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MULTIPLE FACTOR ANALYSIS OF PIPING PLOVERS AND OTHER BEACH-
DEPENDENT SPECIES HABITAT USE AND POPULATION DYNAMICS
FOLLOWING STORM AND HUMAN CREATED CHANGES TO BARRIER ISLAND
HABITATS WITHIN THE FIRE ISLAND NATIONAL SEASHORE

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TABLE OF CONTENTS

Background Information	6
Study Site	7
Part I: Piping plover nest site selection following Hurricane Sandy habitat creation on Fire Island and Cupsogue Beach County Park, New York	13
Introduction	13
Methods	13
Model Covariates	15
Elevation	15
Distance to development.....	15
Distance to ocean/bay high tide	15
Least cost distance to ocean/bay high tide	15
Dry sand within a 500m radius	15
Backshore width.....	15
Analysis	17
Results	17
Discussion.....	25
Literature Cited	26
Part II: Monitoring of Piping Plover on Fire Island and Westhampton Island	29
2016 Executive Summary.....	29
Introduction	29
Field Methods	30
Habitat and Tide Mapping	30
Adult Survey.....	30
Nest Location	31
Location, Elevation and Vegetation Data at Nests (Objective 8).....	32
Egg Masses.....	32
Nest Checks	33
Trapping and Banding	33
Banding Schemes	34
Brood Observations	35
Invertebrate Sampling	36

Core Sampling	37
Fecal Sampling	38
Analytical Methods	38
Objective 1: Compare changes in numbers, density, and distribution of piping plovers in various habitats on Fire Island.....	38
Objective 2: Estimate the “effect distance” of artificially created habitat at New Made and Great Gun Beach	39
Objective 3: Compare egg weights of birds with access to bay side intertidal flats with egg weights of birds without such access	39
Objective 4: Compare piping plover nest and chick survival rates in various habitats across Fire Island	39
Objective 5: Compare the relative contribution of local growth (local recruitment) vs immigration in population growth associated with new habitats	40
Objective 9: Compare prey densities at several habitat types	40
Results.....	41
Objective 1: Compare changes in numbers, density, and distribution of piping plovers in various habitats on Fire Island.....	41
Objective 2: Estimate the “effect distance” of artificially created habitat at New Made and Great Gun Beach	46
Adult Movement.....	46
Fledgling Movement	49
Objective 3: Compare egg weights of birds with access to bay side intertidal flats with egg weights of birds without such access	50
Objective 4: Compare piping plover nest and chick survival rates in various habitats across Fire Island	50
Objective 5: Compare the relative contribution of local growth (recruitment) vs immigration in population growth associated with new habitats.....	57
Objective 8: Location, elevation and vegetation data at nests	59
Objective 9: Compare prey densities at several habitat types	60
Terrestrial Invertebrates.....	60
Core Samples	61
Fecal Samples.....	61
Discussion.....	62
Literature Cited	65
Part III: Red Fox Movements, Habitat Selection, and Demography on Fire Island, New York	67
Introduction	67

Methods.....	68
Study Site	68
Sign, scat, and den surveys	68
Field Methods	68
Lab methods.....	71
Den Monitoring.....	72
Field Methods	72
Analyses	72
Trapping, ear-tagging, and collaring	72
GPS tracking	74
Field Methods	74
Analyses	75
Remote camera surveys.....	76
Field methods	76
Analyses	79
Results and Discussion	79
Objective 1 and 2: Quantify the abundance and occupancy of red foxes, and habitat use vs. availability, and relate changes in these parameters to changes in habitat and predator management activities	79
Abundance estimates from den surveys and transect monitoring	80
Occupancy estimates from remote camera monitoring	81
Objective 3: Quantify home range size, long-range movements, and variation in movement ecology of red foxes and relate to changing habitat composition and predator management.	82
Home range estimates: MCPs, 50% and 95% kernel density contours.....	83
Long distance movements	84
Objective 4: Estimate red fox reproductive success and adult survival, and variation in these population parameters, related to habitat composition and predator management.	92
Reproductive success.....	92
Adult Survival	93
Objective 5: Quantify the interactions of red foxes with shorebird nests and chicks.	94
Diet analyses	94
Spatial overlap with piping plover nests and locations	95
Literature Cited	101
Part IV: Monitoring of shorebirds on Fire Island and Westhampton Island	103

Introduction	103
Study Site	104
Caution with interpreting shorebird counts	105
Field Methods	106
Counting the number of piping plovers.....	106
Shorebird Surveys	106
Data Analysis.....	107
Shorebird abundance and diversity on Fire Island	107
Temporal overlap between beach closure for piping plovers and migration window of shorebirds	107
Space-use overlap between piping plovers and migratory shorebirds	107
Results.....	109
Shorebird abundance and diversity on Fire Island	109
Temporal overlap between beach closure for piping plovers and migration window of shorebirds	110
Space-use overlap between piping plovers and migratory shorebirds	120
Conclusions	122
Literature Cited	124
Summary Remarks	126
Acknowledgements.....	128
Appendices.....	129
Appendix A: Injured Piping Plover Observations.....	129
Appendix B: Response of Piping Plover Prey to Habitats Created by Hurricane Sandy	130
Appendix C: Fox Home Range Maps	148
Fall 2015-Winter 2016	149
Spring-Summer 2016	158
Appendix D: Spatial response of red foxes to nest enclosure setup, pipping, and hatching	162

BACKGROUND INFORMATION

The work described in this report was funded under the Breach Contingency Plan (BCP; USACE 1996), the Fire Island Inlet to Moriches Inlet Stabilization Coastal Storm Risk Reduction Project (FIMI; USACE 2014), the USFWS North Atlantic Landscape Conservation Cooperative Beach Resiliency Project (Resiliency Project), and by Virginia Tech. Both the FIMI project and the Resiliency Project were funded under the Disaster Relief Appropriations Act of 2013 (Public Law 113-2). Because these projects were so closely coordinated, Virginia Tech (hereafter, VT) provide one report, to provide the best overview of conditions of the piping plover population, the habitat that supports it, the red fox predator population and its interactions with piping plovers, and populations of other shorebirds in the study area. The Army Corps of Engineers contributions to this project until June of 2015 were made under the Breach Contingency Plan, and were restricted to plover studies in the Corps Project Areas. The Resiliency project funding was intended to expand the plover project to include areas of Smith Point County Park in 2013-2016, and to fund the shorebird studies.

Hurricane Sandy created 3 breaches in Fire Island and Westhampton Island in October of 2012: one in the Otis Pike Wilderness of Fire Island National Seashore, one in Smith Point County Park on Fire Island, and one within Cupsogue Beach County Park on Westhampton Island. The breaches in the county parks were filled soon after the hurricane, in accordance with the BCP. The FIMI project entailed sections of beach and dune construction along the 30.5 km of Fire Island, and was initiated by USACE in winter 2014.

The USACE formally consulted with the USFWS pursuant to the Endangered Species Act of 1973, as amended, due to the potential direct and indirect adverse impacts of these projects on the federally-listed species. The USFWS's Biological Opinion for the BCP covered the piping plover (*Charadrius melodus*; threatened) and seabeach amaranth (*Amaranthus pumilus*; threatened); the Biological Opinion (BO) for the FIMI included these species as well as the red knot (*Calidris canutus rufa*; threatened; USFWS 1995 and 2014).

The potential adverse effects of the FIMI on piping plovers listed in the BO included habitat loss and degradation and exacerbation of predation. As a result, the FIMI Biological Opinion included a number of conservation measures to address these potential effects and reduce the effect of potential incidental take authorized by the USFWS, including inlet to inlet monitoring, habitat maintenance and restoration, predator management, and reduction in human disturbance. Vegetation was cleared by USACE to modify the topography in approximately 33.7 ha (83.2 ac) of ocean side habitat at Great Gun Beach to mitigate adverse effects of dune and beach construction. To create possible nesting and foraging habitat for piping plovers, USACE also created 6 ha (15.8 ac) of bay side habitat south of New Made.

A program of targeted field studies to evaluate the efficacy of the BO conservation measures, developed by the USFWS, with the assistance of Virginia Tech, are the subject of this report. Both Virginia Tech and the USFWS worked closely with an interagency team consisting of the National Park Service (NPS), New York State Office of Parks, Recreation, and Historic Preservation, the County of Suffolk, and the USACE to obtain the necessary permits to undertake this work.

The goal of this project is to provide a broader ecological understanding of the ways in which the breaches and USACE breach-fill projects affect piping plover populations, their red fox predators and their invertebrate prey communities. VT compared the dynamics of bird use and invertebrate densities in an open breach area, two

filled breach areas, two restoration areas, overwash areas, and other areas. Ultimately VT results will help refine their understanding of the time frame and manner in which piping plover habitat develops and persists. The Scope of Work for piping plover monitoring includes the following objectives:

- Objective 1: Compare changes in numbers, density, and distribution of piping plovers in various habitats on Fire Island
- Objective 2: Estimate the “effect distance” of artificially created habitat at New Made and Great Gun Beach
- Objective 3: Compare egg weights of birds with access to bay side intertidal flats with egg weights of birds without such access
- Objective 4: Compare piping plover nest and chick survival rates in various habitats across Fire Island
- Objective 5: Compare the relative contribution of local growth (recruitment) vs immigration in population growth associated with new habitats
- Objective 6: Estimate numbers and density of piping plovers in various habitats
- Objective 7: Estimate numbers of shorebirds in various habitats
- Objective 8: Collect location, elevation and vegetation data at nests
- Objective 9: Compare prey densities at several habitat types

The Scope of Work for fox monitoring includes the following objectives:

- Objective 1: Quantify the abundance and occupancy of red foxes and relate changes in these parameters to changes in habitat and predator management activities.
- Objective 2: Assess habitat use versus availability by red foxes and any variation in habitat selection related to changing habitat composition and predator management.
- Objective 3: Quantify home range size, long-range movements, and variation in movement ecology of red foxes and relate to changing habitat composition and predator management.
- Objective 4: Estimate red fox reproductive success and adult survival, and variation in these population parameters, related to habitat composition and predator management.
- Objective 5: Quantify the interactions of red fox with shorebird nests and chicks.
- Objective 6: Utilize information collected in objectives 1-5 to make recommendation on utility of, and recommended methodologies for, management of red fox populations in the study area and in other coastal habitats.

