Patterson et al. 1991). We addressed each of these hypotheses, with special emphasis on the forage availability hypothesis.

Bay beach foraging habitats had higher chick survival than ocean beach habitats. We examined these differences by comparing foraging rates, activity budgets, prey abundances, disturbance rates, and human presence among the habitats. Given the survival rates observed in 1986-1987, we made a number of predictions based on our hypotheses. We predicted that 1) indices of predator abundance on the bay beach would be less than those on the ocean beach; 2) disturbance on the bay beach would be lower than on the ocean beach (e.g. indices of non-predators [including humans] on the bay beach would be less than on the ocean beach); and 3) chick foraging rates and prey abundances on the bay beach would be higher than on the ocean beach. We also predicted that chicks on the bay beach would weigh more than those on the ocean beach but recognize this may be the result of a combination of food availability and disturbance.

METHODS

Determining Brood Foraging Habitat

After the eggs of known nests hatched, each brood was located daily to determine the foraging habitat used. All birds were checked for bands, which were read and recorded. The location of each family group was recorded daily, providing us with information on habitat use and brood movements.

We observed the plovers from a sufficiently distant or concealed position so that brood location was unaffected by observation. A portable blind was used occasionally but with little success. The vehicle provided the best blind. We recorded bird locations when first encountered. When we found a brood, we recorded the tidal level (hours past high tide to the nearest quarter hour), temperature, % cloud cover, wind direction and speed (Beaufort scale), brood location (Appendix A), habitat type, and the number of people within 300 m of the brood.

Behavioral Observations

Foraging Behavior

Foraging data were collected by watching focal chicks or adults for 5 minute periods (Altmann 1974). A digital timer¹ with an alarm was used to time the periods. During each observation period, we characterized foraging movements (Table 1) and recorded the number of such movements. If the focal animal was lost from view, the observation was resumed and completed if the animal became visible within approximately 2 minutes (Lehner 1979), otherwise, the observation was terminated. To the extent possible, each chick in the brood was observed in sequential 5-minute observations. Because we felt that foraging rates and behaviors among chicks within a brood may not be statistically independent, we calculated a mean foraging rate for each brood and used this foraging rate in subsequent statistical comparisons.

One or both adults also were observed when possible. We termed adults observed within 25 meters of a brood as "tending adults." We also observed "lone adults" that were not associated with a brood when we had the opportunity. We calculated separate values for the chicks and adults.

We attempted to sample all broods daily, but when time constraints prohibited this, we focused most closely on the 0 to 10 day-old chicks because this age group

¹ Timer Plus, manufactured by Fisher Scientific

experiences the highest mortality rates (Cairns 1982, Patterson 1988, MacIvor 1990, this study; but see Flemming et al. (1988) who reported the greatest mortality between 10 and 17 days of age). In general, we attempted to sample all broods > 90% of the days.

We calculated foraging rates by dividing the number of foraging attempts (pecks) by the observation time and expressing them in attempts per minute for age classes 3-10 days old, 11-20 days old, 21+ days old, lone adults and tending adults. To preserve independence, we calculated a mean value for each age class at each location (Habitat Unit, see Appendix A) and analyzed this data set. Foraging rates were found to be non-Gaussian; therefore, when we compared rates in different habitats we used a Kruskal-Wallis test. Comparisons among bay beach, island interior and ocean beach habitats were made excluding observations of chicks 0-2 days of age because it generally took 2 days for broods to move to the bay beach or island interior habitats from their nests on the ocean beach (i.e. there were no chicks 0 days old observed on the bay beach). After 3 days of age, the number of chicks in each habitat was balanced.

We weighed chicks 4 and 5 days of age in as many broods as possible (See Appendix H). We tested if a relationship existed between this weight and the foraging rate for each respective age class (Spearman's correlation coefficient).

Time Budgets

We gathered time budget information as we conducted the 5-minute foraging observations. A programmable stopwatch beeped at ten-second intervals, at which time the behavior of the focal bird was noted. We recorded both behavior (Table 25) and disturbance sources. We dictated data into a tape recorder and transcribed the tape that evening. For analysis, some behaviors were pooled into more general categories (Table 25). To preserve statistical independence, time budget data were pooled for each brood, and a mean was calculated for each location in the same manner as the foraging data.

Prey Sampling

Approximately once a week, we sampled prey populations (terrestrial arthropods and substrate invertebrates) in 4 areas. Two areas were within randomly selected brood foraging sites, and two areas were selected at random. Brood sites were selected by drawing 2 of the available brood numbers out of a hat. For the random sites, we used a random numbers table to select a random distance south of the Ocean City Inlet. We collected samples from the ocean beach, bay beach, and island interior. We attempted to collect samples from the same relative position on

the beach in each respective habitat. In brood foraging areas, we attempted to center our sample areas where we had observed plovers foraging.

Terrestrial Arthropods

We sampled available arthropods at all sites using 2 sticky paint stirrers exposed for 30 minutes. Tanglefoot® Insect Trap Coating² was used to capture arthropods on these sticks. We placed one stick horizontally on the ground and the other vertically, approximately 10 cm apart. The area exposed was 64.5 cm² (21.5 cm x 3 cm) for the horizontal stick and 129 cm² for the vertical stick. Arthropods were counted by size class and Order.

In 1990, we sampled terrestrial arthropods in all 3 habitats using a sweep net. Ten sweeps ~10 cm above the surface of the sand were taken, and the number of arthropods captured were counted. We used similar sweep techniques in each habitat. Ocean beach samples were taken along the wrack line, bay beach samples were taken along the shore, and island interior samples were taken along the edge of the vegetation or within the sparse vegetation.

Relative arthropod abundances were compared among habitat types using Kruskal-Wallis tests. Random points and brood-rearing territories were compared with a Wilcoxon signed-rank test. To control for temporal variability, we paired samples from random sites and brood-rearing territories by each week. Statistical

² The Tanglefoot Company, Grand Rapids, MI 49504, available from Forestry Suppliers, Inc., Jackson, MS 39284-8397

analyses were performed on the difference between brood-rearing territories and random sites.

Substrate Invertebrates

In 1988, we initiated substrate sampling. We obtained 3 subsamples along the shore or upon a mud flat, if present, on the bay beach; 3 subsamples from the wet sand on the ocean beach; and 3 subsamples from the saturated sand low on the ocean beach. Subsamples were taken 5-10 m apart. Within brood-rearing territories, we attempted to sample areas where we observed plovers foraging. In 1989, one sample each was taken from the bay beach or mud flat, the wet zone and the saturated zone of the ocean tidal zone, and a sample was taken from the island interior, along the margin of the vegetation or within the sparse vegetation (Table 1).

For each sample, we recorded the time of day and tidal level. We preserved samples in 5-10% formalin with Rose Bengal (approx. 1/2 tsp./20 L 10% formalin solution, enough to color all life forms pink). We extracted all life forms ≥ 1 mm from the sand using watchmaker's forceps or by swirling the mixture and decanting the organisms. We manually searched for bivalves following decanting. We identified polychaetes, bivalves, and insect larvae to Class and amphipods to Order (Amphipoda).

We compared relative invertebrate abundances among habitat types using Kruskal-Wallis tests. Wilcoxon Rank Sum tests were used for pairwise comparisons

following significant Kruskal-Wallis tests. Random points and brood-rearing territories were compared with a Wilcoxon signed-rank test as described in the previous section.

Monitoring Human Use and Predator Abundance

Disturbance-predation Transects

In order to compare potential disturbance and predation rates among habitats, we obtained indices of human use and predator use in the 3 habitats. Once a week, in each brood foraging site, we walked a 100-m-long, 4-m-wide transect parallel to the wrack line. The center of the transect was 5 m above the wrack line, and the 50-meter mark was adjacent to the approximate center of plover activity during the preceding week. A second transect, 50-m long and 4-m wide, ran perpendicular to the midpoint of the first transect, away from the water. In brood foraging sites with access to both the high energy beach and the bay beach, we established and traversed transects in both habitats to determine the relative differences in disturbance within each territory. Island interior transects were initiated in 1989.

During each traverse, we recorded the number of human trails, the number and type of human refuse items, the number of ghost crab burrows, and the number and

type of predator and nonpredator trails, by species, using a modified line intercept method (Gysel and Lyon 1980). Because garbage, ghost crabs, or carrion may influence predator foraging patterns, we recorded the number of these items on the transect as well. We ran transects 1 to 3 days after high winds or heavy rains erased all tracks. For analysis, we standardized all track counts for 1 day of exposure.

Statistical comparisons among the 3 habitats were made using Kruskal-Wallis tests. We compared brood-rearing territories and random points using a Wilcoxon signed-rank test. As in the analysis of invertebrate prey, samples were paired by the week of collection and the analysis completed on the difference between brood-rearing territories and random samples. Only trail counts from animals in which we observed 1 or more trails/transect in > 70% of the transects were analyzed statistically (i.e. datasets containing more than 30% zeros (ties) were not analyzed).

We assessed track longevity on AINS in 1990. Tracks were made daily on an experimental plot. The plot was checked daily and track disappearance was recorded.

RESULTS

Brood Movements

On average, piping plover chicks moved less than 200 m from their nest sites in the first 10 days of life (Table 26). After 20 days old, chicks became more mobile, moving more than 1 km in one instance.

Foraging Behavior

Foraging rates for chicks 3-10 and 11-20 days old differed among habitats (Kruskal-Wallis $\chi^2 = 14.4$, 2 df, $P = 0.0007$ and $\chi^2 = 8.0$, 2 df, $P = 0.0186$, respectively, Table 27). Ocean beach foraging rates for these chicks were lower than bay beach and island interior rates. Foraging rates did not differ among habitats in the 21+ days-old age class. This age class used the ocean beach more frequently than the

younger age classes. Tending and lone adult foraging rates similarly were highest in bay beach habitats.

Lone adults foraged at a higher rate than tending adults on the bay and ocean beaches (Wilcoxon Rank Sum [normal approximation with continuity correction] $Z = 2.26$, $P = 0.0235$; $Z = 3.32$, $P = 0.0009$, respectively) but not in the island interior along the vegetation margins ($P = 0.6592$).

Chicks (all age classes) used vegetation gleaning to a greater extent on the bay beach (1.4%) and island interior (0.9%) than on the ocean beach (0.4%)(Kruskal-Wallis [chi-square approximation] $\chi^2 = 9.3$, $P = 0.009$). All other methods of prey capture did not differ among habitats (Table 28). Chicks took prey primarily from the substrate surface, penetrating the substrate only on a few occasions (pers. obs.).

Foraging rate increased with age within the 3-10 day age class in the island interior (linear regression, $F = 12.9$, $P = 0.001$, adjusted- $R^2 = 0.285$, Figure 8) but not in other habitats or age groups ($P > 0.05$).

The Spearman's correlation coefficient showed a positive relationship between chick weight (at 4-5 days old) and foraging rate for chicks 3-10 days of age ($r = 0.38$, $P = 0.013$, $n = 42$) for all habitats combined. Piping plover chicks 3-10 days of age that ultimately fledged showed no relationship between weight (at 4-5 days old) and foraging rate (3-10 days) on the bay beach, island interior, or ocean beach.

Time Budgets

Young piping plover chicks (≤ 20 days) spend most of their time foraging (Table 29). Island interior and bay beach chicks 3-10 and 11-20 days old spent more time foraging than ocean beach chicks (Kruskal-Wallis $\chi^2 = 11.1$, 2 df, $P = 0.004$ and $\chi^2 = 10.1$, 2 df, $P = 0.007$, respectively). The proportion of time spent in locomotion in the 11-20 days old age class was higher on the ocean beach than on the bay beach (intermediate) or the island interior (lowest) (Kruskal-Wallis, $\chi^2 = 7.9$, 2 df, $P = 0.019$). The proportion of time spent in preening, alert, or resting behaviors did not differ among habitats.

Tending adults on the bay beach spent more than 50% of their time foraging, compared to only 6% for tending adults on the island interior and 18% for tending adults on the ocean beach (Table 29).

Disturbance and Foraging Observations

Foraging rates did not differ significantly between observations containing one or more disturbance events and those containing none except 2 age classes on different beaches (Table 30). Foraging rates of chicks 3-10 days old on the ocean beach were higher during observations that were disturbed than observations that were not disturbed ($P = 0.047$). Tending adults also had higher foraging rates during

observations containing disturbance than during observations that were undisturbed in all habitat types, though this was only significant on the bay beach ($P = 0.05$).

Disturbance and Time Budgets

We observed few differences in the time engaged in different behaviors between disturbed and undisturbed observations (Table 31). The time chicks 3-10 days old spent foraging on the bay beach and island interior was lower in observations with disturbance, but the reverse was true on the ocean beach. In general, the time spent in locomotor activities increased in observations with disturbance. Resting time decreased in observations with disturbance in all but 2 combinations of age class and beach.

Human disturbance

Piping plovers in all habitats experienced human disturbance at similar rates ($P = 0.8$). Rates of human disturbance ranged from 0.01 events/minute (1 event/100 min.) on the bay and ocean beaches, to 0.04 events/minute (1 event/25 min.) on the island interior. Human disturbance did not affect foraging rate or behavioral variables to a greater extent than other disturbance sources (Appendix D, We tested observations that were not disturbed with observations that were disturbed by various sources [human, plover, avian, etc.]. We then compared the level of

significance (p-values) of human disturbed observations vs. other disturbance sources. Of 160 comparisons, 86 (54%) observations disturbed by humans were less different (the p-value was closer to 1) than observations disturbed by other sources, 56 (35%) were more different, and 18 (11%) were the same.).

Foraging rates of plovers disturbed by humans did not differ from rates during observations when no human disturbance was noted (Table 32). Time budget variables (% time foraging, locomotion, preening, alert, and resting) likewise showed no differences between observations containing disturbance and those with no disturbance, though sample sizes were < 10 in most cases (Table 33).

Human disturbance in 1990 was greater than in 1988 or 1989 on both the ocean beach (Kruskal-Wallis, $P = 0.0146$) and the bay beach (Kruskal-Wallis, $P = 0.0001$, Table 34). The disturbance levels in 1990 were 8-25 times greater than the human disturbance observed in previous years.

Disturbance during behavioral observations

Disturbance from a number of sources was observed during behavioral observations (Table 35). One or more incidents of avian disturbance was observed in 15% of all observations. Human disturbance was observed in 4.9% of all observations.

The proportion of observations containing avian disturbance was highest for the bay beach (5%), and lower on the island interior (2%) or the ocean beach (3%,

Kruskal-Wallis $\chi^2 = 7.61$, 2 df, $P = 0.022$). Disturbance did not differ among beaches for overall disturbance (Tables 29, 36) or disturbance from plovers, humans, mammals, other or unknown sources (Table 36). Conspecific interaction was the chief avian disturbance factor (26%). These encounters were territorial in nature along shared boundaries or on a common feeding territory.

To address the effects of different sources of disturbance on foraging rates and time budget variables, we compared observations containing one or more disturbance events with those that contained none (Appendix D). Overall disturbance correctly indicated the significance (at $P = 0.05$) of the individual sources of disturbance 97.3% of the time (253 of 260 comparisons). Moreover, overall disturbance correctly indicated the significance of ALL sources of disturbance in 130 of 135 variables compared (96.3%). Thus, our use of "overall disturbance" does not appear to mask any effects of various disturbance sources.

Overall disturbance on the ocean beach in 1990 was higher than in 1988 or 1989 (Kruskal-Wallis, $P = 0.0001$, Table 34).

Behavioral Observations

In 528 attempts to locate broods known to have at least one surviving chick, we were able to find at least one chick 391 times (74%). Of the 367 brood checks when we were able to find one or more chicks in a brood, we initiated behavioral observations 202 times (55%). Of 367 attempts to begin behavioral observations on

a brood, we were unable to begin 83 (23%) because the chicks were obscured by grass or ran behind a dune, 33 (9%) because we caught the chicks for banding, 21 (6%) because fog, rain, or wind obscured our vision or made the use of spotting scopes difficult, 7 (2%) because the chicks were disturbed by other animals, and 7 (2%) because the chicks were disturbed by the researcher's presence (n = 5) or other humans (n = 2).

Of 654 behavioral observations, 81.8% lasted the full 5 minutes. Those under 3 minutes in length (5.8%) did not differ significantly from longer observations in the variables tested (Appendix B). Eighty-three observations (12.7%) were terminated before completion because focal animals ran from view (usually into the vegetation or behind a shallow dune). Twelve birds (1.8%) flew off and 24 (3.7%) were terminated early because of disturbance. Of the observations containing disturbance, no individual disturbance source (human, avian, plover, mammalian, or other) was responsible for a higher proportion of behavioral observations ending early (chi-square test of homogeneity, $\chi^2 = 5.1$, 4 df, $P = 0.277$). Additionally, I tested each disturbance source vs. all other sources pooled, to determine if any one source was particularly disruptive. No individual source was responsible for a disproportionately high or low number of early ending observations (chi-square test of homogeneity, $P = 0.073$, $P = 0.101$, $P = 0.611$, $P = 0.720$, and $P = 0.325$ for human, avian (other than plover), plover, mammalian, and other disturbance sources).

Of the 119 observations that were terminated before the 5-minute scheduled end, 24 (20%) ended because of disturbance. Fourteen (12%) focal animals were lost

from view during observations disturbed by a boat-tailed grackle, crow, a piping plover, a willet, unknown avian, a pony, weather, and 7 humans. In 10 instances (8%), the plover flew off as a result of disturbance from boat-tailed grackles (2), a gull, plovers (3), a willet (1), a turtle (1), and humans (2).

The variation in foraging rates within a brood (intra-) was no different ($P > 0.05$) than the variation among broods (inter-) for any chick age class or beach. Only tending adults had higher interbrood (vs. intrabrood) variation in foraging rates in the island interior ($F = 150.3$, $n = 4, 12$ $P < 0.001$). All other age classes and beaches showed no differences.

Time of day and tidal level biases were found to be minimal (Appendix C). We observed a linear relationship between tidal level (ordinate) and foraging rate (abscissa) only in one age class. Tending adults on the bay and ocean beaches foraged at a greater rate during lower tidal levels (linear regression, $F = 7.8$, 8,9 df, $P = 0.02$ and $F = 5.8$, 40,41 df, $P = 0.02$); however, the relationships were not strong ($\text{Adj-R}^2 = 0.43$, and $\text{Adj-R}^2 = 0.104$).

Relative Prey Abundance

Terrestrial Arthropods

I found no differences in relative arthropod abundances between random points and brood-rearing territories (Wilcoxon signed-rank $P > 0.1$) in any habitat types. Bay beach arthropod counts were greater than those on the island interior or the ocean beach in brood-rearing territories (Kruskal-Wallis, $\chi^2 = 36.5$, 2 df, $P = 0.0001$) and at random points (Kruskal-Wallis, $\chi^2 = 16.7$, 2 df, $P = 0.0002$) (Table 37). Island interior arthropod counts were intermediate and significantly different than either bay beach or ocean beach counts (pairwise Wilcoxon Rank Sum, $P < 0.05$). Ocean beach arthropod counts always were lowest. Variation in arthropod abundances among years was high.

Dipterans composed 91% of all arthropods caught. Various coleopterans, homopterans, and hemipterans made up the balance (Table 38). The upright stick and the horizontal stick had nearly equal numbers of captured arthropods (51%/49%). Scatter plots failed to suggest any seasonal trend in the total number of arthropods captured (Figure 9). Tidal level also appeared to have little effect on the number of arthropods captured (Figure 10).

Sweep net insect counts in brood-rearing territories were not different from random sites for any habitat type (Wilcoxon signed-rank $P > 0.2$, Table 39). Pooling

random and brood-rearing sites, more insects were captured in the island interior than in other habitats (Kruskal-Wallis, $\chi^2 = 12.6$, 2 df, $P = 0.002$). Island interior brood-rearing territories had higher insect counts than ocean or bay beach habitats (Kruskal-Wallis $\chi^2 = 7.90$, $P = 0.019$). Insect counts at random sites, however, were not different among habitat types.

Substrate Invertebrates

Total substrate invertebrates were more numerous in brood-rearing territories than at random points in the island interior (Wilcoxon signed-rank $P = 0.0006$) and the ocean beach (Wilcoxon signed-rank $P = 0.0001$) but not in the bay beach (Wilcoxon signed-rank $P = 0.38$) (Table 40). The invertebrates driving these differences, however, were not the same for each habitat. On the ocean beach, amphipods were more than twice as numerous in brood-rearing territories than at random points (Wilcoxon Rank Sum, $P = 0.004$). Island interior brood-rearing territories had more insects and insect larvae than random sites (Wilcoxon Rank Sum, $P = 0.004$). In the island interior, polychaetes were more numerous in brood-rearing territories than at random points but not significantly so (Wilcoxon Rank Sum, $P = 0.056$). No specific bay beach invertebrate densities differed between random points and brood-rearing territories.

In brood-rearing territories and random sites, total substrate invertebrate densities were greatest on the ocean beach (Table 40). Bay beach values were intermediate and island interior values were the lowest. All habitats were different

from each other in both brood-rearing territories and at random sites (pairwise Wilcoxon Rank Sum, $P < 0.05$). Amphipods showed the most dramatic differences, driving the differences we observed in the total values.

Most amphipods and mole crabs (*Emerita talpoida*) were found on the ocean beach (Table 40). Small bivalves and polychaete worms were most numerous on the bay beaches and mud flats. Insects and insect larvae were most common on the island interior, but far more numerous in the brood-rearing territory samples than in random samples.

Amphipods made up approximately 95% of the ocean beach samples and most were found in the saturated intertidal zone (Table 1, 41). In every category of substrate invertebrates except mole crabs and insects or insect larvae, saturated samples contained the majority of the invertebrates.

Monitoring Human Use and Predator Abundance

Only 22 of 613 brood observations (4%) contained human/plover contacts (Figure 11). However, when broods encountered humans, the humans passed within 5 m of the broods original center of activity 11 of 22 (50%) observations (Figure 12).

Disturbance-predation Transects

The total number of trails did not differ among habitat types (Kruskal-Wallis, $P = 0.8$, Table 42). Potential predator trails, however, were more common on the bay and ocean beaches than in the island interior (Kruskal-Wallis, $P = 0.0019$).

Nonpredator trails were greater on the bay beach and island interior than on the ocean beach ($P = 0.0001$). Human trails were greater on the bay beach than on the island interior or ocean beach ($P = 0.01$).

On the island interior, we counted more trails in brood-rearing territories than at random points for ponies (Wilcoxon signed-rank $P = 0.03$), humans ($P = 0.0095$), nonpredators ($P = 0.0025$), and the total number of trails ($P = 0.013$, Table 43). The number of deer, fox, and total predator trails were not different between brood-rearing territories and random points. The number of trails from other sources could not be compared because they were not abundant enough to meet the minimum needed for statistical analysis. We also found no differences in trail counts between brood-rearing territories and random points on either the bay or ocean beaches.

Most transects (96%) were run a day or two following wind or rain that would have erased all previous trails. Mean exposure period³ was 1.5 days ($SE = 0.07$, $n = 101$). Human tracks were quickly erased. On the experimental plot in 1990, tracks

³ The time since the last wind or rain event that erased all tracks.

lasted 0.59 days ($SE = 0.18$, $n = 51$ days). Tracks were erased by both wind ($n = 14$) and rain ($n = 13$), although we did not note the cause of erasure every time.

DISCUSSION

Foraging Behavior

Younger chicks foraged at greater rates in bay beach and island interior habitats than on the ocean beach, weighed more, and had a higher probability of survival (Chapter 2). These observations support the hypothesis that bay beach and island interior habitats have more food available to young piping plover chicks than the ocean beach, and that chicks reared in ocean beach habitats suffer higher losses as a result of starvation or starvation-related problems.

Similarly, adults on the bay beach foraged more rapidly than adults on the ocean beach or island interior. Tidal level was related to foraging rate only in tending adults on the bay and ocean beaches. Higher tending adult foraging rates at lower tidal levels supports the hypothesis that prey are more available at these tidal levels.

Foraging rate and prey density appear to be good indicators of prey availability for other species. Sanderling (*Calidris alba*) prey capture rates were affected by prey size, prey density, prey spatial distribution (clumped vs. regular vs. random), prey depth, and substrate penetrability (Myers et al. 1980). Wind, rain, cloud cover, temperature, the presence of other predator (bird) species, and prey selection also

influence prey capture rates (Pienkowski 1983a, 1983b, 1983c). As prey density decreases, prey availability decreases, prey capture rates decline, and foraging rates decline (Murton et al. 1966, Maron and Myers 1985). Conversely, higher foraging rates and capture rates have been reported where prey availability and prey density were greater (Goss-Custard 1970, 1977, Puttick 1979, Myers et al. 1980). To plover chicks, prey *availability* is more important than prey density or total numbers of prey (Evans 1976), but little experimental work has been done to determine the availability of prey items to plover chicks. Prey type and size are difficult to determine at great distances. Other studies, however, have shown that foraging rate or prey capture is a positive function of prey density in other species (Holling 1965, 1966; Myers et al. 1980).

Conversely, foraging rates may decrease with increasing prey availability as birds become more selective (Baker and Baker 1973, Pienkowski 1983b, Wilson 1990); however, this hypothesis is based on the premise that foraging individuals can discriminate among prey items. These studies focused on adult shorebirds. Little is known about the relationship between prey availability and foraging rate in developing chicks. Selective foraging is a function of experience (Holling 1965). Young chicks, therefore, may be less selective than adults. Immature and juvenile birds forage more slowly and less efficiently than adults do, suggesting that some learning is involved (Kear 1962, Newton 1967, Orians 1969, Puttick 1979, also see Dawkins 1971, Smith 1983, O'Connor 1984). Pienkowski (1983b) suggested that ringed plover chicks become selective with increasing age while Galbraith (1989) felt that

lapwing (*Vanellus vanellus*) chicks (both Family: Charadriidae) foraged opportunistically, not selectively. Young piping plover chicks may be foraging opportunistically, although I would predict they make the transition to selective foraging strategies early in their first year of life.

From our observations, it appeared that insects were the primary prey on the bay beach and island interior. Most ground strikes did not appear to penetrate the surface. We observed adults taking worms on the bay side, but chicks seldom did. Suspected diet composition on the ocean beach is more difficult to assess. Based on prey availability, chicks foraging at the water's edge most likely were taking various crustaceans. Some, however, foraged along the wrack line, an area with abundant insects and beach fleas (Gosner 1978).

Young birds are typically reared on high protein diets (O'Connor 1984), often different from adult diets. Insects provide high protein and easy to handle prey (Kirkham and Morris 1979). The importance of invertebrate prey to chick growth and development is reviewed by Ricklefs (1983) and O'Connor (1984). Paralleling our daily chick loss, Johnson and Boyce (1990) reported sage grouse chicks raised without insects all died between 4 and 10 days of age while all chicks provided with insects lived. It should be noted, however, that these were feeding trials and the chicks did not have alternative food sources available.

Our data are consistent with the hypothesis that starvation, or a starvation-induced weakened condition, led to decreased survival. The amount of energy that a precocial chick can provide for itself is limited by its small size and

feeding experience (Ricklefs 1968). Although the growth rates for precocial chicks are relatively slow (O'Connor 1984), metabolic demands peak soon after hatching (Ricklefs 1968, 1974). Chicks must become ambulatory soon after hatching and begin to thermoregulate within a few days (Soikkeli 1967, Ricklefs 1968, 1974, 1983, Ricklefs et al. 1978). Yolk reserves provide energy during this period, but they are usually exhausted in 1-6 days (Romanoff 1944, Kear 1965, Marcström 1966, Ricklefs 1974, 1979, 1983, Ricklefs et al. 1978, Kirkham and Morris 1979, Pienkowski 1984a). Chicks that have not acquired the skills to forage effectively or do not have an adequate food supply may suffer from an energy deficit. The fact that most of our plover chicks were lost in the first 10 days of life is consistent with the hypothesis that early chick mortality is the result of starvation.

Chick growth rates and weight gains are directly affected by food supplies (Ashmole 1962, Harris 1966, 1969, 1978, LeCroy and Collins 1972, Boersma 1976, Houston 1976, Ricketts and Prince 1981, Van Heezik and Davis 1990), and weight gains have been used as a measure of growth rates in many species. We also used weight as an indicator of growth (Chapter 2). A lack of food resources may slow or limit development (O'Connor 1977a) to the point that chicks that fail to gain weight above certain thresholds do not survive (e.g. Schreiber 1976 [brown pelicans], Ricklefs 1983 [house wrens]). Initially, precocial chicks devote most of their energy to maintenance and survival (Ricklefs 1973). Therefore, differences in relative weights of young plover chicks may reflect their ability to survive and increase their body weight on the available resources.

The salt content of the prey items in different habitats may affect survival. On the ocean beach, amphipods are the most numerous prey item. They live in a habitat saturated by sea water and probably have a high salt content. Whereas on the island interior and bay beaches, terrestrial insects and insect larvae are abundant and are presumably less salty. Young white ibis (*Eudocimus albus*) have difficulty with high saline diets at very early ages, explaining why adults fly great distances to raise young on freshwater invertebrates (Bildstein et al. 1990, Johnson and Bildstein 1990). Mottled duck chicks have reduced survival and growth rates at higher salinity diets (Moorman et al. 1991). Young piping plover chicks may experience this difficulty with osmoregulation as well. An intolerance to high saline prey could represent a physiological bottleneck for successful reproduction (Johnson and Bildstein 1990); however, this requires further investigation as piping plover chicks feed primarily on the ocean beach elsewhere along the Atlantic Coast (MacIvor 1990). The amount and distribution of wrack in these other areas may increase the availability of insect prey. On Breezy Point, N.Y., Goldin (pers. commun.) reported chicks fed on insects associated with the wrack line. On AINS, piping plover chicks remained relatively close to the nesting and adjacent feeding area for approximately the first 20 days of life, especially those foraging on the island interior and the bay beach. At about 20 days of age, chicks became more mobile, often moving from other brood-rearing habitats to feed on the ocean beach. Factors influencing this use pattern are not known, but an initial intolerance to high saline diets is one possible explanation. Plovers foraging on the bay beach and island interior appeared to be eating mostly

insects (which are presumably lower in salt content), but when plovers move to the ocean beach, they may be switching to amphipods and other prey inhabiting the swash zone (presumably higher in salt content).

Another hypothesis that could explain the pattern of early chick loss on AINS is that predators encounter and eat these newly-hatched chicks. Unfortunately, this hypothesis is extremely difficult to test. Red foxes, AINS's primary predator, are nocturnal. Plover chicks are small and extremely mobile, further complicating observations. Pienkowski (1984a) had similar problems with ringed plovers. He attributed most of the chick losses to predators, primarily because he found no differences in chick weights of surviving and disappearing chicks. Young chicks that disappeared on AINS, however, had lower weights than those that survived. Also, foraging rates and invertebrate indices on the bay beach and island interior were higher than those on the ocean beach. Furthermore, chick survival on the bay beach and island interior was higher than on the ocean beach. For these reasons, I believe that food availability was more important to chick survival than was predation.

Time Budgets

Young chicks spent a majority of their time foraging. Foraging rate generally was greater as the time spent foraging increased.

Tending adults spent more time being alert than in any other behavior. As guardians of the chicks, this is not surprising. The percent of time spent foraging was

highest on the bay beach and lowest on the island interior. This may be because bay beach sites tend to be flat and relatively open, especially on bay side mud flats, which offer good visibility. Ocean beaches are typically steep-sloped and offer limited visibility from below the crest of the berm. Similarly, interior habitats may have vegetation and small dunes which limit visibility. Plovers appear to detect predators visually (Byrkjedal 1987). Thus, in the open habitats, predators may be more readily detected. This ease of detection may allow plovers in such habitats to devote more time to foraging.

Time budget observations frequently have been used to quantify behavior (Verner 1965, Wiens et al. 1970, Stiles 1971, Wolf and Hainsworth 1971, Dwyer 1975, Dunbar 1976, Puttick 1979, Maron and Myers 1985, Burger 1988, Flemming et al. 1988, Eberhardt et al. 1989). Altman (1974) reviews the major techniques available, of which instantaneous sampling and continuous observation are the most commonly used. Because our goal was to assess the distribution of time spent in various activities, instantaneous sampling provides the best choice given the restrictions of a field study (Altman 1974, Lehner 1979, Tyler 1979). Continuous time observations provide the most accurate estimate of the time spent in each activity, although using a 10-second interval, as we used, closely approximates continuous observations (Tyler 1979, Tacha et al. 1985).

Disturbance

Conspecific aggression occurred regularly on the feeding territories. In a few cases, the conflict was between the adults of adjacent broods. Most interactions were between tending adults and a lone plover. Aggressive behavior as described in Cairns (1982) was commonly observed, and the lone plover usually left quickly. Occasionally, a feeding territory of one brood and a nesting territory of another would be adjacent and conflicts were common.

Adult plovers aggressively defended their chicks and feeding territories not only from conspecifics but from potential predators and competitors as well. Adult plovers attacked birds regardless of size, including both sanderlings and great black-backed gulls (*Larus marinus*). We observed one instance of mobbing when a crow flew over a nesting area and was pursued and harassed simultaneously by 4 adult plovers.

Disturbance and Behavioral Observations

Foraging rates for tending adults on the bay beach were greater during disturbed observations than during undisturbed observations. Higher foraging rates of disturbed observations have a number of possible explanations. Although disturbance at these foraging sites was high, prey abundance and availability also may have been high. Areas of quality forage were in demand by other shorebirds, increasing the chance of disturbance. Thus, foraging in these areas may have led to

a higher chance of disturbance, but access was gained to higher forage quantity or quality. Ground pecking in the form of redirected or displacement behavior (Alcock 1984:451) in response to the disturbance also could have contributed to the discrepancy, although I doubt this affected our results. Chicks usually reacted to disturbance by crouching, and I believe they are less likely than adults to engage in ground pecking displacement behavior.

Human disturbance

The data on human disturbance suggest that foraging rates and time budgets do not differ between disturbed and undisturbed observations. In Nova Scotia, Flemming et al. (1988) found human disturbance to significantly reduce the foraging rate and the incidence of foraging in chicks. Goldin et al. (1988) and Laskowski (1987) reported human activities interrupted plover foraging bouts as well. Our data represent human impacts when human visitation rates were low to moderate. Few behavioral observations were completed during periods of high human visitation to the National Seashore. Behavioral observations were difficult if not impossible to obtain on many weekends and holidays (e.g. July 4) when human use was heavy. We were able to locate broods easily in the morning, but this became more difficult as the day progressed. During periods of high human visitation, broods often took refuge in and along the vegetation bayward of the beach. Flemming et al. (1988)

showed that chicks reacted to human disturbance by shifting away from feeding and energy conservation activities to vigilance and predator avoidance.

Thus, I believe our behavioral observations underestimate human disturbance overall. These data are appropriate for characterizing 'typical' weekday human use patterns of the northern 7 km of AINS (approx. 10 visitors/day). On days of high human use, however, I believe that human disturbance may be excluding plovers from foraging sites for much of the day. Extensive disturbance in Nova Scotia plovers was 5-50 pedestrians / day (Flemming et al. 1988). I believe levels equal to or greater than this occur during brief periods of high use on AINS. Long weekends could be particularly devastating.

In 1990, human disturbance increased substantially compared to previous years. Both bay and ocean beaches experienced higher disturbance rates. Unfortunately, we collected few data on the relative numbers of recreational visitors among these years. I believe the observed increase in human disturbance during behavioral observations is related to two other observations. First, there appeared to be increasing recreational use of the northern 8 km of AINS from 1988 to 1990, increasing the chance of human disturbance. Second, proportionally more broods used the ocean beach as a foraging area in 1990 than in previous years. Because the ocean beach is a favorite pathway for recreationists, the number of human-plover contacts increased.

Human Use and Disturbance

In 1988-1990, human use levels on the northern 8 km of Assateague Island National Seashore were moderate and mostly restricted to specific areas. Sinepuxent Campground, the Ocean City Inlet area, various island crossover points, and the ocean tidal zone (pers. obs.) received most of the use. Sinepuxent Campground was consistently used by visitors during the plover breeding season; however, use was limited because it is a hike-in site 3 miles from the parking lot. The inlet area received heavy use, primarily on weekends. I observed as many as 50 boats here on a busy weekend. Visitors who swam across the bay or beached their boats on the bay side of the island often walked around to the ocean beach to recreate. Additionally, many visitors walked the intertidal zone to the inlet and back, inadvertently disrupting plover foraging. Future monitoring of human recreation disturbance pressures should initially concentrate on these areas.

Invertebrate Prey

Bay beach habitats have the highest terrestrial arthropod densities. Island interior values are intermediate, while ocean beach values are the lowest. These data suggest that bay beach habitats are superior with respect to the available terrestrial insects. We observed no difference in arthropod densities between

random points and brood-rearing habitats, perhaps because of the high variation among sites and years. Sweep net data reinforce the availability of insect prey along the island interior. Rates of capture were 5 to 13 times higher on the island interior than in other habitat types.

Ocean beaches have greater substrate invertebrate densities than other habitats; however, these may be unavailable to young chicks. Most of these organisms live in the saturated zone of the intertidal area and migrate up and down the beach with the tide (Vader 1964). Young chicks (< 10 days of age) seldom use this area and restrict their foraging to the wet zone and the wrack line. Older chicks (> 20 days old) and adults do use the saturated zone often. Most of our observations of young chicks foraging in the saturated zone are during low tidal levels when the beach is relatively flat. The perils of foraging along the ocean tidal zone became apparent while observing a chick on a relatively steep beach. The chick was foraging along the edge of the wet/saturated zone until being overwhelmed by an incoming wave. The chick retreated to the island's interior and resumed foraging once it had dried.

