

Piping Plover Population Dynamics and Effects of Beach Management Practices on  
Piping Plovers at West Hampton Dunes and Westhampton Beach, New York

Lawrence M. Houghton

Dissertation submitted to the Faculty of Virginia Polytechnic Institute and State  
University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy  
In  
Fisheries and Wildlife Science

James D. Fraser, Chair  
Marcella Kelly  
Dean Stauffer  
Michael Vaughan  
Jeff Walters

August 9, 2005  
Blacksburg, VA

Keywords: Ornithology, Population Dynamics, Beach Renourishment, Immigration,  
Emigration

Copyright 2005, Lawrence M. Houghton

Piping Plover Population Dynamics and Effects of Beach Management Practices on Piping Plovers at West Hampton Dunes and Westhampton Beach, New York

Lawrence M. Houghton

**ABSTRACT**

In the early 1990's, a series of habitat changes caused by storms and subsequent beach management by the U.S. Army Corps of Engineers (USACE, The Corps) provided a unique opportunity to study piping plover population dynamics in a changing environment. In this study, 1993-2004, we attempt to determine the factors that limit or influence the abundance and distribution of piping plovers in West Hampton Dunes (WHD), Long Island, NY, a renourished, highly developed, and high human disturbance area.

The piping plover population on Westhampton Island increased after the hurricane of 1938, and declined thereafter. The decline co-occurred with beach development and vegetative succession. After storms in the winter of 1992-1993 breached the island at West Hampton Dunes, piping plovers re-colonized the area. The New York District USACE filled the breach in 1993, and renourished the beach in 1996 and 2000-2001. USACE renourished parts of the groinfield in Westhampton Beach in 1997.

Each spring and summer, we monitored plovers intensively at WHD and part of the adjacent town of Westhampton Beach (The Reference Area) 1993-2004. We located nests and estimated reproductive and nest and chick survival rates. We monitored plover management efforts and determined causes of nest loss when possible. We monitored piping plover behaviors and obtained an index to plover food supply. We estimated area of plover habitats and defined areas unsuitable for piping

plover nesting. We also obtained indices to human and predator presence on the beach.

The WHD piping plover population increased from 0 pairs in 1992 to 39 in 2000 then decreased to 18 pairs in 2004. This decline was closely associated with changes in potential nesting habitat which increased from 22.4 ha in 1992 to 50.1 ha in 2000 then declined to 31.1 ha in 2004.

The primary process regulating the WHD population appears to be density dependent immigration and emigration. No other vital rates (clutch size, re-nest rate, fertility, egg survival, nest survival, chick survival, brood survival, chicks fledged/pair) were correlated with density. The higher equilibrium density at WHD (~1 pair/ha) than at The Reference Area (~0.4 pair/ha) appeared to be a function of the large bay intertidal flats at WHD.

The most common nest predators, cats (WHD = 13% of known predated nests), American Crows (17% of known predated nests) and foxes (37% of known predated nests), are newcomers to piping plover habitats. Thus, plovers may be especially vulnerable to them. Predator removal from the study area appeared to improve nest success and chick survival ( $R^2 = 0.79$ ). Predator exclosures at nests reduced nest loss (WHD = 34% exclosed nests lost vs. 43% of unexclosed nests lost, though in one year, one or more foxes learned to exploit plovers in exclosures (22% of all exclosed nests were predated by foxes in 1995).

This study highlights the long suspected piping plover paradox: increasing beach width can temporarily raise the carrying capacity of an area, but preventing overwash can reduce or eliminate the natural formation of the bay side foraging flats

that increase piping plover density, and sometimes, survival. Moreover, beach stabilization allows human development of the habitat which also reduces the carrying capacity of the environment for piping plovers, increases human/plover interactions, and attracts potential predators.

## **DEDICATION**

I would like to dedicate this dissertation to my father who passed away before I was able to finish this project. He was a man who always did things well and managed to accomplish anything he set his mind to. I am sure that it would have made him happy to see me finally complete the process.

## ACKNOWLEDGEMENTS

I give special thanks to the U. S. Army Corps of Engineers for input and funding of this study. In particular, I would like to thank Peter Wepler. I also would like to thank U. S. Fish and Wildlife Service personnel Anne Hecht, Steve Papa, and former employee Bob Murray for providing information and valuable input throughout the study.

I am thankful to all of the great field technicians for their involvement in collecting and entering data on the plovers. I am also grateful for assistance from various employees from the Long Island Chapter of The Nature Conservancy.

I would like to thank my advisor, Jim Fraser who made all of this possible. Also, I wish to thank my committee; Jeff Walters, Dean Stauffer, Mike Vaughan, and Marcella Kelly. I wish a special thanks to Bob Jones and Don Orth who hired me to teach Ornithology for 2 semesters providing me with some of the most enjoyable experiences of my lifetime.

I would like to thank the following people whom I met and somehow managed to stay close to while working on my dissertation in Blacksburg; Michael Anderson, Kate Ballagh, Alan Beach, Cara Bergschneider, Lori Blanc, Devin Brown, George Bumann, Jonathan Cohen, Ken Convery, Jeff Frykholm, Shane Hanlon, Nicholas Polys, Bill Richardson, Keith Tompkins, and Barbara Wright.

Lastly, I wish to thank my friends and family from home; Bill and Susan Babine, Tom and Jen Bellen, Barry Daggett, David Daggett, Neila and Fred Daggett, Adam Engel, Mike Fletcher, Bill and Diane Fitzpatrick, Alice Houghton, Annie Houghton, Chip and Liz Houghton, Charlie Jr. and Laura Starr Houghton, Connor Houghton, Kathy Houghton, Mark Houghton, Monica Houghton, Tim Houghton, Warren Houghton, Jeff

Kennedy, Dave Sanborn, and Dave Saxe. All of these folks have always been incredibly supportive and were particularly helpful when my dad passed away. Thanks!

## Table of Contents

<b>ABSTRACT</b> .....	<b>II</b>
<b>DEDICATION</b> .....	<b>V</b>
<b>LIST OF TABLES:</b> .....	<b>X</b>
<b>LIST OF FIGURES:</b> .....	<b>XIII</b>
<b>LIST OF APPENDICES:</b> .....	<b>XIV</b>
<b>INTRODUCTION</b> .....	<b>1</b>
<b>OBJECTIVES</b> .....	<b>6</b>
POPULATION REGULATION .....	6
U.S. ARMY CORP OF ENGINEERS BEACH MANAGEMENT ACTIVITIES.....	6
<b>STUDY AREA</b> .....	<b>8</b>
<b>METHODS</b> .....	<b>11</b>
FIELD METHODS .....	11
<i>Demographics, Vital Rates, and Nest Density and Distribution.</i> —.....	11
<i>Brood Density and Distribution.</i> —.....	13
<i>Nesting and Foraging Cover Types.</i> —.....	14
<i>Trail Indices</i> .....	15
<i>Changes in Arthropod Abundance.</i> —.....	15
<b>DATA ANALYSES</b> .....	<b>17</b>
PLOVER POPULATION SIZE, GROWTH AND DEMOGRAPHICS .....	17
<i>Population Trends.</i> —.....	17
<i>Demographics.</i> —.....	20
<i>Factors Affecting Vital Rates.</i> —.....	21
<i>Density Dependent Effects.</i> —.....	24
NESTING PAIR DENSITY AND DISTRIBUTION .....	24
<i>Nest Density.</i> —.....	24
<i>Moist Sediment Habitats and Pre-breeding Season Use.</i> —.....	24
<i>Cover Type Assessment.</i> —.....	25
IMPACTS OF STORM DAMAGE PROTECTION MEASURES .....	26
<i>Indirect Impacts.</i> —.....	26
<i>Direct Impacts.</i> —.....	26
<b>RESULTS</b> .....	<b>27</b>
CHANGES IN HABITAT .....	27
<i>Potential Nesting Habitat.</i> —.....	27
<i>Unusable Areas.</i> —.....	27
<i>Potential Foraging Habitat.</i> —.....	28
<i>Potential Prey.</i> —.....	28
<i>Potential disturbances.</i> —.....	29
PIPING PLOVER POPULATION TRENDS .....	29
<i>Habitat Measurements.</i> —.....	30
<i>Population Density.</i> —.....	30
ADULT PRE-BREEDING SEASON USE AND AVAILABILITY .....	31
PIPING PLOVER NESTING SEASON .....	31
<i>Nesting Chronology.</i> —.....	31
<i>Nest Distribution.</i> —.....	32
<i>Nest Characteristics.</i> —.....	33
<i>Clutch Size</i> .—.....	34

<i>Egg Hatchability.</i> —.....	34
<i>Egg Survival.</i> —.....	34
<i>Nest Survival.</i> —.....	35
<i>Renest rate.</i> —.....	36
<i>Potential Disturbances.</i> —.....	36
<i>Nest Predation.</i> —.....	36
<i>Nest Exclosures.</i> —.....	37
<i>Symbolic Fencing.</i> —.....	38
<b>CHICKS AND BROODS</b> .....	38
<i>Chick and Brood Chronology, Distribution and Movements.</i> —.....	38
<i>Chick Behavior.</i> —.....	39
<i>Chick Foraging Rates.</i> —.....	39
<i>Brood Habitat Use-Availability.</i> —.....	40
<i>Chick Survival.</i> —.....	40
<i>Brood Survival.</i> —.....	41
<i>Chick and Brood Disturbances.</i> —.....	41
<i>Chick Road Crossings.</i> —.....	42
<i>Chick Mortality.</i> —.....	43
<i>Reproductive Output.</i> —.....	43
<i>Population Growth Models.</i> —.....	44
<b>DISCUSSION</b> .....	<b>45</b>
POPULATION REGULATION.....	45
<i>The Role of Density Dependence.</i> —.....	45
<i>Immigration, Emigration and Population Regulation.</i> —.....	45
<i>Reproductive Output and Population Regulation.</i> —.....	48
EQUILIBRIUM DENSITY.....	49
RATE OF INCREASE.....	51
<i>Factors Affecting Reproductive Output.</i> —.....	52
LIMITING FACTORS.....	57
HABITAT MANAGEMENT.....	57
SUMMARY.....	59
<i>Population Dynamics.</i> —.....	59
<i>Land Form Alterations.</i> —.....	59
<i>Nest and Chick losses.</i> —.....	60
<i>Study Areas.</i> —.....	60
<b>MANAGEMENT IMPLICATIONS</b> .....	<b>60</b>
HABITAT MANIPULATION.....	60
PREDATOR MANAGEMENT.....	63
<b>LITERATURE CITED</b> .....	<b>65</b>

**LIST OF TABLES:**

TABLE 1. BEACH ZONES USED IN THIS PAPER. ALL ZONES EXCEPT FOR DENSE VEGETATION WERE USED BY PIPING PLOVERS (ELIAS-GERKEN 1994).....	71
TABLE 2. BEHAVIORS USED IN THE ANALYSIS OF PIPING PLOVER BROOD TIME BUDGETS IN WEST HAMPTON DUNES, AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-03. ....	72
TABLE 3. STRUCTURE OF POPULATION GROWTH MODELS FIT TO OBSERVED DATA. ....	73
TABLE 4. HYPOTHETICAL LIFE TABLE USED TO CALCULATE INTRINSIC RATE OF INCREASE (R) FOR PIPING PLOVERS AT WEST HAMPTON DUNES, NEW YORK, 1993-2004.....	74
TABLE 5. DEFINITIONS OF VITAL RATES, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2004. ....	75
TABLE 6. MEAN NUMBER OF ARTHROPODS CAPTURED IN COVER TYPES IN WEST HAMPTON DUNES AND THE REFERENCE AREA, WESTHAMPTON ISLAND, LONG ISLAND, NEW YORK, 1993-2003.....	76
TABLE 7. HUMAN AND CAT TRAIL INDICES IN COVER TYPES USED FOR NESTING, WEST HAMPTON DUNES AND THE REFERENCE AREA, WESTHAMPTON ISLAND, LONG ISLAND, NEW YORK, 1996-2003.....	77
TABLE 8. CORRELATION OF POPULATION GROWTH AND VITAL RATES WITH POPULATION DENSITY (PAIRS/HA) WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2004. ....	78
TABLE 9. PERCENT AVAILABILITY OF COVER TYPES AND PERCENT USE BY <b>FORAGING ADULT PLOVERS</b> , WEST HAMPTON DUNES AND THE REFERENCE AREA, WESTHAMPTON ISLAND, LONG ISLAND, NEW YORK, MARCH–MAY, 1997-2003. ....	79
TABLE 10. PERCENT USE OF BEACH COVER TYPES BY <b>RESTING ADULT PLOVERS</b> , WEST HAMPTON DUNES AND THE REFERENCE AREA, WESTHAMPTON ISLAND, LONG ISLAND, NEW YORK, MARCH–MAY, 1997-2003. ....	80
TABLE 11. DISTANCE (M) FROM PLOVER NESTS TO OCEAN HIGH TIDE LINE, BAY HIGH TIDE LINE, NEAREST NEIGHBORING FIRST NEST ATTEMPT, AND BETWEEN FIRST NEST ATTEMPTS AND RENESTS, WEST HAMPTON DUNES AND THE REFERENCE AREA, WESTHAMPTON ISLAND, LONG ISLAND, NEW YORK, 1993-2004.....	81
TABLE 12. PIPING PLOVER NEST DISTRIBUTION WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2004. ....	82
TABLE 13. MEAN DISTANCE (M) OF PIPING PLOVER NESTS TO NEAREST NEIGHBORING PIPING PLOVERS NEST BY YEAR, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1994-2003. ....	83
TABLE 14. NEST CHARACTERISTICS OF PIPING PLOVERS IN WEST HAMPTON DUNES AND THE REFERENCE AREA, WESTHAMPTON ISLAND, LONG ISLAND, NEW YORK, 1993-2004. ....	84
TABLE 15. TEMPERATURE (C) AND PRECIPITATION (CM), FROM NOAA WEATHER STATION, WESTHAMPTON, NEW YORK (APPROXIMATELY 3 MILES FROM WEST HAMPTON DUNES AND THE REFERENCE AREA), 1993-2004. 85	
TABLE 16. LOGISTIC REGRESSION MODEL OF MEAN CLUTCH SIZE VS. DAYS AFTER JANUARY 1ST NEST WAS INITIATED, AND NEST ORDER, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1994-2003..	86
TABLE 17. LINEAR REGRESSION MODEL OF MEAN ANNUAL EGG SURVIVAL OF UNEXCLOSED NESTS VERSUS MEAN MAXIMUM DAILY TEMPERATURE AND TOTAL PRECIPITATION APRIL THROUGH JULY, NESTING PAIR DENSITY, AND NUMBER CATS AND FOXES TRAPPED, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1994-2003..	87
TABLE 18. LINEAR REGRESSION MODEL OF EGG SURVIVAL OF UNEXCLOSED NESTS VS. NEST FENCED (Y/N), NEST SUBSTRATE TOPOGRAPHY, NEST IN VEGETATION (Y/N), NEST LINING, DISTANCE TO BAY HIGH TIDE LINE, DISTANCE TO NEAREST NEIGHBORING NEST, DISTANCE TO DENSE VEGETATION, DAYS AFTER JANUARY 1ST NEST WAS INITIATED, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1994-2003..	88
TABLE 19. ANNUAL NEST SURVIVAL AND RENEST RATE FOR NESTS ON THE BAY SIDE AND OCEAN SIDE WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2003. ....	89
TABLE 20. LINEAR REGRESSION MODEL OF MEAN ANNUAL NEST SURVIVAL OF UNEXCLOSED NESTS VERSUS MEAN MAXIMUM DAILY TEMPERATURE AND TOTAL PRECIPITATION APRIL THROUGH JULY, NESTING PAIR DENSITY, AND NUMBER CATS AND FOXES TRAPPED, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1994-2003. ....	90
TABLE 21. LOGISTIC REGRESSION MODEL OF NEST SURVIVAL OF UNEXCLOSED NESTS VS. NEST FENCED (Y/N), NEST SUBSTRATE TOPOGRAPHY, NEST IN VEGETATION (Y/N), NEST LINING, DISTANCE TO BAY HIGH TIDE LINE, DISTANCE TO NEAREST NEIGHBORING NEST, DISTANCE TO DENSE VEGETATION, DAYS AFTER JANUARY 1ST NEST WAS INITIATED, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1994-2003..	91
TABLE 22. LOGISTIC REGRESSION MODEL OF RENEST RATE VS. NEST LOCATION (OCEAN OR BAY), NEST EXCLOSED (YES OR NO), NEST FENCED (YES OR NO), NEST PREDATED BY MAMMAL (YES OR NO), NEST PREDATED BY BIRD (YES OR	

NO), NEST INITIATION DATE, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1994-2003.....	92
TABLE 23. LOGISTIC REGRESSION MODEL OF RENEST RATE VS NEST INITIATION DATE, A) MEAN NUMBER OF PEDESTRIANS, GULLS, OTHER POTENTIAL DISTURBANCES WITHIN 100 METERS OF NESTS, B) THE PROPORTION OF OBSERVATIONS IN WHICH AT LEAST 1 PEDESTRIAN, GULL OR OTHER POTENTIAL DISTURBANCE WAS PRESENT WITHIN 100 M OF NESTS, WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1997-2000.....	93
TABLE 24. NEST SURVIVAL IN RELATION TO MEAN NUMBER OF POTENTIAL DISTURBANCES WITHIN 100 METERS OF PIPING PLOVER NESTS AND PROPORTION OF OBSERVATIONS IN WHICH AT LEAST 1 POTENTIAL DISTURBANCE WAS PRESENT WITHIN 100 M OF NESTS, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK 1993-2003. ....	94
TABLE 25. RESULTS OF CONTRACTED PREDATOR TRAPPING AT WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1996-2004. ....	95
TABLE 26. REGRESSION RESULTS FOR PREDATION FREQUENCY VS. NESTING PAIR DENSITY, WEST HAMPTON DUNES AND WESTHAMPTON BEACH, WESTHAMPTON ISLAND, LONG ISLAND, NEW YORK, 1994-2003. ....	96
TABLE 27. PERCENT SURVIVAL OF EXCLOSED VS UNEXCLOSED NESTS WEST HAMPTON DUNES AND THE REFERENCE AREA, WESTHAMPTON ISLAND, LONG ISLAND, NEW YORK, 1993 -2004. ....	97
TABLE 28. CAUSES OF LOSS OF NESTS AT WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2003. ....	98
TABLE 29. PIPING PLOVER CHICK FORAGING DISTRIBUTION WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2004.....	100
TABLE 30. MEAN PROPORTION OF TIME OCEAN-SIDE HATCHED BROODS FORAGED ON BAY SIDE AND MEAN PROPORTION OF TIME BAY-HATCHED BROODS FORAGED ON OCEAN SIDE, WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2003.....	101
TABLE 31. AVERAGE DISTANCE (M) BETWEEN NEST AND FORAGING LOCATIONS FOR BROODS THAT HATCHED ON THE OCEAN SIDE VS. BROODS THAT HATCHED ON THE BAY SIDE, WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2003.....	102
TABLE 32. YEARLY CHICK ACTIVITY BUDGETS IN WEST HAMPTON DUNES AND THE REFERENCE AREA 1997-2003.	103
TABLE 33. LEAST-SQUARES (LS) MEAN CHICK FORAGING RATES (PECKS/MIN), CHICKS AGE 3-25 DAYS, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2003. ....	104
TABLE 34. PERCENT USE OF BEACH COVER TYPES BY FORAGING CHICK PLOVERS. USE SURVEYS CONDUCTED WITHIN 3 HOURS OF HIGH AND LOW TIDES. AVAILABILITY DATA IS ADAPTED FROM TRANSECT AND AERIAL PHOTO DATA (SEE METHODS) IN WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, MAY-AUGUST, 1993-2003.....	105
TABLE 35. ANNUAL CHICK AND BROOD SURVIVAL FOR BROODS FORAGING ON THE BAY SIDE, OCEAN SIDE OR BOTH THE OCEAN AND BAY SIDE ( $N$ = NUMBER OF BROODS), WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2004. ....	106
TABLE 36. LINEAR REGRESSION MODEL OF MEAN CHICK SURVIVAL VS. MEAN MAXIMUM DAILY TEMPERATURE AND TOTAL PRECIPITATION MAY THROUGH AUGUST, NESTING PAIR DENSITY, AND NUMBER CATS AND FOXES TRAPPED, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1994-2003. ....	107
TABLE 37. BROOD SURVIVAL IN RELATION TO MEAN NUMBER OF POTENTIAL DISTURBANCES WITHIN 100 METERS OF BROODS AND PROPORTION OF OBSERVATIONS IN WHICH AT LEAST 1 POTENTIAL DISTURBANCE WAS PRESENT WITHIN 100 M OF BROODS, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2003.....	108
TABLE 38. LOGISTIC REGRESSION MODEL OF BROOD SURVIVAL VS. CHICK FORAGING LOCATION, PECK RATE, % TIME RESTING, % TIME DISTURBED, % TIME OTHER BEHAVIORS, DAYS AFTER JANUARY 1ST NEST HATCHED, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1997-2003. ....	109
TABLE 39. MODEL OF BROOD SURVIVAL VS. HATCH DATE, INITIAL BROOD SIZE, A) MEAN NUMBER OF PEDESTRIANS, GULLS, OTHER POTENTIAL DISTURBANCES WITHIN 100 METERS OF NESTS, B) THE PROPORTION OF OBSERVATIONS IN WHICH AT LEAST 1 PEDESTRIAN, GULL OR OTHER POTENTIAL DISTURBANCE WAS PRESENT WITHIN 100 M OF NESTS, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1997-2003. ....	110
TABLE 40. ANNUAL REPRODUCTIVE RATE (CHICKS FLEDGED/PAIR) OF PAIRS THAT NESTED ON THE BAY SIDE OR OCEAN SIDE, WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2004. ....	111
TABLE 41. PEARSON'S CORRELATIONS AMONG REPRODUCTIVE VITAL RATES, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2004.....	112
TABLE 42. REPRODUCTIVE VITAL RATES DATA, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2003.....	113

TABLE 43. INFORMATION-THEORETIC RESULTS FOR THE REGRESSION OF MODELED POPULATION SIZE ON OBSERVED POPULATIONS SIZE, WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2004. ....117

**LIST OF FIGURES:**

FIGURE 1. WEST HAMPTON DUNES AND THE REFERENCE AREA AND VICINITY, LONG ISLAND, NEW YORK (U.S. ARMY CORPS OF ENGINEERS 1980).....	118
FIGURE 2. AERIAL PHOTOGRAPHS DEPICTING CHANGES IN HABITAT WHD AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1941, 1985, AND 1993-2003.....	119
FIGURE 3. CHANGES IN NESTING HABITAT AND UNUSABLE AREA IN A) WEST HAMPTON DUNES AND B) THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1992-2004.....	121
FIGURE 4. HECTARES OF NESTING HABITAT AND NUMBER OF PIPING PLOVER PAIRS ON THE A) OCEAN AND B) BAY SIDE OF WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2004. ....	122
FIGURE 5. AREAS UNUSABLE FOR NESTING PLOVERS IN WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1992-2004. LINES INDICATE HECTARES IN 1993. ....	123
FIGURE 6. AREA OF MOIST SEDIMENT HABITAT (MOSH) AT WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1992-2004. LINE INDICATES HECTARES IN 1993.....	124
FIGURE 7. MONTHLY TREND IN RELATIVE ARTHROPOD CATCH, WEST HAMPTON DUNES AND THE REFERENCE AREA (SITES POOLED), LONG ISLAND, NEW YORK, 1993-2003. . ....	125
FIGURE 8. RELATIVE ARTHROPOD CATCH, BAY AND OCEAN HABITATS BY YEAR, WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2003. ....	126
FIGURE 9. OBSERVED AND EXPECTED PAIRS A) WEST HAMPTON DUNES AND B) THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1992-2004.....	127
FIGURE 10. NESTING PAIR DENSITY WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1992-2004.....	128
FIGURE 11. ESTIMATED EMIGRATION AND IMMIGRATION PLOTTED AGAINST DENSITY IN A) WEST HAMPTON DUNES AND B) THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2003. ....	129
FIGURE 12. INITIATION, HATCH AND FLEDGE DATES FOR PIPING PLOVERS AT WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2003. ....	130
FIGURE 13. BOX PLOT OF FIRST NEST INITIATION DATES WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1995-2003.. ....	131
FIGURE 14. FIRST NEST ATTEMPTS WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2004. ....	132
FIGURE 15. PERCENT OF UNEXCLOSED NESTS LOST TO PREDATORS A) WEST HAMPTON DUNES AND B) THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1994-2003. ....	133
FIGURE 16. FORAGING RATES BAY AND OCEAN SIDE HABITATS WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2003.....	134
FIGURE 17. BROOD HABITAT USE ON THE BAY SIDE, ADULT NESTING USE ON THE BAY SIDE, BROOD USE OF THE BAY INTERTIDAL ZONE (ONLY FOR BROODS THAT WERE FOUND ON THE BAY SIDE), BAY INTERTIDAL ZONE ARTHROPOD CATCH, AND BAY INTERTIDAL ZONE FORAGING RATES COMPARED TO CYCLES OF ARMY CORPS ACTIVITIES, WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2004. ....	135
FIGURE 18. CHICK SURVIVAL VS. TOTAL CATS AND FOXES TRAPPED, WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1993-2003. ....	136
FIGURE 19. CHICK SURVIVAL RATES IN RELATION TO ARMY CORPS ACTIVITIES, A) WEST HAMPTON DUNES, AND B) THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2004. ....	137
FIGURE 20. PROPORTION OF CHICKS DYING BETWEEN THE AGES OF 0-25 DAYS IN WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2003.....	138
FIGURE 21. REPRODUCTIVE OUTPUT (CHICKS FLEDGED/PAIR) WEST HAMPTON DUNES AND THE REFERENCE AREA, LONG ISLAND, NEW YORK, 1993-2004. ....	139
FIGURE 22. OBSERVED AND MODELLED POPULATION CURVES FOR WEST HAMPTON DUNES, NEW YORK, 1992-2004 .....	140

**LIST OF APPENDICES:**

APPENDIX 1. LINEAR REGRESSION MODEL OF A) POPULATION RATE OF CHANGE VERSUS CLUTCH SIZE, EGG HATCHABILITY, EGG SURVIVAL, NEST SURVIVAL, RENEST RATE, CHICK SURVIVAL, AND BROOD SURVIVAL, AND B) POPULATION SIZE AT TIME T+1 VERSUS CLUTCH SIZE, EGG HATCHABILITY, EGG SURVIVAL, NEST SURVIVAL, RENEST RATE, CHICK SURVIVAL, AND BROOD SURVIVAL, WEST HAMPTON DUNES AND WESTHAMPTON BEACH, LONG ISLAND, NEW YORK, 1994-2003..	141
APPENDIX 2. LINEAR REGRESSION MODEL OF MEAN CLUTCH SIZE OF FIRSTS NESTS VERSUS MEAN MAXIMUM DAILY TEMPERATURE AND TOTAL PRECIPITATION APRIL THROUGH MAY, NESTING PAIR DENSITY, AND NUMBER CATS AND FOXES TRAPPED, WEST HAMPTON DUNES AND WESTHAMPTON BEACH, LONG ISLAND, N.Y., 1994-2003.	142
APPENDIX 3. LINEAR REGRESSION MODEL OF EGG HATCHABILITY VS. MEAN MAXIMUM DAILY TEMPERATURE AND TOTAL PRECIPITATION APRIL THROUGH JULY, AND NESTING PAIR DENSITY, WEST HAMPTON DUNES AND WESTHAMPTON BEACH, LONG ISLAND, N.Y., 1994-2003.....	143
APPENDIX 4. LINEAR REGRESSION MODEL OF HATCHABILITY VERSUS NEST FENCED (Y/N), NEST SUBSTRATE TOPOGRAPHY, NEST IN VEGETATION (Y/N), NEST LINING, DISTANCE TO BAY HIGH TIDE LINE, DISTANCE TO NEAREST NEIGHBORING NEST, DISTANCE TO DENSE VEGETATION, DAYS AFTER JANUARY 1ST NEST WAS INITIATED, WEST HAMPTON DUNES, LONG ISLAND, N.Y., 1994-2003. ....	144
APPENDIX 5. LINEAR REGRESSION MODEL OF HATCHABILITY VERSUS MEAN NUMBER OF PEDESTRIANS, GULLS, OTHER POTENTIAL DISTURBANCES WITHIN 100 METERS OF NESTS, WEST HAMPTON DUNES, LONG ISLAND, N.Y., 1997-2000. ....	145
APPENDIX 6. LINEAR REGRESSION MODEL OF HATCHABILITY VERSUS THE PROPORTION OF OBSERVATIONS IN WHICH AT LEAST 1 PEDESTRIAN, GULL OR OTHER POTENTIAL DISTURBANCE WAS PRESENT WITHIN 100 M OF NESTS, WEST HAMPTON DUNES, LONG ISLAND, N.Y., 1997-2000..	146
APPENDIX 7. LINEAR REGRESSION MODEL OF EGG SURVIVAL VERSUS MEAN NUMBER OF PEDESTRIANS, GULLS, OTHER POTENTIAL DISTURBANCES WITHIN 100 METERS OF NESTS, WEST HAMPTON DUNES, LONG ISLAND, N.Y., 1997-2000. ....	147
APPENDIX 8. LINEAR REGRESSION MODEL OF EGG SURVIVAL VERSUS THE PROPORTION OF OBSERVATIONS IN WHICH AT LEAST 1 PEDESTRIAN, GULL OR OTHER POTENTIAL DISTURBANCE WAS PRESENT WITHIN 100 M OF NESTS, WEST HAMPTON DUNES, LONG ISLAND, N.Y., 1997-2000.....	148
APPENDIX 9. LINEAR REGRESSION MODEL OF MEAN ANNUAL RENEST RATE VS. MEAN MAXIMUM DAILY TEMPERATURE AND TOTAL PRECIPITATION APRIL THROUGH JULY, NESTING PAIR DENSITY, AND NUMBER CATS AND FOXES TRAPPED, WEST HAMPTON DUNES AND WESTHAMPTON BEACH, LONG ISLAND, N.Y., 1994-2003.....	149
APPENDIX 10. LINEAR REGRESSION MODEL OF CHICK SURVIVAL VS. HATCH DATE, MEAN NUMBER OF PEDESTRIANS, GULLS, OTHER POTENTIAL DISTURBANCES WITHIN 100 METERS OF NESTS, WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1994-2003. ....	150
APPENDIX 11. LINEAR REGRESSION MODEL OF CHICK SURVIVAL VS. HATCH DATE, THE PROPORTION OF OBSERVATIONS IN WHICH AT LEAST 1 PEDESTRIAN, GULL OR OTHER POTENTIAL DISTURBANCE WAS PRESENT WITHIN 100 M OF NESTS, WEST HAMPTON DUNES, LONG ISLAND, NEW YORK, 1994-2003. ....	151
APPENDIX 12. LINEAR REGRESSION MODEL OF MEAN BROOD SURVIVAL VS. MEAN MAXIMUM DAILY TEMPERATURE AND TOTAL PRECIPITATION MAY THROUGH AUGUST, NESTING PAIR DENSITY, AND NUMBER CATS AND FOXES TRAPPED, WEST HAMPTON DUNES AND WESTHAMPTON BEACH, LONG ISLAND, N.Y., 1994-2003.....	152

## INTRODUCTION

Understanding factors that regulate populations and influence their densities is fundamental to effective management related to conservation of birds (Newton 1994). Krebs (1994) defines a population as a group of randomly interbreeding individuals of the same species occupying a particular space at a particular time. The boundaries of a population are vague in both space and time, and in practice are typically fixed arbitrarily by the investigator. A population has group characteristics which are statistical measures that can not be applied to individuals (Krebs 1994). It can increase through birth (natality) and immigration, or decrease due to death (mortality) and emigration. It will remain stationary if these factors are in balance (Krebs 1994). Because a population typically occupies a limited suitable area, its size normally increases, decreases, or remains the same along with its density (the number of individuals per unit suitable area, Ricklefs 1990). Immigration or lack thereof from a wider region may mask or inflate local variations in the population size (DeSante 1990, George et al. 1992). Therefore, a population's density may not accurately reflect population viability due to source-sink dynamics (Van Horne 1983, Pulliam 1988).

Populations may fluctuate due to density-independent factors such as climate, or natural catastrophes. These fluctuations are essentially random where mortality or natality rates are unaffected by population density (Krebs 1994, Lack 1954). A population is limited by environmental factors such as food, water, shelter and space. Population regulation is the process that keeps the population at or close to that limit. It is said to be regulated when it tends to return to a particular density (the equilibrium density) which is determined by environmental conditions such as competition, predation, and/or resource limitations (Rodenhouse et al. 1997).

Population regulation requires that some or all vital rates (natality, mortality, immigration and emigration rates) are density-dependent. That is, the rates change depending upon population density (Lack 1954, Krebs 1994, Ricklefs 1990), and they change in a direction that tends to make the population increase if it is below equilibrium density, and decrease if it is above equilibrium density. The net effect of these rates determines the rate of a population's growth or decline (Lack 1954, Krebs 1994).

Vital rate estimates are a particularly important component of bird population monitoring and research (Baillie 1990). Any environmental pressures and/or management actions will affect vital rates directly (Temple and Wiens 1989). Vital rates provide decisive information about the viability of the population being monitored, and about the quality of the area where it occurs. Estimating vital rates is essential to understanding the population ecology of any species.

Piping plovers (*Charadrius melodus*) were first listed as threatened under the endangered species act in 1986 (*Federal Register* 1985). Since then research efforts have focused on understanding their demographic parameters and general ecology in an attempt to establish management goals and procedures to guide piping plover conservation (Haig and Oring 1988, Johnson and Baldassarre 1988, Nicholls and Baldassarre 1990a, MacIvor et al. 1990, Nordstrom 1990, Patterson et al. 1991, Powell and Cuthbert 1992, Melvin et al. 1991, Melvin et al. 1992, Flemming et al. 1992, Loegering and Fraser 1995, USFWS 1996). Despite these efforts, factors that determine the range-wide distribution and abundance of this species are poorly understood. This gap in understanding inhibits recovery efforts because plover conservation involves manipulating distribution and abundance. It is thought that habitat

loss from development and other human disturbance currently drives the distribution of piping plovers (Haig 1992). Many coastal beaches traditionally used by piping plovers for breeding, and wintering have been lost to commercial, residential, and recreational developments.

Comprehending population dynamics is fundamental to elucidating species abundance, evaluating success of biological controls, and designing and implementing management plans for species conservation (Rodenhouse et al. 1997).

Atlantic Coast piping plovers are known to breed on coastal beaches and barrier islands from Newfoundland to North Carolina, specifically at the ends of sand spits, gently sloped foredunes, sparsely vegetated dunes, and washover areas (Flemming et al. 1992, Elias-Gerken 1994, Goldin 1998). They winter primarily along Atlantic and Gulf Coast barrier islands from North Carolina to Florida, though some over winter in the Bahamas and West Indies (Haig and Plissner 1993, USFWS 1996).

Piping plovers arrive on the breeding grounds between early March and mid-May (USFWS 1996). They lay 3 to 4 eggs in shallow scraped depressions that are often lined with pebbles and/or shell fragments (Cairns 1982). Both sexes incubate the eggs which hatch within 30 days, and usually both sexes forage with the young until they fledge approximately 25 days after hatching (Cairns 1982). Plovers depart for the wintering grounds from mid-July through late October (USFWS 1996).

Plovers feed in intertidal areas, wrack lines, washover passes, mud and sand flats, ephemeral ponds (moist sediment habitats, MOSH), and salt marshes, and use the ocean backshore adjacent to foraging areas for roosting and preening (USFWS 1996, Elias et al. 2000). Over the past 50-75 years there has been a sharp increase in

human recreation and development in potential plover foraging and nesting habitat. During this time, beach management practices for increased recreational opportunities and protection of human structures from storm and wave action have negatively impacted plover breeding and wintering habitat (Elias-Gerken 1994). For example, on Long Island, New York, major storms since 1938 have been followed by efforts to stabilize the shoreline (Leatherman and Allen 1985). The United States Army Corps of Engineering (The Corps, USACE) has used a variety of techniques to accomplish this, including beach nourishment, and the construction of dunes, seawalls and groinfields (a series of jetties or groins).

These activities have decreased the impacts of storms on shorelines and facilitated commercial and residential shoreline development (Leatherman and Allen 1985, Schubel et al. 1991). This, in turn, has reduced the availability and accessibility of early successional stage, storm-maintained habitats such as overwash, sand spits, ephemeral pools, tidal flats, and open vegetation (Elias-Gerken 1994) which are key nesting and foraging areas for the piping plover (Elias-Gerken 2000).

In the early 1990's, a series of habitat changes caused by storms and subsequent beach management by The Corps provided a unique opportunity to study piping plover population dynamics in a changing environment. These events allowed us to observe the establishment, growth and regulation of a plover population, and to describe the effects of the USACE Westhampton Interim Storm Damage Protection Project on piping plover ecology at WHD and Westhampton Beach in 1993-2004.

In this study we attempted to determine the factors that limit or influence the abundance and distribution of piping plovers in West Hampton Dunes, Long Island, NY,

a renourished, highly developed, and high human disturbance area. We hypothesize that on Westhampton Island, NY, the availability of nesting and/or foraging habitat limits nesting pair density of the piping plover. We also looked at the consequences of The Corps' activities on the vital rates, population regulation, habitat and food availability of the piping plover, and provide management recommendations that stem from analyses of the results from this project and from the relevant scientific and management literature.

**OBJECTIVES****Population Regulation**

- 1) Estimate piping plover population parameters including natality rate, mortality rate, and immigration and emigration rates in WHD and The Reference Area
- 2) Determine trends in vital rates over time in WHD and The Reference Area
- 3) Examine the ecological factors and management activities that may have affected vital rates over years
- 4) Assess density dependent effects on vital rates, behavior, and predation in WHD and The Reference Area
- 5) Describe and explain trends in plover density over time within and between WHD and The Reference Area
- 6) Examine the value of moist sediment habitats in attracting adult plovers in the pre-breeding season
- 7) Determine factors affecting the distribution of nests, chicks and broods in space and time within WHD and The Reference Area in terms of habitat use and availability, brood movements, arthropod catch among habitats, and foraging rates within habitats.

**U.S. Army Corp of Engineers Beach Management Activities**

- 1) Examine direct impacts of large-scale changes in the quality (arthropod numbers, foraging rates) and quantity of nesting and foraging habitat areas that resulted from the severe storm in December of 1992, following storms in the spring of 1993, USACE activities, erosion, development, and growth of dense vegetation

- 2) Describe the impacts of the USACE project on any changes in the number of pairs, plover density, and chick survival
- 3) Examine indirect impacts of renourishment and beach repair in terms of changes in the number of predators and predation rates, disturbance, and road mortality.
- 4) Provide management recommendations based on findings

## STUDY AREA

The study was conducted on Westhampton Island, a barrier island on the South Shore of Long Island, New York (Fig. 1). The island is 24.8 km long and is bounded on the south by the Atlantic Ocean and on the north by Moriches Bay and Shinnecock Bay. The western end of the island is at Moriches Inlet and the eastern end is at Shinnecock Inlet. Our study area is divided into WHD (latitude 40.79° N, longitude 72.62° W), which is 2.2-5.1-km east of Moriches Inlet, and an adjacent Reference Area, which is 5.1-8.4 km east of Moriches Inlet in the town of Westhampton Beach (Fig. 1).

Historical records of breeding piping plovers on Westhampton Island date back to 1929. At this time only 3-4 plover pairs nested on the Island, but the number of pairs increased to 20 within a 3.5-km stretch of beach after a 1931 storm and subsequent storms formed Moriches Inlet and nearby overwash areas (Wilcox 1959). On 21 September, 1938 the center of the great hurricane of 1938 passed over Westhampton Island. It produced more than 6 km of continuous nesting area. Plovers nesting in this area (Moriches inlet to Shinnecock Inlet) reached a peak of 64 nesting pairs in 1940-1942. The population gradually declined thereafter, concurrent with beach stabilization, deposition of dredged materials on the backshore, and beach grass planting (Wilcox 1959).

In the 1950's, a surge of beach-front real estate development resulted in a high density of houses on Westhampton Island. In 1965-1970 a groinfield was established in the center of Westhampton Island (Schubel et al. 1991, Fig. 2). After installation, areas to the west of the groinfield, in what is now WHD, began to erode. Overwashes were frequent and inlets formed and filled periodically (Tanski 1988).

During the 1980's, erosion lowered and narrowed much of the beach west of the groinfield and many dwellings were damaged by water (Fig. 2). There were no known plover breeding activities in this area from 1986 to 1990 (Downer and Leibelt 1990). In December 1992, a severe storm caused the ocean to overwash the area several times and 2 inlets formed (Fig. 2). The Corps' closed the smaller, westernmost inlet in January 1993 (USACE 1994, Fig. 2). The easternmost inlet expanded to more than 900-m wide and more than 3.6-m deep by the spring of 1993 (USACE 1994, Fig. 2). A sand spit grew on the western side of the inlet and extended into Moriches Bay, and unvegetated intertidal flats developed nearby. Many houses were ruined and most island interior vegetation was scoured away. The western-most portions of the developed area remained populated with houses and/or dense vegetation (*Phragmites* sp., *Ammophila* sp., and *Spartina* sp., Fig. 2). The USACE closed the easternmost inlet in the fall of 1993 (Fig. 2). The Reference Area was not overwashed, but the storms of 1992 and 1993 eroded the ocean backshore.

The area west of the groinfield and east of Cupsogue County Park was incorporated as the Village of West Hampton Dunes (WHD) in 1993. From 1993-1996, beach zones and development in the easternmost half of WHD (~ 1600 m), from the ocean side to the bay side, were approximately parallel with the ocean shoreline and included the ocean intertidal zone, fresh wrack, old wrack, ocean backshore, ocean sparse vegetation, dune sparse vegetation, a line of houses, a dirt road, bay backshore, bay sparse vegetation, old wrack, fresh wrack, and bay intertidal zones (for descriptions of beach zones, see table 1). The westernmost half of WHD differed from the easternmost half only in that there were a considerable number of houses on the

bayside of the road. These houses were interspersed with sparse and dense vegetation (Fig. 2).

In 1996, the Village began redevelopment of residences and Dune Road, the main street of WHD. The USACE expanded the ocean side backshore and constructed an artificial dune along the entire length of WHD to prevent future property damage (Fig. 2). They also lowered the seaward ends of the westernmost 2 groins in The Reference Area and added a third shorter groin to increase sand flow into WHD (Fig. 2). In winter of 1997, the USACE renourished all groinfield compartments in The Reference Area (Fig. 2). In 2000-2001, they renourished the ocean backshore in WHD and areas between groins 13-15 and 8-10.

By 2004, the Village of West Hampton Dunes was largely rebuilt (Fig. 2). All ocean side residences in WHD were set back from the backshore 20–30 m and were separated from the beach by a human-constructed dune. The foredune, dune, and back dune areas were initially sparsely vegetated and provided nesting habitat for piping plovers.

Throughout the study, The Reference Area remained highly developed and densely populated with beach homes, beach clubs, and paved roads (Fig. 2). All ocean side residences and clubs in The Reference Area were set back from the backshore 17–114 m and were separated from the beach by a dune. The dune and back dune areas were densely vegetated. The foredune was sparsely vegetated and provided nesting habitat for piping plovers. There were scattered sandflats of < 2 ha total on the bay side.

## **METHODS**

### **Field Methods**

*Demographics, Vital Rates, and Nest Density and Distribution.*— We searched WHD and The Reference Area daily for adult plovers in all potential piping plover habitats (beach zones, Table 1) from mid-March through the end of July 1993-2004. When we found an adult, we recorded its location, habitat type and behavior on a photocopy of aerial photographs of WHD and The Reference Area. We observed adult plovers daily to locate breeding areas and to observe breeding behavior. In 1996-2000, we noted specific band, bill, and leg characteristics on data sheets made from photos of plovers where bands, bill and leg colors were omitted. Each data sheet contained two plover photos. We identified pairs of plovers based on their location and specific plumage, bill and leg characteristics. We used this information to identify piping plover pairs. From 2001-2003 approximately 2% of adult plovers at WHD and The Reference Area were captured prior to nesting using noose carpets and walk-in traps. During incubation, approximately 30-35% of adult plovers were captured on their nest with box-shaped drop traps at WHD and The Reference Area. A single plastic numbered color-band was applied to each tibiotarsus to identify individuals.

When we determined the breeding location of a pair, we searched the area for a nest. When we found a nest, we recorded the date, time, and surrounding habitat characteristics (nest lining, substrate, and topography). We also recorded the nest location on a map made from aerial photographs. At the end of the field season we used a GPS to mark nest locations.