STUDY SITE

VT study area consisted of 27.1 km of Fire Island and Westhampton Island within the administrative boundaries of the National Park Service (Otis Pike Wilderness Area and the Fire Island Lighthouse Tract), Suffolk County Parks (Cupsogue Beach County Park and Smith Point County Park) and the New York State Office of Parks, Recreation, and Historic Preservation (Robert Moses State Park). From 2013 to June 2015, the study area consisted of Otis Pike Wilderness Aare, Smith Point County Park, and Cupsogue Beach County Park (17.3 km of beachfront). In June 2015, when the FIMI funding became available, the study area was expanded to include Robert Moses State Park and the Fire Island Lighthouse Tract (9.8 km).

Prior to Hurricane Sandy, VT study area consisted of sandy backshores largely backed by dunes. In October 2012, hurricane Sandy overwashed several areas of the island. It created a new breach at Old Inlet and breaches at Cupsogue Beach County Park that was filled with a berm 9+ ft NGVD in elevation, 150 ft wide and 2000 ft long (presentation on Coastal Breach Closures, Bocamazo 2013). The Narrow Bay West breach was filled with a berm about 12 ft NGVD in elevation (based on a completion drawing of Smith Point breach fill, 2013). Prior to the 2015 piping plover breeding season, the USACE constructed two restoration areas to provide potential plover nesting and foraging habitat. This construction consisted of 33.7 ha of flat sand Oceanside habitat at Great Gun, and 6 ha of flat sand bayside at New Made.

Two bayside foraging habitats have formed on the north side of Cupsogue Beach County Park. Sand bars have developed on flood shoals within Moriches Inlet where tidal currents are strong enough to keep fine sediments in suspension. However, mud flats developed where finer-grained sediments from the bay have been deposited in the low-energy shallows behind the island adjacent to the inlet. Habitats that did not fall into the classifications of mud flat, flood shoal, overwash, breach fill or restoration area can generally be considered backshore habitat.

Throughout the season, all beaches were open to pedestrians. Smith Point County Park and Robert Moses State Park also allowed recreation vehicles to drive onto the beaches. Every year, these beaches closed to vehicles around the time chicks hatched and re-opened around the time the chicks were flying (Table 1). However, in 2013 there was still vehicle presence at Smith Point County Park. Official dates of closures for that year are uncertain. These closures did not apply to law enforcement, park staff and researchers, who continued to drive All-Terrain Vehicles (ATVs) or Utility-Terrain Vehicles (UTVs) in those areas.

Table 1. Beach closure dates for vehicle use at Smith Point County Park and Robert Moses State Park 2013-2016.

Management Unit	2013	2014	2015	2016
Smith Point County Park	closed, but dates unknown	09 Jun–01 Aug	09 Jul–13 Aug	22 May–25 Aug
Robert Moses State Park - North	-	-	06 Jun–04 Aug	06 Jul–22 Jul
Robert Moses State Park - South	-	-	10 Jul–04 Aug	25 Jun–05 Aug

Each study site was divided into multiple smaller subsites intended to be of a similar geomorphological and ecological structure (e.g. overwash areas were distinct from highly vegetated tall dunes, Table 2, Figure 1 and Figure 2). These subsites allowed for general location referencing when GPS accuracy was not available. Monitoring surveys were performed by subsite.

Table 2. Subsite names, location descriptions, and habitat at Fire Island and Westhampton Island, 2016.

Name	Subsite Code	Description	Habitat Type
Demo Point	DMP	Begins at stone jetties on bay and ocean side at the east ends of OSS and STP, and extends west to the inlet.	Mature dunes and inlet
Ocean South Side	OSS	Begins at blue hut at the west end of Field 3 and extends west to the western stone jetty on the ocean side.	Backshore
Stockpile	STP	Sand stock pile area on bay side of island; begins at west end of golf course and extends west to the northernmost rock jetty.	Sand stock pile
The Golf Course	GOLF	Begins at the west side of the Field 2 parking lot behind the primary dune line and extends west to the beginning of the sand stock pile area and north to the major roadway. Not plover habitat.	Golf course
Field 3	FLD3	Begins at blue hut at the west end of Field 4 and extends west to the next blue hut in front of the Field 2 parking lot.	Backshore
Field 4	FLD4	Begins at blue hut at the west end of Field 5 and extends west to the next blue hut in front of the Field 3 parking lot.	Unvegetated backshore
Field 5	FLD5	Begins at signage at west end of Fire Island Lighthouse and extends west to the blue hut at the boundary of Field 4.	Backshore
Fire Island Lighthouse	FIL	Fire Island Lighthouse Tract of NPS; begins at eastern edge of sand ORV track running inland before housing begins and extends west to signage indicating the boundary with Robert Moses State Park.	Mature dunes
Old Inlet West Reference	OIWR	Stretch of beach between the east end of Old Inlet West and extends west to Bellport Beach.	Backshore and overwash
Old Inlet West	OIW	Begins at west side of Old Inlet and extends to the point where large primary dunes begin.	Overwash and inlet
Flood Shoals	FS	Flood shoals associated with Old Inlet.	Flood shoals
Old Inlet East	OIE	Begins where the primary duneline ends and extends west to Old Inlet.	Overwash and inlet
Bridge West	BRW	Stretch of backshore with primary duneline between Bridge Overwash and Old Inlet East.	Backshore

Bridge Overwash	BRO	Overwash in the Otis Pike Wilderness, just west of the NPS Visitor Center.	Overwash
Bridge East	BRE	Begins where the primary duneline begins at west end of Pattersquash Overwash and extends to the Otis Pike Wilderness at NPS Visitor Center.	Backshore
Pattersquash Overwash	PSO	Overwash west of Pattersquash East.	Overwash
Pattersquash East	PSE	Stretch of backshore with primary duneline between Narrow Bay West and Pattersquash overwashes.	Backshore
Narrow Bay West	NBW	Includes the overwash and small breach-fill west of the Hazardous Area.	Overwash and filled-breach
New Made	MWPF	Begins at the east end of the filled dredge spoil and extends west to the east edge of the small breach-fill	Filled dredge spoil
Narrow Bay East	NBE	Begins at Cut 2 on Burma Road and extends west to the west end of the Hazardous Area.	Overwash
Smith Point West	SPTW	Begins at Cut 3 on Burma Road and extends to Cut 2 of Burma Road.	Backshore
Smith Point East	SPTE	Begins on west side of Moriches Inlet and extends west to to Cut 3 on Burma Road.	Backshore
Cupsogue West	CSW	Breach-fill and Moriches Inlet area of the Cupsogue County Park. Begins at Moriches Inlet and extends east to the west edge of the breach-fill.	Filled breach
Cupsogue Sandbar	CSB	Large low energy sandbar/shoal north of Cupsogue West	Sand bar
Cupsogue East	CSE	Beach and narrow strip of bayside intertidal zone at east end of the Cupsogue Beach County Park. Begins at the east edge of the breach-fill and extends east the west end of the parking lot.	Backshore
Cupsogue Mud Flats	CMF	Mud flats north of the Cupsogue parking lot, and south of the high bare Island in Moriches Bay.	Mud flat