Monitoring Human Use and Predator Abundance

Disturbance-predation Transects

The total number of trails indicating potential disturbance sources did not differ among habitats. Trails of nonpredators, however, were more numerous along the bay beach than in other habitats. This may be because many animals used the bay beach as a pathway. Ocean beach values also were high, probably for the same reason. The ocean beach and wrack line is a major foraging area for red foxes, AINS's primary predator.

Tracking substrates were not completely comparable among habitats. Bay beach substrates were more compact. Finer, more compact substrates may have caused us to underestimate track densities, especially those of lighter animals. Heavier animals (such as humans), however, could have been overestimated as tracks were not erased as easily in the bay beach habitats. Island interior and ocean beach substrates were comparable, mostly dry sand. Given these considerations, bay beach habitats may have been used by light animals more frequently than we observed. Although the number of human trails could have been overestimated on the bay beach because of the tracking substrate, we believe this is not a large bias. Human tracks on the bay side were not counted if they were not fresh (sharp edges, distinct) or had any indication of being created before we started our sampling period.

(exposure time). We recognize this imprecision in aging tracks; however, we believe that the bias is small relative to the differences we observed.

SUMMARY

Chicks reared on the bay beach or island interior habitats had higher survival than chicks reared on the ocean beach. Foraging rates, indices of invertebrate prey abundances, and disturbance rates all are consistent with the hypothesis that poor chick survival may be the result of low food availability. Chick predation also could account for these differences, but we believe it is not as important as food availability. The foraging rates of young chicks on the bay beach and island interior were higher than the foraging rates of chicks raised on the ocean beach. These chicks also spent more time foraging than those on the ocean beach.

Terrestrial arthropods, which were mostly insects, were more abundant on the bay beach and island interior than on the ocean beach. Chicks mostly preyed upon insects, and insects occurred mostly on the bay beach and the island interior. Substrate invertebrates were most numerous along the saturated ocean tidal zone, but we question the availability of these prey to young plovers.

Disturbance on AINS was low to moderate. Overall disturbance did not differ among habitats. We found no difference in foraging rates or time budget variables between observations that were disturbed and those that were not. Human disturbance in 1990 was greater than in 1988 or 1989.

Chapter 4. SURVIVAL AND POPULATION MODELS

A knowledge of survival (or mortality) rate is essential for the adequate management of a population (White and Garrott 1990). An estimate of the rate at which members of a population disappear is an important consideration when addressing population growth or recovery. Reproductive rates are determined relatively easily. Mortality, however, is more difficult to estimate because plovers are migratory and spend a majority of their annual cycle dispersed from the breeding areas.

The AINS piping plover population has declined in the past 10 years from ~50 pairs in 1980 to 14 pairs in 1990 (Table 10). This decline may be the result of increased mortality, decreased fecundity, changes in immigration or emigration rates, or a combination of these factors. Individually color-marked plovers allowed us to estimate annual survival for adults and first year birds. These estimates of survival allowed us to model the current population, set goals for the reproductive success necessary for recovery, and predict future population levels, given the past reproductive success.

METHODS

Survival Rates

Sightings and recaptures of piping plovers color-banded on Assateague Island National Seashore, Maryland provided estimates of survival. Plovers banded by Patterson (1988) in Maryland were included in the analysis; however, those banded on Assateague Island in Virginia were excluded from survival estimates.

I calculated annual survival rates for adult and first year piping plovers. The number of birds known or assumed alive one year later was divided by the number known alive in a given year (Table 44). I calculated 3 estimates of survival using this method. Of the 3 estimates (detailed below), the first was based on birds we positively identified, the second included a correction for color-band loss, and the third estimate included corrections for band loss and band-induced mortality. We believe this last estimate was warranted because we observed birds with leg injuries that probably resulted from banding. Although the injured birds seemed to behave normally, we thought that the band-related injuries may have caused some mortality. Since we were most interested in the survival of the unbanded population, we attempted to estimate this value.

Complete color-band combinations - I calculated survival based on the number of individuals observed in a given year compared to the number observed or banded the previous year. I calculated juvenile or first year survival in a similar manner for birds banded as chicks in 1988 and 1989 and observed the following year. This estimate was based solely on birds that were positively identified.

Complete plus incomplete color-band combinations - To account for birds observed with partial combinations, I assumed that these individuals had lost their band(s) between the previous year and the year observed. We could not identify birds banded as chicks without a complete color-band combination; therefore, only adult survival was estimated using this method. This estimate added 6 additional birds (2 were observed in 2 years) to our first survival estimate. In 1989, we observed 2 birds with partial band combinations that could not be positively identified. Also included are 2 birds observed in 1989 and 2 birds observed in 1989 and 1990 that had incomplete color-band combinations but were identifiable⁴.

Complete plus incomplete color-band combinations plus estimated deaths - My third estimate of survival attempts to correct for higher mortality rates in the banded population as a result of band-related injuries. We observed 11 injured birds in 1988 and 1989, 4 of which were observed in the following year. Assuming these 11 birds survived at a rate similar to the birds that did not lose any bands (67%), we would have expected to see 7 birds return in later years ($11 \times 0.67 = 7$). The difference between the number of birds we expected to see (7) and the number we saw (4) was

⁴ These birds include those in which the remaining bands were still a unique color-band combination and 2 birds that had distinct leg injuries and partial combinations that matched birds returning to breed in the same territory the following year (see Appendix on Leg Injuries for further details).

our estimate (3) of the number of birds that died because of band-related injuries in 1988 and 1989. These birds were then added to the Complete plus incomplete color-band combinations estimate in the appropriate years and survival was calculated.

Population Model

I modeled the AINS population using a deterministic population model. The model simply accounts for changes in a population based on a life-equation, exponential model as tabulated by the PD (Population Dynamics) software, version 4.5, by J.W. Grier (Grier 1991). I used data from the past 5 years on AINS to calculate a mean that was used as an input for reproductive variables. Survival data from this study also were used. Model inputs are listed in Table 45.

I also determined the reproductive rate necessary to maintain population stability for 100 years, given our survival estimates. To do this, I used the survival estimates calculated in this study and varied the number of young produced per successful female until the population was stationary (did not increase or decrease by 1 individual) for 100 years. I calculated a range of estimated reproductive rates required for population stability by using the upper and lower 95% confidence interval for each survival estimate.

RESULTS

Survival Rates

Annual adult survival in 1988-1990 was 67-72% (Table 46), depending on the estimate, and ranged from 44-86% (Table 44) among years. Chick first year survival was consistently 41%. Birds returning to AINS (Appendix F) composed the majority of the resightings (91 of 92 adults sighted were seen on AINS, 8 of 12 first year birds were sighted on AINS). Others were sighted elsewhere during migration or the breeding season (Table 47).

Population Model

Reproductive output necessary to provide population stability was 1.4-1.6 chicks fledged/breeding pair (Table 48). Given the current reproductive rates, we predict a continued population decline on AINS (Figure 13). Using the 5-year mean reproductive values, the models using the adult survival estimates (67%, 71% and 72%) all predict local extinction by 2016. The lower 95% confidence interval values

for adult and first year survival forecast population decline for all models.

Conversely, the upper 95% confidence intervals of adult and first year survival all predict expanding populations.

DISCUSSION

Survival Rates

I based survival rates on recaptures and sightings of previously color-banded birds. Reported rates reflect the minimum number of birds known to be alive 1 year following the initial banding or resighting. Actual survival may be somewhat higher. Return rates were similar to other reported resighting rates for piping plovers (Table 49). Resightings of adults returning to AINS made up nearly all (99%) of our resightings and were greater than reported for other study sites (Haig and Oring 1988b-71%). Occurrence of chicks known to be alive returning to the natal site (75% of known survivors) also was higher than reported elsewhere (Wilcox 1959-72%). Eight (28%) chicks returned to their natal site to breed. Haig and Oring (1988c) reported natal philopatry between 2.9-21% in the Northern Great Plains. Whyte (1985) found 8.3% ($n = 12$) of chicks banded returned to their natal site the following year.

Band, foot, and leg loss possibly lead to a negative bias in survival rates (which would inflate our estimate of productivity needed to maintain population stability). We observed two adults in 1989 with incomplete band combinations and had no way to identify these individuals via the elimination of known combinations. Banding also

may reduce survival; however, we have no direct evidence. We attempted to conservatively correct for band loss by adjusting survival assuming that birds with incomplete band combinations were identified the previous year. We also estimated survival correcting for the number of birds that died because of band-related burden or injury. It should be noted that we observed piping plovers returning, and breeding, despite foot and leg loss. In 1989, a female plover missing both feet laid 3 full clutches (4 eggs each, all were lost to foxes). For this reason, I believe the Complete plus incomplete band combinations estimate most accurately reflects survival in the actual AINS population.

This annual adult survival rate is higher than reported in the Great Plains (Prindiville Gaines and Ryan 1988 - 63.4%, Whyte 1985 - 42%), but similar to other Atlantic Coast sites (Melvin et al. 1991 - 74%). Most previous studies have primarily relied on return rate estimates.

Dispersal to alternate breeding sites may have reduced our estimates of survival, although I believe it did not affect our estimates greatly. Few sightings from other areas were reported (Table 47, Appendix F), and only 1 of 10 (10%) adults sighted elsewhere was NOT seen on AINS. Additionally, intensive surveys and monitoring were conducted adjacent to the study area. If adults were dispersing to other sites and not stopping over on sites known to the birds (AINS), one would expect a greater number of sightings off the study area. I do not believe that dispersal greatly affected our survival estimates.

Piping plovers will live 10 or more years on AINS. In 1988, we trapped a bird banded as a chick on AINS on 9 June 1979. We observed it again in 1989, ten years after it hatched. Clapp et al. (1982) reported a male plover returning 14 years after being banded on Long Island, N.Y. by Wilcox (1962).

Population Model

Reproductive productivity on AINS was below the estimated level necessary to maintain a stationary population. We report 1.41 young fledged/breeding pair as the necessary reproductive level per year to achieve this goal. Confidence intervals (95%, Table 46) for the survival estimates predicted expanding populations for the upper limits and declining populations for the lower limits. Prindiville Gaines and Ryan (1988) and Melvin et al. (1991) have offered levels of 1.15-1.44 and 0.8-0.9 chicks fledged/breeding pair for population stability, respectively. Though our methods are different, our results are directly comparable to Prindiville Gaines and Ryan's (1988) method. In the future, I recommend using their method⁵ (Page et al. 1988) as it is much simpler and easier to calculate than our methods. Current reproductive data predict a decline in the AINS breeding population. The actual breeding population declined from 25 pairs in 1988 to 14 in 1990. At present, it appears the AINS population is declining. Although local extinction may be postponed by immigration

⁵ Prindiville Gaines and Ryan (1988) used the equation: $Z = 2(1 - S_a)/S_j$ where Z is the mean number of young produced / female to maintain a stable population, S_a is the annual adult survival, and S_j is the juvenile survival.

from other sites, unless recruitment increases, AINS will lose its piping plover population or function as a population sink (Pulliam 1988, Pulliam and Danielson 1991).

SUMMARY

We observed color-banded piping plovers returning to AINS for three years and estimated annual survival. Annual adult survival estimates were 67% (complete color-band combinations), 71% (complete plus incomplete color-band combinations), and 72% (complete plus incomplete color-band combinations plus assumed deaths). We believe the estimate corrected for incomplete color-band combinations most closely approximates the actual annual adult survival. First year survival was consistently 41%.

We report 1.41 (1.4-1.6 range) chicks fledged/breeding pair as necessary levels of reproduction to maintain population stability. Predicted population trends on AINS suggest a declining population, although immigration from surrounding sites may postpone local extirpation.

CONCLUSIONS

Factors Limiting Productivity

Brood Rearing Habitat

Our observations in this study support the hypothesis that decreased availability of high-quality brood rearing habitat limits reproductive rates. On Assateague Island National Seashore, chicks reared in bay beach and island interior habitats have significantly higher survival rates than chicks raised on the ocean beach. Chicks on the bay beach and island interior also had higher foraging rates, spent a greater proportion of their time foraging, and weighed more than chicks on the ocean beach. Terrestrial invertebrate prey (mostly insects) also were more abundant on the bay beach and island interior than on the ocean beach. Disturbance from natural and human sources, however, did not differ among brood-rearing habitats.

Chicks, however, do not always have access to these bay beach and island interior brood-rearing habitats. Vegetation-free strips to the bay side of the island serve as paths for the young chicks. Storm generated waves scour paths to the bay side; however, in the absence of storm activity, these strips revegetate and become a barrier to chick movements. Previous human activity can also restrict chick

movements. For example, the creation of dunes from dredge spoil can block access to the bay side or encourage vegetation to proliferate and serve as a barrier.

If access paths to the bay side are maintained, island interior habitats also will be maintained. Each island interior habitat that was used by a brood was an overwash beginning to revegetate. Frequent disturbance of overwash areas maintains both access to the bay beach and desirable island interior habitats. However, if overwashing is infrequent, interior habitat can degenerate. As an overwash revegetates, succession leads to dense cover or woody vegetation, which plover broods do not use.

It is desirable to maintain access to both bay beach and island interior habitats in light of the variable nature of insect abundances among years and habitats. Bay beaches appeared to have consistently high terrestrial arthropod abundances. Island interior habitats also had moderate arthropod abundances, but were quite variable. By maintaining both brood-rearing habitats, the opportunity for successful reproduction is greater, even in years with low arthropod abundance.

Nesting Habitat

Nest predation limited plover productivity in the egg stage. Red foxes were responsible for 77% of nest predations and were the sole predator in 1989-1990. Nests not protected by predator exclosures seldom survived. We extensively used predator exclosures in 1989 and 1990, but they were not always effective. Once red foxes learned how to get inside an exclosure, losses of exclosed nests increased.

The Importance of Natural Storm Events

The AINS piping plover population appears to respond to major storm events. In the fall of 1985 and 1986, hurricane-generated waves extensively overwashed the northern 8 km of the island. Subsequently, peak numbers of nesting plovers were recorded in 1987 and 1988. Since 1988, the number of breeding plovers has declined. Reproductive success (chicks fledged/breeding pair) also peaked in years following these storm events. Only in 1986 and 1987 were rates above 1.0 chicks fledged/breeding pair. Access to the high quality brood-rearing habitats (e.g. bay beach), however, has been reduced since 1987. As overwash paths revegetate, largely because of a lack of severe winter storms, these high quality habitats become unavailable, as in 1990. Chick survival was reduced and the overall reproductive rate dropped. Our evidence suggests that the availability of overwash paths that provide chicks with access to high quality brood rearing habitat (bay beach, island interior) influences successful reproduction and is a function of the storm regime (and resulting overwash) on AINS.

MANAGEMENT RECOMMENDATIONS

Reproductive success on AINS was below a level needed for a stationary population. Future productivity could be enhanced by 1) providing chicks access to high quality brood-rearing habitats and 2) protecting plover nests from predation.

Maintain Overwash Paths

To boost recruitment into the AINS piping plover population, it is essential for chicks to have access to bay beach habitats. In years following large storm events, such as occurred in 1985 and 1986, there were numerous paths to the bay beach. In the following years, however, access paths began to revegetate and productivity declined.

Activities that reduce natural overwash need to be restricted or mitigated. Dredge spoil deposition sites should be carefully planned. Historical human "improvements" to the island, such as dune building, have altered the habitat. Shoaling off the northern end of AINS, as a result of the stabilization of Ocean City Inlet, currently may be reducing the wave energy that reaches the island (Allen, pers. commun.). Dredge spoil deposition to control the erosion of the northern 8 km also

may reduce the natural overwashing and should be mitigated. Steps should be taken to reverse previous human alterations of the island which have increased encroachment of woody vegetation and have cut off access to bay beach habitats. Options to mimic natural processes include physical vegetation disturbance or removal, or pumping seawater across the island to mimic natural overwashing, but this needs further testing.

Island interior habitats also are created by overwashing, maintaining access paths to the bay beach should provide access to both habitats.

Monitor Human Activity

Bay beach and mudflat habitats must be preserved and protected from destruction, alteration, or excessive disturbance. Human activities in the adjacent bay, such as boat traffic, and recreational visits to the island need to be monitored for adverse effects. Currently, human disturbance to foraging broods usually is low to moderate. Recent proposals for additional mainland marinas, however, could be particularly threatening to AINS piping plovers. The sizes, placement, and restrictions on customers of these marinas are of utmost concern. Increasing easy access to summer residents could be harmful as this may increase human disturbance to unacceptable levels. Recreational pressures on coastal ecosystems in the past 40 years has greatly increased (Sidle 1985, Leatherman 1982) and seem to be accelerating around AINS (pers. obs.).

Recreational opportunities are currently available on more than 24 km of beach on AINS developed primarily for human recreation. Only one pair of piping plovers nest on this 24 km. Further recreational pressures on the northern 8 km of AINS could negatively impact the piping plover population, although the levels that would be harmful are difficult to predict. Management strategies shifting increasing human demand from the northern 8 km to other areas on the island established primarily for human recreation need to be developed and considered. To provide access to boaters, a bay side boat landing adjacent to a developed beach may relieve some pressure from the northern 8 km.

Reduce Nest Predation

Red foxes are limiting plover productivity in the egg stage. Potential management options to reduce fox predation on piping plover nests include fox removal, fox reproductive inhibition, conditioned taste aversion, or improved exclosure design. Red fox eradication may be difficult to fully accomplish on AINS; however, selective trapping and nightlighting prior to and during the plover breeding season could temporarily and substantially reduce predation pressures on the northern 8 km of AINS. Because the plover breeding area contains only two fox territories (Bashore pers. commun.), the elimination of a breeding pair or the disruption of the breeding cycle would reduce the number of foraging foxes and lower the predation pressure. Refugia for denning foxes and pups, such as the dense

vegetation on the northern 1 km of the island, should be removed to discourage fox use. If a new inlet forms ~3-4 km south of the Ocean City inlet, as has been predicted (Kumer pers. commun.), an opportunity will exist to create a fox-free island for shorebird nesting. Eradication of the exotic (Churcher 1959) red fox from this future island should be a high priority. Inhibition of successful reproduction through hormonal or immunological fertility control (Turner and Kirkpatrick 1991) or male sterilization may reduce predation pressures while maintaining territories and discouraging immigration, although little research has been done on this. Reducing the number of foraging foxes (by reducing the number of pups) and lowering the energy requirements of breeding adults may decrease predation. Pups on AINS are born earlier than on the mainland (Bashore pers. commun.) and begin to leave the den in early June, contributing to the predation pressure. Unfortunately, non-lethal fox management may be difficult to implement as foxes have been difficult to trap on Assateague Island in the past (Cross 1989, Bashore pers. commun.).

Predator Exclosures as a Management Tool

Reproductive failure is one of the chief factors limiting piping plover populations (Dyer et al. 1988). As shown in 1989, when used properly, predator exclosures can substantially increase nesting success (Table 20). It is crucial, therefore, to develop management strategies to keep the individual foxes that have learned to circumvent predator exclosures separated from piping plovers. Problem foxes must be relocated

or eliminated. Improvements on exclosure design (such as extending a lip or flange horizontally on the top edge) may reduce predation, although early attempts on AINS in 1990 were not successful (MacIvor pers. commun.). Conditioned taste aversion to dummy exclosed nests set up prior to the breeding season needs further testing as a non-lethal alternative.

LITERATURE CITED

- Ailes, I. W. 1988. Piping plover monitoring program. Unpubl. Report. Chincoteague National Wildlife Refuge, Chincoteague, Virginia. 83pp.
- Alcock, J. 1984. Animal behavior, an evolutionary approach. 3rd ed. Sinauer Assoc. Inc., Sunderland, Massachusetts. 596pp.
- Allen, J. R. Personal Communication. National Parks Service, Boston, Massachusetts.
- Altmann, J. 1974. Observational study of behavior sampling methods. *Behav.* 49:227-267.
- Arbib, R. 1972. The Blue List for 1973. *Am. Birds* 26:932-933.
- _____. 1973. The Blue List for 1974. *Am. Birds* 27:943-945.
- _____. 1974. The Blue List for 1975. *Am. Birds* 28:971-974.
- _____. 1975. The Blue List for 1976. *Am. Birds* 29:1067-1072.
- _____. 1976. The Blue List for 1977. *Am. Birds* 30:1031-1037.
- _____. 1977. The Blue List for 1978. *Am. Birds* 31:1087-1096.
- _____. 1978. The Blue List for 1979. *Am. Birds* 32:1106-1113.
- _____. 1979. The Blue List for 1980. *Am. Birds* 33:830-835.
- Ashmole, N. P. 1962. The black noddy *Anous tenuirostris* on Ascension Island. Part I. General Biology. *Ibis* 103:235-273.
- Baker, M. C., and A. E. M. Baker. 1973. Niche relationships among six species of shorebirds on their wintering and breeding ranges. *Ecol. Monogr.* 43:193-212.
- Baldwin, S. P., H. C. Oberholser, and L. G. Worley 1931. Measurements of birds. Scientific Publications of the Cleveland Museum of Natural History, Vol. 2. 165pp.
- Bart, J., and D. S. Robson. 1982. Estimating survivorship when the subjects are visited periodically. *Ecology* 63:1078-1090.
- Bashore, T. L. Personal Communication. Univ. Maryland, Eastern Shore, Princess Anne.

- _____, and P. M. Krim. 1986. Census and ecological aspects of the red fox breeding population within Assateague Island National Seashore (Maryland section), April-August 1985. Unpubl. Rep. 96pp.
- Bent, A. C. 1929. Life histories of North American shore birds Pt. 2. U. S. Natl. Mus. Bull. No. 146.
- Bildstein, K. L., W. Post, J. Johnston, and P. Frederick. 1990. Freshwater wetlands, rainfall, and the breeding ecology of white ibises in coastal South Carolina. *Wilson Bull.* 102:84-98.
- Boersma, P. D. 1976. An ecological and behavioral study of the Galapagos penguin. *Living Bird* 15:43-93.
- Brown, J. M. 1986. Breeding biology and the effects of tide and time of day on the distribution of piping plovers on Plymouth Beach, Massachusetts. Manomet bird observatory unpubl. rep. 14pp.
- Brown, M. Personal Communication. P.O. Box 239, Summerland Key, FL 32960.
- _____. 1990. Protection of Ohio Key, Florida. Unpubl. abstract presented at the piping plover winter recovery meeting, Clearwater Beach, FL.
- Buckley, P. A., and N. P. Psuty. 1986. General Information Papers, Assateague Island National Seashore Erosion Control Workshop. 25-28 February. Center for Coastal and Environmental Studies, Rutgers State Univ., New Jersey.
- Assateague Island reference # 84 4642 DI NPS.
- Burger, J. 1987. Physical and social determinants of nest-site selection in piping plover in New Jersey. *Condor* 89:811-818.
- _____. 1988. Foraging behavior in a beach-nesting species: the piping plover. Atlantic coast piping plover management and research meeting, Unpubl. rep.
- _____, M. A. Howe, D. C. Hahn, and J. Chase. 1977. Effects of tide cycles on habitat selection and habitat partitioning by migrating shorebirds. *Auk* 94:743-758.
- Byrkjedal, I. 1987. Antipredator behavior and breeding success in greater golden plover and Eurasian dotterel. *Condor* 89:40-47.
- Cairns, W. E. 1977. Breeding biology of the piping plover in southern Nova Scotia. M.S. Thesis. Dalhousie Univ, Halifax. 115 pp.
- _____, and I. A. McLaren 1980. Status of the piping plover on the east coast of North America. *Am. Birds* 34:206-208.

- _____. 1982. Biology and behavior of breeding piping plovers. *Wilson Bull.* 94(4):531-545.
- Churcher, C. S. 1959. The specific status of the New World red fox. *J. Mammology* 40:513-520.
- Clapp, R. B., M. K. Klimkiewicz, and J. H. Kennard. 1982. Longevity records of North American birds: Gaviidae through Alcidae. *J. Field Ornithol.* 53:81-124.
- Coutu, S. D. Personal Communication.
- _____, J. D. Fraser, J. L. McConnaughey, and J. P. Loegering. 1990. Piping plover distribution and reproductive success on Cape Hatteras National Seashore. 67 pages. Unpubl. Rep. submitted to the National Park Service.
- Cross, R. R. Personal Communication. Chincoteague National Wildlife Refuge, Chincoteague, Virginia.
- _____. 1987. Report of piping plover research activities on Metompkin Island 1987. Unpubl. manuscript. 11 pp.
- _____. 1989. Monitoring, management, and research of the piping plover at Chincoteague National Wildlife Refuge. Unpubl. Report. Chincoteague National Wildlife Refuge, Chincoteague, Virginia. 80pp.
- Dawkins, M. 1971. Perceptual changes in chicks: another look at the "search image" concept. *Anim. Behav.* 19:566-574.
- Defant, A. 1958. Ebb and flow, the tides of earth, air and water. Univ. of Michigan Press.
- Dolan, R. 1973. Barrier islands: Natural and controlled. pages 263-278 in D. R. Coates, ed. *Coastal Geomorphology, Proceedings of the third Annual Geomorphology Symposia Series*, Binghamton, N.Y.
- Dunbar, R. I. M. 1976. Some Aspects of research design and their implications in the observational study of behavior. *Behav.* 58:78-98.
- Dwyer, T. J. 1975. Time budgets of breeding gadwalls. *Wilson Bull.* 87:335-343.
- Dyer, R. W., A. Hecht, S. Melvin, C. Raithel, and K. Terwilliger. 1988. Atlantic coast piping plover recovery plan. U.S. Fish and Wildlife Service, Newton Corner, Massachusetts. 77 pp.
- Eberhardt, L. E., G. G. Brooks, R. G. Anthony, and W. H. Rickard. 1989. Activity budgets of Canada geese during brood rearing. *Auk* 106:218-224.

- Evans, P. R. 1976. Energy balance and optimal foraging studies in shorebirds: some implications for their distributions and movements in the non-breeding season. *Ardea* 64:117-139.
- Flemming, S. P. 1984. The status and responses of piping plovers to recreational activity in Nova Scotia. Honors Thesis, Acadia Univ. 150 pp.
- _____, R. D. Chiasson, P. C. Smith, P. J. Austin-Smith, and R. P. Bancroft. 1988. Piping plover status in Nova Scotia related to its reproductive and behavioral responses to human disturbance. *J. Field Ornithol.* 59:321-330.
- Galbraith, H. 1989. The diet of lapwing *Vanellus vanellus* chicks on Scottish farmland. *Ibis* 131:80-84.
- Gilmore, R. M. 1946. Mammals in Archaeological collections from southwestern Pennsylvania. *J. Mammology.* 27:227-234.
- Godfrey, P. J., and M. M. Godfrey. 1973. Comparison of ecological and geomorphologic interactions between altered and unaltered barrier island systems in North Carolina. pages 239-258 in D. R. Coates, ed. Coastal Geomorphology, Proceedings of the third Annual Geomorphology Symposia Series, Binghamton, N.Y.
- Goldin, M. Personal communication. Univ. of Mass., Amherst.
- Goldin, M., C. R. Griffin, and S. M. Melvin. 1988. Productivity, foraging ecology, human disturbance, and management of piping plovers at Breezy Point, Gateway National Recreation Area, New York. Unpubl. progress report, Univ. of Mass., Amherst. 28pp.
- Gosner, K. L. 1978. A field guide to the Atlantic seashore from the Bay of Fundy to Cape Hatteras. Peterson field guide series. Houghton Mifflin Co., Boston. 329pp.
- Goss-Custard, J. D. 1970. The responses of redshank (*Tringa totanus* (L.)) to spatial variations in the density of their prey. *J. Anim. Ecol.* 39:91-113.
- Goss-Custard, J. D. 1977. Responses of redshank, *Tringa totanus*, to the absolute and relative densities of two prey species. *J. Anim. Ecol.* 46:867-874.
- Graul, W. D. 1973. Possible functions of head and breast markings in Charadriinae. *Wilson Bull.* 85:60-70.
- Grier, J. W. 1991. Population modeling: an introduction and overview. Pages 134-157 in Proc. Midwest Raptor Mgmt. Symp. and Workshop. National Wildlife Federation, Washington, D. C.
- Griffin, C. R. Personal communication. Univ. of Mass., Amherst.

- Gysel, L. W., and L. J. Lyon. 1980. Habitat analysis and evaluation. Pages 305-327 in S. D. Schemnitz, ed. Wildlife management techniques manual, 4th ed. The Wildlife Society, Washington, D.C.
- Haig, S. M. Personal Communication.
- _____. 1985. The status of the piping plover in Canada. A status update prepared for the Committee on the status of endangered wildlife in Canada. 23pp.
- _____. 1987. Population biology and life history strategies of the piping plover. Ph.D. Dissertation. Univ. North Dakota, Grand Forks. 121pp.
- _____, and L. W. Oring. 1985. The distribution and status of the piping plover throughout the annual cycle. J. Field Ornithol. 56:334-345.
- _____, and _____. 1988a. Genetic differentiation of piping plovers across North America. Auk 105:260-267.
- _____, and _____. 1988b. Mate, site and territory fidelity in piping plovers. Auk 105:268-277.
- _____, and _____. 1988c. Distribution and dispersal in the piping plover. Auk 105:630-638.
- Harris, M. P. 1966. Breeding biology of the Manx shearwater *Puffinus puffinus*. Ibis 108:17-33.
- _____. 1969. Food as a factor controlling the breeding of *Puffinus therminier*. Ibis 111:139-156.
- _____. 1978. Supplementary feeding of young puffins, *Fratercula arctica*. J. Anim. Ecol. 47:15-23.
- Hecht, A. Personal Communication, U.S. Fish and Wildlife Service, Newton Corner, MA.
- _____. 1988. Atlantic coast piping plover status report. U.S. Fish Wildlife Service, Newton Corner, MA.
- _____. 1989. Atlantic coast piping plover status report. U.S. Fish Wildlife Service, Newton Corner, MA.
- _____. 1990. Atlantic coast piping plover status report. U.S. Fish Wildlife Service, Newton Corner, MA.
- Heisy, D. M., and T. K. Fuller. 1985. Estimation of survival and cause-specific mortality rates using telemetry data. J. Wildl. Manage. 49:668-674.

- Hensler, G. L. 1985. Estimation and comparison of functions of daily nest survival probabilities using the Mayfield method. Pages 289-301 in B. J. T. Morgan and P. M. North, eds. *Statistics in Ornithology*. Springer-Verlag, N.Y.
- Hoffman, M. L. 1985. Status of the piping plover in coastal Maryland. Investigator's Annual Report. Assateague Island National Seashore. 2pp.
- Hollander, M. and D. A. Wolfe. 1973. *Nonparametric Statistical Methods*. John Wiley & sons, New York. 503pp.
- Holling, C. S. 1965. The functional response of predators to prey density and its role in mimicry and population regulation. *Mem. Entomol. Soc. Can.*, No. 45. 60pp.
- _____. 1966. The functional response of invertebrate predators to prey density. *Mem. Entomol. Soc. Can.*, No. 48. 86pp.
- Hoopes, E. M., C. R. Griffin, and S. M. Melvin. 1988. Effects of human recreation on piping plover foraging ecology and chick survival. Unpubl. Rep. Univ. of Mass., Amherst. 33pp.
- Houston, D. C. 1976. Breeding of the white-backed and Ruppell's griffon vultures, *Gyps africaenus* and *G. ruppellii*. *Ibis* 118:14-40.
- Johnsgard, P. A. 1981. *The plovers, sandpipers and snipes of the world*. Univ. of Neb. Press, Lincoln. 493pp.
- Johnson, C. M. 1987. Aspects of the wintering ecology of piping plovers in coastal Alabama. M.S. Thesis. Auburn Univ., Auburn, Alabama. 29pp.
- _____, and G. A. Baldassarre. 1988. Aspects of the wintering ecology of piping plovers in coastal Alabama. *Wilson Bull.* 100:214-223.
- Johnson, D. H. 1979. Estimating nest success: the Mayfield method and an alternative. *Auk* 96:651-661.
- _____, and T. L. Shaffer. 1990. Estimating nest success: when Mayfield wins. *Auk* 107:595-600.
- Johnson, G. D., and M. S. Boyce. 1990. Feeding trials with insects in the diet of sage grouse chicks. *J. Wildl. Manage.* 54:89-91.
- Johnson, J. W., and K. L. Bildstein. 1990. Dietary salt as a physiological constraint in white ibis breeding in an estuary. *Physiol. Zool.* 63:190-217.
- Kear, J. 1962. Food selection in finches with special reference to interspecific differences. *Proc. Zool. Soc. Lond.* 138:163-204.
- Kear, J. 1965. The internal food reserves of hatching mallard ducklings. *J. Wildl. Manage.* 29:523-528.

- Kirkham, I. R., and R. D. Morris. 1979. Feeding ecology of ring-billed gull (*Larus delawarensis*) chicks. *Can. J. Zool.* 57:1086-1090.
- Kumer, J. Personal communication. Assateague Island National Seashore, Maryland.
- Laskowski, H. 1987. A report on disturbance rates and reactions of feeding piping plovers (*Charadrius melodus*) at Holgate Unit - Edwin B. Forsythe National Wildlife Refuge. USFWS Unpubl. Rep. 12pp.
- Leatherman, S. P. 1979. Barrier island handbook. 2nd ed. Univ. of Maryland, College Park. 109pp.
- LeCroy, M., and T. C. Collins. 1972. Growth and survival of roseate and common tern chicks. *Auk* 89:595-611.
- Lehner, P. N. 1979. Handbook of ethological methods. Garland STPM press, New York. 403pp.
- Lock, A. R. 1988. Recent increases in the breeding population of ring-billed gulls, *Larus delawarensis*, in Atlantic Canada. *Can. Field-Nat.* 102:627-633.
- MacIvor, L. H. Personal communication. Maryland Natural Heritage Program, Fredrick, MD.
- _____. 1988. Use of flags on piping plovers: potential adverse effects. Atlantic coast piping plover management and research meeting, Unpubl. rep.
- _____. 1990. Population dynamics, breeding ecology, and management of piping plovers on outer Cape Cod, Massachusetts. M.S. Thesis, Univ. of Mass., Amherst. 100pp.
- _____, S. M. Melvin, and C. R. Griffin. 1990. Effects of research activity on piping plover nest predation. *J. Wild. Manage.* 54:443-447.
- Marcström, V. 1966. Mallard ducklings (*Anas platyrhynchos* L.) during the first days after hatching. A physiological study with ecological considerations and a comparison with Capercaillie chicks (*Tetrao urogallus* L.). *Viltrety* 4:343-370.
- Maron, J. L., and J. P. Myers. 1985. Seasonal changes in feeding success, activity patterns, and weights of non-breeding sanderlings (*Calidris alba*). *Auk* 102:580-586.
- Maryland Dept. of Natural Resources. 1981. The role of boat wakes in shore erosion in Anne Arundel County, Maryland. Maryland Coast Report 5.
- Mayer, P. M., and M. R. Ryan. 1991. Electric fences reduce mammalian predation on piping plover nests and chicks. *Wildl. Soc. Bull.* 19:59-63.

- Mayfield, H. F. 1961. Nesting success calculated from exposure. *Wilson Bull.* 73:255-261.
- _____. 1975. Suggestions for calculating nest success. *Wilson Bull.* 87:456-466.
- McConnaughey, J. L. Personal Communication.
- _____, J. D. Fraser, S. D. Coutu, and J. P. Loegering. 1990. Piping plover distribution and reproductive success on Cape Lookout National Seashore. Unpubl. rep. submitted to the National Park Service. 83pp.
- McGarigal, K., R. G. Anthony, and F. B. Isaacs. 1991. Interactions of humans and bald eagles on the Columbia River Estuary. *Wildl. Monographs* No. 115, 47 pages.
- Melvin, S. M., L. H. MacIvor, C. R. Griffin, and L. K. Jones. 1991. Piping plover research and management within the Cape Cod National Seashore 1985-1991. Pages 205-208 in *National Park Service Conference on Science and Natural Resource Management in the North Atlantic Region*. Newport, R.I.
- Miller, H. W., and D. H. Johnson. 1978. Interpreting the results of nesting studies. *J. Wildl. Manage.* 42:471-476.
- Mills, J. A., and J. P. Ryder. 1979. Trap for capturing shore and seabirds. *Bird Banding* 50:121-123.
- Moorman, A. M., T. E. Moorman, G. A. Baldassarre, and D. M. Richard. 1991. Effects of saline water on growth and survival of mottled duck ducklings in Louisiana. *J. Wildl. Manage.* 55:471-476.
- Murton, R. K., A. J. Isaacson, and N. J. Westwood. 1966. The relationship between wood-pigeons and their clover food supply and the mechanisms of population control. *J. Appl. Ecol.* 3:55-96.
- Myers, J. P., J. C. Maron, E. Ortiz T., G. Gastro V., M. A. Howe, R. I. G. Morrison, and B. A. Harrington. 1983. Rationale and suggestions for a hemispheric color-marking scheme for shorebirds: a way to avoid chaos. *Wader Study Group Bull.* 38:30-32.
- _____, S. L. Williams, and F. A. Pitelka. 1980. An experimental analysis of prey availability for sanderlings (Aves:Scolopacidae) feeding on sandy beach crustaceans. *Can. J. Zool.* 58:1564-1574.
- Neu, C. W., C. R. Byers, and J. M. Peek. 1974. A technique for analysis of utilization-availability data. *J. Wildl. Manage.* 38:541-545.
- Newton, I. 1967. The adaptive radiation and feeding ecology of some British finches. *Ibis* 107:33-98.