We informed WHD and U.S. Fish and Wildlife Service personnel of all known breeding and nest locations in WHD, and we informed The Nature Conservancy (TNC)

personnel when a nest was found in The Reference Area. In WHD, FWS, New York State Department of Environmental Conservation (DEC), and WHD personnel used symbolic (string) fencing to exclude people from some breeding sites. In The Reference Area, TNC personnel erected symbolic fencing around nests on public and private property when they were able to obtain permission from land managers or landowners. Buffer zones were set by the responsible authority at 20-50-m wide depending on the breeding location or nest site. Buffers were smaller in areas on private lands when managers or landowners requested smaller boundaries. Predator exclosures were used in WHD in 1993-96. There also was limited use of exclosures in 1997 and 2004 in WHD. TNC personnel erected predator exclosures around specific nests (when permission was granted from private land owners) located in The Reference Area 1993-2004. The Village of West Hampton Dunes contracted a trapper to remove predators (feral cats, foxes, opossum, raccoons, etc.) in WHD 1996-2002. Village personnel provided the number of animals of each species captured. Feral cats were trapped in The Reference Area in 2002 and 2004. Trapping duration and intensity varied among years.

We observed plover nests daily from a distance of 20-200 m. If we thought a nest had been predated, abandoned or that eggs had hatched, we approached the nest to determine hatch dates and cause of nest or egg loss. During each visit, we also recorded potential disturbances or predators within 100 m of nests. If a nest was lost or abandoned, we recorded the date and cause of loss which we determined by predator/pedestrian tracks or flood marks at the nest. If eggs hatched, we recorded the hatch date and the number of chicks hatched.

We attempted to observe each brood daily for a period of  $\geq 25$  days. We determined daily survival, rates of survival to fledging, habitat use, and foraging behaviors. When possible, we observed broods from distant (30-200 m) or concealed locations so that brood movements were unaffected. We observed broods through 25 days of age or until we observed chicks in flights of at least 15 m. If chicks were missing from a brood, we searched the immediate area for at least 0.5 h. If the chicks failed to reappear over the course of the pre-fledging period, we assumed they died 0.4 of the way between the last time they were observed and the first time we failed to find them (Flint et al. 1995).

*Brood Density and Distribution.*— After chicks hatched, we searched for them daily in all potential brood-rearing habitats except during heavy rain. We did not attempt to locate chicks during severe rain to avoid moving them from cover and creating thermal stress.

When we located a brood, we observed the behavior of a focal chick for 5 min. We stayed as far away as possible, usually 50-200m, to avoid disturbance. Birds that were disturbed by our presence were not included in the sample. We recognized 4 general categories of behavior (Table 2).

We used an instantaneous sampling method to estimate the time broods spent in habitats and behaviors (Altmann 1974, Lehner 1979, Tyler 1979). We recorded foraging habitat, behavior, and source of disturbance (if any) for the focal bird once every 10 sec (10-sec observations) for a 5-min period. The observer recited the information to a human recorder in the field, or we recorded the observations on a tape recorder and transcribed the data to data sheets later in the day.

We used continuous sampling to estimate foraging rates for chicks (Tyler 1979, Tacha et al. 1985). During the same 5-min observation in which instantaneous observations were made, we noted each foraging attempt (Table 2). During the course of other activities, we recorded opportunistic observations of piping plovers walking and flying below 2.5 m across Dune Road in WHD 1999-2003.

In 1999 and 2000, once per day, at random times between 0500 and 1800 h, March through August, we walked Dune Road from the easternmost end of WHD to the western most point where plovers were rarely observed crossing the road. We recorded the number of piping plovers that walked or flew across this 1250 m section of Dune Road.

*Transects.*— We randomly selected the location of our first transect in WHD. It was located near the western end of WHD. The remaining transects were located to the east at approximately 420 m intervals and continued to the eastern boundary of The Reference Area. There were 14 transects, 6 in WHD and 8 in The Reference Area. Each transect ran perpendicular to the shoreline. We used the transects for collecting cover type, trail index, and arthropod data.

*Nesting and Foraging Cover Types.*— Weekly, from the last week of March through the end of July, we measured the width of each habitat (Table 1) by pacing along transects from the waters' edge on the ocean side to the dense vegetation or the bay-side waters' edge. Each observer calculated the length of his/her own pace by counting the number of paces in known distances in beach habitats. In WHD, we considered the artificial dune to be the boundary between the ocean and bay backshores. In The Reference Area, there only were ocean-side transects which ended

at the seaward edge of the dense vegetation because the rest of the island was almost entirely covered with buildings, roads, driveways, lawns and other vegetation. We recorded the number of paces along each transect for each habitat. We used a 5-m measuring tape to measure fresh wrack (Table 1) and old wrack to the nearest decimeter.

We plotted nest locations on digitized true color or black and white Kodak professional aerial (spring) photos 1992-2004, scale 1:800 in ArcView (ESRI, Redlands, CA, 2001). We measured area ( $m^2$ ) of potential nesting habitats as backshore and sparse vegetation  $> 2$  m from development (the closest distance a piping plover nested to human development). We also measured the area of low-wave energy moist sediment habitats (MOSH, bay intertidal zone and ephemeral pools), distances (m) from each nest to the nearest nest, to the ocean and bay intertidal areas, and to dense vegetation.

*Trail Indices.*— We used a "point intercept-step" technique to estimate the percent of substrate covered by potential predator trails within each habitat. We adapted this technique from Hays et al. (1981). We made weekly measurements between March and August. Once per week, we paced along each transect and recorded predator trail abundance at the same time that we collected habitat availability data. We recorded 1 "hit" and the species that made the trail each time the toe of our shoe intersected the trail of a potential predator.

*Changes in Arthropod Abundance.*— We collected arthropod samples along the transects weekly in 1993-2000 and monthly in 2001-2003 from the last week in March through the first week in August. Arthropods were not sampled in 2004 because

funding was not provided for this activity. We attempted to sample all transects on the same day each week to reduce temporal variability. We used a 3-h sampling period that always began between 0700-1000. The 3-h sampling period was based on Elias-Gerken et al. (2000) and was long enough to allow us to capture a sufficient number of arthropods for analysis, even in zones with few arthropods.

We coated paint stirrers, except for the handles, with Tanglefoot Insect Trap Coating (The Tanglefoot Company, Grand Rapids, MI) on each transect. We placed one pair of paint stirrers in the middle of each cover type, except in the intertidal zones, where we placed them 1-2 m from the backshore to avoid splashing and submergence. We placed one stirrer vertically in the sand with the uncoated handle buried and the flat surface facing the water's edge. The other stirrer was horizontal on the ground 10 cm south of the vertical stick, with its long axis parallel to the water's edge. The area exposed was  $64.5 \text{ cm}^2$  (21.5 cm x 3 cm) for the horizontal stick (coated on the upper side) and  $129 \text{ cm}^2$  for the vertical stick (coated on both sides, cf. Loegering et al. 1995).

## **DATA ANALYSES**

Statistical procedures were done using SAS Version 8.02 (SAS Institute, Cary, NC) except where otherwise stated. We examined data sets for suitability of use of normal statistics, and when assumptions of such tests were not met we used non parametric statistics. We used the following non parametric tests when the normality assumption was violated. We used Wilcoxon rank sum test to test the null hypothesis that the distribution functions were the same between two levels of a single factor, vs. the alternative hypothesis that one of the levels tended to yield different values than the other level. If the factor of interest had more than two levels, we used a one-way ANOVA on ranks (ANOVA<sub>r</sub>, Conover and Iman 1981) to test the null hypothesis that all distribution functions were equal. When simultaneously comparing the effects of two factors with at least two levels each, we used a 2 way ANOVA on ranks (Hora and Conover 1984, Akritas 1990, Akritas et al. 1997). If the global model for the ANOVA was significant we used the Conover-Iman test (i.e., Fishers LSD on the rank transformed data) to detect pairwise differences (Conover and Iman 1981).

### **Plover population size, growth and demographics**

*Population Trends.*— To better understand the role of immigration and emigration in population dynamics at WHD and The Reference Area, we estimated immigration/emigration rate indirectly and modelled hypothetical growth curves (A banding program that would have permitted measurement of immigration and emigration was not feasible during most of our study (1993-2000), due to regulatory constraints).

To estimate the immigration/emigration rate, we calculated an expected number of pairs for each year based on adult survival estimated by banding/resighting in the

study area in 2000-2003. We estimated annual adult survival at 0.74, using the Cormack-Jolly-Seber model in program MARK (White and Burnham 1999). We used the value 0.48 for juvenile survival rates as estimated by USFWS 1996. We used these values in concert with the previous summer's age-specific (adult/juvenile) population size. We assumed that 50% of one-year-old plovers breed (USFWS 1996), 100% of plovers > 1 year old breed (USFWS 1996). We further assumed 100% site fidelity of both age classes. We calculated expected pairs as:

$$N_{t+1} = N_t S_{as} P_{as} + 0.5 N_t R_t S_s P_s + 0.5 N_{t-1} R_{t-1} S_s S_{as} P_s P_{as}, \text{ where}$$

$N_t$  = Number of pairs in year t

$N_{t-1}$  = Number of pairs in year t-1

$P_s$  = Proportion of second year birds breeding = 0.5

$P_{as}$  = Proportion of after second year birds breeding = 1.0

$S_{as}$  = Survival Rate after second year = 0.74

$S_s$  = Survival Rate second year = 0.48

$R_t$  = Reproductive Success (Chicks Fledged / Pair) in year t

$R_{t-1}$  = Reproductive Success (Chicks Fledged / Pair) in year t-1.

We estimated immigration/emigration rate ( $M_t$ ) each year as:

$$M_t = (N_{t(\text{observed})} - N_{t(\text{expected})}) / N_{t(\text{expected})}$$

We later included  $M_t$  in several regression models of population growth rate.

For WHD, we further examined the influence of immigration/emigration on population dynamics by comparing several models of population growth to the observed pattern (Table 3). Models were discrete deterministic models based either on density-dependent logistic growth (Logistic) or density-independent exponential growth

(Exponential). For all models, hypothetical life tables (Table 4) were used to calculate  $r$ , the intrinsic rate of increase. We used values of 0.74 for annual adult survival, 0.48 for annual survival of fledglings, and assumed that 100% of surviving adults (> 1 year old) and 50% of surviving second year birds returned to the site to breed each year (U.S. Fish and Wildlife Service 1996). For Logistic models, carrying capacity ( $K$ ) was estimated yearly as one pair per hectare of available nesting habitat (backshore plus sparse vegetation > 2 m from development), as measured on annual aerial photographs. This estimate for  $K$  was based on the average annual nesting pair density attained after the site apparently reached carrying capacity in 2000 ( $0.96 \pm 0.05$  pairs/ha), but before it declined in 2004. Fecundity was entered into the life tables as the 12-year average productivity for WHD, which was 1.31 chicks fledged per pair per year, or 0.66 females fledged/female/year (0.33 for second year breeders). Immigration was considered to be either zero (0 Imm), density independent (DI Imm), or density dependent (DD Imm). We assumed that immigrants entered the population after the return of surviving territory holders and their offspring.

For density independent immigration models, we added a constant number of immigrants per year regardless of carrying capacity. We determined this constant through trial and error, changing the number up or down until the model trajectory was as close as possible to the observed trajectory. We added more immigrants (5 immigrants) in the first year (1994) than in subsequent years (3 immigrants, in the logistic model, and 2 immigrants in the exponential model) to adjust for the large population increase immediately after colonization.

For models incorporating density dependent immigration, we fit a line to the relationship between  $N_{\text{observed}} - N_{\text{estimated before immigration}}$  (the estimated number of immigrants each year) and  $K - N_{\text{estimated before immigration}}$  (the estimated “space” left after return of surviving breeders and recruits). For both Logistic and Exponential growth models, this relationship was fairly strong, and significant (Logistic Model,  $R^2 = 0.70$ ,  $P = 0.001$ ; Exponential Model,  $R^2 = 0.78$ ,  $P < 0.001$ ). We used the fitted lines to add immigrants each year based on the  $K$  for that year and the estimated population size before immigration. We fit model-predicted  $N_t$  to observed  $N_t$  with simple linear regression and used information-theoretic criteria to choose the model or models that best fit the observed population trend.

*Demographics.*— To determine if any vital rates showed trends over time or between WHD and The Reference Area, we tested the effects of year and site (WHD and The Reference Area) on clutch size, egg survival, chick survival, egg fertility (hatch) rate, eggs and nests hatched per pair, broods fledged per pair, and reproductive output (chicks fledged per pair) using ANOVA<sub>r</sub>. We used Chi-square tests on binomially-distributed vital rates (nest success, renesting, and brood success) vs. year and site.

Annual nest survival was the % of nests that hatched  $\geq 1$  egg. We also calculated Mayfield (1975) nest success following Heisey and Fuller (1985). We used Pearson’s correlation to examine the relationship between observed and Mayfield (1975) nest survival, where each sample was the nest survival for a year.

Egg survival was the % of eggs that hatched per nest. Chick survival was the % of chicks that fledged per brood. Chick survival was determined using (Flint et al. 1995) which accounts for days of observation (like Mayfield) and inflates the variance to

account for non independence within broods. We used Pearson's correlation to test the relationship of observed and Flint et al. (1995) chick survival, where each sample was the average for a year.

Because we censused the entire population daily, and our chance of detecting a nest on its initiation date, or brood on its hatch date, or being able to estimate its initiation and hatch date was high, and because Mayfield/Flint and observed rates were highly correlated  $r = 0.88$ ,  $P < 0.001$  for nest, and  $r = 0.91$ ,  $P < 0.001$  for chick survival, we based analyses on observed nest and chick survival rates.

Brood survival was the % of broods that fledged  $\geq 1$  chick. Egg hatchability rate was the % of eggs in non-abandoned nests to survive the full laying/incubation period (until 34 days from the laying of the first egg, or until some eggs in the clutch hatched) that hatched. Renest rate was the % of adults that lost a nest before 15 July that renested.

We used linear regression to determine the relationship between vital rates (we do not include adult and juvenile survival) and population growth. We regressed the population rate of change,  $(N_{t+1} - N_t)/N_t$ , on average vital rates in year  $t$  at WHD and The Reference Area. We tested for correlations among the vital rates.

*Factors Affecting Vital Rates.*— We used an incomplete block-design ANOVA to determine whether chick foraging rates differed among cover types, where each brood was a block, and pairwise least-squares means comparisons to compare foraging rates between specific cover types.

We performed an exploratory analysis to determine which ecological factors were most important in explaining variations in vital rates (clutch size, egg hatchability,

egg survival, nest survival, re-nest rate, chick survival, and brood survival). We had three separate, but overlapping data sets.

The first data set consisted of average annual vital rates and ecological factors (monthly temperature and precipitation, number of predators removed by trapping, and population density) that were measured for the entire population each year, rather than for individual pairs or nests. We modeled these relationships with linear regression and used information theoretic criteria to identify important variables.

The second data set consisted of data for individual pairs or nests and ecological factors measured for each pair. These data were collected from 1993-2004. We modeled vital rates of individual unexclosed nests as a function of nest characteristics (ocean side vs. bay side (0,1) nest lining (0,1), slope ( $<7.5\%$  = 0,  $\geq 7.5\%$  = 1), substrate (sand = 1, or cobble = 1), vegetation (0,1), symbolic fencing (0,1), distance from the nest to the ocean high tide line, the bay high tide line, dense vegetation line, to its nearest neighbor (m), and nest initiation date. We modeled vital rates of individual broods as a function of foraging location (ocean vs. bay side), mean brood foraging rate (attempts/min), mean % time the brood spent foraging, resting, disturbed, or in other activities, and hatch date. We structured models of continuous vital rates as linear regressions, and models of binomial vital rates as logistic regressions.

The third data set also consisted of data for individual pairs or nests and ecological factors measured for each pair. However, these data were collected from 1997-2004. We modeled vital rates of individual nests or broods as a function of the mean number of potential disturbances (pedestrians, gulls, and least terns) observed

within 100 m of the nest or brood during daily surveys, and in separate models the percent of surveys in which at least one potential disturbance was seen within 100 m of the nest or brood.

Prior to evaluating the data sets, we computed Pearson's product-moment correlation coefficients for all pairs of continuous variables and censored one member of any pair having a correlation  $> 0.6$ . We tested for multicollinearity using variance inflation factors (VIF).

We fit models and evaluated and ranked candidate models for each vital rate using information-theoretic model selection techniques (Burnham and Anderson 2002). This approach to model selection favors models having greater explanatory power and penalizes models based on complexity, helping to identify the most parsimonious model that adequately fits the data. Models within each set were evaluated using Akaike's Information Criterion adjusted for sample size ( $AIC_c$ ),  $AIC_c$  differences ( $\Delta_i$ ),  $R^2_{adj}$  (linear models), discordance and concordance (logistic models) and Akaike weights ( $\omega_i$ , Burnham and Anderson 2002). Akaike weight estimates the likelihood that a particular model is the best model in the candidate set. We included a null model (i.e. intercept only) in each set of candidate models to examine the explanatory power of our models. Reductions in  $AIC_c > 2$  from the null model indicated the candidate model fit better than the null model (Burnham and Anderson 2002). For simplicity we report only the null model plus the "best" models for each model set (Burnham and Anderson 2002). We defined subsets of "best" candidate models as all those models having  $AIC_c$  differences ( $\Delta_i$ )  $\leq 2$  from the model with the lowest  $AIC_c$  value.

For each model set we assessed the fit of the global model (model containing all explanatory variables) through the inspection of residual plots and residual analysis (linear models) and/or a goodness of fit test (linear and logistic models, Hosmer and Lemeshow 2000).

*Density Dependent Effects.*— We examined the relationship between annual nesting pair density (pairs/ha of potential nesting cover type) at each site and annual mean vital rates using Spearman's rank correlation.

We used linear regression to analyze the relationship between the % time a plover chick spent disturbed by other plovers and nesting pair density. We used linear regression to examine the effect of nesting pair density on chick foraging rates and % time chicks spent foraging. We used linear regression of percent of nests lost to specific predators or all predators pooled on nesting pair density to determine if predation was density dependent.

### **Nesting Pair Density and Distribution**

*Nest Density.*— We calculated nesting density as nesting pairs/ha of potential nesting habitat.

*Moist Sediment Habitats and Pre-breeding Season Use.*— We used a confidence interval method (Neu et al 1974, Marcum and Loftsgaarden 1980) to determine if adults used the bay intertidal zone more than expected based on availability. A cover type was considered to be “used more than expected” if the lower 95% confidence bound on mean % use was > the upper 95% confidence bound on % availability, and “used less than expected” if the upper 95% confidence bound on % use was < the lower confidence bound on % availability. Percent use was determined

separately for high and low tide +/- 3h, as the percent of adults found foraging or resting in different cover types on daily surveys from 1997-2003.

We used Pearson's correlation for ha of cover type (as measured on aerial photos) and average cover type widths (m) determined by transects to determine if transects accurately represented total cover type area. We modified our transect-based approach at WHD. We calculated the area of a rectangle representing the non-MOSH cover types by multiplying the average total transect width in a particular month (excluding the portion of the transect in MOSH) times the length of the site. We added the area of this rectangle to the area of MOSH as measured on aerial photos, and calculated % availability of MOSH. We then calculated the mean % availability of each non-MOSH cover type as the mean % width of that cover type on the transects times the percent of the total habitat made up by the rectangle. Since our photos were taken at low tide, we had to modify this approach still further to calculate % availability for measurements taken within 3 hours of high tide. Using the MOSH transects collected at different tidal stages, we found that within 3 hours of high tide, an average of 70% of the MOSH area was still exposed. Thus, for high tide data, we adjusted the area of MOSH downward by 30%, and recalculated availability of all cover types. Finally, we estimated the area of ocean intertidal zone at each site by creating a rectangle based on the average transect width in that zone, for high and low tide separately.

*Cover Type Assessment.*—To determine if there was a relationship between brood foraging rates and arthropod catch in different cover types, we used linear regression of the foraging rates of individual broods in cover types on the mean arthropod catch from May-August in those cover types, calculated by year and site. To

insure that our sampling units were individual broods and not brood-cover type combinations, i.e., to avoid pseudoreplication, we determined if the relationship between foraging rate and arthropod catch was significant by performing a one-sample t-test on the regression coefficients for each brood to determine if they were  $< \text{zero}$  (Olsson et al. 2002).

### **Impacts of Storm Damage Protection Measures**

*Indirect Impacts.*— We used Spearman rank correlation to analyze the relationship between percent time broods were disturbed and hectares of human land use and dense vegetation. We performed a similar correlation analysis on the mean number of potential disturbances within 100 m of broods, and the percent of brood observations in which at least one potential disturbance was recorded within 100 m. We tallied road mortality and calculated an index of frequency of piping plovers crossings by dividing the observed number of piping plover crossings by the total time (hours) spent on the transect. We examined changes related to the timing of various beach management practices.

*Direct Impacts.*— To look for direct impacts of The Corps' activities (breach repair, beach nourishment, and beach renourishment) on plover habitat and demographics, we examined changes in nesting habitat, foraging habitat, survival, foraging rates, and arthropod abundance in relation to the timing of various beach management practices.

## RESULTS

### Changes in Habitat

*Potential Nesting Habitat.*— In WHD, potential piping plover nesting habitat increased after the storms in December 1992 and early spring 1993 from 22.4 ha in 1992 to 31.6 ha in 1993 (Fig. 3a). Most of the increase in potential nesting habitat between 1992 and 1993 occurred on the bay side (Fig. 4b). After breach repair in 1993, potential nesting habitat had increased from 31.6 ha to 51.8 ha in 1994. Most of this increase occurred on the ocean side of WHD (Fig. 4a). After initial beach nourishment at WHD, which occurred prior to the 1997 piping plover breeding season, potential nesting habitat increased to a high of 55.2 ha in 1997, then declined to 31.1 ha by 2004 (Fig. 3a). Following initial beach nourishment, potential nesting habitat increased on the ocean side to a high of 28.0 ha in 2001, then declined to 25.4 ha by 2003 (Fig. 4a). On the bay side, potential nesting habitat decreased from 35.2 ha in 1997 (the breeding season following nourishment) to 4.5 ha in 2004 (Fig. 4b).

In The Reference Area, potential piping plover nesting habitat was lowest in 1992 (16.4 ha) and 1996 (17.8 ha), but varied little among the other years (22.7 – 33.2 ha), including years when beach renourishment occurred (Fig. 3b). Nesting habitat was low in 1996 because there was no nesting habitat between groins 13 through 15 due to heavy Corps construction. Nesting habitat increased from 1996 to 1997 in The Reference Area because the area between groins 13 and 15 became available for nesting in 1997.

*Unusable Areas.*— In WHD, areas unusable for piping plovers as potential nesting habitat (dense vegetation, human land use areas, other unusable areas) changed throughout the study (Figs. 3a and 5). Initially, dense vegetation decreased

from 33.0 ha, prior to the storms of 1992 and 1993, to 21.2 ha in the 1993 piping plover breeding season. Thereafter, dense vegetation increased to 40.1 ha in 2004 (Fig. 5). In The Reference Area, dense vegetation also varied among years (Fig. 3b). In WHD, human land use (areas unusable for piping plovers for nesting, i.e asphalt, buildings, other structures) decreased from 6.3 ha prior to the storms in December 1992 and early spring 1993 to 5.1 ha by the piping plover breeding season in 1993, then increased to 18.5 ha by 2004 (Fig. 5). Other unusable areas (areas within 2 m of human land use or sites heavily impacted by construction and construction vehicles) increased from 0.1 ha in 1992 to 20.5 ha in 2001, then decreased to 16.1 by 2004 (Fig. 5).

*Potential Foraging Habitat.*— In WHD the moist sediment habitat (MOSH) increased after the storms in December 1992 and early spring 1993 from 1.5 ha in 1992 to 15.8 ha in 1993. The area of MOSH increased to 23.2 ha by 1995, then varied little until 2004 (Fig. 6). MOSH was not measured in The Reference Area except in 2001 (1.2 ha), 2002 (0.9 ha) and 2003 (1.0 ha).

*Potential Prey.*— Arthropod catch did not differ between sites or among years in most cover types (Table 6). The exception was arthropod catch in dune sparse vegetation, which was higher in WHD in 2000, 2002, and 2003 than in 1995 and 1996 (ANOVA<sub>r</sub>,  $F_{9,130} = 6.54$ ,  $P < 0.001$ , Table 6). With sites and years pooled, mean arthropod catch was highest in bay intertidal zone and bay fresh wrack, and lowest in backshore and sparse vegetation cover types, and ocean old wrack ( $F_{10,98} = 22.57$ ,  $P < 0.001$ , Table 6). Mean arthropod catch was low in March and April, and increased significantly by May (Fig. 7). Renourishment apparently had little effect on arthropod catch (Figs. 8a-d).

*Potential disturbances.*— In WHD in the ocean backshore, dune sparse vegetation, and ocean sparse vegetation the human trail index did not differ among years (Table 7). But, in bay backshore, and bay sparse vegetation the human trail index did vary (Table 7). The human trail index did not differ among years at The Reference Area in the dune sparse vegetation or ocean sparse vegetation (Table 7), but it did vary in the ocean backshore (Table 7).

In the ocean backshore and dune sparse vegetation the cat trail index did not differ among years at WHD while in the bay backshore and sparse vegetation, the cat trail index varied (Table 7). In the ocean sparse vegetation, the cat trail index was highest in years 2002 and 2003 (ANOVA<sub>r</sub>,  $F_{3,43} = 5.57$ ,  $P = 0.003$ , Table 7). At The Reference Area the ocean backshore cat trail index was highest in 1996 ( $F_{5,73} = 5.67$ ,  $P < 0.001$ , Table 7). In the dune sparse vegetation the cat trail index was highest in 1997 and 2003 ( $F_{5,44} = 8.28$ ,  $P < 0.001$ , Table 7). In the ocean sparse vegetation it was highest in years 2002 and 2003 ( $F_{3,41} = 3.10$ ,  $P = 0.037$ , Table 7).

### **Piping Plover Population Trends**

In WHD, the number of piping plover nesting pairs increased from 0 pairs in 1992 to 39 pairs by 2000, then declined to 18 pairs by 2004 (Fig. 9a). In The Reference Area, the number of pairs declined from 12 pairs in 1993 to 5 pairs by 1997, then increased to 20 pairs by 2002, but declined again to 10 pairs in 2004 (Fig. 9b). At WHD, the observed number of pairs was > expected in 1994-1997, and 1999-2000 based on actual reproductive rates and adult survival rates of 0.74 and juvenile survival rates of 0.48. That is, the estimated immigration rate was positive (Fig. 9a).

*Habitat Measurements.*— Correlations of mean annual transect habitat measurements and hectares of habitat as measured on yearly aerial photos indicated that transects accurately ( $r > 0.8$ ) represented total potential nesting habitat (backshore and sparse vegetation  $> 2$  m from buildings) in WHD ( $r = 0.86$ ,  $P = 0.006$ ), and in The Reference Area ( $r = 0.82$ ,  $P = 0.023$ ).

*Population Density.*— Nesting pair density at WHD increased from 1993-2001, then declined 2002-2004 (Fig. 10). Density at The Reference Area varied with no apparent trend (Fig. 10). No models incorporating reproductive vital rates (clutch size, egg hatchability, egg survival, nest survival, renest rate, chick survival, and brood survival) explained population rate of increase better than null models in WHD or The Reference Area (Appendix 1). No models incorporating reproductive vital rates (clutch size, egg hatchability, egg survival, nest survival, renest rate, chick survival, and brood survival) at year T explained population size at year T+1 better than null models in WHD or The Reference Area (Appendix 1).

Population rate of increase was negatively related to density at WHD (Pearson's  $r = -0.814$ ,  $P = 0.008$ , Table 8), but not The Reference Area (Pearson's  $r = 0.448$ ,  $P = 0.227$ , Table 8). Estimated immigration/emigration rate for WHD was negatively related to density (Pearson's  $r = -0.799$ ,  $P = 0.003$ , Table 8). The regression equation (Fig. 11a) predicts immigration and emigration = 0 when density = 0.74 pairs/ha. Estimated immigration/emigration in The Reference Area was not related to density (Pearson's  $r = 0.313$ ,  $P = 0.349$ , Table 8, Fig. 11b).

### **Adult Pre-breeding Season Use and Availability**

First sightings of plovers within a season in WHD and The Reference Area ranged from 12-24 March 1993-2003. In WHD, during the pre-nesting season, March through April 1997-2000, foraging adult piping plovers used the bay intertidal zone at both high and low tide more than expected based on cover type availability (Table 9). In The Reference Area, foraging adult plovers used the ocean fresh wrack more than expected based on availability at high tide, and ocean intertidal zone more than expected at low tide (Table 9). We did not survey limited bay side cover types in The Reference Area because of lack of access to private property. At WHD and the Reference Area, resting adult plovers used the ocean backshore at low tide more than expected based on availability (Table 10).

### **Piping Plover Nesting Season**

*Nesting Chronology.*— Initiation dates of first nests in WHD and The Reference Area (1995-2003) ranged from 17 April to 26 June (Fig. 12). There was no detectable difference in the timing of first nest initiation dates between WHD (10 May  $\pm$  0.86 d, n = 237) and The Reference Area (12 May  $\pm$  1.36 d, n = 86, ANOVA<sub>r</sub>,  $F_{1,313} = 2.64$ ,  $P = 0.105$ ). With sites pooled, plovers nested earlier in 1999, 2001, and 2002 (9 May  $\pm$  2.48 d, n = 43, 8 May  $\pm$  1.74 d, n = 52, and 7 May  $\pm$  1.99 d, n = 56) than in 1995 and 2003 (16 May  $\pm$  3.49 d, n = 26, and 14 May  $\pm$  1.82 d, n = 40,  $F_{8,313} = 2.23$ ,  $P = 0.025$ , Fig. 13). With years pooled, plovers that nested closer to the bay high tide line nested earlier than those that nested further from the bay high tide line (n=321, Spearman's  $r = 0.124$ ,  $P = 0.025$ ).

The number of days between first nests and renests was similar in WHD and The Reference Area (WHD:  $n = 56$ ,  $\bar{x} = 8.7 \pm 0.78$  d, The Reference Area:  $n = 30$ ,  $\bar{x} = 6.9 \pm 0.91$  d, ANOVA<sub>r</sub>,  $F_{1, 76} = 0.29$ ,  $P = 0.590$ ). With sites pooled, piping plovers took longer to renest in 1995 than in all other years ( $\bar{x} = 17 \pm 9.1$  d,  $n = 3$ ). In 1996 ( $\bar{x} = 4 \pm 1.0$  d,  $n = 2$ ) and 1998 ( $\bar{x} = 3.4 \pm 3.2$  d,  $n = 5$ ) interval lengths were shorter than in 2000, ( $\bar{x} = 10.5 \pm 1.9$  d,  $n = 15$ ,  $F_{8, 76} = 2.22$ ,  $P = 0.035$ ). Pairs that lost their first nests to predation renested sooner ( $\bar{x} = 5.1 \pm 0.84$  d,  $n = 10$ ) than pairs that abandoned their first attempt ( $\bar{x} = 13.7 \pm 4.18$  d,  $n = 3$ , Wilcoxon rank sum,  $P = 0.004$ ).

The distance between first nests and renests in WHD ranged from 0–1268 m in WHD and 1–839 m in The Reference Area (Table 11). There was no difference in the distance (m) between first nest attempts and renest attempts among years (ANOVA<sub>r</sub>,  $F_{9, 92} = 1.38$ ,  $P = 0.208$ ). Also, there was no difference in the distance (m) between nests and renests for nests lost to predation ( $\bar{x} = 74.7 \pm 19.9$  m,  $n = 63$ ) and nest that were abandoned ( $\bar{x} = 46.4 \pm 9.9$  m,  $n = 14$ , Wilcoxon rank sum,  $P = 0.208$ ,  $n = 77$ ).

*Nest Distribution.*— At WHD, the number of piping plover first nest attempts increased from 1993-2000, then declined from 2001-2004. The number of bay-side and ocean-side first nest attempts also increased from 1993-2000, then declined from 2001-2004 (Fig. 14). The proportion of nest attempts on the bay side declined over time, while the proportion increased on the ocean side (Table 12). Plovers in WHD nested closer to the bay high tide line than plovers in The Reference Area (Wilcoxon rank sum test,  $W = 72,202$ ,  $P < 0.001$ ), and nested further from the ocean high tide line than plovers in The Reference Area ( $W = 41,790$ ,  $P < 0.001$ , Table 11).

There were significant differences in distances from plover nests to their nearest neighbor between sites and among years (ANOVA<sub>r</sub>,  $F_{10, 369} = 12.86$ ,  $P < 0.001$ , Table 11). Plovers nested closer to their nearest neighbor at WHD than at the Reference Area ( $W = 49,509$ ,  $P < 0.001$ , Table 13). In WHD, with years pooled, the average distance among all plover nests ( $83.48 \pm 6.07$  m,  $n = 268$ ) was less than  $\frac{1}{2}$  the average distance in The Reference Area ( $171.48 \pm 16.11$  m,  $n = 112$ , ANOVA<sub>r</sub>,  $F_{1, 369} = 80.12$ ,  $P < 0.001$ , Table 13). Within WHD, nests were farther apart in 1994 than in 1995, 1997, 2000-2002 ( $F_{9, 258} = 3.32$ ,  $P < 0.001$ , Table 13). Within The Reference Area, nests were farther apart in 1994 than in 1995, and 1998-2003 ( $F_{9, 258} = 3.32$ ,  $P < 0.001$ , Table 13). With sites pooled, plover nests were farther apart in 1994 ( $F_{9, 369} = 5.39$ ,  $P < 0.0001$ ) than in other years (Table 13).

In WHD the distance to the nearest neighbor decreased as nesting got further from the ocean high tide line ( $n = 268$ , Spearman's  $r = -0.14$ ,  $P = 0.026$ ), decreased with distance to bay high tide line ( $n = 268$ , Spearman's  $r = -0.22$ ,  $P < 0.001$ ), and was not correlated with distance to dense vegetation ( $n = 268$ , Spearman's  $r = -0.07$ ,  $P = 0.24$ ). In The Reference Area distance to nearest neighbor decreased with distance to ocean high tide line ( $n = 112$ , Spearman's  $r = -0.23$ ,  $P = 0.013$ ), increased with distance to dense vegetation ( $n=112$ , Spearman's  $r = 0.23$ ,  $P = 0.0130$ ), and was not correlated with distance to bay high tide line ( $n = 112$ , Spearman's  $r = -0.03$ ,  $P = 0.75$ ).

*Nest Characteristics.* — Plovers lined their nests with shells more often and nested in vegetation less often in WHD than in The Reference Area (Table 14). There was no difference in substrate or topography of nest locations between the two sites

(Table 14). With sites pooled, plovers more frequently nested on sand than on other substrates, and in flat areas than on slopes (Table 14).

*Clutch Size*.— Models incorporating weather variables (Table 15), predators trapped, and nesting pair density did not explain mean annual clutch size of first nests better than null models at WHD or The Reference Area (Appendix 2). A higher proportion of first nests had 4 eggs (322/383, 84%) than did renests (85/129, 66%, Chi-square,  $\chi^2_1 = 19.57$ ,  $P < 0.001$ ). However, in a logistic regression model of clutch size vs. nest initiation date and nest order (1=first nest, 0 = renest), only initiation date was significant (Table 16). Including number or frequency of potential disturbances within 100 m of nests did not improve the model (i.e., logistic models incorporating potential disturbances had  $\chi^2_i < 1$ ).

*Egg Hatchability*.— Models incorporating mean maximum daily temperature and total precipitation April through July, and nesting pair density did not explain mean annual egg hatchability better than a null model at WHD and The Reference Area (Appendix 3). Models incorporating nest characteristics, and distance to dense vegetation, high tide lines and nest initiation date did not explain egg hatchability better than a null model (Appendix 4). Models incorporating potential disturbances did not explain egg hatchability better than a null model at WHD or The Reference Area (Appendices 5 and 6).

*Egg Survival*.— Egg survival at WHD was best in warm, wet years when higher numbers of foxes were trapped, i.e. fox trapping was most successful (Linear regression, Table 17). At The Reference Area, linear regression models containing

mean maximum monthly temperature, total annual precipitation, and number of foxes trapped did not explain mean annual egg survival better than a null model (Table 17).

Eggs were most likely to survive if they were fenced, lined with shells, close to the bay high tide line, and far from dense vegetation (Table 18). Models incorporating potential disturbances did not explain egg survival better than a null model at WHD or The Reference Area (Appendices 7 and 8).

*Nest Survival.*— At WHD, nest survival on the ocean side differed among years (Chi-square,  $\chi^2_9 = 36.7$ ,  $P < 0.001$ , Table 19) as did nest survival on the bay side ( $\chi^2_9 = 24.6$ ,  $P = 0.006$ , Table 19). On the ocean side, based on partial Chi-squares, most of the variation in nest survival rates was due to low survival in 1995 and especially 2003, and high survival in 1998 and 1999 (Table 19). On the bay side, most of the variation in nest survival rates was due to low survival in 1995 and 2000 and high survival in 1996 (Table 19).

Nests in WHD survived best in warm, wet years when fox trapping was most successful (Table 20). In The Reference Area, models incorporating mean maximum daily temperature and total precipitation April through July, and nesting pair density did not explain mean annual nest survival better than a null model (Table 20). With sites pooled, individual nests were most likely to survive if they were fenced, lined with shells, farther away from the bay high tide line, closer to dense vegetation, and farther away from neighbors (Table 21).

The fit of the global models of the effect of potential disturbances (pedestrians, dogs, off road vehicles (ORVs), gulls, crows, other (anything that is likely to disturb a plover, i.e. terns, oystercatchers, willets, hawks, cats etc.) within 100 meters of nests on

nest survival was poor enough to preclude further analysis (Logistic regression, Mean number of potential disturbances:  $\chi^2_2 = 0.5300$ ,  $P = 0.971$ ; Frequency of observation of potential disturbances:  $\chi^2_2 = 0.5215$ ,  $P = 0.970$ ).

*Renest rate.*— Piping Plovers in WHD and The Reference Area whose nest failed were most likely to renest if they lost their nest early in the season and had their nest predated (Table 22). Piping plovers in WHD were more likely to renest when there were more disturbances within 100 m of first nests (Table 23). Linear regression models incorporating mean maximum daily temperature and total precipitation April through July, and nesting pair density did not explain mean annual renest rate better than a null model at WHD or The Reference Area (Appendix 9). At WHD, renest rate on the ocean side and bay side did not vary among years (Table 19).

*Potential Disturbances.*— Pedestrians, gulls, and least terns were the most prevalent potential disturbances observed within 100 m of nests (Table 24). Dogs and crows were observed less frequently.

*Nest Predation.*— Potential nest and chick predators were trapped by a contractor in WHD from 1996 to 2002. Seventeen red foxes (*Vulpes vulpes*), 15 raccoons (*Procyon lotor*), 26 opossum (*Didelphis virginiana*), and 26 feral cats (*Felis sylvestrus*) were trapped (Table 25).

The percent of nests lost to predators varied among years at WHD (Chi-square,  $\chi^2_9 = 80.78$ ,  $P < 0.001$ , Fig. 15a), but not at The Reference Area ( $\chi^2_9 = 14.67$ ,  $P = 0.10$ , Fig 15b). At WHD, the difference was primarily due to high predation rates in 1995 (13 nests predated, 68.4 %, partial  $\chi^2 = 9.389$ ) and 2003 (35 nests predated, 85.3 %, partial

$\chi^2 = 45.93$ ) and low predation rates in 1998 (3 nests predated, 10.7 %, partial  $\chi^2 = 45.931$ ) and 1999 (6 nests predated, 15.4 %, partial  $\chi^2 = 6.544$ ).

The rate of nest loss to cat predation in WHD (Linear regression,  $n = 10$ ,  $r^2 = 0.51$ ,  $P = 0.021$ ) and fox predation in The Reference Area ( $n = 10$ ,  $r^2 = 0.51$ ,  $P = 0.021$ ) increased with increasing nesting pair density (Table 26). The latter relationship would not be significant without the influence of one year (2002).

There was no difference between the ocean and bay side at WHD in proportion of nests lost to predation (ocean: 40.63%,  $n = 78$ , bay: 35.19%,  $n = 45$ ) or abandonment (ocean: 4.69%,  $n = 9$ , bay: 5.56%,  $n = 9$ ,  $\chi^2_1 = 1.14$ ,  $P = 0.567$ ).

*Nest Enclosures.*— Enclosures were put around 35/392 (9%) of nests to protect them from predators in WHD 1993-1997 and 2003-2004, and 47/198 (24%) nests in The Reference Area 1993-1994 and 1996-2004 (Table 27). Enclosed nests had a higher survival rate (74%) than unenclosed nests (50%,  $\chi^2_1 = 7.38$ ,  $P = 0.007$ ) with sites and years pooled (Table 27).

A greater proportion of unenclosed nests was lost to foxes at WHD than the Reference Area (Chi-square,  $\chi^2_1 = 7.39$ ,  $P = 0.007$ , Table 28). A greater proportion of unenclosed nests was lost to the following causes at The Reference Area than at WHD: cats ( $\chi^2_1 = 5.75$ ,  $P = 0.017$ ), crows ( $\chi^2_1 = 13.88$ ,  $P < 0.001$ ), unidentified predators ( $\chi^2_1 = 12.32$ ,  $P < 0.001$ , Table 28). A greater proportion of enclosed nests was lost to foxes at WHD than the Reference Area ( $\chi^2_1 = 13.25$ ,  $P < 0.001$ , Table 28). There was no difference in the proportion of enclosed nests lost to abandonment between The Reference Area and WHD ( $\chi^2_1 = 3.37$ ,  $P = 0.067$ , Table 28).

There was no difference in proportion of unexclosed nests lost to the following causes between The Reference Area and WHD: grackle (Chi-square,  $\chi^2_1 = 0.03$ ,  $P = 0.872$ ), gull ( $\chi^2_1 = 1.44$ ,  $P = 0.230$ ), raccoon ( $\chi^2_1 = 1.66$ ,  $P = 0.1979$ ), unknown avian predators ( $\chi^2_1 = 0.46$ ,  $P = 0.499$ ), unknown mammalian predators ( $\chi^2_1 = 0.07$ ,  $P = 0.799$ ), or abandonment ( $\chi^2_1 = 1.51$ ,  $P = 0.219$ , Table 28).

*Symbolic Fencing.*— Symbolic fencing was placed around 285/392 (73%) nests in WHD and 106/198 (54%) nests in The Reference Area in 1993-2004. Thirty-two (11%) of the fenced nests were exclosed in WHD and 45 (43%) were exclosed in The Reference Area. There was no difference between nest success of fenced/unexclosed nests (145/253, 57.3%), and unfenced/unexclosed nests (57/104, 45.2%, Chi-square,  $\chi^2_1 = 0.19$ ,  $P = 0.664$ ) in WHD. There was no difference between nest success of fenced/unexclosed nests (22/61, 36.0%), and unfenced/unexclosed nests (28/90, 31.1%,  $\chi^2_1 = 0.40$ ,  $P = 0.526$ ) in The Reference Area.

### **Chicks and Broods**

*Chick and Brood Chronology, Distribution and Movements.*— Hatching dates in WHD and The Reference Area (1993-2003) ranged from 22 May to 29 July (Fig. 12). In WHD, the proportion of broods using the ocean side was variable from 1993-1997, and then increased from 1998-2004 (Table 29). The percent of broods using the bayside was highest in 1993-1997, then decreased from 1998-2004 (Table 29).

At WHD, there was no difference among years in the proportion of time broods that hatched on the bay side foraged on the ocean side (ANOVA,  $F_{9,96} = 1.64$ ,  $P = 0.114$ , Table 30). However, broods that hatched on the ocean side spent more time foraging on the bay side in 2000 than in 1996 and 2001-2003 ( $F_{10,87} = 3.08$ ,  $P = 0.002$ , Table 30).

With yearly proportion as a sample, there was no difference in the proportion of time ocean-hatched broods foraged on the bay side and bay-hatched broods foraged on the ocean side (Paired t-test,  $P = 0.161$ , Table 30).

At WHD, there was no difference among years in distance (m) moved between nests and foraging locations for broods that hatched on the ocean side (ANOVA<sub>r</sub>,  $F_{8,77} = 1.46$ ,  $P = 0.184$ , Table 31). Broods that hatched on the bay side moved farther to reach foraging locations in 1993, 1994 and 2000 than in 1997 ( $F_{8,72} = 3.48$ ,  $P = 0.002$ , Table 31). With yearly averages as a sample, broods that hatched on the bay side and broods that hatched on the ocean side did not travel different distances from their nests to reach foraging locations (Paired t-test,  $P = 0.317$ , Table 31).

*Chick Behavior.*— With years pooled, chicks spent a higher % of their time foraging at WHD than The Reference Area ( $t_{88} = 3.03$ ,  $P = 0.003$ , Table 32) and spent a higher % of time in other behaviors ( $t_{71} = 2.71$ ,  $P = 0.008$ , Table 32) in The Reference Area than in WHD. Mean % time that plover chicks spent foraging was not related to density in WHD (Linear Regression,  $F_{1,8} = 1.47$ ,  $r^2 = 0.1557$ ,  $P = 0.259$ ) or in The Reference Area (Linear Regression,  $F_{1,5} = 0.03$ ,  $r^2 = 0.0052$ ,  $P = 0.878$ ).