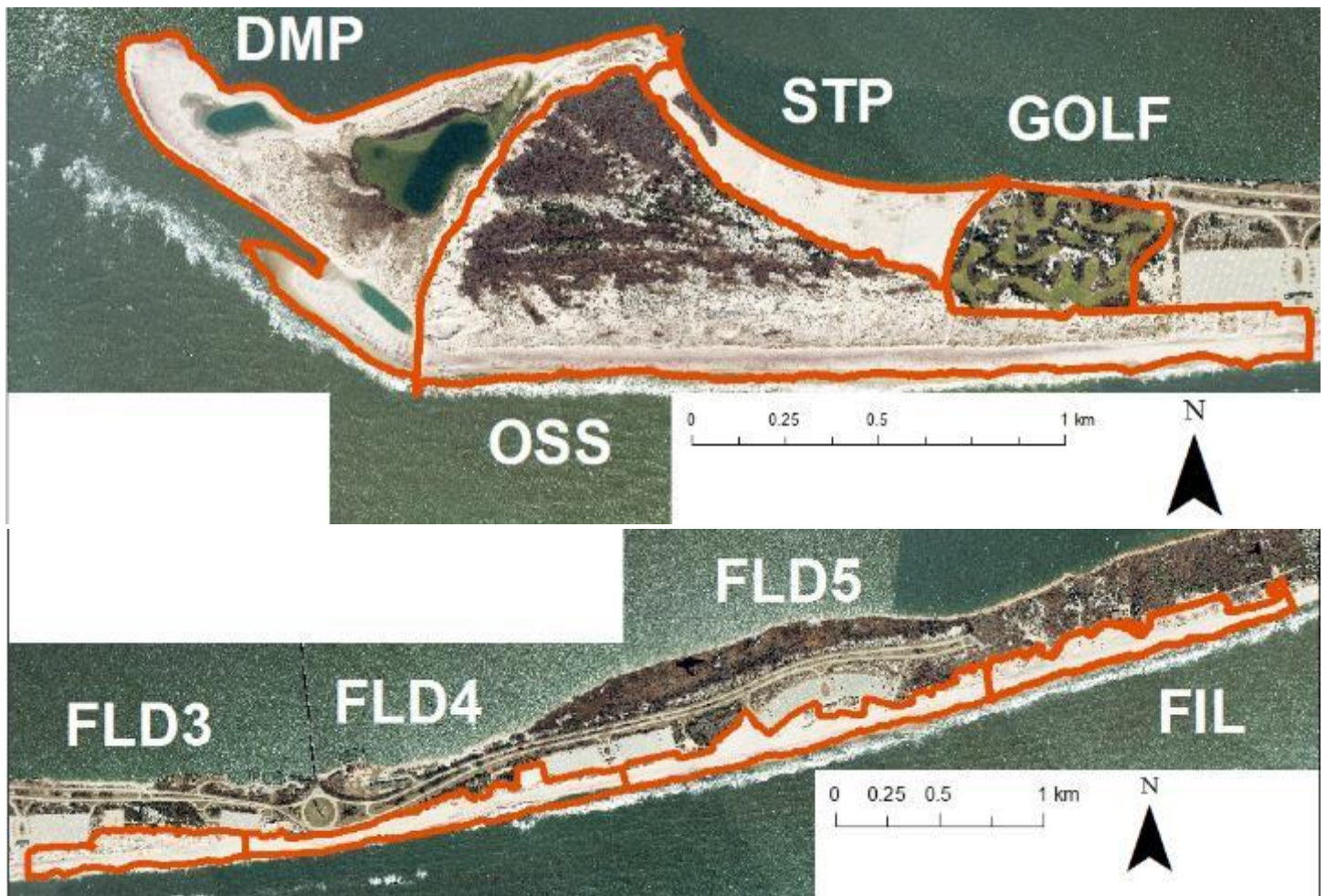


Figure 1. Study area at Robert Moses State Park including Fire Island Lighthouse Tract, shown from west to east. Subsites are highlighted in orange. See Table 2 for subsite names and descriptions. Imagery taken April, 2016.

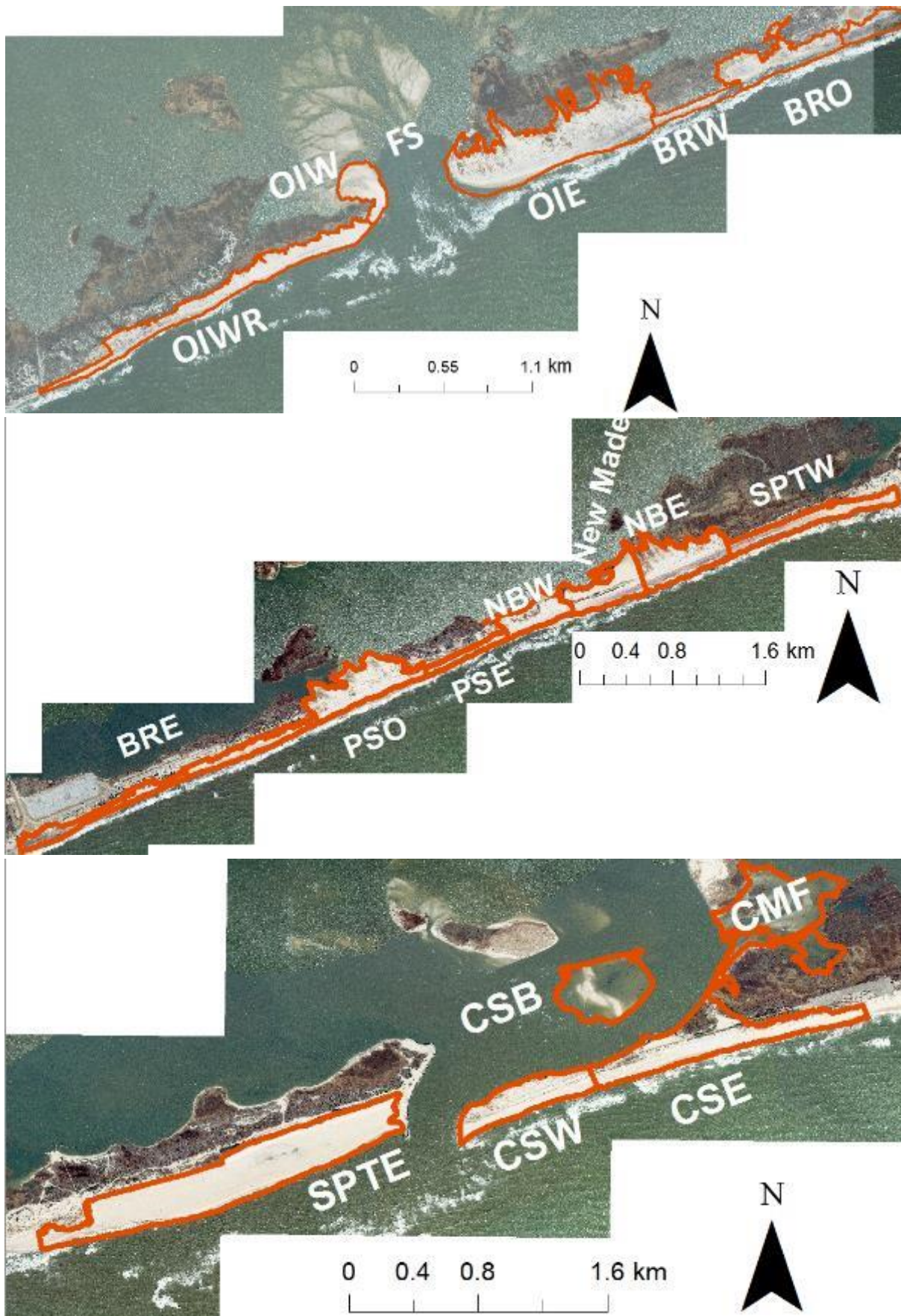


Figure 2. Study area at Eastern Barrier Islands, including Fire Island and Westhampton Island, shown from west to east. Subsites are highlighted in orange. See Table 2 for subsite names and descriptions. Imagery taken in April, 2016.

PART I: PIPING PLOVER NEST SITE SELECTION FOLLOWING HURRICANE SANDY HABITAT CREATION ON FIRE ISLAND AND CUPSOGUE BEACH COUNTY PARK, NEW YORK

INTRODUCTION

Selection refers to the behavioral choices made by animals (Buskirk and Millsaugh 2006). Determining species selection is a common research goal within the wildlife field and is often achieved through the use of resource selection functions. Resource selection functions measure non-random relationships among locations that describe an animal's position within habitats (Morris et al. 2016). The ability to understand what habitat an animal selects is an important component to wildlife management and is especially important in species of conservation concern (Morris et al. 2016).

The Atlantic Coast piping plover (*Charadrius melodus*) is listed as threatened under the Endangered Species Act (USFWS 1985). They nest on sandy to pebbly beaches (e.g., Wilson and Bonaparte 1831, Forbush 1912, Bent 1929, Wilcox 1959, Burger 1987, Patterson et al. 1991, Loegering and Fraser 1995, Elias et al. 2000, Fraser et al. 2005, Cohen et al. 2009, and Cohen and Fraser 2010). Piping plover nesting habitat is susceptible to many changes due to human development, vegetation growth, and storm events. Hurricane Sandy altered habitats on Fire Island and Westhampton Island, and subsequent actions by landowners and the U.S. Army Corps of Engineers (USACE) further changed the landscape. The Army Corps of Engineers' projects have aimed to understand how piping plovers responded to natural and anthropogenic habitat changes and how to provide a basis for adaptive management.

In various studies, piping plover nest site selection has been driven by the need to select habitat features that maximize access to reliable food sources (Loegering and Fraser 1995, Elias et al. 2000, Fraser et al. 2005, Cohen et al. 2009, and Cohen and Fraser 2010), while distancing themselves from the high tide (Cohen 2005) and from predator-prone vegetation (Cohen et al 2009). Additionally, piping plover densities have been found to be lower on beaches with close proximity to development (Houghton 2005). Using this a priori knowledge about piping plover habitat selection, VT set out to model piping plover nest site selection following Hurricane Sandy. With a habitat selection model, VT can evaluate the effects of natural coastal processes on this threatened shorebird and, in particular, compare the suitability of natural, restored, and maintained habitats. The objectives of this study were to: 1) identify coarse-scale habitat variables that influence piping plover nest site selection; 2) determine if piping plovers selected for Hurricane Sandy-created habitat; 3) estimate how much suitable piping plover habitat was present pre- and post-Hurricane Sandy; 4) highlight areas of high probability nesting for management use.

METHODS

VT study site spanned Robert Moses State Park to Cupsogue Beach County Park (Figure 3). VT modeled piping plover habitat in ArcGIS 10.2.2 using 15cm resolution multispectral imagery from April, 2015. VT fit the model on nest locations from 2015 and then applied the model to 2010 15cm imagery (New York State 2010). VT used spring imagery to ensure that the vegetation growth stage in the imagery approximately matched the vegetation stage when piping plovers return to the breeding grounds in March and select their territories.