- Nichols, J. T. 1941. On piping plover feeding. *Proc. Linn. Soc. N.Y.* 52-53:130.
- Nol, E., and Brooks, R. J. 1982. Effects of predator exclosures on nesting success of killdeer. *J. Field Ornithol.* 53:263-268.
- O'Connor, R. J. 1977a. Differential growth and body composition in altricial passerines. *Ibis* 119:147-166.
- O'Connor, R. J. 1984. Growth and development of birds. John Wiley & sons, New York. 315pp.
- Orians, G. H. 1969. Age and hunting success in the brown pelican (*Pelecanus occidentalis*). *Anim. Behav.* 17:316-319.
- Page, G. W., D. W. Winkler, and C. W. Swarth. 1983. Spacing out at Mono Lake: breeding success, nest density, and predation in the snowy plover. *Auk* 100:13-24.
- Palmer, R. S. 1967. Piping plover. Pages 168-169 in G. D. Stout, ed. *The shorebirds of North America*. Viking Press, New York.
- Patterson, M. E. Personal Communication. Virginia Polytechnic Institute and State University.
- Patterson, M. E. 1988. Piping plover breeding biology and reproductive success on Assateague Island. M.S. Thesis. Virginia Polytechnic Institute and State University. 131pp.
- _____, J. D. Fraser, and J. W. Roggenbuck. 1991. Factors affecting piping plover productivity on Assateague Island. *J. Wildl. Manage.* 55:525-531.
- Picozzi, N. 1975. Crow predation on marked nests. *J. Wildl. Manage.* 39:151-155.
- Pienkowski, M. W. 1982. Diet and energy intake of grey and ringed plovers, *Pluvialis squatarola* and *Charadrius hiaticula*, in the non-breeding season. *J. Zoology* 197:511-549.
- _____. 1983a. Changes in the foraging pattern of plovers in relation to environmental factors. *Anim. Behav.* 31:244-264.
- _____. 1983b. Development of feeding and foraging behavior in young ringed plovers *Charadrius hiaticula*, in Greenland and Britain. *Dansk Orn. Foren. Tidsskr.* 77:133-147.
- _____. 1983c. Surface activity of some intertidal invertebrates in relation to temperature and the foraging behavior of their shorebird predators. *Mar. Ecol. Prog. Ser.* 11:141-150.

- _____. 1984a. Behavior of young ringed plovers *Charadrius hiaticula* and its relationship to growth and survival to reproductive age. *Ibis* 126:133-155.
- Pollock, K. H., and W. L. Cornelius. 1988. A distribution-free nest survival model. *Biometrics* 44:397-404.
- Prindiville Gaines, E. M., and M. R. Ryan. 1988. Piping plover habitat use and reproductive success in North Dakota. *J. Wildl. Manage* 52:266-273.
- Pulliam, H. R. 1988. Sources, sinks and population regulation. *Am. Naturalist* 132:652-666.
- _____, and B. J. Danielson. 1991. Sources, sinks, and habitat selection: a landscape perspective on population dynamics. *Am. Naturalist* 137:50-66.
- Puttick, G. M. 1979. Foraging behaviour and activity budgets of curlew sandpipers. *Ardea* 67:111-122.
- Raithel, C. 1983. The piping plover in Rhode Island. Rhode Island Natural Heritage Program. 16pp.
- Rhoads, S. N. 1903. The mammals of Pennsylvania and New Jersey. Privately printed, Philadelphia. 266 pp.
- Ricketts, C., and P. A. Prince. 1981. Comparisons of growth of albatrosses. *Ornis Scand.* 12:120-124.
- Ricklefs, R. E. 1968. Patterns of growth in birds. *Ibis* 110:419-451.
- _____. 1973. Patterns of growth in birds. II. Growth rate and mode of development. *Ibis* 115:177-201.
- _____. 1974. Energetics of reproduction in birds. Pages 152-297 in R. A. Paynter, Jr., ed. *Avian energetics*. Nuttall Ornithological Club, No. 15. Cambridge, Massachusetts
- _____. 1979. Patterns of growth in birds. V. A comparative study of development in the starling, common tern, and Japanese quail. *Auk* 96:10-30.
- _____. 1983. Avian postnatal development. Pages 1-83 in D. S. Farner, J. R. King, and K. C. Parkes, eds. *Avian Biology*, Vol 7. Academic Press, New York.
- _____, D. C. Hahn, and W. A. Montevecchi. 1978. The relationship between egg size and chick size in the laughing gull and Japanese quail. *Auk* 95:135-144.
- Rimmer, D. W., and R. D. Deblinger. 1990. Use of predator exclosures to protect piping plover nests. *J. Field Ornithol.* 61:217-223.
- Robert, M., R. McNeil, and A. Leduc. 1989. Conditions and significance of night feeding in shorebirds and other water birds in a tropical lagoon. *Auk* 106:94-101.

- Romanoff, A. L. 1944. Avian spare yolk and its assimilation. *Auk* 61:235-241.
- Sanderson, G. C. 1977. Management of migratory shore and upland game birds in North America. Univ. Nebraska Press, Lincoln. 358pp.
- Schreiber, R. W. 1976. Growth and development of nesting brown pelicans. *Bird banding* 47:19-39.
- Scott, F. R., and D. A. Cutler. 1972. Middle Atlantic Coast region. *Am. Birds* 26:745-748.
- Sidle, J. G. Personal communication. U.S. Fish and Wildlife Service, Grand Island, Neb.
- _____. 1985. Determination of endangered and threatened status for the piping plover. *Federal Register* 50:50726-50734.
- _____. 1989. Piping plover banding injuries. Preliminary draft prepared for discussion at a piping plover symposium, Clearwater Beach, FL. Unpubl. Rep. 10pp.
- Smith, S. M. 1983. The ontogeny of avian behavior. Pages 85-160 in D. S. Farner, J. R. King, and K. C. Parkes, eds. *Avian Biology*, Vol 7. Academic Press, New York.
- Soikkeli, M. 1967. Breeding cycle and population dynamics in the dunlin (*Calidris alpina*). *Annales Zoologici Fennici* 4:158-198.
- Stiles, F. G. 1971. Time, energy, and territoriality of the Anna hummingbird (*Calyppe anna*). *Science* 173:818-821.
- Strang, C. A. 1980. Incidence of avian predators near people searching for waterfowl nests. *J. Wildl. Manage.* 44:220-222.
- Strauss, E. Personal communication. Tufts Univ., Medford, Mass.
- Tacha, T. C., P. A. Vohs, and G. C. Iverson. 1985. A comparison of interval and continuous sampling methods for behavioral observations. *J. Field Ornithol.* 56:258-264.
- Tate, J. T. 1981. The Blue List for 1981. *Am. Birds* 35:3-10.
- _____. 1986. The Blue List for 1986. *Am. Birds* 40:227-236.
- _____, and D. J. Tate 1982. The Blue List for 1982. *Am. Birds* 36:126-135.
- Tinbergen, N., M. Impekoven, and D. Franck. 1967. An experiment in spacing-out as a defense against predation. *Behav.* 28:307-321.
- Turner, J. W., Jr., and J. F. Kirkpatrick. 1991. New developments in feral horse contraception and their potential applications to wildlife. *Wildl. Soc. Bull.* 19:350-359.

- Tyler, S. 1979. Time-sampling: a matter of convention. *Anim. Behav.* 27:801-810.
- U.S. Department of Commerce. 1985. Storm Data. Weather Bureau. National Climatic Data Center.
- U.S. Department of Commerce. 1986. Storm Data. Weather Bureau. National Climatic Data Center.
- U.S. Department of Commerce. 1988a. Tide Tables 1988 - East coast of North America and South America, including Greenland. National Oceanic and Atmospheric Administration.
- U.S. Department of Commerce. 1988b. Maryland/Delaware Climatological data. Weather Bureau. National Climatic Data Center. Vol. 92.
- U.S. Department of Commerce. 1989a. Tide Tables 1989 - East coast of North America and South America, including Greenland. National Oceanic and Atmospheric Administration.
- U.S. Department of Commerce. 1989b. Maryland/Delaware Climatological data. Weather Bureau. National Climatic Data Center. Vol. 93.
- U.S. Department of Commerce. 1990a. Tide Tables 1990 - East coast of North America and South America, including Greenland. National Oceanic and Atmospheric Administration.
- U.S. Department of Commerce. 1990b. Maryland/Delaware Climatological data. Weather Bureau. National Climatic Data Center. Vol. 94.
- Vader, W. J. M. 1964. A preliminary investigation into the reactions of the infauna of the tidal flats to tidal fluctuations in water level. *Neth. J. Sea Res.* 2:189-222.
- Van Heezik, Y., and L. Davis. 1990. Effects of food variability on growth rates, fledging sizes and reproductive success in the yellow-eyed penguin (*Megadyptes antipodes*). *Ibis* 132:354-365.
- Verner, J. 1965. Time budget of the male long-billed marsh wren during the breeding season. *Condor* 67:125-139.
- Via, J. W. 1979. Piping plover. Pages 431-432 in D. W. Linzey, ed. *Proceedings of the Symposium on Endangered and Threatened Plants and Animals of Virginia*. VPI and SU, Blacksburg. 665pp.
- Vince, M. A. 1966. Potential stimulation produced by avian embryos. *Anim. Behav.* 14:34-40.

- _____. 1969. Embryonic communication, respiration and the synchronization of hatching. Pages 233-260 in R. A. Hinde (ed). Bird Vocalization. Cambridge University Press, Cambridge.
- _____. 1972. Communication between quail embryos and the synchronization of hatching. Proc. of the XVth International Ornithological Congress, 357-362. E. J. Brill, Leiden.
- Welty, J. C. 1982. The life of birds, Third ed. Saunders College Publishing, Philadelphia, PA. 754pp.
- White, G. C., and R. H. Garrott. 1990. Analysis of wildlife radio-tracking data. Academic Press, Inc. San Diego, CA.
- Wittow, G. C. 1976. Energy metabolism. Pages 174-184 in P. D. Sturkie, ed. Avian physiology, 3rd ed. Springer-Verlag, New York.
- Whyte, A. J. 1985. Breeding ecology of the piping plover (*Charadrius melodus*) in central Saskatchewan. M.S. thesis. Univ. of Saskatchewan, Saskatoon. 153pp.
- Wiens, J. A., S. G. Martin, W. R. Holthaus, and F. A. Iwen. 1970. Metronome timing in behavioral ecology studies. Ecology 51:350-352.
- Wiens, T. P., and F. J. Cuthbert. 1984. Status and reproductive success of the piping plover in Lake of the Woods. Loon 56:106-109.
- Wilcox, L. 1959. A twenty year banding study of the piping plover. Auk 76:129-152.
- _____. 1962. Oldest known shorebird in North America. Eastern Bird Banding Assoc. pp45-46.
- Williams, J. W., J. W. Akers, R. A. Beck, K. Terwilliger, and J. W. Via. 1988. The piping plover of the eastern shore of Virginia. Unpubl. manuscript. 5 pp.
- Wilson Jr., W. H. 1990. Relationship between prey abundance and foraging site selection by semipalmated sandpipers on a bay of Fundy mudflat. J. Field Ornithol. 61:9-19.
- Wolf, L. L., and F. R. Hainsworth. 1971. Time and energy budgets of territorial hummingbirds. Ecology 52:980-988.

TABLES

Table 1. Definitions of terms used.

Beach Characteristics	
Bay Beach	The beach along Sinepuxent Bay, adjacent to mud- and sand-flats.
Berm	The area of nonvegetated, horizontal beach extending from the crest of the berm (see below) bayward to the base of a dune or to nearly continuous vegetation if a dune is not present.
Crest of the Berm	A small crest of sand marking the highest extent of the spring tides. The crest marks the boundary between the Ocean Tidal Zone and the Berm.
High Energy Beach	The portion of the beach experiencing wave action from the Atlantic Ocean. Also called the Ocean Tidal Zone.
Ocean Tidal Zone	See high energy beach.
Overwash Gap	A break in the continuous dune line, usually the result of storms. These are found only in the ORV section of the island.
Swash Zone	The area of the ocean tidal zone from the point where waves are breaking to where the waves run up the beach forming a thin film of water temporarily covering the beach. The portion of the ocean tidal zone that is inundated with nearly every wave.
Vegetation Margin/Sparse Vegetation	The area on the island between the berm and continuous vegetation, typically characterized by sparse vegetation (American Three square, <i>Scirpus americanus</i>).
Wrack line	Debris that accumulates on or above the previous high tide line. Wrack is composed of debris including aquatic vegetation, dead and decaying plants and animals, etc.
Foraging Attempts	
Running peck	Ground strike at a prey item immediately following a run.
Stationary peck	Ground strike at a prey item from a stationary position, not preceded by a run.
Glean	Taking prey off vegetation.
Aerial Snap	Attempting to take flying invertebrates in mid-air.
Foot trembling	A foraging attempt immediately preceded by the plover standing on one foot and vibrating the other on the ground surface. Presumably this is an attempt to stimulate surface- or near surface-living small crustaceans or other prey, making them more visible. Pienkowski (1983) observed ringed plovers (<i>Charadrius hiaticula</i>) using this technique and described it in detail.

continued.

Table 1. Definitions of terms used (continued).

Behavior	
Foraging	Engaged in foraging behavior. Usually having made a foraging attempt at a prey item (as described above) within the last 10 seconds.
Locomotion	Running, walking or flying not associated with attempts to take prey items.
Preening	Actively preening feathers.
Alert	Standing with head up, usually scanning the surroundings.
Resting	Brooding young, sitting down, or standing with one leg tucked into the breast feathers. We seldom observed birds tucking their bills into their feathers.

Location of Substrate Invertebrate Samples

In all cases we attempted to sample areas where plovers would typically be observed foraging.

Bay Beach	Along the bayside beach near the water's edge or upon a mud flat if present.
Island Interior	Immediately adjacent to the continuous vegetation, or within the sparse vegetation.
Ocean Tidal Zone	
Saturated Sand	Located low on the beach, subject to frequent swash with nearly every breaking wave.
Wet Sand	Located on the beach adjacent and above the saturated zone. It receives infrequent, but regular, wave action (on the order of a wave every 1 to 2 minutes).

Miscellaneous

Nest Scrape	A small, shallow divot in the sand made in the beginning stages of nest initiation. Typically, a pair will make more than one nest scrape and select one in which to lay the eggs.
--------------------	--

Table 2. Habitat type codes used in location identification on Assateague Island National Seashore, Maryland, 1988-1990.

Habitat Type:	
	01 = Mud flat
	02 = Wet sand flat
	03 = Ocean tidal zone
	04 = Berm (includes area between high tide line and dune and the entire width of the island in places on north end where there is no dune line)
	05 = Dune
	06 = Overwash gaps (breaks in the dune line found in ORV section)
	07 = Interdune (area bayward of an unbroken dune line)
	08 = Levels (e.g Big levels)
	09 = Lake shore
	10 = Inlet tidal zone
	11 = Bayside overwash
	12 = Bayside beach
	13 = Spoil pile
	14 = Vegetation margin/Sparse vegetation
	15 = Spoil dune
	16 = Ephemeral rainwater pool
The beaches for analysis were composed of:	
Bay Beach	Mudflats, Wet sandflat, Levels, the Inlet tidal zone, and the Bayside beach.
Island Interior	Pond shores, Bayside overwash, Spoil piles, Vegetation margins/Sparse vegetation, and an Ephemeral rainwater pool.
Ocean Beach	Ocean tidal zone, Berm, Dunes, Overwash gaps, Interdune, and Spoil dunes.

Table 3. Climatological data for April - August on Assateague Island National Seashore, Maryland, 1988-1990.

	Temperature			Precipitation			
	Avg. Max.	Avg. Min.	Avg.	Total	Days w/ > 0.25 (cm)	Days w/ > 1.27 (cm)	Days w/ > 2.54 (cm)
1988							
March	-	-	-	-			
April	18.0	6.3	12.1	8.3	5	3	1
May	21.9	11.0	16.4	7.3	6	2	0
June	27.4	15.3	21.3	2.7	4	1	0
July	28.3	17.3	22.8	12.1	9	3	2
August	-	-	-	-			
1989							
March	-	-	-	-			
April	14.8	6.4	10.6	11.7	8	4	2
May	22.4	13.4	17.9	6.8	6	1	1
June	29.4	18.8	24.2	7.4	8	2	0
July	30.3	19.6	25.0	16.9	4	2	2
August	28.5	19.2	23.9	22.6	8	4	3
1990							
March	13.6	2.3	7.9	9.1	9	4	0
April	15.8	6.1	10.9	8.6	8	4	0
May	20.6	11.8	16.2	14.6	6	2	1
June	24.9	16.1	20.6	3.7	2	2	0
July	27.2	20.2	23.7	5.7	4	1	0
August	-	-	-	-			

Source: Maryland/Delaware Climatological data. U.S. Department of Commerce, Weather Bureau. National Climatic Data Center.

Location: Assateague Island National Seashore Ranger Station.

Table 4. Piping plovers observed on mud flats, bay beaches, the ocean tidal zone and the berm during foraging habitat surveys on Assateague Island National Seashore, Maryland, 1990. Analysis follows Neu et al. (1974).

Location	Available linear beach distance	Proportion ¹ of beach distance (p_{i_0})	Number of plovers observed	Expected ² number of plovers observed	Proportion observed in each habitat ($\bar{p}_i$)	Confidence interval on proportion of occurrence (p_i) ³ (95% family confidence coefficient)
Mud flats	2704	0.117	43	12.0	0.417	$0.284 \leq p_1 \leq 0.551$
Bay beach	4650	0.200	33	20.6	0.320	$0.194 \leq p_2 \leq 0.446$
Berm	7920	0.341	13	35.2	0.126	$0.037 \leq p_3 \leq 0.216$
Ocean TZ ⁴	7920	0.341	14	35.2	0.136	$0.043 \leq p_4 \leq 0.228$
Total	23,194		103			

¹ Proportion of total beach distance represents expected plover observations if plovers used each habitat in exact proportion to availability.

² Calculated by multiplying $p_{i_0} \times n$.

³ p_i represents theoretical proportion of occurrence and is compared to corresponding p_{i_0} to determine if hypothesis of proportional use is accepted or rejected, i.e. $p_i = p_{i_0}$.

⁴ Ocean tidal zone

Table 5. Observer effort and piping plovers observed, by survey blocks, during foraging habitat surveys on Assateague Island National Seashore, Maryland, 1990.

Habitat blocks	n	shoreline length (m) ¹	observer effort in block (min) ² x SE	birds observed x SE	birds/km of shoreline ¹	available ³ shoreline length (m)	birds/km of available shoreline
Bay side							
1	9	520		0.22	0.22	500	0.4
2	9	580	17.8	0.33	0.24	572	0.6
3	9	720		1.56	0.53	1248	1.3
4	9	660	25.9	0.66	0.33	600	1.1
5	9	680		0	0	480	0
6	9	660	18.7	0	0	712	0
7	9	600		0.89	0.31	680	1.3
8	9	740	27.0	1.78	0.49	580	3.1
9	9	1180		0.66	0.33	444	1.5
10	9	1130	18.1	0	0	60	0
11	9	1540		0.11	0.11	280	0.4
12	9	760	30.0	1.33	0.55	640	2.1
13	9	700		0.22	0.22	480	0.5
14	9	650	20.0	0	0	158	0
15	9	880		0	0	0	0
16	9	1080	14.2	0	0	0	0
Bay side Total	9	13080	171.6	8.44	1.78	7354	1.1

continued

¹ Does not include mudflat perimeters, as available habitat does.
² Observer effort (time in each block) was recorded for consecutive blocks (1-2, 3-4, 5-6, . . . , 15-16) on the bay side and for each section (Northern or Southern) for the ocean side.
³ Available foraging habitat.
⁴ Each ocean side block was 500 m long except Habitat Block 1 (450 m) and Habitat Block 16 (470 m).

Table 5. continued

Habitat blocks	n	shoreline length (m) ¹	observer effort in block (min) ² $\bar{x}$ SE	birds observed $\bar{x}$ SE	birds/km of shoreline ¹	available ³ shoreline length (m)	birds/km of available shoreline
Ocean side ⁴							
1	9	450		0.11 0.11	0.2	450	0.2
2	9	500		0 0	0	500	0
3	9	500		0.22 0.22	0.4	500	0.4
4	9	500		0.22 0.22	0.4	500	0.4
5	9	500		0.67 0.47	1.3	500	1.3
6	9	500		0 0	0	500	0
7	9	500		0.11 0.11	0.2	500	0.2
8	9	500		0.22 0.15	0.4	500	0.4
9	9	500		0 0	0	500	0
10	9	500		0.11 0.11	0.2	500	0.2
11	9	500		0.33 0.24	0.7	500	0.7
12	9	500		0.11 0.11	0.2	500	0.2
13	9	500		0.56 0.38	1.1	500	1.1
14	9	500		0.22 0.22	0.4	500	0.4
15	9	500		0 0	0	500	0
16	9	470		0 0	0	470	0
Northern Sect.	9	3950	70.4 3.63	1.55 0.60	0.39	3950	0.39
Southern Sect.	9	3970	67.2 3.40	1.44 0.56	0.36	3970	0.36
Ocean side Total	9	7920	137.7 2.14	3.00 0.53	0.38	7920	0.38

¹ Does not include mud flat perimeters, as available habitat does.

² Observer effort (time in each block) was recorded for consecutive blocks (1-2, 3-4, 5-6, . . . , 15-16) on the bay side and for each section (Northern or Southern) for the ocean side.

³ Available foraging habitat.

⁴ Each ocean side block was 500 m long except Habitat Block 1 (450 m) and Habitat Block 16 (470 m).

Table 6. Number of piping plovers observed during foraging habitat surveys on the northern 8 km of Assateague Island National Seashore, Maryland, 1990.

	n	$\bar{x}$		SE	range
Number of plovers observed					
bay side					
High tide	6	1.17	A	0.48	0-3
Mid-tide	6	5.67	B	0.80	4-8
Low tide	6	5.83	B	1.38	2-10
Significance ¹		P=0.005			
Ocean side					
High tide	6	2.0	A	0.97	0-5
Mid-tide	6	1.33	A	0.62	0-4
Low tide	6	1.17	A	0.48	0-3
Significance ¹		P=0.926			
Plovers observed/kilometer²					
bay side					
High tide	6	0.32	A	0.10	0-0.6
Mid-tide	6	1.76	B	0.29	0.8-2.9
Low tide	6	1.64	B	0.26	0.8-2.4
Significance ¹		P=0.003			
Ocean side					
High tide	6	0.51	A	0.24	0-1.3
Mid-tide	6	0.34	A	0.16	0-1.0
Low tide	6	0.29	A	0.12	0-0.8
Significance ¹		P=0.924			

¹ Kruskal-Wallis test (chi-square approximation).

² Plovers / kilometer of available foraging habitat.

Means with the same letter on the bay side or on the Ocean side are not different ($P > 0.05$, pairwise Wilcoxon Rank Sum).

Comparison of bay side vs. Ocean side - Wilcoxon Rank Sum test results
(normal approximation w/ continuity correction)

	n	Number of plovers observed		Plovers observed/kilometer	
High tide	6	Z=0.25	P=0.803	Z=0.0	P=0.999
Mid-tide	6	Z=2.62	P=0.009	Z=2.66	P=0.008
Low tide	6	Z=2.58	P=0.010	Z=2.81	P=0.005
Overall	18	Z=2.78	P=0.006	Z=3.2	P=0.001

Table 7. Number of piping plovers observed during foraging habitat surveys in the morning (0630-0930), mid-day (1030-1330), and evening (1430-1730) on the northern 8 km of Assateague Island National Seashore, Maryland, 1990.

	n	$\bar{x}$	SE	range
Number of plovers				
Morning (0800 centered)	12	2.58	0.53	0-6
Mid-day (1200 centered)	12	2.92	0.94	0-10
Evening (1600 centered)	12	3.08	0.98	0-10
Significance ¹	$\chi^2 = 0.12$, 2 df, P=0.944			
Plovers observed/kilometer²				
Morning (0800 centered)	12	0.77	0.22	0-2.9
Mid-day (1200 centered)	12	0.82	0.25	0-2.4
Evening (1600 centered)	12	0.84	0.24	0-1.9
Significance ¹	$\chi^2 = 0.07$, 2 df, P=0.964			

¹ Kruskal-Wallis test results (Chi-square approximation)

² Plovers / kilometer of available foraging habitat.

Table 8. Piping plovers observed at mid-tide rising and mid-tide falling during foraging habitat surveys on the northern 8 km of Assateague Island National Seashore, Maryland, 1990.

	n	$\bar{x}$	SE	range
Number of plovers observed				
Mid-tide Rising	8	3.63	0.93	0-8
Mid-tide Falling	4	3.25	1.80	0-8
Significance ¹	Z=0.26 P=0.794			
Plovers observed/kilometer²				
Mid-tide Rising	8	1.11	0.34	0-2.9
Mid-tide Falling	4	0.93	0.47	0-1.9
Significance ¹	Z=0.17 P=0.864			

¹ Wilcoxon Rank Sum (normal approximation w/ continuity correction).

² Plovers / kilometer of available foraging habitat.

Table 9. Distances (m) at which piping plovers were detected and reacted to an observer's approach during foraging habitat surveys of the northern 8 km on Assateague Island National Seashore, Maryland, 1990.

	n	median	$\bar{x}$	SE	range
Detection Distance ¹					
Bay side	7	70	62.14	8.99	30-100
Ocean side	6	147.5	148.33	42.63	30-280
Significance ²	Z=1.21 P=0.223				
Reaction Distance ³					
Bay side	7	30	30.71	2.54	20-40
Ocean side	6	40	83.33	35.02	30-245
Significance ²	Z=1.25 P=0.211				
Difference ⁴					
Bay side	6	42.5	35.83	10.68	0-70
Ocean side	6	5	65.00	40.89	0-230
Significance ²	Z=0.41 P=0.683				

¹Distance at which I detected plovers.
²Wilcoxon Rank Sum test results.
³Distance at which plovers reacted to my presence.
⁴Difference between the detection and reaction distances (reaction distance-detection distance).

Results of the Moses Rank-Like Test for equal dispersion (Hollander and Wolfe 1973), comparing bay side vs. ocean side distances.

Detection distance	W = 15	P > 0.5
Reaction distance	W = 12.5	P > 0.5
Difference	W = 10	P > 0.5

Table 10. General statistics for piping plovers on Assateague Island National Seashore, Maryland, 1972-1991.

	Breeding Population ¹	Total Nests	Chicks fledged/breeding pair
1972 ²	85		
1980 ³	50		
1985 ⁴	18-20		
1986 ⁵	17	23	1.06
1987 ⁵	23	33	1.17
1988	25	34	0.52
1989	20	27	0.90
1990	14	20	0.78
1991 ⁶	17	20	0.41

¹ Breeding pairs (except the 1972 estimate).
² Scott and Cutler (1972), population estimate is 85 birds, not pairs.
³ Cairns and McLaren (1980).
⁴ Hoffman (1985).
⁵ Patterson (1988).
⁶ MacIvor (pers. commun.).

Table 11. Observer effort while searching for piping plover nests on Assateague Island National Seashore, Maryland, 1988-1990.

	n	$\bar{x}$ (min)	SE	range	observers	linear beach distance
1989						
Northern section	5 ¹	209.8	36.3	175-354	2	4 km
Southern section	4 ¹	121.75	14.3	85-145	2	4 km
Total	4 ¹	336.5	45.0	260-467	2	8 km
ORV section	2	278.0	6.0	272-284	1-3	20 km
1990						
Northern section	15	189.0	10.8	131-244	2	4 km
Southern section	14	112.6	8.4	75-189	2	4 km
Total	14	297.7	13.5	212-382	2	8 km
ORV section	3	360.7	21.9	323-399	1	20 km

¹ Small sample sizes in 1989 do not reflect survey frequency. Only a few surveys were timed.

Table 12. Distances at which piping plovers flushed from their nest as an observer approached on Assateague Island National Seashore, Maryland, 1988-1990.

	n (nests)	median (meters)	$\bar{x}$ (meters)		SE	range (meters)
1988	21	63.3	65.2	A	3.1	45.0-101
1989	12	65.5	67.1	A	8.3	20.0-119
1990	10	120.0	119.2	B	10.0	76.5-174
Kruskal-Wallis, $\chi^2 = 18.0$, $P = 0.0001$						
TOTAL	43	73.75	78.3		4.9	20.0-174.0

Means with the same letters are not different (pairwise Wilcoxon Rank Sum, $P > 0.05$).

Table 13. Fate of 81 piping plover nests on Assateague Island National Seashore, Maryland, 1988-1990.

	Hatched n %	Abandoned ¹ n %	Flooded n %	Predated				Unknown ² n %	Total n %
				Red Fox n %	Other n %				
1988									
Northern 8 km	11 37%	3 10%	2 7%	6 20%	6 ³ 20%			2 7%	30 37%
ORV Zone	2 50%	1 25%	0	0	1 ⁴ 25%			0	4 5%
Total	13 38%	4 12%	2 6%	6 18%	7 21%			2 6%	34 42%
1989									
Northern 8 km	10 38%	1 4%	0	8 31%	0			7 ⁵ 27%	26 32%
ORV Zone	1 100%	0	0	0	0			0	1 1%
Total	11 41%	1 4%	0	8 30%	0			7 26%	27 33%
1990									
Northern 8 km	7 37%	1 ⁶ 5%	1 5%	9 47%	0			1 ⁷ 5%	19 23%
ORV Zone	1 100%	0	0	0	0			0	1 1%
Total	8 40%	1 5%	1 5%	9 45%	0			1 5%	20 25%
1988-1990									
Northern 8 km	28 37%	5 7%	3 4%	23 31%	6 8%			10 13%	75 93%
ORV Zone	4 67%	1 17%	0	0	1 17%			0	6 7%
Total	32 40%	6 7%	3 4%	23 28%	7 9%			10 12%	81 100%

¹ Nests with all eggs abandoned.
² Wind or rain erased all evidence of the source of loss.
³ Includes 1 nest lost to gulls and 5 nests lost to unidentified avian predators.
⁴ Unidentified avian predator.
⁵ Includes 4 nests lost while I returned to Virginia Tech to pick up equipment and a summer technician. It stormed the night of my return.
⁶ Abandoned because of human disturbance.
⁷ I suspect the adults disposed of the 3 eggs as they appeared to be addled. One egg was cracked and oozing.

Table 14. Fate of 284 eggs from 81 piping plover nests on Assateague Island National Seashore, Maryland, 1988-1990.

	Hatched	Disappearing	Abandoned ¹	Known	Unknown	Total
	n	n	n	n	n	n
	%	%	%	%	%	%
1988						
Northern 8km	33	3	12	49	8 ²	105
ORV Zone	31%	3%	11%	47%	8%	37%
Total	4	3	1	3	0	11
	36%	27%	9%	27%		4%
	37	6	13	52	8	116
	32%	5%	11%	45%	7%	41%
1989						
Northern 8km	32	2	7	30	17	88
ORV Zone	36%	2%	8%	34%	19%	31%
Total	4	0	0	0	0	4
	100%					1%
	36	2	7	30	17	92
	39%	2%	8%	33%	18%	32%
1990						
Northern 8km	21 ³	1	8 ⁴	42 ⁵	0	72
ORV Zone	29%	1%	11%	58%		25%
Total	4	0	0	0	0	4
	100%					1%
	25	1	8	42	0	76
	33%	1%	11%	55%		27%
1988-1990						
Northern 8km	86	6	27	121	25	265
ORV Zone	32%	2%	10%	46%	9%	93%
Total	12	3	1	3	0	19
	63%	16%	5%	16%		7%
	98	9	28	124	25	284
	35%	3%	10%	44%	9%	100%

¹ Includes those abandoned on the nest at hatching time.

² Includes 1 egg that disappeared during incubation.

³ Three chicks suspected loss to fox. Fox(es) were digging around the enclosure during hatch.

⁴ Four eggs abandoned because of human disturbance.

⁵ I suspect the adults disposed of 3 eggs as they appeared to be added. One egg was cracked and oozing.

Table 15. Cause of loss for 124 piping plover eggs with identifiable causes on Assateague Island National Seashore, Maryland, 1988-1990.

	Red Fox n %	Unidentified Avian n %	Gull n %	Flooding n %	Plover ¹ n %	Trapping n %	Total n %
1988							
Northern 8 km	21 43%	18 37%	4 8%	5 10%	0	1 2%	49 40%
ORV Zone	0	3 100%	0	0	0	0	3 2%
Total	21 40%	21 40%	4 8%	5 10%	0	1 2%	52 42%
1989							
Northern 8 km	28 93%	0	0	0	0	2 7%	30 24%
ORV Zone	0	0	0	0	0	0	0
Total	28 93%	0	0	0	0	2 7%	30 24%
1990							
Northern 8 km	35 83%	0	0	4 10%	3 7%	0	42 34%
ORV Zone	0	0	0	0	0	0	0
Total	35 83%	0	0	4 10%	3 7%	0	42 34%
1988-1990							
Northern 8 km	84 69%	18 15%	4 3%	9 7%	3 2%	3 2%	121 98%
ORV Zone	0	3 100%	0	0	0	0	3 2%
Total	84 68%	21 17%	4 3%	9 7%	3 2%	3 2%	124 100%

¹ I suspect the adults disposed of 3 eggs as they appeared to be addled. One egg was cracked and oozing.

Table 16. Clutch size of 68 complete¹ piping plover clutches on Assateague Island National Seashore, Maryland, 1988-1990.

	n	$\bar{x}$	SE	range
1988				
Northern 8 km	27	3.70	0.0895	3-4
ORV Zone	2	3.50	0.5	3-4
Total	29	3.69	0.0874	3-4
1989				
Northern 8 km	19	3.84	0.0859	3-4
ORV Zone	1	4.0		
Total	20	3.85	0.0819	3-4
1990				
Northern 8 km	18	3.89	0.0762	3-4
ORV Zone	1	4.0		
Total	19	3.89	0.0723	3-4
1988-1990				
Northern 8 km	64	3.80	0.0507	3-4
ORV Zone	4	3.75	0.25	3-4
Total	68	3.79	0.0491	3-4

¹ A complete clutch consisted of a nest with 4 eggs or 3 eggs for 3 consecutive days. I did not observe any clutches with <3 eggs for 3 consecutive days.

Table 17. Qualitative characteristics of piping plover nest sites on Assateague Island National Seashore, Maryland 1988-1990.

	1988 n	1989 n	1990 n	Total n	%
Shell Fragments ¹					
Present as a scrape lining	15	20	17	52	84%
Absent as a scrape lining	1	7	2	10	16%
Shells, cobble and/or debris in substrate					
None	4	5	0	9	15%
Light (< 10 / m ²)	2	4	3	9	15%
Moderate (10-60 / m ²)	1	10	6	17	28%
Heavy (> 60 / m ²)	8	8	10	26	43%
Vegetation ² at nest site ³					
None	7	20	19	46	81%
Center of small goldenrod clump	0	4	0	4	7%
Sparse vegetation (grasses, sedges)	2	2	0	4	7%
Center of dead goldenrod or bayberry	2	1	0	3	5%
Topography					
Flat	6	14	17	37	70%
Small shallow dunes (<0.75m high)	3	5	1	9	17%
Near base of small dune(< 1m high)	0	1	0	1	2%
Gently sloping dune	0	4	0	4	8%
Top of spoil dune	0	1	0	1	2%
Overwash ridge (<0.3 m high)	0	0	1	1	2%
Method used to find the nest					
Tracking	1	14	8	23	50%
Sit and wait	0	12	9	21	46%
Resource Management staff	0	0	1	1	2%
Other researchers	0	0	1	1	2%

¹ Bits of weathered shells (not egg shells).

² See Appendix G for scientific names.

³ 1-m² centered on nest.

Table 18. Daily survival rates of piping plover nests on Assateague Island National Seashore, Maryland, 1988-1990.

	n	Daily Survival	SE	Interval ¹ Survival	Significance
Overall	79	0.96243	0.000599	0.26729	
No access to the bayside	41	0.96569	0.00107	0.29643	P=0.5035
Access to bayside	38	0.95848	0.00135	0.22653	
Nest initiated on/before 21 May	49	0.96442	0.000927	0.28434	P=0.6260
Nest initiated on/after 22 May	30	0.95892	0.00168	0.22772	
No Shell fragments as a nest scrape lining	10	0.93277	0.00726	0.06196	P=0.0766
Shell fragments present	52	0.97440	0.000701	0.40779	
Nest < 75 m from STL ²	50	0.96144	0.000960	0.25531	P=0.8079
Nest > 75 m from STL ²	29	0.96410	0.00159	0.27575	
0-10 shells/m ² in substrate	18	0.97083	0.00226	0.34547	P=0.9689
11+ shells/m ² in substrate	43	0.97038	0.000928	0.35183	
No vegetation near nest	46	0.97169	0.000858	0.36911	P=0.4993
Some vegetation near nest	11	0.96122	0.00433	0.22791	
Flat Topography	37	0.97139	0.00104	0.36388	P=0.6576
Any relief	16	0.96537	0.00301	0.27540	
Found by sit & wait	21	0.96519	0.00207	0.28360	P=0.8340
Found by tracking	23	0.96226	0.00214	0.25313	

¹ The probability that a nest initiated will survive to hatching. Interval survival rates are bias adjusted (Heisey and Fuller 1985).