*Chick Foraging Rates.*— At WHD, mean foraging rate was highest in the bay intertidal zone (ANOVA<sub>r</sub>,  $F_{10,571} = 17.05$ ,  $P < 0.001$ , Table 33). In the Reference Area, mean foraging rate was highest in the ocean intertidal zone and ocean fresh wrack ( $F_{10,149} = 4.53$ ,  $P = 0.017$ , Table 33).

Mean foraging rate of piping plover chicks was not related to nest density in WHD (Linear Regression,  $F_{1,8} = 2.06$ ,  $r^2 = 0.2044$ ,  $P = 0.190$ ) or The Reference Area

( $F_{1,5} = 0.70$ ,  $r^2 = 0.1230$ ,  $P = 0.441$ ). Renourishment did not appear to affect chick foraging rates (Fig. 16a-d).

*Brood Habitat Use-Availability.*— Movement barriers such as dense vegetation and houses likely affected actual availability of cover types. Consequently, we report “apparent availability”. Foraging broods apparently preferred all wrack cover types regardless of tidal stage at WHD (Table 34). In WHD, when broods had immediate access to bay side habitats, they were seen most frequently in the bay intertidal zone in all years (Fig. 17ab). They preferred ocean old wrack in The Reference Area, regardless of tidal stage (Table 34).

*Chick Survival.*— Chick survival at WHD differed among years for chicks that foraged on the ocean side only (ANOVA<sub>r</sub>,  $F_{8,75} = 2.15$ ,  $P = 0.042$ , Table 35) and for chicks that foraged on the bay side only ( $F_{9,64} = 7.44$ ,  $P < 0.001$ , Table 35), but not for chicks that foraged both on the ocean and bay side ( $F_{6,45} = 1.99$ ,  $P = 0.088$ , Table 35). No linear trend in survival over the years was evident (Table 35). With years pooled, there was no difference in survival for chicks that foraged on the ocean side only, bay side only or both ( $F_{2,207} = 0.89$ ,  $P = 0.413$ , Table 35).

Mean annual chick survival at WHD was higher in years when more foxes and cats were trapped (Linear regression, Table 36, Fig. 18). At The Reference Area, chick survival was more likely to be higher in years when more cats were trapped and temperatures were cooler (Table 36).

Regression models incorporating chick foraging location, peck rate, % time resting, % time disturbed, % time other behaviors, and date hatched did not explain chick survival better than a null model (Appendix 10). Models incorporating potential

mean number of potential disturbances within 100 m of chicks and the proportion of observations in which at least 1 potential disturbance was present within 100 m of chicks did not explain nest survival better than a null model at WHD or The Reference Area (Appendix 11). Renourishment did not appear to directly impact chick survival at WHD or The Reference Area (Fig. 19ab).

*Brood Survival.*— Brood survival at WHD differed among years for broods that foraged on the bay side only ( $\chi^2_9 = 41.79$ ,  $P < 0.001$ , Table 37), but not for broods that foraged on the ocean side only ( $\chi^2_8 = 0.73$ ,  $P = 0.694$ , Table 37) or both sides ( $\chi^2_6 = 6.61$ ,  $P = 0.358$ , Table 37). With years pooled, there was no difference in brood survival for broods that foraged on the ocean side only, bay side only or both ( $P = 0.755$ , Table 37).

Linear regression models incorporating mean maximum monthly temperature, total annual precipitation, number of cats trapped, and number of foxes trapped did not explain brood survival better than a null model (Appendix 12).

A logistic regression model for survival of individual broods suggests that broods with higher peck rates, greater % time resting, and larger initial brood size had higher survival rates (Table 38). A separate logistic regression model for survival of individual broods as a function of potential disturbances suggests that individual broods were more likely to survive when there were more “other” potential disturbances (90% least terns) within 100 m of broods, and initial brood size was higher (Table 39).

*Chick and Brood Disturbances.*— Pedestrians, gulls, and least terns were the most common potential disturbances observed within 100 m of broods (Table 39). Dogs and crows were observed less frequently at both sites (Table 39). At WHD, we

found no correlation between hectares of human land use and % time broods were disturbed (Spearman's  $r = 0.18$ ,  $P = 0.602$ ,  $n = 11$ ), mean number of potential disturbances within 100 m of broods [Spearman's correlations ( $n = 6$ ): pedestrians ( $r = 0.54$ ,  $P = 0.266$ ), gulls, ( $r = -0.37$ ,  $P = 0.469$ ), crows, ( $r = -0.26$ ,  $P = 0.623$ ) other ( $r = 0.49$ ,  $P = 0.329$ )], or % of observations in which at least one potential disturbance was seen within 100 m of broods [Spearman's correlations ( $n = 6$ ): pedestrians ( $r = 0.77$ ,  $P = 0.072$ ), gulls, ( $r = -0.54$ ,  $P = 0.266$ , crows, ( $r = -0.26$ ,  $P = 0.623$ ) other ( $r = 0.49$ ,  $P = 0.329$ )].

Mean % time that plover chicks were disturbed by adult plovers during 5-min observations was not related to nesting pair density in WHD (Linear Regression,  $F_{1,8} = 1.61$ ,  $r^2 = 0.17$ ,  $P = 0.240$ ). Disturbance by adults was related to density at The Reference Area (Linear Regression,  $\beta_1 = 0.40 \pm 0.15$ ,  $F_{1,5} = 6.59$ ,  $r^2 = 0.57$ ,  $P = 0.050$ ), but this relationship was driven by one year (2002) in which density and disturbance rates were high.

*Chick Road Crossings.*— During systematic observations of road crossings in 1999-2001 (total time 76 h 21 m) we recorded 40 observations of plovers walking (0.5/h), 106 observations of plovers flying below truck height (1.6/h), and 202 observations of plovers flying above truck height (2.6/h) across Dune Road. We recorded 5,784 observations of vehicles driving on the road in WHD during these observations. During opportunistic observations of road crossings in 1999-2001, we recorded 441 observations of plovers walking, 550 observations of plovers flying below truck height, and 913 observations of plovers flying above truck height across Dune

Road in WHD. At least 7 plover chicks and 2 adults were run over by vehicles on Dune Road in WHD.

*Chick Mortality.*— In WHD, 15/349 (4%) of chick losses were to known causes. One chick had a broken leg and died after being brought to a wildlife rehabilitation center, 1 chick died after entangling its leg in a horseshoe crab (*Limulus polyphemus*) carcass, 1 chick was found dead with a puncture wound, 4 chicks were found dead immediately following a severe rain storm. Seven chicks were run over by vehicles on Dune Road in 1998 and 1999. In The Reference Area (1/121, <0.01%) chicks were lost to known causes. One chick was found partially eaten.

Approximately, 71% (WHD) and 66% (The Reference Area) of chick mortality (chicks dying/total hatched) occurred within the first 10 days after hatching (Fig. 20). There was no difference in the mean age at which chicks were lost between WHD ( $7.6 \pm 0.71$  days,  $[\bar{x} \pm SE]$ ,  $n = 353$ ), and The Reference Area ( $7.6 \pm 1.2$  days,  $n = 119$ , Wilcoxon rank sum, 1 df,  $P = 0.870$ ).

*Reproductive Output.*— Fledging dates in WHD and The Reference Area (1993-2003) ranged from 8 June to 20 August (Fig. 12). Reproductive output at WHD and The Reference Area was similar in all years (Fig 21). At WHD, reproductive output of pairs (chicks fledged/pair) that nested on the ocean side and pairs that nested on the bay side varied among years (Table 40). Reproductive output (chicks fledged/pair) was correlated with egg, nest, chick, and brood survival at WHD, but only with reneest rate at The Reference Area (Pearson's correlation, Table 41). Clutch sizes, egg fertility, reneest rates, and brood survival were similar in all years. Other reproductive rates differed

among years (Table 42). Egg survival, nest survival, and nests hatched/pair were higher at WHD than The Reference Area.

*Population Growth Models.*— Population growth models that did not include immigration predicted that the population in WHD would either become extinct soon after colonization (Model “Logistic, Observed Productivity”) or grow very slowly (Model “Logistic, 0 Immigration”, Fig. 22). Models incorporating density dependent immigration appeared to be closest to the observed population growth trend in WHD (Fig. 22). Of the 2 models based on density dependent immigration there was slightly more support for the model incorporating density dependence (model “Logistic, Density Dependent Immigration”, Table 43), than for the one with density independent survival and recruitment (model “Exponential, Density Dependent Immigration”).

## DISCUSSION

### Population Regulation

*The Role of Density Dependence.*— Annual changes in animal populations result from the relative values of natality, mortality, immigration and emigration rates (Lack 1967). Population regulation is the process that causes a population to tend to return to an equilibrium density determined by some combination of environmental and behavioral variables (Rodenhouse et al. 1997). In this study, the rate of increase of the West Hampton Dunes piping plover population was negatively correlated with density, supporting the idea that the population was regulated by density dependent factors.

For regulation to occur, and for the rate of increase to be negatively correlated with density, one or more population parameters (natality, mortality, immigration and emigration) must be density dependent, such that the parameter value changes result in a population increase when the population is below the equilibrium density and in a population decrease when the population is above the equilibrium density (Krebs 1994, Rodenhouse et al. 1997).

*Immigration, Emigration and Population Regulation.*— In this study, only estimated net immigration/emigration was correlated with density. Estimated net immigration occurred during the period the population was low and was increasing except for 1998. Net estimated emigration may have occurred in 2000-2004 when the population was decreasing, but the observed population size was within the 95% confidence bounds for the expected population size at that time. However, band returns suggest that an increasing proportion of surviving adults dispersed from 2002-2004 (Cohen et al. in prep). These results suggest that the main process regulating the population during this study was immigration and possibly emigration. This inference is

further supported by the modeling results. Only models that incorporated density dependent immigration and emigration came close to duplicating the observed population trends at WHD. Models that used observed or average WHD reproductive output and published mortality values but that did not include immigration declined to zero or increased very slowly. In contrast, similar models that incorporated density independent net immigration/emigration increased well beyond the year 2000, unlike the actual population.

We used the estimated annual survival rates of 0.74 for adults, and 0.48 for first year birds, based on our estimate of adult survival (0.74, Cohen et al. in prep) and the estimate of Melvin and Gibbs (1995) of 0.48 for juvenile survival on the outer beaches of Cape Cod in 1985-1988. These values correspond closely to other survival estimates (minimum observed survival in Maryland of 0.71 for adults and 0.41 for juveniles when the population was declining (Loegering 1992); adult survival of 0.74 on the outer beaches of Cape Cod (Melvin and Gibbs 1995) when the outer cape population was declining but the state population was stationary, (Melvin pers. Commun); adult survival of 0.74 and juvenile survival of 0.32 in the Alkali wetlands of North Dakota (Larson et al. 2000), when the study population was fluctuating (M. Ryan, pers. Commun.) but the regional population was declining at 4.2% per year). Larson et al. (2000) believed that their juvenile survival rate was low due to failure to resight living birds.

The similarity of these estimates in widely distributed populations with different trajectories suggests that the values we assumed for mortality are reasonable. Nevertheless, future studies should include real time estimates of mortality, immigration and emigration using a marked population throughout the study. Our inference that

emigration contributed to the population decline to equilibrium is further supported by observations of Cohen (in prep) of individually marked birds behaving territorially early in the season, and then disappearing and, in some cases, being observed only during migration in later years.

Population regulation through immigration and emigration requires a source of immigrants when the population is below equilibrium density. Moreover, for emigration to be a selected strategy, the cost of emigration when the density is above the equilibrium density must often be less than the cost of staying in the population at the higher density (Fretwell and Lucas 1970). These conditions are most likely met by species which, like the piping plover, live in rapidly changing habitats. Historically, the formation and subsequent succession to marsh from tidal flats was likely more common than it is today in the era of stabilized beaches (Dolan et al. 1973). Piping plovers likely exploited this dynamic environment by colonizing newly formed breeding/foraging habitats when former sites surpassed equilibrium density.

Piping plover populations are thought to have declined since the 1940's due to "habitat loss and degradation, disturbance by humans and pets, and increased predation" (USFWS 1996). However, management that primarily focused on reducing disturbance and predation, and therefore increasing reproductive output, resulted in population increases throughout most of the range, with the Atlantic Coast population increasing from an estimated 1111 pairs in 1993 to 1438 in 2000 and 1676 pairs in 2003 (USFWS unpublished data). This indicates that Atlantic Coast piping plovers were increasing range-wide during the time of our study. Thus, some populations were likely below equilibrium density, providing unoccupied habitat for emigrants from other

populations. If most populations reach equilibrium density, the benefits of emigration will be less as there will be no open sites in other populations, and it might be more advantageous for birds to remain on their current breeding sites or to return to their natal areas, and either compete for territories or “float” awaiting a vacancy. In that case we might expect to see density dependent changes in natality or mortality.

*Reproductive Output and Population Regulation.*— We found no evidence that reproductive output (chicks fledged/pair) or any constituent of reproductive output was positively or negatively correlated with density (Table 6). The Charadriidae generally are classified as determinate layers and there is little variation in clutch size (Haig 1992, this study), so it is not surprising that there was no evidence of density dependence of this parameter (clutch size).

The most common cause of nest loss was predation, and although observations of chick losses were few, we assume predation accounted for most chick disappearance. Overall, nest predation rates were not correlated with density, but this may have been biased by predator trapping. The percent of nests lost to cats in WHD and the percent of nests lost to foxes in The Reference Area were positively correlated with plover nesting density. Predators may increase their searching intensity as nest density increases (Martin 1988). The number of cat tracks in WHD backshore and ocean sparse vegetation increased during the years of highest plover nesting density. While it is possible that this was caused by a numerical response to piping plover density, it seems more likely that the increase in cats was caused by the increase in the the number of people inhabiting houses in WHD during this time. Many of these people brought cats and allowed them to run free on the beach.

## **Equilibrium Density**

After the WHD population peaked in 2000, the density ranged from 0.86–1.05 pairs/ha for several years, suggesting an equilibrium density of approximately 1 pair/ha nesting habitat, or more than twice the average density (0.42 pairs/ha) observed in The Reference Area from 1993-2004. Moreover, the density at WHD exceeded the density in The Reference Area for all but the first two years of the study.

We assume the population at The Reference Area was varying about its equilibrium density, or that the equilibrium density in The Reference Area varied slightly throughout the study. In either case, the results suggest that the equilibrium density at WHD was about twice that of the Reference Area, at least from 2000-2003. The mean distance from plover nests to the closest plover nest in WHD was about half the mean distance observed in The Reference Area, consistent with the contention that the equilibrium density in WHD is twice that in The Reference Area.

The most striking ecological difference between WHD and The Reference Area was the presence of the large intertidal flats on the bay side of WHD. Before egg laying, this habitat was preferred by foraging piping plovers at both tidal stages. Mean arthropod abundance and plover chick foraging rates were higher in this habitat than in others and survival of chicks and broods was positively associated with foraging rate. Moreover, early in the study, when broods could most readily move between ocean and bay, broods spent most of their time in bay side habitats. During the incubation and brood-rearing periods, we observed marked plover adults flying up to 2 km to forage on the flats, and during the post breeding and migration periods adult and fledgling plovers were commonly observed there.

Other studies have shown that plovers prefer nesting adjacent to moist substrates including bay intertidal flats, storm or rain-filled ephemeral pools, and impoundments (Patterson et al. 1991, Loegering and Fraser 1995, Elias et al. 2000), that chick survival was higher when chicks foraged in these rich habitats (Loegering and Fraser 1995, Elias et al. 2000), and that adult plovers forage in these habitats before nesting, and during nesting even when flightless chicks cannot reach them (Loegering 1992, Keane and Fraser 2005, Cohen et al. in prep). Chicks weigh about 40 g when they begin to fly compared to adult weights in the upper 50's at the beginning of nesting (Cohen, LeFer and Fraser unpublished data), so chicks may increase their weight by as much as 50% while foraging in these habitats immediately after fledging.

Similarly, wintering birds forage primarily on intertidal flats. On the Alabama coast, piping plovers used mudflats or sandflats 93% of the time observed (Johnson and Baldassare 1988). As before breeding, this use is tide-dependent. Johnson and Baldassarre (1988) reported a negative correlation between tide height and foraging activity. Nicholls and Baldassare (1990) surveyed 1422 km of shoreline from Virginia to Key West, and 1283 km from Everglades National Park to Brownsville, Texas. Using discriminant analysis, they found that percent of habitat classified as mudflat, sand flat and tide pool helped distinguish used from unused habitats on the Atlantic coast, and percent mudflat helped discriminate used from unused areas on the gulf coast. They noted "piping plovers were observed foraging most frequently on sandflats and sandy mudflats." Likewise, Zonick (2000) found that during the winter on the Texas Gulf Coast barrier islands, plover densities were greater in bay side feeding areas than on Gulf side areas. Drake et al. (2001) used radio telemetry and estimated use of algal flats, lower

sandflats and mudflats to comprise 74%, 89%, and 78% of habitat use in Fall, Winter and Spring, respectively.

In 2004, however, the density in WHD fell to 0.58 pairs/ha nesting habitat. This may have resulted from demographic variability, including the effects of poor reproduction in 2003 in sites adjacent to WHD. However, even with the poor reproduction in 2003, we estimate that, with constant survival rates, emigration from West Hampton Dunes was necessary to produce the low breeding numbers in 2004 (Fig. 9). This is consistent with the idea that the equilibrium density at WHD decreased in 2004. It is possible that the increased fragmentation of the habitat due to vegetative succession and construction made the area less attractive to plovers, despite the proximity of the large intertidal flats there. Future years of study will be required to determine if the lower density will persist and, if it does, to infer the causes of this decrease in density.

### **Rate of Increase**

While annual survival estimates have been consistent across studies in different areas (Loefering 1992, Melvin and Gibbs 1995, Larson et al. 2000, Cohen et al. in prep), reproductive output has been highly variable among and within populations, and usually well below the approximate maximum reproductive output of 4 fledglings/pair (Haig 1992). Reproductive rate required for a stationary population has been variously estimated as 1.41 (Maryland, Loefering 1992), 1.25 (Atlantic Coast, Melvin and Gibbs 1995) and 1.1-1.25 young/pair (Great Plains, Larson et al. 2002). During this study, the average reproductive rate at WHD was 1.31 fledglings/pair. Thus, as confirmed by our modeling, reproduction may have been at or slightly below that required for population

stationarity, and could not support a rapid increase without immigration. Assuming that over-winter survival, age at first breeding, and % of breeding plovers >2 y varies little, the rate of increase of a population below equilibrium density will be determined by the reproductive output and the immigration rate.

*Factors Affecting Reproductive Output.*— The greatest cause of nest loss identified during this study was predation by cats, foxes, and crows. These species are common nest predators on the Atlantic Coast (USFWS 1996). Other terrestrial predators including striped skunks (*Mephitis mephitis*), Norway rats (*Rattus norvegicus*), raccoons, and opossums also take piping plover nests. Predation pressure from such species was likely lower during most of the piping plover's evolution. Foxes apparently were absent from the barrier islands and most of the Great Plains in pre-Columbian times (Kamler and Ballard 2002). The Norway rat was introduced to North America in about 1775 (Silver 1927) and the domestic cat is thought to have entered North America several hundred years ago (Coleman et al. 1997).

All of these species, whether introduced or native, probably are more common on barrier islands now than during the piping plover's evolution. At the beginning of this study, foxes dened in abandoned and partially-destroyed houses. Feral cats lived beneath some of the beach clubs, and under houses in WHD and The Reference Area, and were fed by residents. Domestic cats living in beachfront houses often were allowed to roam freely. Crows are likely attracted by human garbage and often are seen perched on roof tops. All of these species may be attracted to piping plover nesting areas by fish entrails and other trash discarded by people.

Predation by these species varied over time. Predator reduction by trapping was one source of variation. In addition, nest exclosures reduced predation. In 1995, one or more foxes apparently learned to key in on predator exclosures in West Hampton Dunes. We observed tracks circling exclosures. Some of the nests listed as abandoned may have failed because of harassment by predators or because one of the adults was captured by a predator.

Although our sample size was small, and trapping efforts varied from year to year, regression analyses showing higher chick survival in the years when most foxes and cats were trapped were consistent with the hypothesis that an important cause of chick loss in WHD was predation by foxes and cats. In The Reference Area, the regression pointed only to cats. This is consistent with our observations that most foxes on the study area denned in the western part of WHD or west of the western boundary of WHD, and that cat track densities were higher in The Reference Area than in WHD.

In the Great Plains, the fledging rate of pairs protected by both predator exclosures at nests and electric fences around the brood use area was 2.25 fledglings/pair, compared to 1.15 fledglings/pair for pairs supplied only with predator exclosures at the nests (Larson et al. 2002). This higher fledging rate of birds protected by electric fence likely reflects, at least in part, a reduction in predation on chicks by terrestrial predators.

It is likely that predation on nests and young is a key factor in the decline of this species (Rimmer and Deblinger 1990). Although range-wide habitat improvements have not been noted, an Atlantic coast effort to reduce nest predation using predator exclosures and occasionally predator removal has been followed by population

increases in many places (USFWS unpublished data). Through simulation and optimization analyses, Larson et al. (2003) projected that, despite apparent current declines, the Great Plains population of piping plovers could be recovered by fencing nests and brood rearing areas if adult mortality is not induced.

Piping plover chick survival often is higher when chicks have access to MOSH, such as the bay intertidal zone or ephemeral pools (Loefering and Fraser 1995, Goldin and Regosin 1998, Elias et al. 2000). Moreover, several studies have shown that chicks gaining weight rapidly early in life, may have a better chance of fledging (Cairns 1982, Loefering and Fraser 1995, Lefer in prep.). In this study, the probability that a brood would fledge at least one chick increased with observed chick foraging rate, and foraging rate was positively linked with prey availability. We did not find a similar relationship between foraging rate and chick survival, probably because high levels of chick predation obscured the food-survival relationship. Occasionally high reproductive rates of piping plovers that had access only to ocean beach habitats suggests that ocean beaches in this study area, at least in some years, had adequate food and sufficiently few predators for chick rearing. Moreover, high predation rates may have obscured effects of habitat quality on chick survival that might be evident if predation was lower.

The number of observed chicks killed by cars combined with chicks lost due to adult parent mortality by vehicles was < 2% of the total chick loss. These losses occurred in 1998-2000. During this period, construction and other traffic on Dune Road was substantial, yet there was much open sand between the ocean and bay sides which may have encouraged plovers to move their broods across the island. After

1998, the year of the highest road kill, danger was initially reduced by careful monitoring. When broods prepared to cross the road, traffic was stopped. In later years, as the habitat continuity between the ocean and the bay was reduced by development and vegetative succession, road crossings by broods became fewer, and risk of road kill was reduced.

Pedestrians and their dogs and vehicles have been reported to reduce piping plover reproductive output by crushing eggs or chicks (Shaffer and Laporte 1992, Wilcox 1959, Patterson et al. 1991, Melvin et al. 1994). In this study, only 6 nests (1% of total nests) were lost due to pedestrians and only 2 nests (0.3%) were known to be taken by dogs. No nests were lost due to vehicles. The low loss rate due to direct pedestrian influence may be attributable in part to the relatively low beach use in the study area. Little public parking was available in the study area, so beach use was confined largely to residents and those renting homes or other rental units in the area. Thus, human densities were much lower than at many public beaches.

Moreover, throughout much of the study, there existed an aggressive program of symbolically fencing potential plover nest sites before nesting began in WHD. This program provided spatial separation between humans and plovers throughout much of the nesting season. Symbolic or string fencing commonly is used to prevent humans from approaching piping plover nests. We did not do a controlled study with randomly selected areas with and without symbolic fencing. The location of string fencing in this study was determined by a variety of biological and socio-political considerations. A careful study using randomized placement of fences would be required to better evaluate the effects of string fencing. Therefore, we can not say whether symbolic

fencing decreased nest losses due to pedestrians, particularly, as losses due to predation obscured our results. Though human traffic was relatively light on most of WHD during this study, a few symbolically-fenced nests were crushed by pedestrians who chose to ignore the fencing.

Vehicular traffic was extremely rare during the nesting season in both WHD and The Reference Area. This relatively low human use of the beach and the spatial separation between people and plovers, plus the fact that early in the study many plovers nested on the more isolated bay side of the island, may have contributed to the relatively low human disturbance rate found in this study and to the lack of an apparent effect of human disturbance on piping plover vital rates. The percent time plover chicks were disturbed by all sources, including natural sources (7.4% and 10.5% for WHD and The Reference Area, respectively) was similar to the percent time of disturbed broods in the foot access only portion of Assateague Island (7.2%, Loegering and Fraser 1995) and slightly higher than on South Monomoy Island, a wilderness area near Cape Cod (2.5%, Keane 2002).

Clutch size decreased as the season progressed. This decline in clutch size during the nesting period has been noted for many species (Klomp 1970, Krapu et al. 2004). The smaller clutch sizes in re-nest attempts appear to be best explained by time in the nesting season. This has been observed for other species including mallards (*Anas platyrhynchos*, Batt and Prince 1979) northern pintails (*Anas acuta*, Duncan 1987), and Eurasian sparrowhawks (*Accipiter nisus*, Newton and Marquiss 1984). This decreasing clutch size as the season progresses has been linked to decreasing juvenile or adult survival throughout the breeding season (Charnov and Krebs 1973). Although

several of our weaker regression models of chick survival included nest initiation date, we did not find strong evidence of decreasing survival throughout the nesting season. It is possible that a higher mortality of late hatched chicks occurs after fledging when we were no longer monitoring survival of individual chicks

### **Limiting Factors**

Prior to the 1993 plover nesting season, piping plovers were absent from WHD for at least 8 years. Their absence likely was a result of limited potential nesting and foraging habitat. The recolonization of WHD in 1993 after storms and The Corps created extensive bay side nesting and foraging areas supports this hypothesis.

This hypothesis is further supported by changes in piping plover distribution and abundance throughout the study concurrent with changes in distribution, abundance, and accessibility of nesting and foraging areas. These changes mostly resulted from redevelopment and The Corps activities in WHD. Prior to redevelopment of WHD, which began in 1996, piping plovers nested on open areas of bay side backshore and sparse vegetation near bay side foraging areas (MOSH). As bay side nesting areas and access to bay side foraging areas declined due to redevelopment and growth of dense vegetation, the number of plovers nesting there declined as well. On the ocean side, the number of nesting plovers increased concurrently with the increase in ocean side nesting habitat. During this study, availability of nesting and bay side foraging areas appeared to limit the WHD piping plover population.

### **Habitat Management**

After the WHD population peaked in 2000, nesting pair density was twice as high adjacent to bay tidal flats as it was on beaches that were not near such cover

types. Moreover, Elias et al. (2000), and Elias et al. (in review) illustrated the value of sparse vegetation to nesting plovers. Thus, the ideal piping plover cover types in WHD are those with nesting beaches, sparse vegetation, and bay intertidal flats juxtaposed. In more pristine times, overwash and breaching followed by succession likely created such areas repeatedly. Under more natural conditions, naked beaches were no doubt colonized by sparse vegetation (Dolan et al. 1973). In the absence of new disturbance, the sparse vegetation would have become dense and unsuitable for piping plovers, similar to what occurred in WHD.

Stabilized beaches such as WHD differ from the more pristine beaches in three important ways, however. First, because stabilized beaches may be raised to a higher elevation than natural beaches, overwashes and high salt water and spray levels that set back plant succession are less frequent than on unmanaged beaches. Thus, dense vegetation may be able to cover a beach more rapidly (exacerbated by beach grass planting and fertilization). Second, the less frequent overwash inhibits the movement of sand across the islands, which reduces the “feeding” of bay side intertidal flats. When erosional forces work on these bay side areas, absent natural renourishment, these flats can shrink or disappear. Third, when beaches are stabilized, human development is often extensive. Because a very large proportion of barrier beaches are now stabilized and developed, it follows that prime piping plover habitat is less extensive than in pristine times. The Reference Area is a good example of a highly developed beach with piping plover densities lower than likely would occur if the area had more open nesting areas and extensive flats from frequent overwashes like those that occurred at WHD.

## Summary

*Population Dynamics.*— In this study, the number of piping plovers nesting at WHD increased, leveled off, then declined. In The Reference Area the number of nesting piping plovers varied with no clear trend. The rate of increase at WHD was negatively correlated with plover density, supporting the idea that the population was regulated by density-dependent factors. There was no evidence of regulation in The Reference Area. Our modeling suggests that reproduction was at or slightly below that required for population stationarity, and could not experience such a rapid increase (as noted in this study) without immigration.

In WHD, only estimated net immigration/emigration was correlated with density. Estimated net immigration was high during most of the period the population was increasing and estimated net emigration occurred when the population was decreasing suggesting that the main process regulating the population during this study was density-dependent immigration and emigration. Equilibrium density at WHD appeared to be about twice the average density observed in The Reference Area during this study.

*Land Form Alterations.*— The most obvious ecological difference between WHD and The Reference Area was the presence of the large intertidal flats on the bay side of WHD. These flats were used consistently by foraging piping plovers. Mean arthropod abundance and plover chick foraging rates also were higher in these areas than in other cover types. Early in the study, when broods could most readily move between ocean and bay, broods spent most of their time in bay side habitats. During the post breeding and migration periods adult and fledgling plovers were commonly observed feeding on

the flats. Development of WHD from 1996-2004 decreased potential nesting habitat and chick access to bay side intertidal flats in WHD.

*Nest and Chick losses.*— The greatest cause of nest predation identified during this study was by cats, foxes, and crows. Predation by these species varied over time. Predator reduction by trapping was one source of variation. Most known nest losses were to crows in The Reference Area and fox in WHD. In addition, nest enclosures reduced predation, particularly in The Reference Area where foxes were less of a problem. Most chick deaths were unknown; a few chicks were killed by vehicles. These losses occurred when construction and other traffic was substantial in WHD. Very few nests were stepped on by pedestrians, and no nests were lost to vehicles. This likely occurred because pedestrian and vehicular traffic were low during most of the study and breeding areas were symbolically fenced to keep people away from plover areas.

*Study Areas.*— Piping plover ecology at WHD was similar to that at The Reference Area. The most conclusive difference was that WHD was able to support approximately twice the density of piping plovers during this study. This was apparently related to the large bay side intertidal flats adjacent to the nesting habitat in WHD. Patterns of beach succession, re-development of houses, and piping plover habitat selection suggest that activities indirectly associated with the Corp's activities have reduced plover habitat suitability and decreased carrying capacity at WHD. This in turn is increasingly making WHD ecologically similar to The Reference Area.

## **MANAGEMENT IMPLICATIONS**

### **Habitat Manipulation**

The results of this study suggest that increasing the amount of nesting habitat could lead to increasing the number of piping plover nesting pairs. This could be

accomplished in two ways. First, we should identify areas in which overwash and succession could be allowed to proceed naturally. Currently, even National Seashores may follow overwash or breaches with rapid filling and stabilization. This occurs even when property is not jeopardized, such as the “wilderness area” on Fire Island National Seashore. Operational changes and perhaps policy changes will be required if natural processes are to be allowed to take place unfettered by beach management.

Second, we believe that, where property protection precludes allowing natural processes to occur, we can design and create piping plover habitats. It has long been known that piping plovers will nest readily on sand or gravel that has been worked by humans. In or before 1929, E. R. Ford wrote “At Dune park ind., the piping plover, to the number of five or six pairs has taken advantage of the widening of the beach (through the operations of a sand company which has removed part of the dunes) and lays its eggs at a considerable distance from the waters edge” (Tyler 1979). Our study demonstrated that piping plovers can nest successfully on beaches created or augmented by artificial means. This also has been observed previously at Fire Island, New York and Stone Harbor, Sea Bright, and Monmouth Beach, New Jersey.

Beach grass commonly is planted during beach stabilization. For stabilization, plants typically are spaced at 12”-18” (Miller and Peterson 2000). A sparser planting, perhaps on the order of 3m x 3m without fertilization would increase the longevity of the sparse stage, and therefore of the value for piping plovers. More study will be required to find the optimum density of beach grass for piping plovers.

Beach nourishment at WHD and The Reference Area did not always result in an increase in nesting habitat. This was due to construction of houses, an increase in

growth of dense vegetation, and erosion before or after the nesting season. In fact, it is expected that the sand from nourished beaches will migrate to the ocean intertidal or near shore subtidal zone, where it provides protection for the shoreline (J. Vietri, Pers. Commun.) but does not provide plover nesting habitat.

If the intent is to build plover nesting benefits into beach nourishment activities, it must be clear that potential associated affects such as beach construction activities, and increased dense vegetation growth can potentially offset any benefits of nourishment. Also, the beach must be designed to retain the increased size of the backshore. In planning such a beach, however, engineers must be mindful of the fact that any construction that decreases overwash is likely to interfere with the natural creation and maintenance of the crucially important bay side intertidal flats.

Piping plover densities will be greatest in nesting habitat that is adjacent to bay intertidal flats (this study, Elias et al. 2000, Keane 2004). However, this habitat is scarce due, in large measure, to beach protection activities and housing development.

Artificial creation of intertidal foraging habitat has not yet been attempted for coastal piping plovers. However, there are good reasons to think that this can be readily done. First, a substantial proportion of the intertidal area used by piping plovers at WHD was created when the Corps filled in the breach. This area was expanded by sand blown from the reconstructed beach. Secondly, it is increasingly common for coastal wildlife refuges to manage artificial impoundments for shorebirds (Rundle and Fredrickson 1981, Erwin et al. 1994, Weber and Haig 1996).

The ideal dimensions of these habitats are unknown. In this study the area of the backshore at West Hampton Dunes ranged from 32–55 ha, with backshore widths,

excluding the spit, averaging 35.4 m wide. The large intertidal flats ranged from 16-27 ha, with widths varying from 1-600 m. We recommend experimental creation of intertidal foraging habitats on piping plover densities and vital rates.

### **Predator Management**

Protection of ideal cover types will be of scant use if predators take so many nests and birds that the local population becomes a sink, maintained only by immigrants from other areas. Predator management has long been an important part of piping plover management, and has been a key to reversing the decline of the species (Smith et al. 1993, USFWS 1996, Larson and Ryan 2002, Larson et al. 2003). However, much of the predator management to date has protected nests by means of predator exclosures, and has not adequately protected chicks. In a few cases, entire nesting areas, and large portions or all of chick rearing areas have been protected by electric fencing (Larson and Ryan 2002, Larson et al. 2003).

In this study, effective control of cats and foxes was correlated with higher survival rates of chicks in WHD. Reproductive output (chicks fledged/pair) in turn, was highly correlated with chick survival. Protection of nests and chicks from predators, such as cats, crows, and foxes will be necessary to allow populations to recover and flourish.

Because individual predators can learn to associate predator exclosures with food, and can then become persistent and pursue birds or eggs inside the exclosures, we recommend use of such devices only when egg predation is seriously reducing nest success. When a predator begins to focus its attention on exclosures, that predator must quickly be removed. In general, removal or exclusion of predators from entire

nesting areas is likely to be much more effective than predator exclosures at nests because the former practice protects chicks as well as nests. The success of fencing to exclude terrestrial predation from brood rearing areas in the alkali wetlands of the midwest (Larson et al. 2003) suggests that this may be a useful technique for some situations in coastal populations, particularly where chicks forage on MOSH and large expanses of sparse vegetation.

**LITERATURE CITED**

- Aebischer, N. J., Peter A. Robertson, and Robert E. Kenward. 1993. Compositional analysis of habitat use from animal radio-tracking data. *Ecology*. 74(5) pp. 1313-1325.
- Altman, J. 1974. Observational study of behavior sampling methods. *Behaviour*. 49: 227-267.
- Baillie, S.R. 1990. Integrated population monitoring of breeding birds in Britain and Ireland. *Ibis* 132:151-166.
- Batt, B.D.J. and H.H. Prince. 1979. Laying dates, clutch size and egg weight of captive mallards. *Condor* 81:35-41.
- Burger, J. 1994. The effect of human disturbance on foraging behavior and habitat use in piping plover. *Estuaries*. 17(3) 695-701.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd Edition. Springer-Verlag, New York, New York, USA. 488 pp.
- Cairns, W. E. 1982. Biology and behavior of breeding piping plovers. *Wilson Bull.* 94:531-545.
- Charnov, E. L. and J. R. Krebs. 1973. On clutch size and fitness. *Ibis* 116:217-219.
- Conover, W. J. and Inman, R. L. 1981. Rank transformation as a bridge between parametric and nonparametric statistics. *American Statistician*. 35: 124-133.
- DeSante, D.F. 1990. The role of recruitment in the dynamics of a Sierran subalpine bird community. *American Naturalist* 136, pp. 429-455.
- Dolan, R., P.J. Godfrey, and W.E. Odum. 1973. Man's impact on the Barrier Islands of North Carolina. *American Scientist* 61:152-162.
- Downer, R.H, and C.E. Leibelt. 1990. 1989 Long Island colonial waterbird and piping plover survey. Research report of the New York State Department of Environmental Conservation, Stony Brook, New York. 200 pp.
- Duncan, D. C. 1987, Nesting of Northern Pintails in Alberta: Laying date, clutch size, and re-nesting: *Canadian Journal of Zoology*. 65: 234-246.
- Elias, S.P., J.D. Fraser, and P.A. Buckley. 2000. Piping plover brood foraging ecology on New York barrier island ecology. *J. Wildl. Manage.* 64 (2): in press.

- Elias-Gerken, S. P. 1994. Piping plover habitat suitability on central Long Island, New York barrier islands. M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg. 248 pp.
- Flemming, S.P., 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(4): 321-330.
- \_\_\_\_\_, S. P., R. D. Chiasson, P.C. Smith, P.J. Austin-Smith. 1992. Piping Plover nest site selection in New Brunswick and Nova Scotia. *J. Wildl. Manage.* 56:578-583.
- Flint, Paul L., K. H. Pollock, D. Thomas, and J. S. Sedinger. 1995. Estimating pre-feldging survival: Allowing for brood mixing and dependence among brood mates. *J. Wildl. Manage.* 59(3):448-455.
- Fretwell, S. D., and H.L. Lucas. 1970. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. *Acta Biotheoretica* 19:16-36
- George, T.L., Fowler, A.C., Knight, R.L., and McEwen, L.D. 1992. Impacts of a severe drought on grassland birds in western North America. *Ecological Applications* 2:275-284.
- Goldin, Meryl R. and Jonathan V. Regosin. 1998. Chick Behavior, habitat use, and reproductive success of piping plovers at Goosewing Beach, RI. *J. Field Ornithol.* 69(2): 228-234.
- \_\_\_\_\_, M. R., 1993a. Effects of human disturbance and off-road vehicles on piping plover reproductive success and behavior at Breezy Point, Gateway National Recreation Area, New York. M.S. Thesis, Univ. of Massachusetts, Amherst. 128 pp.
- \_\_\_\_\_, M. R., 1993b. Piping plover (*Charadrius melodus*) management, reproductive ecology, and chick behavior at Goosewing and Briggs Beaches, Little Compton, Rhode Island, 1993. Unpubl. rep. to The Nature Conservancy, Providence, RI. 64 pp.
- Haig, S. M., and L.W. Oring. 1988.. Mate, site and territory fidelity in piping plovers. *Auk* 105: 268-277.
- Haig, S.M. 1992. The piping plover. Pages 1-18 in A. Poole, P. Stettenheim, and F. Gill, ed. *Birds of North America*. American Ornithologists' Union, Washington, DC.
- Haig, S.M., and J.H. Plissner. 1993. Distribution and abundance of piping plovers: results and implications of the 1991 International Census. *Condor* 95:145-156.

- Hays, R. L., W. Seitz, and C. Summers. 1981. Estimating wildlife habitat variables. U.S. Fish and Wildlife Service, Office of Biological Services, U.S. Department of the Interior, Washington, D.C. 111pp.
- Heisey, D. M., and T. K. Fuller. 1985. Evaluation of survival and cause-specific mortality rates using telemetry data. *J. Wildl. Manage.* 49(3): 668-674.
- Johnson, C. M., and G. A. Baldassarre. 1988. Aspects of the winter ecology of piping plovers in coastal Alabama. *Wilson Bull.* 100:2 14-233.
- Kamler, J. F. and W. B. Ballard. 2002. A review of native and nonnative red foxes in North America. *Wildlife Society Bulletin* 30:370-379.
- Keane, S.E., J.D. Fraser, and P.A. Buckley. 2002. Effects of herring gulls and great black-backed gulls on breeding piping plovers, South Monomoy Island, Massachusetts. M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA 251 pp.
- \_\_\_\_\_, S.E., J.D. Fraser, and P.A. Buckley. 2004. Prenesting use of intertidal habitats by piping plovers on South Monomoy Island, Massachusetts. *J Wildl. Manage.* In press.
- Klomp, H. 1970. the determination of clutch size in birds: a review. *Ardea* 58:1-124.
- Krapu, G. L., Reynolds, R. E., Sargeant, G.A., and R. W. Renner. 2004. Patterns of variation in clutch sizes in a guild of temperate-nesting dabbling ducks *Auk*: 121, 695–706.
- Krebs, C. J. 1994. *Ecology: the experimental analysis of distribution and abundance.* Fourth edition. Harper Collins College Publishers, New York, New York, USA.
- Krebs, J. R. 1971. Territory and breeding density in the Great Tit, *Parus major*.. *Ecology* 52: 2–22.
- Lack, D. 1954. *The natural regulation of animal numbers.* Oxford University Press, London.
- Larson, M. A., Ryan, M. R. and R. K. Murphy. 2003. Assessing recovery feasibility for piping plovers using optimization and simulation. *Wildlife Society Bulletin.* 31:1105-1116.
- Larson, M. A., Ryan, M. R. and R.K. Murphy. 2002. Population viability of piping plovers: Effects of predator exclusion, *Journal-of-Wildlife-Management.* 66(2): 361-371

- Leatherman, S. P. 1982. Barrier Island Handbook, 2<sup>nd</sup> ed.. University of Md. Press, College Park.
- \_\_\_\_\_, S. P. and James R. Allen. 1985. Geomorphologic Analysis of South Shore of Long Island Barriers, New York. Report to U.S. Army Corps of Engineers, New York District, New York, New York. 292pp.
- Lehner, P. N. 1979. Handbook of ethological methods. Garland STPM Press, N.Y. 403 pp.
- Loegering, . and J. D. Fraser. 1995. Factors affecting piping plover chick survival in different brood-rearing habitats. *J. Wildl. Manage.* 59(4): 646-655.
- Marcum, C.L. and D.O. Loftsgaarden. 1980. A nonmapping technique for studying habitat preferences. *J. Wildl. Manage.* 44: 963-968.
- 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. 1975. Suggestions for calculating nest success. *Wilson Bull.* 87(4): 456-466.
- Melvin, S. M., C. R. Griffin, and L. H. MacIvor. 1991. Recovery strategies for Piping Plovers in managed coastal landscapes. *Coastal Manage.* 19:21-34.
- Melvin, S. M., L. H. MacIvor and C. R. Griffin. 1992. Predator exclosures: a technique to reduce predation at Piping Plover nests. *Wildl. Soc. Bull.* 20:143-148.
- Neu, C.W., Byers, C.R., and J.M Peek. 1974. A technique for analysis of utilization-availability data. *J. Wildl. Manage.* 38:541-545.
- Newton I. and M. Marquiss. 1984. Seasonal trend in the breeding performance of sparrowhawks. *J. Animal Ecology.* 53:809-829.
- \_\_\_\_\_, I. 1994. Experiments on the limitation of bird breeding densities: a review. *Ibis* 136: 397-411
- Nordstrom, L. M. 1990. Evaluation of Piping Plover habitat and food availability in the Great Lakes National Seashores. MS. thesis, Missouri Univ., Columbia, Missouri.
- Olsson, O., Bruun, M., and H.G. Smith. 2002. Starling foraging success in relation to agricultural land-use. *Ecography* 25:363-371.
- Patterson, M.E., J.D. Fraser, and J.W. Roggenbuck. 1991. Factors affecting piping plover productivity on Assateague Island. *J. Wildl. Manage.* 55(3): 525-531.