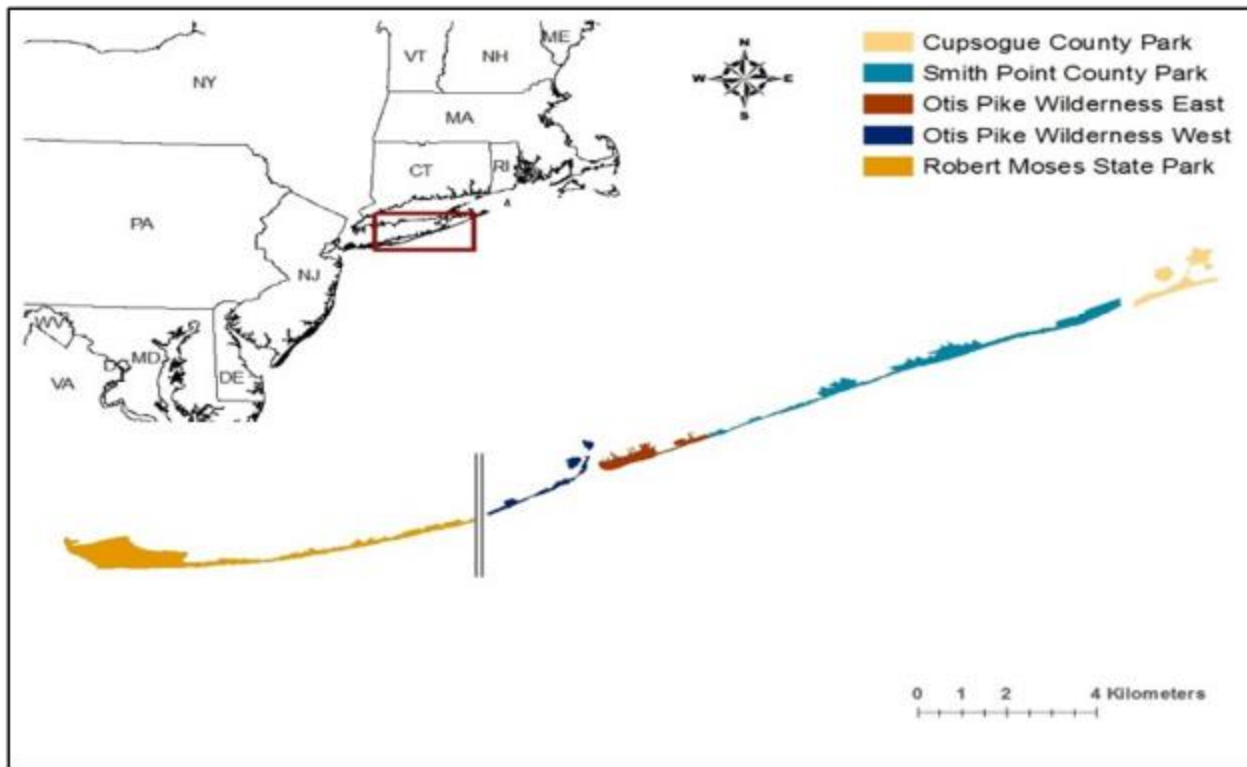


Figure 3. Fire Island and Cupsogue Beach County Park study site, divided by management unit.

VT used habitat above spring high tide for habitat classifications. Spring tides are semidiurnal tides of increased range that occur with new or full moons (Pugh 1987). VT used the spring high tide line to approximate the ocean- and bayside limits of useable nesting habitat. If a nest was below the spring high tide line, it would not persist through an incubation cycle (approximately 34 days from first egg to hatch) without a high probability of tidal flooding. Spring high tide lines within the study area were mapped by foot and by ATV in May and June of 2015 using handheld, Trimble GPS units.

Field mapping did not cover the entire ocean shoreline, therefore, VT used the elevation of the mapped line to complete the ocean high tide line across the study site. In ArcMap, VT buffered the field-mapped ocean high tide line by 3m on each side. VT extracted 1m LiDAR elevation values (collected in April, 2015) to these buffers to determine the difference in elevation below and above the field-mapped ocean high tide line. VT calculated the 75th percentile values from the buffer below the high tide line (2.23 m) and the buffer above the high tide line (2.31 m). VT reclassified the LiDAR to contain only values from 2.23–2.31 meters. This created a line of elevation values within this range across the entire ocean shoreline. For areas that hadn't been field-mapped, VT digitized these pixels to complete the ocean high tide line. Bay high tide lines were mapped entirely in the field at the same time as the ocean high tide line.

VT determined the coordinates of piping plover nest locations using a Trimble GPS unit during the 2015 breeding season, and VT generated an equal number of random points. 2010 nest locations were provided by Steve Papa, USFWS Long Island Field Office. VT limited their random points to dry sand because VT wanted to know the characteristics of dry sand locations piping plovers selected. VT used a maximum likelihood supervised classification to classify each 15cm pixel into one of four cover type classes within the imagery: dry

sand, wet sand, vegetation, and water. Because pixels were so small, VT was able to identify sand pixels even within areas that may have been considered sparsely vegetated.

MODEL COVARIATES

VT created an ArcGIS-based dataset using 8 covariates. VT used ArcGIS tools and created raster layers for each covariate, from which VT characterized nests and random points with respect to the covariates.

Elevation

VT extracted 1m resolution LiDAR elevation values to every nest and random location.

Distance to development

VT digitized development polygons using April 2015 imagery. Development included all man-made structures including roads, buildings, parking lots, and boardwalks. VT calculated the Euclidean distance from nests and random points to development polygons.

Distance to ocean/bay high tide

In addition to the field-mapped bay high tide line, VT digitized bay access areas that were accessible to a flying bird. VT used the field-mapped/digitized spring high tide lines to determine Euclidean distances from nests and random points to the ocean and bay high tide lines. Bay access areas included areas of foraging habitat (intertidal sand) on the island that were disconnected from dry sand habitat but may have been accessible to adult plovers by flight.

Least cost distance to ocean/bay high tide

VT estimated the least cost path distance to the ocean spring high tide and bay spring high tide lines. Ocean spring high tide access included all ocean side intertidal access, as well as high-energy tidal access along inlets. Bay high tide consisted of all sandy, low-energy, bay tidal access as well as persisting, low-energy, eutrophic pools. VT estimated the least cost distance to these features, such that the path did not pass through a pixel of vegetation or water but only through wet and dry sand.

Dry sand within a 500m radius

To obtain an index to the amount of open sand habitat near nests, VT counted the number of pixels of dry sand that were within a 500m radius of each sand pixel.

Backshore width

VT defined backshore width as the distance perpendicular to the ocean tideline to the nearest back-beach barrier. The back-beach barrier (BBB) was defined as the farthest bayward barrier that would prevent plover chick movement. The BBB was digitized using 2015 imagery and LiDAR. VT digitized where the sandy backshore met dunes, vegetation, development, roads, and bay high tide lines.

VT first created lines that were perpendicular to the ocean high tide. These lines were converted to polygons and given a backshore width value. Due to the differences in azimuth of the spring tide line on various parts of the ocean front, VT created a number of polygons to ensure that polygons were as close to perpendicular to the shore as possible. Each polygon was 10 meters wide and covered the entire width of the island at that location. VT determined the distance to ocean from every polygon where it met the BBB line. VT then

attributed these distance-to-ocean values to the entire width of the polygon, from the high tide line to the BBB. Therefore, along the same perpendicular, a pixel 100 meters from the shore has the same beach width value as a pixel 1,000 meters from the shore (Figure 4). VT converted the polygons and their corresponding backshore width values to a continuous raster so that every pixel had a backshore width value.