² STL = spring tide line

Table 19. Daily survival rates of piping plover nests with and without predator exclosures on Assateague Island National Seashore, Maryland, 1988-1990. Nests lost in 1988 and 1989 before clutch completion or before we could band the adults have been excluded from this analysis.

	n	Daily Survival	SE	Interval ¹ Survival	Significance ²
1988					
Not Exclosed	16	0.97460	0.00222	0.39766	P=0.7996
Exclosed	11	0.97087	0.00353	0.33614	
1989					
Not Exclosed	8	0.92500	0.0104	0.03046	P=0.0109
Exclosed	9	1.00000	0	1.00000	
1990					
Not Exclosed	1	0.77778	0.19598	0	P=0.3227
Exclosed	18	0.97176	0.00198	0.36176	
1988-1990					
Not Exclosed	25	0.96245	0.00190	0.25730	P=0.1242
Exclosed	38	0.97900	0.000818	0.47874	

Interval survival rates are bias adjusted (Heisey and Fuller 1985).

¹ Probability of an initiated nest hatching.

² Wilcoxon Rank Sum.

Table 20. Predator exclosure construction and return times (minutes) for adults resuming incubation at piping plover nests on Assateague Island National Seashore, Maryland, 1988-1990. Times are for construction by 2 persons.

	Construction Time				Resume Incubation Time				comments
	n	$\bar{x}$	SE	range	n	$\bar{x}$	SE	range	
1988	7	9.9	0.67	8-12	6	4.8	1.2	2-10	w/o tops
	4	17.8	1.11	15-20	2	5.0	3.0	2-8	w/ tops
					1	17.0			¹
1989	9	17.1	0.59	15-20	2	8.0	3.0	5-11	w/ tops
					4	15.8	5.9	5-27	¹
1990	17	18.1	0.8	11-25	11	7.1	3.2	1-34	w/ tops
Total	7	9.9	0.7	8-12	6	4.8	1.25	2-10	w/o tops
	30	17.7	0.5	11-25	16	6.6	2.24	1-34	w/ tops
					5	16.0	4.60	5-27	¹

¹ Adults were trapped and banded prior to exclosure construction.

Table 21. Daily survival rates of piping plover chicks on Assateague Island National Seashore, Maryland, 1988-1990.

	n	Daily Survival	SE	Interval Survival	Significance
Overall	98	0.95756	0.000561	0.33476	
Chicks ≤ 10 days old	98	0.92331	0.00106	0.44763	P < 0.0001
Chicks ≥ 11 days old	49	0.98971	0.000553	0.85497	
No access to the bay side	50	0.92824	0.00163	0.14823	P = 0.0002
Access to bay side	48	0.97554	0.000780	0.53353	
Nest initiated on/before 21 May	60	0.95696	0.000932	0.32722	P = 0.8944
Nest initiated on/after 22 May	38	0.95846	0.00141	0.33767	
Bay beach	16	0.96893 A	0.00012	0.45429	below
Island interior	39	0.98583 A	0.00002	0.69992	
Ocean beach	43	0.87048 B	0.00039	0.03119	

Comparisons were made using Henslers’s (1985) techniques.

The interval survival is for the first 25 days of life.
Interval survival rates are bias adjusted (Heisey and Fuller 1985).

Means with the same letters are not different (pairwise Z-test, P > 0.05).

Pairwise comparisons
Bay side vs. Island interior P = 0.146
Bay side vs. Ocean side P = 0.00001
Island interior vs. Ocean side P < 0.00001

Table 22. Mass (grams) of piping plover chicks 4-5 days old reared in different habitats on Assateague Island National Seashore, Maryland, 1988-1990.

	n	median	$\bar{x}$	SE	range
Bay beach	5	8.5	7.6 AB	0.8	5.5-9.5
Island interior	17	8.0	8.5 B	0.4	6.5-12.0
Ocean beach	6	6.75	6.6 A	0.2	5.5-7.0
Kruskal-Wallis, $\chi^2 = 8.06$, 2 df, $P = 0.0178$					

Means with the same letters are not different (pairwise Wilcoxon Rank Sum, $P > 0.01$).

Table 23. Morphometric measurements of piping plovers chicks 4-5 days old surviving to fledging and those that did not on Assateague Island National Seashore, Maryland, 1988-1990.

	n	$\bar{x}$	SE	range	Significance ¹
Mass (g)					
Fledged	8 ²	8.6	0.4	7.5-10.0	P=0.0076
Didn't Fledge	9 ³	6.9	0.3	5.5-8.5	
Culmen length (mm)					
Fledged	8	7.8	0.3	6.0-9.0	P=0.0387
Didn't Fledge	8	7.1	0.2	6.5-8.0	
Tarsus length (mm)					
Fledged	8	18.1	0.6	16.0-20.0	P=0.2648
Didn't Fledge	8	17.1	0.4	16.0-19.0	
Mid-toe length (mm)					
Fledged	8	15.0	0.6	12.5-17.0	P=0.1264
Didn't Fledge	8	13.9	0.3	12.5-15.5	

¹ Wilcoxon Rank Sum.

² Contained five 4-day-old and three 5-day-old chicks.

³ Contained five 4-day-old and four 5-day-old chicks.

Table 24. Chick survival in different brood-rearing habitats on Assateague Island National Seashore, 1988-1990. I defined the habitat type as the area in which the brood was located most frequently during the first 10 days of life.

	1986 ¹ % (F/H) ²	1987 ¹ % (F/H)	1988 % (F/H)	1989 % (F/H)	1990 % (F/H)	1988-1990 % (F/H)
Bay Beach	70% (14/20)	77% (20/26)	67% (6/9)	67% (2/3)	none	67% (8/12)
Island Interior	0% (0/4)	100% (3/3)	60% (6/10)	85% (11/13)	67% (8/12)	71% (25/35)
Ocean Beach	25% (3/12)	21% (3/14)	7% (1/15)	25% (5/20)	25% (3/12)	19% (9/47)
Miscellaneous ³	33% (1/3)	33% (1/3)	0% (0/3)		0% (0/1)	0% (0/4)
Total	47% (18/38)	59% (27/46)	35% (13/37)	50% (18/36)	44% (11/25)	43% (42/98)
Significance ⁴ χ^2 degrees of freedom P-value			77.6 2 P<0.0001	118.9 2 P<0.0001	18.2 1 P<0.001	84.7 2 P<0.0001

¹ from Patterson (1988).

² (# fledged / # hatched).

³ Chicks did not fit well into any habitat category.

⁴ Chi-square goodness of fit, testing if bay beach, island interior, and ocean beach fledging success(%) are the same.

Table 25. Piping plover behaviors used in the analysis.

Behavioral categories used in the analysis	Behaviors or behavioral sequences recorded in the field
Foraging	Run/peck, Stand/peck, Gleen, Aerial Snap, Foot tremble, Foraging run ¹ , Foraging walk ¹ , and Foraging stand ¹ .
Resting	Sit, and Brood.
Locomotion	Run, Walk, Fly, and Hop.
Alert	Standing
Preening	Preening

¹ A run, walk, or stand between foraging attempts.

Table 26. Distance from the nest (m) that piping plover broods moved following hatching on Assateague Island National Seashore, Maryland, 1988-1990.

	n	$\bar{x}$	SE	range
0-5 days old				
Bay beach	10	195	51	0-500
Island interior	36	141	33	0-700
Ocean beach	41	131	26	0-600
Significance ¹	$\chi^2 = 3.0$ P=0.2253			
6-10 days old				
Bay beach	10	111	19	0-150
Island interior	32	151	37	0-500
Ocean beach	21	170	31	20-500
Significance ¹	$\chi^2 = 4.0$ P=0.1384			
11-20 days old				
Bay beach	8	119	20	25-150
Island interior	37	216	48	0-850
Ocean beach	56	154	23	0-600
Significance ¹	$\chi^2 = 0.4$ P=0.8012			
21+ days old				
Bay beach	1	850		
Island interior	10	464	130	0-1000+
Ocean beach	69	187	29	0-850
Significance ¹	$\chi^2 = 7.6$ P=0.0227			

¹ Kruskal-Wallis test

Table 27. Foraging rates (attempts/minute) of piping plover chicks and adults on Assateague Island National Seashore, Maryland 1988-1990. To preserve independence, values were pooled by habitat unit. **1988-90** samples sizes are less than the sum of the 3 years because some habitat units were used in more than one year.

	3-10 days old			11-20 days old			21+ days old			Tending Adults			Lone Adults		
	$\bar{x}$	SE	n	$\bar{x}$	SE	n	$\bar{x}$	SE	n	$\bar{x}$	SE	n	$\bar{x}$	SE	n
1988															
Bay Beach	13.8	2.6	(2)	16.9	3.0	(3)	10.4	1.8	(3)	9.8	3.5	(5)	16.0	0.9	(4)
Island Interior	10.8	3.8	(4)	9.8	3.5	(3)	26.8		(1)	2.1	1.7	(6)			
Ocean Beach	5.2	1.4	(8)	2.1	1.2	(5)	12.1	4.1	(6)	2.9	1.0	(14)	10.3	1.6	(9)
Significance ¹	P=0.1833			P=0.0159			P=0.4412			P=0.1469			P=0.0308		
1989															
Bay Beach	14.0	1.4	(5)	26.9		(1)				11.8	5.6	(5)	21.9	4.9	(4)
Island Interior	12.7	3.1	(4)	18.6	0.9	(6)	15.4	6.9	(3)	0.8	0.4	(7)	9.0	9.0	(2)
Ocean Beach	6.7	2.9	(8)	10.8	2.8	(13)	15.0	4.9	(7)	1.1	0.5	(18)			
Significance ¹	P=0.0508			P=0.0193			P=0.9999			P=0.1685			P=0.2472		
1990															
Bay Beach	11.1	3.8	(2)	9.6		(1)				6.6	2.5	(3)			
Island Interior	11.6	2.3	(5)	17.3	0.9	(4)				1.5	1.0	(7)			
Ocean Beach	5.6	1.7	(6)	12.9	2.1	(11)	12.7	3.2	(11)	4.9	1.4	(14)	6.7	4.8	(3)
Significance ¹	P=0.1353			P=0.1483			P=0.1815								
1988-90															
Bay Beach	13.3 A	1.1	(9)	17.4 A	3.2	(5)	10.5 A	1.8	(3)	10.0 A	3.0	(10)	19.0 A	2.5	(8)
Island Interior	10.8 A	1.6	(11)	15.6 A	1.7	(10)	18.3 A	5.7	(4)	0.9 B	0.4	(16)	9.0 AB	9.0	(2)
Ocean Beach	5.9 B	1.3	(21)	10.7 B	1.7	(26)	13.5 A	2.3	(23)	2.9 B	0.6	(42)	9.4 B	1.6	(12)
Significance ¹	P=0.0007			P=0.0186			P=0.6280			P=0.0056			P=0.0286		

¹ Wilcoxon 2-sample Rank Sum test [for 2 samples] or Kruskal-Wallis test (Chi-square approximation) [for 3 samples].

Means with different letters are significantly different (Pairwise Wilcoxon Rank Sum, $P < 0.01$).

Table 28. Different foraging attempts used by piping plovers to capture prey on Assateague Island National Seashore, Maryland, 1988-1990. Reported are the proportion (%) of use in each category. See Table 1 for definitions of foraging movements.

	n	Run/Peck %	Stand/Peck %	Aerial Snap %	Glean %	Foot Tremble %
3-10 days old						
Bay beach	9	65	32	1.8	1.4	0
Island interior	11	66	31	0.5	1.6	0.010
Ocean beach	21	77	22	3.3	0	0
Significance ¹		P=0.063	P=0.217	P=0.035	P=0.053	P=0.256
11-20 days old						
Bay beach	5	69	28	0.2	2.3	0
Island interior	10	61	37	1.3	0.5	0
Ocean beach	24	70	28	1.2	1.1	0.07
Significance ¹		P=0.132	P=0.119	P=0.564	P=0.177	P=0.732
21+ days old						
Bay beach	3	70	30	0	0	0.5
Island interior	4	68	31	0	0	0
Ocean beach	21	66	33	0.7	0	0.006
Significance ¹		P=0.781	P=0.800	P=0.232	P=0.999	P=0.153
All chicks						
Bay beach	17	67	30	1.0	1.4	0.09
Island interior	25	65	34	0.7	0.9	0.005
Ocean beach	66	71	28	0.8	0.4	0.03
Significance ¹		P=0.057	P=0.099	P=0.778	P=0.0094	P=0.855
Tending adult						
Bay beach	9	77	22	0.01	0.1	0
Island interior	9	75	22	2.7	0	0
Ocean beach	28	81	15	0.2	3.6	0
Significance ¹		P=0.316	P=0.190	P=0.605	P=0.116	P=0.999
Lone adult						
Bay beach	8	67	33	0.04	0	0.08
Island interior	1	67	33	0	0	0
Ocean beach	11	66	25	0	0	9.1
Significance ¹		P=0.738	P=0.513	P=0.472	P=0.999	P=0.934

¹ Kruskal-Wallis (Chi-square approximation).

Table 29. Mean time (%) spent in various behavioral categories in different habitats by piping plovers on Assateague Island National Seashore, Maryland 1988-1990. Samples sizes are not uniform because some behaviors were not recorded in 1988. Disturbance data were collected independently of other behavior data. For this reason, time spent disturbed is not additive with the other categories.

Behavior	Bay beach			Island interior			Ocean beach			Significance ¹
	$\bar{x}$	SE	n	$\bar{x}$	SE	n	$\bar{x}$	SE	n	
3-10 days old										
Foraging	76	7	(7)	80	6	(8)	37	8	(14)	P=0.0039
Locomotion	9	4	(7)	7	2	(8)	22	5	(14)	P=0.1261
Preening	0	0	(9)	0.3	0.2	(11)	1	1	(21)	P=0.4409
Alert	7	4	(7)	8	2	(8)	22	6	(14)	P=0.1623
Resting	3	2	(9)	10	7	(11)	15	6	(21)	P=0.8271
Disturbed	10	6	(9)	1	0.4	(11)	11	4	(21)	P=0.5424
11-20 days old										
Foraging	82	6	(2)	88	3	(8)	56	6	(24)	P=0.0065
Locomotion	10	6	(2)	4	1	(8)	17	3	(24)	P=0.0188
Preening	1	1	(5)	0.2	0.2	(10)	7	3	(26)	P=0.1243
Alert	6	1	(2)	7	3	(8)	15	3	(24)	P=0.1961
Resting	0.2	0.2	(5)	0	0	(10)	7	3	(26)	P=0.0351
Disturbed	2	2	(5)	9	6	(10)	6	2	(26)	P=0.9051
21+ days old										
Foraging			(0)	76	19	(3)	59	9	(18)	P=0.3920
Locomotion			(0)	12	8	(3)	12	3	(18)	P=0.9193
Preening	4	4	(3)	0	0	(4)	3	2	(23)	P=0.4964
Alert			(0)	13	13	(3)	14	5	(18)	P=0.4424
Resting	1	1	(3)	0	0	(4)	8	5	(23)	P=0.4523
Disturbed	1	0.4	(3)	0	0	(4)	6	2	(23)	P=0.1195
Tending Adults										
Foraging	50	13	(8)	6	3	(12)	18	5	(31)	P=0.0184
Locomotion	12	4	(8)	10	2	(12)	16	3	(31)	P=0.7622
Preening	3	1	(10)	4	2	(16)	3	1	(42)	P=0.1591
Alert	28	10	(8)	46	9	(12)	38	4	(31)	P=0.2489
Resting	1	1	(10)	30	10	(16)	24	5	(42)	P=0.1302
Disturbed	4	2	(10)	10	4	(16)	6	2	(42)	P=0.4776
Lone Adults										
Foraging	95	3	(4)	33	33	(2)	61	30	(3)	P=0.1241
Locomotion	5	3	(4)	50	17	(2)	6	4	(3)	P=0.1139
Preening	0	0	(8)	8	8	(2)	3	3	(12)	P=0.1812
Alert	0	0	(4)	8	8	(2)	10	5	(3)	P=0.0723
Resting	0	0	(8)	0	0	(2)	3	3	(12)	P=0.6592
Disturbed	3	2	(8)	0	0	(2)	1	1	(12)	P=0.5416

¹ Kruskal-Wallis test (Chi-square approximation)[3 samples] and Wilcoxon Rank Sum (Normal approximation)[2 samples].

Table 30. Total foraging rates (attempts/minute) of disturbed and undisturbed piping plover chicks and adults on Assateague Island National Seashore, Maryland 1988-1990.

	Undisturbed				Disturbed				Significance ¹
	$\bar{x}$		SE	n	$\bar{x}$		SE	n	
3-10 days old									
Bay beach	13.3	A	1.1	(5)	13.3	A	2.4	(4)	P=0.9999
Island interior	10.4	A	2.2	(7)	11.5	A B	2.4	(4)	P=0.7768
Ocean beach	4.9	B	2.0	(12)	7.1	B	1.3	(9)	P=0.0465
	P=0.0120				P=0.0909				
11-20 days old									
Bay beach	16.4	A B	3.5	(3)	18.9	A	7.9	(2)	P=0.7728
Island interior	17.1	A	0.5	(6)	13.4	A	4.2	(4)	P=0.9151
Ocean beach	10.6	B	2.5	(16)	10.9	A	2.1	(10)	P=0.5799
	P=0.0336				P=0.5351				
21+ days old									
Bay beach					10.5	A	1.8	(3)	
Island interior	18.3	A	5.7	(4)					
Ocean beach	14.8	A	4.1	(10)	12.4	A	2.6	(13)	P=0.8768
	P=0.5241				P=0.9999				
Tending Adults									
Bay beach	0.2	A	0.2	(2)	12.4	A	3.1	(8)	P=0.0502
Island interior	0.3	A	0.2	(8)	1.5	B	0.7	(8)	P=0.1706
Ocean beach	2.7	A	0.8	(25)	3.3	B	1.0	(17)	P=0.3339
	P=0.3564				P=0.0025				
Lone Adults									
Bay beach	15.8	A	2.2	(5)	24.3	A	4.6	(3)	P=0.1360
Island interior	9.0	A	9.0	(2)					
Ocean beach	9.6	A	1.9	(9)	8.7	A	3.7	(3)	P=0.7115
	P=0.1733				P=0.1904				

¹ Wilcoxon 2-sample Rank Sum test [for 2 samples] or Kruskal-Wallis test (Chi-square approximation) [for 3 samples].

Means with the same letter are not different (pairwise Wilcoxon Rank Sum, $P > 0.05$).

Table 31. Mean time (%) spent engaged in different behaviors of disturbed and undisturbed piping plovers in different habitat types on Assateague Island National Seashore, Maryland 1988-1990.

Behavior	Bay beach			Island interior			Ocean beach			Significance ¹
	$\bar{x}$	SE	(n)	$\bar{x}$	SE	(n)	$\bar{x}$	SE	(n)	
3-10 days old										
Undisturbed Foraging	90	2	(4)	90	6	(4)	26	15	(6)	P=0.0877
Disturbed Foraging	56	5	(3)	69	7	(4)	45	8	(8)	P=0.1869
Undisturbed Locomotion	3	2	(4)	5	3	(4)	21	11	(6)	P=0.4195
Disturbed Locomotion	17	8	(3)	9	2	(4)	24	6	(8)	P=0.3637
Undisturbed Preening	0	0	(5)	0	0	(7)	1	1	(12)	P=0.6065
Disturbed Preening	0	0	(4)	1	0.6	(4)	1	1	(9)	P=0.2048
Undisturbed Alert	2	1	(4)	5	4	(4)	19	10	(6)	P=0.6754
Disturbed Alert	14	8	(3)	11	2	(4)	23	7	(8)	P=0.4373
Undisturbed Resting	3	2	(5)	11	11	(8)	23	9	(12)	P=0.3002
Disturbed Resting	4	4	(4)	9	5	(4)	3	2	(9)	P=0.2947
11-20 days old										
Undisturbed Foraging	77	.	(1)	87	5	(6)	54	9	(15)	P=0.0777
Disturbed Foraging	89	.	(1)	93	0.1	(2)	59	8	(9)	P=0.0419
Undisturbed Locomotion	17	.	(1)	4	1	(6)	18	4	(15)	P=0.1986
Disturbed Locomotion	4	.	(1)	4	2	(2)	16	3	(9)	P=0.0439
Undisturbed Preening	0	0	(3)	0.4	0.2	(6)	7	5	(16)	P=0.4252
Disturbed Preening	4	4	(2)	0	0	(4)	8	4	(10)	P=0.1088
Undisturbed Alert	7	.	(1)	8	3	(6)	19	4	(15)	P=0.2971
Disturbed Alert	5	.	(1)	2	1	(2)	9	2	(9)	P=0.1481
Undisturbed Resting	0.3	0.3	(3)	0	0	(6)	7	4	(16)	P=0.3924
Disturbed Resting	0	0	(2)	0	0	(4)	6	4	(10)	P=0.0426
21+ days old										
Undisturbed Foraging				76	19	(3)	55	18	(7)	P=0.4875
Disturbed Foraging							62	10	(11)	
Undisturbed Locomotion				12	7	(3)	9	5	(7)	P=0.8079
Disturbed Locomotion							14	2	(11)	
Undisturbed Preening				0	0	(4)	3	2	(10)	P=0.4167
Disturbed Preening	4	4	(3)				4	2	(13)	P=0.9999
Undisturbed Alert				13	13	(3)	9	6	(7)	P=0.6381
Disturbed Alert							18	7	(11)	
Undisturbed Resting				0	0	(4)	16	10	(10)	P=0.2791
Disturbed Resting	1	1	(3)				3	1	(13)	P=0.8701

continued.

Table 31. Continued.

Behavior	Bay beach			Island interior			Ocean beach			Significance ¹
	$\bar{x}$	SE	(n)	$\bar{x}$	SE	(n)	$\bar{x}$	SE	(n)	
Tending Adults										
Undisturbed Foraging	3	.	(1)	2	1	(6)	19	7	(18)	P=0.5274
Disturbed Foraging	57	13	(7)	9	5	(6)	16	7	(13)	P=0.0435
Undisturbed Locomotion	13	.	(1)	7	2	(6)	15	5	(18)	P=0.5588
Disturbed Locomotion	12	5	(7)	13	3	(6)	19	4	(13)	P=0.3898
Undisturbed Preening	5	5	(2)	3	2	(8)	* 4	2	(25)	P=0.2965
Disturbed Preening	3	1	(8)	5	3	(8)	* 3	1	(17)	P=0.8246
Undisturbed Alert	73	.	(1)	52	16	(6)	35	6	(18)	P=0.4579
Disturbed Alert	22	9	(7)	41	10	(6)	41	6	(13)	P=0.0951
Undisturbed Resting	0	0	(2)	39	18	(8)	26	7	(25)	P=0.4011
Disturbed Resting	2	1	(8)	22	10	(8)	21	7	(17)	P=0.2250
Lone Adults										
Undisturbed Foraging	100	0	(2)	33	33	(2)	0	.	(1)	P=0.1738
Disturbed Foraging	91	3	(2)				91	3	(2)	P=0.9999
Undisturbed Locomotion	0	0	(2)	50	17	(2)	13	.	(1)	P=0.1504
Disturbed Locomotion	10	4	(2)				3	3	(2)	P=0.2453
Undisturbed Preening	0	0	(5)	8	8	(2)	4	4	(9)	P=0.2609
Disturbed Preening	0	0	(3)				1	1	(3)	P=0.5050
Undisturbed Alert	0	0	(2)	8	8	(2)	20	.	(1)	P=0.2231
Disturbed Alert	0	0	(2)				5	1	(2)	P=0.2207
Undisturbed Resting	0	0	(5)	0	0	(2)	3	3	(9)	P=0.6778
Disturbed Resting	0	0	(3)				0	0	(3)	P=0.9999

¹ Wilcoxon Rank Sum (normal approximation) [for 2 samples] and Kruskal-Wallis (Chi-square approximation) [for 3 samples].

* Means of undisturbed/disturbed observations are significantly different (Wilcoxon Rank Sum, $P \leq 0.05$).

Table 32. Total foraging rates (attempts/minute) of human disturbed and undisturbed piping plovers on Assateague Island National Seashore, Maryland 1988-1990.

	Undisturbed			Human Disturbed			Significance ¹
	$\bar{x}$	SE	n	$\bar{x}$	SE	n	
3-10 days old							
Bay beach	13.3	1.1	(5)	11.9	4.5	(2)	P=0.8465
Island interior	10.4	2.2	(7)				
Ocean beach	4.9	2.0	(12)	8.1	4.8	(2)	P=0.2348
	P=0.0120			P=0.6985			
11-20 days old							
Bay beach	16.4	3.5	(3)				
Island interior	17.1	0.5	(6)	6.3	0.4	(2)	P=0.0668
Ocean beach	10.6	2.5	(16)	10.0	5.4	(2)	P=0.9440
	P=0.0336			P=0.9999			
21+ days old							
Bay beach							
Island interior	18.3	5.7	(4)				
Ocean beach	14.8	4.1	(10)	12.9	6.8	(4)	P=0.9436
	P=0.5241						
Tending Adults							
Bay beach	0.2	0.2	(2)	7.1	5.4	(2)	P=0.2453
Island interior	0.3	0.2	(8)	1.2	0.9	(4)	P=0.1866
Ocean beach	2.7	0.8	(25)	4.2	3.6	(3)	P=0.4210
	P=0.3564			P=0.2333			
Lone Adults							
Bay beach	15.8	2.2	(5)				
Island interior	9.0	9.0	(2)				
Ocean beach	9.6	1.9	(9)				
	P=0.1733						

¹ Wilcoxon 2-sample Rank Sum test [for 2 samples] or Kruskal-Wallis test (Chi-square approximation) [for 3 samples].

Table 33. Mean time (%) engaged in different behaviors of undisturbed and human disturbed piping plovers in different habitat types on Assateague Island National Seashore, Maryland 1988-1990.

Behavior	Bay beach			Island interior			Ocean beach			Significance ¹
	$\bar{x}$	SE	(n)	$\bar{x}$	SE	(n)	$\bar{x}$	SE	(n)	
3-10 days old										
Undisturbed Foraging	90	2	(4)	90	6	(4)	26	15	(6)	P=0.0877
Disturbed Foraging	50	.	(1)				42	.	(1)	
Undisturbed Locomotion	3	2	(4)	5	3	(4)	21	11	(6)	P=0.4195
Disturbed Locomotion	28	.	(1)				43	.	(1)	
Undisturbed Preening	0	0	(5)	0	0	(7)	1	1	(12)	P=0.6065
Disturbed Preening	0	0	(2)				0	0	(2)	P=0.9999
Undisturbed Alert	2	1	(4)	5	4	(4)	19	10	(6)	P=0.6754
Disturbed Alert	17	.	(1)				12	.	(1)	
Undisturbed Resting	3	2	(5)	11	11	(8)	23	9	(12)	P=0.3002
Disturbed Resting	0.2	0.2	(2)				0	0	(2)	P=0.6171
11-20 days old										
Undisturbed Foraging	77	.	(1)	87	5	(6)	54	9	(15)	P=0.0777
Disturbed Foraging							81	.	(1)	
Undisturbed Locomotion	17	.	(1)	4	1	(6)	18	4	(15)	P=0.1986
Disturbed Locomotion							10	.	(1)	
Undisturbed Preening	0	0	(3)	0.4	0.2	(6)	7	5	(16)	P=0.4252
Disturbed Preening				0	0	(2)	0.3	0.3	(2)	P=0.6171
Undisturbed Alert	7	.	(1)	8	3	(6)	19	4	(15)	P=0.2971
Disturbed Alert							5	.	(1)	
Undisturbed Resting	0.3	0.3	(3)	0	0	(6)	7	4	(16)	P=0.3924
Disturbed Resting				0	0	(2)	2	2	(2)	P=0.6171
21+ days old										
Undisturbed Foraging				76	19	(3)	55	18	(7)	P=0.4875
Disturbed Foraging							56	26	(3)	
Undisturbed Locomotion				12	7	(3)	9	5	(7)	P=0.8079
Disturbed Locomotion							12	2	(3)	
Undisturbed Preening				0	0	(4)	3	2	(10)	P=0.4167
Disturbed Preening							7	7	(4)	
Undisturbed Alert				13	13	(3)	9	6	(7)	P=0.6381
Disturbed Alert							24	24	(3)	
Undisturbed Resting				0	0	(4)	16	10	(10)	P=0.2791
Disturbed Resting							5	3	(4)	

continued

Table 33. Continued.

Behavior	Bay beach			Island interior			Ocean beach			Significance ¹
Tending Adults										
Undisturbed Foraging	3	.	(1)	2	1	(6)	19	7	(18)	P=0.5274
Disturbed Foraging	41	25	(2)	2	1	(3)	15	15	(3)	P=0.2326
Undisturbed Locomotion	13	.	(1)	7	2	(6)	15	5	(18)	P=0.5588
Disturbed Locomotion	5	1	(2)	15	4	(3)	19	8	(3)	P=0.2359
Undisturbed Preening	5	5	(2)	3	2	(8)	4	2	(25)	P=0.2965
Disturbed Preening	4	2	(2)	6	6	(4)	5	4	(3)	P=0.6688
Undisturbed Alert	73	.	(1)	52	16	(6)	35	6	(18)	P=0.4579
Disturbed Alert	44	30	(2)	54	14	(3)	35	11	(3)	P=0.3889
Undisturbed Resting	0	0	(2)	39	18	(8)	26	7	(25)	P=0.4011
Disturbed Resting	1	1	(2)	12	7	(4)	19	18	(3)	P=0.8368
Lone Adults										
Undisturbed Foraging	100	0	(2)	33	33	(2)	0	.	(1)	P=0.1738
Disturbed Foraging	91	3	(2)							
Undisturbed Locomotion	0	0	(2)	50	17	(2)	13	.	(1)	P=0.1504
Disturbed Locomotion	10	4	(2)							
Undisturbed Preening	0	0	(5)	8	8	(2)	4	4	(9)	P=0.2609
Disturbed Preening	0	0	(3)							
Undisturbed Alert	0	0	(2)	8	8	(2)	20	.	(1)	P=0.2231
Disturbed Alert	0	0	(2)							
Undisturbed Resting	0	0	(5)	0	0	(2)	3	3	(9)	P=0.6778
Disturbed Resting	0	0	(3)							

¹ Wilcoxon Rank Sum (normal approximation) [for 2 samples] and Kruskal-Wallis (Chi-square approximation) [for 3 samples].

Disturbed and undisturbed categories did not differ ($P > 0.05$).

Table 34. Mean time (%) disturbed during behavioral observations of piping plovers on Assateague Island National Seashore, Maryland, 1988-1990. Only the disturbance sources that differed among years are listed.

	n	$\bar{x}$	SE	range	Significance ¹
Avian disturbance					
Bay Beach					
1988	78	1.8%	1.3	0-100%	P = 0.0044
1989	24	7.9%	2.8	0-48%	
1990	11	3.8%	2.5	0-28%	
Island Interior					
1988	39	0.7%	0.3	0-10%	P = 0.3260
1989	56	1.7%	0.9	0-33%	
1990	38	4.6%	2.7	0-100%	
Ocean Beach					
1988	76	0.86%	0.3	0-13%	P = 0.0001
1989	69	1.6%	0.8	0-47%	
1990	81	6.4%	1.6	0-90%	
Human disturbance					
Bay Beach					
1988	78	0.19%	0.15	0-11%	P = 0.0001
1989	24	0%	0		
1990	11	5.3%	2.5	0-23%	
Island Interior					
1988	39	8.2%	4.1	0-100%	P = 0.1079
1989	56	0.2%	0.2	0-12%	
1990	38	0.2%	0.2	0-7%	
Ocean Beach					
1988	76	0.61%	0.35	0-23%	P = 0.0146
1989	69	0.05%	0.05	0-3.3%	
1990	81	4.7%	1.8	0-100%	
Overall disturbance					
Bay Beach					
1988	78	2.4%	1.3	0-100%	P = 0.0040
1989	24	8.5%	2.8	0-48%	
1990	11	9.1%	4.2	0-40%	
Island Interior					
1988	39	9.1%	4.1	0-100%	P = 0.4209
1989	56	2.5%	1.0	0-33%	
1990	38	6.5%	2.9	0-100%	
Ocean Beach					
1988	76	2.7%	0.7	0-31%	P = 0.0001
1989	69	4.1%	1.4	0-57%	
1990	81	15.2%	2.6	0-100%	

¹ Comparisons among years using Kruskal-Wallis.

Table 35. Sources of disturbance during behavioral observations of piping plovers on Assateague Island National Seashore, Maryland 1988-1990. Reported are the number of 5-minute observations in which a disturbance occurred and the number of instantaneous samples in which a disturbance event occurred. The total number of observations containing disturbance is less than the addition of all sources because some observations experienced disturbance from more than one source. Scientific names are listed in Appendix G.

Source of Disturbance	# of observations	%	# of instantaneous samples	%
Avian Sources				
Piping Plover/territorial encounters	25	3.8%	99	0.55%
Boat-tailed Grackle	19	2.9%	99	0.55%
Ring-billed Gull	11	1.7%	40	0.22%
Sanderling	10	1.5%	23	0.13%
Willet	10	1.5%	44	0.25%
Herring Gull	8	1.2%	48	0.27%
Laughing Gull	8	1.2%	33	0.18%
Red-winged Blackbird	8	1.2%	26	0.15%
Crow sp.	5	0.8%	25	0.14%
Gull sp.	5	0.8%	11	0.06%
Ruddy Turnstone	5	0.8%	10	0.56%
Tern sp.	5	0.8%	12	0.067%
Black-backed Gull	4	0.6%	36	0.22%
Least Tern	2	0.3%	15	0.08%
sparrow sp.	2	0.3%	2	0.011%
Barn Swallow	1	0.2%	1	0.0056%
Gull-billed Tern	1	0.2%	9	0.05%
Osprey	1	0.2%	8	0.045%
Song Sparrow	1	0.2%	4	0.022%
Unidentified Avian	9	1.4%	14	0.078%
Total Avian	98	15.0%	559	3.13%
Mammalian Sources				
Ponies	4	0.6%	15	0.084%
Ghost Crab	7	1.1%	14	0.078%
Snake	1	0.2%	4	0.022%
Turtle sp.	1	0.2%	2	0.011%
Weather	1	0.2%	14	0.078%
Anthropogenic Sources				
Human	29	4.4%	208	1.17%
Airplane	3	0.5%	16	0.09%
Unknown -	11	1.7%	60	0.34%
Total Disturbance	161	24.6%	892	5.0%
Total observation periods	654			
Total instantaneous samples			17,848	

Table 36. Proportion of time (%) piping plovers were disturbed by various sources during behavioral observations on Assateague Island National Seashore, Maryland 1988-1990.

	n	Overall $\bar{x}$ SE	Avian $\bar{x}$ SE	Plover $\bar{x}$ SE	Human $\bar{x}$ SE	Mammalian $\bar{x}$ SE	Other $\bar{x}$ SE	Unknown $\bar{x}$ SE
Bay Beach	37	5.9 2.0	4.8 1.9	0.4 0.4	0.6 0.5	0.02 0.02	0.03 0.03	0.03 0.03
Island Interior	46	5.8 2.0	1.9 1.1	0.3 0.2	3.4 1.7	0.1 0.1	0.03 0.03	0.1 0.1
Ocean Beach	132	6.3 1.0	2.9 0.7	1.2 0.5	1.1 0.4	0.2 0.2	0.2 0.1	0.5 0.2
χ^2		1.53	7.61	2.77	0.68	0.24	0.23	1.63
Significance ¹		P=0.4661	P=0.0222	P=0.2504	P=0.7110	P=0.8873	P=0.8902	P=0.4437

¹ Kruskal-Wallis test results.

Table 37. Arthropod abundance indices on Assateague Island National Seashore, Maryland 1988-1990. Values represent total counts from 2 sticky paint stirrers (30-minute sampling period).

	Brood-rearing territories			Random Points			Significance ¹
	$\bar{x}$	SE	n	$\bar{x}$	SE	n	
1988							
Bay beach	26.3	9.7	(7)	34.8	23.7	(5)	
Island interior	1.0		(1)				
Ocean beach	0.5	0.3	(8)	0.7	0.3	(6)	
Significance ²	P=0.0034			P=0.0074			
1989							
Bay beach	8.3	1.8	(7)	3.2	0.9	(6)	
Island interior	5.1	2.3	(11)	3.9	1.5	(10)	
Ocean beach	1.5	0.7	(16)	4.5	2.1	(11)	
Significance ²	P=0.0029			P=0.7535			
1990							
Bay beach	6.4	1.6	(5)	16.6	8.4	(7)	
Island interior	12.3	6.9	(16)	5.9	2.6	(15)	
Ocean beach	1.4	0.4	(16)	1.9	1.1	(14)	
Significance ²	P=0.0029			P=0.0085			
1988-1990							
Bay beach	14.4	A	4.1 (19)	17.2	A	7.5 (18)	P=0.6514
Island interior	9.1	B	4.0 (28)	5.1	B	1.6 (25)	P=0.1526
Ocean beach	1.3	C	0.3 (40)	2.6	C	0.9 (31)	P=0.3790
Significance ²	P=0.0001			P=0.0002			

¹ Wilcoxon signed-rank on the differences between samples (brood-rearing territories - random sites) paired each week of collection.