- Powell, A. N., and F. J. Cuthbert. 1992. Habitat and reproductive success of Piping Plovers nesting on Great Lakes islands. *Wilson Bull.* 104:155-161.
- Pulliam, H.R. 1988. Sources, sinks, and population regulation. *American Naturalist* 132:652-661.
- Ricklefs, R. E. 1990. *Ecology*. Third edition. W. H. Freeman, New York, New York, USA.
- Rimmer, D. W., Deblinger, R. D. 1990. Use of predator exclosures to protect Piping Plover nests. *J. Field Ornithol.* 61(2):217-223
- Rodenhouse, N. L., Sherry, T. W. & Holmes, R. T. 1997 Site-dependent regulation of population size: a new synthesis. *Ecology* 78, 2025-2042.
- Shaffer, F. and Pierre LaPorte. 1994. Diet of piping plovers on the Quebec (Magdalian Isles). *Wilson Bull.*, 106 (3) pp 531-536.
- Schubel, J. R., T. M. Bell, and H. H. Carter, eds. 1991. *The Great South Bay. Marine Sciences Research Center, State University of New York, Stony Brook, N.Y. State University of New York Press.* 107 pp.
- Smith, K. A., R. K. Murphy, D. L. Michaelson, and W. C. Viehl. 1993. Habitat and predation management for nesting piping plovers at Lostwood National Wildlife Refuge, North Dakota. *Prairie Naturalist* 25:139-147.
- Tanski, J. 1988. Proceedings of a Workshop. In *Westhampton Beach: Options for the Future*, convened by J. Tanski and H. Bokuniewicz. Stony Brook: New York Sea Grant.
- Tacha, T. C., P. A. Vohs, and G. C. Iverson. 1985. A comparison of interval and continuous sampling methods for behavioral observations. *J. Field Ornith.* 56: 258-264.
- Temple, S. A., and Wiens, J. A. 1989. Bird populations and environmental changes: can birds be bio-indicators?. *American Birds*, 43, pp. 260-270.
- Tyler, S. 1979. Time-sampling: a matter of convention. *Anim. Behav.* 27: 801-810.
- U.S. Army Corps of Engineers (USACE). 1994. *Fire Island to Montauk Point, New York Moriches to Shinnecock Reach, Interim plan for storm damage protection*, New York: NY District. 114pp.
- U.S. Army Corps of Engineers (USACE). 2002. *Coastal engineering manual: EM 1110-2-1100*, 30 April 2002

- U.S. Fish and Wildlife Service. 1996. Piping Plover (*Charadrius melodus*), Atlantic Coast Population, Revised Recovery Plan. Hadley, Massachusetts. 258 pp.
- U.S. Fish and Wildlife Service. 2001. 2000 status update: U.S. Atlantic Coast piping plover population, Sudbury, Massachusetts. 8 pp.
- Verbeek, N. A. M. and C. Caffrey. 2002. American Crow (*Corvus brachyrhynchos*) In, the Birds of North America, No. 647 A. Pool and F. Gill, eds.).
- Van Horne, B. 1983. Density as a misleading indicator of habitat quality. *Journal of Wildlife Management* 47:893-901.
- Whyte, A. J. 1985. Breeding ecology of the Piping Plover (*Charadrius melodus*) in central Saskatchewan. M.S. thesis, Saskatchewan Univ., Saskatoon, Saskatchewan.
- White, G.C. and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. *Bird Study* 46 Supplement, 120-138.
- Wilcox, L. 1959. A twenty year banding study of the piping plover. *Auk* 76: 129-152.

## TABLES

Table 1. Beach zones used in this paper. All zones except for dense vegetation were used by piping plovers (Elias-Gerken 1994).

---

Intertidal Zone	Bare sand zone (damp to saturated sand) found between the last high tide and the most recent tide line.
Fresh Wrack	Fresh, wet lines of organic materials (usually vegetation) deposited on the seaward edge of the backshore or throughout the intertidal zone at the peak of the last high tide, normally associated with the mean high water line. Fresh wrack typically gets washed out with the next high tide.
Backshore	A zone of dry sand, shell, cobble and beach debris (<10% vegetative cover) landward of the mean high water line and seaward of human structures, seaward of the toe of the dune, dune sparse vegetation zone, dense vegetation zone, and/or overwash corridor.
Old Wrack	Any drying organic matter, usually vegetation, dry or drying above the intertidal zone. Typically located on the backshore, or scattered throughout clumps of sparse vegetation rooted near the intertidal zone and landward of the fresh wrack.
Sparse Vegetation	A zone of vegetation, usually American Beach Grass ( <i>Ammophila breviligulata</i> ), which plover chicks can move through freely. It is characteristic of early succession found landward of the backshore, but seaward of dunes, dune vegetation, human structures, dense vegetation zone, or an overwash corridor. Percent cover generally ranges from 10-90%.
Dune	Elevated areas of dry sand deposited by wind action or human action. It is well drained, often covered with sparse vegetation.
Dune Sparse Vegetation	A zone of vegetation usually American Beach Grass ( <i>Ammophila breviligulata</i> ) which plover chicks can move through freely. It is characteristic of early succession found on dunes landward of the ocean backshore, but seaward of human structures, dense vegetation zone (late succession habitat), or an overwash corridor. Percent cover generally ranges from 10-90%.
Dense Vegetation	A zone of live or dead, thick and matted vegetation (grasses, forbs, and/or shrubs) too thick for chicks to move through. It is characteristic of mid to late succession. It is typically located in areas landward of sparse vegetation or within an old overwash corridor. Percent cover generally ranges from 90-100%.
Overwash Corridor	Typically, a bare or sparsely vegetated zone that occurs in areas adjacent to dune flanks or in areas where overwash or breaching has occurred and is often connected to or links bayside and ocean side habitats.
Ephemeral Pools	A mosaic of wetland and moist sandy/muddy areas that occur in low lying backshore areas or in interdunal corridors. Moisture content fluctuates reflecting changes in groundwater level or the affect of meteorological overwash and breaching events.

---

Table 2. Behaviors used in the analysis of piping plover brood time budgets in West Hampton Dunes, and The Reference Area, Long Island, New York, 1993-03.

Behavioral Categories used in the analyses	Behaviors or Behavioral Sequences recorded in the field
Foraging	Run/Peck, Stand/Peck, Glean, Aerial Snap, Foot Tremble, Foraging Run <sup>a</sup> , Foraging Walk <sup>a</sup> , Foraging Stand <sup>a</sup> , Probe.
Disturbed	Anxious, Uneasy, Unsettled, Distracted, (Disturbed Run, Disturbed Sit, Disturbed Walk, and Disturbed Stand), Crouched.
Resting	Brood, Preen
Other	Undisturbed, Non-Foraging Stand, Run, Walk, Fly, Hop

<sup>a</sup>run, walk, or stand between foraging attempts.

Table 3. Structure of piping plover population growth models fit to observed data, West Hampton Dunes and Westhampton Beach, Long Island, New York.

Model	Model Structure <sup>a</sup>
Exponential, Observed Prod, 0 Imm	$N_{t+1} = N_t + rN_t$ , r varies annually with observed productivity
Logistic, Observed Prod, 0 Imm	$N_{t+1} = N_t + rN_t(1 - N_t/K_t)$ , r varies annually with observed productivity
Exponential, 0 Imm	$N_{t+1} = N_t + rN_t$ , r based on productivity of 1.31 fledges/pair
Logistic, 0 Imm	$N_{t+1} = N_t + rN_t(1 - N_t/K_t)$ , r based on productivity of 1.31 fledges/pair
Exponential, DI Imm <sup>b</sup>	$N_{t+1} = N_t + rN_t + (5 \text{ in } 1994, 2 \text{ in subsequent years})$
Logistic, DI Imm	$N_{t+1} = N_t + rN_t(1 - N_t/K_t) + (5 \text{ in } 1994, 3 \text{ in subsequent years})$
Exponential, DD Imm <sup>c</sup>	$N_{t+1} = N_t + rN_t + [0.2728(K_{t+1} - rN_t) - 3.7811]$
Logistic, DD Imm	$N_{t+1} = N_t + rN_t(1 - N_t/K_t) + \{0.2355 [K_{t+1} - rN_t(1 - N_t/K_t)] - 2.1477\}$

<sup>a</sup> K = Ha of nesting habitat measured on aerial photos, varies by year. Imm = Immigration, Prod = Productivity. DD = Density Dependent,

<sup>b</sup>For density independent (DI) immigration models, we added a constant number of immigrants per year regardless of carrying capacity. We determined this constant through trial and error, changing the number up or down until the model trajectory was as close as possible to the observed trajectory. We added more immigrants (5 immigrants) in the first year (1994) than in subsequent years (3 immigrants, in the logistic model, and 2 immigrants in the exponential model) to adjust for the large population increase immediately after colonization.

<sup>c</sup>For density dependent (DD) immigration models, we fit a line to the relationship between  $N_{\text{observed}} - N_{\text{estimated before immigration}}$  (the estimated number of immigrants each year) and  $K - N_{\text{estimated before immigration}}$  (the estimated "space" left after return of surviving breeders and recruits). We used the fitted lines to add immigrants each year based on the K for that year and the estimated population size before immigration.

Table 4. Hypothetical life table used to calculate intrinsic rate of increase ( $r$ ) for piping plovers at West Hampton Dunes, New York, 1993-2004.

Age (x)	Survival ( $l_x$ )	Fecundity( $m_x$ )	( $l_x m_x$ )
0	1.00	0.00	0.000
1	0.48	0.33	0.157
2	0.36	0.66	0.233
3	0.26	0.66	0.172
4	0.19	0.66	0.127
5	0.14	0.66	0.094
6	0.11	0.66	0.070
7	0.08	0.66	0.052
8	0.06	0.66	0.038
9	0.04	0.66	0.028
10	0.03	0.66	0.021
11	0.02	0.66	0.015
12	0.02	0.66	0.011
13	0.01	0.66	0.008
14	0.01	0.66	0.006
15	0.01	0.66	0.005
		$R_0$	1.039
		$\ln(R_0)$	0.038

Table 5. Definitions of piping plover vital rates, West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2004.

Vital Rate	Definition
Nest	A scrape with at least one egg
Clutch size	Number of eggs laid in a single nesting
Egg survival	Number of eggs hatched/total eggs laid
Nest survival	Number of nests where at least one egg hatched/total nests
Chick Survival	Number of chicks fledged/chicks
Brood Survival	Number of broods where at least one chick fledged/total broods
Egg Hatchability Rate	Number of eggs that hatch from non-abandoned clutches/(total eggs laid in non-abandoned clutches – total eggs lost to predators, tides, or weather prior to the expected hatch date)
Renest rate	Number of renests/total nests
Eggs hatched per pair	Number of eggs hatched/total number of pairs
Nests hatched per pair	Number of nests in which at least 1 egg hatched/total number of pairs
Broods fledged per pair	Number of broods in which at least 1 chick fledged/total number of pairs
Reproductive output	Chicks fledged/pair

Table 6. Mean number of arthropods captured in cover types in West Hampton Dunes and The Reference Area, Westhampton Island, Long Island, New York, 1993-2003.

Year	Ocean Habitats															Bay Habitats																			
	Intertidal Zone			Fresh Wrack			Back Shore			Old Wrack			Sparse Veg			Dune Sp. Veg			Intertidal zone			Fresh Wrack			Back Shore			Old Wrack			Sparse Veg				
	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$
1993	8	3.0	1.7	8	6.3	1.2	8	6.7	1.9	8	4.7	1.8	.	.	.	.	.	.	4	13.1	1.7	5	20.1	7.3	.	.	.	.	.	.	.	.	4	6.1	2.2
1994	8	6.7	2.5	8	9.6	3.0	8	1.6	0.5	8	2.1	0.9	.	.	.	.	.	.	8	17.1	5.3	8	17.6	4.8	.	.	.	.	.	.	.	5	7.4	2.5	
1995	13	10.5	2.1	13	10.4	2.0	13	3.2	0.8	13	4.3	0.7	.	.	.	13	2.2	1.0	13	15.1	3.8	13	15.2	3.7	13	2.1	0.4	13	8.0	1.8	13	3.2	1.0		
1996	14	7.6	1.8	14	7.3	1.7	14	3.8	1.2	14	4.1	1.1	.	.	.	14	0.0	0.0	14	13.2	2.9	14	7.0	1.7	14	2.3	0.8	14	3.9	0.9	14	3.6	0.7		
1997	30	6.5	1.4	30	9.9	2.0	30	6.0	2.0	29	7.8	2.2	.	.	.	30	4.7	1.2	24	17.0	4.0	26	16.3	2.8	25	2.7	0.7	26	12.7	4.0	26	3.7	0.5		
1998	21	5.4	1.4	21	8.1	1.7	21	2.2	0.6	19	5.4	1.2	.	.	.	21	4.9	1.0	19	17.8	3.3	19	20.2	3.5	18	2.7	0.8	19	6.8	1.3	19	3.8	0.7		
1999	17	9.2	2.6	18	9.4	2.4	18	3.6	0.9	18	6.3	1.5	17	3.7	0.9	18	5.6	1.0	16	17.0	3.9	16	15.9	3.5	16	2.3	0.6	16	9.9	2.0	16	3.5	0.7		
2000	15	11.1	3.2	15	10.8	3.2	15	5.5	2.4	14	10.1	3.4	15	5.3	2.4	15	5.7	1.4	14	13.7	4.1	13	14.7	3.8	15	4.8	1.9	14	9.4	2.6	15	5.3	1.1		
2001	10	11.2	3.9	10	12.4	4.3	10	1.9	0.7	10	4.1	1.6	10	3.0	1.2	10	2.7	1.2	5	23.8	14.1	5	15.1	8.1	5	6.5	3.1	4	2.1	1.3	5	3.0	1.4		
2002	10	9.4	4.0	10	8.3	3.3	10	2.1	0.8	10	2.3	1.2	10	5.3	1.3	10	6.1	1.5	5	16.1	8.6	5	12.2	6.4	5	7.1	3.3	5	6.3	3.7	5	5.0	1.5		
2003	9	11.1	5.0	9	14.6	6.4	9	4.5	2.0	9	5.5	2.6	9	5.9	2.0	9	5.7	1.5	5	19.9	10.7	5	19.1	9.2	5	7.8	4.3	5	6.2	2.6	5	3.7	1.3		
93-04 <sup>a</sup>	11	8.3BC	0.8	11	9.7B	0.7	11	3.7D	0.5	11	5.2D	0.7	5	4.6D	0.6	9	4.2D	0.7	11	16.7A	0.9	11	15.8A	1.1	9	4.3D	0.8	9	7.3C	1.1	11	4.4D	0.4		

<sup>a</sup>Test among cover types:  $F_{10,98} = 22.57$ ,  $P < 0.001$ , cover types with the same letter are not significantly different

\*Site:  $F_{1,130} = 0.11$ ,  $P = 0.743$ , Year:  $F_{8,130} = 5.49$ ,  $P < 0.001$

\*\* Global test for each cover type (years): Ocean Intertidal Zone ( $F_{11,143} = 0.96$ ,  $P = 0.485$ ), Ocean Fresh Wrack ( $F_{11,144} = 0.31$ ,  $P = 0.983$ ), Ocean Back Shore ( $F_{11,144} = 1.00$ ,  $P = 0.448$ ), Ocean Old Wrack ( $F_{11,140} = 0.63$ ,  $P = 0.805$ ), Ocean Sparse Vegetation ( $F_{5,55} = 0.65$ ,  $P = 0.664$ ), Dunes Sparse Vegetation ( $F_{9,130} = 6.54$ ,  $P < 0.001$ ), Bay Intertidal Zone ( $F_{10,116} = 0.52$ ,  $P = 0.877$ ), Bay Fresh Wrack ( $F_{10,118} = 0.98$ ,  $P = 0.468$ ), Bay Back Shore ( $F_{8,107} = 0.99$ ,  $P = 0.449$ ), Bay Old Wrack ( $F_{8,107} = 1.19$ ,  $P = 0.314$ ), Bay Sparse Vegetation ( $F_{10,116} = 0.73$ ,  $P = 0.696$ )

Table 7. Human and cat trail indices in cover types used for nesting, West Hampton Dunes and The Reference Area, Westhampton Island, Long Island, New York, 1996-2003. Means are equal to the percent of substrate covered by trails within each cover type.

	Year	n	WHD				The Reference Area				
			Human		Cat		Human		Cat		
			$\bar{x}$ (%)	SE	$\bar{x}$ (%)	SE	$\bar{x}$ (%)	SE	$\bar{x}$ (%)	SE	
Ocean backshore <sup>a</sup>	1996	15	5.14	1.59	0.10	0.06					
	1997	19	16.81	4.63	0.14	0.08	17	36.11 A <sup>f</sup>	6.73	0.88 A	0.21
	1998	18	6.66	1.92	0.21	0.11	15	9.80 B	4.47	0.38 B	0.22
	1999	18	7.81	2.38	0.05	0.03	17	13.53 AB	3.19	0.22 B	0.08
	2000	20	7.33	1.97	0.20	0.08	19	8.94 B	2.65	0.11 B	0.04
	2002	6	13.31	7.17	0.50	0.23	6	15.99 B	10.03	0.48 B	0.38
	2003	6	22.05	11.61	0.37	0.30	5	22.44 AB	10.72	1.09 B	1.09
	96-03	7	11.30	1.41	0.22	0.04	6	17.80	1.41	0.53	0.15
Dune sparse vegetation <sup>b</sup>	1997	18	1.29	0.63	0.21	0.10	17	1.21	0.19	5.10 A <sup>f</sup>	0.51
	1998	18	1.62	0.57	0.76	0.38	5	0.60	0.60	2.43 B	2.24
	1999	18	2.34	0.27	0.13	0.06	1	0.00	0.00	0.84 B	0.00
	2000	20	2.24	0.83	0.50	0.16	17	1.14	0.37	0.85 B	0.31
	2002	6	2.06	1.06	2.40	0.92	5	0.11	0.11	1.17 B	0.73
	2003	6	1.87	1.08	1.17	0.86	5	1.27	0.91	2.36 AB	1.18
	97-03	6	1.90	0.13	0.86	0.16	6	0.72	0.14	2.12	0.33
Ocean sparse vegetation <sup>c</sup>	1999	15	2.44	0.88	0.10 B <sup>f</sup>	0.10	16	7.62	1.76	0.98 C <sup>f</sup>	0.43
	2000	20	1.60	0.93	0.21 B	0.15	19	4.15	1.46	0.47 BC	0.19
	2002	6	5.71	3.91	2.61 A	1.31	5	7.46	6.77	3.38 AB	2.24
	2003	6	10.49	7.05	0.73 A	0.32	5	2.29	1.68	1.60 A	0.63
	99-03	4	5.06	1.47	0.91	0.28	4	5.38	1.29	1.61	0.47
Bay backshore <sup>d</sup>	1996	15	1.24 C <sup>f</sup>	0.48	0.33 A <sup>f</sup>	0.08					
	1997	19	8.43 AB	2.12	0.15 ABC	0.07					
	1998	18	7.10 A	1.94	0.47 ABC	0.16					
	1999	18	8.70 A	1.97	0.11 ABC	0.05					
	2000	20	10.93 A	2.24	0.05 C	0.02					
	2002	6	7.94 C	7.48	1.51 AB	0.90					
	2003	6	2.30 BC	1.07	0.79 BC	0.79					
		96-03	7	6.66	0.87	0.49	0.14				
Bay sparse vegetation <sup>e</sup>	1996	15	1.72 C <sup>f</sup>	1.72	0.00 C <sup>f</sup>	0.00					
	1997	19	1.86 BC	0.88	0.25 B	0.11					
	1998	18	1.40 BC	0.57	1.01 AB	0.49					
	1999	17	2.71 AB	0.64	0.29 BC	0.11					
	2000	20	5.71 A	1.30	0.10 BC	0.05					
	2002	6	2.40 AB	1.37	1.08 A	0.42					
	2003	6	8.98 BC	6.54	0.32 AB	0.19					
		96-03	7	3.54	0.80	0.44	0.07				

<sup>a</sup>Ocean Backshore: WHD, Human, Year ( $F_{6,95} = 0.46$ ,  $P = 0.835$ ), Cat, Year ( $F_{6,95} = 1.39$ ,  $P = 0.225$ ), Reference Area, Human, Year ( $F_{5,73} = 3.22$ ,  $P = 0.011$ ), Cat, Year ( $F_{5,73} = 5.67$ ,  $P < 0.001$ ),

<sup>b</sup>Dune Sparse Vegetation: WHD, Human, Year ( $F_{5,80} = 2.02$ ,  $P = 0.084$ ), Cat, Year ( $F_{5,80} = 2.03$ ,  $P = 0.083$ ), Reference Area, Human, Year ( $F_{5,44} = 2.00$ ,  $P = 0.098$ ), Cat, Year ( $F_{5,44} = 8.28$ ,  $P < 0.001$ ),

<sup>c</sup>Ocean Sparse Vegetation: WHD, Human, Year ( $F_{3,43} = 0.76$ ,  $P = 0.520$ ), Cat, Year ( $F_{3,43} = 5.57$ ,  $P = 0.003$ ), Reference Area, Human, Year ( $F_{3,41} = 1.44$ ,  $P = 0.245$ ), Cat, Year ( $F_{3,41} = 3.10$ ,  $P = 0.037$ ),

<sup>d</sup>Bay Backshore: WHD, Human, Year ( $F_{6,95} = 5.69$ ,  $P < 0.001$ ), Cat, Year ( $F_{6,95} = 2.21$ ,  $P = 0.049$ )

<sup>e</sup>Bay Sparse Vegetation: WHD, Human, Year ( $F_{6,94} = 5.10$ ,  $P < 0.001$ ), Cat, Year ( $F_{6,94} = 3.34$ ,  $P = 0.005$ ),

<sup>f</sup>Years with the same letter are not significantly different.

Table 8. Correlation of population growth and piping plover vital rates with population density (pairs/ha) West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2004.

Vital Rate	<i>n</i>	WHD		Reference Area	
		<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
Population size year t+1	9	0.579	0.102	0.448	0.227
Population rate of increase	9	-0.814	0.008	-0.525	0.147
First nest clutch size	10	0.029	0.937	-0.514	0.128
Second nest clutch size	10	-0.610	0.061	-0.236	0.542
Renest rate	10	0.590	0.073	0.062	0.865
Fertility	10	-0.054	0.883	0.039	0.916
Egg survival	10	-0.155	0.669	0.279	0.436
Nest survival	10	-0.161	0.658	0.159	0.660
Chick survival	10	0.096	0.792	0.559	0.093
Brood survival	10	0.010	0.978	0.460	0.181
Chicks fledged/pair (Reproductive output)	10	0.031	0.946	0.243	0.500
Estimated immigration rate	11	-0.799	0.003	0.313	0.349

Table 9. Percent availability of cover types and percent use by **foraging adult piping plovers**. Surveys were conducted within 3 hours of high and low tides during the pre-nesting season in West Hampton Dunes and The Reference Area, Westhampton Island, Long Island, New York, March–May, 1997–2003.

Site	Tide	Cover types	% Availability					% Use				
			<i>n</i>	$\bar{x}$	SE	LCL	UCL	<i>n</i>	$\bar{x}$	SE	LCL	UCL
WHD	High	Ocean intertidal zone	6	7.35	1.03	4.69	10.01	6	12.16	4.20	1.37	22.94
		Ocean fresh wrack	6	0.30	0.12	0.00	0.61	6	6.72	2.86	0.00	14.08
		Ocean backshore <sup>b</sup>	6	16.45	1.66	12.19	20.70	6	4.40 <sup>b</sup>	2.78	0.00	11.55
		Ocean old wrack	6	0.14	0.10	0.00	0.40	6	3.70	2.70	0.00	10.63
		Dunes sparse vegetation	6	11.20	1.09	8.39	14.00	6	0.00	0.00	0.00	0.00
		Ocean sparse vegetation	6	3.44	1.84	0.00	8.18	6	0.18	0.18	0.00	0.63
		Bare Dune	6	0.88	0.82	0.00	2.98	6	0.00	0.00	0.00	0.00
		Bay intertidal zone <sup>a</sup>	6	24.21	1.65	19.97	28.45	6	70.60 <sup>a</sup>	4.26	59.66	81.54
		Bay fresh wrack	6	0.10	0.09	0.00	0.34	6	0.28	0.19	0.00	0.78
		Bay backshore <sup>b</sup>	6	19.15	5.21	5.75	32.55	6	0.93 <sup>b</sup>	0.93	0.00	3.31
	Low	Bay old wrack	6	0.13	0.08	0.00	0.34	6	0.23	0.23	0.00	0.83
		Bay sparse vegetation <sup>b</sup>	6	16.65	1.03	14.01	19.30	6	0.81 <sup>b</sup>	0.58	0.00	2.28
		Ocean intertidal zone	7	8.50	1.33	5.25	11.76	7	9.24	2.98	1.94	16.54
		Ocean fresh wrack	7	1.16	0.70	0.00	2.88	7	1.99	1.09	0.00	4.65
		Ocean backshore <sup>b</sup>	7	15.37	1.71	11.18	19.57	7	1.29 <sup>b</sup>	0.96	0.00	3.65
		Ocean old wrack	7	0.11	0.08	0.00	0.30	7	0.49	0.32	0.00	1.28
		Dunes sparse vegetation	7	10.45	0.64	8.88	12.03	7	0.00	0.00	0.00	0.00
		Ocean sparse vegetation	7	2.98	1.24	0.00	6.00	7	0.03	0.03	0.00	0.11
		Bare Dune	7	0.81	0.64	0.00	2.39	7	0.00	0.00	0.00	0.00
		Bay intertidal zone <sup>a</sup>	7	29.85	1.78	25.49	34.22	7	85.41 <sup>a</sup>	3.16	77.68	93.15
Reference area	High	Bay fresh wrack	7	0.08	0.04	0.00	0.19	7	0.55	0.53	0.00	1.84
		Bay backshore <sup>b</sup>	7	17.03	4.80	5.29	28.77	7	0.63 <sup>b</sup>	0.43	0.00	1.68
		Bay old wrack	7	0.09	0.06	0.00	0.23	7	0.23	0.15	0.00	0.61
		Bay sparse vegetation <sup>b</sup>	7	13.56	1.33	10.29	16.82	7	0.12 <sup>b</sup>	0.12	0.00	0.40
		Ocean intertidal zone	6	18.79	2.13	13.32	24.27	6	47.59	11.77	17.35	77.84
		Ocean fresh wrack <sup>a</sup>	6	0.56	0.23	0.00	1.16	6	26.92 <sup>a</sup>	7.75	7.01	46.84
	Low	Ocean backshore	6	34.87	3.34	26.29	43.45	6	4.31 <sup>b</sup>	2.89	0.00	11.75
		Ocean old wrack	6	0.33	0.23	0.00	0.93	6	17.54	16.51	0.00	59.99
		Dunes sparse vegetation <sup>b</sup>	6	27.18	7.32	8.35	46.01	6	0.29 <sup>b</sup>	0.29	0.00	1.04
		Ocean sparse vegetation	6	18.26	7.25	0.00	36.90	6	3.33	3.33	0.00	11.90
Bare Dune		6	0.00	0.00	0.00	0.00	6	0.00	0.00	0.00	0.00	
Ocean intertidal zone <sup>a</sup>		7	24.04	4.17	13.83	34.25	7	68.93 <sup>a</sup>	11.69	40.34	97.52	
Ocean fresh wrack		7	0.76	0.27	0.09	1.43	7	13.11	8.97	0.00	35.07	
Ocean backshore		7	33.40	3.82	24.05	42.75	7	14.91	4.09	4.89	24.93	
Ocean old wrack		7	0.29	0.21	0.00	0.81	7	2.12	1.44	0.00	5.65	
Dunes sparse vegetation <sup>b</sup>		7	24.96	5.21	12.20	37.71	7	0.71 <sup>b</sup>	0.71	0.00	2.46	
Ocean sparse vegetation <sup>b</sup>		7	15.16	4.86	3.26	27.07	7	0.22 <sup>b</sup>	0.22	0.00	0.75	
Bare Dune		7	1.38	1.38	0.00	4.77	7	0.00	0.00	0.00	0.00	

<sup>a</sup>% use greater than expected based on % availability

<sup>b</sup>% use less than expected based on % availability

Table 10. Percent use of beach cover types by **resting adult piping plovers**, surveys within 3 hours of high and low tides during the pre-nesting season in West Hampton Dunes and The Reference Area, Westhampton Island, Long Island, New York, March–May, 1997–2003 (% availability of cover types, see table 7).

Site	Tide	Cover types	n	% Use			
				$\bar{x}$	SE	LCL	UCL
WHD	High	Ocean intertidal zone	6	12.69	8.07	0.00	33.44
		Ocean fresh wrack <sup>c</sup>	6	0.00 <sup>c</sup>	0.00	0.00	0.00
		Ocean back shore	6	43.29	9.89	17.87	68.70
		Ocean old wrack	6	4.27	2.74	0.00	11.30
		Dune sparse vegetation <sup>b</sup>	6	1.11 <sup>b</sup>	1.11	0.00	3.97
		Ocean sparse vegetation	6	6.98	4.42	0.00	18.33
		Bare Dune <sup>c</sup>	6	0.00 <sup>c</sup>	0.00	0.00	0.00
		Bay intertidal zone	6	16.61	6.00	1.20	32.02
		Bay fresh wrack <sup>c</sup>	6	0.00 <sup>c</sup>	0.00	0.00	0.00
		Bay back shore	6	14.75	8.66	0.00	37.02
		Bay old wrack <sup>c</sup>	6	0.00 <sup>c</sup>	0.00	0.00	0.00
		Bay sparse vegetation <sup>b</sup>	6	0.31 <sup>b</sup>	0.31	0.00	1.10
	Low	Ocean intertidal zone <sup>b</sup>	7	1.31 <sup>b</sup>	1.18	0.00	4.19
		Ocean fresh wrack <sup>c</sup>	7	0.00 <sup>c</sup>	0.00	0.00	0.00
		Ocean back shore <sup>a</sup>	7	51.37 <sup>a</sup>	11.31	23.69	79.06
		Ocean old wrack	7	2.94	2.94	0.00	10.12
		Dune sparse vegetation <sup>b</sup>	7	0.29 <sup>b</sup>	0.29	0.00	1.00
		Ocean sparse vegetation	7	6.95	5.21	0.00	19.71
		Bare Dune <sup>c</sup>	7	0.00 <sup>c</sup>	0.00	0.00	0.00
		Bay intertidal zone	7	30.65	13.62	0.00	63.97
		Bay fresh wrack <sup>c</sup>	7	0.00 <sup>c</sup>	0.00	0.00	0.00
		Bay back shore	7	5.42	3.05	0.00	12.89
		Bay old wrack <sup>c</sup>	7	0.00 <sup>c</sup>	0.00	0.00	0.00
		Bay sparse vegetation <sup>b</sup>	7	1.06 <sup>b</sup>	0.94	0.00	3.36
Reference area	High	Ocean intertidal zone <sup>b</sup>	6	4.61 <sup>b</sup>	2.28	0.00	10.46
		Ocean fresh wrack <sup>c</sup>	6	0.00 <sup>c</sup>	0.00	0.00	0.00
		Ocean backshore	6	71.14	13.23	37.14	105.14
		Ocean old wrack	6	5.08	3.44	0.00	13.92
		Dunes sparse vegetation	6	1.39	1.39	0.00	4.96
		Ocean sparse vegetation	6	17.79	9.40	0.00	41.95
	Low	Bare Dune <sup>c</sup>	6	0.00 <sup>c</sup>	0.00	-	-
		Ocean intertidal zone <sup>b</sup>	7	2.38 <sup>b</sup>	2.38	0.00	8.21
		Ocean fresh wrack	7	3.57	3.57	0.00	12.31
		Ocean back shore <sup>a</sup>	7	70.55 <sup>a</sup>	7.90	51.21	89.89
		Ocean old wrack	7	4.51	2.97	0.00	11.77
		Dune sparse vegetation <sup>b</sup>	7	4.67 <sup>b</sup>	2.64	0.00	11.14
	Ocean sparse vegetation	7	14.32	9.52	0.00	37.62	
	Bare Dune <sup>c</sup>	7	0.00 <sup>c</sup>	0.00	-	-	

<sup>a</sup>% use greater than expected based on % availability

<sup>b</sup>% use less than expected based on % availability

<sup>c</sup>not used

Table 11. Distance (m) from plover nests to ocean high tide line, bay high tide line, nearest neighboring first nest attempt, and between first nest attempts and re-nests, West Hampton Dunes and The Reference Area, Westhampton Island, Long Island, New York, 1993-2004.

Distance to:	<i>n</i>	$\bar{x}$	SE	Min	Max
Ocean side high tide line <sup>a</sup>					
WHD	377	135.42	7.06	5	555
The Reference Area	187	66.98	3.51	0	411
Bay side high tide line <sup>b</sup>					
WHD	377	148.29	5.10	4	635
The Reference Area	187	241.67	6.19	41	484
Nearest neighbor					
WHD	311	84.07	5.87	2	1067
The Reference Area	156	193.84	17.67	17	1249
Dense vegetation					
WHD	377	185.96	11.52	0	1124
The Reference Area	186	98.96	6.67	0	448
First re-nest <sup>c</sup>					
WHD	77	70.62	16.23	0	1268
The Reference Area	51	78.22	17.73	1	839
Second re-nest <sup>d</sup>					
WHD	10	82.20	29.24	17	271
The Reference Area	8	107.58	36.75	1	344
Second re-nest from first re-nest <sup>e</sup>					
WHD	10	75.20	27.96	9	292
The Reference Area	8	68.75	25.93	1	193

<sup>a</sup>( $W = 41,790$ ,  $P < 0.001$ )

<sup>b</sup>( $W = 72,202$ ,  $P < 0.001$ )

<sup>c</sup>( $W = 3169$ ,  $P = 0.560$ )

<sup>d</sup>( $W = 90$ ,  $P = 0.247$ )

<sup>e</sup>( $W = 71$ ,  $P = 0.694$ )

Table 12. Piping plover nest distribution West Hampton Dunes, Long Island, New York, 1993-2004.

Year	Ocean nests		Bay nests		All nests
	<i>n</i>	%	<i>n</i>	%	<i>n</i>
1993	1	20.0	4	80.0	5
1994	4	25.0	12	75.0	16
1995	4	15.4	22	84.6	26
1996	3	14.3	18	85.7	21
1997	7	22.6	24	77.4	31
1998	6	22.2	21	77.8	27
1999	14	40.0	21	60.0	35
2000	32	59.3	22	40.7	54
2001	36	76.6	11	23.4	47
2002	41	82.0	9	18.0	50
2003	46	93.9	3	6.1	49
2004	22	100.0	0	0.0	22

Table 13. Mean distance (m) of piping plover nests to nearest neighboring piping plovers nest by year, West Hampton Dunes and The Reference Area, Long Island, New York, 1994-2003.

Year	Sites pooled			WHD			Reference area		
	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE
1994	20	214 A <sup>a</sup>	35.93	12	138 A <sup>a</sup>	48.19	8	327 A <sup>a</sup>	14.42
1995	25	88 BC	14.57	17	64 CD	6.51	8	139 BC	38.90
1996	28	183 BC	52.34	20	119 ABC	50.55	8	345 ABC	120.03
1997	31	137 CD	41.61	26	101 CD	31.13	5	328 AB	195.39
1998	35	128 BC	19.46	25	103 ABC	17.63	10	194 BC	47.74
1999	43	95 BC	9.73	32	87 ABC	11.83	11	121 BC	14.37
2000	52	65 D	7.67	38	53 D	8.47	14	97 C	13.92
2001	52	83 C	7.95	37	71 BC	6.50	15	114 C	20.80
2002	54	85 BC	8.77	34	66 CD	7.23	20	118 BC	18.31
2003	40	120 B	16.24	27	90 AB	7.89	13	182 BC	41.31
1994-03	380	109	6.71	268	84	6.07	112	172	16.11

<sup>a</sup>Years with the same letter are not significantly different

Table 14. Nest characteristics of piping plovers in West Hampton Dunes and The Reference Area, Westhampton Island, Long Island, New York, 1993-2004.

Nest Characteristic	WHD		Reference Area		Site comparison	
	<i>n</i>	%	<i>n</i>	%	$\chi^2_1$	<i>P</i>
Shell lining <sup>a</sup>						
Yes	301	78.6	117	60.0		
No	82	21.4	78	40.0	22.31	<0.001
Substrate <sup>b</sup>						
Shell	11	3.0	6	3.1		
Cobble	119	31.0	54	27.4		
Sand	254	66.2	137	69.5	0.46	0.495
In vegetation <sup>c</sup>						
Yes	139	36.2	90	45.7		
No	245	63.8	107	54.3	4.90	0.026
Topography <sup>d</sup>						
Flat	299	77.9	141	71.6		
Moderate Slope	78	20.3	54	27.4		
Steep Slope	7	1.8	2	1.0	4.11	0.127

<sup>a</sup>Shell lining: WHD ( $\chi^2_1=125.2$ ,  $P < 0.001$ ), Reference Area ( $\chi^2_1=7.8$ ,  $P = 0.005$ )

<sup>b</sup>Substrate: WHD ( $\chi^2_2=231.6$ ,  $P < 0.001$ ), Reference Area ( $\chi^2_2=133.8$ ,  $P < 0.001$ )

<sup>c</sup>Vegetation: WHD ( $\chi^2_1=29.26$ ,  $P < 0.001$ ), Reference Area ( $\chi^2_1=1.47$ ,  $P = 0.226$ )

<sup>d</sup>Topography (<7.5% slope = 0,  $\geq 7.5\%$  slope = 1): WHD ( $\chi^2_1=362.36$ ,  $P < 0.001$ ), Reference Area ( $\chi^2_2=150.2$ ,  $P < 0.001$ )

Table 15. Temperature (C) and precipitation (cm), from NOAA weather station, Westhampton, New York (approximately 3 miles from West Hampton Dunes and The Reference Area), 1993-2004.

YEAR	Mean Maximum Temperature (°C)					Total Precipitation (cm)					
	April	May	June	July	August	April	May	June	July	August	
1993	15	23	27	30	29	26	4	16	15	8	
1994	17	21	29	31	27	14	18	1	5	47	
1995	16	21	26	30	30	16	19	17	10	5	
1996	15	22	27	27	28	41	23	19	31	18	
1997	15	20	27	30	28	22	16	12	16	26	
1998	15	23	25	29	28	48	44	43	20	6	
1999	17	22	28	32	28	12	23	5	24	53	
2000	15	22	27	27	27	38	27	27	30	16	
2001	17	22	27	27	29	11	42	39	22	31	
2002	17	21	26	30	29	22	29	31	8	20	
2003	14	18	23	27	28	35	14	21	7	7	
2004	14	20	24	26	26	17	8	3	7	11	
93-04	$\bar{x}$	15.6	21.3	26.3	28.8	28.1	25.2	22.3	19.5	16.3	20.7
	SE	0.3	0.5	0.5	0.6	0.3	3.9	3.5	4.0	2.8	4.9
	Min	14	18	23	26	26	11	4	1	5	5
	Max	17	23	29	32	30	48	44	43	31	53

Table 16. Logistic regression model of piping plover mean clutch size vs. days after January 1st nest was initiated, and nest order, West Hampton Dunes and The Reference Area, Long Island, New York, 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	-2loglik	AIC <sub>C</sub>	$\Delta_i$	$w_i$
1 <sup>ab</sup>	Nest initiation date	-0.04	0.01	<0.001	443	2	403.82	407.85	0.000	0.733
	intercept	7.37	1.07	<0.001						
2	Nest initiation date, nest order	NC <sup>c</sup>	NC	NC	443	3	403.82	409.87	2.023	0.267
Null					443	1	438.88	440.89	33.042	0.000

<sup>a</sup>Global model,  $\chi^2_{2} = 35.06$ ,  $p = <0.001$ .

<sup>b</sup>For best model, % Concordant = 67.5, % Discordant = 30.9, % Tied = 1.6

<sup>c</sup>Not calculated

Table 17. Linear regression model of piping plover mean annual egg survival of unexclosed nests versus mean maximum daily temperature and total precipitation April through July, nesting pair density, and number cats and foxes trapped, West Hampton Dunes and The Reference Area, Long Island, New York, 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Site	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	P	n	k	SSE	AIC <sub>C</sub>	$\Delta_i$	wi	Adj R <sup>2</sup>	
WHD <sup>a</sup>	1	Mean max monthly temp, total precip, # fox trapped	-	-	0.003	10	5	0.04	-30.75	0.000	0.336	0.834	
		Intercept	-3.03	0.57	0.002								
		Mean max monthly temperature	0.14	0.02	0.001								
		Total precipitation	6.83E-05	1.97E-05	0.013								
		# foxes trapped	0.03	0.01	0.015	10	3	0.19	-29.43	1.323	0.173	0.363	
	2	Mean max monthly temperature, total precip	nc <sup>c</sup>	nc	nc	10	4	0.11	-29.10	1.657	0.147	0.587	
	3	Mean max monthly temperature, # fox trapped	nc	nc	nc	10	4	0.11	-28.76	1.991	0.124	0.573	
	Null					10	2	0.34	-28.04	2.719	0.086	-	
Reference Area <sup>b</sup>	Null					10	2	0.13	-37.81	0.000	0.297	-	
		1	Mean maximum monthly temperature				10	3	0.09	-36.88	0.922	0.187	0.196
		2	# cats trapped				10	3	0.09	-36.65	1.151	0.167	0.178

<sup>a</sup>Global Model,  $F_{5,4}=8.15$ ,  $P = 0.032$ ,  $R^2 = 0.9106$ ,  $Adj R^2 = 0.7988$ .

<sup>b</sup>Global Model,  $F_{5,4}=1.39$ ,  $P = 0.387$ ,  $R^2 = 0.6343$ ,  $Adj R^2 = 0.1772$ .

<sup>c</sup>Not calculated

Table 18. Linear regression model of piping plover egg survival of unexclosed nests vs. nest fenced (Y/N), nest substrate topography, nest in vegetation (Y/N), nest lining, distance to bay high tide line, distance to nearest neighboring nest, distance to dense vegetation, days after January 1st nest was initiated, West Hampton Dunes and The Reference Area, Long Island, New York, 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Model <sup>a</sup>	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	n	k	SSE	AIC <sub>C</sub>	$\Delta_i$	$w_i$	Adj R <sup>2</sup>
1	Nest fenced, nest lined, distance bay high tide line, distance to dense vegetation	-	-	<0.001	342	6	4409908.37	3249.13	0.000	0.096	0.080
	Intercept	165.46	24.77	<0.001							
	Nest fenced	0.11	0.06	0.063							
	Nest lined	0.18	0.07	0.008							
	Distance to bay high tide line	-0.13	0.05	0.016							
	Distance to dense vegetation	0.14	0.05	0.006							
2	Nest fenced, nest lined, distance to bay high tide line, distance to dense vegetation, Nest in vegetation	NC <sup>b</sup>	NC	NC	342	7	4390155.11	3249.68	0.549	0.073	0.081
3	Nest lined, distance to bay high tide line, distance to dense vegetation	NC	NC	NC	342	5	4455532.48	3250.58	1.448	0.046	0.073
4	Nest fenced, nest lined, distance to bay high tide line, distance to dense vegetation, nest initiation date	NC	NC	NC	342	7	4404434.05	3250.79	1.660	0.042	0.078
5	Nest fenced, nest lined, distance to bay high tide line, distance to dense vegetation, Topography	NC	NC	NC	342	7	4406941.99	3250.98	1.854	0.038	0.078
6	Nest fenced, nest lined, distance to bay high tide line, distance to dense vegetation, topography, nest in veg	NC	NC	NC	342	8	4380312.10	3251.01	1.879	0.037	0.081
Null		-	-	-	342	2	4850254.00	3273.46	24.332	0.000	-

<sup>a</sup>Global Model:  $F_{8,333} = 4.56$   $p < 0.001$ ,  $R^2 = 0.0988$ ,  $\text{Adj } R^2 = 0.0772$ .

<sup>b</sup>Not calculated

Table 19. Piping plover annual nest survival and reneest rate for nests on the bay side and ocean side West Hampton Dunes, Long Island, New York, 1993-2003.