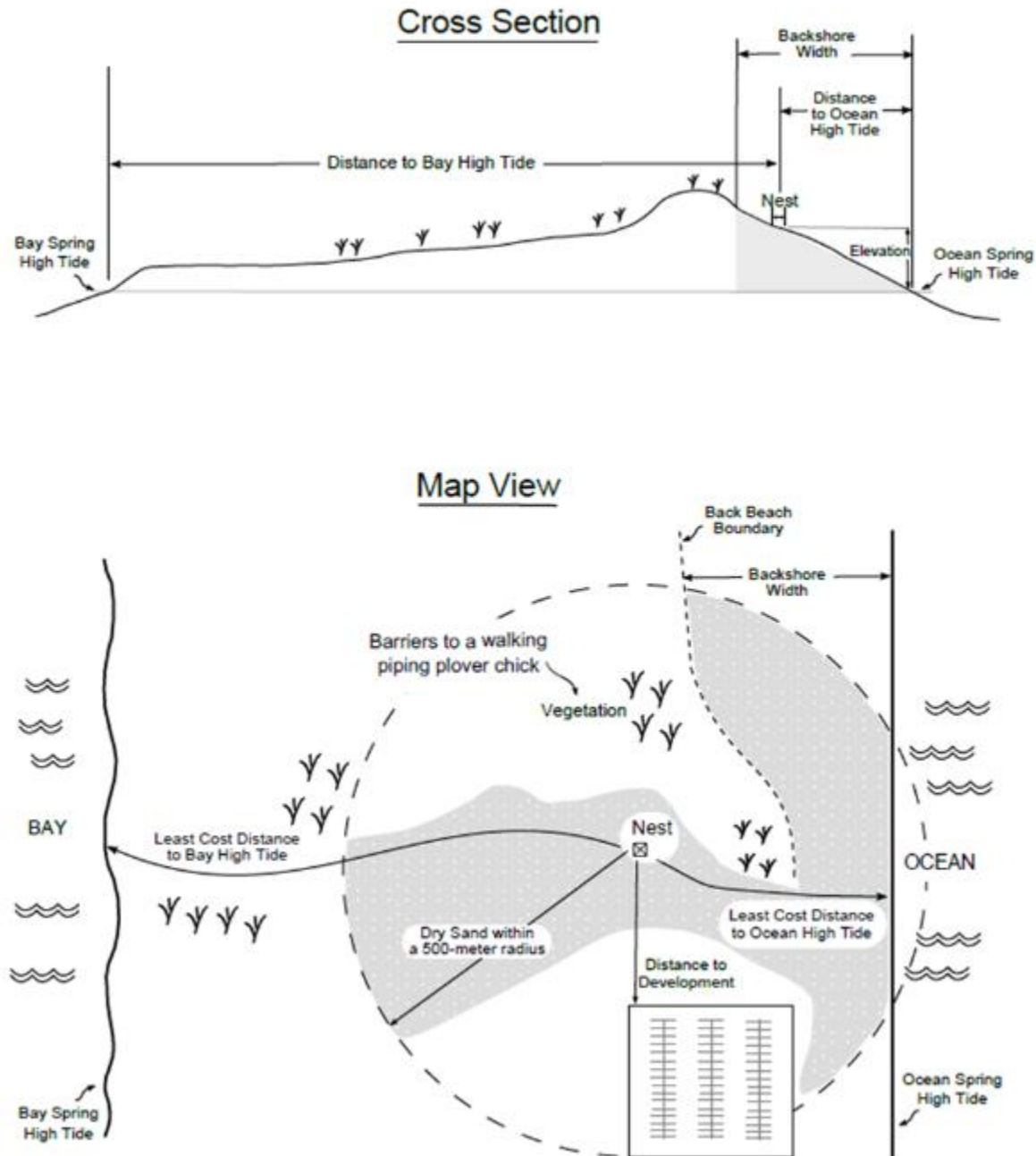


Figure 4. Cross-section and overhead diagram illustrating the 8 covariates used in model selection.

ANALYSIS

VT fit the logistic regression model using 46 nests and 46 random points. VT standardized all covariates prior to analysis and checked for correlations among them. Least cost distance to ocean and distance to ocean were highly correlated ($r=0.99$), so VT removed distance to ocean before fitting the regression. Backshore width and dry sand within 500m were correlated ($r=0.78$). VT removed dry sand within 500m because VT felt backshore width was a more accurate measurement of dry sand habitat size. VT considered each nest, including renests, to be independent because the random effect of female did not explain variability within the regression. VT conducted a backward selection logistic regression in SAS on the six remaining covariates. VT used Akaike's Information Criterion corrected for small sample bias (AICc) to rank backward selected models. VT started with the global model and removed variables until the AICc increased. VT selected the model with the lowest AICc as the top model (Burnham and Anderson 2002). Within the top model, VT considered 95% confidence intervals that did not contain 0 to be significant.

VT created a standardized raster for each covariate. VT input the estimates from their top model into the logistic regression equation and VT generated a raster with a probability of nest occurrence (0–1) for every pixel. VT established a suitability threshold, at which values above were considered suitable piping plover habitat, and below were considered unsuitable. VT selected a threshold for suitability by determining the highest proportion of nest and random points that were correctly classified at any given threshold.

Using the selected model, VT calculated the amount of suitable habitat before (2010) and after (2015) Hurricane Sandy. USACE restored some areas on Fire Island between 2010 and 2015, therefore, all comparisons were divided into Sandy-created habitat and restoration-created habitat, and a small area of sand stockpile-created habitat.

RESULTS

Piping plovers selected nest sites that were close to both the bay and the ocean (i.e. as quantified by short least cost path distances) and with wide backshores. The best model (AICc, 105.87; Table 3) contained least cost distance to bay, least cost distance to ocean, and backshore width. Least cost distance to bay was the strongest predictor of nest site selection ($\beta=-2.82$), followed by least cost distance to ocean ($\beta=-0.60$), and then backshore width ($\beta=0.41$; Table 4). The 95% confidence interval for least cost distance to bay and least cost distance to ocean did not include 0, but the confidence interval for backshore width included 0. Removal of backshore width from the model increased AICc from 105.87 to 106.14, therefore, backshore width was retained in the final model.

Table 3. Logistic regression models for determining the suitability of 15cm pixels for piping plover nesting on Fire Island and Cupsogue Beach County Park, New York. Models were created using piping plover nest locations (n = 46) and random points (n = 46) and 2015 multispectral imagery. Model ranking was based on a backward selection using Akaike's Information Criterion corrected for small sample size (AIC_c), differences between those values (ΔAIC_c), and Akaike's weights (w_i).

Model	AIC_c	K	ΔAIC_c	w_i
Least cost distance to bay + least cost distance to ocean + backshore width	105.87	4	0	0.58
Least cost distance to bay + least cost distance to ocean + backshore width + elevation	107.05	5	1.42	0.28
Least cost distance to bay + least cost distance to ocean + backshore width + elevation + distance to bay	108.80	6	3.46	0.10
Least cost distance to bay + least cost distance to ocean + backshore width + elevation + distance to bay + distance to development	110.63	7	5.64	0.04

Table 4. Standardized estimates (β), standard errors (SE), lower 95% confidence intervals (LCL) and upper 95% confidence intervals (UCL) for covariates affecting nest site selection of piping plovers on Fire Island and Cupsogue Beach County Park, NY.

Parameter	β	SE	LCL	UCL
Intercept	-0.76	0.55	-1.85	0.32
Least cost distance to bay	-2.82	1.33	-5.43	-0.20
Least cost distance to ocean	-0.60	0.29	-1.17	-0.04
Backshore width	0.41	0.28	-0.14	0.96

The highest percent of nest and random points (72%) were correctly classified at the 0.4 threshold (Figure 5). With a 0.4 threshold, all but 4 nest sites were classed as suitable habitat. The four nests that were incorrectly classified by the model had low backshore width, and 3 of the 4 incorrectly classified nests had high least cost distance to the bay. Forty-one of 46 nests were less than 1405m least cost from the bay (Figure 6).

Probability of occurrence maps (Figure 7–Figure 11) from the model illustrate that suitable piping plover habitat primarily occurs along inlets and within Hurricane Sandy-created overwashes. Unsuitable piping plover habitat occurs closer to communities, human use areas, and along narrow backshores.

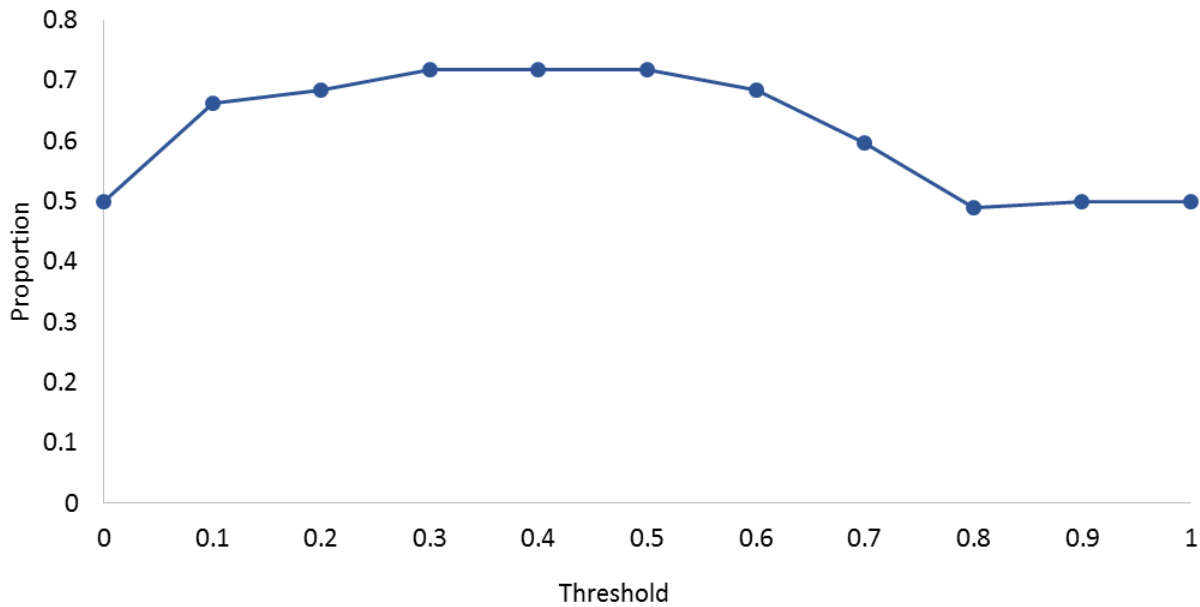


Figure 5. Proportion of piping plover nests and random points correctly classified as presence/absence points under any given threshold based on the logistic regression model.