² Wilcoxon Rank Sum test [two samples] or Kruskal-Wallis test (Chi-square approximation) [three samples]

Means with different letters are significantly different (pairwise Wilcoxon Rank Sum, P<0.02).

Table 38. Composition of terrestrial arthropod samples taken on Assateague Island National Seashore, Maryland, 1988-1990. Listed are insect orders.

	n ¹	Diptera	Hemiptera	Hymenoptera	Coleoptera	Homoptera	Insect larvae	Other ²
Bay beach	36	97%	1%	0.1%	1%	0.5%	<0.1%	0.2%
Island interior	45	83%	0.3%	10%	0.6%	0	0.1%	6%
Ocean beach	40	93%	0	3%	0	0	0	4%
Significance ³		0.0029	0.0819	0.0009	0.1896	0.0925	0.5981	0.5096
Total	121	91%	0.4%	5%	0.5%	0.1%	<0.1%	3%

¹ Sampling periods when ≥ 1 arthropod was caught.² Other samples include: beach fleas (C. Crustacea, O. Amphipoda) and small spiders (C. Arachnida, O. Araneae).³ Kruskal-Wallis [Chi-Square approximation]

Table 39. Sweep net insect counts on Assateague Island National Seashore, Maryland 1990.

	Brood-rearing territories			Random Points			Significance ¹
	$\bar{x}$	SE	n	$\bar{x}$	SE	n	
Bay beach	1.0	AB	(1)	1.3	A	1.3 (3)	P=0.9999
Island interior	7.7	B	2.1 (6)	17.0	A	10.9 (6)	P=0.2812
Ocean beach	0.5	A	0.3 (6)	0.5	A	0.3 (6)	P=0.9999
Significance ²			P=0.0193			P=0.1025	

¹ Wilcoxon signed-rank on the differences between samples (brood-rearing territories - random sites) paired each week of collection.
¹ Wilcoxon Rank Sum test [two samples] or Kruskal-Wallis test [three samples]

Means with the same letters are not different (pairwise Wilcoxon Rank Sum, P>0.05).

Table 40. Substrate invertebrates on Assateague Island National Seashore, Maryland 1988-1990. Presented are numbers per 0.0081 m² plot.

	Brood-rearing territories			Random Points			Significance ¹
	$\bar{x}$	SE	n	$\bar{x}$	SE	n	
1988-90							
Total Invertebrates							
Bay beach	25.8	A	6.3 (17)	15.0	A	6.9 (15)	P=0.3750
Island interior	5.3	B	2.1 (24)	0.3	B	0.1 (21)	P=0.0001
Ocean beach	294.5	C	86.9 (33)	110.3	C	50.4 (30)	P=0.0006
Significance ²		P=0.0001			P=0.0001		
Amphipods							
Bay beach	0.4		0.2 (17)	0.7		0.5 (15)	P=0.9583
Island interior	0.1		0.1 (24)	0		0 (21)	P=0.3730
Ocean beach	286.3		86.4 (33)	103.9		50.3 (30)	P=0.0036
Significance ²		P=0.0001			P=0.0001		
"Digger" Amphipods							
Bay beach	0.5		0.5 (17)	0		0 (15)	P=0.3806
Island interior	0		0 (24)	0		0 (21)	P=0.9999
Ocean beach	3.6		0.8 (33)	2.4		0.8 (30)	P=0.2540
Significance ²		P=0.0001			P=0.0001		
Bivalves							
Bay beach	3.6		2.7 (17)	2.5		2.1 (15)	P=0.2433
Island interior	0		0 (24)	0		0 (21)	P=0.9999
Ocean beach	1.5		0.4 (33)	1.8		0.9 (30)	P=0.0119
Significance ²		P=0.0001			P=0.0008		
Polychaetes							
Bay beach	19.5		4.6 (17)	11.5		5.7 (15)	P=0.1005
Island interior	1.1		0.5 (24)	0.05		0.05 (21)	P=0.0559
Ocean beach	1.8		1.7 (33)	0.6		0.4 (30)	P=0.3852
Significance ²		P=0.0001			P=0.0001		
Mole Crabs							
Bay beach	0		0 (17)	0		0 (15)	P=0.9999
Island interior	0		0 (24)	0		0 (21)	P=0.9999
Ocean beach	1.4		0.4 (33)	1.7		0.5 (30)	P=0.5464
Significance ²		P=0.0001			P=0.0001		
Insects & Larvae							
Bay beach	1.9		1.2 (17)	0.4		0.3 (15)	P=0.4214
Island interior	4.3		1.9 (24)	0.3		0.1 (21)	P=0.0042
Ocean beach	0.06		0.03 (33)	0.02		0.02 (30)	P=0.2063
Significance ²		P=0.0001			P=0.0339		

continued.

¹ Wilcoxon signed-rank on the differences between samples (brood-rearing territories - random sites) paired each week of collection for the 1988-1990 Total Invertebrates. Wilcoxon 2-sample Rank Sum test - Random points vs. Brood-rearing territories for all other comparisons.

²Kruskal-Wallis test (Chi-square approximation)

Table 40. Continued.

	Brood-rearing territories			Random Points			Significance ¹
	$\bar{x}$	SE	n	$\bar{x}$	SE	n	
1988							
Total Invertebrates							
Bay beach	37.0	11.4	(8)	55.8	23.3	(3)	P=0.6098
Ocean beach	71.6	18.8	(9)	26.3	5.6	(7)	P=0.0199
Significance ²		P=0.0541			P=0.3619		
Amphipods							
Bay beach	0.2	0.1	(8)	0	0	(3)	P=0.4468
Ocean beach	66.8	18.7	(9)	20.1	4.6	(7)	P=0.0081
Significance ²		P=0.0005			P=0.0210		
"Digger" Amphipods							
Bay beach	0	0	(8)	0	0	(3)	P=0.9999
Ocean beach	2.9	0.9	(9)	1.3	0.3	(7)	P=0.2023
Significance ²		P=0.0003			P=0.0449		
Bivalves							
Bay beach	7.5	5.6	(8)	12.5	9.7	(3)	P=0.5308
Ocean beach	0.8	0.3	(9)	0.8	0.4	(7)	P=0.8724
Significance ²		P=0.6257			P=0.3560		
Polychaetes							
Bay beach	27.7	6.8	(8)	43.3	21.4	(3)	P=0.6098
Ocean beach	0.2	0.2	(9)	2.5	1.7	(7)	P=0.0474
Significance ²		P=0.0004			P=0.0396		
Mole Crabs							
Bay beach	0	0	(8)	0	0	(3)	P=0.9999
Ocean beach	0.7	0.3	(9)	1.6	0.8	(7)	P=0.3918
Significance ²		P=0.0081			P=0.0202		
Insects & Larvae							
Bay beach	1.5	0.9	(8)	0	0	(3)	P=0.2990
Ocean beach	0.1	0.1	(9)	0	0	(7)	P=0.2306
Significance ²		P=0.3390			P=0.9999		

continued.

¹Wilcoxon 2-sample Rank Sum test - Random points vs. Brood-rearing territories.²Kruskal-Wallis test (Chi-square approximation)

Table 40. Continued.

	Brood-rearing territories			Random Points			Significance ¹
	$\bar{x}$	SE	n	$\bar{x}$	SE	n	
1989							
Total Invertebrates							
Bay beach	24.8	8.0	(4)	6.8	2.9	(5)	P=0.0491
Island interior	6.4	2.0	(8)	0.5	0.2	(6)	P=0.0065
Ocean beach	381.9	122.7	(9)	52.8	16.9	(8)	P=0.0750
Significance ²		P=0.0227			P=0.0027		
Amphipods							
Bay beach	0	0	(4)	2.0	1.5	(5)	P=0.1073
Island interior	0	0	(8)	0	0	(6)	P=0.9999
Ocean beach	375.6	120.6	(9)	47.3	14.2	(8)	P=0.0606
Significance ²		P=0.0001			P=0.0008		
"Digger" Amphipods							
Bay beach	0	0	(4)	0	0	(5)	P=0.9999
Island interior	0	0	(8)	0	0	(6)	P=0.9999
Ocean beach	2.6	1.6	(9)	2.6	1.0	(8)	P=0.5253
Significance ²		P=0.0058			P=0.0043		
Bivalves							
Bay beach	0.3	0.3	(4)	0	0	(5)	P=0.3711
Island interior	0	0	(8)	0	0	(6)	P=0.9999
Ocean beach	3.1	1.1	(9)	2.6	2.6	(8)	P=0.0193
Significance ²		P=0.0015			P=0.5028		
Polychaetes							
Bay beach	19.5	10.0	(4)	3.6	1.9	(5)	P=0.2109
Island interior	1.6	1.0	(8)	0	0	(6)	P=0.1260
Ocean beach	0	0	(9)	0	0	(8)	P=0.9999
Significance ²		P=0.0099			P=0.0092		
Mole Crabs							
Bay beach	0	0	(4)	0	0	(5)	P=0.9999
Island interior	0	0	(8)	0	0	(6)	P=0.9999
Ocean beach	0.6	0.3	(9)	0.3	0.1	(8)	P=0.7929
Significance ²		P=0.0453			P=0.0382		
Insects & Larvae							
Bay beach	5.0	5.0	(4)	1.2	1.0	(5)	P=0.9999
Island interior	4.5	1.6	(8)	0.5	0.2	(6)	P=0.0103
Ocean beach	0.1	0.07	(9)	0.06	0.06	(8)	P=0.6625
Significance ²		P=0.0026			P=0.2278		

continued.

¹Wilcoxon 2-sample Rank Sum test - Random points vs. Brood-rearing territories.

²Kruskal-Wallis test (Chi-square approximation)

Table 40. Continued.

	Brood-rearing territories			Random Points			Significance ¹
	$\bar{x}$	SE	n	$\bar{x}$	SE	n	
1990							
Total Invertebrates							
Bay beach	8.8	4.3 (5)		3.4	2.1 (7)		P=0.2058
Island interior	4.8	3.0 (16)		0.3	0.1 (15)		P=0.0110
Ocean beach	375.7	172.6 (15)		180.2	98.6 (15)		P=0.1198
Significance ²		P=0.0001			P=0.0001		
Amphipods							
Bay beach	1.0	0.8 (5)		0	0 (7)		P=0.1046
Island interior	0.2	0.2 (16)		0	0 (15)		P=0.3662
Ocean beach	364.5	172.1 (15)		173.2	98.6 (15)		P=0.1247
Significance ²		P=0.0001			P=0.0001		
"Digger" Amphipods							
Bay beach	1.6	1.6 (5)		0	0 (7)		P=0.33105
Island interior	0	0 (16)		0	0 (15)		P=0.9999
Ocean beach	4.6	1.5 (15)		2.8	1.5 (15)		P=0.1620
Significance ²		P=0.0001			P=0.0001		
Bivalves							
Bay beach	0	0 (5)		0	0 (7)		P=0.9999
Island interior	0	0 (16)		0	0 (15)		P=0.9999
Ocean beach	1.0	0.4 (15)		1.8	1.1 (15)		P=0.2375
Significance ²		P=0.0001			P=0.0008		
Polychaetes							
Bay beach	6.2	4.6 (5)		3.4	2.1 (7)		P=0.6641
Island interior	0.9	0.5 (16)		0.1	0.1 (15)		P=0.2930
Ocean beach	3.7	3.7 (15)		0	0 (15)		P=0.3506
Significance ²		P=0.0492			P=0.0080		
Mole Crabs							
Bay beach	0	0 (5)		0	0 (7)		P=0.9999
Island interior	0	0 (16)		0	0 (15)		P=0.9999
Ocean beach	2.3	0.9 (15)		2.4	0.9 (15)		P=0.7048
Significance ²		P=0.0001			P=0.0001		
Insects & Larvae							
Bay beach	0	0 (5)		0	0 (7)		P=0.9999
Island interior	4.1	2.8 (16)		0.2	0.1 (15)		P=0.0901
Ocean beach	0	0 (15)		0	0 (15)		P=0.9999
Significance ²		P=0.0055			P=0.0974		

¹Wilcoxon 2-sample Rank Sum test - Random points vs. Brood-rearing territories.²Kruskal-Wallis test (Chi-square approximation)

Table 41. Ocean beach substrate invertebrates taken from the wet and saturated intertidal zone on Assateague Island National Seashore, Maryland 1989-1990. Presented are # / 0.0081 m².

	Brood-rearing territories			Random Points		
	$\bar{x}$	SE	n	$\bar{x}$	SE	n
Total Invertebrates						
Wet samples	14	4	(50)	7	2	(44)
Saturated samples	419	118	(50)	160	70	(44)
Pooled samples ¹	294	87	(33)	110	50	(30)
Amphipods						
Wet samples	11	4	(50)	2	0.7	(44)
Saturated samples	406	118	(50)	152	69	(44)
Pooled samples ¹	286	86	(33)	103	50	(30)
"Digger" Amphipods						
Wet samples	2.0	0.5	(50)	1.3	0.4	(44)
Saturated samples	4.9	1.0	(50)	2.9	1.0	(44)
Pooled samples ¹	3.6	0.8	(33)	2.4	0.8	(30)
Bivalves						
Wet samples	0.2	0.1	(50)	0.7	0.3	(44)
Saturated samples	2.3	0.5	(50)	2.2	1.2	(44)
Pooled samples ¹	1.5	0.4	(33)	1.8	0.9	(30)
Polychaetes						
Wet samples	0	0	(50)	2.1	1.7	(44)
Saturated samples	3.6	3.3	(50)	0.2	0.1	(44)
Pooled samples ¹	1.8	1.7	(33)	0.6	0.4	(30)
Mole Crabs						
Wet samples	2.0	0.5	(50)	0.7	0.3	(44)
Saturated samples	1.6	0.6	(50)	2.6	1.0	(44)
Pooled samples ¹	1.4	0.4	(33)	1.7	0.5	(30)
Insects & Larvae						
Wet samples	0.06	0.06	(50)	0.02	0.02	(44)
Saturated samples	0.1	0.06	(50)	0	0	(44)
Pooled samples ¹	0.06	0.03	(33)	0.02	0.02	(30)

¹ Pooled sample values were used in all analyses.

Table 42. Animal trails (number/linear 100 m) from random and brood-rearing territory transects on Assateague Island National Seashore, Maryland 1988-1990. See Appendix G for the scientific names of the animals mentioned.

	Ghost crab ¹		B-tailed grackle		Gulls		Egret sp.		Red fox		Raccoon		Dog		
	n	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE		
Bay beach	27	1.2	1.1	1.8	0.8	11.1	4.9	1.2	0.7	1.9	0.7	2.1	1.0	0.02	0.02
Island interior	45	0.4	0.1	6.3	1.6	0	0	0	0	8.8	2.2	0.08	0.05	0	0
Ocean beach	70	5.2	0.7	1.4	0.4	4.4	1.1	0.02	0.02	5.1	0.8	0.2	0.2	0.07	0.05
Significance										P=0.0005					

	Wild pony		Sika deer		Fiddler crab ¹		American Oystercatcher		Willet		Turtle		Duck sp.		
	n	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE		
Bay beach	27	21.5	6.0	5.3	1.3	1.4	0.8	0	0	4.6	2.7	0.08	0.06	1.0	1.0
Island interior	45	25.3	4.5	8.7	1.4	0	0	0	0	0.3	0.3	0.07	0.04	0	0
Ocean beach	70	9.7	1.5	0.9	0.4	0	0	0.6	0.2	0.5	0.2	0.05	0.03	0	0
Significance										P=0.0001					

	Predators ²		Nonpredators ²		Humans		ATV		Miscellaneous		Trash		Total trails		
	n	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE		
Bay beach	27	22.9	7.6	38.1	8.4	11.0	4.6	0.1	0.1	0	0	0	0	72.1	13.4
Island interior	45	16.7	2.9	34.3	5.0	2.3	0.6	0.06	0.06	0	0	0.02	0.02	53.3	6.0
Ocean beach	70	32.2	3.5	11.8	1.7	5.2	1.0	0.2	0.06	0.1	0.04	0.2	0.07	49.3	3.8
Significance															P=0.8079

¹ Ghost crab and fiddler crab values are expressed as burrows/100 m².
² Total predators (ghost crab burrows, boat-tailed grackles, gulls, egrets, red foxes, raccoons, and dogs) and Total nonpredators (ponies, deer, fiddler crab burrows, American oystercatchers, willets, turtles, and ducks).
³ Wilcoxon Rank Sum test [for 2 samples] or Kruskal-Wallis test (Chi-square approximation) [for 3 samples].

Table 43. Animal trail counts (number/linear 100 m) differing between random and brood-rearing territory transects on Assateague Island National Seashore, Maryland 1988-1990. See Appendix G for the scientific names of the animals mentioned.

	Wild pony			Humans		Nonpredators		Total Trails	
	n	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Island Interior									
Brood territories	27	30.9	5.9	3.5	1.0	42.3	6.6	58.9	8.0
Random Plots	18	16.9	6.5	0.5	0.2	22.4	7.0	44.9	9.0
Significance ¹	P=0.0339			P=0.0095		P=0.0025		P=0.0129	
Bay Beach	No differences were observed between random plots and brood-rearing territories.								
Ocean Beach	No differences were observed between random plots and brood-rearing territories.								

¹ Wilcoxon signed-rank on the differences between samples (brood-rearing territories - random sites) paired each week of collection.

Table 44. Number of piping plovers banded on Assateague Island National Seashore, Maryland, 1987-1989 and resighted the following year. This includes 1 adult and 3 first-year birds observed elsewhere and not on AINS. Shown also are hypothetical estimates of the return rates, given estimated corrections for incomplete color-band combinations and band-related deaths.

Year in which adults and chicks were banded	Number of birds resighted each year after being banded			
	1987	1988	1989	1990
Complete color-band combinations				
Adults				
1987	9 ¹	7 ²	4	2
1988		35 ¹	28 ³	17
1989			9 ¹	4
Chicks				
1988		12 ¹	5	1
1989			17 ¹	7
Complete plus incomplete color-band combinations				
Adults				
1987	9 ¹	7	6	3
1988		35 ¹	32	18
1989			9 ¹	4
Complete plus incomplete color-band combinations plus estimated deaths				
Adults				
1987	9 ¹	7	6	3
1988		35 ¹	35	18
1989			9 ¹	4

¹ The number of piping plovers banded in the given year.

² Includes 1 bird not observed but known to be alive because it was sighted the following year.

³ Includes 3 birds not observed but known to be alive because they were sighted the following year.

Table 45. Input variables and values used for population modeling of plovers on Assateague Island National Seashore. The population was modeled with POPULATION DYNAMICS 4.5 software. Also shown are the values used when determining population stability.

Input Variable	Values used
Age at which plovers first begin to breed	1 year
Estimated % of adult females that produce young each year	Mean value observed on AINS during 1986-1990 was 43.4%. 100% was used when determining the reproductive rate needed for population stability since this is usually expressed as chicks fledged/BREEDING pair.
Average annual number of young produced per successful female	Mean value observed on AINS during 1986-1990 was 2.023. This variable was varied (while holding all others constant) to achieve a stable population at different survival estimates.
Estimated first year mortality	59% (41% survival) was used in all cases based on our observed survival rates.
Estimated annual mortality rate for older plovers	33%, 29%, and 28% (67%, 71%, and 72% survival) were used based on our observed survival rates.
Duration of simulation	I ran simulations of 100 years.
Starting number of male and female young of the year	Mean number of chicks fledged on AINS during 1986-1990 was 8.7,8.7.
Starting number of male and female adults	Mean number of breeding adults on AINS during 1986-1990 was 19.8, 19.8.

Table 46. Survival estimates ($\frac{N_{t+1}}{N_t}$) for piping plovers banded on Assateague Island National Seashore, Maryland, 1987-1990. Also shown are estimated survival corrections based on incomplete band combinations and assumed deaths from band-related injuries.

Estimate based on:	Survival Estimate	95% Confidence Interval ¹
Complete color-band combinations		
Adults		
Survival 1 year to next	67% (62/92)	56.5% - 76.4%
Survival 1 year to 3rd year	46% (23/50)	31.8% - 60.7%
Chicks		
First year survival	41% (12/29)	24.0% - 59.2%
Complete plus incomplete color-band combinations		
Adults		
Survival 1 year to next	71% (70/98)	61.0% - 79.7%
Survival 1 year to 3rd year	53% (27/51)	38.6% - 67.1%
Complete plus incomplete color-band combinations plus assumed deaths		
Adults		
Survival 1 year to next	72% (73/101)	62.2% - 80.5%

¹ Calculated using the Binomial Distribution.

Corrected survival estimates could not be calculated for first year survival because we could not identify returning chicks without a complete color-band combination and no chicks were observed with band-related injuries.

Table 47. Piping plovers color-banded on Assateague Island National Seashore, Maryland, 1987-1989 and sighted elsewhere. For band combinations, see Appendix E.

USFWS#	Date Banded	Date(s) Sighted	Location
800190338	5/24/88	12/17/88 3/20/89 10/15/89 4/04/90	Ohio Key, Florida ¹ Chincoteague National Wildlife Refuge, VA ² Bahai Honda State Park, Florida ³ Chincoteague National Wildlife Refuge, VA ²
800190317	1987	5/24-6/30	N.J. ⁴ ⁹
800190347	4/30/88	June 1988	NJ ⁵
800190357	6/14/88	3/20/89	Chincoteague National Wildlife Refuge, VA ²
800190360	6/17/88	3/26/89	Cape Lookout National Seashore, NC ⁶
800190325	1987	3/27/89	Chincoteague National Wildlife Refuge, VA ²
139112622 *	7/18/88	4/20/89	Cape Hatteras National Seashore, NC ⁷
139112620 *	7/10/88	4/25/89	Cape Hatteras National Seashore, NC ⁷
800190502 ⁸		6/13-7/89 8/13-8/20/89	Chincoteague National Wildlife Refuge, VA ² Cape Lookout National Seashore, NC ⁶
800190334	5/19/88	7/6/89	Chincoteague National Wildlife Refuge, VA ²
800190369	5/31/89	7/27/89	Chincoteague National Wildlife Refuge, VA ²
139112617 *	7/8/88	8/17/89	Cape Lookout National Seashore, NC ⁶
800190333 *	5/15/88	3/23/90	Chincoteague National Wildlife Refuge, VA ²
800190374	6/01/89	6/6/90	Chincoteague National Wildlife Refuge, VA ²
800190335	5/19/88	7/7/90	Chincoteague National Wildlife Refuge, VA ²

* Birds that were sighted during migration and NOT sighted on AINS that year.

¹ Marge Brown, pers. commun. P.O. Box 239, Summerland Key, FL 33042.

² Robert Cross, pers. commun.

³ Susan Haig, pers. commun.

⁴ Observed by Ted C. Nichols, N.J. Department of Environmental Protection.

⁵ Observed by Jack Conner, 89 Powhatan Trail, Medland Lakes, NJ 08055

⁶ Jay McConnaughey, pers. commun.

⁷ Suzanne Coutu, pers. commun.

⁸ Banded on Chincoteague NWR, VA. Breeder on AINS, MD.

⁹ Banded on Patterson (1988) in Virginia (excluded from analysis).

Table 48. Reproductive success necessary to maintain stationary piping plover populations on Assateague Island National Seashore, Maryland.

Estimate based on	Adult Survival	1st year Survival	Chicks fledged/ Breeding pair	Range ¹
Complete color-band resightings (minimum known alive)	67%	41%	1.610	0.80-3.63
Complete color-band resightings plus corrections for incomplete combinations	71%	41%	1.415	0.68-3.26
Complete color-band resightings plus corrections for incomplete combinations plus corrections assuming the banded population was negatively biased by band-related death	72%	41%	1.366	0.66-3.15

¹ Calculated from the upper and lower 95% Confidence Interval for adult and first-year survival.

Table 49. Annual piping plover survival estimates based on the re-sightings and recaptures.

L = USFWS leg bands only C = color leg bands		Adults Sighted % (n)	Chicks Sighted % (n)
Griffin (pers. commun.)	C	73%	43%
Loefering (1992)	C	67% (92) ¹	41% (29)
- this study			
Prindiville Gaines and Ryan (1988)	C	63.4%	
Cross (1989)	C	56.6% (30) ³	
Whyte (1985)	C	42.8% (14) ³	8.3% (12) ³
Cairns (1977)	C	15% (67) ³	
Wilcox (1959) ²	L	25.2% (1504)	

¹ Resighted bird-years (a bird sighted in 3 years = 3 bird years).

² Wilcox (1959) only reported the number of band returns regardless of the number of years observed; therefore, this is not a survival rate. Wilcox also reported recaptures, NOT resightings. This is pooled for chicks and adults.

³ One year of observations.

Table 50. Color band combinations of piping plovers sighted on Assateague Island National Seashore, Maryland, 1988-1990, but not banded by the author or Patterson (1988). Color bands have been sorted by band combination. See the key below for band colors and locations.

Left Top	Left Bot	Right Top	Right Bot	Sex	Inclusive Dates Observed	Activity ^a	A bird it was observed With ^b Location ^c		Result
ALU	RED	RF	WHI	♀	4/4-6/2/89	N 5/19-6/2/89	800190354	32069	Hatch-chicks lost ^d
					6/7-7/20/90	N 6/14-7/28/90	800190354	32069	Hatch-chicks lost
BWBW	ALU	BLK	GRE	♀	5/18-7/23/90	N 6/13-6/20/90	800190340	03043	Loss-fox
BWBW	ALU	WHI	GRE	♂	7/16/90			32039	
BWBW	ALU	YEL	BLK		6/22/89			03042	
RF	BLU	ORA	ALU		5/13-7/6/88	N 5/13-7/3/88	800190320	07045	Fledge 1 chick ^{e,f}
					3/16-4/14/89				
YEL	ALU	BF	YEL		4/3/90			05043	Identification questionable

^a N = Nested.

^b USFWS #.

^c See key below for locations.

^d USFWS # 8001-90502. Banded on Chincoteague National Wildlife Refuge in 1988? Both top bands were loose enough to slip up over heel.

^e USFWS # 851-53724. Banded on Assateague Island National Seashore as a chick in 1979.

^f Bird captured with ALU band present. Color bands added in 1988.

COLORS

ALU = USFWS Aluminum band
 BF = Black Flag (Massachusetts)
 BLK = Black
 BLU = Blue
 BWBW = Black / White narrow stripe band
 GRE = Green
 ORA = Orange
 RED = Red
 RF = Red Flag
 WHI = White

LOCATIONS

MD = Maryland (Loefering's study area)
 VA = Virginia
 HOOK = Toms Cove Hook, VA
 WB = Wild Beach, VA
 WF = Wash Flats, VA

Five digit numbers located in MD,
 description in text under
 Location Assignment.

Table 51. Morphometric measurements of adult piping plovers on Assateague Island National Seashore, Maryland, 1988-1990. The first row represents all birds captured. The second and third rows represent birds that we could reliably determine sex.

	n	$\bar{x}$	SE	range	Significance ¹
Mass (g)	70	53.6	0.3	46.5-62.0	
Females	26	52.6	0.5	46.5-56.0	P=0.0288
Males	32	54.5	0.4	50.5-62.0	
Culmen length (mm)	70	13.4	0.1	12.0-18.0	
Females	26	13.3	0.2	12.0-18.0	P=0.0230
Males	32	13.5	0.1	12.0-15.0	
Culmen width (mm)	69	5.3	0.04	4.5-6.5	
Females	26	5.2	0.07	5.0-6.5	P=0.0482
Males	31	5.4	0.06	4.5-6.0	
Culmen depth (mm)	69	5.9	0.03	5.0-6.5	
Females	26	5.8	0.6	5.5-6.5	P=0.0189
Males	31	6.0	0.05	5.0-6.5	
Tarsus length (mm)	70	21.8	0.2	18.0-24.5	
Females	26	21.8	0.3	18.0-24.0	P=0.8197
Males	32	22.0	0.3	19.0-24.5	
Mid-toe length (mm)	70	15.3	0.2	11.0-18.0	
Females	26	15.3	0.3	11.0-17.5	P=0.1939
Males	32	15.9	0.2	13.0-18.0	
Wing chord (mm)	68	117.8	0.3	110.0-122.0	
Females	26	117.1	0.6	110.0-122.0	P=0.0615
Males	31	118.5	0.3	115.0-121.0	
Tail length (mm)	70	53.1	0.3	47.0-60.0	
Females	26	53.2	0.6	48.0-60.0	P=0.7177
Males	32	53.3	0.3	50.0-57.0	
Breast-band gap (mm)	67	14.3	0.9	0-39.5	
Females	25	15.3	1.5	0-31.0	P=0.2834
Males	31	13.3	1.5	0-39.5	
Forehead band length (mm)	70	15.7	0.2	10.0-19.5	
Females	26	14.7	0.3	10.0-17.5	P=0.0001
Males	32	16.8	0.2	14.0-19.5	
Forehead band width (mm)	70	4.7	0.1	2.0-7.0	
Females	26	4.0	0.2	2.5-5.5	P=0.0001
Males	32	5.4	0.1	4.0-7.0	

¹ Wilcoxon Rank Sum test on each measurement, testing males vs. females.

Table 52. Categorical data collected while banding adult piping plovers on Assateague Island National Seashore, Maryland, 1988-1989.

	Females		Males		Total ¹	
	n	%	n	%	n	%
Brood Patch						
Bare	8	36%	10	38%	20	38%
Downy around the edges	2	9%	4	15%	6	11%
Downy midline only	1	5%	4	15%	5	9%
Downy	11	50%	8	31%	22	42%
	<u>22</u>		<u>26</u>		<u>53</u>	
Parasite Load						
None	14	64%	17	74%	36	68%
Few present in axillary /crown regions	8	36%	6	26%	17	32%
	<u>22</u>		<u>23</u>		<u>53</u>	

¹ Contains males, females, and birds that the sex could not be reliably determined.

Table 53. Morphometric measurements of piping plovers chicks 4-5 days old on Assateague Island National Seashore, Maryland, 1988-1990.

	n	median	$\bar{x}$	SE	range
Mass (g)	37	7.5	7.8	0.3	4.5-12.0
Culmen length (mm)	31	7.0	7.3	0.1	6.0-9.0
Tarsus length (mm)	31	17.0	17.4	0.2	15.0-20.0
Mid-toe length (mm)	31	15.0	14.6	0.2	12.5-17.0

Table 54. Injured piping plovers observed on Assateague Island National Seashore, Maryland, 1988-1990. Birds with apparent leg injuries usually limped, or held their leg up, and/or hopped when they moved. Bands have been sorted by band combination. See key below for band colors.

Left Top	Left Bot	Right Top	Right Bot	Dates Observed	Injury / Information
ALU	.	RF	ALU	4/11-7/16/90	Left foot missing. Nested successfully. ²
		RF	.	5/2-5/18/89	Both feet missing.
					Bird (♀) observed copulating.
ALU	BLU	RF	ORA	8/1/89	Right leg appeared injured.
ALU	ORA	RF	BLK	7/17/90	Limping, leg appeared injured.
ALU	ORA	RF	YEL	5/13/89	Right leg appeared injured. ³
ALU	WHI	.	.	7/13/88	Right leg appeared injured, foot appeared black.
ALU	YEL	RF	.	7/31/89	Both feet missing.
¹ GRE	.	.	.	4/14-5/3/89	Right foot missing. Rebanded as GRE ALU . . (8001-90385) in 1988. Banded by Patterson in 1987. Nested in 1989, predated 3 times.
¹ GRE	ALU	.	.	4/7-7/21/90	Right foot missing.
GRE	ALU	RF	RED	6/23/88	Right leg appeared injured.
GRE	ALU	RF	.	5/3-6/15/89	Right foot missing.
ORA	ALU	RF	.	5/8/89	Right foot missing.
ORA	BLU	RF	.	7/13/88	Right foot missing. Right foot and ALU band lost.
ORA	GRE	RF	.	7/15/88	Right foot missing. Good use of stump. Right foot amputated at or above tarsus joint. Looks like 1987 bands.
⁷ WHI	WHI	.	.	7/16/88	Right leg appeared injured.
⁷ WHI	WHI	RF	ALU	6/28/88	Right leg appeared injured, Bird was holding leg up and hopping.
YEL	ALU	RF	BLU	4/7-7/9/89	Left leg broken. Removed lower leg, bird recovered.

¹ I suspect this is the same bird.

² Probably USFWS # 8001-90366.

³ Removed RF YEL and the bird fully recovered (USFWS # 8001-90360).

⁴ Probably ALU YEL RF BLK because this is the only possible combination.

⁵ Probably GRE ALU RF WHI because this is the only possible combination.

⁶ Probably USFWS # 8001-90329, RED GRE RF ALU because this is the only possible combination. The 1987 bands were NOT stable in ultraviolet light and faded to the colors observed (this was confirmed by trapping birds with known color-band combinations).

⁷ This is the same bird.

COLORS

ALU = USFWS Aluminum band
BLK = Black
BLU = Blue
GRE = Green

ORA = Orange
RED = Red
RF = Red Flag
WHI = White

FIGURES

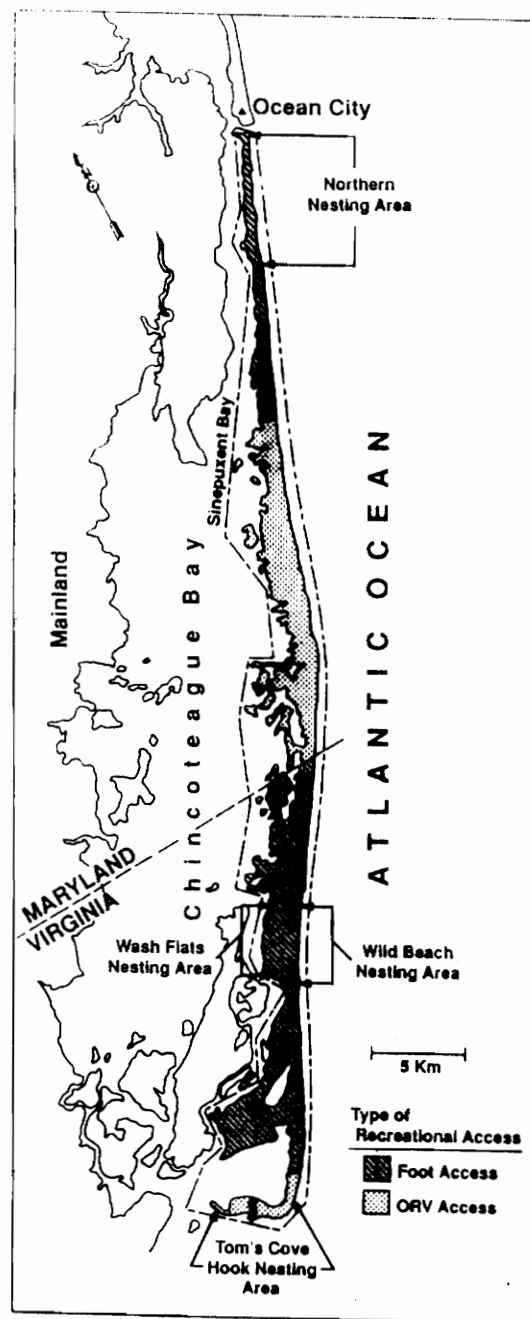


Figure 1. Piping plover nesting areas and types of recreational access on Assateague Island (from Patterson et al. 1991).

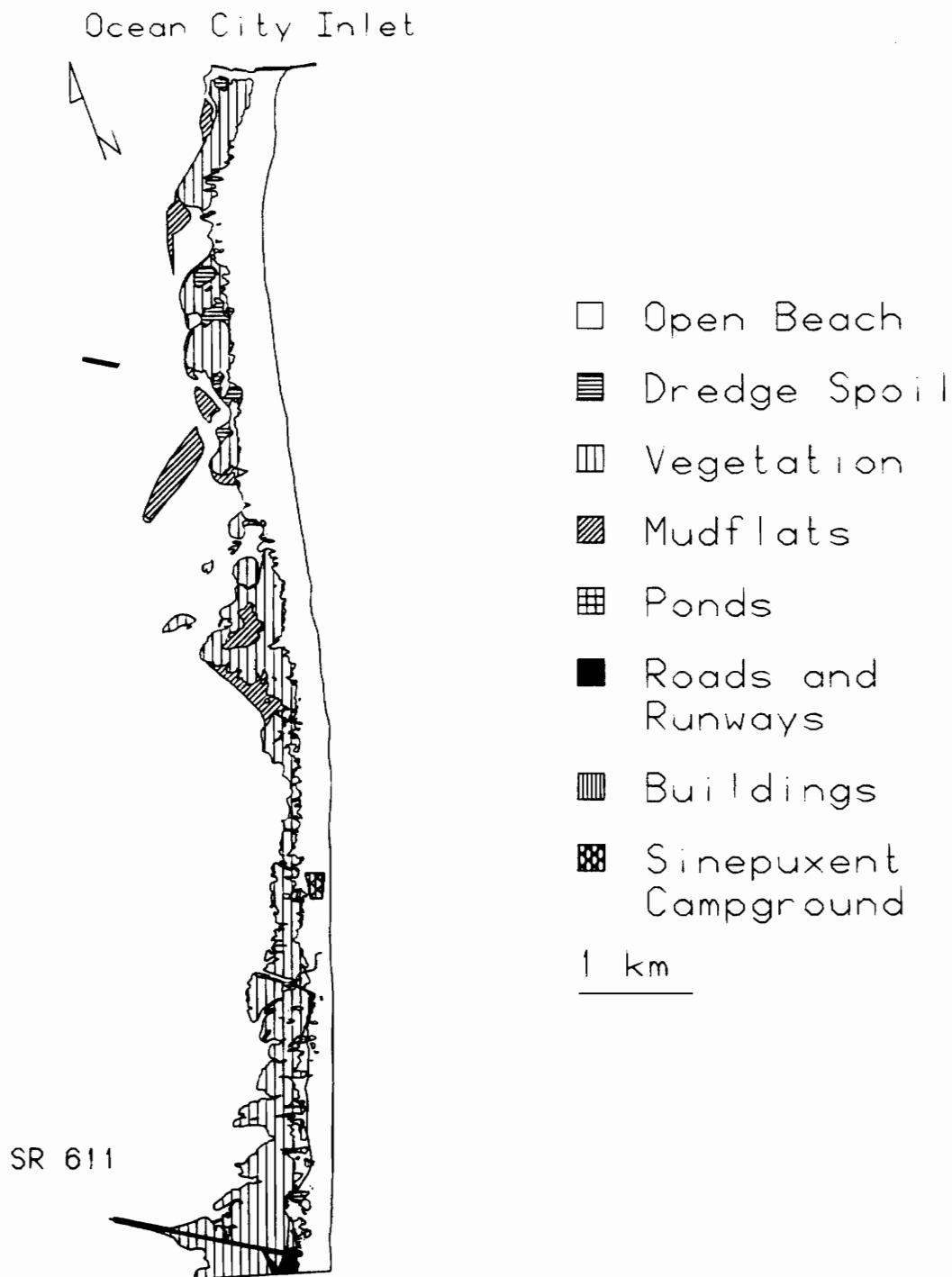


Figure 2. Northern 8 km of Assateague Island National Seashore. Habitat patterns were digitized from aerial photographs taken in 1988. Scale 1:60,000.