Vital Rate		Ocean				Bay			
		<i>n</i>	$\bar{x}$	SE	Par $\chi^{2b}$	<i>n</i>	$\bar{x}$	SE	Par $\chi^{2b}$
Nest Survival <sup>a</sup>	1993	1	1.00	-	-	4	0.75	0.25	0.470
	1994	4	0.75	0.25	0.718	12	0.58	0.15	0.000
	1995	4	0.00	0.00	4.674	22	0.27	0.10	8.578
	1996	3	0.33	0.33	0.510	18	0.83	0.09	4.714
	1997	7	0.71	0.18	0.867	24	0.67	0.10	0.726
	1998	6	1.00	0.00	5.135	21	0.71	0.10	1.536
	1999	14	0.86	0.10	5.708	21	0.76	0.10	2.828
	2000	32	0.63	0.09	0.956	22	0.36	0.10	4.263
	2001	36	0.64	0.08	1.450	11	0.55	0.16	0.057
	2002	41	0.56	0.08	0.081	9	0.44	0.18	0.688
	2003	46	0.24	0.06	16.631	3	0.33	0.33	0.755
	93-03 <sup>c</sup>	194	0.54	0.04		167	0.58	0.04	
Renest Rate <sup>d</sup>	1993	1	-	-		1	0.00	-	
	1994	4	0.00	0.00		5	0.60	0.22	
	1995	2	0.50	0.25		15	0.40	0.13	
	1996	2	0.00	0.00		3	0.33	0.27	
	1997	2	0.50	0.35		8	0.50	0.18	
	1998	0	-	-		6	0.33	0.19	
	1999	2	1.00	0.00		5	0.20	0.18	
	2000	11	0.82	0.12		14	0.21	0.11	
	2001	12	0.50	0.14		5	0.60	0.22	
	2002	17	0.76	0.10		5	0.40	0.22	
	2003	35	0.60	0.08		2	0.50	0.35	
	93-03 <sup>e</sup>	86	0.52	0.11		69	0.37	0.06	

<sup>a</sup>Nest survival = Ocean side (Year:  $\chi^2_9 = 36.7$ ,  $P < 0.001$ ), Bay side (Year:  $\chi^2_{10} = 24.6$ ,  $P = 0.006$ )

<sup>b</sup>Par = Partial

<sup>c</sup>Nest Survival: Ocean vs. Bay,  $\chi^2_1 = 4.9$ ,  $P = 0.027$

<sup>d</sup>Renest Rate = Ocean side (Year:  $\chi^2_8 = 5.64$ ,  $P = 0.688$ ), Bay side (Year:  $\chi^2_{10} = 7.36$ ,  $P = 0.691$ )

<sup>e</sup>Renest Rate: Ocean vs. Bay,  $\chi^2_1 = 2.0$ ,  $P = 0.157$

Table 20. Linear regression model of piping plover mean annual nest survival of unexclosed nests versus mean maximum daily temperature and total precipitation April through July, nesting pair density, and number cats and foxes trapped, West Hampton Dunes and The Reference Area, Long Island, New York, 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	SSE	AIC <sub>C</sub>	$\Delta_i$	<i>w<sub>i</sub></i>	Adj R <sup>2</sup>
WHD <sup>a</sup>	1	Mean max temp, total precip, # fox trapped			<0.001	10	5	0.03	-32.17	0.000	0.688	0.880
		Intercept	-3.35	0.53	<0.001							
		Mean maximum temperature	0.15	0.02	0.004							
		Total precipitation	8.40E-05	1.84E-05	0.004							
		# foxes trapped	0.03	0.01	0.007							
		Null				10	2	0.41	-26.22	5.943	0.035	-
The Reference Area <sup>b</sup>	Null				10	2	0.17	-35.09	0.000	0.312	-	
	1	Mean maximum temperature	NC <sup>c</sup>	NC	NC	10	3	0.12	-34.55	0.533	0.239	0.227
		Intercept	NC	NC	NC	10	3	0.13	-33.65	1.437	0.152	0.154

<sup>a</sup>Global Model:  $F_{5,4} = 8.15$ ,  $P = 0.032$ ,  $R^2 = 0.9106$ , Adj  $R^2 = 0.7988$ .

<sup>b</sup>Global Model:  $F_{5,4} = 1.39$ ,  $P = 0.387$ ,  $R^2 = 0.6343$ , Adj  $R^2 = 0.1772$ .

<sup>c</sup>Not calculated

Table 21. Logistic regression model of piping plover nest survival of unexclosed nests vs. nest fenced (Y/N), nest substrate topography, nest in vegetation (Y/N), nest lining, distance to bay high tide line, distance to nearest neighboring nest, distance to dense vegetation, days after January 1st nest was initiated, West Hampton Dunes and The Reference Area, Long Island, New York, 1994-2003 with sites pooled. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. Likelihood analysis table for best model is shown.

Model <sup>a</sup>	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	P	n	k	-2loglik	AIC <sub>C</sub>	$\Delta_i$	$w_i$
1 <sup>b</sup>	Nest fenced, nest lined, distance to bay high tide line, distance to dense vegetation, distance to nearest neighbor			<0.001	342	6	431.06	443.31	0.000	0.268
	Intercept	-0.58	0.36	0.112						
	Nest fenced	0.50	0.26	0.052						
	Distance to dense vegetation	1.34E-03	6.84E-04	0.050						
	Distance to bay high tide line	-1.94E-03	1.25E-03	0.121						
	Distance to nearest neighbor	-1.27E-03	8.05E-04	0.116						
	Nest lined	1.00	0.28	0.003						
2	Fenced, nest lined, distance to nearest neighbor, distance to dense veg	NC	NC	NC	342	5	433.49	443.67	0.366	0.223
3	Nest lined, distance to nearest neighbor, dist to dense veg	NC	NC	NC	342	4	435.78	443.90	0.596	0.199
	Nest fenced, nest lined, distance to bay high tide line, dist to dense veg, distance to nearest neighbor, nest in veg	NC <sup>c</sup>	NC	NC	342	7	430.31	444.64	1.335	0.137
5	Nest fenced, nest lined, distance to bay high tide line, distance to dense veg, dist to nearest neighbor, topography	NC	NC	NC	342	8	429.35	445.78	2.471	0.078
6	Nest lined, distance to dense vegetation	NC	NC	NC	342	3	440.53	446.60	3.296	0.052
7	Nest fenced, nest lined, distance to bay high tide line, distance to dense veg, distance to nearest neighbor, topography, nest initiation date	NC	NC	NC	342	9	429.19	447.13	3.828	0.040
8	Nest lined	NC	NC	NC	342	2	447.72	451.75	8.445	0.004
Null					342	1	469.42	471.46	28.153	0.000

<sup>a</sup>Global Model  $\chi^2_8 = 40.23$ ,  $P = <0.001$ .

<sup>b</sup>For best model, % Concordant = 68.5, % Discordant = 31.1, % Tied = 0.3

<sup>c</sup>Not calculated

Table 22. Logistic regression model of piping plover re-nest rate vs. nest location (ocean or bay), nest enclosed (yes or no), nest fenced (yes or no), nest predated by mammal (yes or no), nest predated by bird (yes or no), nest initiation date, West Hampton Dunes and The Reference Area, Long Island, New York, 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown.  $\chi^2$  table for best model is shown.

Model <sup>a</sup>	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	-2loglik	AIC <sub>C</sub>	$\Delta_i$	$w_i$
1 <sup>b</sup>	Nest Initiation Date	8.79E-06	3.80E-06	0.021	247	2	331.69	335.74	0.000	0.411
	Intercept	-0.58	0.36	0.111						
2	Nest Initiation Date, Nest Predated by Mammal	NC <sup>c</sup>	NC	NC	247	3	330.33	336.43	0.687	0.292
3	Nest Initiation Date, Nest Predated by Bird	NC	NC	NC	247	3	331.35	337.35	1.610	0.184
	Null				247	1	337.44	349.44	13.699	0.000

<sup>a</sup>Global model,  $\chi^2_5 = 2.3057$ , *P* = 0.805.

<sup>b</sup>For best model, % Concordant = 47.3, % Discordant = 33.6, % Tied = 19.1

<sup>c</sup>Not calculated

Table 23. Logistic regression model of piping plover re-nest rate vs nest initiation date, a) mean number of pedestrians, gulls, other potential disturbances within 100 meters of nests, b) the proportion of observations in which at least 1 pedestrian, gull or other potential disturbance was present within 100 m of nests, West Hampton Dunes, Long Island, New York, 1997-2000. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown.  $\chi^2$  table for best model is shown.

a)

Model <sup>a</sup>	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	P	n	k	-2loglik	AIC <sub>C</sub>	$\Delta_i$	$w_i$
1 <sup>b</sup>	Nest initiation date, mean no. gulls w/in 100m	-	-	<0.001	75	3	82.78	89.12	0.000	0.434
	Intercept	10.59	2.89	<0.001						
	Nest initiation date	-0.08	0.02	<0.001						
	Mean no. gulls w/in 100m	0.50	0.30	0.092						
2	Nest initiation date	NC <sup>a</sup>	NC	NC	75	2	85.68	89.84	0.728	0.301
Null		NC	NC	NC	75	1	103.85	106.02	16.903	0.059

b)

Model <sup>c</sup>	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	P	n	k	-2loglik	AIC <sub>C</sub>	$\Delta_i$	$w_i$
1 <sup>d</sup>	Nest initiation date	-0.08	0.02	<0.001	75	2	85.68	89.84	0.000	0.708
	Intercept	9.34	2.67	<0.001						
2	Nest initiation date, % observation > 1 gull seen	NC <sup>e</sup>	NC	NC	75	3	85.48	91.82	1.978	0.263
Null		NC	NC	NC	75	1	103.85	106.02	16.175	0.000

<sup>a</sup>Global model, a)  $\chi^2_4 = 21.5434$ ,  $P < 0.001$

<sup>b</sup>For best model, a) % Concordant = 77.3, % Discordant = 22.2, % Tied = 0.6

<sup>c</sup>Global model, b)  $\chi^2_2 = 18.4448$ ,  $P < 0.001$

<sup>d</sup>For best model, b) % Concordant = 76.7, % Discordant = 21.1, % Tied = 2.2

<sup>e</sup>Not calculated

Table 24. Piping Plover nest survival in relation to mean number of potential disturbances within 100 meters of piping plover nests and proportion of observations in which at least 1 potential disturbance was present within 100 m of nests, West Hampton Dunes and The Reference Area, Long Island, New York 1993-2003.

Variable	<i>n</i>	Pedestrian		Gulls		Crows		Dogs		Least terns	
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
WHD											
Mean number of disturbances											
Survived	97	0.28	0.07	0.56	0.13	0.03	0.01	0.01	0.00	1.23	0.31
Failed	48	0.38	0.21	0.49	0.13	0.02	0.01	0.00	0.00	1.30	0.55
Proportion of observations											
Survived	97	0.07	0.01	0.14	0.02	0.02	0.00	0.00	0.00	0.13	0.03
Failed	48	0.07	0.02	0.16	0.03	0.02	0.01	0.00	0.00	0.13	0.04
Reference area											
Mean number of disturbances											
Survived	31	0.69	0.15	0.62	0.16	0.01	0.00	0.07	0.02	1.42	0.48
Failed	28	0.51	0.13	0.38	0.19	0.02	0.01	0.02	0.01	1.97	0.78
Proportion of observations											
Survived	31	0.15	0.02	0.12	0.02	0.00	0.00	0.05	0.01	0.19	0.06
Failed	28	0.14	0.03	0.10	0.03	0.01	0.01	0.02	0.01	0.18	0.06

Mean number of disturbances: WHD, Pedestrians,  $t_{57} = -0.45$ ,  $P = 0.657$ , Gulls,  $t_{121} = 0.38$ ,  $P = 0.701$ , Crows,  $t_{96} = 1.08$ ,  $P = 0.283$ , Dogs,  $t_{91} = 0.56$ ,  $P = 0.579$ , Least terns,  $t_{78} = -0.11$ ,  $P = 0.910$ , The Reference Area, Pedestrians,  $t_{57} = 0.93$ ,  $P = 0.357$ , Gulls,  $t_{54} = 0.96$ ,  $P = 0.339$ , Crows,  $t_{34} = -1.24$ ,  $P = 0.224$ , Dogs,  $t_{42} = 2.32$ ,  $P = 0.026$ , Least terns,  $t_{45} = -0.60$ ,  $P = 0.549$

Proportion of observations: WHD, Pedestrians,  $t_{77} = 0.24$ ,  $P = 0.809$ , Gulls,  $t_{74} = -0.53$ ,  $P = 0.599$ , Crows,  $t_{98} = -0.02$ ,  $P = 0.983$ , Dogs,  $t_{96} = 0.65$ ,  $P = 0.518$ , Least terns,  $t_{99} = -0.19$ ,  $P = 0.849$ , The Reference Area, Pedestrians,  $t_{43} = 0.13$ ,  $P = 0.900$ , Gulls,  $t_{45} = 0.81$ ,  $P = 0.421$ , Crows,  $t_{34} = -1.30$ ,  $P = 0.203$ , Dogs,  $t_{48} = 2.25$ ,  $P = 0.029$ , Least terns,  $t_{56} = 0.21$ ,  $P = 0.83$

Table 25. Results of contracted predator trapping at West Hampton Dunes and The Reference Area, Long Island, New York, 1996-2004.

Predator	WHD						The Reference Area		Total
	1996	1997	1998	1999	2000	2001	2002 <sup>a</sup>	2004	1996-04
Raccoons	5	1	0	3	6	0	0	0	15
Opossum	4	4	0	4	11	1	2	0	26
Feral Cats	2	1	0	9	7	5	2	18	44
Adult Foxes									
Male	0	1	1	0	0	0	0	0	2
Female	1	0	0	0	0	0	0	0	1
Pregnant Female	0	1	0	0	0	1	0	0	2
Nursing Female	1	1	0	0	0	0	0	0	2
Yearling Foxes									
Male	2	1	0	0	0	0	0	0	3
Female	0	0	0	0	0	0	0	0	0
Fox Pups								0	
Male	3	3	0	0	0	0	0	0	6
Female	0	1	0	0	0	0	0	0	1
Total foxes	7	8	1	0	0	1	0	0	17

<sup>a</sup>Limited trapping was done in WHD in 2002, no trapping occurred there in WHD in 2003-2004 or in The Reference Area in 2003.

Table 26. Regression results for predation frequency vs. piping plover nesting pair density, West Hampton Dunes and Westhampton Beach, Westhampton Island, Long Island, New York, 1994-2003.

Predation source	Site	<i>n</i>	$F_{1,8}$	<i>P</i>	$r^2$
Fox	WHD	10	0.92	0.367	0.1027
	Reference Area	10	8.30	0.020	0.5093
Cat	WHD	10	8.25	0.021	0.5076
	Reference Area	10	1.00	0.346	0.1114
Crow	WHD	10	0.56	0.476	0.0653
	Reference Area	10	0.71	0.424	0.0815
Gull	WHD	10	0.04	0.850	0.0048
	Reference Area	10	NC <sup>a</sup>	NC	NC
All mammals	WHD	10	0.20	0.670	0.0238
	Reference Area	10	0.49	0.504	0.0576
All birds	WHD	10	0.66	0.441	0.0759
	Reference Area	10	0.29	0.604	0.0351

<sup>a</sup>Not calculated – No data

Table 27. Percent survival of exclosed vs unexclosed piping plover nests West Hampton Dunes and The Reference Area, Westhampton Island, Long Island, New York, 1993 -2004.

Year	Exclosed	WHD <sup>a</sup>			The Reference Area <sup>b</sup>		
		<i>n</i>	% survival	SE	<i>n</i>	% survival	SE
1993	Yes	0	-	-	3	100.0	0.00
	No	5	80.0	20.00	19	21.1	9.61
1994	Yes	5	80.0	20.00	2	100.0	0.00
	No	12	58.3	14.86	8	25.0	16.37
1995	Yes	8	0.0	0.00	0	-	-
	No	19	36.8	11.37	8	50.0	18.90
1996	Yes	5	80.0	20.00	2	100.0	0.00
	No	17	76.5	10.60	8	25.0	16.37
1997	Yes	2	50.0	50.00	1	100.0	0.00
	No	29	69.0	8.74	9	33.3	16.67
1998	Yes	0	-	-	6	66.7	21.08
	No	28	78.6	7.90	8	50.0	18.90
1999	Yes	0	-	-	6	83.3	16.67
	No	39	82.1	6.23	10	50.0	16.67
2000	Yes	0	-	-	6	66.7	21.08
	No	54	51.9	6.86	14	42.9	13.73
2001	Yes	0	-	-	11	54.5	15.75
	No	49	63.3	6.96	8	50.0	18.90
2002	Yes	0	-	-	1	0.0	0.00
	No	50	54.0	7.12	28	46.4	9.60
2003	Yes	8	87.5	12.50	3	33.3	33.33
	No	41	12.2	5.17	21	9.5	6.56
2004	Yes	7	100.0	0.00	6	50.0	22.36
	No	15	46.7	13.33	10	10.0	10.00
1993-04 <sup>c</sup>	Yes	35	65.7	8.14	47	66.0	7.00
	No	358	56.7	2.62	151	33.1	3.84

<sup>a</sup>WHD ( $\chi^2_1 = 1.06$ ,  $P = 0.303$ )

<sup>b</sup>Reference Area ( $\chi^2_1 = 16.00$ ,  $P < 0.001$ )

<sup>c</sup>Test with sites and years pooled: ( $\chi^2_1 = 7.38$ ,  $P = 0.007$ ).

Table 28. Causes of loss of piping plover nests at West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2003.

Site	Year	Total Nests	Cat	Crow spp.	Dog	Fox	COGR <sup>c</sup>	Gull spp.	Raccoon	Abandoned	Flood Peds <sup>d</sup>	Unid <sup>e</sup>	Total Nests Lost	
WHD (UE <sup>a</sup> )	1993	5	0	0	0	0	0	0	0	0	0	1	1	
	1994	12	0	0	0	1	0	1	0	0	0	3	5	
	1995	19	0	0	0	10	0	0	0	0	0	3	13	
	1996	17	0	0	0	2	0	0	0	1	1	0	4	
	1997	29	0	0	0	1	0	2	0	2	2	2	9	
	1998	28	0	0	0	1	0	0	2	3	0	0	6	
	1999	39	0	4	0	0	0	0	1	0	0	1	7	
	2000	54	3	0	0	1	0	2	1	13	0	0	6	26
	2001	49	1	0	0	2	0	2	0	1	1	0	11	18
	2002	50	5	0	0	9	0	1	0	3	0	0	5	23
	2003	41	1	10	2	0	2	0	0	0	0	0	21	36
2004	15	2	0	0	0	0	0	0	0	5	0	1	8	
Total	93-04	358	12	14	2	27	2	8	4	28	4	1	54	156
		% total	3.4	3.9	0.6	7.5	0.6	2.2	1.1	7.8	1.1	0.3	15.1	43.6
WHD (E <sup>b</sup> )	1993	0	-	-	-	-	-	-	-	-	-	-	-	
	1994	5	0	0	0	0	0	0	0	1	0	0	1	
	1995	8	0	0	0	8	0	0	0	0	0	0	8	
	1996	5	0	0	0	0	0	0	0	0	1	0	1	
	1997	2	0	0	0	0	0	0	0	1	0	0	1	
	1998	0	-	-	-	-	-	-	-	-	-	-	-	
	1999	0	-	-	-	-	-	-	-	-	-	-	-	
	2000	0	-	-	-	-	-	-	-	-	-	-	-	
	2001	0	-	-	-	-	-	-	-	-	-	-	-	
	2002	0	-	-	-	-	-	-	-	-	-	-	-	
	2003	8	0	0	0	0	0	0	0	1	0	0	1	
2004	7	0	0	0	0	0	0	0	0	0	0	0		
Total	93-04	35	0	0	0	8	0	0	0	3	1	0	12	
		% total	0.0	0.0	0.0	22.9	0.0	0.0	0.0	8.6	2.6	0.0	34.3	

<sup>a</sup>UE = Unexclosed<sup>b</sup>E = Exclosed<sup>c</sup>COGR = Common Grackle<sup>d</sup>unid = unidentified predators

Table 28. continued.

Site	Year	Total Nests	Cat	Crow spp.	Dog	Fox	COGR	Gull spp.	Raccoon	Abandoned	Flood Peds <sup>c</sup>	Unid <sup>d</sup>	Total nests lost	
Reference Area (UE <sup>a</sup> )	1993	19	3	5	0	0	0	1	0	1	0	2	3	15
	1994	8	0	0	0	0	0	0	0	0	0	0	6	6
	1995	8	0	0	0	0	0	0	0	0	0	0	4	4
	1996	8	0	0	0	0	0	0	0	0	0	0	6	6
	1997	9	1	3	0	0	0	0	0	1	0	1	0	6
	1998	8	0	3	0	0	0	0	0	0	0	0	1	4
	1999	10	0	1	0	0	0	0	0	1	0	0	3	5
	2000	14	1	2	0	0	0	0	0	3	0	0	2	8
	2001	8	0	0	0	0	0	0	0	0	2	0	2	4
	2002	28	3	2	0	2	1	0	0	1	3	0	3	15
	2003	21	3	3	0	0	0	0	0	0	3	0	10	19
	2004	10	0	0	0	0	0	0	0	0	5	1	2	8
Total	93-04	151	11	19	0	2	1	1	0	15	6	3	42	100
			% total	7.3	12.6	0.0	1.3	0.7	0.7	9.9	4.0	2.0	27.8	66.2
Reference Area (E <sup>b</sup> )	1993	3	0	0	0	0	0	0	0	0	0	0	0	0
	1994	2	0	0	0	0	0	0	0	0	0	0	0	0
	1995	0	-	-	-	-	-	-	-	-	-	-	-	-
	1996	2	0	0	0	0	0	0	0	0	0	0	1	1
	1997	1	0	0	0	0	0	0	0	0	0	0	0	0
	1998	6	0	0	0	0	0	0	0	2	0	0	0	2
	1999	6	0	0	0	0	0	0	0	1	0	0	0	1
	2000	6	0	0	0	0	0	0	0	2	0	0	0	2
	2001	11	0	0	0	0	0	0	0	5	0	0	0	5
	2002	1	0	0	0	0	0	0	0	1	0	0	0	1
	2003	3	0	0	0	0	0	0	0	1	1	0	0	2
	2004	6	0	0	0	0	0	0	0	1	0	0	3	4
Total	93-04	47	0	0	0	0	0	0	0	13	1	0	4	18
			% total	0.0	0.0	0.0	0.0	0.0	0.0	27.7	2.1	0.0	8.5	38.3

<sup>a</sup>UE = Unexclosed<sup>b</sup>E = Exclosed<sup>c</sup>COGR = Common Grackle<sup>d</sup>unid = unidentified predators

Table 29. Piping plover chick foraging distribution West Hampton Dunes, Long Island, New York, 1993-2004.

Year	<i>n</i>	Ocean side only	Bay side only	Ocean and bay side
1993	4	1(25%)	3(75%)	0(0%)
1994	11	1(9%)	10(91%)	0(0%)
1995	7	3(43%)	4(57%)	0(0%)
1996	17	1(6%)	16(94%)	0(0%)
1997	21	2(10%)	15(71%)	4(19%)
1998	22	5(23%)	5(23%)	12(54%)
1999	32	9(28%)	10(31%)	13(41%)
2000	28	16(57%)	5(18%)	7(25%)
2001	31	12(39%)	7(23%)	12(38%)
2002	27	17(63%)	4(15%)	6(22%)
2003	12	10(83%)	1(8%)	1(9%)
2004	14	12(86%)	0(0%)	2(14%)

Table 30. Mean proportion of time piping plover ocean-side hatched broods foraged on bay side and mean proportion of time bay-hatched broods foraged on ocean side, West Hampton Dunes, Long Island, New York, 1993-2003. ANOVA on ranks used for among-year comparisons.

Year	<sup>a</sup> Oceanside Hatched			<sup>b</sup> Bayside Hatched			
	<i>n</i>	P bay	SE	<i>n</i>	P ocean	SE	
1993	1	0.00AB <sup>c</sup>	.	3	0.04	0.04	
1994	3	0.58AB	0.30	8	0.06	0.06	
1995	0	.	.	6	0.29	0.16	
1996	1	0.04B	.	15	0.00	0.00	
1997	5	0.38AB	0.23	16	0.06	0.05	
1998	6	0.28AB	0.18	15	0.23	0.11	
1999	12	0.30AB	0.11	16	0.40	0.12	
2000	20	0.21A	0.07	8	0.30	0.16	
2001	24	0.12B	0.06	6	0.00	0.00	
2002	23	0.08B	0.05	4	0.00	0.00	
2003	11	0.08B	0.08	1	0.00	-	
93-03	106	0.19	0.03	98	0.15	0.03	P = (0.161)

<sup>a</sup>Ocean side: Year ( $F_{10,87} = 3.08$ ,  $P = 0.002$ )

<sup>b</sup>Bay side: Year ( $F_{9,96} = 1.64$ ,  $P = 0.114$ )

<sup>c</sup>Years with the same letter are not significantly different

Table 31. Average distance (m) between piping plover nest and foraging locations for broods that hatched on the ocean side vs. broods that hatched on the bay side, West Hampton Dunes, Long Island, New York, 1993-2003. Based on daily observations of broods. Wilcoxon Rank Sum Test used for within-year comparisons. ANOVA on ranks used for among-year comparisons.

Year	Ocean Side Hatched			Bay Side Hatched			
	N	$\bar{x}$	SE	N	$\bar{x}$	SE	
1993	0	.	.	3	127 A <sup>a</sup>	13.68	
1994	2	66	31.50	7	140 A	30.69	
1995	0	.	.	6	75 BC	39.24	
1996	1	51	-	14	49 BC	5.31	
1997	5	72	6.40	16	52 C	6.92	
1998	5	90	24.94	11	108 ABC	17.47	
1999	11	78	13.91	16	63 BC	9.31	
2000	18	112	24.08	8	109 AB	21.84	
2001	20	61	10.84	3	110 BC	55.08	
2002	17	58	13.64	0	.	.	
2003	7	52	18.70	0	.	.	
93-03	86	75	7.05	84	80	6.17	$P = (0.172)$

<sup>a</sup>Years with the same letter are not significantly different

<sup>b</sup>Ocean: Year ( $F_{8,77} = 1.46$ ,  $P = 0.184$ )

<sup>c</sup>Bay: Year ( $F_{8,72} = 3.48$ ,  $P = 0.002$ )

Table 32. Yearly piping plover chick activity budgets in West Hampton Dunes and The Reference Area 1997-2003.

Year	Site	N	Foraging	SE	Disturbed	SE	Resting	SE	Other	SE
1993	WHD	3	85.7	7.52	3.4	2.91	8.9	5.67	1.9	1.57
	The Reference Area	6	41.1	9.35	20.0	6.03	30.3	11.31	8.6	3.04
1994	WHD	9	77.3	4.99	6.1	2.68	8.5	3.81	8.1	1.99
	The Reference Area		.	.	.	.	.	.	.	.
1995	WHD	6	82.5	4.37	0.3	0.20	1.0	0.76	16.2	4.01
	The Reference Area		.	.	.	.	.	.	.	.
1996	WHD	17	82.5	5.30	4.4	1.59	10.0	5.10	3.0	0.85
	The Reference Area		.	.	.	.	.	.	.	.
1997	WHD	21	81.5	2.29	2.4	0.59	11.6	1.85	4.5	1.58
	The Reference Area	4	77.1	13.77	3.1	1.46	11.2	6.47	8.5	6.90
1998	WHD	19	43.3	5.52	23.3	4.57	21.6	5.77	11.8	2.16
	The Reference Area	7	36.6	7.82	13.3	5.78	11.8	4.42	38.3	11. 77
1999	WHD	29	58.2	2.72	8.7	1.96	16.5	1.92	16.6	1.51
	The Reference Area	10	37.5	3.19	18.6	4.79	21.5	4.18	22.4	5.44
2000	WHD	27	46.6	3.58	6.0	1.52	22.4	3.18	25.0	1.99
	The Reference Area	10	25.8	8.04	3.7	2.50	37.8	9.52	32.8	7.07
2001	WHD	23	77.5	3.84	2.8	0.80	14.3	3.54	5.5	2.19
	The Reference Area	10	75.6	7.73	3.7	2.06	13.8	4.14	6.9	3.48
2002	WHD	18	61.8	5.96	11.6	3.46	21.9	4.96	4.7	1.29
	The Reference Area	11	72.0	7.29	12.0	5.52	8.0	6.00	8.0	2.90
2003	WHD	10	37.3	6.54	2.3	1.37	48.4	6.51	11.9	3.59
	The Reference Area	2	37.9	0.45	6.8	1.49	26.5	3.67	28.7	1.73
93-03	WHD	182	63.6	1.80	7.4	0.86	17.7	1.40	11.2	0.83
	The Reference Area	60	51.1	3.74	10.5	1.79	19.7	2.78	18.7	2.63

Table 33. Least-squares (LS) mean piping plover chick foraging rates (pecks/min), chicks age 3-25 days, West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2003.

Cover types	Foraging Rate					
	<i>n</i>	WHD <sup>a</sup>		Reference Area <sup>b</sup>		
		LS $\bar{x}$	LS SE	<i>n</i>	LS $\bar{x}$	LS SE
Ocean Intertidal Zone	86	4.1 B <sup>c</sup>	0.52	35	4.3 A <sup>c</sup>	0.65
Ocean Fresh Wrack	74	3.7 BC	0.56	36	4.5 A	0.64
Ocean Backshore	95	1.2 E	0.49	53	1.9 B	0.50
Ocean Old Wrack	79	3.2 BC	0.54	44	2.9 AB	0.58
Dune sparse vegetation	30	0.2 E	0.83	20	0.9 B	0.90
Ocean sparse vegetation	55	1.3 DE	0.65	27	1.2 B	0.75
Bay Intertidal Zone	97	7.4 A	0.49			
Bay Fresh Wrack	67	3.0 BCD	0.59			
Bay Backshore	56	1.0 E	0.65			
Bay Old Wrack	52	2.1 CDE	0.67			
Bay Sparse Vegetation	73	1.4 DE	0.56			

<sup>a</sup>WHD ( $F_{10,571}=17.07$ ,  $P < 0.001$ )

<sup>b</sup>Reference Area ( $F_{5,149}=4.53$ ,  $P < 0.001$ )

<sup>c</sup>Cover types with the same letter are not significantly different

Table 34. Percent use of beach cover types by foraging chick plovers. Use surveys conducted within 3 hours of high and low tides. Availability data is adapted from transect and Aerial photo data (see methods) in West Hampton Dunes and The Reference Area, Long Island, New York, May-August, 1993-2003.

Site	Tide	Cover type	% availability					% use				
			<i>n</i>	$\bar{x}$	SE	LCL	UCL	<i>n</i>	$\bar{x}$	SE	LCL	UCL
WHD	High	Ocean intertidal zone	9	7.95	1.30	4.87	11.03	9	13.22	4.48	2.89	23.54
		Ocean fresh wrack	9	0.52	0.12	0.22	0.81	9	12.28 <sup>a</sup>	3.20	4.90	19.66
		Ocean berm	9	18.49	2.22	13.25	23.74	9	8.20	2.94	1.42	14.98
		Ocean old wrack	9	0.09	0.06	0.00	0.25	9	7.24 <sup>a</sup>	2.75	0.91	13.57
		Dunes sparse vegetation	9	9.28	2.19	4.10	14.46	9	0.31 <sup>b</sup>	0.16	0.00	0.69
		Ocean sparse vegetation	9	3.25	1.60	0.00	7.03	9	4.48	2.80	0.00	10.93
		Bay intertidal zone	9	23.44	1.29	20.38	26.50	9	28.68	6.52	13.65	43.72
		Bay fresh wrack	9	0.07	0.04	0.00	0.17	9	12.18 <sup>a</sup>	4.02	2.92	21.44
		Bay berm	9	23.04	5.16	10.83	35.25	9	4.36 <sup>b</sup>	2.03	0.00	9.03
		Bay old wrack	9	0.08	0.06	0.00	0.22	9	3.50 <sup>a</sup>	0.87	1.50	5.50
	Bay sparse vegetation	9	13.49	2.18	8.32	18.65	9	5.56	1.92	1.14	9.98	
	Low	Ocean intertidal zone	11	8.55	0.87	6.59	10.51	11	11.19	3.78	2.77	19.61
		Ocean fresh wrack	11	1.00	0.38	0.13	1.87	11	10.54 <sup>a</sup>	3.85	1.97	19.12
		Ocean berm	11	16.74	1.77	12.73	20.75	11	8.23	2.87	1.83	14.62
		Ocean old wrack	11	0.07	0.04	0.00	0.16	11	7.03 <sup>a</sup>	3.08	0.17	13.89
		Dunes sparse vegetation	11	7.52	1.70	3.67	11.36	11	0.91 <sup>b</sup>	0.43	0.00	1.86
		Ocean sparse vegetation	11	2.61	1.03	0.29	4.93	11	4.09	2.21	0.00	9.01
		Bay intertidal zone	11	31.57	2.42	26.08	37.05	11	40.40	8.77	20.86	59.95
		Bay fresh wrack	11	0.08	0.05	0.00	0.21	11	8.23 <sup>a</sup>	2.17	3.40	13.07
		Bay berm	11	20.41	4.07	11.20	29.63	11	2.80 <sup>b</sup>	1.47	0.00	6.08
Bay old wrack		11	0.08	0.05	0.00	0.19	11	2.99 <sup>a</sup>	0.76	1.30	4.69	
Bay sparse vegetation	11	11.22	1.88	6.97	15.46	11	3.58 <sup>b</sup>	1.46	0.32	6.84		
Reference Area	High	Ocean intertidal zone	7	16.86	2.15	11.61	22.12	7	23.71	9.89	0.00	47.91
		Ocean fresh wrack	7	3.36	2.24	0.00	8.83	7	18.64	4.89	6.68	30.60
		Ocean berm	7	39.00	3.11	31.38	46.62	7	19.04	5.24	6.20	31.87
		Ocean old wrack	7	0.24	0.17	0.00	0.64	7	25.11 <sup>a</sup>	8.82	3.52	46.70
		Dunes sparse vegetation	7	26.56	5.60	12.85	40.27	7	4.85 <sup>b</sup>	2.48	0.00	10.93
		Ocean sparse vegetation	7	13.98	5.86	0.00	28.32	7	8.65	5.26	0.00	21.52
	Low	Ocean intertidal zone	8	21.11	2.30	15.66	26.56	8	22.56	6.78	6.54	38.59
		Ocean fresh wrack	8	4.17	2.62	0.00	10.36	8	12.05	3.32	4.20	19.89
		Ocean berm	8	35.23	2.45	29.43	41.02	8	27.16	4.90	15.58	38.75
		Ocean old wrack	8	0.24	0.17	0.00	0.64	8	27.20 <sup>a</sup>	8.82	6.33	48.07
		Dunes sparse veg	8	0.83	0.83	0.00	2.79	8	4.16 <sup>b</sup>	2.12	0.00	9.18
		Ocean sparse veg	8	25.21	4.40	14.79	35.62	8	6.87	3.36	0.00	14.82

<sup>a</sup>% use greater than expected based on % availability

<sup>b</sup>% use is less than expected based on % availability

Table 35. Piping plover annual chick and brood survival for broods foraging on the bay side, ocean side or both the ocean and bay side ( $n$  = number of broods), West Hampton Dunes, Long Island, New York, 1993-2004.

Vital Rate	Foraging on Ocean side			Foraging on Bay side				Foraging on Both sides			All Chicks			
	$n$	$\bar{x}$	SE	$n$	$\bar{x}$	SE	Partial $\chi^2$	$n$	$\bar{x}$	SE	$n$	$\bar{x}$	SE	
Chick survival <sup>a</sup>	1993	1	1.00	.	3	0.11 F <sup>b</sup>	0.11	-	0	-	-	4	0.33	0.24
	1994	1	0.00	.	9	0.50 BDEC	0.10	-	0	-	-	11	0.41	0.10
	1995	3	0.33 B <sup>b</sup>	0.22	3	0.17 EF	0.17	-	0	-	-	7	0.25	0.13
	1996	1	0.00	.	15	0.73 AB	0.05	-	0	-	-	17	0.69	0.07
	1997	2	0.50 AB	0.50	15	0.87 A	0.04	-	4	0.58	0.25	21	0.78	0.07
	1998	5	0.43 B	0.19	4	0.38 CDEF	0.14	-	12	0.26	0.08	22	0.33	0.07
	1999	8	0.91 A	0.05	10	0.61 ABC	0.11	-	10	0.51	0.11	32	0.66	0.06
	2000	16	0.53 AB	0.13	5	0.60 ABCD	0.13	-	7	0.70	0.10	28	0.58	0.08
	2001	11	0.38 B	0.11	6	0.24 DEF	0.15	-	12	0.55	0.11	31	0.42	0.07
	2002	17	0.69 AB	0.07	4	0.00 F	0.00	-	6	0.28	0.16	27	0.50	0.08
	2003	10	0.45 B	0.12	1	0.00	-	-	1	0.33	-	12	0.40	0.11
	2004	12	0.42 B	0.10	0	-	-	-	2	0.75	0.25	14	0.46	0.10
		93-04	87	0.53	0.03	75	0.56	0.03	-	54	0.47	0.06	226	0.52
Brood Survival <sup>c</sup>	1993	1	1.00	.	3	0.33	0.33	3.996	0	-	-	4	0.50	0.29
	1994	1	0.00	.	9	0.89	0.11	0.467	0	-	-	11	0.73	0.14
	1995	3	0.67	0.33	3	0.33	0.33	3.996	0	-	-	7	0.57	0.20
	1996	1	0.00	-	15	1.00	0.00	3.814	0	-	-	17	0.88	0.08
	1997	2	0.50	0.50	15	1.00	0.00	3.814	4	0.75	0.25	21	0.90	0.07
	1998	5	0.60	0.24	4	0.75	0.25	0.055	12	0.58	0.15	22	0.64	0.10
	1999	8	1.00	0.00	10	0.90	0.10	0.653	10	0.80	0.13	32	0.88	0.06
	2000	16	0.69	0.12	5	1.00	0.00	1.271	7	1.00	0.00	28	0.82	0.07
	2001	11	0.73	0.14	6	0.33	0.21	7.992	12	0.75	0.13	31	0.65	0.09
	2002	17	1.00	0.00	4	0.00	0.00	15.733	6	0.50	0.22	27	0.74	0.09
	2003	10	0.70	0.15	1	0.00	-	-	1	1.00	-	12	0.67	0.14
	2004	12	0.75	0.13	0	-	-	-	2	1.00	0.00	14	0.79	0.11
		93-04	87	0.77	0.05	75	0.79	0.05		54	0.74	0.06	226	0.76

<sup>a</sup>Chick Survival: Ocean side, year ( $F_{8,75} = 2.15$ ,  $P = 0.042$ ), Bay side, year ( $F_{9,64} = 7.44$ ,  $P < 0.001$ ), Both sides, year ( $F_{6,45} = 1.99$ ,  $P = 0.088$ ), Ocean, bay, both sides, All years pooled ( $F_{2,207} = 0.89$ ,  $P = 0.413$ ).

<sup>b</sup>Years with the same letter are not significantly different

<sup>c</sup>Brood Survival: Ocean side, year ( $\chi^2_8 = 0.73$ ,  $P = 0.694$ ), Bay side, year ( $\chi^2_9 = 41.79$ ,  $P < 0.001$ ), Both sides ( $\chi^2_6 = 6.61$ ,  $P = 0.359$ ), Ocean, bay, both sides, All years pooled ( $P = 0.755$ )

Table 36. Linear regression model of piping plover mean chick survival vs. mean maximum daily temperature and total precipitation May through August, nesting pair density, and number cats and foxes trapped, West Hampton Dunes and The Reference Area, Long Island, New York, 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Site	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	P	n	k	SSE	AIC <sub>c</sub>	$\Delta_i$	wi	Adj R <sup>2</sup>
WHD <sup>a</sup>	1	No. foxes trapped, No. cats trapped			0.003	10	4	0.05	-37.25	0.000	0.783	0.761
		Intercept	0.35	0.04	<0.001							
		No. foxes trapped	0.03	0.01	0.009							
		No. cats trapped	0.04	0.01	0.002							
	Null					10	2	0.26	-30.69	6.557	0.030	-
The Reference Area <sup>b</sup>	1	Mean max monthly temp, No. cats trapped			0.004	10	4	0.12	-28.42	0.000	0.753	0.742
		Intercept	5.97	1.19	0.002							
		No. cats Trapped	0.06	0.01	0.006							
		Mean maximum monthly temperature	-0.21	0.05	0.003							
		Null					10	2	0.59	-22.65	5.774	0.042

<sup>a</sup>Global Model,  $F_{5,4} = 5.28$ ,  $P = 0.066$ ,  $R^2 = 0.8683$ ,  $\text{Adj } R^2 = 0.7038$ .

<sup>b</sup>Global Model,  $F_{5,4} = 7.99$ ,  $P = 0.033$ ,  $R^2 = 0.9090$ ,  $\text{Adj } R^2 = 0.7951$ .

Table 37. Piping plover brood survival in relation to mean number of potential disturbances within 100 meters of broods and proportion of observations in which at least 1 potential disturbance was present within 100 m of broods, West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2003.

Site	Variable	n	Peds		Gulls		Crows		Dogs		Least terns	
			$\bar{x}$ survival	SE	$\bar{x}$ survival	SE	$\bar{x}$ survival	SE	$\bar{x}$ survival	SE	$\bar{x}$ survival	SE
WHD	Mean disturbances											
	Survived	107	1.34	0.15	0.84	0.10	0.01	0.00	0.07	0.01	1.97	0.30
	Failed	25	1.05	0.33	0.60	0.19	0.00	0.00	0.11	0.05	0.89	0.39
	Proportion of observations											
	Survived	107	0.31	0.02	0.21	0.02	0.01	0.00	0.05	0.01	0.27	0.03
	Failed	25	0.28	0.07	0.17	0.05	0.00	0.00	0.08	0.04	0.15	0.05
Reference area	Mean disturbances											
	Survived	47	1.57	0.21	0.45	0.08	0.04	0.02	0.15	0.03	2.02	0.36
	Failed	4	1.30	0.70	0.66	0.26	0.00	0.00	0.17	0.09	0.78	0.78
	Proportion of observations											
	Survived	47	0.45	0.03	0.15	0.02	0.02	0.01	0.11	0.02	0.32	0.05
	Failed	4	0.38	0.14	0.36	0.15	0.00	0.00	0.12	0.05	0.03	0.03

Table 38. Logistic regression model of piping plover brood survival vs. chick foraging location, peck rate, % time resting, % time disturbed, % time other behaviors, days after January 1st nest hatched, West Hampton Dunes and The Reference Area, Long Island, New York, 1997-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown.

Model <sup>a</sup>	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	P	n	k	-2loglik	AIC <sub>c</sub>	$\Delta_i$	$w_i$
1 <sup>b</sup>	Peck rate, % time resting, initial brood size			0.033	218	4	150.57	158.76	0.000	0.399
	Intercept	-0.16	0.83	0.847						
	Peck rate	0.11	0.06	0.077						
	% time resting	2.49	1.42	0.078						
	initial brood size	0.35	0.22	0.114						
2	Peck rate, % time disturbed, % time resting, initial brood size	NC <sup>c</sup>	NC	NC	218	5	149.55	159.83	1.072	0.233
3	Peck rate, % time disturbed, initial brood size	NC	NC	NC	218	4	152.02	160.21	1.449	0.193
Null					218	1	163.56	165.58	6.822	0.013

<sup>a</sup>Global model,  $\chi^2_6 = 9.9845$ ,  $P = 0.125$ .

<sup>b</sup>For best model, % Concordant = 67.4, % Discordant = 31.7, % Tied = 0.8.

<sup>c</sup>Not calculated

Table 39. Logistic regression model of piping plover brood survival vs. a) mean number of pedestrians, gulls, other potential disturbances within 100 meters of nests, b) the proportion of observations in which at least 1 pedestrian, gull or other potential disturbance was present within 100 m of nests, West Hampton Dunes and The Reference Area, Long Island, New York, 1997-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown.

a)

Model <sup>a</sup>	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	-2loglik	AIC <sub>C</sub>	$\Delta_i$	<i>w<sub>i</sub></i>
1 <sup>b</sup>	mean no. other w/in 100m, initial brood size			0.018	179	3	143.76	149.89	0.000	0.387
	Intercept	-0.17	0.82	0.828						
	mean no. other w/in 100m	0.22	0.12	0.063						
	initial brood size	0.48	0.24	0.041						
2	mean no. gulls w/in 100m, mean no. other w/in 100m, initial brood size	NC	NC	NC	179	4	143.13	151.36	1.468	0.186
3	mean no. other w/in 100m	NC	NC	NC	179	2	147.75	151.82	1.922	0.148
Null					179	1	151.85	153.87	3.978	0.053

b)

Model <sup>c</sup>	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	-2loglik	AIC <sub>C</sub>	$\Delta_i$	<i>w<sub>i</sub></i>
1 <sup>d</sup>	% observations >1 other seen w/in 100m, initial brood size			0.007	179	3	141.97	148.11	0.000	0.440
	Intercept	-0.31	0.83	0.708						
	% observations >1 other seen w/in 100m	2.16	0.95	0.023						
	initial brood size	0.48	0.24	0.045						
2	% observations > 1 gull seen w/in 100m, > 1 other seen w/in 100m. initial brood size				179	4	141.62	149.85	1.740	0.184
3	% observations > 1 other seen w/in 100m				179	2	145.84	149.91	1.797	0.179
Null					179	4	154.04	153.27	5.157	0.033

<sup>a</sup>Global model, a)  $\chi^2_5 = 8.9093$ , *P* = 0.113.

<sup>b</sup>For best model, % Concordant = 59.9%, Discordant = 32.2%, Tied = 7.9.

<sup>c</sup>Global model, b)  $\chi^2_5 = 10.3919$ , *P* = 0.0649.

<sup>d</sup>For best model, % Concordant = 63.3%, Discordant = 28.7%, Tied = 8.0.

Table 40. Piping plover annual reproductive rate (chicks fledged/pair) of pairs that nested on the bay side or ocean side, West Hampton Dunes, Long Island, New York, 1993-2004.