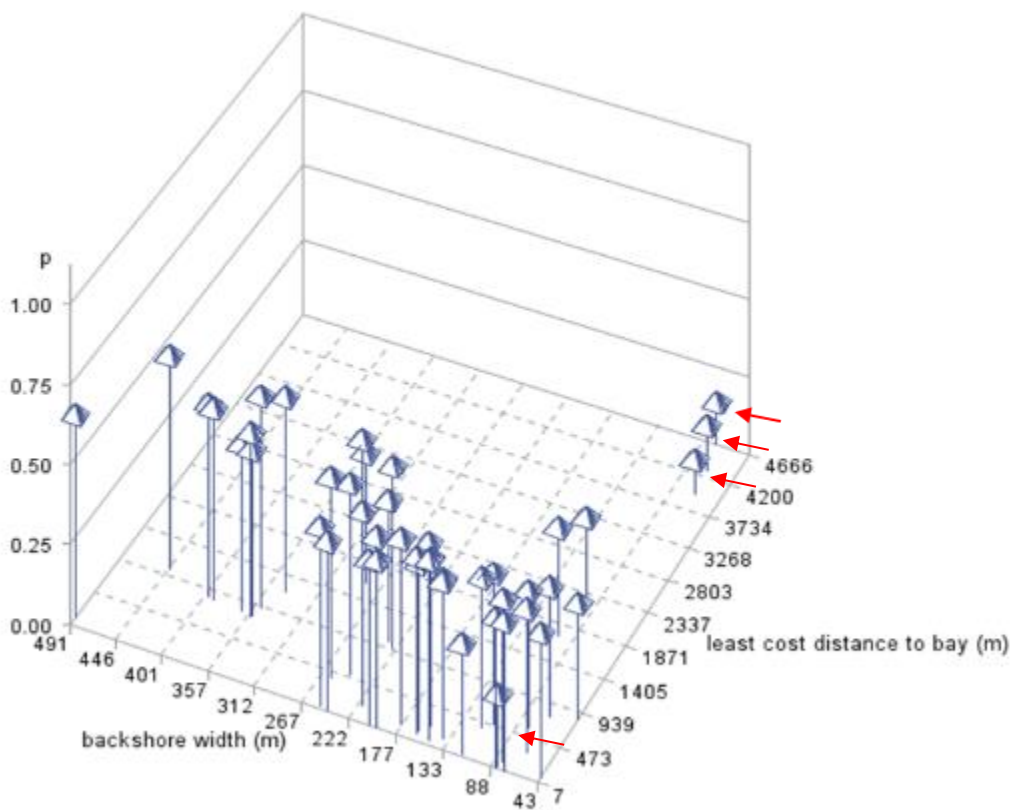


Figure 6. Three-dimensional graph plotting 46 nests. Axes are least cost distance to bay, backshore width, and logistic regression predicted probability of nest occurrence, with values from 0–1. The least cost distance to ocean was used to predict probability values but is not visible in this graph. The four nests below the 0.4 suitability threshold are indicated by red arrows.

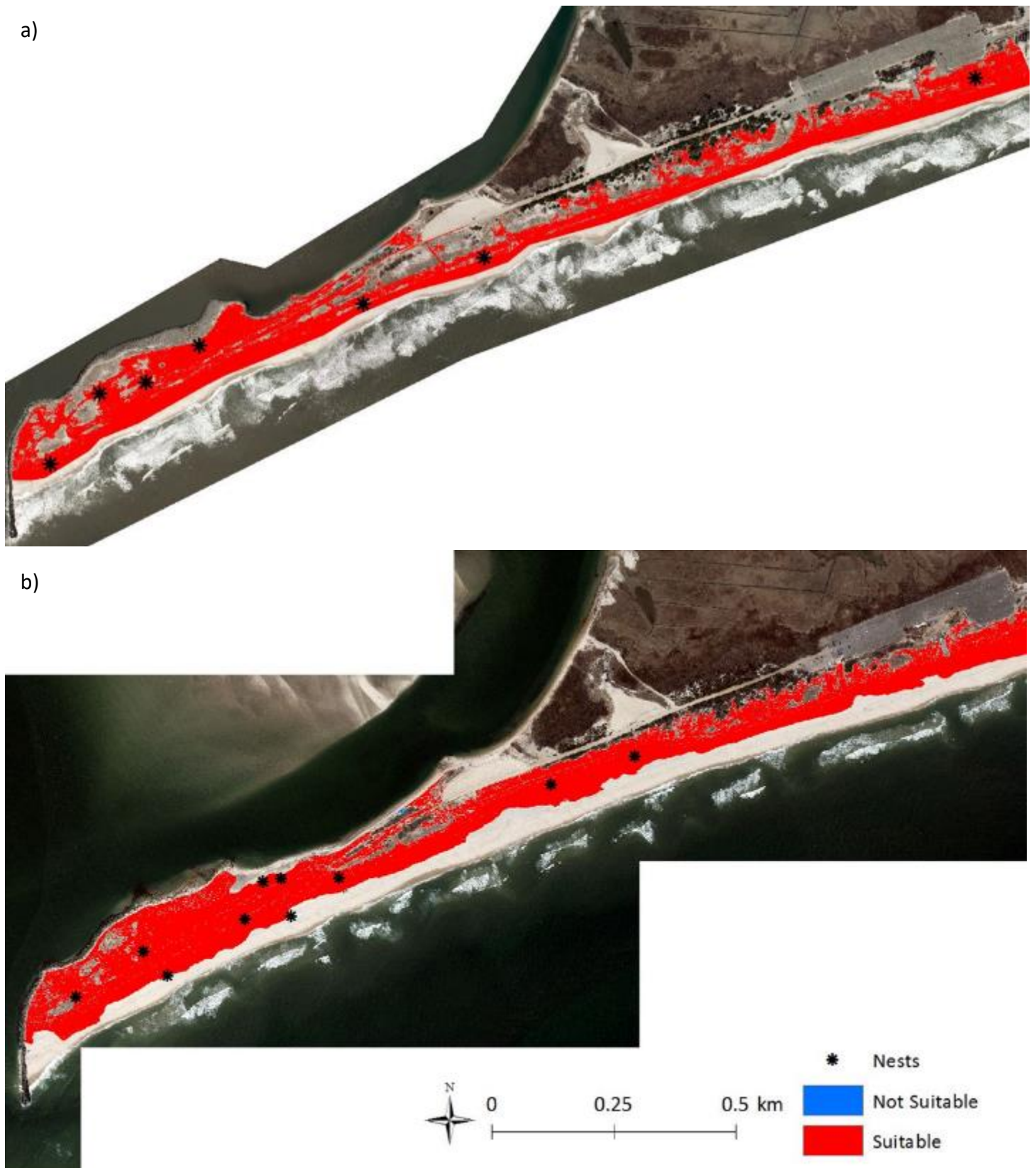


Figure 7. Cupsogue Beach County Park in a) 2010 and b) 2015. $P \geq 0.4$ is suitable habitat; $P < 0.4$ is unsuitable habitat.

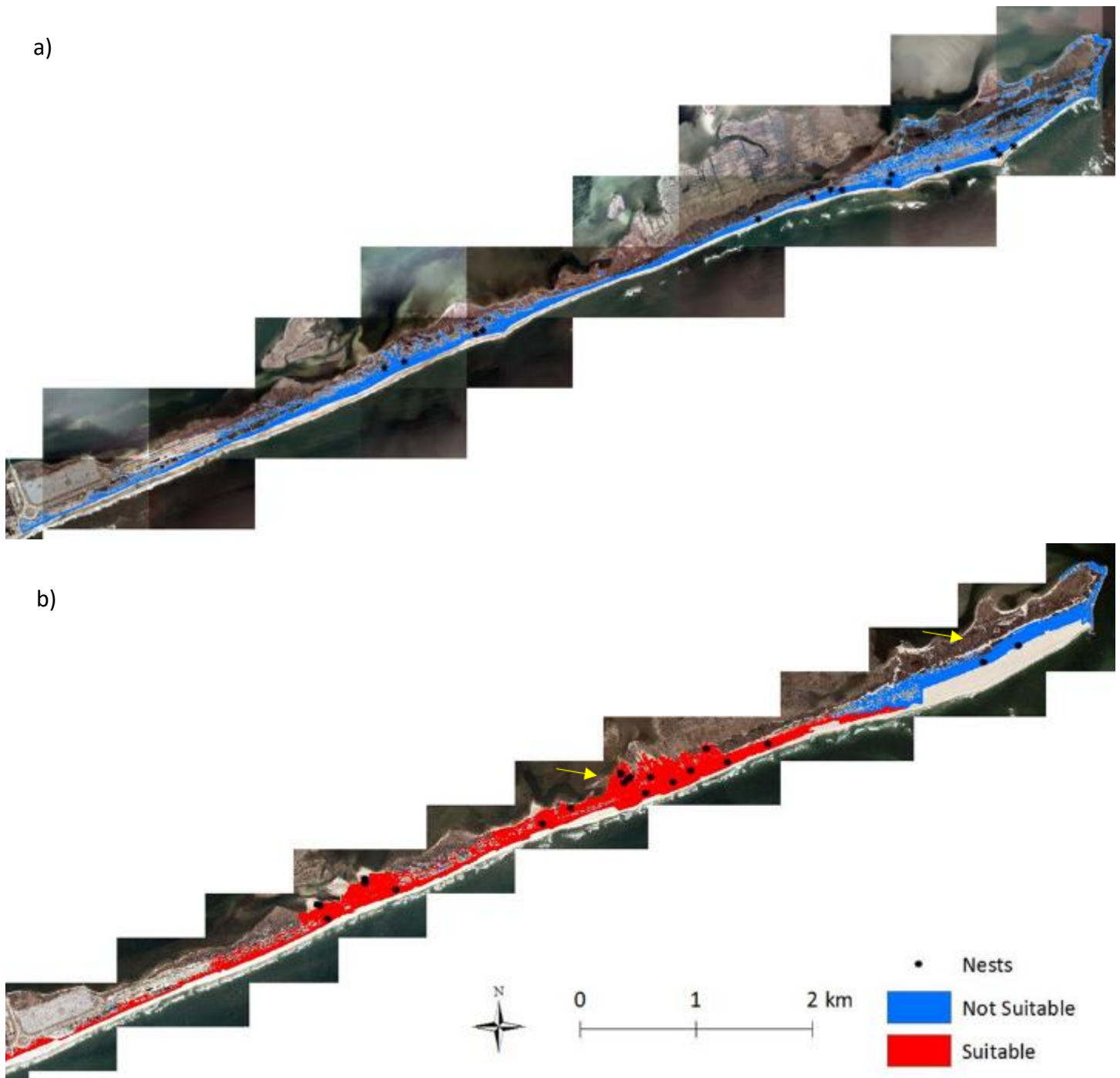
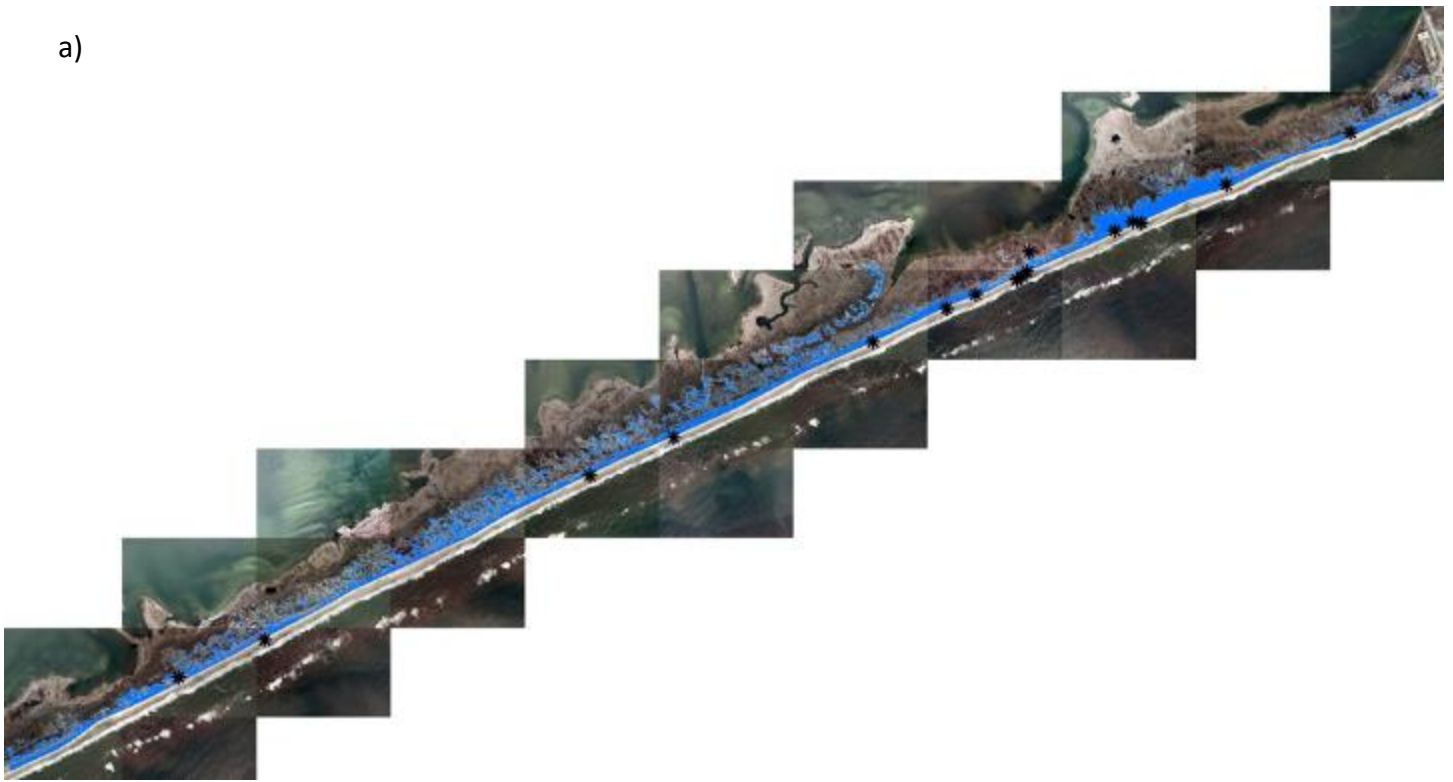