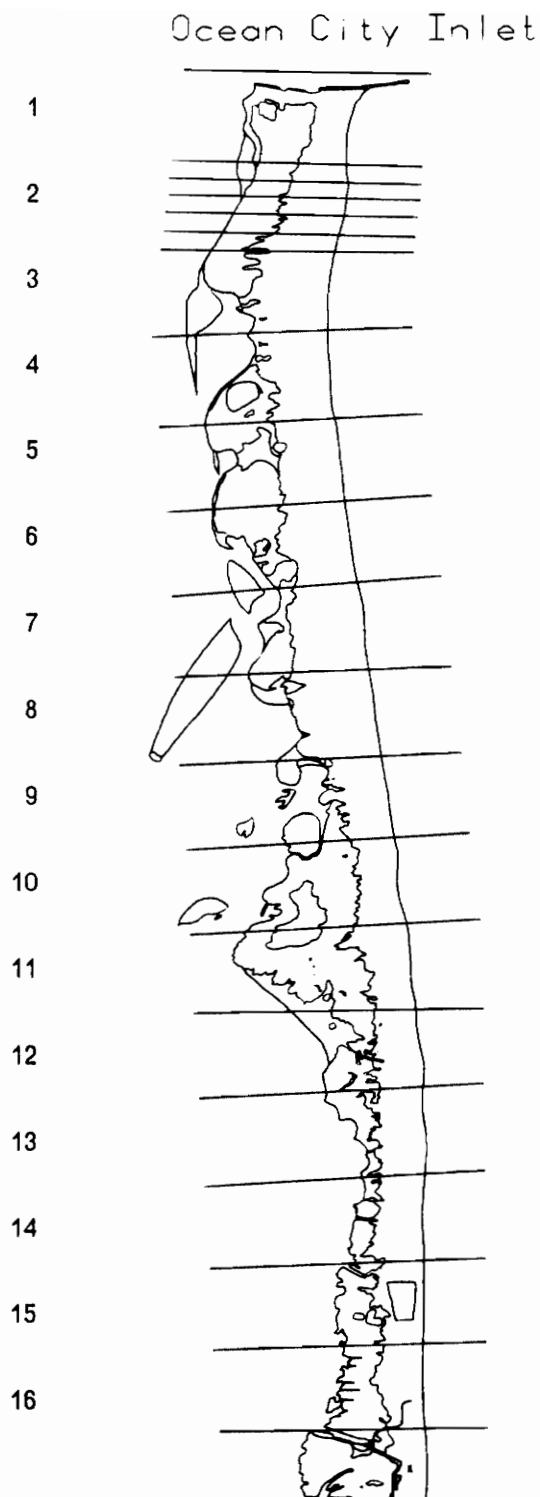


Figure 3. Habitat units used for location assignment on Assateague Island National Seashore. Scale 1:45,000.

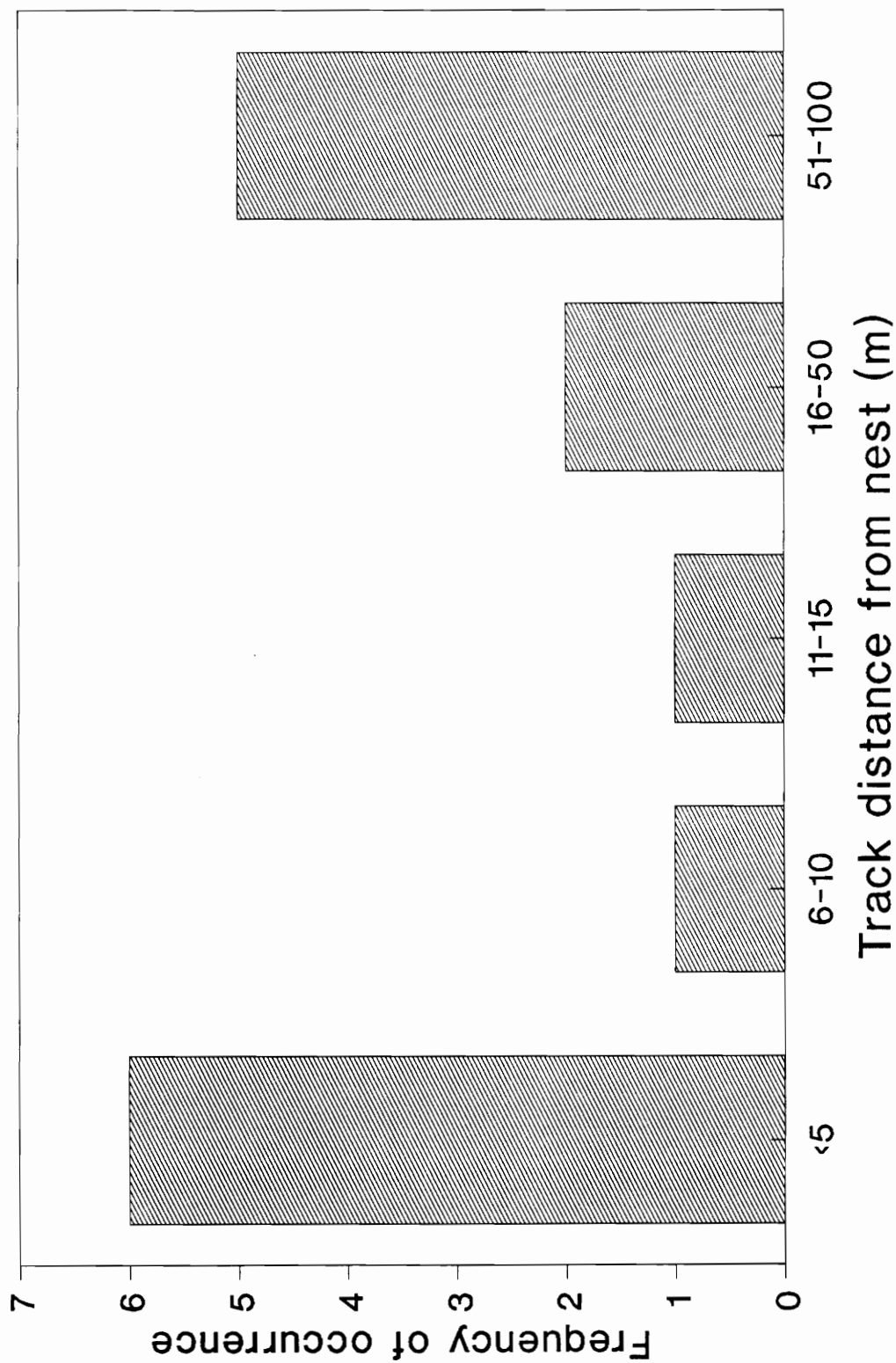


Figure 4. Distances (m) of human tracks from piping plover nests observed when we approached nests for trapping or enclosure construction on Assateague Island National Seashore, Maryland, 1988-1990. Only observations ($n = 15$) in which human tracks were observed within 100 m of the nest are included; 253 approaches disclosed no human tracks within 100 m of the nest.

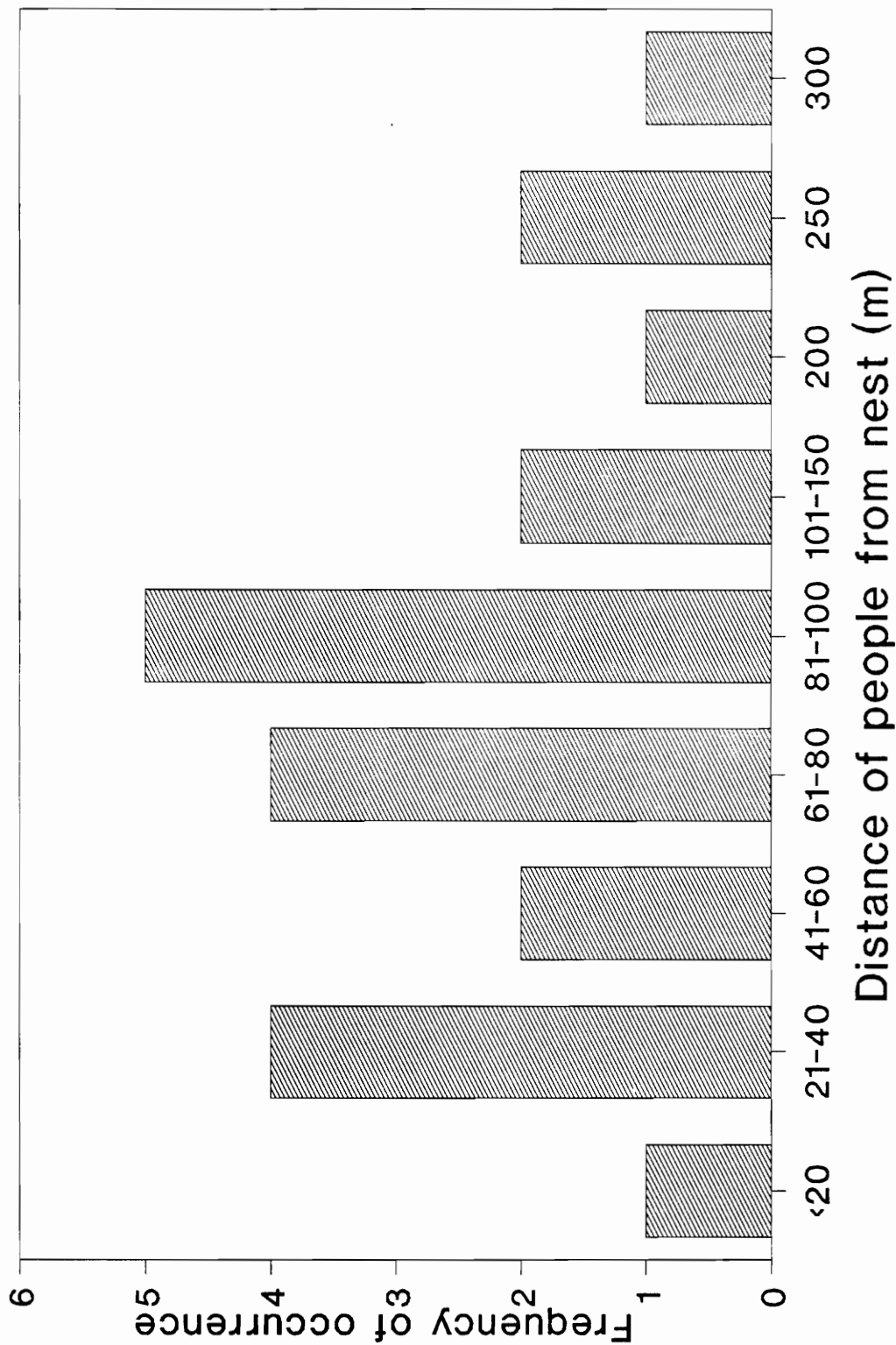


Figure 5. Distances (m) of humans from piping plover nests that we observed during nest checks on Assateague Island National Seashore, Maryland, 1988-1990. Only observations (n = 22) in which humans were observed within 300 m of the nest are included; 722 nest checks had no humans within 300 m of the nest.

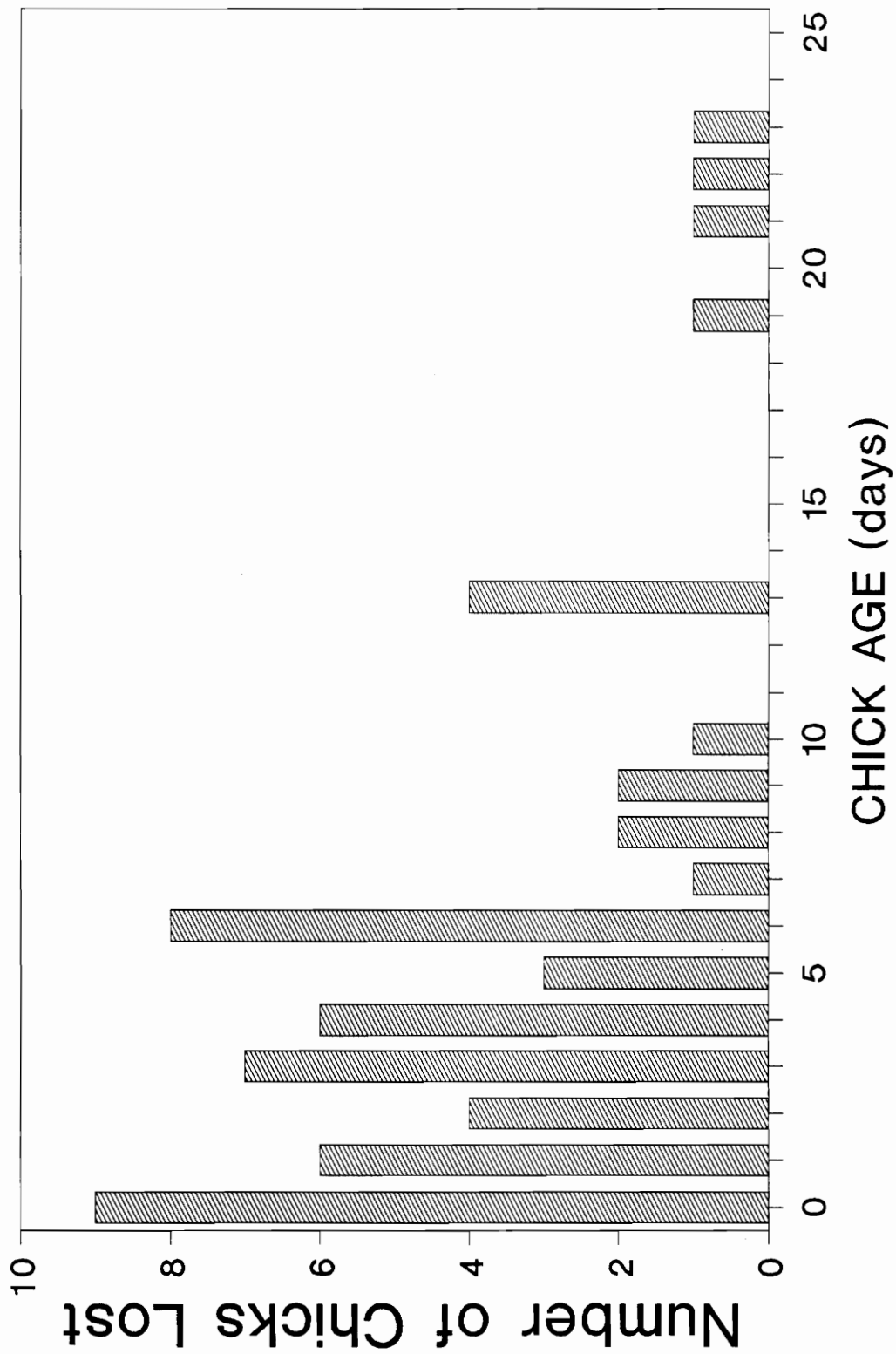


Figure 6. Daily piping plover chick loss on Assateague Island National Seashore, Maryland, 1988-1990.

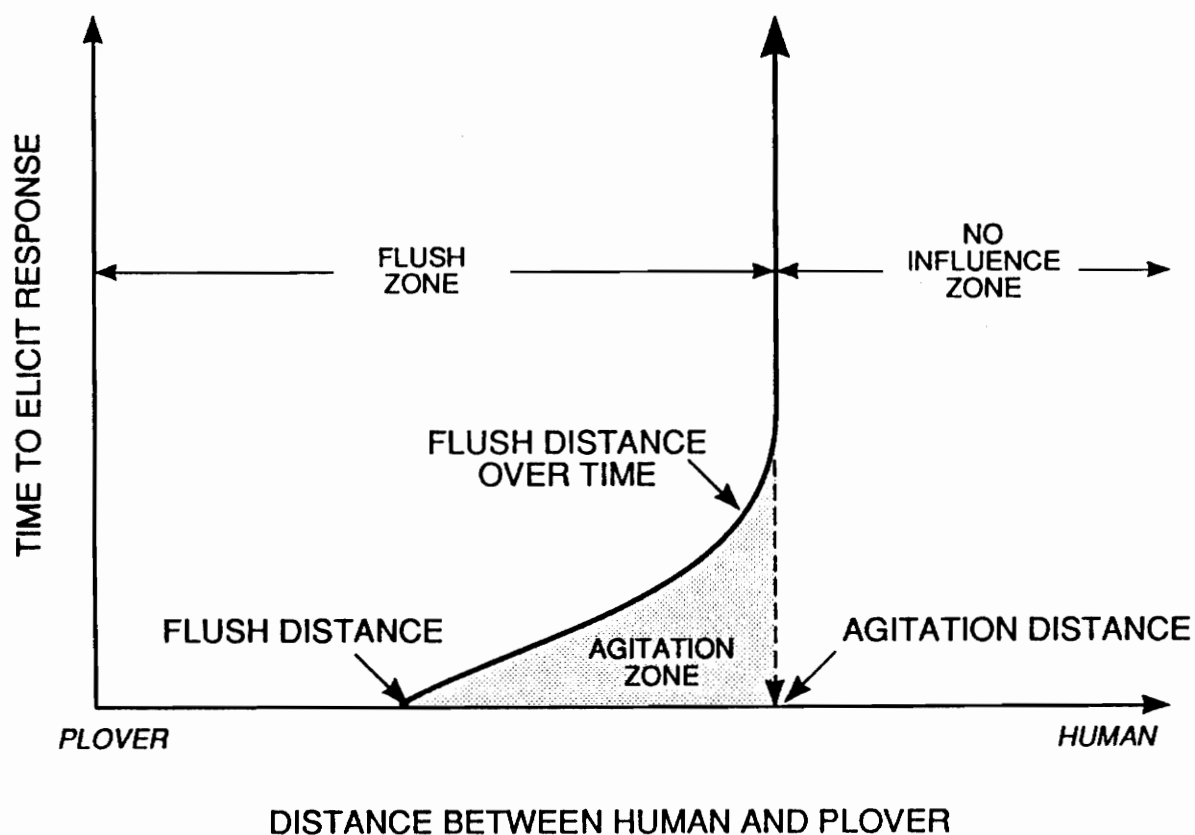


Figure 7. Conceptual model relating the time required to elicit flushing and the distance between human and plover (modified from McGarigal et al. 1991).

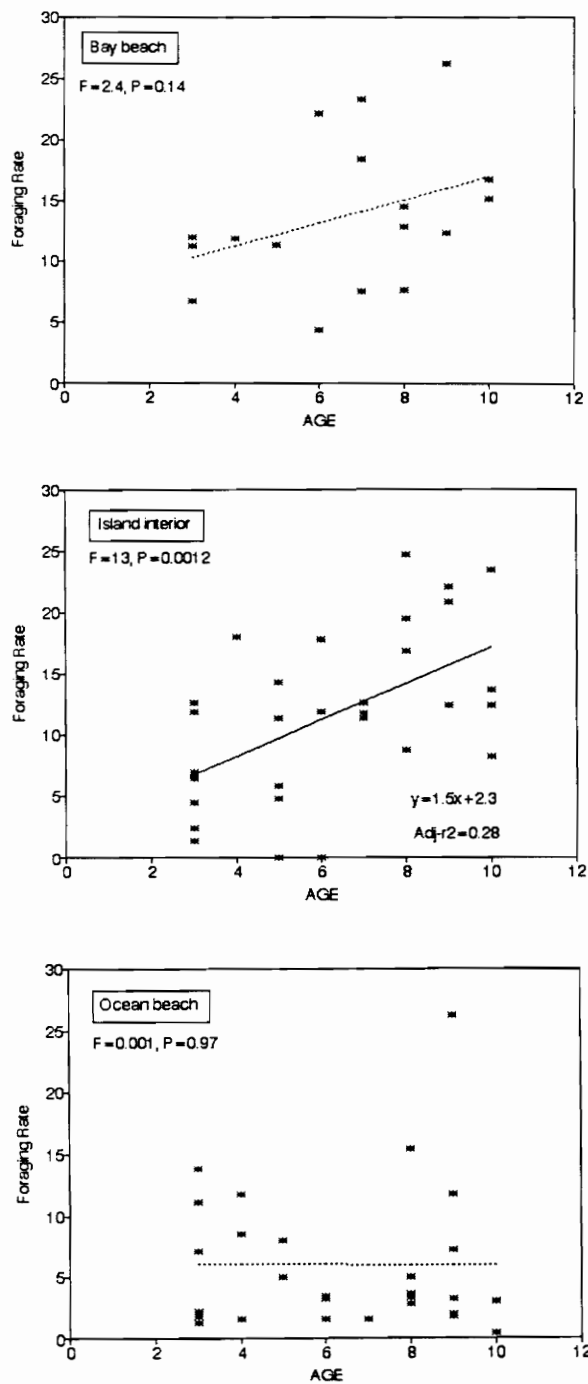


Figure 8. Foraging rate (attempts / minute) of 3-10 day-old piping plover chicks on the bay beach, island interior, and ocean beach on Assateague Island National Seashore, Maryland, 1988-1990. Foraging rate increases with age only in island interior habitats.

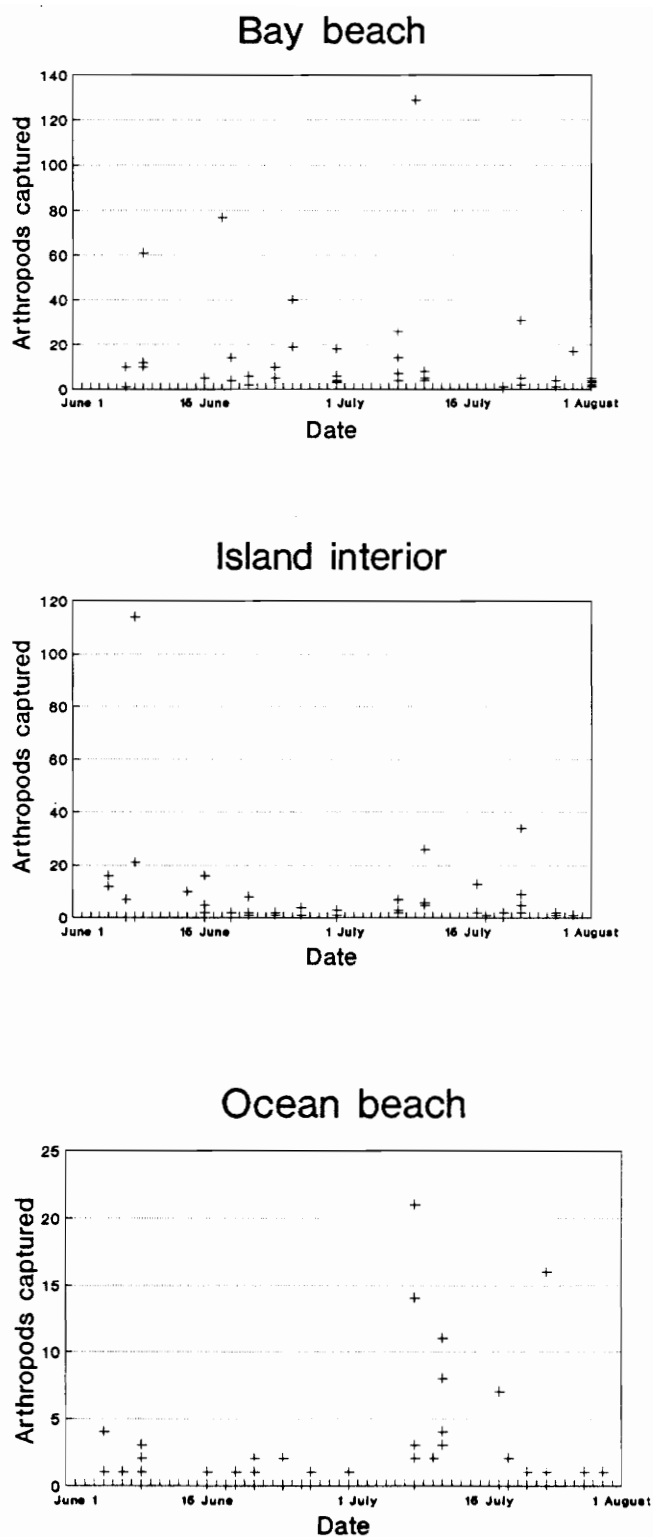


Figure 9. Arthropods captured (30 minute sampling period), by date, on the bay beach, island interior, and ocean beach on Assateague Island National Seashore, Maryland, 1988-1990. Each point represents one sample.

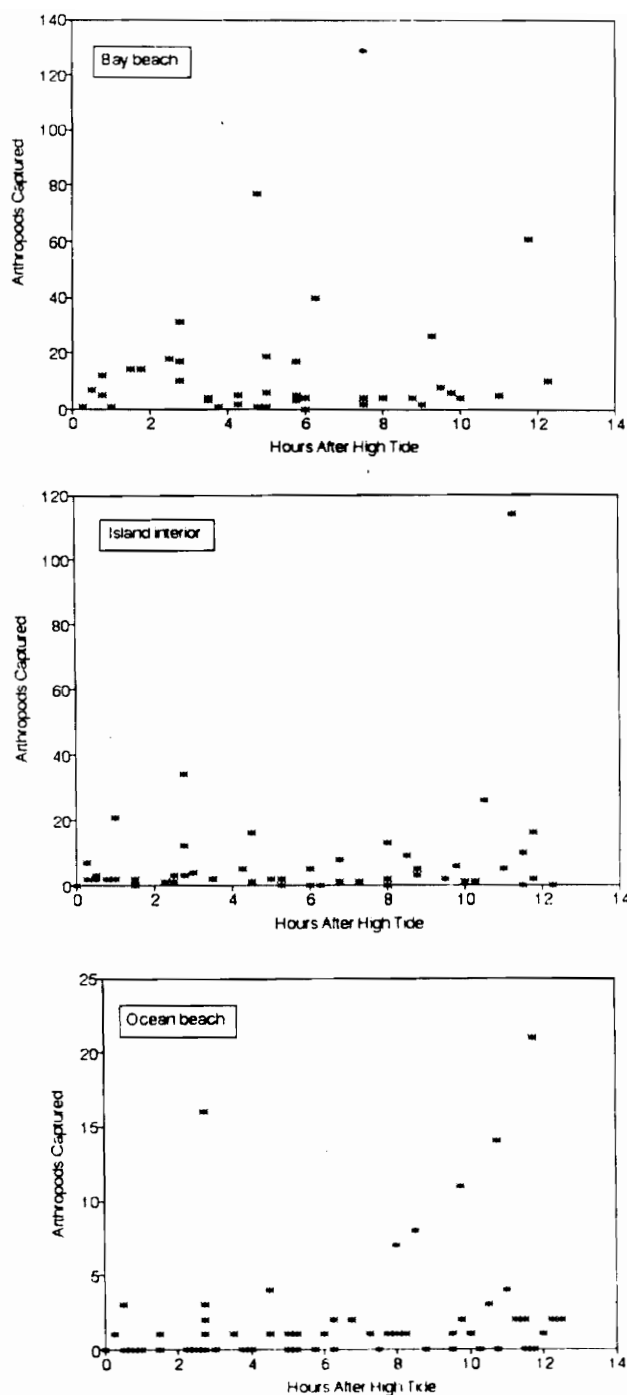


Figure 10. Arthropods captured (30 minute sampling period) at different tidal levels on the bay beach, island interior, and ocean beach on Assateague Island National Seashore, Maryland, 1988-90. Each point represents one sample.

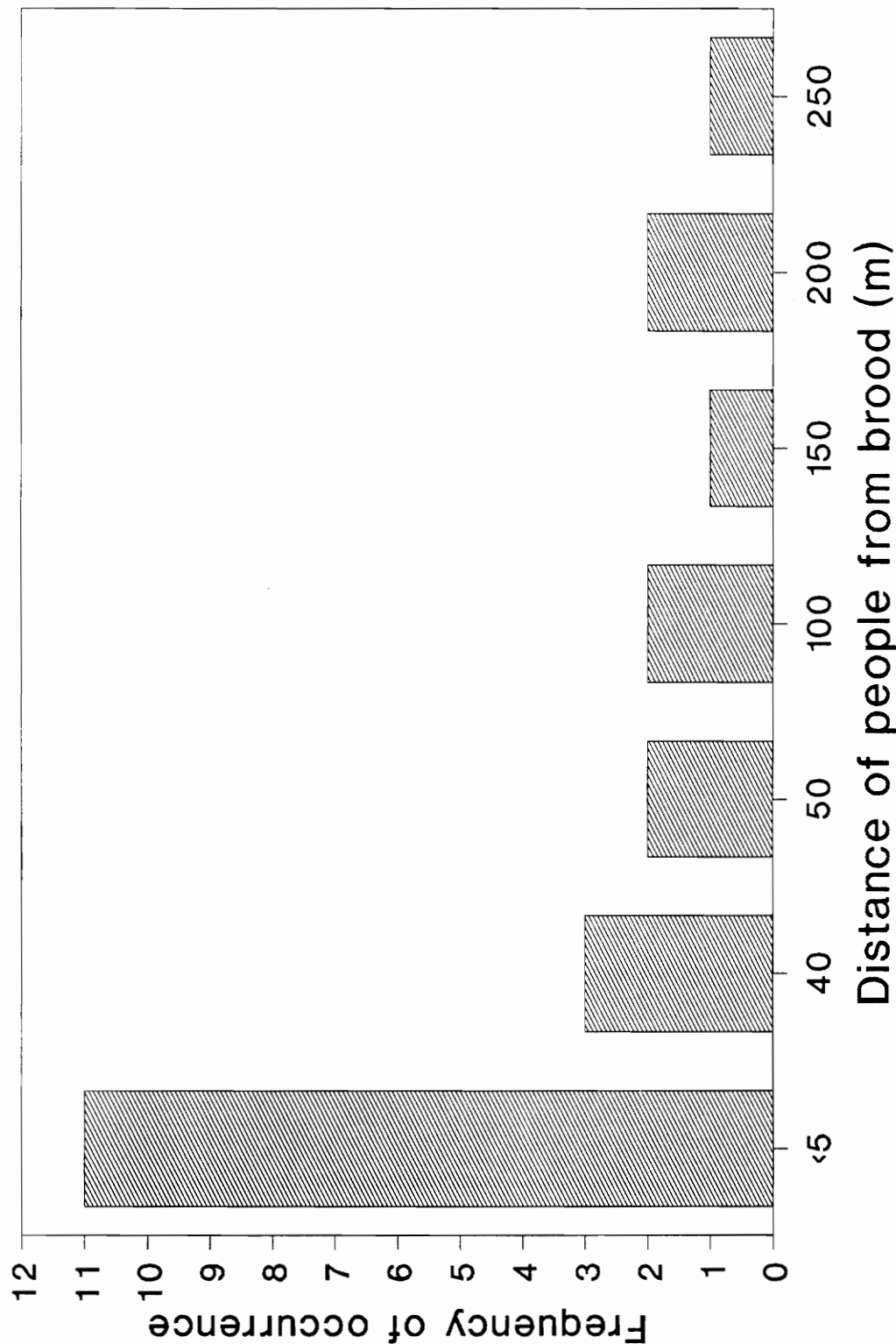


Figure 11. Distances (m) of humans from piping plover broods on Assateague Island National Seashore, Maryland, 1988-1990. Only observations (n=22) in which humans were observed within 300 m of a brood are included; 591 brood observations had no humans within 300 m of the brood.

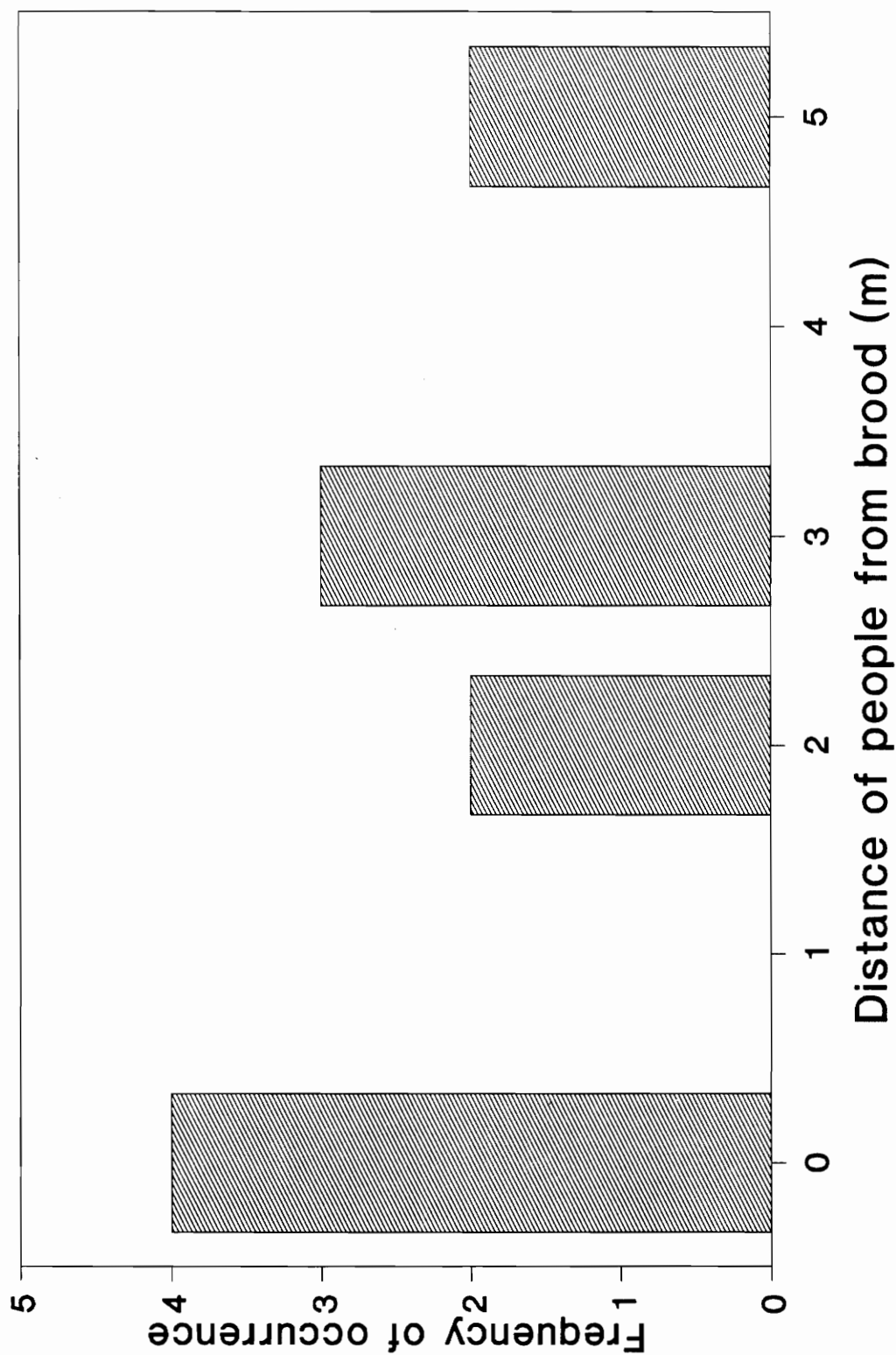


Figure 12. Distances (m) of humans from piping plover broods on Assateague Island National Seashore, Maryland, 1988-1990. Shown are 11 observations when humans were observed passing within 5 m of a broods center of activity. The complete dataset is shown in Figure 11.