Year	Ocean Side			Bay Side			$P^{bc}$	All		
	$n$	$\bar{x}$ (chicks/pair)	SE	$n$	$\bar{x}$ (chicks/pair)	SE		$n$	$\bar{x}$ (chicks/pair)	SE
1993	1	4.00	-	4	0.25 ED <sup>a</sup>	0.25	0.020	5	1.00	0.77
1994	4	0.75 ABC <sup>a</sup>	0.48	9	1.22 BCD	0.40	0.507	14	1.00	0.30
1995	2	0.00 C	0.00	15	0.40 ED	0.24	0.542	19	0.32	0.19
1996	2	0.00 C	0.00	17	2.06 AB	0.28	0.018	21	1.76	0.28
1997	5	1.25 ABC	0.95	19	3.00 A	0.20	0.003	26	2.71	0.28
1998	6	1.33 AB	0.33	19	0.87 ED	0.24	0.265	26	0.95	0.19
1999	12	1.75 AB	0.41	18	2.22 AB	0.34	0.378	36	1.83	0.25
2000	20	2.24 A	0.41	17	1.88 ABC	0.40	0.818	39	2.15	0.29
2001	28	1.18 ABC	0.24	8	0.63 ED	0.42	0.222	38	1.00	0.20
2002	27	1.59 AB	0.27	6	0.00 E	0.00	0.005	34	1.32	0.24
2003	25	0.52 BC	0.16	2	0.00 E	0.00	0.376	27	0.48	0.15
2004	18	1.28 ABC	0.32	0	-	-	-	18	1.28	0.32
93-04	140	1.29	0.11	134	1.47	0.13		303	1.36	0.08

\*ANOVA for test among years, Ocean side:  $F_{9,117} = 2.99$ ,  $P = 0.003$ , Bay Side:  $F_{10,107} = 10.00$ ,  $P < 0.001$

\*\*ANOVA for test among nest locations,  $F_{1,244} = 0.98$ ,  $P = 0.324$ . Pairs that had at least one nest on both the bay side and the ocean side (10 over 10 years) were excluded from the analyses due to low sample size.

<sup>a</sup>Years with the same letter are not significantly different within ocean and bay sides.

<sup>b</sup>No adult plovers nested on the bay side in 2004, therefore 2004 data were not included in the table

<sup>c</sup>Comparison between ocean side and bay side nesters within years.

Table 41. Pearson's correlations among piping plover reproductive vital rates, West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2004.

Site	Vital rate 1	Vital rate 2	<i>n</i>	<i>r</i>	<i>P</i>
WHD	Egg Survival	Chicks fledged/pair <sup>a</sup>	10	0.7411	0.014
	Egg Survival	Nest Survival	10	0.9940	<0.001
	Nest Survival	Chicks fledged/pair	10	0.6859	0.029
	Chick Survival	Chicks fledged/pair	10	0.9481	<0.001
	Chick Survival	Brood Survival	10	0.9756	<0.001
	Brood Survival	Chicks fledged/pair	10	0.9398	<0.001
The Reference Area	Egg Survival	Nest Survival	10	0.9660	<0.001
	Renest rate	Chicks fledged/pair	10	0.7171	0.010
	Chick Survival	Brood Survival	10	0.8851	<0.001

<sup>a</sup>Chicks fledged/pair = Reproductive output

Table 42. Piping plover reproductive vital rates data, West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2003.

Vital Rate	Year	WHD			Reference area				
		<i>n</i>	$\bar{x}$	SE	<i>n</i>	$\bar{x}$	SE		
Clutch size <sup>a</sup>	1993	5	4.00	0.00	A	12	3.83	0.17	AB
	1994	14	3.69	0.17	BC	8	4.00	0.00	A
	1995	18	3.94	0.06	ABC	8	3.63	0.38	AB
	1996	20	3.60	0.18	C	8	3.75	0.25	AB
	1997	26	3.88	0.08	ABC	5	3.80	0.20	AB
	1998	25	3.80	0.10	ABC	10	3.60	0.31	AB
	1999	32	3.72	0.11	ABC	11	3.73	0.19	AB
	2000	39	3.74	0.12	ABC	14	3.57	0.23	AB
	2001	37	3.97	0.03	AB	15	3.93	0.07	AB
	2002	34	3.68	0.16	ABC	20	3.35	0.25	ABC
	2003	27	3.67	0.14	ABC	13	3.38	0.27	BC
	2004	18	3.94	0.06	ABC	10	3.10	0.28	C
		93-04	295	3.79	0.04		134	3.61	0.07
Egg Survival <sup>b</sup>	1993	5	0.55	0.17	AB	22	0.22	0.08	BC
	1994	17	0.55	0.12	AB	10	0.35	0.15	ABC
	1995	27	0.21	0.08	C	8	0.38	0.16	ABC
	1996	22	0.70	0.09	AB	10	0.40	0.16	ABC
	1997	31	0.60	0.08	AB	10	0.38	0.15	ABC
	1998	28	0.66	0.08	AB	14	0.55	0.13	A
	1999	39	0.75	0.07	A	16	0.57	0.12	A
	2000	54	0.44	0.06	BC	20	0.44	0.11	AB
	2001	49	0.52	0.07	AB	19	0.47	0.11	AB
	2002	50	0.49	0.07	AB	29	0.43	0.09	AB
	2003	49	0.20	0.05	C	24	0.10	0.06	C
	2004*	22	0.59	0.10	AB	16	0.22	0.10	BC
		93-04	393	0.50	0.02		198	0.36	0.03
Fertility <sup>d</sup>	1993	4	0.69	0.12		8	0.92	0.05	
	1994	11	0.88	0.08		4	0.88	0.13	
	1995	8	1.00	0.00		5	0.75	0.18	
	1996	17	0.87	0.06		4	1.00	0.00	
	1997	22	0.85	0.05		4	1.00	0.00	
	1998	21	0.87	0.05		7	0.96	0.04	
	1999	29	0.93	0.03		10	0.92	0.04	
	2000	32	0.88	0.05		12	0.86	0.10	
	2001	31	0.89	0.05		10	0.92	0.06	
	2002	31	0.94	0.02		14	0.92	0.04	
	2003	14	0.84	0.07		7	0.83	0.08	
	2004	15	0.87	0.08		5	0.88	0.13	
		93-04	235	0.89	0.02		90	0.91	0.02

Table 42 continued. Piping plover reproductive output data, West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2003.

Vital Rate	Year	WHD				Reference area			
		<i>n</i>	$\bar{x}$	SE	Par $\chi^2$	<i>n</i>	$\bar{x}$	SE	Par $\chi^2$
Nest survival <sup>e</sup>	1993*	5	0.80	0.20	0.60	22	0.32	0.10	0.31
	1994	17	0.65	0.12	0.21	10	0.40	0.16	0.00
	1995	27	0.26	0.09	6.34	8	0.50	0.19	0.11
	1996*	22	0.77	0.09	2.02	10	0.40	0.16	0.00
	1997	31	0.68	0.09	0.76	10	0.40	0.16	0.00
	1998	28	0.79	0.08	2.92	14	0.57	0.14	0.62
	1999	39	0.82	0.06	5.53	16	0.63	0.13	1.26
	2000	54	0.52	0.07	0.41	20	0.50	0.11	0.27
	2001	49	0.63	0.07	0.38	19	0.53	0.12	0.44
	2002	50	0.54	0.07	0.15	29	0.45	0.09	0.07
	2003	49	0.24	0.06	12.57	24	0.13	0.07	3.28
	2004*	22	0.64	0.10	0.19	16	0.25	0.11	0.68
		93-04	393	0.58	0.03		198	0.41	0.04
Renest rate <sup>f</sup>	1993	1	0.00	0.00		15	0.67	0.12	
	1994	6	0.50	0.20		6	0.33	0.19	
	1995	19	0.42	0.11		4	0.00	0.00	
	1996	5	0.20	0.18		6	0.33	0.19	
	1997	9	0.56	0.17		5	0.80	0.18	
	1998	6	0.33	0.19		6	0.50	0.20	
	1999	7	0.43	0.19		5	0.80	0.18	
	2000	25	0.48	0.10		9	0.67	0.16	
	2001	17	0.53	0.12		9	0.44	0.17	
	2002	22	0.68	0.10		16	0.56	0.12	
	2003	37	0.59	0.08		21	0.52	0.11	
	2004	8	0.50	0.18		11	0.55	0.15	
		93-04	162	0.52	0.04		113	0.54	0.05
Eggs hatched/pair <sup>g</sup>	1993	5	2.20	0.66	BC	12	1.50	0.42	CD
	1994	14	2.50	0.62	AB	8	1.75	0.70	ABCD
	1995	19	1.06	0.40	C	8	1.50	0.65	ABCD
	1996	21	2.80	0.35	AB	8	1.75	0.70	ABCD
	1997	26	2.85	0.31	AB	5	3.00	0.77	AB
	1998	26	2.84	0.29	AB	11	2.73	0.54	ABC
	1999	36	3.09	0.24	A	11	3.18	0.54	A
	2000	39	2.36	0.31	AB	14	2.36	0.45	ABCD
	2001	38	2.49	0.27	AB	15	2.27	0.46	ABCD
	2002	34	2.82	0.27	AB	20	2.25	0.42	ABCD
	2003	27	1.26	0.30	C	13	0.77	0.41	D
	2004	18	2.83	0.40	AB	10	1.40	0.60	BCD
		93-04	303	2.47	0.10		135	2.02	0.16

Table 42 continued. Piping plover reproductive output data, West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2003.

Vital Rate	Year	WHD				Reference area			
		<i>n</i>	$\bar{x}$	SE		<i>n</i>	$\bar{x}$	SE	
Nests hatched/pair <sup>h</sup>	1993	5	0.80	0.20	A	12	0.58	0.15	ABC
	1994	14	0.79	0.15	A	8	0.50	0.19	ABC
	1995	19	0.37	0.11	C	8	0.50	0.19	ABC
	1996	21	0.81	0.09	A	8	0.50	0.19	ABC
	1997	26	0.81	0.08	A	5	0.80	0.20	AB
	1998	26	0.85	0.07	A	11	0.73	0.14	AB
	1999	36	0.89	0.05	A	11	0.91	0.16	A
	2000	39	0.72	0.09	AB	14	0.71	0.13	AB
	2001	38	0.82	0.06	A	15	0.67	0.13	AB
	2002	34	0.79	0.07	A	20	0.65	0.11	ABC
	2003	27	0.44	0.10	BC	13	0.23	0.12	C
	2004	18	0.78	0.10	A	10	0.40	0.16	BC
		93-04	303	0.75	0.03		135	0.60	0.04
Chick Survival <sup>i</sup>	1993	4	0.33	0.24	DE	7	0.57	0.14	ABC
	1994	11	0.41	0.10	BCDE	4	0.19	0.06	D
	1995	7	0.25	0.13	E	4	0.25	0.18	CD
	1996	17	0.69	0.07	AB	4	0.69	0.12	A
	1997	21	0.78	0.07	A	4	0.65	0.10	AB
	1998	22	0.33	0.07	DE	8	0.19	0.08	D
	1999	32	0.66	0.06	ABC	10	0.63	0.14	ABC
	2000	28	0.58	0.08	ABCD	10	0.72	0.10	A
	2001	31	0.42	0.07	BCDE	10	0.78	0.09	A
	2002	27	0.50	0.08	BCDE	13	0.62	0.08	ABC
	2003	12	0.40	0.11	CDE	3	0.89	0.11	A
2004	14	0.46	0.10	BCDE	4	0.31	0.12	BCD	
	93-04	226	0.52	0.03		81	0.57	0.04	
Chicks fledged/pair <sup>j</sup>	1993	5	1.00	0.77	BCD	12	1.57	0.37	AB
	1994	14	1.00	0.30	ED	8	0.38	0.18	D
	1995	19	0.32	0.19	E	8	1.00	0.71	ABCD
	1996	21	1.76	0.28	BC	8	1.13	0.44	ABCD
	1997	26	2.71	0.28	A	5	2.00	0.63	A
	1998	26	0.95	0.19	ED	11	0.60	0.27	BCD
	1999	36	1.83	0.25	AB	11	2.30	0.50	A
	2000	39	2.15	0.29	AB	14	1.57	0.34	ABCD
	2001	38	1.00	0.20	CD	15	1.67	0.37	ABC
	2002	34	1.32	0.24	BCD	20	1.30	0.27	ABCD
	2003	27	0.48	0.15	E	13	0.69	0.38	BCD
	2004	18	1.17	0.32	CDE	10	0.50	0.27	CD
		93-04	303	1.31	0.08		135	1.23	0.12

Table 42 continued. Piping plover reproductive output data, West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2003.

Vital Rate	Year	WHD				Reference area			
		<i>n</i>	$\bar{x}$	SE	Par $\chi^2$	<i>n</i>	$\bar{x}$	SE	Par $\chi^2$
Brood survival <sup>k</sup>	1993	4	0.50	0.29	1.14	7	0.86	0.14	0.00
	1994	11	0.73	0.14	0.05	4	0.75	0.25	0.28
	1995	7	0.57	0.20	1.05	4	0.50	0.29	3.34
	1996	17	0.88	0.08	1.05	4	1.00	0.00	0.59
	1997	21	0.90	0.07	1.81	4	1.00	0.00	0.59
	1998	22	0.64	0.10	1.43	8	0.50	0.19	6.69
	1999	32	0.88	0.06	1.74	10	0.80	0.13	0.18
	2000	28	0.82	0.07	0.43	10	1.00	0.00	1.48
	2001	31	0.65	0.09	1.74	10	1.00	0.00	1.48
	2002	27	0.74	0.09	0.05	13	0.92	0.08	0.45
	2003	12	0.67	0.14	0.45	3	1.00	0.00	0.44
	2004	14	0.79	0.11	0.04	4	0.75	0.25	0.28
	93-04	226	0.76	0.03		77	0.86	0.04	
	Broods fledged/pair <sup>l</sup>	1993	5	0.50	0.29	C	12	0.86	0.14
1994		14	0.80	0.13	ABC	8	0.75	0.25	AB
1995		19	0.57	0.20	BC	8	0.50	0.29	B
1996		21	0.88	0.08	AB	8	1.00	0.00	A
1997		26	0.90	0.07	A	5	1.00	0.00	A
1998		26	0.64	0.10	ABC	11	0.50	0.19	B
1999		36	0.88	0.06	AB	11	0.89	0.11	AB
2000		39	0.88	0.06	AB	14	1.00	0.00	A
2001*		38	0.65	0.09	ABC	15	1.00	0.00	A
2002		34	0.74	0.09	ABC	20	0.92	0.08	A
2003*		27	0.67	0.14	ABC	13	1.00	0.00	A
2004		18	0.79	0.11	ABC	10	0.75	0.25	AB
93-04		303	0.77	0.03		135	0.86	0.04	

<sup>a</sup>Clutch size = Site ( $F_{1,415} = 2.62, P = 0.011$ )

<sup>b</sup>Egg Survival = Site ( $F_{1,568} = 6.09, P = <0.001$ )

<sup>c</sup>Years with the same capital letter are not significantly different (sites pooled)

<sup>d</sup>Fertility = Site ( $F_{1,288} = 0.62, P = 0.815$ )

<sup>e</sup>Nest survival = Site ( $\chi^2_1 = 14.5, P = 0.001$ )

<sup>f</sup>Renest rate = Site ( $\chi^2_1 = 0.0009, P = 0.976$ )

<sup>g</sup>Eggs hatched/pair = Site ( $F_{1,417} = 3.19, P = 0.075$ )

<sup>h</sup>Nests hatched/pair = Site ( $F_{1,425} = 7.68, P = 0.006$ )

<sup>i</sup>Chick Survival = Site ( $F_{1,284} = 2.13, P = 0.145$ )

<sup>j</sup>Chicks fledged/pair = Site ( $F_{1,392} = 0.24, P = 0.621$ )

<sup>k</sup>Brood survival = Site ( $\chi^2_1 = 2.91, P = 0.088$ )

<sup>l</sup>Broods fledged/pair = Site ( $F_{1,290} = 4.65, P = 0.032$ )

\*Sites are significantly different ( $\alpha < 0.05$ )

Table 43. Information-theoretic results for the regression of modeled piping plover population size on observed populations size, West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2004.

Regression model structure is: " $N_{i,observed} = \beta_0 + \beta_1 N_{i,model} + \epsilon_i$ "

Model <sup>a</sup>	N	K <sup>b</sup>	SSE	AICc	$\Delta_i$	$w_i$
Logistic, DD imm <sup>c</sup>	12	3	220.286	43.920	0.000	0.513
Exponential, DD imm	12	3	223.113	44.073	0.153	0.475
Logistic, Observed Prod, 0 imm	12	3	431.719	51.994	8.074	0.009
Logistic, DI imm	12	3	577.588	55.488	11.567	0.002
Logistic, 0 imm	12	3	753.831	58.683	14.763	0.000
Exponential, DI imm	12	3	762.636	58.823	14.902	0.000
Null	12	2	1088.670	59.427	15.507	0.000

<sup>a</sup>Models "Exponential, Observed Prod, 0 Imm" and "Exponential, 0 Imm" were not included in the analysis because they behaved identically to their corresponding Logistic models.

<sup>b</sup>In this table,  $K = (2 + \text{No. of Regressors})$

<sup>c</sup>DD = Density Dependent, DI = Density Independent, Imm = Immigration, Prod = Productivity. Productivity = 1.31 fledges/pair except for the models where Productivity = Observed Productivity.

FIGURES

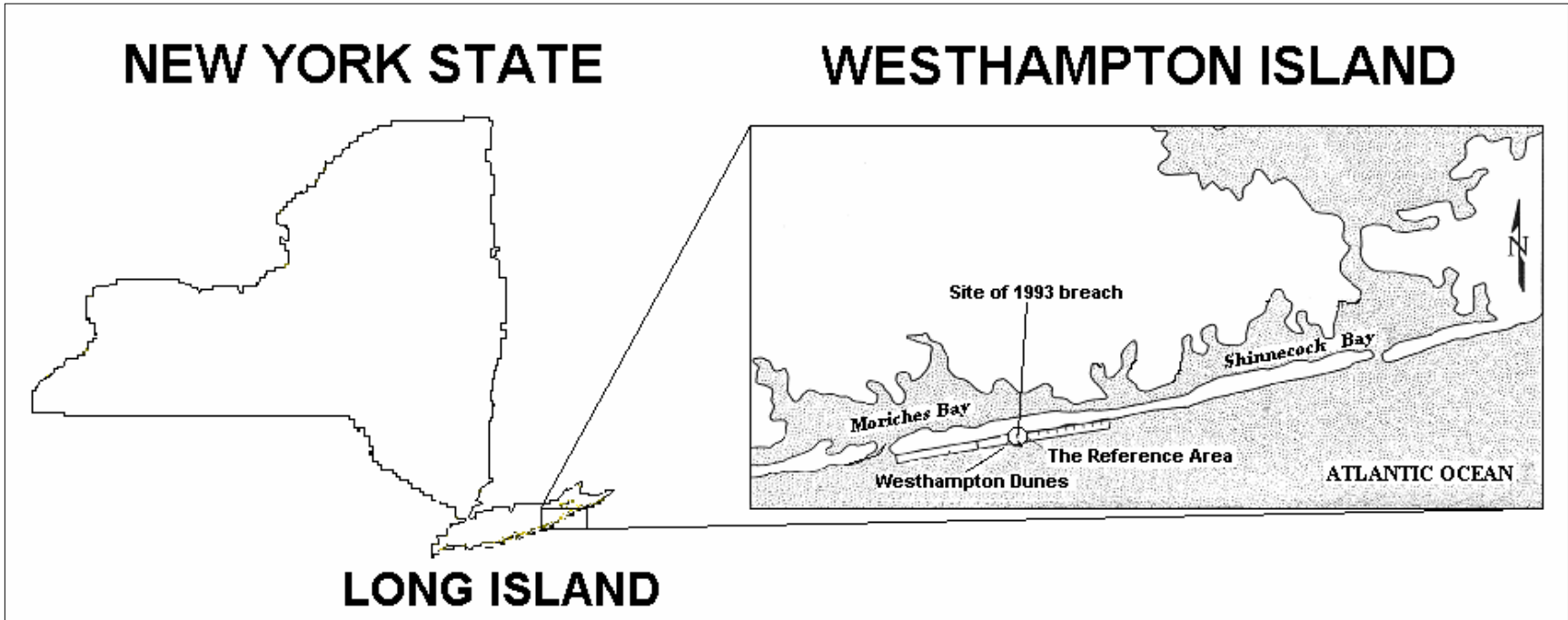


Figure 1. West Hampton Dunes and The Reference Area and vicinity, Long Island, New York (U.S. Army Corps of Engineers 1980)

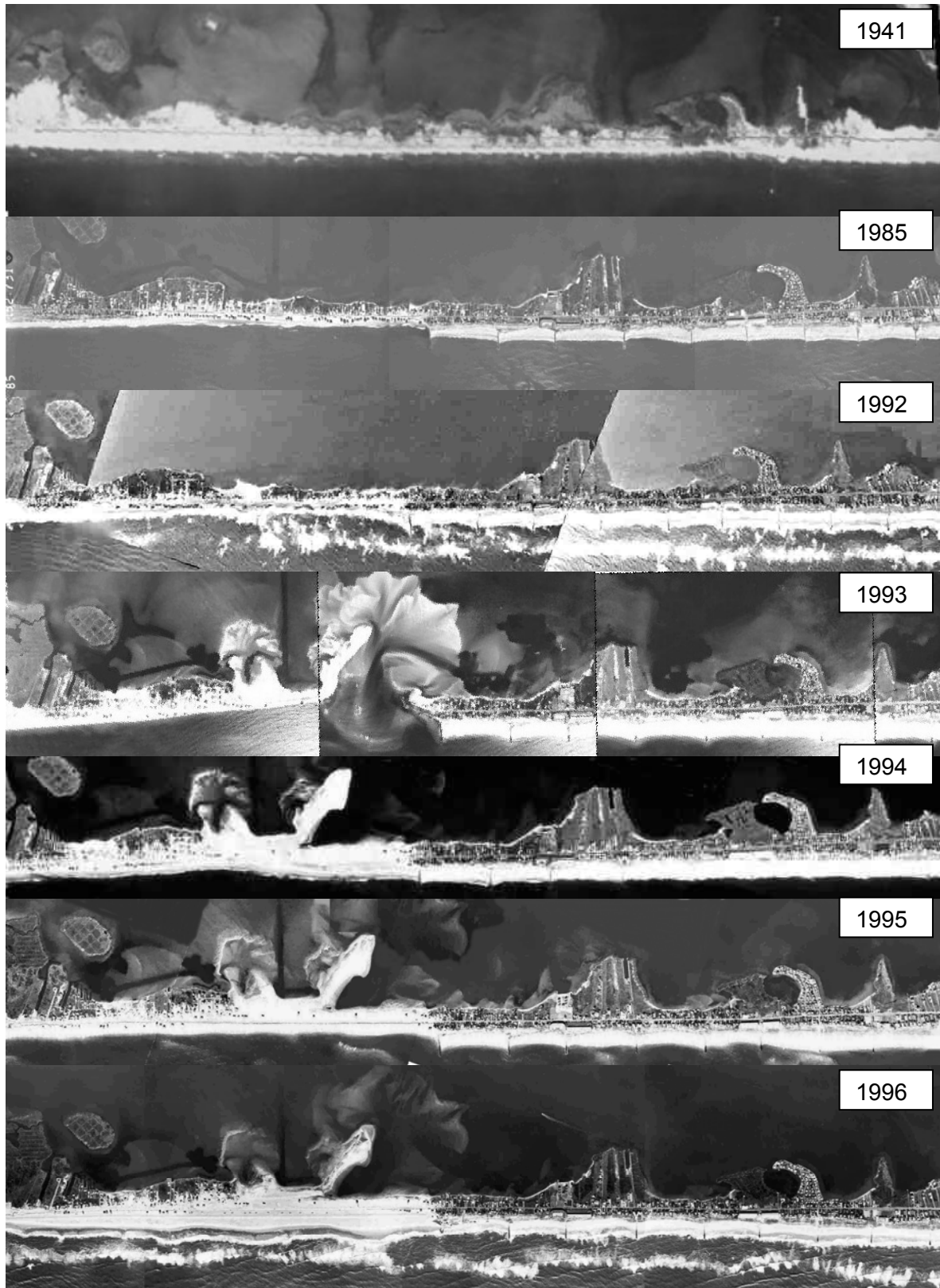


Figure 2. Aerial photographs depicting changes in habitat WHD and The Reference Area, Long Island, New York, 1941, 1985, and 1993-2004.

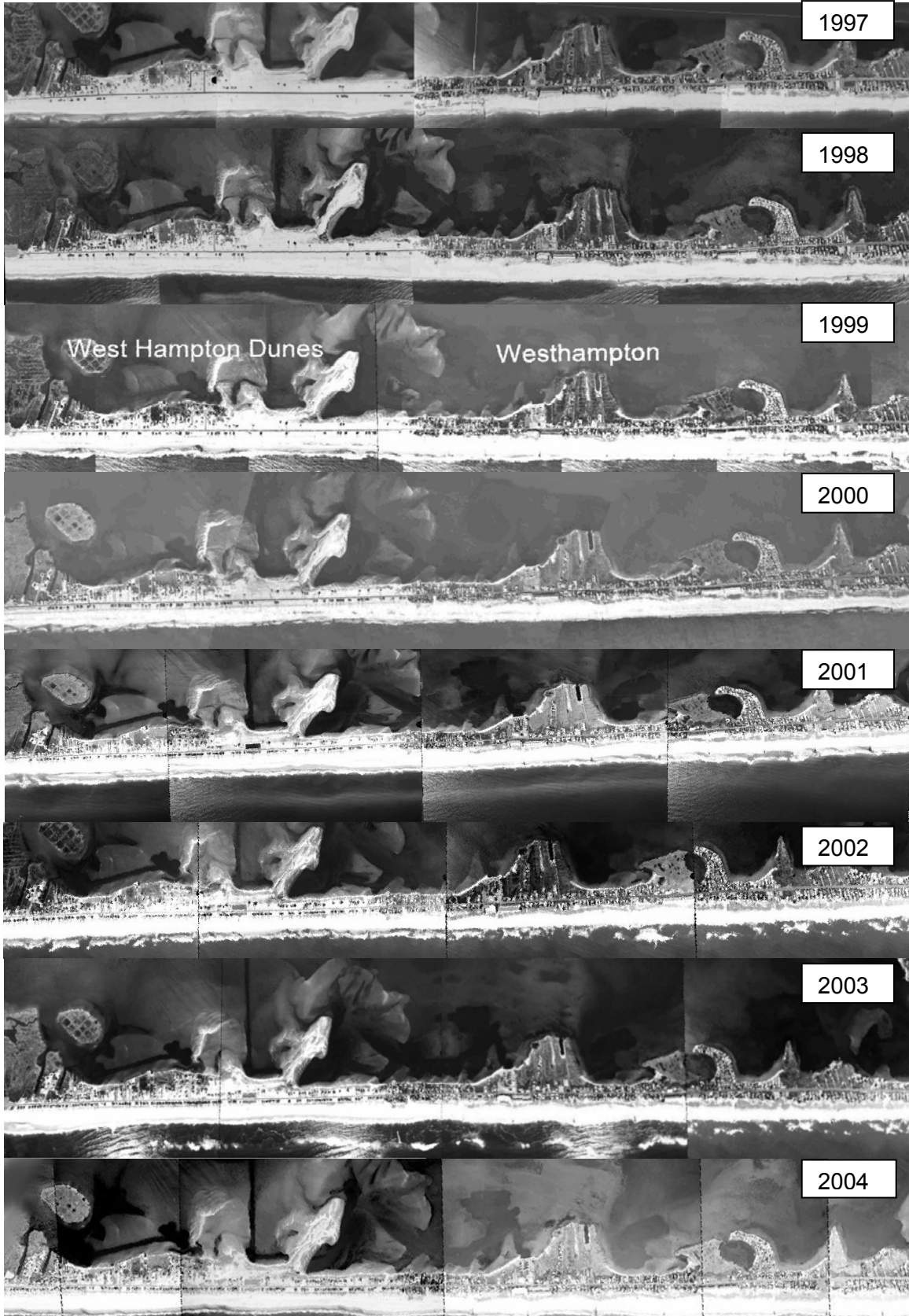


Figure 2 cont. Aerial photographs of WHD and The Reference Area 1941, 1985, and 1993-2004.

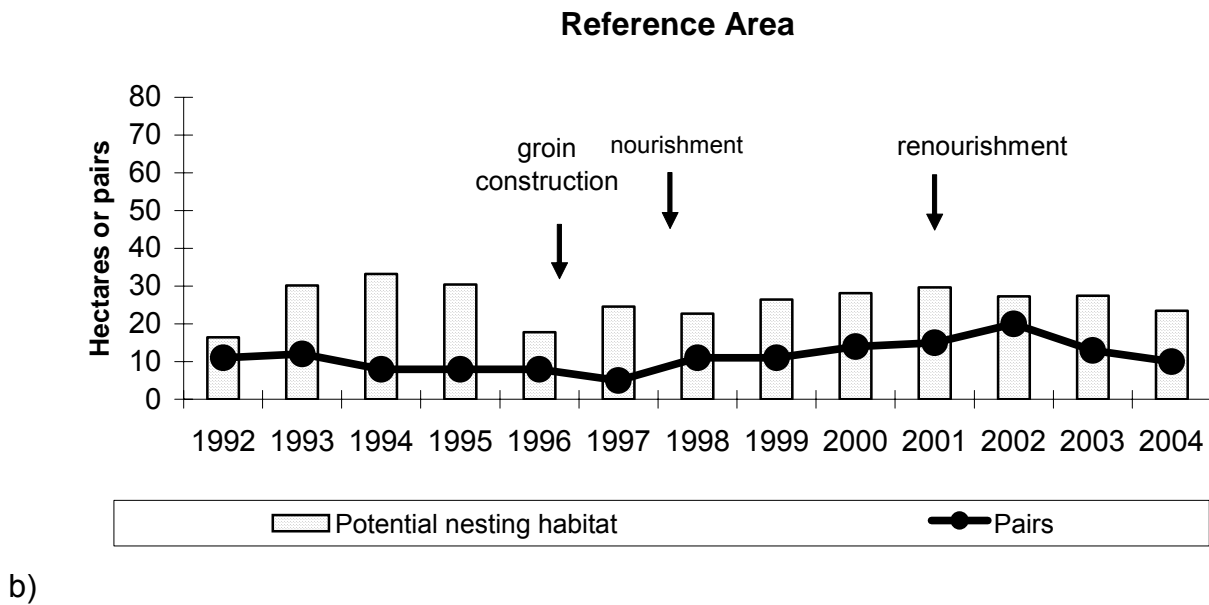
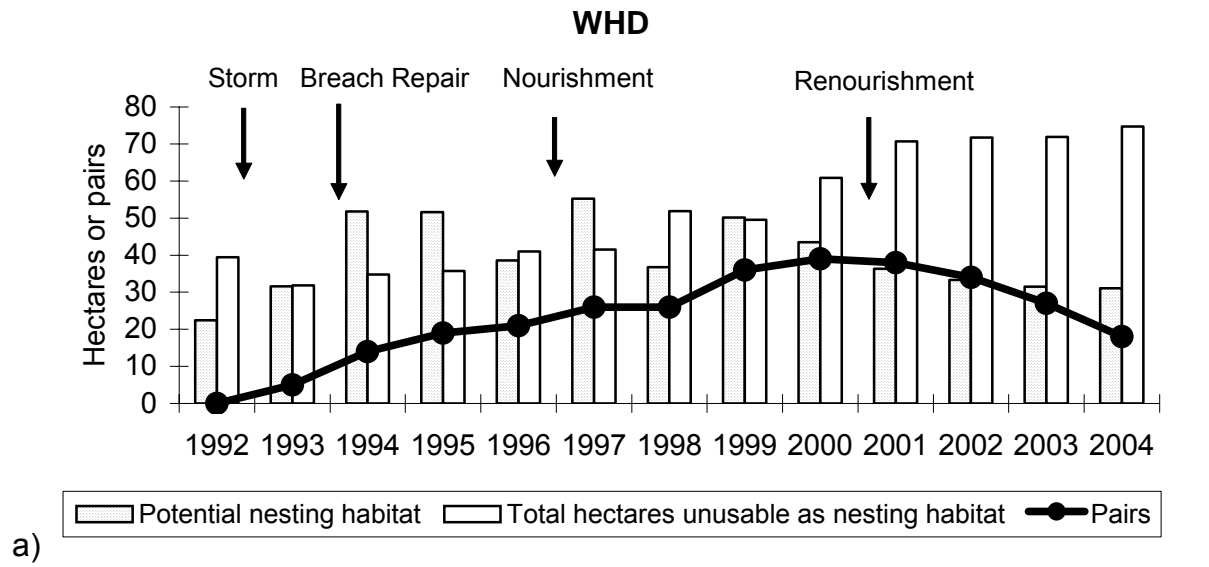
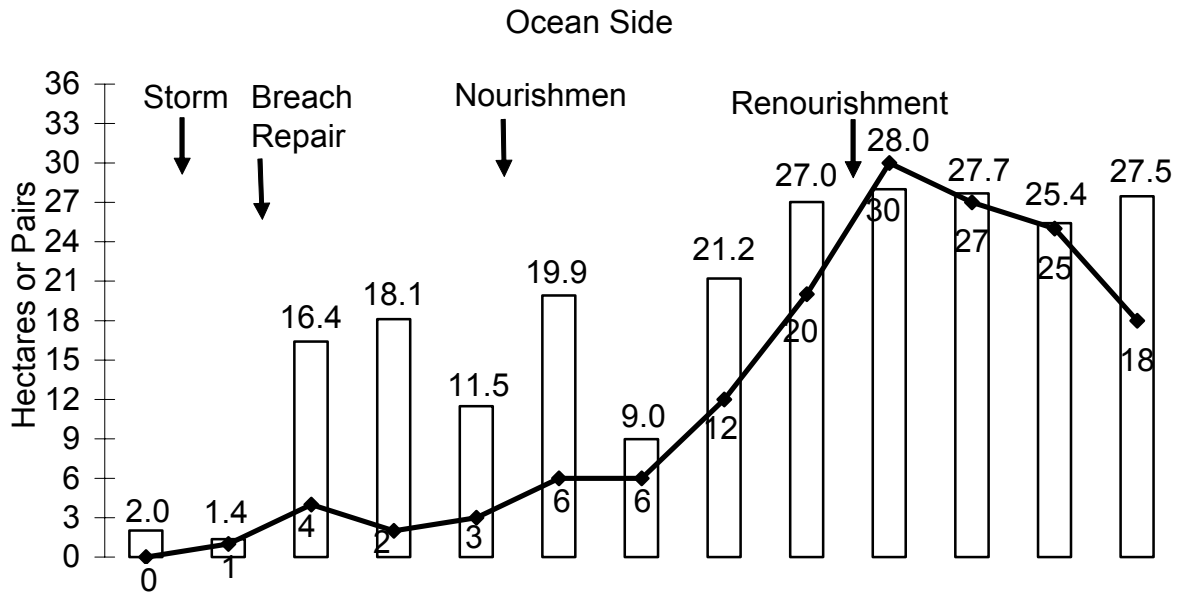
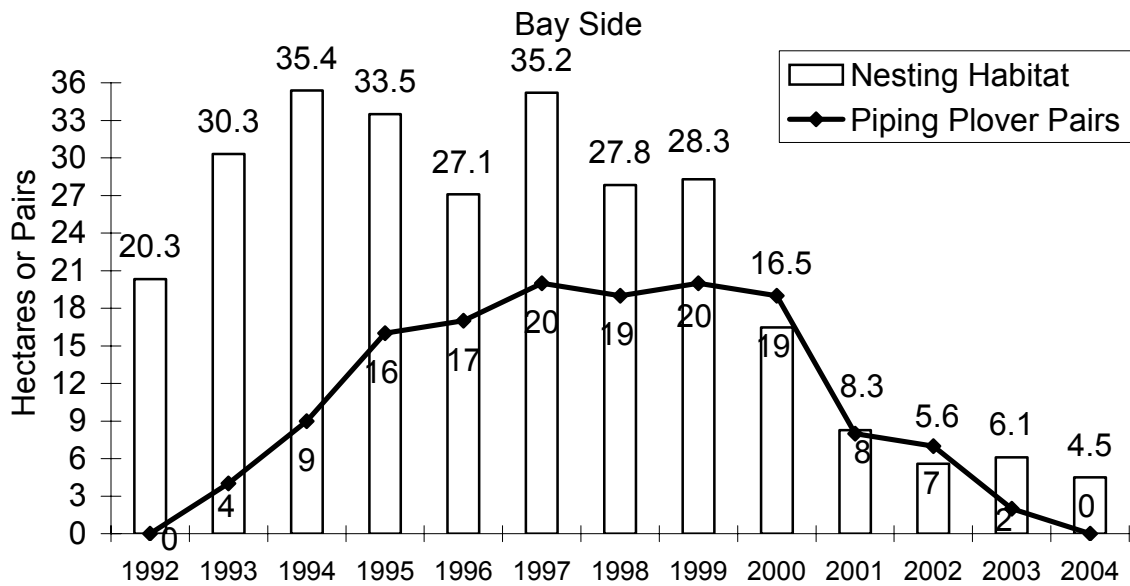


Figure 3. Changes in piping plover nesting habitat and unusable area in a) West Hampton Dunes and b) The Reference Area, Long Island, New York, 1992-2004. Population trends are included for reference.



a)



b)

Figure 4. Hectares of nesting habitat and number of piping plover pairs on the a) ocean and b) bay side of West Hampton Dunes, Long Island, New York, 1993-2004. Numbers above the line are hectares of habitat, numbers below the line are piping plover pairs.

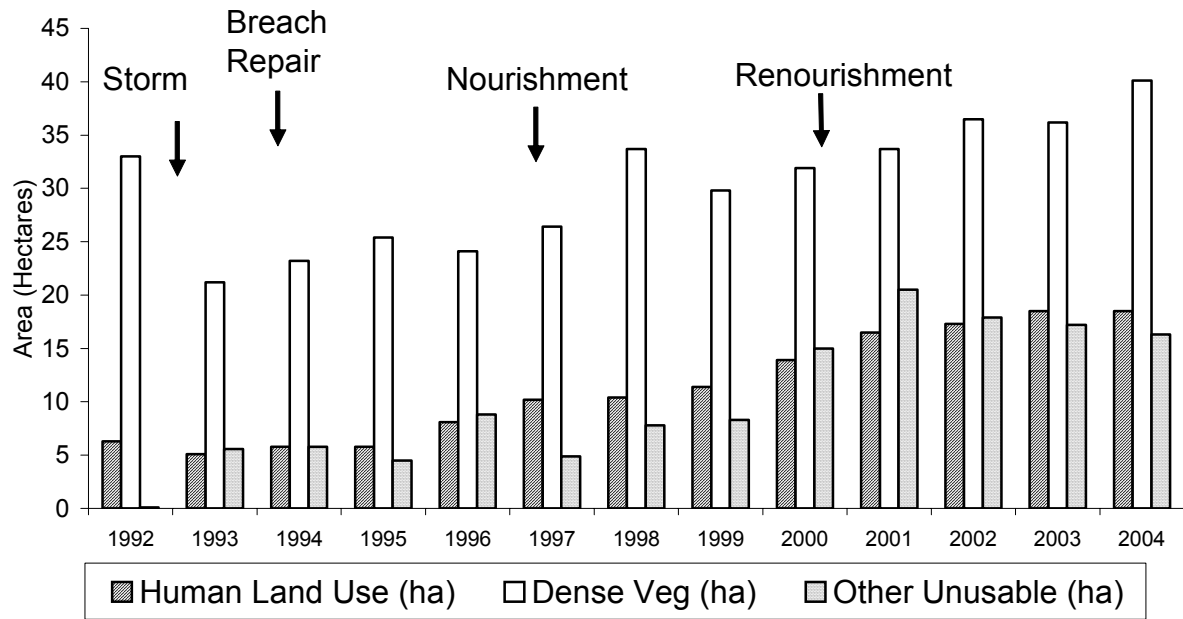


Figure 5. Areas unusable for nesting piping plovers in West Hampton Dunes, Long Island, New York, 1992-2004. Lines indicate hectares in 1993. Human land use areas = asphalt, buildings, homes, and other structures built by people. Other unusable habitat = areas within 2 meters of human land use.

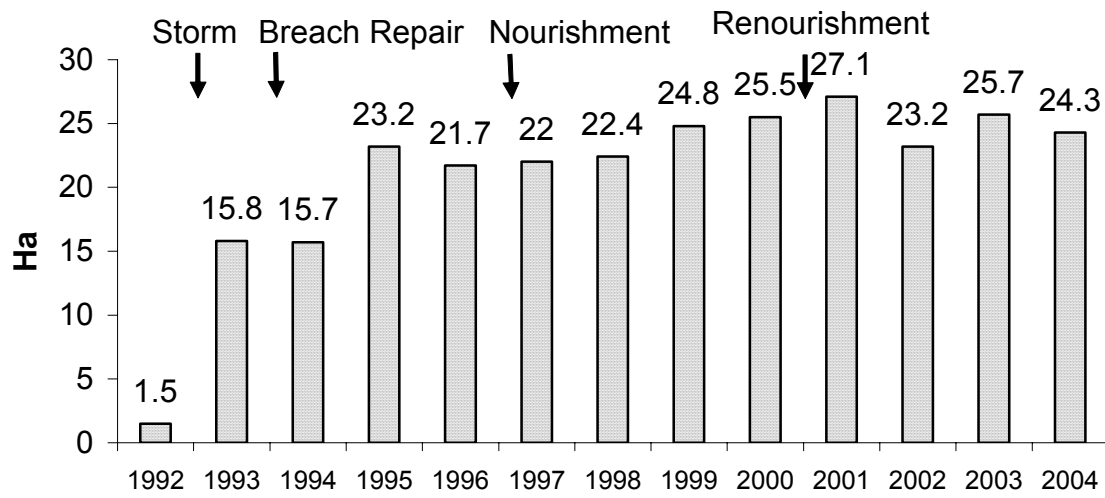


Figure 6. Area of moist sediment habitat (MOSH) at West Hampton Dunes, Long Island, New York, 1992-2004. Line indicates hectares in 1993.

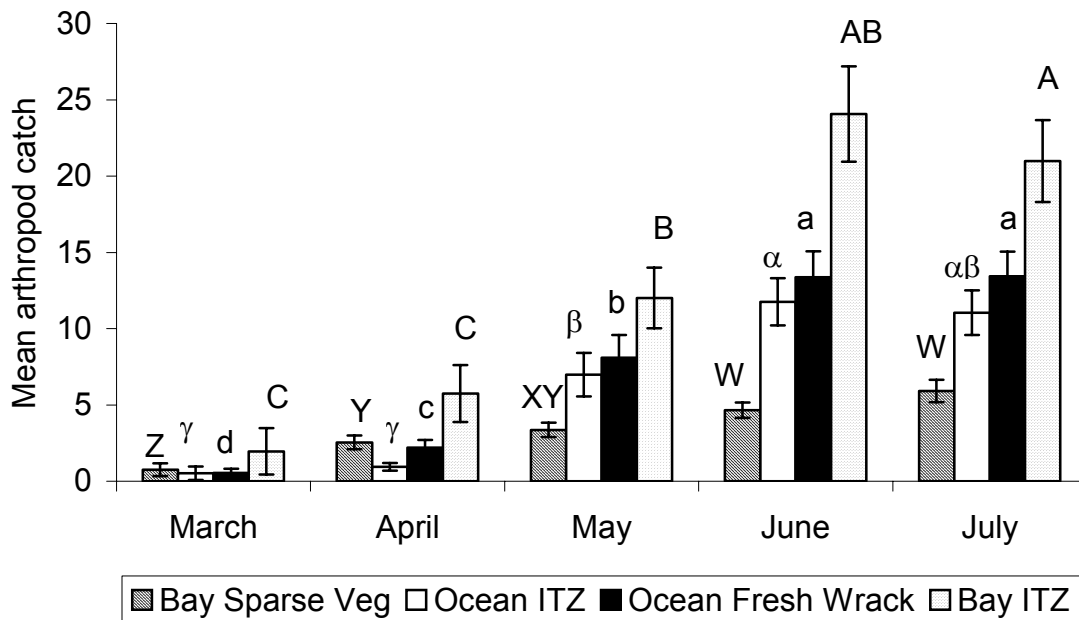


Figure 7. Monthly trend in relative arthropod catch, West Hampton Dunes and The Reference Area (sites pooled), Long Island, New York, 1993-2003. Cover types with the same letter or symbol are not statistically different (Fisher's LSD,  $\alpha=0.05$ ).

<sup>1</sup>ANOVA for differences among months: Bay Sparse Vegetation,  $F_{4,122} = 7.62$ ,  $P < 0.001$ ; Ocean Intertidal Zone,  $F_{4,150} = 18.91$ ,  $P < 0.001$ ; Ocean Fresh Wrack,  $F_{4,151} = 24.77$ ,  $P < 0.001$ ; Bay Intertidal Zone,  $F_{4,122} = 13.56$ ,  $P < 0.001$ .