Figure 8. Smith Point County Park in a) 2010 and b) 2015. USACE restoration areas are indicated with yellow arrows. $P \geq 0.4$ is suitable habitat; $p < 0.4$ is unsuitable habitat.

a)



b)

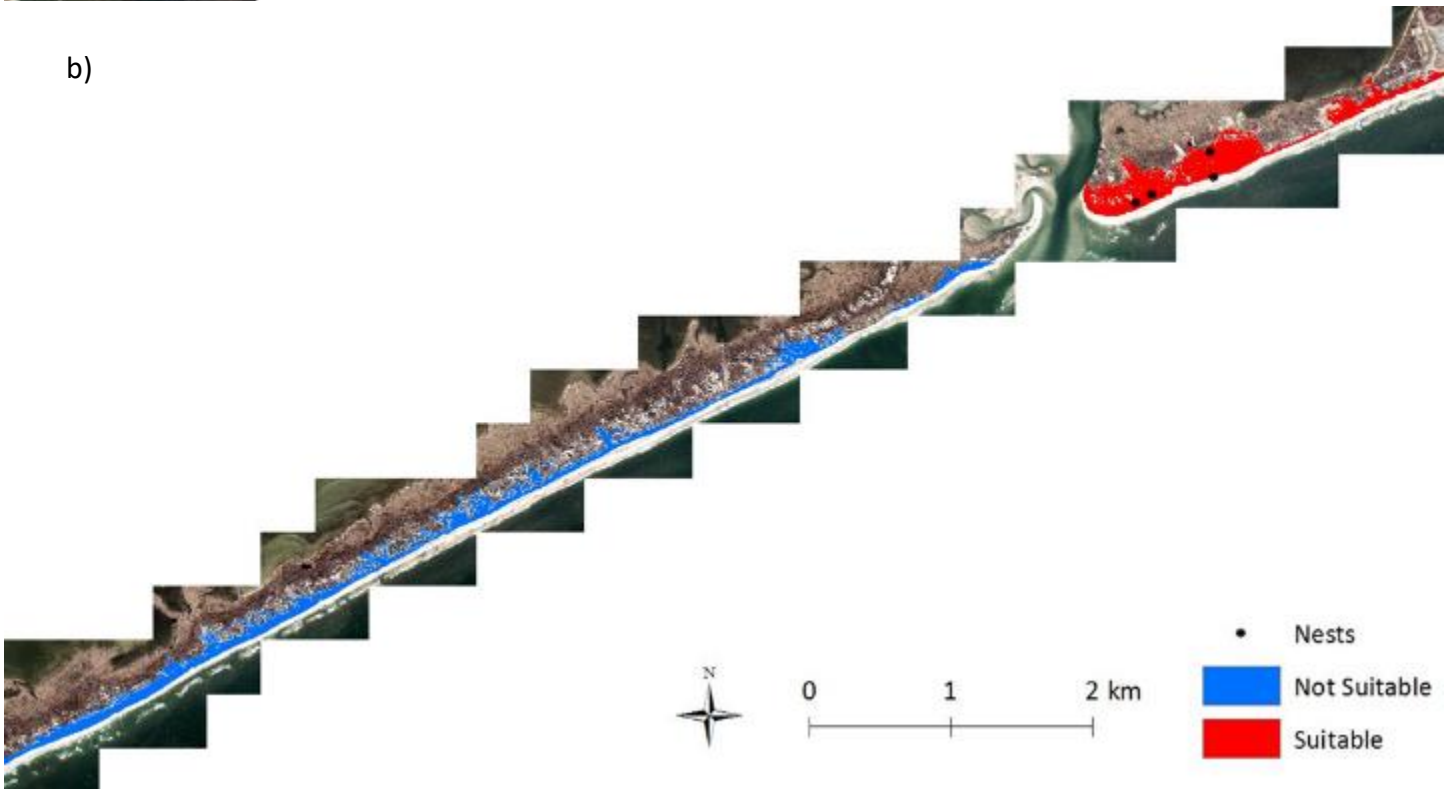


Figure 9. Otis Pike Wilderness Area in a) 2010 and b) 2015. $P \geq 0.4$ is suitable habitat; $p < 0.4$ is unsuitable habitat.