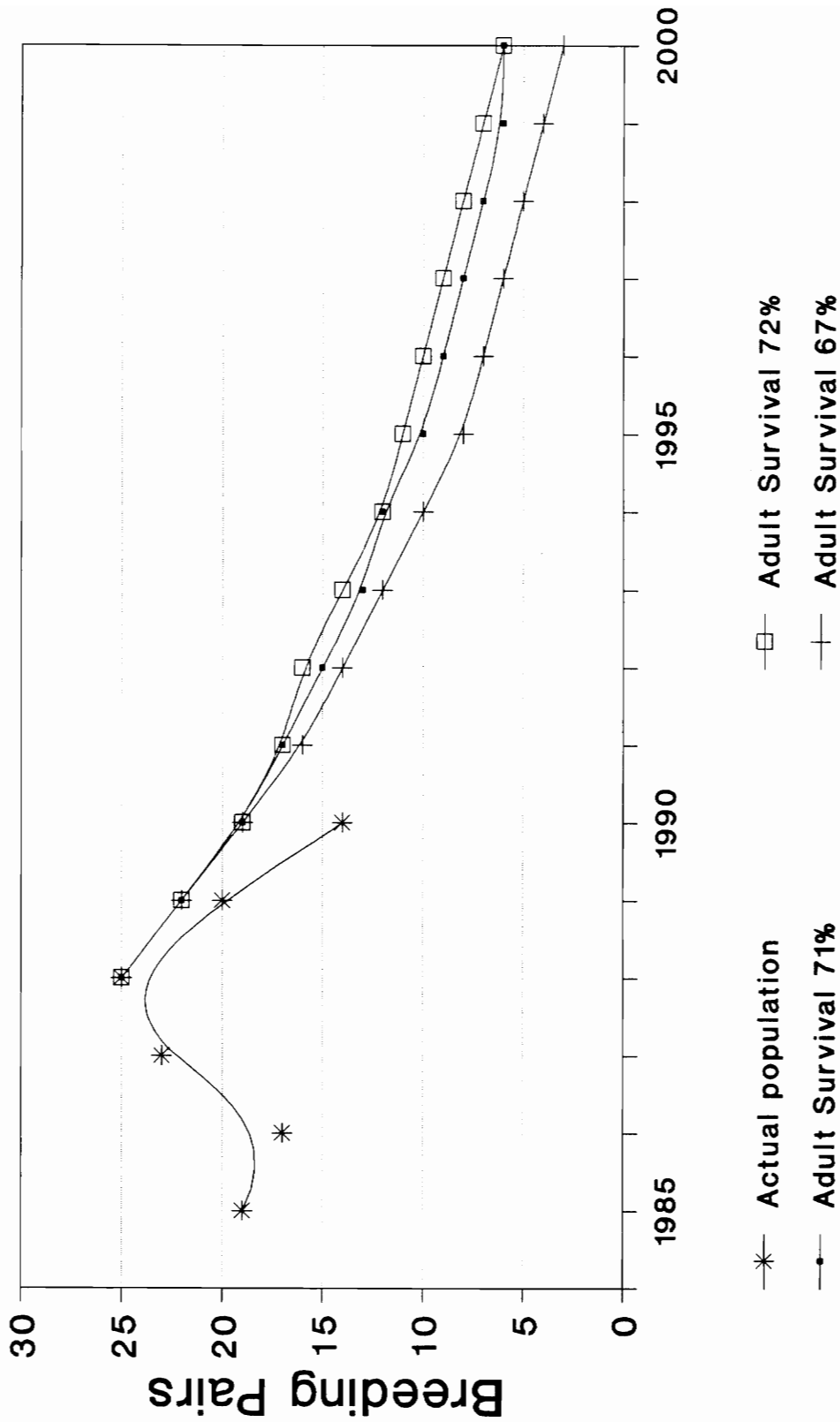


Figure 13. Predicted piping plover breeding population trends on Assateague Island National Seashore based on 3 estimates of adult survival. The same reproductive rate (1986-1990 $\bar{x}$ = 2.023 chicks fledged/breeding pair) and first year survival (41%) from AINS were used in all the models. Adult survival for the first estimate (67%) is based on known color-band sightings. Adult survival for the second estimate (71%) is based on known and incomplete color-band sightings. Adult survival for the third estimate (72%) is based on known and incomplete color-band combinations and assumed mortality in the banded population. See Chapter 4 for details.

Appendix A. Methods for Location Assignment

Because of the difficulty in locating and relocating sites on AINS, I developed a method of recording locations that would allow us to accurately record the positions of plovers, nests, broods, etc. The northern 8 km of the island was divided into 16 habitat blocks. Each block was 500 meters north to south and extended over the width of the island. Each block was further divided into five 100-m strips (Figure 3). Locations in each parallel band were identified further by the habitat type of each location (Ocean tidal zone, berm, mud flat, etc.). I used a five digit location code to represent these areas: XXYYZ, where XX = the habitat block, YY = the habitat type code (Table 2), and Z = the habitat strip. For example, a location in habitat block 3, on the berm (code 04), in the second 100-m strip would be 03042.

I divided the ORV zone, located south of the NPS developed zone, in a similar manner. I used the dune crossings (1-13) to delineate the habitat blocks and further divided the blocks into 160-m strips (0.1-mile). To avoid duplication of habitat block numbers, I assigned ORV zone blocks values of 20 + the dune crossing number. For example, a bird observed 110 meters south of dune crossing 13 on the ocean tidal zone (code 03) would have a location code of 33031.

I clustered habitat blocks into 3 groups: the northern section (blocks 1-8), the southern section (blocks 9-16) and the ORV section (blocks 21-33). This was

necessary because only one section could be practically surveyed during a given day for some surveys.

To the extent possible, these units were discrete segments of habitat, easily identified and mapped, and stable from one year to the next. I made units as small as practical. I mapped these units on aerial photo overlays and transferred them to a GIS database (ARC/INFO) as a permanent record. The length of shoreline in each habitat block was estimated.

Appendix B. Long vs. short behavioral observations.

Appendix B. Test results between short and long behavioral observations of piping plovers on Assateague Island National Seashore, Maryland 1988-1990. Short observation periods are defined as those ending before 3 minutes. Long observations were between 3 and 5 minutes. Reported are P-values for each test (Wilcoxon Rank Sum).

Variable	Bay Beach	Island Interior	Ocean Beach
3-10 days old			
Foraging rate	0.8472	0.8413	0.3138
% time spent foraging	0.1405	0.1719	0.4320
% time spent locomoting	0.2770	0.0343	0.4658
% time spent preening	0.9999	0.4161	0.5194
% time spent resting	0.6914	0.2698	0.9999
% time spent disturbed	0.4589	0.1020	0.1562
11-20 days old			
Foraging Rate	0.1771	0.5859	0.3757
% time spent foraging		0.8832	0.3066
% time spent locomoting		0.8409	0.0995
% time spent preening	0.5604	0.4129	0.5637
% time spent resting	0.8501	0.9999	0.3244
% time spent disturbed	0.6788	0.0202	0.5205
21+ days old			
Foraging Rate	0.8277	0.1052	0.1487
% time spent foraging		0.9999	0.2075
% time spent locomoting		0.9999	0.0192
% time spent preening	0.5587	0.9999	0.3172
% time spent resting	0.7488	0.3476	0.8291
% time spent disturbed	0.4291	0.9999	0.2737
Tending adult			
Foraging Rate	0.8001	0.2181	0.9937
% time spent foraging	0.0699	0.4276	0.7886
% time spent locomoting	0.7689	0.6078	0.0305
% time spent preening	0.3691	0.5455	0.0583
% time spent resting	0.1344	0.1330	0.0243
% time spent disturbed	0.2787	0.7042	0.8379
Lone adult			
Foraging Rate	0.3840		0.4175
% time spent foraging	0.2765		
% time spent locomoting	0.2765		
% time spent preening	0.9999		0.8449
% time spent resting	0.9999		0.9999
% time spent disturbed	0.7038		0.0688

5 of 78 (6.4%) comparisons differ at $\alpha=0.05$.

Appendix C. Behavioral observation biases

I addressed the possible bias related to the time of day observations were completed. Behavioral observations occurred between 0722 and 1717 hours. Tending adults were observed earlier in the day on the ocean beach than in other habitats. Mean time of observation for tending adults was 1258, 1214, and 1120 hours for the bay beach, island interior, and ocean beach respectively. The time of day of observations differed among habitats only for the tending adult age class (Kruskal-Wallis [Chi-square approximation] $\chi^2 = 7.8$, $df = 2$, $P = 0.020$).

Observations of tending adults were completed earlier in the day on the ocean beach than in other habitats. A possible explanation for this sampling bias may stem from our desire to collect as many data as possible. The first task every morning was to check all nests to determine their status. To do this, we drove the length of the study area and observed each nest. Typically, if broods were encountered during nest checks, we would stop and complete a behavioral observation before moving past and disturbing the brood. Since the ocean beach served as our 'road,' only ocean beach broods were encountered.

Mean tidal levels during behavioral observations (stated in hours past the last high tide [0-12.25 range]) for the bay beach, island interior, and ocean beach were 6.6, 5.6, and 5.7 respectively. No difference among the different habitat types was

detected in any age class ($P > 0.05$). Median tides of 6.3, 5.5, and 5.2 respectively suggest falling tides were slightly biased. The absolute tidal level (stated in hours past or until high tide [0-6 range]) also did not differ ($P > 0.05$). Mean absolute tides were 3.1, 2.8, and 3.1 for the bay beach, island interior, and ocean beach.

The distribution (variance) of tidal level and absolute tidal level were compared visually and did not appear different among habitats. All pairwise F-tests between habitat types for each age class were non-significant ($P > 0.05$).

Therefore, although we did not structure the observation schedule to sample during a variety of tides, we apparently did not bias our sampling relative to the habitats we are comparing. Neither the height of the tide in a full cycle nor its relative or absolute level differed. This is important as tidal level has been identified as a factor influencing shorebird foraging habitat use (Burger et al. 1977, Robert et al. 1989).

Appendix D. Effects of disturbance source on behavioral observations

Appendix D. Foraging rate (attempts/minute) and the proportion of time spent (%) in various behavioral categories, by disturbance sources, of piping plovers on Assateague Island National Seashore, Maryland 1988-1990. Observations containing no disturbance and those containing one or more incidence of disturbance from the identified source are shown. Sample sizes (n) also are shown.

	Undisturbed Overall Disturbance			Avian Disturbance		Plover Disturbance		Human Disturbance	
	$\bar{x}$	$\bar{x}$	P-value	$\bar{x}$	P-value	$\bar{x}$	P-value	$\bar{x}$	P-value
3-10 days old, Bay Beach									
Foraging rate	13.3 (5)	13.3 (4)	0.9999	13.3 (4)	0.9999			11.9 (2)	0.8465
% Foraging	90.3 (4)	56.4 (3)	0.0518	56.4 (3)	0.0518			50.0 (1)	0.2888
% Locomotion	3.5 (4)	17.0 (3)	0.3768	17.0 (3)	0.3768			27.8 (1)	0.2888
% Preening	0 (5)	0 (3)	0.9999	0 (4)	0.9999			0 (2)	0.9999
% Alert	2.2 (4)	14.4 (3)	0.4755	14.4 (3)	0.4755			17.3 (1)	0.2888
% Resting	7.7 (5)	4.0 (4)	0.8933	4.0 (4)	0.8933			0.2 (2)	0.9999
% Disturbed	0 (5)	23.3 (4)	0.0108	23.3 (4)	0.0108			16.0 (2)	0.0297
3-10 days old, Island Interior									
Foraging rate	10.4 (7)	11.5 (4)	0.7768	12.1 (2)	0.6605	16.1 (1)	0.3827		
% Foraging	90.0 (4)	69.5 (4)	0.1102	69.4 (2)	0.1002	87.6 (1)	0.9999		
% Locomotion	4.6 (4)	8.6 (4)	0.3094	9.3 (2)	0.4811	3.5 (1)	0.9999		
% Preening	0 (7)	0.9 (4)	0.0685	0.7 (2)	0.1088	2.3 (1)	0.0233		
% Alert	5.4 (4)	10.5 (4)	0.3094	10.0 (2)	0.4811	5.7 (1)	0.7168		
% Resting	11.0 (7)	9.1 (4)	0.1548	9.2 (2)	0.5476	0.4 (1)	0.2531		
% Disturbed	0 (7)	2.1 (4)	0.0031	0.7 (2)	0.0092	2.5 (1)	0.0233		
3-10 days old, Ocean Beach									
Foraging rate	4.9 (12)	7.1 (9)	0.0465	7.6 (8)	0.0447	8.6 (1)	0.2285	8.1 (2)	0.2348
% Foraging	25.8 (6)	45.2 (8)	0.1066	45.7 (7)	0.1336	43.3 (1)	0.4533	41.7 (1)	0.4533
% Locomotion	20.5 (6)	23.5 (8)	0.4381	20.7 (7)	0.5672	21.7 (1)	0.8026	43.3 (1)	0.4533
% Preening	1.4 (12)	0.7 (9)	0.9444	0.8 (8)	0.8823	6.7 (1)	0.0559	0 (2)	0.8383
% Alert	19.1 (6)	23.4 (8)	0.3324	25.1 (7)	0.3524	28.3 (1)	0.8008	11.7 (1)	0.8008
% Resting	23.3 (12)	3.3 (9)	0.2073	3.8 (8)	0.2718	0 (1)	0.4669	0 (2)	0.2655
% Disturbed	0 (12)	24.7 (9)	0.0001	24.3 (8)	0.0001	50.0 (1)	0.0015	21.9 (2)	0.0006

Appendix D. Continued.

	Undisturbed $\bar{x}$	Total Disturbance $\bar{x}$	P-value	Avian Disturbance $\bar{x}$	P-value	Plover Disturbance $\bar{x}$	P-value	Human Disturbance $\bar{x}$	P-value
11-20 days old, Bay Beach									
Foraging rate	16.4 (3)	18.9 (2)	0.7728	18.9 (2)	0.7728				
% Foraging	76.7 (1)	88.9 (1)		88.9 (1)					
% Locomotion	16.7 (1)	3.9 (1)		3.9 (1)					
% Preening	0 (3)	3.6 (2)	0.4142	3.6 (2)	0.4142				
% Alert	6.7 (1)	5.0 (1)		5.0 (1)					
% Resting	0.3 (3)	0 (2)	0.6831	0 (2)	0.6831				
% Disturbed	0 (3)	4.6 (2)	0.1066	4.6 (2)	0.1066				
11-20 days old, Island Interior									
Foraging rate	17.1 (6)	13.4 (4)	0.9151	20.6 (2)	0.1336			6.3 (2)	0.0668
% Foraging	87.2 (6)	93.5 (2)	0.6171	93.5 (2)	0.6171				
% Locomotion	4.1 (6)	3.6 (2)	0.8660	3.6 (2)	0.8660				
% Preening	0.4 (6)	0 (4)	0.2869	0 (2)	0.5127			0 (2)	0.5127
% Alert	8.3 (6)	2.1 (2)	0.6150	2.1 (2)	0.6150				
% Resting	0 (6)	0 (4)	0.9999	0 (2)	0.9999			0 (2)	0.9999
% Disturbed	0 (6)	23.1 (4)	0.0057	3.3 (2)	0.0164			42.9 (2)	0.0164
11-20 days old, Ocean Beach									
Foraging rate	10.6 (16)	10.9 (10)	0.5799	13.2 (6)	0.3377	10.6 (2)	0.6733	10.0 (2)	0.9440
% Foraging	53.8 (15)	58.6 (9)	0.9524	59.8 (6)	0.8456	65.6 (2)	0.8228	81.1 (1)	0.5146
% Locomotion	18.0 (15)	15.8 (9)	0.9762	14.4 (6)	0.9689	12.6 (2)	0.8226	9.7 (1)	0.8278
% Preening	6.6 (16)	8.1 (10)	0.1674	9.4 (6)	0.1561	4.2 (2)	0.2170	0.3 (2)	0.9999
% Alert	18.6 (15)	9.3 (9)	0.1888	8.4 (6)	0.1978	10.4 (2)	0.6005	5.3 (1)	0.5133
% Resting	6.6 (16)	6.4 (10)	0.0837	7.7 (6)	0.0519	7.2 (2)	0.1119	1.7 (2)	0.6567
% Disturbed	0 (16)	16.7 (10)	0.0001	16.8 (6)	0.0001	13.3 (2)	0.0001	19.4 (2)	0.0001
21+ days old, Bay Beach									
Foraging rate		10.5 (3)		9.8 (2)				11.8 (1)	
% Foraging									
% Locomotion		4.3 (3)		0 (2)				12.8 (1)	
% Preening									
% Alert									
% Resting		0.9 (3)		0 (2)				2.8 (1)	
% Disturbed		1.0 (3)		1.2 (2)				0.6 (1)	

Appendix D. Continued.

	Undisturbed x	Total Disturbance x P-value	Avian Disturbance x P-value	Plover Disturbance x P-value	Human Disturbance x P-value
21 + days old, Island Interior					
Foraging rate	18.3 (4)				
% Foraging	75.8 (3)				
% Locomotion	11.7 (3)				
% Preening	0 (4)				
% Alert	12.5 (3)				
% Resting	0 (4)				
% Disturbed	0 (4)				
21 + days old, Ocean Beach					
Foraging rate	14.8 (10)	12.4 (13)	17.6 (5)	5.4 (4)	12.9 (4)
% Foraging	55.0 (7)	62.0 (11)	84.1 (5)	36.9 (2)	56.2 (3)
% Locomotion	9.3 (7)	14.1 (11)	8.1 (5)	23.9 (2)	12.5 (3)
% Preening	2.8 (10)	3.9 (13)	1.0 (5)	11.1 (4)	7.4 (4)
% Alert	9.3 (7)	17.6 (11)	4.8 (5)	28.3 (2)	24.4 (3)
% Resting	15.8 (10)	2.6 (13)	0 (5)	0.9 (4)	5.1 (4)
% Disturbed	0 (10)	11.0 (13)	7.7 (5)	2.8 (4)	16.8 (4)
					0.9436
					0.3574
					0.8826
					0.1688
					0.2496
					0.1858
					0.8594
					0.0006
					0.9999
					0.4805
					0.7679
					0.9999
					0.6803
					0.0006
Tending adults, Bay Beach					
Foraging rate	20.0 (2)	12.4 (8)	13.9 (7)	12.5 (1)	7.1 (2)
% Foraging	3.3 (1)	56.7 (7)	63.4 (6)	66.7 (1)	41.3 (2)
% Locomotion	13.3 (1)	11.7 (7)	13.0 (6)	6.7 (1)	5.3 (2)
% Preening	5.0 (2)	2.7 (8)	2.2 (7)	1.3 (1)	3.7 (2)
% Alert	73.3 (1)	21.8 (7)	13.1 (6)	13.3 (1)	43.7 (2)
% Resting	0 (2)	1.8 (8)	2.1 (7)	2.9 (1)	1.5 (2)
% Disturbed	0 (2)	5.1 (8)	5.3 (7)	1.9 (1)	2.6 (2)
					0.2453
					0.5403
					0.5403
					0.9999
					0.9999
					0.6171
					0.2207
Tending adults, Island Interior					
Foraging rate	0.3 (8)	1.5 (8)	1.9 (6)	1.4 (2)	1.2 (4)
% Foraging	1.8 (6)	9.2 (6)	11.1 (5)	14.6 (2)	1.6 (3)
% Locomotion	6.9 (6)	13.2 (6)	14.3 (5)	9.8 (2)	15.0 (3)
% Preening	3.4 (8)	5.3 (8)	6.8 (6)	3.2 (2)	5.9 (4)
% Alert	52.0 (6)	40.6 (6)	33.8 (5)	60.3 (2)	54.1 (3)
% Resting	38.5 (8)	22.4 (8)	27.2 (6)	14.3 (2)	12.0 (4)
% Disturbed	0 (8)	19.8 (8)	16.0 (6)	9.1 (2)	23.5 (4)
					0.1866
					0.6714
					0.1539
					0.9999
					0.6973
					0.9999
					0.0017

Appendix D. Continued.

	Undisturbed	Total Disturbance	Avian Disturbance	Plover Disturbance	Human Disturbance
	$\bar{x}$	$\bar{x}$ P-value	$\bar{x}$ P-value	$\bar{x}$ P-value	$\bar{x}$ P-value
Tending adults, Ocean Beach					
Foraging rate	2.7 (25)	3.3 (17) 0.3339	5.3 (9) 0.0428	1.4 (7) 0.9254	4.5 (3) 0.4210
% Foraging	19.0 (18)	16.0 (13) 0.9825	28.7 (7) 0.4144	1.3 (5) 0.4340	15.4 (3) 0.8672
% Locomotion	14.7 (18)	18.9 (13) 0.1317	19.8 (7) 0.2226	25.6 (5) 0.0782	19.3 (3) 0.3112
% Preening	3.5 (25)	3.0 (17) 0.0405	4.3 (9) 0.0127	0.9 (7) 0.4013	4.7 (3) 0.1567
% Alert	35.3 (18)	40.9 (13) 0.5085	36.4 (7) 0.9276	51.4 (5) 0.1916	35.2 (3) 0.9599
% Resting	26.0 (25)	20.9 (17) 0.9785	9.7 (9) 0.5636	21.3 (7) 0.9999	18.8 (3) 0.9376
% Disturbed	0 (25)	14.7 (17) 0.0001	15.9 (9) 0.0001	17.3 (7) 0.0001	20.4 (3) 0.0001
Lone adults, Bay Beach					
Foraging rate	15.7 (5)	24.3 (3) 0.1360	28.5 (2) 0.0814	15.8 (1) 0.9999	
% Foraging	100 (2)	90.7 (2) 0.2207	90.7 (2) 0.2207		
% Locomotion	0 (2)	10.3 (2) 0.2207	10.3 (2) 0.2207		
% Preening	0 (5)	0 (3) 0.9999	0 (2) 0.9999	0 (1) 0.9999	
% Alert	0 (2)	0 (2) 0.9999	0 (2) 0.9999		
% Resting	0 (5)	0 (3) 0.9999	0 (2) 0.9999	0 (1) 0.9999	
% Disturbed	0 (5)	7.3 (3) 0.0168	4.3 (2) 0.0297	13.3 (1) 0.0736	
Lone adults, Island Interior					
Foraging rate	9.0 (2)				
% Foraging	33.3 (2)				
% Locomotion	50.0 (2)				
% Preening	8.3 (2)				
% Alert	8.3 (2)				
% Resting	0 (2)				
% Disturbed	0 (2)				
Lone adults, Ocean Beach					
Foraging rate	9.6 (9)	8.7 (3) 0.7115		5.1 (2) 0.1949	
% Foraging	0 (1)	90.8 (2) 0.5403		93.3 (1)	
% Locomotion	13.3 (1)	2.5 (2) 0.5403		0 (1)	
% Preening	4.1 (9)	0.8 (3) 0.5697		0 (2) 0.8137	
% Alert	20.0 (1)	5.4 (2) 0.5403		6.7 (1)	
% Resting	3.3 (9)	0 (3) 0.7003		0 (2) 0.8137	
% Disturbed	0 (9)	5.1 (3) 0.0016		6.5 (2) 0.0030	

Appendix D. Continued.

	Undisturbed	Mammalian	Disturbance	Other	Disturbance	Unknown	Disturbance
	x	x	P-value	x	P-value	x	P-value
3-10 days old, Bay Beach							
Foraging rate	13.3 (5)						
% Foraging	90.3 (4)						
% Locomotion	3.5 (4)						
% Preening	0 (5)						
% Alert	2.2 (4)						
% Resting	3.0 (5)						
% Disturbed	0 (5)						
3-10 days old, Island Interior							
Foraging rate	10.4 (7)	5.6 (1)	0.3827				
% Foraging	90.0 (4)	51.4 (1)	0.2765				
% Locomotion	4.6 (4)	12.2 (1)	0.2765				
% Preening	0 (7)	0 (1)	0.9999				
% Alert	5.4 (4)	16.4 (1)	0.7168				
% Resting	11.0 (7)	17.8 (1)	0.2531				
% Disturbed	0 (7)	4.4 (1)	0.0233				
3-10 days old, Ocean Beach							
Foraging rate	4.9 (12)			7.1 (1)	0.3489	12.8 (1)	0.2285
% Foraging	25.8 (6)			68.9 (1)	0.4533		
% Locomotion	20.5 (6)			24.4 (1)	0.8026		
% Preening	1.4 (12)			0 (1)	0.9999	0 (1)	0.9999
% Alert	19.1 (6)			5.6 (1)	0.9999		
% Resting	23.3 (12)			0 (1)	0.4669	0 (1)	0.4669
% Disturbed	0 (12)			21.1 (1)	0.0015	15.4 (1)	0.0015
11-20 days old, Bay Beach							
Foraging rate	16.4 (3)						
% Foraging	76.7 (1)						
% Locomotion	16.7 (1)						
% Preening	0 (3)						
% Alert	6.7 (1)						
% Resting	0.3 (3)						
% Disturbed	0 (3)						

Appendix D. Continued.

Undisturbed			Mammalian Disturbance			Other Disturbance			Unknown Disturbance		
	$\bar{x}$	P-value	$\bar{x}$	P-value	$\bar{x}$	P-value	$\bar{x}$	P-value	$\bar{x}$	P-value	
11-20 days old, Island Interior											
Foraging rate	17.1 (6)										
% Foraging	87.2 (6)										
% Locomotion	4.1 (6)										
% Preening	0.4 (6)										
% Alert	8.3 (6)										
% Resting	0 (6)										
% Disturbed	0 (6)										
11-20 days old, Ocean Beach											
Foraging rate	10.6 (16)		7.0 (1)	0.9999			13.2 (4)	0.3949			
% Foraging	53.8 (15)		45.9 (1)	0.6639			67.5 (4)	0.5820			
% Locomotion	18.0 (15)		16.7 (1)	0.9999			14.5 (4)	0.9999			
% Preening	6.6 (16)		16.7 (1)	0.1374			4.8 (4)	0.2770			
% Alert	18.6 (15)		15.0 (1)	0.9999			9.3 (4)	0.3158			
% Resting	6.6 (16)		6.7 (1)	0.2544			3.9 (4)	0.2023			
% Disturbed	0 (16)		1.7 (1)	0.0002			17.1 (4)	0.0001			
21 + days old, Bay Beach											
Foraging rate											
% Foraging											
% Locomotion											
% Preening											
% Alert											
% Resting											
% Disturbed											
21 + days old, Island Interior											
Foraging rate	18.3 (4)										
% Foraging	75.8 (3)										
% Locomotion	11.7 (3)										
% Preening	0 (4)										
% Alert	12.5 (3)										
% Resting	0 (4)										
% Disturbed	0 (4)										

Appendix D. Continued.

		Undisturbed		Mammalian Disturbance		Other Disturbance		Unknown Disturbance	
		$\bar{x}$	$\bar{x}$	P-value	$\bar{x}$	P-value	$\bar{x}$	P-value	
21 + days old, Ocean Beach									
Foraging rate	14.8 (10)	2.9 (1)	0.4281				18.4 (2)	0.5906	
% Foraging	55.0 (7)	19.2 (1)	0.9999				63.3 (2)	0.8826	
% Locomotion	9.3 (7)	29.2 (1)	0.3524				19.4 (2)	0.4446	
% Preening	2.8 (10)	1.7 (1)	0.3147				0 (2)	0.6203	
% Alert	9.3 (7)	40.0 (1)	0.3799				10.0 (2)	0.7678	
% Resting	15.8 (10)	10.0 (1)	0.3599				5.6 (2)	0.7982	
% Disturbed	0 (10)	27.5 (1)	0.0044				15.1 (2)	0.0017	
Tending adults, Bay Beach									
Foraging rate	20.0 (2)			2.8 (1)	0.5403		12.5 (1)	0.5403	
% Foraging	3.3 (1)						66.7 (1)		
% Locomotion	13.3 (1)						6.7 (1)		
% Preening	5.0 (2)			1.9 (1)	0.9999		1.3 (1)	0.9999	
% Alert	73.3 (1)						13.3 (1)		
% Resting	0 (2)			4.9 (1)	0.4795		2.9 (1)	0.4795	
% Disturbed	0 (2)			1.9 (1)	0.4795		1.9 (1)	0.4795	
Tending adults, Island Interior									
Foraging rate	0.3 (8)			2.7 (1)	0.1376		3.7 (1)	0.1376	
% Foraging	1.8 (6)			29.2 (1)	0.1678		3.3 (1)	0.4079	
% Locomotion	6.9 (6)			11.9 (1)	0.4492		21.7 (1)	0.2072	
% Preening	3.4 (8)			5.4 (1)	0.5422		0 (1)	0.5224	
% Alert	52.0 (6)			46.3 (1)	0.8008		28.3 (1)	0.8008	
% Resting	38.5 (8)			13.0 (1)	0.8368		31.1 (1)	0.8368	
% Disturbed	0 (8)			6.0 (1)	0.0133		24.4 (1)	0.0133	
Tending adults, Ocean Beach									
Foraging rate	2.7 (25)			11.4 (1)	0.1655				
% Foraging	19.0 (18)			46.2 (1)	0.2771				
% Locomotion	14.7 (18)			27.1 (1)	0.3106				
% Preening	3.5 (25)			0.7 (1)	0.2063				
% Alert	35.3 (18)			23.1 (1)	0.5223				
% Resting	26.0 (25)			2.0 (1)	0.9999				
% Disturbed	0 (25)			40.8 (1)	0.0001				

Appendix D. Continued.

	Undisturbed	Mammalian Disturbance	Other Disturbance	Unknown Disturbance
	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$
		P-value	P-value	P-value
Lone adults, Bay Beach				
Foraging rate	15.7 (5)			
% Foraging	100. (2)			
% Locomotion	0 (2)			
% Preening	0 (5)			
% Alert	0 (2)			
% Resting	0 (5)			
% Disturbed	0 (5)			
Lone adults, Island Interior				
Foraging rate	9.0 (2)			
% Foraging	33.3 (2)			
% Locomotion	50.0 (2)			
% Preening	8.3 (2)			
% Alert	8.3 (2)			
% Resting	0 (2)			
% Disturbed	0 (2)			
Lone adults, Ocean Beach				
Foraging rate	9.6 (9)			16.0 (1) 0.2963
% Foraging	0 (1)			88.3 (1)
% Locomotion	13.3 (1)			5.0 (1)
% Preening	4.1 (9)			2.5 (1) 0.1360
% Alert	20.0 (1)			4.2 (1)
% Resting	3.3 (9)			0 (1) 0.9999
% Disturbed	0 (9)			2.5 (1) 0.0077

Tests of significance using Wilcoxon Rank Sum.

Appendix E. Piping plovers banded on AINS

Appendix E. Color-band combinations of piping plovers banded on Assateague Island National Seashore, Maryland, 1987-1989. Bands have been sorted by color combination. See key below for band colors and locations. Some birds banded by Patterson (1988) were banded in Virginia.

USFWS# ^a	Left Top	Left Bottom	Right Top	Right Bottom	Sex	Age at Capture ^b	Date of Capture	Banding Location	Comments
800190387	.	.	B/W	ALU		5 days	06/02/89	07145	
87162506	ALU	BLK	RF	BLK		AHY	1987	HOOK	
139112606	ALU	BLK	RF	GRE		4 days	06/14/88	MD	
139112603	ALU	BLK	RF	ORA		4 days	06/12/88	MD	
800190359	ALU	BLK	RF	YEL	female	AHY	06/17/88	MD	
800190354	ALU	BLU	RF	BLK	male	AHY	06/11/88	MD	
139112608	ALU	BLU	RF	GRE		4 days	06/17/88	MD	
800190358	ALU	BLU	RF	ORA	male	AHY	06/15/88	MD	
800190353	ALU	GRE	RF	BLK	female	AHY	06/11/88	MD	
139112605	ALU	GRE	B/W	GRE	male	4 days	06/14/88	MD	c
800190333	ALU	GRE	RF	ORA	female	AHY	05/15/88	MD	
800190338	ALU	ORA	RF	BLK	female??	AHY	05/24/88	MD	
139112607	ALU	ORA	RF	GRE		4 days	06/14/88	MD	
800190336	ALU	ORA	RF	ORA		AHY	05/20/88	MD	
800190360	ALU	ORA	.	.	male	AHY	06/17/88	MD	d
139112601	ALU	RED	RF	BLK		5 days	06/04/88	MD	
87162507	ALU	RED	RF	GRE		AHY	1987	WF	
139112604	ALU	RED	RF	ORA		4 days	06/12/88	MD	
139112602	ALU	WHI	RF	BLK		5 days	06/04/88	MD	
139112612	ALU	WHI	RF	GRE		5 days	06/28/88	MD	
800190357	ALU	WHI	B/W	ORA	female	AHY	06/14/88	MD	c
800190352	ALU	YEL	RF	BLK	male??	AHY	06/01/88	MD	
800190361	ALU	YEL	RF	GRE	male	AHY	06/17/88	MD	
800190356	ALU	YEL	RF	ORA	female	AHY	06/12/88	MD	
139112609	BLK	ALU	RF	BLU		5 days	06/23/88	MD	
139112618	BLK	ALU	RF	GRE		4 days	07/10/88	MD	
139112622	BLK	ALU	RF	ORA		6 days	07/18/88	MD	
800190347	BLK	ALU	RF	WHI		AHY	05/30/88	MD	
800190363	BLK	ALU	RF	YEL	male	AHY	07/01/88	MD	

continued

Appendix E. Continued.

USFWS# ^a	Left Top	Left Bottom	Right Top	Right Bottom	Sex	Age at Capture ^b	Date of Capture	Banding Location	Comments
800190305	BLK	BLK	RF	ALU		AHY	1987	WF	
800190313	BLK	BLU	RF	ALU		AHY	1987	MD	
800190325	BLK	GRE	RF	ALU	female	AHY	1987	MD	
800190317	BLK	ORA	RF	ALU		AHY	1987	WF	
800190326	BLK	RED	RF	ALU		AHY	1987	HOOK	
800190346	BLU	ALU	RF	WHI		AHY	05/30/88	MD	
800190341	BLU	ALU	RF	BLU	male	AHY	05/27/88	MD	
139112614	BLU	ALU	RF	GRE		5 days	06/28/88	MD	
139112620	BLU	ALU	RF	ORA		4 days	07/10/88	MD	
800190340	BLU	ALU	RF	RED	male	AHY	05/26/88	MD	
800190337	BLU	ALU	RF	YEL		AHY	05/24/88	MD	
800190339	BLU	ALU	B/W	YEL	male	AHY	05/24/88	MD	c
800190346	BLU	ALU	B/W	WHI	female	AHY	05/30/88	MD	c
800190378	BLU	BLK	B/W	ALU	male?	8 days	06/12/89	13044	
800190303	BLU	BLU	RF	ALU		AHY	1987	WB	
800190374	BLU	BLU	B/W	ALU	male	AHY	06/01/89	06043	
800190310	BLU	GRE	RF	ALU		AHY	1987	HOOK	
800190376	BLU	GRE	B/W	ALU		7 days	06/03/89	03123	
800190328	BLU	ORA	RF	ALU		AHY	1987	WF	
800190377	BLU	ORA	B/W	ALU	male?	8 days	06/12/89	13044	
800190309	BLU	RED	RF	ALU		AHY	1987	WF	
800190375	BLU	RED	B/W	ALU		7 days	06/03/89	03123	
800190311	BLU	WHI	RF	ALU		AHY	1987	MD	
800190373	BLU	WHI	B/W	ALU	female	AHY	06/01/89	06043	
800190316	BLU	YEL	RF	ALU		AHY	1987	WF	
800190379	BLU	YEL	B/W	ALU	male	AHY	06/14/89	13043	
139112610	GRE	ALU	RF	BLU		10 days	06/28/88	MD	
139112616	GRE	ALU	RF	GRE		4 days	07/03/88	MD	
800190331	GRE	ALU	RF	RED		AHY	05/14/88	MD	
800190342	GRE	ALU	RF	WHI		AHY	05/28/88	MD	
800190362	GRE	ALU	RF	YEL	female	AHY	06/28/88	MD	
800190385	GRE	ALU	STU	STU	female	AHY	06/22/89	01042	
800190393	GRE	BLK	B/W	ALU		4 days	07/01/89	06035	
800190320	GRE	BLU	RF	ALU	female	AHY	1987	MD	
800190391	GRE	BLU	B/W	ALU		7 days	06/30/89	11042	
800190306	GRE	GRE	RF	ALU		AHY	1987	WB	
800190392	GRE	ORA	B/W	ALU		7 days	06/30/89	11042	
800190319	GRE	RED	RF	ALU		AHY	1987	HOOK	
800190390	GRE	WHI	B/W	ALU		7 days	06/30/89	11042	
800190308	GRE	YEL	RF	ALU		AHY	1987	WF	

continued

Appendix E. Continued.