<sup>2</sup>Catch is the number of arthropods caught on one vertical and one horizontal paint stirrer covered with tanglefoot during a 3-hour morning trapping period.

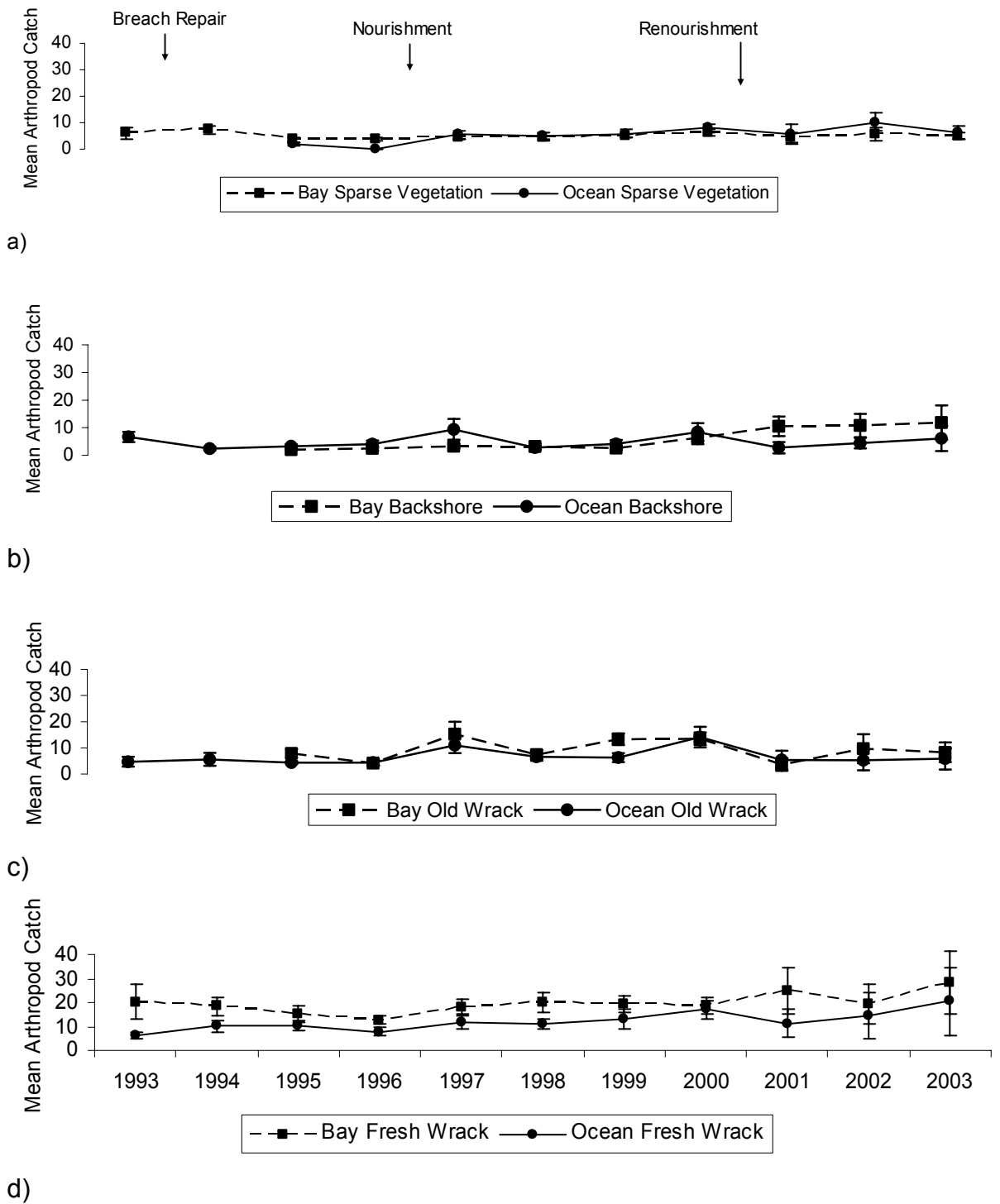
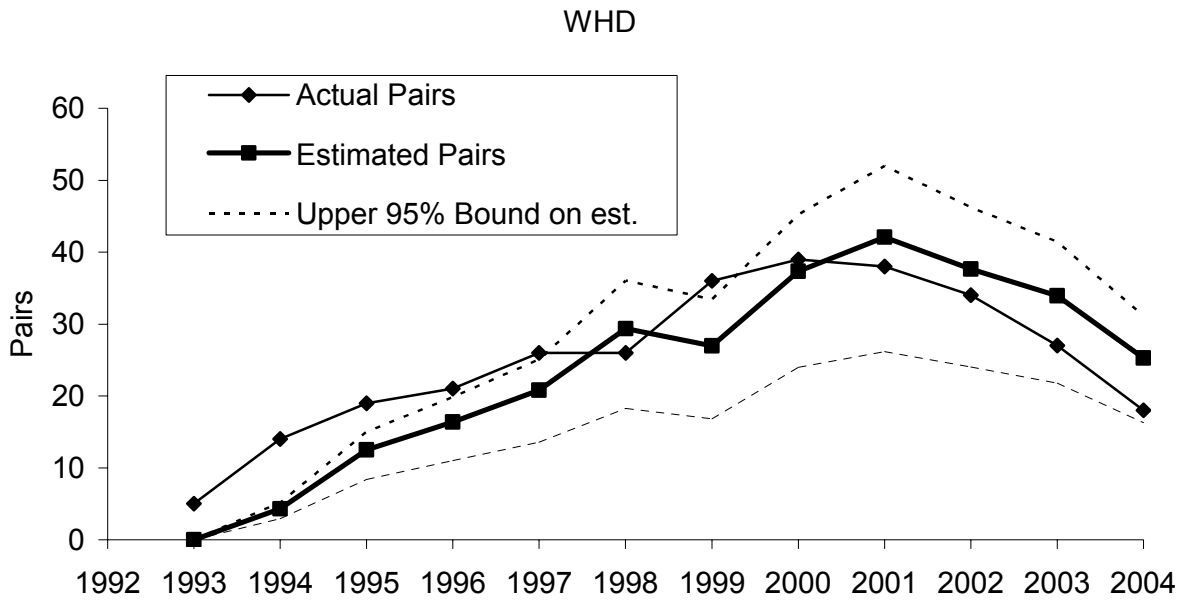
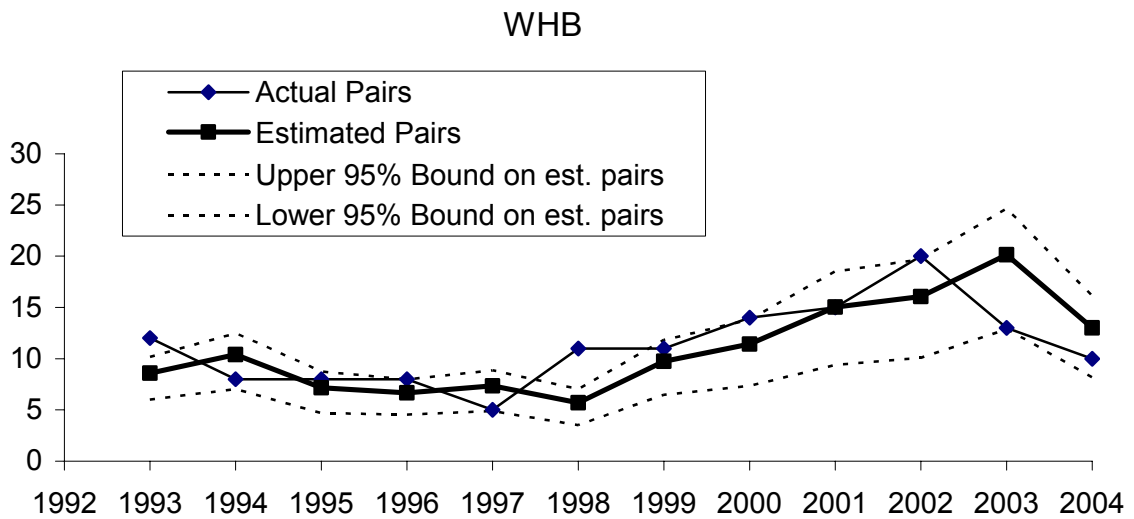


Figure 8. Relative arthropod catch, bay and ocean habitats by year, West Hampton Dunes, Long Island, New York, 1993-2003. The bay side was not renourished.



a)



b)

Figure 9. Observed and expected piping plover pairs a) West Hampton Dunes and b) The Reference Area, Long Island, New York, 1992-2004. Expected pairs were calculated by applying published survival rates (0.48 for first year birds, 0.74 for after first year birds). For return rates, we used 0.5 for first year birds and 1.0 for after first year birds to the population counts for the previous year.

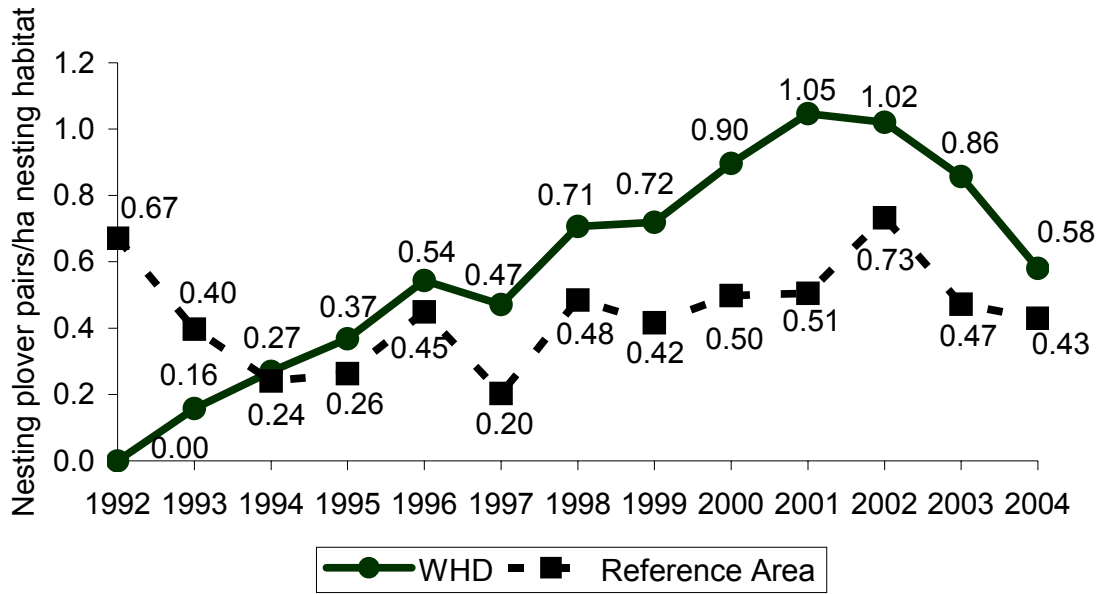


Figure 10. Piping plover nesting pair density West Hampton Dunes and The Reference Area, Long Island, New York, 1992-2004.

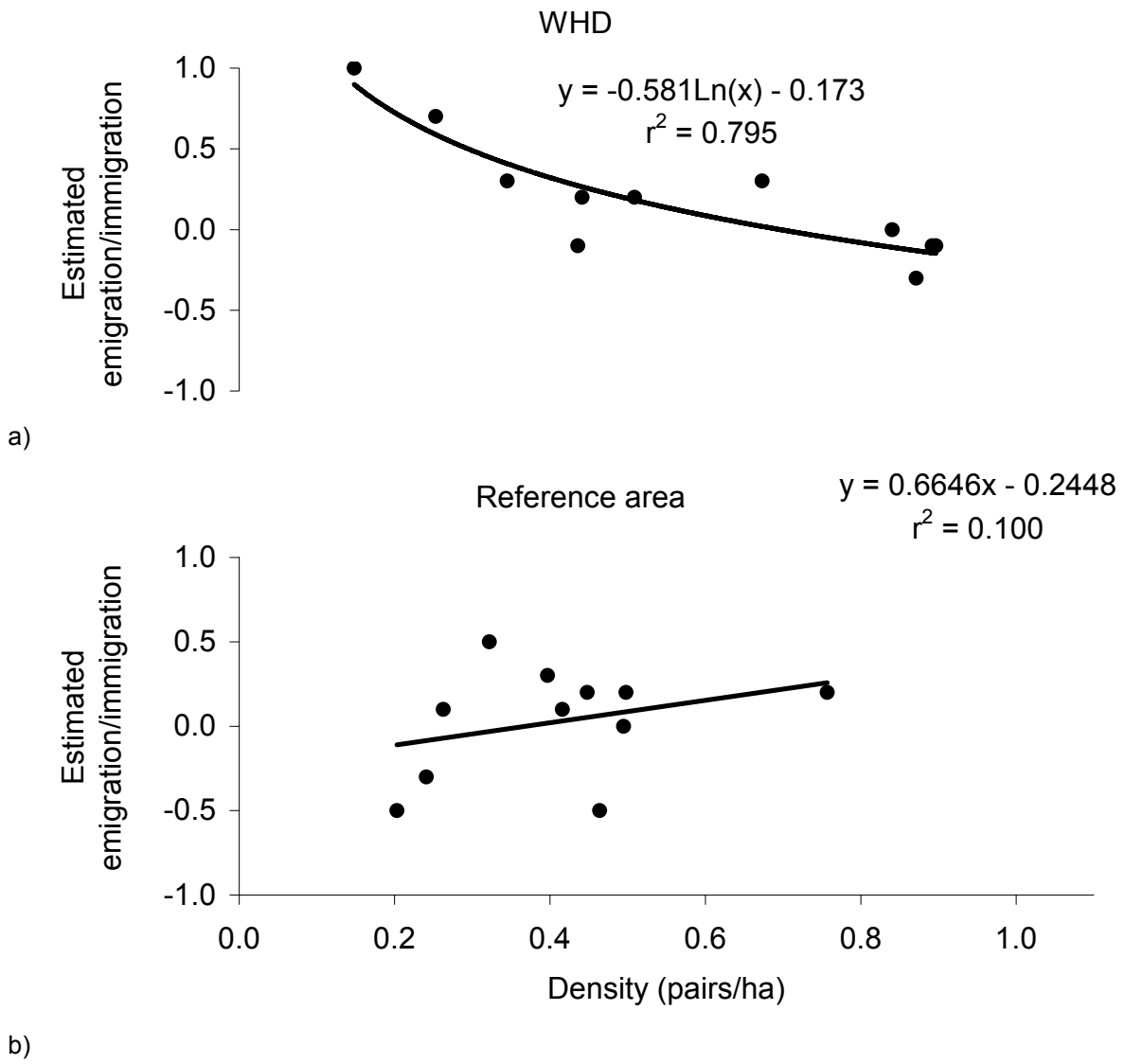


Figure 11. Estimated piping plover emigration and immigration plotted against density in a) West Hampton Dunes and b) The Reference Area, Long Island, New York, 1993-2003.

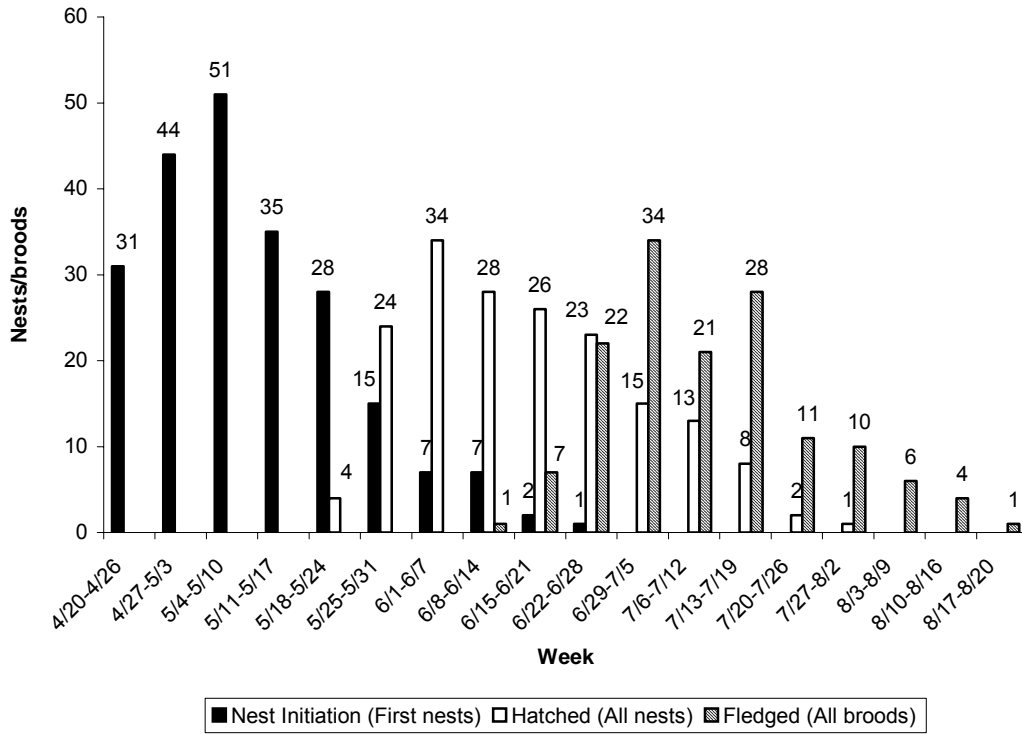


Figure 12. Piping plover initiation, hatch and fledge dates for piping plovers at West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2003.

WHD and Reference area

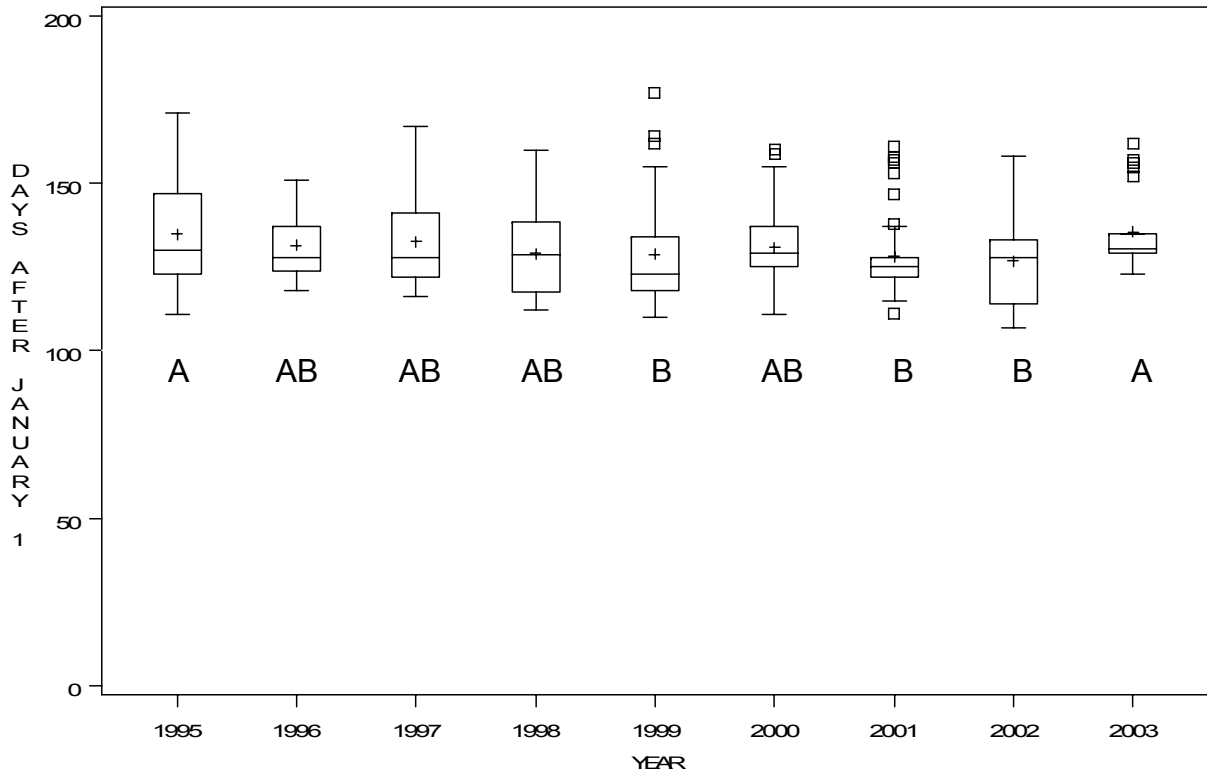


Figure 13. Box plot of first piping plover nest initiation dates West Hampton Dunes and The Reference Area, Long Island, New York, 1995-2003. Global model with site and year; ANOVA<sub>r</sub>,  $F_{9,313} = 2.24$ ,  $P = 0.010$ . Boxplots with the same capital letter are not significantly different. Multiple range test was Fishers LSD. Boxes represent interquartile range (IQR, or 25<sup>th</sup> to 75<sup>th</sup> percentile). Interior line is the median, + = mean, whiskers extend to 1.5\*IQR, squares represent outliers.

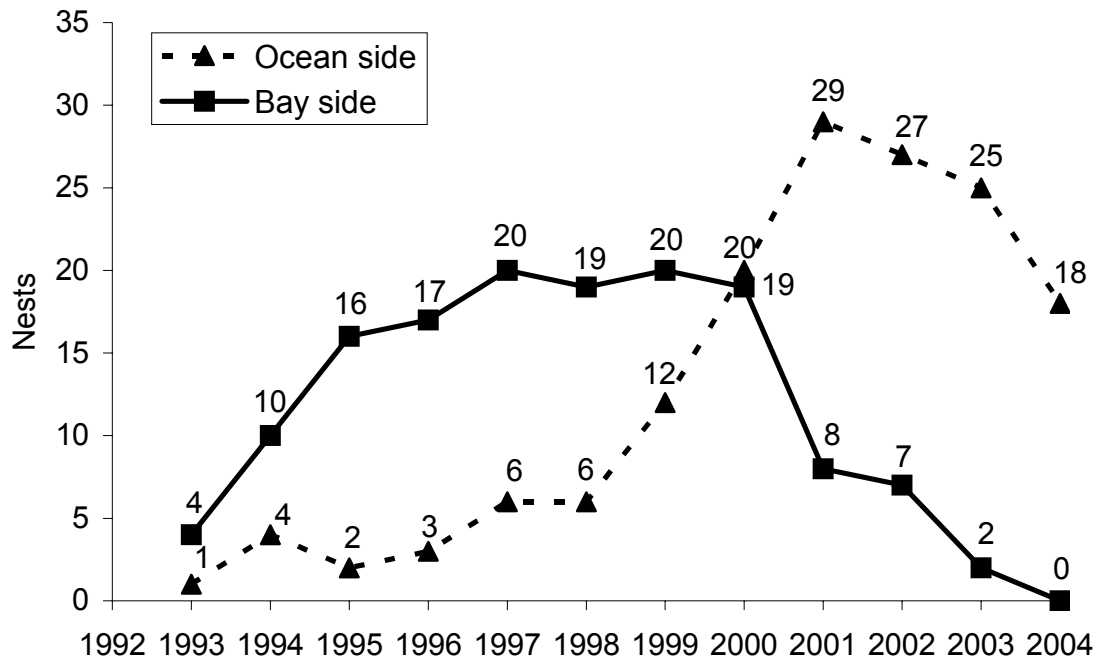
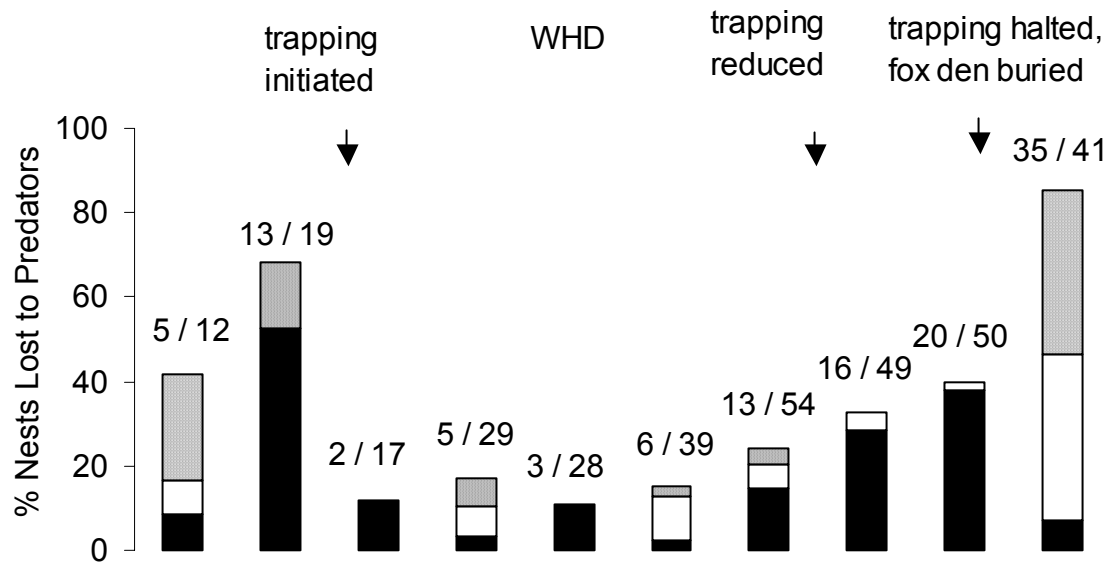
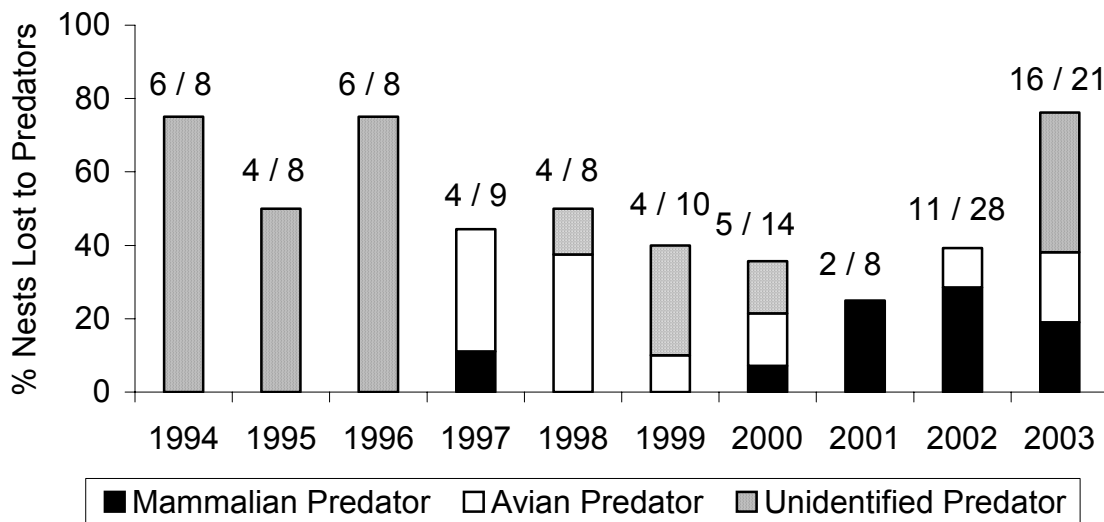


Figure 14. Piping plover first nest attempts West Hampton Dunes, Long Island, New York, 1993-2004.



a)

The Reference Area



b)

Figure 15. Percent of unexclosed plover nests lost to predators a) West Hampton Dunes and b) The Reference Area, Long Island, New York, 1994-2003. Changes in predator trapping strategies are shown. Numbers over bars are number of nests lost to predators / number of nests laid. Test for difference among years, West Hampton Dunes ( $\chi^2_9 = 80.78, P < 0.001$ ), The Reference Area ( $\chi^2_9 = 14.67, P = 0.103$ ).

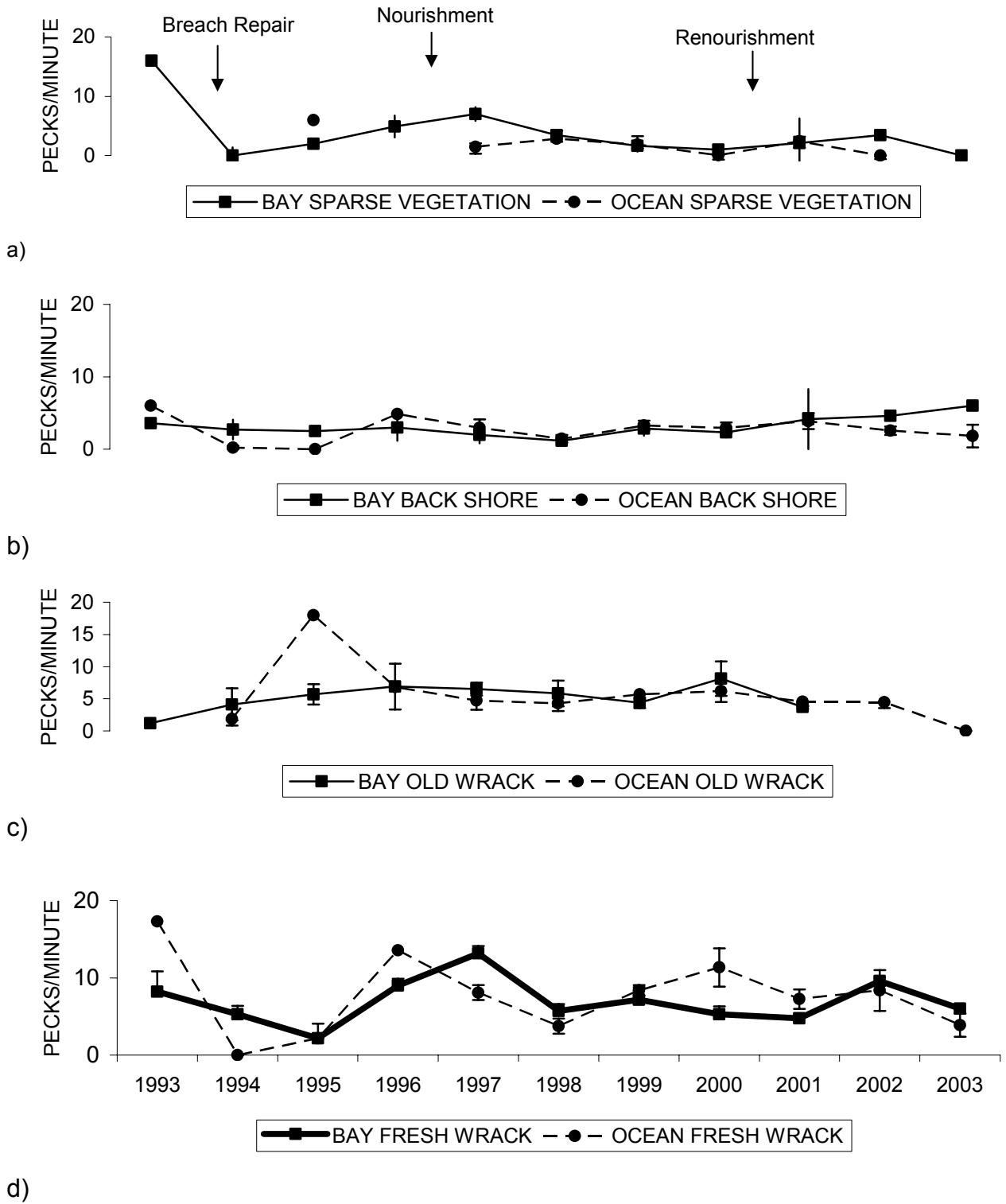
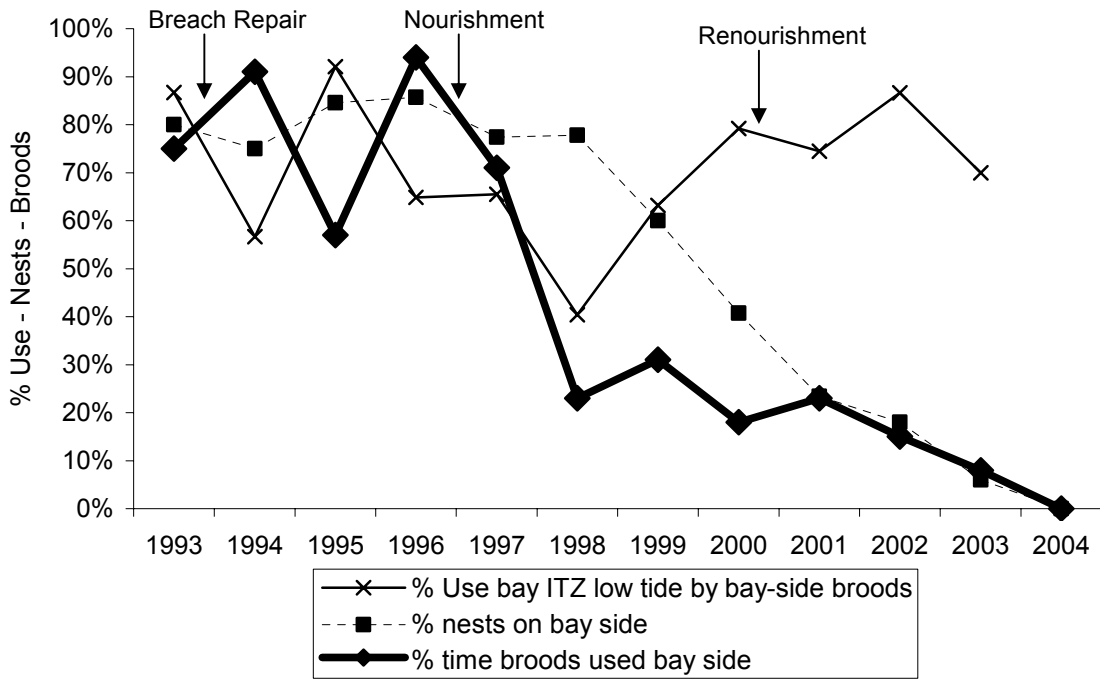
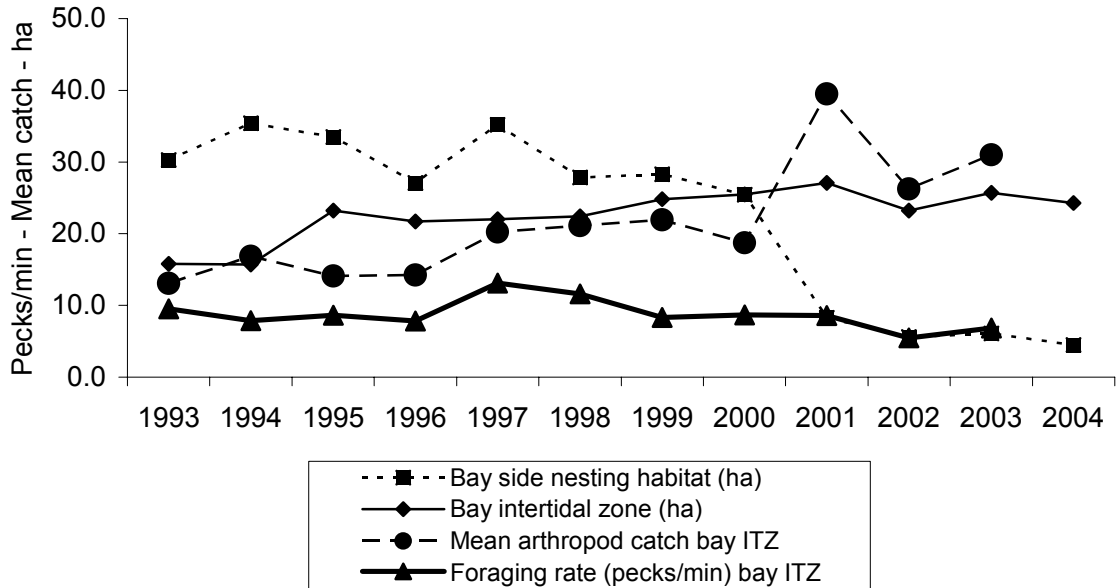


Figure 16. Piping plover foraging rates bay and ocean side habitats West Hampton Dunes, Long Island, New York, 1993-2003.



a)



b)

Figure 17. Piping plover brood habitat use on the bay side, adult nesting use on the bay side, brood use of the bay intertidal zone (only for broods that were found on the bay side), bay intertidal zone arthropod catch, and bay intertidal zone foraging rates compared to cycles of Army Corps Activities, West Hampton Dunes, Long Island, New York, 1993-2004.

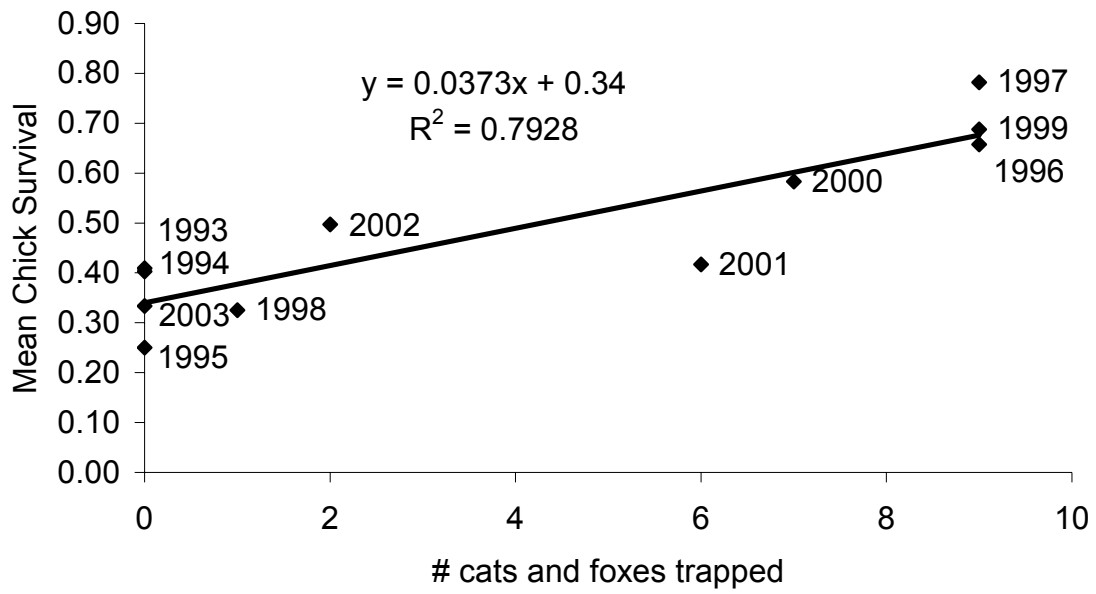
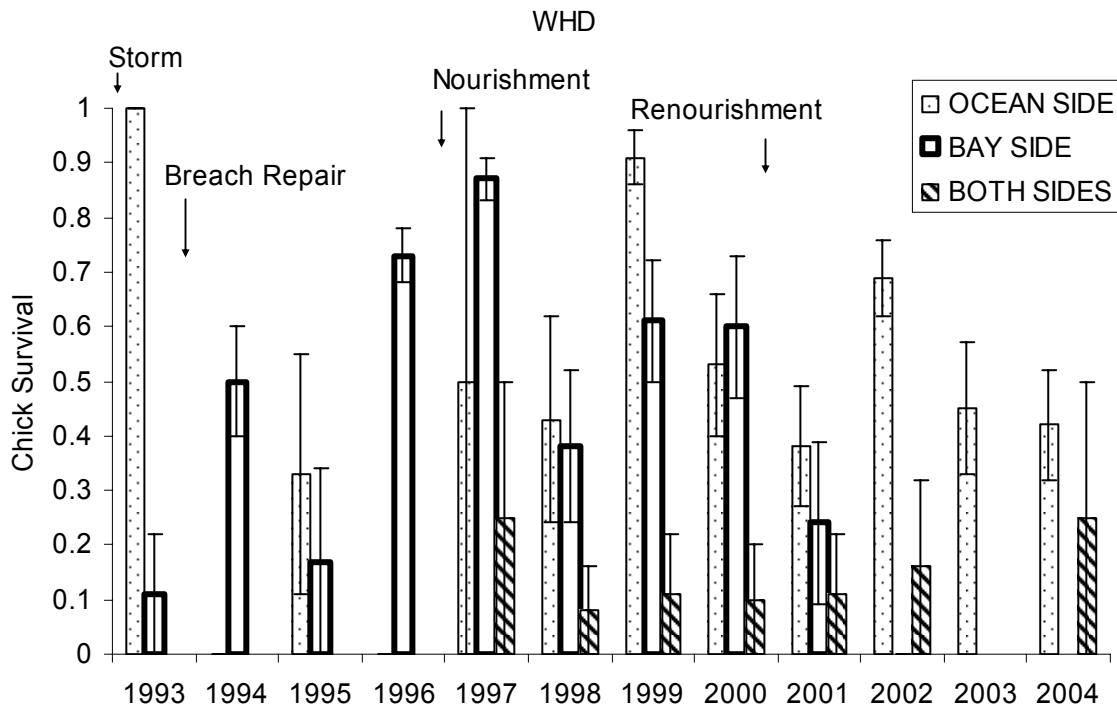
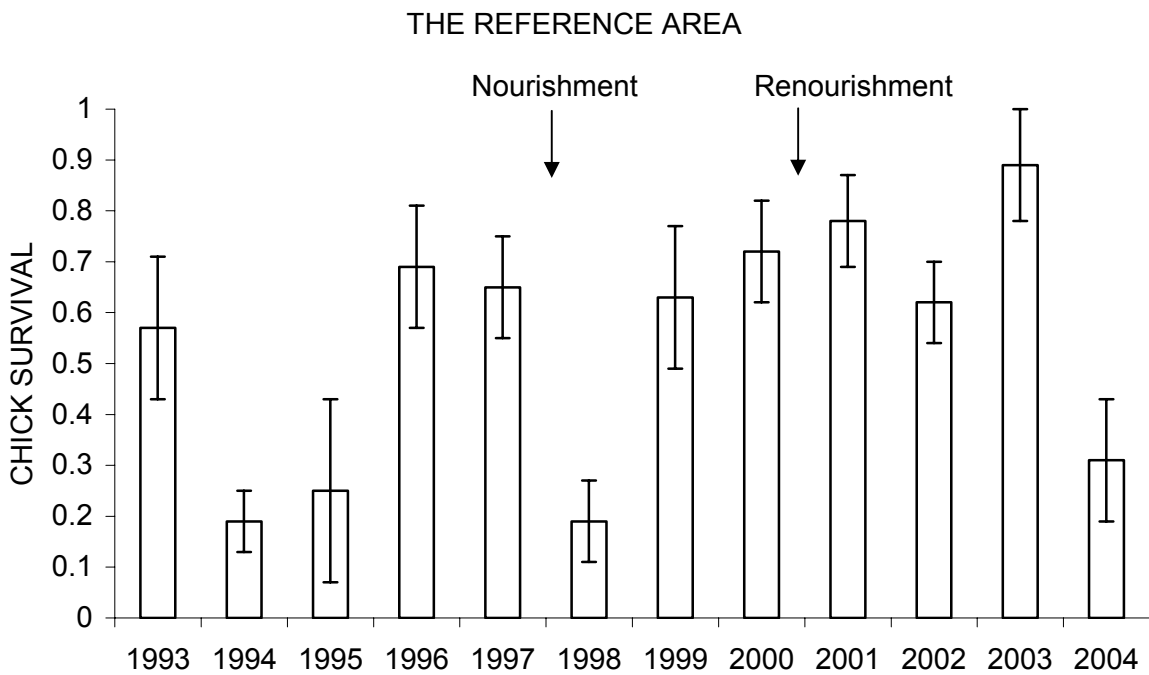


Figure 18. Piping plover chick survival vs. total cats and foxes trapped, West Hampton Dunes, Long Island, New York, 1993-2003.



a)



b)

Figure 19. Piping plover chick survival rates in relation to Army Corps Activities, a) West Hampton Dunes, and b) The Reference Area, Long Island, N.Y., 1993-04.