USFWS# ^a	Left Top	Left Bottom	Right Top	Right Bottom	Sex	Age at Capture ^b	Date of Capture	Banding Location	Comments
800190349	ORA	ALU	RF	BLU		AHY	05/31/88	MD	
139112617	ORA	ALU	RF	GRE		9 days	07/08/88	MD	
800190332	ORA	ALU	B/W	WHI	male	AHY	05/15/88	MD	c
87162489	ORA	ORA	RF	ALU		AHY	1987	WF	
800190395	ORA	RED	B/W	ALU		27 days	07/20/89	12041	
800190394	ORA	WHI	B/W	ALU		4 days	07/01/89	06035	
800190315	ORA	YEL	RF	ALU		AHY	1987	WF	
139112611	RED	ALU	RF	BLU		5 days	06/28/88	MD	
139112615	RED	ALU	RF	GRE		4 days	07/03/88	MD	
139112621	RED	ALU	RF	ORA		5 days	07/13/88	MD	
800190350	RED	ALU	RF	RED	female?	AHY	05/31/88	MD	
800190351	RED	ALU	RF	WHI	male	AHY	06/01/88	MD	
800190330	RED	ALU	RF	YEL		AHY	05/12/88	MD	
800190389	RED	BLK	B/W	ALU	male?	19 days	06/26/89	MD	
800190382	RED	BLU	B/W	ALU		12 days	06/19/89	09045	
800190329	RED	GRE	RF	ALU		AHY	1987	MD	
800190386	RED	GRE	B/W	ALU	female	25 days	06/23/89	08042	
800190307	RED	ORA	RF	ALU		AHY	1987	WB	
800190388	RED	ORA	B/W	ALU		5 days	06/26/89	07145	
800190301	RED	RED	RF	ALU		AHY	1987	WF	
800190383	RED	RED	B/W	ALU		23 days	06/21/89	08041	
800190312	RED	WHI	RF	ALU	female	AHY	1987	MD	
800190380	RED	WHI	B/W	ALU	female	AHY	06/14/89	01154	•
800190381	RED	WHI	B/W	ALU		12 days	06/19/89	09045	•
800190304	RED	YEL	RF	ALU		AHY	1987	HOOK	
800190384	RED	YEL	B/W	ALU	female	AHY	06/21/89	07045	
85153724	RF	BLU	ORA	ALU	male	AHY	05/28/88	MD	f
800190366	STU	STU	RF	ALU	male	AHY	05/15/89	09042	g
800190348	WHI	ALU	RF	BLU	male	AHY	05/31/88	MD	
139112613	WHI	ALU	RF	GRE		5 days	06/28/88	MD	
139112619	WHI	ALU	RF	ORA		4 days	07/10/88	MD	
800190355	WHI	ALU	RF	RED	male	AHY	06/12/88	MD	
800190345	WHI	ALU	B/W	WHI	female	AHY	05/29/88	MD	c
800190334	WHI	ALU	B/W	YEL	male	AHY	05/19/88	MD	c
800190369	WHI	BLK	B/W	ALU		4 days	05/31/89	14115	
800190367	WHI	BLU	B/W	ALU	male	AHY	05/18/89	14045	
800190370	WHI	GRE	B/W	ALU		4 days	05/31/89	14115	
800190321	WHI	ORA	B/W	ALU	female	AHY	1987	MD	• c
800190371	WHI	ORA	B/W	ALU		4 days	05/31/89	14115	•
800190324	WHI	RED	RF	ALU		AHY	1987	MD	
800190368	WHI	RED	B/W	ALU	male	AHY	05/29/89	11041	

continued

Appendix E. Continued.

USFWS# ^a	Left Top	Left Bottom	Right Top	Right Bottom	Sex	Age at Capture ^b	Date of Capture	Banding Location	Comments
800190314	WHI	WHI	RF	ALU	female	AHY	1987	MD	
800190365	WHI	WHI	B/W	ALU	female	AHY	05/15/89	08045	
800190327	WHI	YEL	RF	ALU		AHY	1987	HOOK	
800190372	WHI	YEL	B/W	ALU	male	AHY	06/01/89	06045	
800190343	YEL	ALU	RF	BLU	male	AHY	05/28/88	MD	^h
800190344	YEL	ALU	B/W	RED	male	AHY	05/29/88	MD	^c
800190335	YEL	ALU	B/W	WHI	female	AHY	05/19/88	MD	^c
800190322	YEL	BLU	RF	ALU		AHY	1987	WF	
800190323	YEL	RED	RF	ALU		AHY	1987	WF	
800190318	YEL	WHI	RF	ALU		AHY	1987	WB	
800190302	YEL	YEL	RF	ALU	male	AHY	1987	HOOK	

^a 800190301 -- 800190329, 87162489, 87162506, & 87162507 banded by Patterson (1988) in 1987.

^b AHY = After Hatch Year

^c Banded previously, RF replaced with B/W in 1989.

^d Originally banded as ALU ORA RF YEL. Bands removed in 1989 because of apparent leg injury. Right leg recovered fully.

^e Birds accidentally banded with the same color combination.

^f Bird captured with ALU band present. Color bands added in 1988.

^g Bird formerly banded as 800190343. Rebanded because of leg injury. Left leg amputated below mid-tarsus.

^h Bird rebanded as 800190366 in 1989 because of leg amputation. Band combination now --- --- RF ALU.

COLORS

ALU = USFWS Aluminum band
 B/W = Black / White broad stripe band
 BLK = Black
 BLU = Blue
 GRE = Green
 ORA = Orange
 RED = Red
 RF = Red Flag
 STU = Stump - bird is missing its foot
 WHI = White

LOCATIONS

MD = Maryland (Loefering's study area)
 VA = Virginia
 HOOK = Toms Cove Hook, VA
 WB = Wild Beach, VA
 WF = Wash Flats, VA
 Key to five digit numbers is in the text under Location Assignment.

Appendix F. Piping plover breeding histories

Appendix F. Breeding history and sightings of banded piping plovers on Assateague Island National Seashore, Maryland, 1987-1990. Band combinations are in the previous appendix.

USFWS # ^a	Dates Observed	Activity ^b	With	Location ^c	Result
85153724	5/13-7/6/88	N 5/13-7/3/88	800190320	07045	Fledge 1 chick
	3/16-4/14/89			MD	
87162489	1987			VA	
87162506	1987			VA	
	5/3/89			MD	
	4/12/90			HOOK ⁱ	
87162507	1987			VA	
139112601	1988			MD	Didn't fledge
139112602	1988			MD	Didn't fledge
139112603	1988			MD	Didn't fledge
139112604	1988			MD	Fledged
	4/25/89			MD	
139112605	1988			MD	Fledged
	6/13-8/1/89	N 6/13-6/18/89	800190380	01154	Loss-unknown
	4/6-7/23/90	N 5/20-6/2/90	800190386	02042	Loss-fox
		N 6/10-7/11/90	800190386	01042	Loss-fox
139112606	1988			MD	Fledged
139112607	1988			MD	Fledged
139112608	1988			MD	Didn't fledge
139112609	1988			MD	Didn't fledge
139112610	1988			MD	Fledged
139112611	1988			MD	Fledged
139112612	1988			MD	Didn't fledge
139112613	1988			MD	Didn't fledge
139112614	1988			MD	Fledged
139112615	1988			MD	Didn't fledge
139112616	1988			MD	Didn't fledge
139112617	1988			MD	Fledged
	8/17/89	Migrating		CLNS ^d	
139112618	1988			MD	Fledged
139112619	1988			MD	Fledged
139112620	1988			MD	Fledged
	4/25/89	Migrating		CHNS ^e	
139112621	1988			MD	Didn't fledge
139112622	1988			MD	Fledged
	4/20/89	Migrating		CHNS ^e	
800190301	1987			VA	
	3/27/90			HOOK ⁱ	
800190302	1987			VA	
	5/13-7/13/88	N 5/13-6/23/88	800190347	02042	Hatch-chicks lost
	3/28-7/6/89	N 5/9-5/15/89	NOBA ^f	02043	Loss-fox
	4/8-7/30/90	N 5/8-5/28/90	NOBA	02045	Loss-fox
		N 6/13-6/20/90	NOBA	03041	Loss-fox
		S 6/26/90		03042	

Appendix F. Continued.

USFWS # ^a	Dates Observed	Activity ^b	With	Location ^c	Result
800190303	1987 3/23/90			VA WB ⁱ	
800190304	1987			VA	
800190305	1987			VA	
800190306	1987			VA	
800190307	1987			VA	
800190308	1987 6/15/88			VA MD	
800190309	1987 4/6/90			VA WB ⁱ	
800190310	1987			VA	
800190311	1987			MD	
800190312	1987 5/10-7/18/88			MD	
		N 5/10-5/16/88	800190348	13045	Loss-fox
		N 5/27-7/18/88	800190348	13045	Fledge 2 chicks
	3/28-7/7/89	N 5/11-7/2/89	800190366	09042	Fledge 3 chicks
	4/9-5/24/90	N 5/2-5/23/90	NOBA	09043	Loss-flooded
800190313	1987			MD	
	5/8-5/23/88	N 5/8-5/22/88	800190334	04041	Loss-unknown
800190314	1987 5/28-7/16/88			MD	
		N 5/28-7/7/88	800190358	02044	Hatch-chicks lost
800190315	1987			VA	
800190316	1987			VA	
800190317	1987 5/-/7/88			VA	
		N 5/24-6/30/88	?	NJ	Fledge 3 chicks ^g
800190318	1987			VA	
800190319	1987			VA	
800190320	1987 5/13-7/6/88			MD	
		N 5/13-7/3/88	85153724	07045	Fledge 1 chick
	3/16-6/9/89			MD	
800190321	1987 5/11-7/29/88			MD	
		N 5/11-5/16/88	NOBA	09045	Loss-fox
		N 6/15-7/4/88	800190361	09045	Loss-fox
	3/30-8/1/89	N 5/9-5/13/89	800190363	04045	Loss-fox
		N 6/7-6/16/89	800190379	13043	Loss-unknown
	4/7-7/23/90	N 5/19-6/8/90	800190341	07045	Loss-abandoned
800190322	1987			VA	
800190323	1987			VA	
800190324	1987			MD	
800190325	1987 5/11-7/13/88			MD	
		N 5/11-5/25/88	800190339	04042	Loss-unknown
	3/28-5/22/89	N 4/25/89	?	05043	Loss-unknown
800190326	1987 7/27/90			VA	
				CNWR	
800190327	1987 5/14-5/30/88			VA	
		N 5/14-5/25/88	NOBA	09043	Loss-avian
800190328	1987			VA	
800190329	1987			MD	
800190330	5/2-7/9/88	N 5/2-5/17/88	NOBA	16046	Loss-abandoned
800190331	4/27-6/23/88 5/3-5/25/90	N 4/27-6/22/88 S 5/25/90	800190335	01041 03042	Hatch-chicks lost

Appendix F. Continued.

USFWS # ^a	Dates Observed	Activity ^b	With	Location ^c	Result
800190332	5/8-7/15/88	N 5/8-5/31/88	800190333	02041	Loss-fox
		N 6/11-7/13/88	800190333	01043	Hatch-chicks lost
	3/22-6/27/89	N 4/25/89	800190385	01042	Loss-unknown
		N 5/18-5/31/89	800190385	01042	Loss-unknown
		N 6/19-6/27/89	800190385	01042	Loss-fox
	4/6-7/23/90	N 4/25-6/9/90	800190385	01042	Hatch-chicks lost
800190333	5/8-7/16/88	N 5/8-5/31/88	800190332	02041	Loss-fox
		N 6/11-7/13/88	800190332	01043	Hatch-chicks lost
	3/23/90			HOOK ⁱ	
800190334	5/8-7/13/88	N 5/8-5/22/88	800190313	04041	Loss-unknown
	3/22-6/14/89	N 4/25/89		05043	Loss-unknown
		N 5/28-6/9/89	?	06043	Loss-abandoned
800190335	4/27-7/29/88	N 4/27-6/22/88	800190331	01041	Hatch-chicks lost
	4/5-7/31/89	S 4/17/89		04044	
		N 5/9-5/14/89	800190339	04044	Loss-fox
		N 5/28-6/24/89	800190336	04045	Hatch-chicks lost
	4/6-5/24/90	N 4/23-5/24/90	800190340	03043	Loss-fox
		7/7/90		HOOK ⁱ	
800190336	4/25-7/13/88	N 4/25-5/2/88	800190341	32069	Loss-avian
		N 5/14-6/18/88	800190341	33061	Hatch-chicks lost
	5/6-5/12/89			MD	
800190337	5/12-5/25/88	N 5/12-5/25/88	800190338	10041	Loss-avian
	3/22/89			MD	
800190338	5/12-7/29/88	N 5/12-5/25/88	800190337	10041	Loss-avian
	6/30-7/6/89			MD	
	4/4/90			WB ⁱ	
	7/17/90			MD	
800190339	6/21-7/13/88	N 5/11-5/25/88	800190325	04042	Loss-unknown
	3/22-6/24/89	N 5/9-5/14/89	800190335	04044	Loss-fox
		N 5/28-6/24/89	800190335	04045	Hatch-chicks lost
	4/6-7/3/90	N 5/8-5/28/90	800190362	04041	Loss-fox
		N 6/13-6/19/90	800190362	04043	Loss-fox
800190340	5/24-7/20/88	N 5/24-7/13/88	800190342	03043	Fledge 1 chick
	3/28-8/3/89	N 4/25/89	NOBA	03043	Loss-unknown
		S 6/12/89		MD	
	4/6-7/20/90	N 4/23-5/24/90	800190335	03043	Loss-fox
		N 6/13-6/20/90	"	03043	Loss-fox
		S 7/14/90		03043	
800190341	4/25-6/18/88	N 4/25/88	800190336	32069	Loss-avian
		N 5/14-6/18/88	800190336	33061	Hatch-chicks lost
	5/6-6/23/89	N 6/15-6/23/89	800190384	07045	Loss-fox
	4/7-6/29/90	N 5/19-6/8/90	800190321	07045	Loss-abandoned
		S 6/13/90		07045	
800190342	5/24-7/13/88	N 5/24-7/13/88	800190340	03043	Fledge 1 chick
	5/2-6/25/89	N 5/27-5/29/89	?	01041	Loss-fox ^h
800190343	5/23-7/24/88	N 5/23-6/18/88	800190345	09043	Loss-unknown
	4/7-6/27/89	amputated L leg, rebanded as 800190366			

Appendix F. Continued.

USFWS # ^a	Dates Observed	Activity ^b	With	Location ^c	Result
800190344	5/26-7/26/88 4/7-7/24/89	N 5/26-7/6/88 S 4/18/89 S 4/21/89 N 5/20-6/29/89	800190346 800190346 800190346 800190345	13044 13044 13044 13043	Fledge 4 chicks Fledge 2 chicks
	4/7-7/23/90	N 4/28-6/1/90 N 6/22-7/8/90	800190345 NOBA	13045 13045	Hatch-chicks lost Loss-human disturb.
800190345	5/23-7/5/88 4/13-7/24/89 4/7-8/3/90	N 5/23-6/18/88 N 5/28-7/18/89 N 4/28-6/1/90 N 6/18-8/3/90	800190343 800190368 800190344 800190366	09043 11041 13045 11042	Loss-unknown Fledge 4 chicks Hatch-chicks lost Fledge 1 chick
800190346	5/26-7/16/88 4/18-6/29/89	N 5/26-7/6/88 S 4/18/89 N 5/20-6/29/89	800190344 800190344 800190344	13044 13044 13043	Fledge 4 chicks Fledge 2 chicks
800190347	5/13-6/23/88	N 5/13-6/23/88	800190302	02042	Hatch-chicks lost
800190348	5/10-7/25/88	N 5/10-5/16/88 N 5/27-7/18/88	800190312 800190312	13045 13045	Loss-fox Fledge 2 chicks
800190349	5/23-7/7/88 3/22/89	N 5/23-6/4/88	800190351	08045 MD	Loss-flooded
800190350	5/23-7/18/88	N 5/23-6/12/88	800190352	08041	Loss-gull
800190351	5/23-6/21/88 3/22-6/23/89 4/6-7/30/90	N 5/23-6/4/88 N 5/9-6/23/89 N 4/27-6/19/90	800190349 800190365 800190365	08045 08045 08041	Loss-flooded Fledge 3 chicks Fledge 1 chick
800190352	5/23-6/12/88 7/31/89	N 5/23-6/12/88	800190350	08041 MD	Loss-gull ⁿ
800190353	6/7-6/26/88	N 6/7-6/26/88	800190354	25069	Hatch-chicks lost
800190354	6/7-6/26/88 4/4-6/2/89 5/4-7/30/90	N 6/7-6/26/88 N 5/19-6/2/89 N 6/14-7/28/90	800190353 800190502 800190502	25069 32069 32069	Hatch-chicks lost Hatch-chicks lost Hatch-chicks lost
800190355	5/29-7/28/88	N 5/29-7/24/88	800190356	14045	Fledge 1 chick
800190356	5/29-7/24/88 4/7-6/24/89	N 5/29-7/24/88 N 5/11-6/21/89 N 4/27-6/21/89	800190355 800190367 800190367	14045 14045 14045	Fledge 1 chick Fledge 2 chicks Fledge 2 chicks
800190357	6/13-8/6/88 4/14-8/1/89 4/2-7/24/90	N 6/13-8/6/88 N 4/25/89 N 5/28-7/16/89	800190363 NOBA 800190372	04045 07042 06045	Fledge 1 chick Loss-unknown Fledge 2 chicks
800190358	5/28-7/19/88 3/28-8/1/89	N 5/28-7/7/88 N 4/25-6/21/89	800190360 800190362	12044 03042	Fledge 3 chicks Hatch-chicks lost
800190359	6/15-7/31/88 3/30-7/18/89 6/30/90	N 6/15-7/31/88 N 5/13-6/5/89	800190360 800190360	12042 12043	Fledge 3 chicks Hatch-chicks lost
800190360	6/15-8/10/88 3/30-7/18/89 3/26/89 4/7-7/23/90	N 6/15-7/31/88 N 5/13-6/5/89 Migrating N 5/4-6/29/90	800190359 800190359 800190357	12042 12043 12044	Fledge 3 chicks Hatch-chicks lost Fledge 3 chicks
800190361	6/15-7/4/88 6/30-7/25/90	N 6/15-7/4/88	800190321	09045 MD	Loss-fox
800190362	6/18-7/21/88 3/22-7/24/89 4/6-7/25/90	N 6/18-7/2/88 N 4/25-6/21/89 N 5/8-5/28/90 N 6/13-6/19/90	NOBA 800190353 800190339 800190339	01045 03042 04041 04043	Loss-fox Fledge 2 chicks Loss-fox Loss-fox

Appendix F. Continued.

USFWS # ^a	Dates Observed	Activity ^b	With	Location ^c	Result
800190363	6/3-8/6/88	N 6/13-8/6/88	800190357	04045	Fledge 1 chick
	3/18-5/18/89	N 5/9-5/13/89	800190321	04045	Loss-fox
800190365	5/9-6/23/89	N 5/9-6/23/89	800190351	08045	Fledge 3 chicks
	4/6-6/19/90	N 4/27-6/19/90	800190351	08041	Fledge 1 chick
800190366 ⁱ	5/11-7/21/89	N 5/11-7/2/89	800190312	09042	Fledge 3 chicks
	4/11-8/3/90	N 6/18-8/3/90	800190345	11042	Fledge 1 chick
800190367	5/11-7/18/89	N 5/11-6/21/89	800190356	14045	Fledge 2 chicks
	4/7-7/23/90	N 4/27-6/21/90	800190356	14045	Fledge 2 chicks
800190368	5/28-7/24/89	N 5/28-7/18/89	800190345	11041	Fledge 4 chicks
800190369	1989			MD	Fledged
800190370	1989			MD	Fledged
800190371	1989			MD	Didn't fledge
800190372	5/28-7/16/89	N 5/28-7/16/89	800190357	06045	Fledge 2 chicks
800190373	5/29-7/24/89	N 5/29-7/3/89	800190374	06043	Hatch-chicks lost
	5/8-7/23/90			MD	
800190374	5/29-7/6/89	N 5/29-7/3/89	800190373	06043	Hatch-chicks lost
	4/3/90-7/23/90			MD	
	6/6/90			HOOK ⁱ	
800190375	1989			MD	Fledged
800190376	1989			MD	Fledged
800190377	1989			MD	Fledged
	6/7-7/22/90	S 6/29/90		08043	
800190378	1989			MD	Fledged
	5/2-7/3/90	S 5/15/90		03043	
		S 7/3/90		03043	
800190379	6/7-7/21/89	N 6/7-6/16/89	800190321	13043	Loss-unknown
800190380	6/13-7/31/89	N 6/13-6/18/89	139112605	01154	Loss-unknown
800190381	1989			MD	Fledged
j	5/4-7/23/90	N 5/4-5/9/90	NOBA	09042	Loss-fox
j		N 6/25-7/21/90	NOBA	08045	Fledge 4 chicks
800190382	1989			MD	Fledged
800190383	1989			MD	Fledged
	5/18/90			MD	
800190384	6/15-6/23/89	N 6/15-6/23/89	800190341	07045	Loss-fox
800190385 ^k	4/25-7/18/89	N 4/25-5/1/89	800190332	01042	Loss-unknown
		N 5/18-5/31/89	800190332	01042	Loss-unknown
		N 6/19-6/27/89	800190332	01042	Loss-fox
	4/7-7/21/90	N 4/25-6/9/90	800190332	01042	Hatched-chicks lost
800190386	1989			MD	Fledged
	4/27-7/11/90	N 5/20-6/2/90	139112605	02042	Loss-fox
		N 6/10-7/11/90	139112605	01042	Loss-fox
800190387	1989			MD	Fledged
	4/27-7/24/90			MD	
800190388	1989			MD	Fledged
800190389	1989			MD	Fledged
	5/5-7/23/90			MD	
800190390	1989			MD	Fledged
	4/27-5/29/90	S 4/27/90		03044	

Appendix F. Continued.

USFWS # ^a	Dates Observed	Activity ^b	With	Location ^c	Result
800190391	1989			MD	Fledged
800190392	1989			MD	Fledged
800190393	1989			MD	Didn't fledge
800190394	1989			MD	Didn't fledge
800190395	1989			MD	Fledged
800190502	4/4-6/2/89	N 5/19-6/2/89	800190354	32069	Hatch-chicks lost
	8/13-8/20/89	Migrating		CLNS ^d	
	6/7-7/20/90	N 6/14-7/28/90	800190354	32069	Hatch-chicks lost

^a 800190301 -- 800190329, 87162489, 87162506, & 87162507 banded by Patterson (1988) in 1987.

^b N = Nested; S = Creating nest scrapes, courting.

^c See description below for locations.

^d Cape Lookout National Seashore, NC. McConnaughey (1990).

^e Cape Hatteras National Seashore, NC. Suzanne D. Coutu (pers. comm.)

^f NOBA = No Bands - an unbanded bird.

^g Observed by Ted C. Nichols, N.J. Department of Environmental Protection, near Avalon, N.J.

^h Observations based on sightings of birds with incomplete band combinations. However, this is the only possible combination.

ⁱ Formerly banded as 8001-90343. Rebanded because of leg injury.

^j These entries are for 800190380 or 800190381.

^k Banded by Patterson in 1987. Rebanded because of band and foot loss. Former band number not known, however, the old color bands were those used by Patterson (1988).

^l Susan Haig, pers. comm.

^m LL:narrow BLK/WHI/B/W over ALU RL: BLK over GRE.

LOCATIONS

MD = Maryland (Loefering's study area)

NJ = New Jersey

VA = Virginia

HOOK = Tom's Cove Hook, VA

WB = Wild Beach, VA

WF = Wash Flats, VA

Key to five digit numbers is in the text under Location Assignment.

Appendix G. Scientific names of selected species

Appendix G. Scientific names of species mentioned in the text.

Common name	Scientific name
Plants	
American Beach Grass	<i>Ammophila breviligulata</i>
Salt Meadow Cord Grass	<i>Spartina patens</i>
American Three Square	<i>Scirpus americanus</i>
Northern Bayberry	<i>Myrica pensylvanica</i>
Southern Bayberry	<i>Myrica cerifera</i>
Goldenrod spp.	<i>Solidago</i> spp.
Seaside goldenrod	<i>Solidago sempervirens</i>
Invertebrates	
Ghost Crab	<i>Ocypode quadrata</i>
Fiddler Crab	<i>Uca</i> species
Reptiles	
Northern Diamondback Terrapin (Turtle)	<i>Malaclemys terrapin terrapin</i>
Mammals	
Red Fox	<i>Vulpes vulpes</i>
Raccoon	<i>Procyon lotor</i>
Striped Skunk	<i>Mephitis mephitis</i>
Domestic Dog	<i>Canis familiaris</i>
Wild Pony	<i>Equus caballus</i>
Sika Deer	<i>Cervus nippon</i>
Birds	
Egret sp.	<i>Egretta</i> spp. or <i>Casmerodius albus</i>
Great-blue Hereon	<i>Ardea herodias</i>
Duck sp.	<i>Anas</i> sp., probably <i>Anas rubripes</i>
American Oystercatcher	<i>Haematopus palliatus</i>
Piping Plover	<i>Charadrius melodus</i>
Willet	<i>Catoptrophorus semipalmatus</i>
Ruddy Turnstone	<i>Arenaria interpres</i>
Sanderling	<i>Calidris alba</i>
Gull sp.	<i>Larus</i> spp.
Laughing Gull	<i>Larus atricilla</i>
Ring-billed Gull	<i>Larus delawarensis</i>
Herring Gull	<i>Larus argentatus</i>
Great Black-backed Gull	<i>Larus marinus</i>
Tern sp.	<i>Sterna</i> spp.
Gull-billed Tern	<i>Sterna nilotica</i>
Least Tern	<i>Sterna antillarum</i>
Osprey	<i>Pandion haliaetus</i>
Barn Swallow	<i>Hirundo rustica</i>
Crow sp.	<i>Corvus</i> sp.
American Crow	<i>Corvus brachyrhynchos</i>
Fish Crow	<i>Corvus ossifragus</i>
Song Sparrow	<i>Melospiza melodia</i>
Red-winged Blackbird	<i>Agelaius phoeniceus</i>
Boat-tailed Grackle	<i>Quiscalus major</i>

Appendix H. Piping Plover Morphometrics

METHODS

We banded piping plover adults and chicks in 1988 and 1989. We captured adults on nests using a 44 x 50 x 32 cm drop trap (Mills and Ryder 1979, Cairns 1982). The trap frame was constructed of 6-mm (1/4 in) iron rods, painted tan, and was covered with mist net. This provided good camouflage and trap success (72 captures in 87 trapping attempts (83%)).

To reduce the probability of nest abandonment, we did not trap adults until incubation had begun. We avoided trapping in extremely hot or inclement weather. All trappings took place in the morning, when the sand was cool to the touch, generally before 1000 hours.

We banded all birds with a U.S. Fish and Wildlife Service (USFWS) aluminum leg band and 2 plastic color bands. In 1988, we placed an international flag (Myers et al. 1983) on all birds captured but discontinued this practice in 1989 following concerns about band-related injuries.

We banded chicks at 4 days of age whenever possible. If they were not banded at 4 days of age, we banded them as soon thereafter as possible, but not earlier. Banding ages were determined after talking with experienced banders (Strauss pers. commun.). More recently, MacIvor (1990) suggested that birds this young may have trouble carrying the bands; however, we observed no problems with the chicks

carrying the bands. Banding parties consisted of 2 or more people. One or more person(s) closely watched through a spotting scope or binoculars as a researcher approached to retrieve the chicks by hand. They directed the retriever to the locations of the crouched, cryptically-colored chicks. Banding proceeded only if all chicks could be captured within 10 minutes. We released chicks as a group to prevent the adults from departing with part of the brood. When consistent with chick safety, we weighed and measured individuals during banding.

We used USFWS aluminum bands, size 1A, on all adults. In 1988, we banded chicks with USFWS aluminum bands, size 1B. Strauss (pers. commun.) reported that some plovers fitted with the USFWS prescribed band sizes [1A (3.18mm inside diameter) and 1B (2.78mm inside diameter)] experienced chafing and swelling of the tarsi. In the event that the smaller bands encouraged chaffing, we switched to size 1A bands for chicks in 1989. The larger inside diameter was desirable since it reduced the chance of restricting blood flow as the chick grew, and we observed no losses of the larger bands.

In 1988, we used Darvic color bands (size 1FB) made by A.C. Hughes⁶ because they are color stable in ultra-violet light. We trimmed the bands to 5-mm high and 20-mm long with a 70% overlap, so that final band size was similar to USFWS band size 1A. These bands were sized in the field. We glued the overlapping section with super glue and used PVC cement to smooth the outside joint.

⁶ A.C. Hughes, 1 High Street, Hampton Hill, Middlesex TW12 1NA, England.

We observed piping plovers that we banded in 1988 later that summer with apparent leg injury. In 1989, we observed birds returning with leg injuries. Because we feared that these injuries were the result of banding, we modified our techniques. In 1989, we used colored Darvic butt-end bands (size XB) and discontinued the use of flags. We trimmed these butt-end bands to achieve a 3.1 mm inside diameter and sealed them using a heated dissecting probe to melt the ends of the band together.

During banding we weighed birds using a Pesola spring scale and measured the length of the exposed culmen, and culmen width and depth at the nostrils using techniques of Baldwin et al. (1931). We also measured forecrown band length and width, the gap in the breastband, the tarsus and middle toe length, an unflattened wing chord, and the dorsal length of the central rectrix, from the oil gland to the tip.

We determined the sex of the plovers using breast and forecrown plumage and bill characteristics. Males typically had darker (black) breast and forecrown bands compared to females (brownish). The length and width of the forecrown band was usually greater in males, compared to females. Additionally, the demarkation between the orange and black on the bill was distinct in the male birds and smudged in the females. These characteristics have been used by others to sex breeding piping plovers (Haig and Oring 1988b, MacIvor 1990), and copulatory position often supports these classifications; however, little work has been done to unequivocally confirm the validity of using these characteristics (e.g. examine the gonads). We recognize this as a potential pitfall to our analysis and proceed assuming these

classifications are reliable. We determined the sex of most pairs with both birds in the hand, when comparisons were most reliable.

RESULTS

We color-marked 86 piping plovers in 1988-1989, 44 adults and 42 chicks (Appendix E). We compiled a breeding history for each bird as unique color-band combinations allowed us to identify individuals (Appendix F). Occasionally on AINS, we observed birds that were banded at other study areas (Table 50).

We compared morphometric data for known males and females (Table 51). Males were heavier, had greater culmen length, width and depth, and had longer and wider forecrown bands. Male and female brood patch and parasite load conditions appeared similar, though were not tested statistically (Table 52).

We also measured chicks (Table 53). I focused on chicks 4 and 5 days old in the analysis to reduce age-related variation. These observations made up 61% of all chicks captured.

We also trapped 17 birds that previously had been banded. We inspected the bands for positive identification and to determine their integrity. We replaced damaged bands if the correct combination was known. We also inspected the birds' legs for chafing or possible injury. When an injury was detected, we removed all color bands from the injured leg (occurred once).

DISCUSSION

Morphometric data for piping plovers confirm there is little sexual dimorphism. Males were found to be heavier; however, this may not accurately reflect year-round relative male/female plover weights. We trapped plovers soon after clutch completion. Females may have been lighter because of substantial energy investment into the eggs and the associated "normal" weight loss (Ricklefs 1974). We found an average clutch weight to be about 73% of the mean female body weight ($n = 7$ clutches, $\bar{x} = 38.2\text{g}/4\text{-egg-clutch}$). Nevertheless, males may be slightly larger if culmen dimensions reflect body size. Wilcox (1959), on the other hand, found females to be heavier on Long Island, New York. Palmer (1967) also reported that the male's bill appeared heavier during the breeding season.

Forecrown band lengths and widths were greater for males. These characteristics often have been used to separate the sexes (Palmer 1967, Johnsgard 1981, Haig and Oring 1988b, MacIvor 1990). Male forecrown and breast bands also tend to be more black compared with the brownish-black bands of the females. Graul (1973) addresses possible functions of forecrown and breast bands as disruptive camouflage or as social signals. Body weights, wing chord, culmen length, and tail length are within the range reported for adult piping plovers (Wilcox 1959, Palmer 1967, Graul 1973, Sidle 1985).

Chick measurements showed chick legs are nearly adult size. Considering piping plover natural history, this is not surprising. There is little parental care other

than the adults serving as guardians. Chicks, therefore, must feed themselves and be highly mobile soon after hatching to move to food and avoid predators.

Appendix I. Piping Plover Leg Injuries

We observed 4 (10%), 8 (21%), and 3 (13%) color-banded birds in 1988, 1989, and 1990 with apparent leg injuries (Table 54). In all cases, the birds were limping or holding a leg up, just off the ground. A bird that we suspect was banded in 1987 was missing the lower leg from mid-tarsus. The remaining birds were banded in 1988. We were able to determine the year that a plover was banded because different types of color-bands were used in 1987, 1988, and 1989.

I suspect one bird observed in 1989 was the same individual as observed in 1988. The same foot was injured, it returned to nest within 25 m of the previous year's nest, it was the same sex, and the partial band combination matched the bird injured the previous year. For the same reasons, I believe a bird observed in 1990 was first observed injured in 1989, although it nested ~300 m from the previous year's nest.

All injured birds observed carried leg bands, and all were initially banded with red flags. No unbanded piping plovers were observed with leg injuries. In 1989, we used a black/white broad striped band in place of the red flag and observed no injuries using these bands.

In 2 instances, we trapped birds with leg injuries. The first bird suffered a fractured tarsus above the leg bands. The leg and foot below the bands were grossly

swollen and necrotic. We were unable to determine if the leg bands were responsible for the fracture or only for restricting the swelling following the fracture. We amputated the swollen, necrotic foot since it was dangling by skin only. We observed the bird 10 days later running across the beach, although it was limping. This bird returned to near the same site and bred successfully the following year.

The second instance was a limping bird (USFWS# 8001-90360). We examined the injured leg upon capture and found the color-bands to be compacted with sand and sloughed skin. We removed the 2 color bands from that leg and the bird recovered fully (we left the color-band and USFWS aluminum band on the bird's other leg). This second instance suggested our 1988 banding technique, using wrap-around bands, may not be appropriate for piping plovers. We switched to a trimmed butt-end band and observed no injured birds with this type of band. We banded 26 birds (17 chicks, 9 adults) in 1989 with these bands and saw no injuries in 1989 or 1990, although we only observed 11 (42%) of the birds in 1990.

DISCUSSION

Piping plovers with leg bands had a higher incidence of leg injury than unbanded plovers (Sidle, unpublished data). We suspect that the bands themselves or compaction of sand or sloughed skin between the leg and band may restrict or halt normal blood circulation. Our observations of foot and leg loss support this hypothesis as do the 2 instances in which we trapped birds that were injured.

Although we observed no injured birds when we switched to the trimmed butt-end bands in 1989, this technique may not be the solution to the banding problems. MacIvor (pers. commun.) and Cross (pers. commun.) used similar methods and observed injured birds following banding.

The cause of these injuries is unknown. Our observed injuries were from birds banded in 1987 and 1988, when we placed red flags on all birds. The majority of the injuries were to the right leg (Table 54), which was the leg on which we placed the flag. MacIvor (1988) suggested that flags were linked to piping plover leg injuries, if not the direct cause itself. In a more detailed survey of piping plover banders, however, Sidle (1989) found leg injuries were observed on legs with all combinations of flags, color-bands, and USFWS aluminum bands, and he could not identify a single cause of band related leg injuries. Piping plovers may be sensitive to leg bands of all kinds. Similar problems have been observed in snowy plovers (*Charadrius alexandrinus*, Sidle pers. commun.). A careful evaluation of future banding projects is warranted.

Appendix J. Migration and Winter Sightings

We received incidental reports of birds color-banded by us from various persons in the field (Table 47). Most birds were observed during migration. Two birds were sighted at Cape Hatteras National Seashore and 1 at Cape Lookout National Seashore. We observed the Cape Lookout bird 4 days later on AINS, approximately 490 km (305 miles) from where it was seen on Cape Lookout.

One individual was observed wintering in two consecutive years on adjacent Florida Keys (Table 47). These sightings took place in October and December. Additional observations of red-flagged birds were reported from the same site, but the color-band combinations of these birds were not reported.

One bird nested in New Jersey in 1988 after being banded by Patterson (1988) in 1987. Because this plover was banded in Virginia, it was not included in any analysis.

DISCUSSION

During migration, piping plovers were observed in relatively large numbers at

specific sites⁷ in North Carolina (Coutu et al. 1990, McConnaughey et al. 1990).

Northbound birds appeared to move through quickly and were not sighted on more than one day. However, these sightings indicate that plovers do not always fly non-stop from winter to breeding areas as suggested by Haig (1987). Southward migration appeared to proceed more slowly, and birds were observed on multiple days in August. I suspect these sites in North Carolina are of few remaining undisturbed areas used by plovers. The protection of these stop-over sites is imperative to migrating plovers, as well as other shorebirds.

Additionally, wintering sites also are in need of protection. A site on Ohio Key (Sunshine Key), Florida has been used regularly by wintering plovers (and other shorebirds) (Brown 1990, pers. commun.). Plovers from Minnesota, North Dakota, Virginia, and Maryland have been observed to winter there. Unfortunately, planning is underway to develop this wetland (into a trailer park).

⁷ Sites on Cape Hatteras National Seashore: Cape Point and Hatteras Inlet. Sites on Cape Lookout National Seashore: Ocracoke Inlet and New Drum Inlet.

Vita

John Paul Loegering was born on September 12, 1964. He graduated from Barnesville High School, Barnesville, Minnesota, in 1983. He attended North Dakota State University and received his Bachelor of Science degrees in Biology and Zoology in May, 1988. During the summer of 1984, he worked in western North Dakota on a prairie falcon and golden eagle survey. He worked in northern Wisconsin on an aquatic invertebrate project during the summer of 1985. During the summer of 1987, he worked as a volunteer at Alaska Peninsula National Wildlife Refuge collecting baseline data. He was granted an assistantship at Virginia Polytechnic Institute and State University and began his graduate program in May, 1988. In March, 1991, he was awarded the A. B. Massey Award for outstanding academic and professional leadership by the School of Forestry and Wildlife Resources. He was granted an assistantship at Oregon State University to continue his education in January, 1992.