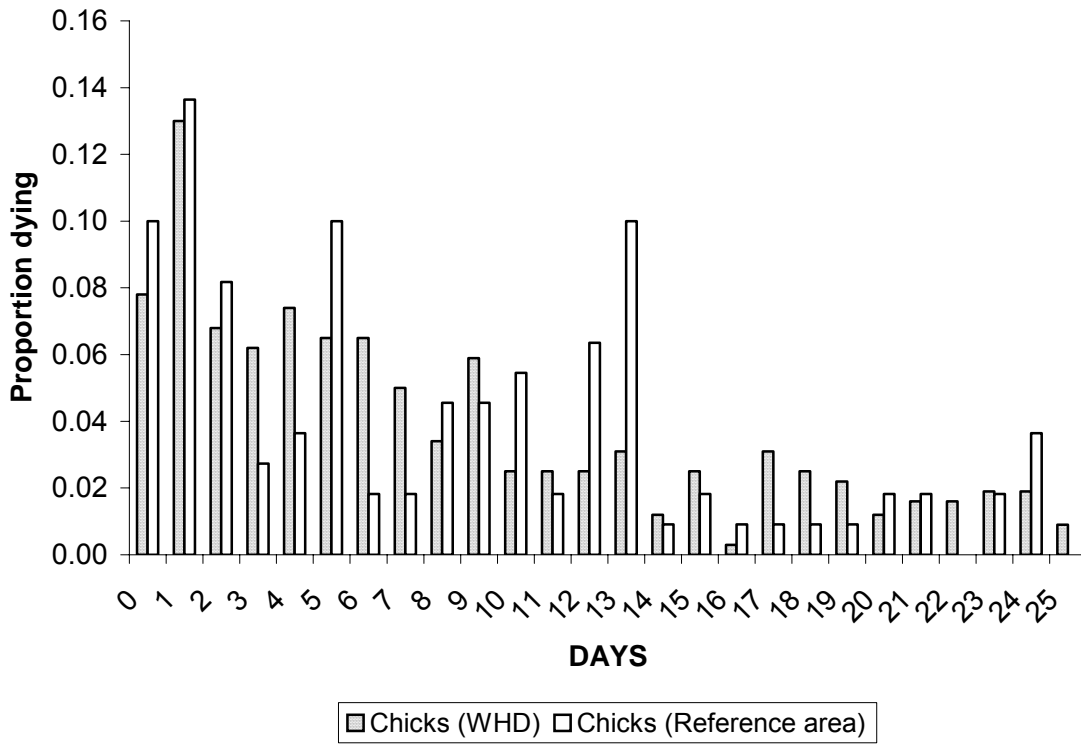


Figure 20. Proportion of piping plover chicks dying between the ages of 0-25 days in West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2003.

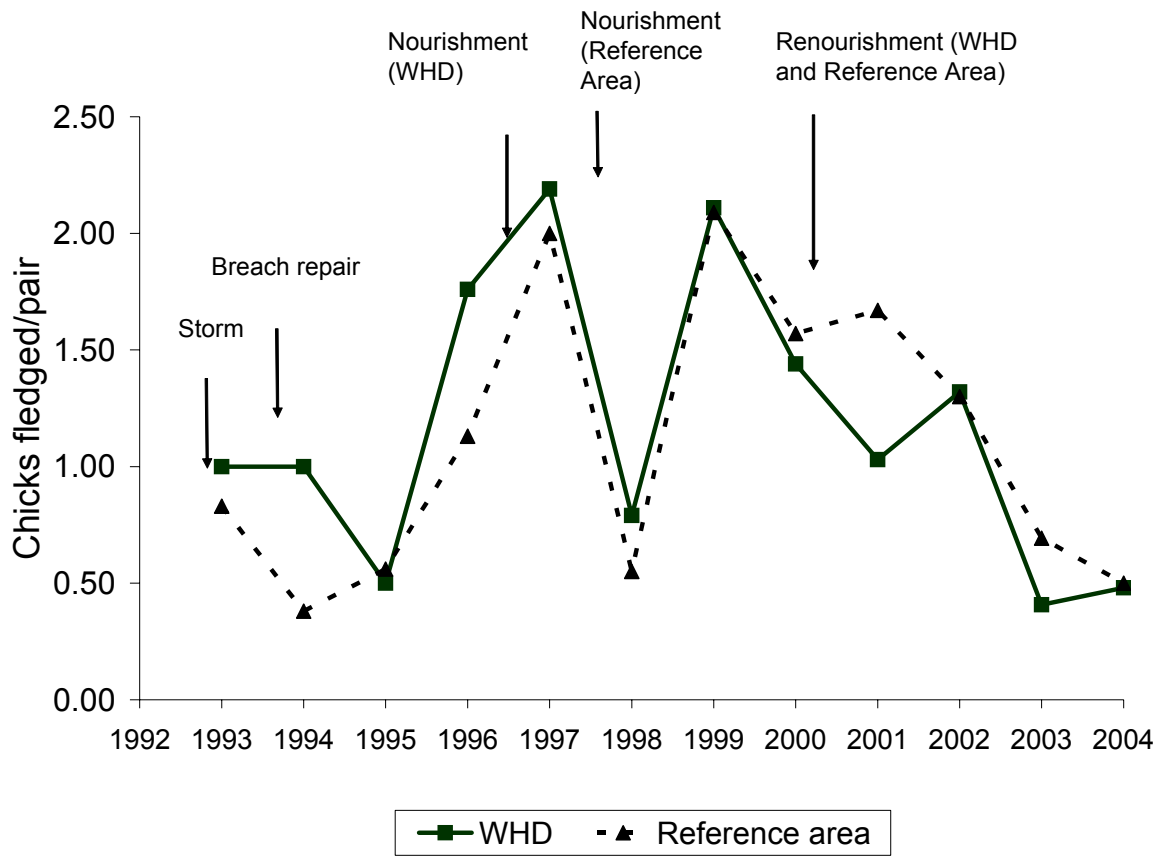


Figure 21. Piping plover reproductive output (chicks fledged/pair) West Hampton Dunes and The Reference Area, Long Island, New York, 1993-2004.

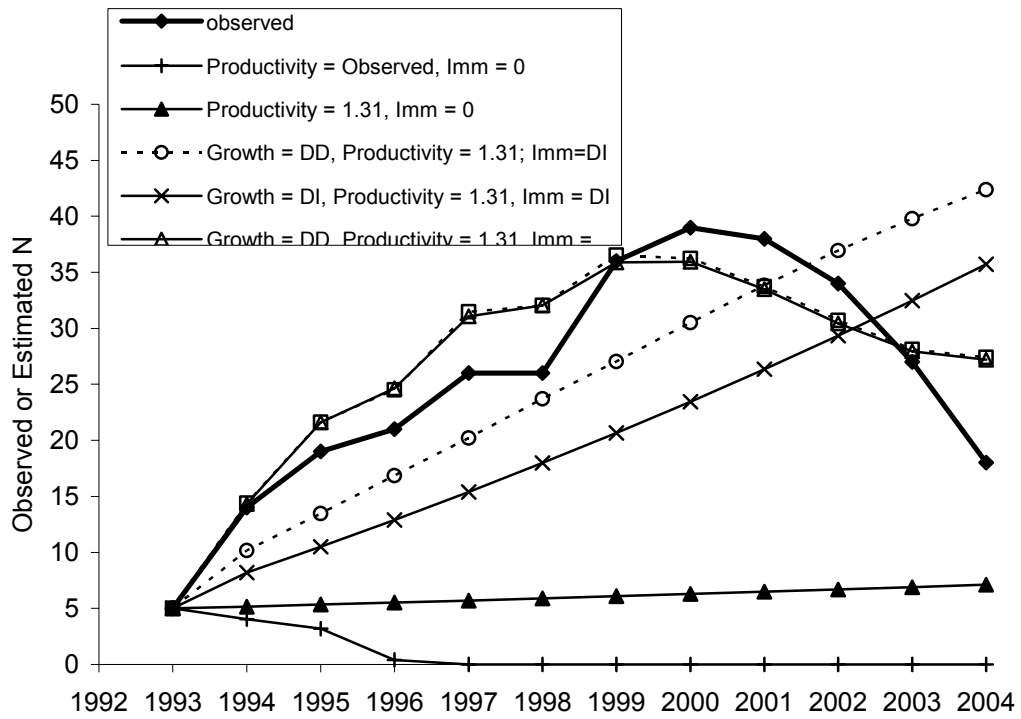


Figure 22. Observed and modelled piping plover population curves for West Hampton Dunes, New York, 1992-2004 based on logistic and exponential growth models. DD = Density Dependent, DI = Density Independent, Imm = Immigration, Prod = Productivity. Productivity = 1.31 fledges/pair except for the models where Productivity = Observed Productivity.

Appendix 1. Linear regression model of piping plover a) population rate of change versus clutch size, egg hatchability, egg survival, nest survival, reneest rate, chick survival, and brood survival, and b) population size at Time t+1 versus clutch size, egg hatchability, egg survival, nest survival, reneest rate, chick survival, and brood survival, West Hampton Dunes and Westhampton Beach, Long Island, New York, 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Response Variable:	Model	n	k	SSE	AIC <sub>c</sub>	$\Delta_i$	$w_i$	Adj R <sup>2</sup>
Population Rate of Change								
WHD <sup>a</sup>	Null	9	2	0.33	-23.69	0.00	0.9309	-
Reference Area <sup>b</sup>	Null	9	2	1.75	-8.74	0.00	0.9623	-
Population size at Time t+1								
WHD <sup>c</sup>	Null	9	2	438.22	40.97	0.00	0.9967	-
Reference Area <sup>d</sup>	Null	9	2	160.00	31.90	0.00	0.9891	-

<sup>a</sup>Global Model:  $F_{4,4}=2.38$ ,  $P = 0.2110$ ,  $R^2 = 0.7040$ , Adj R<sup>2</sup> = 0.4079

<sup>b</sup>Global Model:  $F_{4,4}=1.15$ ,  $P = 0.4489$ ,  $R^2 = 0.5341$ , Adj R<sup>2</sup>= 0.068

<sup>c</sup>Global Model:  $F_{4,4}=0.24$ ,  $P = 0.9005$ ,  $R^2 = 0.1953$ , Adj R<sup>2</sup> = 0.6094

<sup>d</sup>Global Model:  $F_{4,4}=1.67$ ,  $P = 0.3153$ ,  $R^2 = 0.6258$ , Adj R<sup>2</sup>= 0.2516

Appendix 2. Linear regression model of piping plover mean clutch size of firsts nests versus mean maximum daily temperature and total precipitation April through May, nesting pair density, and number cats and foxes trapped, West Hampton Dunes and Westhampton Beach, Long Island, N.Y., 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Site	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	$P$	$n$	$k$	SSE	AIC <sub>C</sub>	$\Delta_i$	$w_i$	Adj R <sup>2</sup>
WHD <sup>a</sup>	Null					10	2	0.14	-36.90	0.000	0.679	-
Reference Area <sup>b</sup>	1	mean maximum temperature	0.10	0.04	0.037	10	3	0.20	-29.16	0.000	0.456	0.440
	Null	Intercept	1.36	0.93	0.182	10	2	0.36	-27.64	1.516	0.214	-

<sup>a</sup>Global Model:  $F_{3,6}=0.30$ ,  $P = 0.8273$ ,  $R^2 = 0.1290$ , Adj  $R^2 = 0.3066$ .

<sup>b</sup>Global Model:  $F_{3,6}=3.05$ ,  $P = 0.1139$ ,  $R^2 = 0.6037$ , Adj  $R^2 = 0.4010$

Appendix 3. Linear regression model of piping plover egg hatchability vs. mean maximum daily temperature and total precipitation April through July, and nesting pair density, West Hampton Dunes and Westhampton Beach, Long Island, N.Y., 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

	MODEL	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	SSE	AIC <sub>C</sub>	$\Delta_i$	<i>w<sub>i</sub></i>	Adj R <sup>2</sup>
WHD <sup>a</sup>		Null				10	2	0.021	-55.920	0	0.70953	-
The Reference Area <sup>b</sup>		Null				10	2	0.054	-46.492	0	0.67488	-

<sup>a</sup>Global Model:  $F_{3,6} = 0.50$ ,  $P = 0.6958$ ,  $R^2 = 0.2001$ , Adj  $R^2 = 0.1999$ .

<sup>b</sup>Global Model:  $F_{3,6} = 0.58$ ,  $P = 0.6497$ ,  $R^2 = 0.2246$ , Adj  $R^2 = 0.1630$ .

Appendix 4. Linear regression model of piping plover hatchability versus nest fenced (Y/N), nest substrate topography, nest in vegetation (Y/N), nest lining, distance to bay high tide line, distance to nearest neighboring nest, distance to dense vegetation, days after January 1st nest was initiated, West Hampton Dunes, Long Island, N.Y., 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Site	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	SSE	AIC <sub>C</sub>	$\Delta_i$	$w_i$	Adj R <sup>2</sup>
WHD <sup>a</sup>	1	Nest in vegetation	0.07	0.04	0.0823	242	3	1194486.56	2064.14	0.000	0.042	0.0084
		Intercept	138.59	10.32	<0.0001							
	2	Nest in vegetation, Nest initiation date	NC <sup>b</sup>	NC	NC	242	4	1184995.01	2064.28	0.137	0.039	0.0122
	Null					242	2	1209636.07	2065.14	0.999	0.026	
	3	Nest initiation date	NC	NC	NC	242	3	1199465.56	2065.15	1.007	0.026	0.0062
	4	Nest in vegetation, Distance to nearest neighbor	NC	NC	NC	242	4	1192131.00	2065.73	1.590	0.019	0.0096
	5	Nest initiation date, Nest in vegetation, Distance to nearest neighbor	NC	NC	NC	242	5	1183059.99	2065.97	1.827	0.017	0.0050
6	Nest fenced, Nest in vegetation	NC	NC	NC	242	4	1193615.03	2066.03	1.891	0.016	0.0048	
7	Nest in vegetation, Nest lined	-	-	-	242	4	1193883.72	2066.08	1.946	0.016	0.0088	

<sup>a</sup>Global Model:  $F_{8,233} = 0.74$ ,  $P = 0.6545$ ,  $R^2 = 0.0248$ , Adj  $R^2 = -0.0086$ .

<sup>b</sup>Not calculated

Appendix 5. Linear regression model of piping plover hatchability versus mean number of pedestrians, gulls, other potential disturbances within 100 meters of nests, West Hampton Dunes, Long Island, N.Y., 1997-2000. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

a)

Site	Model	Regressors in model	$\beta_j$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	SSE	AIC <sub>c</sub>	$\Delta_i$	<i>w<sub>i</sub></i>	Adj R <sup>2</sup>
WHD <sup>a</sup>	1	Nest initiation date	-0.09	0.05	0.0869	141	3	162043.13	999.78	0.000	0.189	0.014
		Intercept	85.87	6.07	<0.0001							
	Null					141	2	165507.97	1000.68	0.895	0.121	-
	2	Mean no.gulls w/in 100m, nest initiation date	NC <sup>b</sup>	NC	NC	141	4	160936.46	1000.93	1.153	0.106	0.014
	3	Mean no.other w/in 100m, nest initiation date	NC	NC	NC	141	4	161194.72	1001.16	1.379	0.095	0.012
4	Mean no.other w/in 100m	NC	NC	NC	141	3	163733.94	1001.25	1.464	0.091	0.004	

<sup>a</sup>Global Model:  $F_{4,136} = 1.09$ ,  $P = 0.3634$ ,  $R^2 = 0.0311$ , Adj  $R^2 = 0.0026$ .

<sup>b</sup>Not calculated

Appendix 6. Linear regression model of piping plover hatchability versus the proportion of observations in which at least 1 pedestrian, gull or other potential disturbance was present within 100 m of nests, West Hampton Dunes, Long Island, N.Y., 1997-2000. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Site	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	SSE	AIC <sub>C</sub>	$\Delta_i$	<i>w<sub>i</sub></i>	Adj R <sup>2</sup>
WHD <sup>a</sup>	1	Nest initiation date	-0.09	0.05	0.0869	141	3	162043.13	999.78	0.000	0.184	0.014
		Intercept	85.87	6.07	<0.0001							
		Null				141	2	165507.97	1000.68	0.895	0.118	
	2	% observations >1 other	NC <sup>b</sup>	NC	NC	141	3	163285.66	1000.86	1.077	0.108	0.006
	3	% observations >1 other, nest initiation date	NC	NC	NC	141	4	160957.56	1000.95	1.171	0.103	0.013
	4	% observations >1 gull, nest initiation date	NC	NC	NC	141	4	161219.49	1001.18	1.400	0.091	0.012

<sup>a</sup>Global Model:  $F_{4,136} = 1.07$ ,  $P = 0.3721$ ,  $R^2 = 0.0209$ , Adj  $R^2 = 0.0021$

<sup>b</sup>Not calculated

Appendix 7. Linear regression model of piping plover egg survival versus mean number of pedestrians, gulls, other potential disturbances within 100 meters of nests, West Hampton Dunes, Long Island, N.Y., 1997-2000. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Site	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	SSE	AIC <sub>C</sub>	$\Delta_i$	<i>w<sub>i</sub></i>	Adj R <sup>2</sup>
WHD <sup>a</sup>	1	Mean no. pedestrians w/in 100m, mean no. gulls w/in 100m	-	-	0.0332	197	4	576322.36	1580.51	0.000	0.234	0.024
		Intercept	80.88	10.39	<0.0001							
		Mean no. pedestrians w/in 100m	0.13	0.07	0.0564							
		Mean no. gulls w/in 100m	0.12	0.07	0.0772							
	Null					197	2	596907.31	1583.28	1.086	0.059	-
	2	Mean no. pedestrians w/in 100m	NC <sup>b</sup>	NC	NC	197	3	585701.59	1581.60	1.096	0.135	0.013
	3	Mean no. gulls w/in 100m	NC	NC	NC	197	3	587266.64	1582.13	1.622	0.104	0.011
	4	Mean no. pedestrians w/in 100m, mean no. gulls w/in 100m, nest initiation date	NC	NC	NC	197	5	575407.09	1582.30	1.793	0.095	0.101

<sup>a</sup>Global Model:  $F_{4,192} = 1.79$   $p < 0.1317$ ,  $R^2 = 0.0360$ , Adj  $R^2 = 0.0159$

Appendix 8. Linear regression model of piping plover egg survival versus the proportion of observations in which at least 1 pedestrian, gull or other potential disturbance was present within 100 m of nests, West Hampton Dunes, Long Island, N.Y., 1997-2000. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Site	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	SSE	AIC <sub>C</sub>	$\Delta_i$	<i>w<sub>i</sub></i>	Adj R <sup>2</sup>
WHD <sup>a</sup>	1	Proportion of obs in which at least 1 pedestrian, gull was present w/in 100m	-	-	0.076	197	4	581261.09	1582.19	0.000	0.172	0.016
		Intercept	84.03	10.48	<0.0001							
			Proportion of obs in which at least 1 pedestrian, was present w/in 100m	0.11	0.07	0.1038						
			Proportion of obs in which at least 1 gull was present w/in 100m	0.1	0.07	0.1151						
	2	Proportion of obs in which at least 1 pedestrian, was present w/in 100m	NC <sup>b</sup>	NC	NC	197	3	588766.71	1582.63	0.444	0.138	0.009
3	Proportion of obs in which at least 1 gull was present w/in 100m	NC	NC	NC	197	3	589264.40	1582.80	0.610	0.127	0.008	
	Null				197	2	596907.31	1583.28	1.086	0.100	-	

<sup>a</sup>Global Model:  $F_{4,192} = 1.31$   $P = 0.2658$ ,  $R^2 = 0.0267$ , Adj  $R^2 = 0.0064$ .

<sup>b</sup>Not calculated

Appendix 9. Linear regression model of piping plover mean annual reneest rate vs. mean maximum daily temperature and total precipitation April through July, nesting pair density, and number cats and foxes trapped, West Hampton Dunes and Westhampton Beach, Long Island, N.Y., 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Site	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	$P$	$n$	$k$	SSE	AIC <sub>C</sub>	$\Delta_i$	$w_i$	Adj R <sup>2</sup>
<sup>a</sup> WHD	Null					10	2	0.18	-34.6	0.000	0.247	-
	1	Density	NC <sup>c</sup>	NC	NC	10	3	0.12	-34.6	0.006	0.247	0.267
	2	Density, Total precipitation	NC	NC	NC	10	4	0.07	-34.3	0.346	0.208	0.524
<sup>b</sup> The Reference Area	Null					10	2	0.62	-22.0	0.000	0.511	-

<sup>a</sup>Global model:  $F_{5,4} = 4.00$ ,  $P = 0.1019$ ,  $R^2 = 0.8334$ , Adj  $R^2 = 0.6251$ .

<sup>b</sup>Global model:  $F_{5,4} = 0.38$ ,  $P = 0.8391$ ,  $R^2 = 0.3241$ , Adj  $R^2 = -0.5207$ .

<sup>c</sup>Not calculated

Appendix 10. Linear regression model of piping plover chick survival vs. hatch date, mean number of pedestrians, gulls, other potential disturbances within 100 meters of nests, West Hampton Dunes, Long Island, New York, 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Site	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	n	k	SSE	AIC <sub>C</sub>	$\Delta_i$	$w_i$	Adj R <sup>2</sup>
WHD <sup>a</sup>	1	Mean no. pedestrians w/in 100m	0.13	0.09	0.1301	178	3	640102.76	1463.53	0.000	0.257	0.007
		Intercept	102.92	9.18	<0.0001							
		Null				178	2	648512.55	1463.78	0.254	0.227	-
	2	Mean no. other w/in 100m	NC <sup>b</sup>	NC	NC	178	3	645335.63	1464.98	1.449	0.125	-0.001
	3	Mean no. gulls w/in 100m	NC	NC	NC	178	3	646678.50	1465.35	1.819	0.104	-0.003
	4	Mean no. pedestrians w/in 100m, mean no. gulls w/in 100m	NC	NC	NC	178	4	639296.60	1465.40	1.869	0.101	0.003
5	Mean no. pedestrians w/in 100m, mean no. other w/in 100m	NC	NC	NC	178	4	639418.59	1465.43	1.903	0.099	0.003	

Global Model:  $F_{4,173} = 0.68$ ,  $P = 0.6087$ ,  $R^2 = 0.0154$ ,  $\text{Adj } R^2 = -0.0074$ .  
<sup>b</sup>Not Calculated

Appendix 11. Linear regression model of piping plover chick survival vs. hatch date, the proportion of observations in which at least 1 pedestrian, gull or other potential disturbance was present within 100 m of nests, West Hampton Dunes, Long Island, New York, 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

Site	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	<i>P</i>	<i>n</i>	<i>k</i>	SSE	AIC <sub>C</sub>	$\Delta_i$	<i>w<sub>i</sub></i>	Adj R <sup>2</sup>
WHD	Null					178	2	648512.55	1463.78	0.000	0.198	-
	1	% observations > 1 other	NC <sup>a</sup>	NC	NC	178	3	644501.37	1464.75	0.965	0.122	5.000E-04
	2	% observations >1 gull	NC	NC	NC	178	3	644795.84	1464.83	1.046	0.117	1.000E-04
	3	% observations > 1 pedestrian	NC	NC	NC	178	3	645291.32	1464.97	1.183	0.109	-7.000E-04

<sup>a</sup>Global Model:  $F_{4,173} = 0.52$ ,  $P = 0.7223$ ,  $R^2 = 0.0118$ , Adj  $R^2 = -0.0110$ .

<sup>b</sup>Not calculated

Appendix 12. Linear regression model of mean piping plover brood survival vs. mean maximum daily temperature and total precipitation May through August, nesting pair density, and number cats and foxes trapped, West Hampton Dunes and Westhampton Beach, Long Island, N.Y., 1994-2003. Information-theoretic results for best model, null model, and all models with  $\Delta_i \leq 2$  are shown. ANOVA table for best model is shown.

	Model	Regressors in model	$\beta_i$	SE ( $\beta_i$ )	$P$	n	k	SSE	AIC <sub>c</sub>	$\Delta_i$	$w_i$	Adj R <sup>2</sup>
WHD <sup>a</sup>	1	No. foxes trapped, No. cats trapped			0.0145	10	4	0.04	-40.11	0.000	0.428	0.616
		Intercept	0.65	0.03	<0.0001							
		No. foxes trapped	0.03	0.01	0.0119							
		No. cats trapped	0.02	0.01	0.0246							
		No. foxes trapped	NC <sup>c</sup>	NC	NC	10	3	0.08	-38.39	1.712	0.182	0.274
	Null				10	2	0.12	-38.30	1.802	0.174	-	
The Reference Area <sup>b</sup>	Null				10	2	0.37	-27.12	0.000	0.333	-	
	1	Mean maximum monthly temperature	NC	NC	NC	10	3	0.29	-25.56	1.561	0.153	0.143

<sup>a</sup>Global Model:  $F_{5,4} = 2.62$ ,  $P = 0.1862$ ,  $R^2 = 0.7659$ , Adj  $R^2 = 0.4732$ .

<sup>b</sup>Global Model:  $F_{5,4} = 2.28$ ,  $P = 0.2218$ ,  $R^2 = 0.7406$ , Adj  $R^2 = 0.4165$ .

<sup>c</sup>Not calculated

## Education

**Bachelor of Science in Resource Development**, major: Nutritional Science, minor Biology  
University of Rhode Island, Kingston, RI 1993

**Master of Science in Biology**, concentration: Wildlife Biology  
East Stroudsburg University, East Stroudsburg, PA 1995  
Thesis: US Osprey Breeding Status and Dispersal Patterns and Trends 1994

**Doctor of Philosophy in Fisheries and Wildlife Science**: Wildlife Biology  
Virginia Polytechnic Institute and State University, Blacksburg, VA 2005  
Dissertation: Piping Plover Ecology on a Storm-destroyed and Re-built Barrier Island

## Teaching Experience

**Job Title:** Instructor for Ecology 2804 (Ornithology)  
**Employer:** Virginia Tech, Blacksburg, VA 24061-0321  
**Supervisor:** Dr. Fred Benfield  
**Date of Employment:** 8/22-present

**Job Description:**

- Instructor for Ecology (2005)
- Designed course lectures, projects, exams, and website
- Taught ecology and related topic to over 80 students

**Job Title:** Instructor for Biology 4404 (Ornithology)  
**Employer:** Virginia Tech, Blacksburg, VA 24061-0321  
**Supervisor:** Dr. James D. Fraser  
**Date of Employment:** 1/14-5/7/2002, 1/13-5/6/2003

**Job Description:**

- Main instructor for Ornithology class and labs (2002-03)
- Designed all course and lab lectures, projects, exams, and website
- Taught bird biology, ecology, and identification of birds and bird songs

**Job Title:** Substitute Teacher  
**Employer:** Goffstown Regional School District, Goffstown, NH  
**Supervisor:** Rose Colby  
**Date of Employment:** 1/89-2/96 (During university and seasonal employment breaks/holidays, equivalent in teaching hours to approximately 2 years full-time)

**Job Description:**

- Taught and/or supervised Elementary, Junior, and Senior High School students

**Job Title:** Environmental Educator  
**Employer:** Nature's Classroom, Freedom, NH  
**Supervisor:** Mike Vecchiarelli  
**Date of Employment:** 9/95-12/95

**Job Description:**

- Taught environmental education and natural history to 5th-8th graders
- Designed and implemented outdoor wildlife education courses
- Presented special lectures on predator/prey relations and birds of prey

---

1704 Meadowbrook • Blacksburg, VA 24060 • (540) 951-2249

## Assistantships

**Job Title:** Teaching assistant for Biology 4404 (Ornithology)

**Employer:** Virginia Tech, Blacksburg, VA 24061-0321

**Supervisor:** Dr. James D. Fraser

**Date of Employment:** 1/19/2004-5/14/2004

**Job Description:**

- Teach bird biology, ecology and identification of birds and bird songs
- Designed website, all lab lectures, projects, and exams

**Job Title:** Research Assistant

**Employer:** Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

**Supervisor:** Dr. James Fraser

**Date of Employment:** 8/18/00-12/26/2003

**Job Description:**

- Data analysis, course work, report writing, scientific presentations

**Job Title:** Graduate Assistant (1/2 teaching/1/2 research)

**Employer:** East Stroudsburg University, East Stroudsburg, PA 18301

**Supervisor:** Dr. Larry M. Rymon

**Date of Employment:** 9/7/93-12/16/94

**Job Description:**

- Assisted in teaching ecology, behavior, and identification of eastern birds and mammals
- Assisted with field research, supervised two student workers, held office hours, and advised students
- East Stroudsburg University Natural History Museum Curator including preparation of study skins

## Internships

**Job Title:** Graduate Intern

**Employer:** Osprey Reintroduction Project, East Stroudsburg, PA 18301

**Supervisor:** Dr. Larry M. Rymon

**Date of Employment:** 4/1/94-8/31/94

**Job Description:**

- Recorded Osprey courting, incubation, brooding, fishing, feeding and fledging behaviors
- Assisted with Osprey banding, handling, and nest climbs
- Aided in research on identification of individuals by plumage patterns
- Helped with northeast Pennsylvania Osprey nesting survey

**Job Title:** Raptor Project Assistant

**Employer:** Western Foundation of Vertebrate Zoology, San Juan Capistrano, CA

**Supervisor:** Pete Bloom

**Date of Employment:** 5/23/95-6/31/95

**Job Description:**

- Trapped Red-Tailed, Red-Shouldered and Cooper's Hawks using BC and Dho Gaza traps
- Assisted in banding, weighing, taking wing chord and tail length measurements, checking feather molts and overall health of trapped birds
- Recorded vital statistics for several species of adult Falconiformes
- Climbed nest trees and assisted with banding of Red-Shouldered and Cooper's Hawks
- Surveyed potential nesting habitat

---

1704 Meadowbrook • Blacksburg, VA 24060 • (540) 951-2249

## General Employment (Related)

**Job Title:** Research Associate

**Employer:** Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

**Supervisor:** Dr. James Fraser

**Date of Employment:** 3/18/96-8/17/00

**Job Description:**

- Worked in conjunction with the USFWS, USACE, NYSDEC, and The Nature Conservancy
- Monitored and recorded the breeding biology of Piping Plovers and other shorebirds
- Supervised and trained 15 field technicians and/or students over the course of the project
- Developed and implemented piping plover management strategies
- Assisted with grant and proposal writing
- Data Analysis, report writing, scientific presentations

**Job Title:** Guest Lecturer

**Employer:** Goffstown, John Stark and Souhegan High Schools, NH

**Supervisors:** Lisa Nelson, Barbara Beers, and Dan Bassachio

**Date of Employment:** 2/95, 1/96, 10/98, 12/99

**Job Description:**

- Special Lectures on the Ecology of Birds of Prey and Shorebirds (1-2 hour sessions)

**Job Title:** Green House Supervisor

**Employer:** East Stroudsburg University, East Stroudsburg, PA

**Supervisor:** Ray Milewski

**Date of Employment:** 9/93-11/93

**Job Description:**

- General greenhouse care and supervision of 3 work-study students

**Job Title:** Scientists Aide

**Employer:** Normandeau Associates, Bedford, NH

**Supervisor:** Hanna Proctor

**Date of Employment:** 6/93-8/93

**Job Description:**

- Taxonomic identification/classification of invertebrate and vertebrate specimens

**Job Title:** Building Supervisor, Intramural Supervisor, and Fitness Instructor

**Employer:** University of Rhode Island, Kingston, RI

**Supervisor:** Art Tuveson

**Date of Employment:** 9/89-5/93

**Job Description:**

- Supervised 100's of work study students and monitored the URI Athletic Center
- Oversaw intramural workers, recreation sports programs and fitness rooms

**Job Title:** Laboratory Assistant

**Employer:** University of Rhode Island, Kingston, RI

**Supervisor:** Clifford Cosgrove

**Date of Employment:** 9/88-5/89

**Job Description:**

- General Laboratory duties
- Assisted with lab assignments and paper grading

## Primary Volunteer Work Experience

**Title:** Field Assistant

**Volunteered for:** Audubon Society of New Hampshire, Concord, NH

**Supervised by:** Chris Martin

**Dates Volunteered:** 3/95, 8/96, 3/98, 10/98, and 12/99

**Duties performed:**

- Searched for and predator guarded osprey nests in northern NH (2-4day trips)
- Surveyed nests and recorded productivity data
- Recorded nest tree heights and DBH

**Title:** Eagle Monitor

**Volunteered for:** Audubon Society of New Hampshire, Concord, NH

**Supervised by:** Laura Deming

**Dates Volunteered:** 12/94-3/95 and 12/95-2/96

**Duties performed:**

- Surveyed specified rivers and other open waters for eagles (on foot and by vehicle)
- Collected data on abundances, habitat use, movements and behaviors of wintering eagles
- Monitored eagle roost sites, identified, and recorded individual eagle plumage patterns

**Title:** Visitor Center Attendant and Field Assistant

**Volunteered for:** Blackwater National Wildlife Refuge, MD

**Supervised by:** Maggie Briggs

**Dates Volunteered:** 8/95

**Duties performed:**

- Public education, natural history, and public tours of the refuge
- Assisted in trapping and radio-telemetry of endangered Delmarva Fox Squirrels

**Title:** Field Assistant

**Volunteered for:** Neotropical Migrant Nesting Survey, PA

**Supervised by:** Terry Master

**Dates Volunteered:** 4/94-5/94

**Duties performed:**

- Identified song birds by sight and song
- Assisted with recording songbird-nesting data in Delaware Water Gap

**Title:** Field Researcher

**Volunteered for:** University of Rhode Island Botany Department, Kingston, RI

**Supervised by:** Chris Nerone

**Dates Volunteered:** 2/93-5/93

**Duties performed:**

- Assisted in searching for suitable new sites for URI field botany classes
- Keyed out various plant species
- Researched and wrote a proposal on alternative low impact methods of teaching Field Botany

**Title:** Field Assistant

**Volunteered for:** Trustom Pond and Ninigret National Wildlife Refuges, RI

**Supervised by:** Dave Houghton

**Dates Volunteered:** 9/92-5/93

**Duties performed:**

- Assisted in waterfowl and other bird surveys
- Aided in evaluation and construction of bluebird trails

## Publications

Houghton, Lawrence M. and L. M. Rymon. (1997). The US osprey nesting distribution and population status 1994. *J. Raptor Res.* 31(1): 44-53

## Publications in progress

Houghton, Lawrence M., J. Cohen, J.D. Fraser and S. Elias-Gerken. (in progress). Piping plover population dynamics on a storm-destroyed and rebuilt barrier island village 1993-2004. To be submitted to the *Journal of Wildlife Management* as a monograph

## Abstracts

Houghton, Lawrence M., J.D. Fraser and S. Elias-Gerken. 2000. Piping plover population dynamics on a storm-destroyed and rebuilt barrier island village. Colonial Waterbirds Meeting, Manomet, MA. Nov. 2000

Keane, Shannon E., J. D. Fraser, P. Buckley, L. M. Houghton. 2000. Effects of herring and great black-backed gulls on breeding piping plovers on South Monomoy Island, Massachusetts. Colonial Waterbirds Meeting, Manomet, MA. Nov. 2000

Houghton, Lawrence M., and J.D. Fraser. 1998. Piping plover population dynamics on a storm-destroyed and rebuilt barrier island village. Proceedings: The Piping Plover and Least Terns of the Great Plains and nearby: A symposium/workshop, Omaha, NE. Feb. 2-5, 1998

Fraser, James D., P. Buckley, J. P. Loegering, M. E. Patterson, L. M. Houghton, and S. Elias-Gerken. 1998. Piping Plover brood foraging ecology, habitat selection and survival on Atlantic barrier islands. Proceedings: The Piping Plover and Least Terns of the Great Plains and nearby: A symposium/workshop, Omaha, NE. Feb. 2-5, 1998

Houghton, Lawrence M. and L. M. Rymon. 1995. The US osprey population, to hack or not to hack. *J. Raptor Res.* 29 (1):

Rymon, Larry M. and L. M. Houghton. 1994. Osprey. Raptor Conference, Urbino, Italy. Oct. 1996

## Papers Presented (Scientific Meetings)

- Keane, S. E. J. D. Fraser, P. A. Buckley and L. M. Houghton. 2001. The effect of gulls on piping plovers on Monomoy National Wildlife Refuge, MA. Annual meeting, Virginia Chapter of the Wildlife Society. March 6-8. Richmond, VA.
- Cohen, J., L. M. Houghton and J. D. Fraser. 2001. Piping plover population dynamics in Westhampton Dunes, N.Y. Proceedings: The Atlantic Coast Piping Plover Recovery Meeting: A symposium/workshop, January 17-19, 2001. Shepherdstown, WV.
- Keane, S.E., and J. D. Fraser and L. M. Houghton. 2001. Effects of gulls on piping plovers at Monomoy National Wildlife Refuge. Proceedings: The Atlantic Coast Piping Plover Recovery Meeting: A symposium/workshop, January 17-19, 2001. Shepherdstown, WV.
- Houghton, Lawrence M., J.D. Fraser and S. Elias-Gerken. 2000. Piping plover population dynamics on a storm-destroyed and rebuilt barrier island village. Colonial Waterbirds Meeting, Manomet, MA. Nov. 2000
- Keane, Shannon E., J. D. Fraser, P. Buckley, L. M. Houghton. 2000. Effects of herring and great black-backed gulls on breeding piping plovers on South Monomoy Island, Massachusetts. Colonial Waterbirds Meeting, Manomet, MA. Nov. 2000
- Fraser, James D., P. Buckley, J. P. Loegering, M. E. Patterson, L. M. Houghton, S. Keane, and S. Elias-Gerken. 1998. Piping Plover brood foraging ecology, habitat selection and survival on Atlantic barrier islands. Proceedings: The Atlantic Coast Piping Plover Recovery Meeting: A symposium/workshop, Sheperdstown, WV. Dec. 14-16, 1998
- Houghton, Lawrence M., J.D. Fraser and S. Elias-Gerken. 1998. Piping plover population dynamics on a storm-destroyed and rebuilt barrier island village. Proceedings: The Piping Plover and Least Terns of the Great Plains and nearby: A symposium/workshop, Omaha, NE. Feb. 2-5, 1998
- Fraser, James D., P. Buckley, J. P. Loegering, M. E. Patterson, L. M. Houghton, and S. Elias-Gerken. 1998. Piping Plover brood foraging ecology, habitat selection and survival on Atlantic barrier islands. Proceedings: The Piping Plover and Least Terns of the Great Plains and nearby: A symposium/workshop, Omaha, NE. Feb. 2-5, 1998
- Rymon, Larry M. and L. M. Houghton. 1994. Osprey. Raptor Conference, Urbino, Italy. Oct. 1996
- Houghton, Lawrence M. and L. M. Rymon. 1994. The US osprey population, to hack or not to hack. Raptor Research Foundation Conference, Flagstaff, Arizona, Nov. 1994
- Rymon, Larry M. and L. M. Houghton. 1994. Osprey. Endangered Species Coalition Meeting, Mt. Pocono, Pennsylvania. Oct. 1994

## Papers Presented (Army Corps of Engineers Annual Meetings)

Houghton, Lawrence M., and J.D. Fraser. 1999. The effects of the USACE Westhampton interim storm damage proection project on piping plover habitat at the Village of West Hampton Dunes and Westhampton Beach, Long Island, NY, USACE meeting, Islip, N.Y. Jan. 2000

Houghton, Lawrence M., and J.D. Fraser. 1998. The effects of the USACE Westhampton interim storm damage proection project on piping plover habitat at the Village of West Hampton Dunes and Westhampton Beach, Long Island, NY, USACE meeting, New York, NY. Nov. 1998

Houghton, Lawrence M., and J.D. Fraser. 1997. The effects of the USACE Westhampton interim storm damage proection project on piping plover habitat at the Village of West Hampton Dunes and Westhampton Beach, Long Island, NY, USACE meeting, New York, NY. Oct. 1997

Houghton, Lawrence M., and J.D. Fraser. 1996. The effects of the USACE Westhampton interim storm damage proection project on piping plover habitat at the Village of West Hampton Dunes and Westhampton Beach, Long Island, NY, USACE meeting, New York, NY. Nov. 1996

## Posters Presented

Houghton, Lawrence M., and J.D. Fraser. 1998. Piping plover population dynamics on a storm-destroyed and rebuilt barrier island village. Proceedings: The Atlantic Coast Piping Plover Recovery Meeting: A symposium/workshop, Sheperdstown, WV. Dec. 14-16, 1998

Houghton, Lawrence M., and J.D. Fraser. 1997. Piping plover population dynamics on a storm-destroyed and rebuilt barrier island village. Department of Fisheries and Wildlife Sciences Bulletin Board, Virginia Polytechnic Institute and State University, Blacksburg, VA 1997-2000.

## Reports

Houghton, Lawrence M., S.P. Elias-Gerken, and J.D. Fraser. The effects of the USACE Westhampton interim storm damage protection project on piping plover habitat at the Village of West Hampton Dunes and Westhampton Beach, Long Island, NY (1993-2003, Final Report)

Houghton, Lawrence M., A. Novack, S.P. Elias-Gerken, and J.D. Fraser. 2000. The effects of the USACE Westhampton interim storm damage protection project on piping plover habitat at the Village of West Hampton Dunes and Westhampton Beach, Long Island, NY (Annual Report)

Keane, Shannon E., J. D. Fraser, L. M. Houghton. 2000. Effects of Herring and Great Black-Backed Gulls on Breeding Piping Plovers on South Monomoy Island, Massachusetts. (Annual Report)

Houghton, Lawrence M., S.P. Elias-Gerken, and J.D. Fraser. 1999. The effects of the USACE Westhampton interim storm damage protection project on piping plover habitat at the Village of West Hampton Dunes and Westhampton Beach, Long Island, NY (Annual Report)

Keane, Shannon E., J. D. Fraser, L. M. Houghton. 1999. Effects of Herring and Great Black-Backed Gulls on Breeding Piping Plovers on South Monomoy Island, Massachusetts. (Annual Report)

Houghton, Lawrence M., J.D. Fraser, K. Meskill, R. Chambers, K. Donohue, and H. Dohn. 1998. Piping plover monitoring program, The Village of West Hampton Dunes and the Westhampton Beach groinfield, Long Island, New York: The U. S. Army Corps of Engineers Moriches to Shinnecock Reach Interim Storm Damage Protection Project 1996-1998. (Final Report)

Houghton, Lawrence M., S.P. Elias-Gerken, and J.D. Fraser. 1998. The effects of the USACE Westhampton interim storm damage protection project on piping plover habitat at the Village of West Hampton Dunes and Westhampton Beach, Long Island, NY, Nov. 1998

Houghton, Lawrence M., J.D. Fraser, K. Meskill, R. Chambers, K. Donohue, and H. Dohn. 1998. Piping plover monitoring program, The Village of West Hampton Dunes and the Westhampton Beach groinfield, Long Island, New York: The U. S. Army Corps of Engineers Moriches to Shinnecock Reach Interim Storm Damage Protection Project 1997. (Annual Report)

Keane, Shannon E., J. D. Fraser, L. M. Houghton, and M. M. Paul. 1998. Effects of Herring and Great Black-Backed Gulls on Breeding Piping Plovers on South Monomoy Island, Massachusetts. (Annual Report)

Houghton, Lawrence M., S.P. Elias-Gerken, and J.D. Fraser. 1997. The effects of the USACE Westhampton interim storm damage protection project on piping plover habitat at the Village of West Hampton Dunes and Westhampton Beach, Long Island, NY (Annual Report)

Houghton, Lawrence M., S.P. Elias-Gerken, and J.D. Fraser. 1996. The effects of the USACE Westhampton interim storm damage protection project on piping plover habitat at the Village of West Hampton Dunes and Westhampton Beach, Long Island, NY, (Annual Report)

Kuklinski, Michelle L., L. M. Houghton, and J. D. Fraser. 1996. Piping plover breeding ecology on Cape Hatteras National Seashore with special reference to the effect of temperature on productivity. (Final Report)

## Grants

Fraser, James D., and L. M. Houghton. 2000. Effects of beach management practices on piping plovers and associated beach organisms for the Westhampton interim storm damage protection project.  
United States Army Corps of Engineers \$603,500.00

Fraser, James D., and L. M. Houghton. 1997. Effects of beach management practices on piping plovers and associated beach organisms for the Westhampton interim storm damage protection project.  
United States Army Corps of Engineers \$390,000.00

Rymon, Larry M., and L.M. Houghton. 1994. Recovery of Ospreys in Pennsylvania by Hacking  
Pennsylvania Wild Resource Conservation Fund \$1,200.00

## Honors and Awards

12/91-present Golden Key National Honor Society  
9/91 University of Rhode Island General Academic Grant \$1,000.00  
5/88 Goffstown High School Resource Development Scholarship \$ 700.00  
5/88 Goffstown High School Outdoor Recreation Scholarship \$ 300.00

## Professional Memberships and Activities

2000-2004 Colonial Waterbirds Society  
1999-2004 American Ornithological Union  
1996-1998 Raptor Research Foundation  
1993-1996 National Wildlife Society  
1993-1996 Northeast Chapter, The Wildlife Society  
1994-1995 The Society for Conservation Biology  
1992-1993 University of Rhode Island Wildlife Society Student Chapter

## Professional References

Dr. James D. Fraser  
Cheatham Hall  
Department of Fisheries and Wildlife Sciences  
Virginia Polytechnic Institute and State University  
Blacksburg, VA 24061-0321  
(540) 231-6064  
fraser@vt.edu

Dr. Jeff Walters  
Harold Bailey Professor  
Biology Department  
Virginia Polytechnic Institute and State University  
Blacksburg, VA 24061-0321  
(540) 231-3847  
jrwalt@vt.edu

Dr. Larry M. Rymon  
Naturalist/Zoogeographer  
214 Timberline Drive  
Sequim, WA 98382  
(360) 681-6399

Anne Hecht  
Endangered Species Biologist  
United States Fish and Wildlife Service  
Weir Hill Road  
Sudbury, MA 01776  
(978) 443-4325