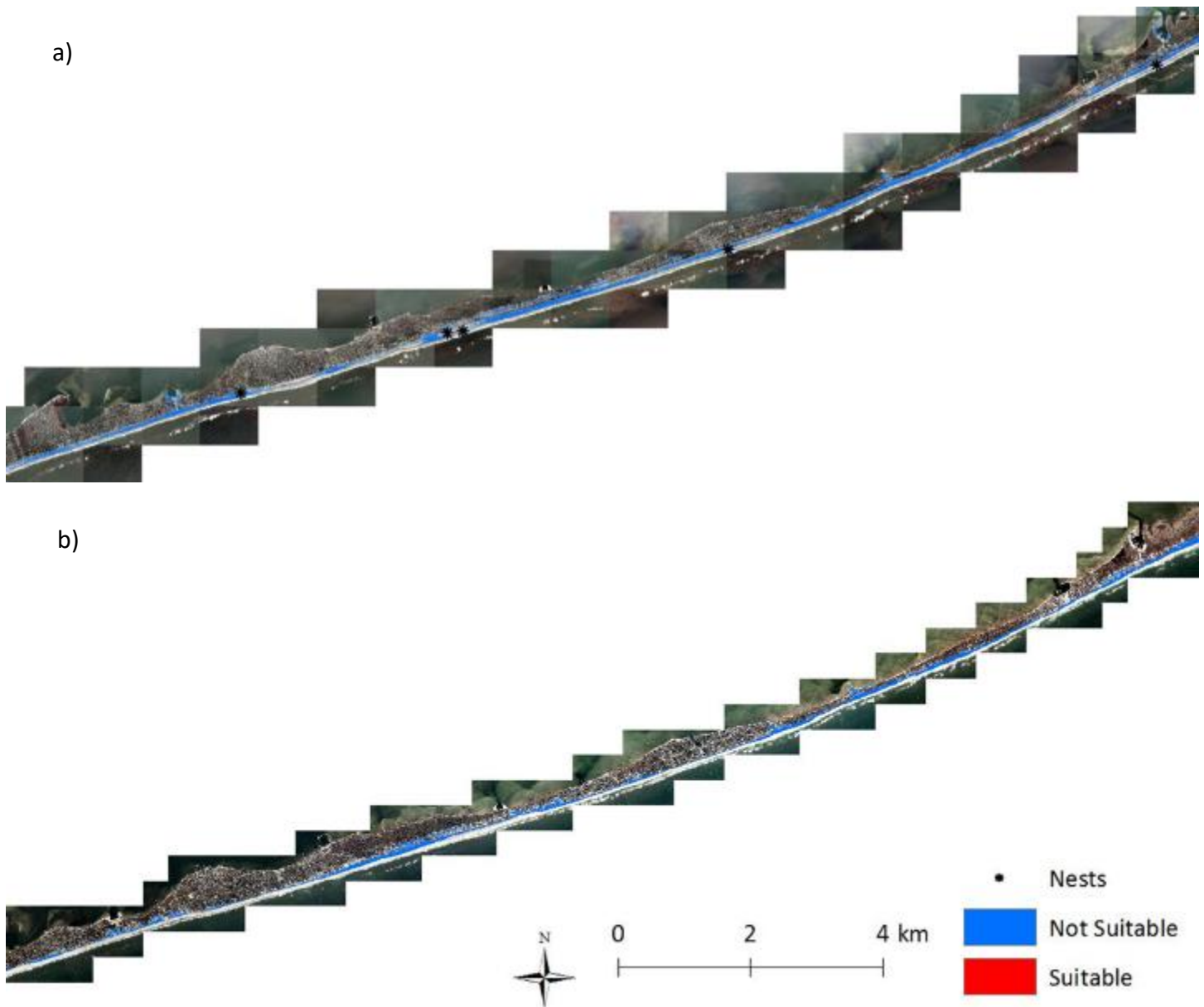


Figure 10. Kismet to Watch Hill in a) 2010 and b) 2015. $P \geq 0.4$ is suitable habitat; $p < 0.4$ is unsuitable habitat.

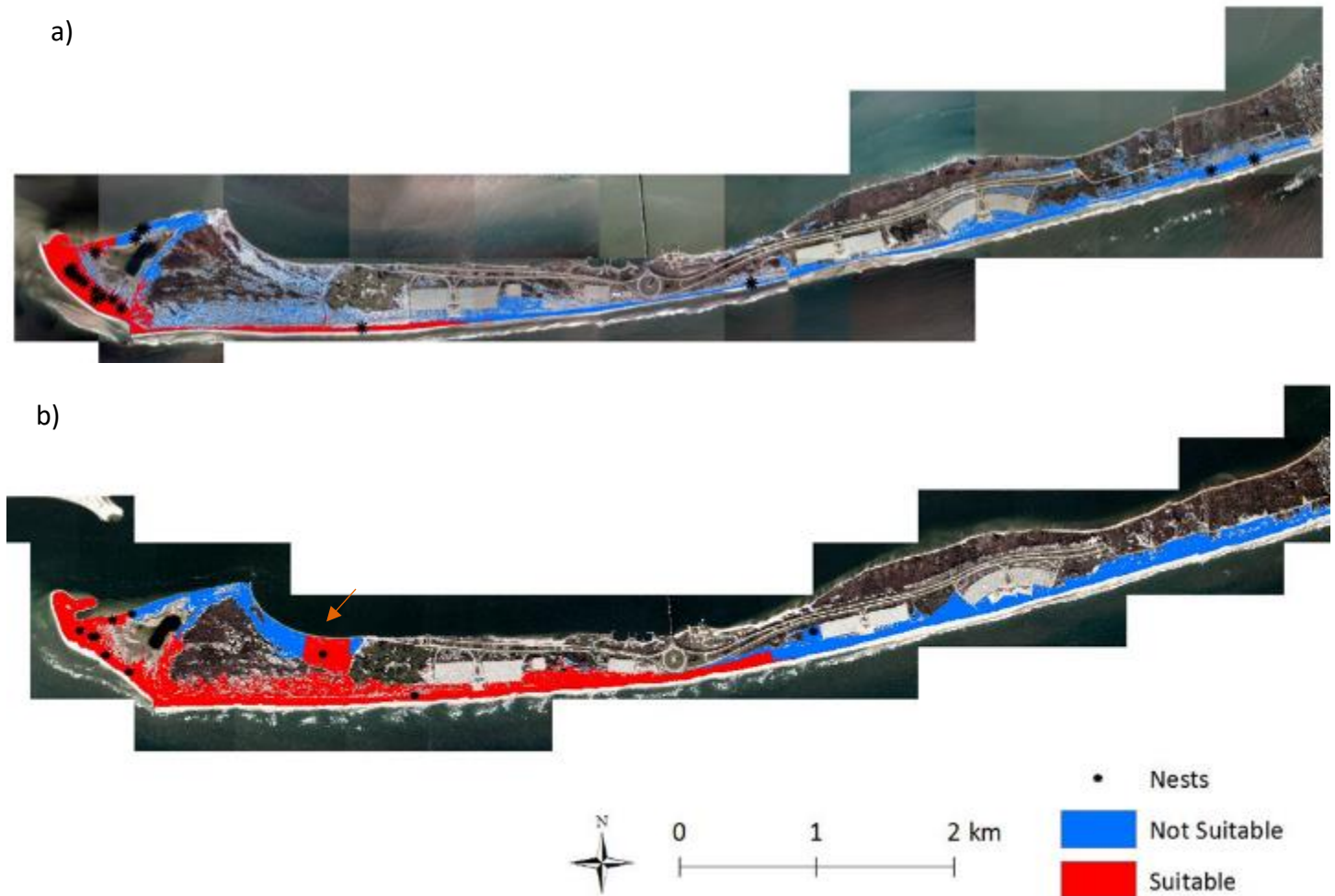


Figure 11. Robert Moses State Park in a) 2010 and b) 2015. The sand stockpile is indicated with an orange arrow. $P \geq 0.4$ is suitable habitat; $p < 0.4$ is unsuitable habitat.

Figures 7-11. Piping plover nest site suitability maps for Cupsogue Beach County Park and Fire Island, New York in 2010 and 2015. Red pixels indicate suitable piping plover nesting habitat, with probability of occurrence values of ≥ 0.4 . Blue pixels indicate non-suitable habitat (< 0.4 probability). Only dry sand pixels above the spring high tide lines were mapped for suitability. Nest locations are in accordance with map year.

Based on the 2015 model, Fire Island and Cupsogue Beach County Park contained more than five times as much suitable piping plover habitat in 2015 than in 2010. Three percent of 2015 suitable habitat was created by USACE piping plover habitat restoration in Smith Point County Park, 3% was created by stockpiled sand in Robert Moses State Park, and 94% was created naturally or as part of USACE beach stabilization efforts (Table 5). Out of all the available dry sand nesting habitat in 2010, 12% was suitable compared to 49% suitable in 2015. The model showed 39 hectares of suitable piping plover habitat on Fire Island and Cupsogue Beach County Park in 2010, compared with 219 hectares of suitable habitat in 2015. Thirty-two percent of 2010 nests were predicted by the 2015 model. In 2010, when many nests were in unsuitable habitat, the Fire Island plover population was declining precipitously.

Table 5. VT used their 2015 habitat suitability model, as described in the text above, to predict the total area (ha) and % of total area that is predicted to be suitable for piping plover nesting.

		Natural/ Nourished ^a		Restored ^b		Sand Stockpile ^c		Total ha		% Suitable ^f
		ha	%	ha	%	ha	%	Suitable ^d	Dry sand ^e	
Robert Moses State Park	2010	26	100	0	0	0	0	26	54	48
	2015	71	90	0	0	8	10	79	143	55
Kismet through Watch Hill	2010	0	0	0	0	0	0	0	105	0
	2015	0	0	0	0	0	0	0	75	0
Otis Pike Wilderness	2010	0	0	0	0	0	0	0	71	0
	2015	34	100	0	0	0	0	34	92	37
Smith Point County Park	2010	0	0	0	0	0	0	0	82	0
	2015	83	93	6	7	0	0	89	120	74
Cupsogue Beach County Park	2010	14	100	0	0	0	0	14	14	100
	2015	17	100	0	0	0	0	17	17	100
Total Study Area	2010	39	100	0	0	0	0	39	326	12
	2015	206	94	6	3	8	3	219	447	49

^a Naturally occurring sand or nourished beach.

^b USACE-restored piping plover habitat.

^c An area of redistributed sand in the Northern bayside region of Robert Moses State Park.

^d Total ha of dry sand with a nesting $p \geq 0.4$, based on the 2015 habitat suitability model.

^e Total ha of dry sand with a nesting $p < 0.4$ (unsuitable habitat), based on the 2015 habitat suitability model.

^f Total suitable ha/total unsuitable habitat.

DISCUSSION

Piping plovers selected nest sites that provided unimpeded proximity to bay and ocean-side foraging. The strongest predictors of site selection were least cost distance to foraging habitats. Proximity to bayside intertidal was the strongest driver of selection potentially because of higher invertebrate abundance than ocean intertidal zones (Patterson et al. 1991, Loegering and Fraser 1995, Elias et al. 2000, Fraser et al. 2005, Cohen et al. 2009, and Cohen and Fraser 2010, Part II Objective 9). Chicks with access to bay habitats had higher daily survival rates than chicks without access to bay on Fire Island from 2014–2016 (Part II, Objective 4). Similarly, in Maryland, chicks foraging on bay beach had higher foraging rates, faster growth, and higher

survival than chicks on ocean beach (Loefering and Fraser 1995). This could explain the selection of nest sites near bay-side foraging habitat. Plover nests in or near vegetation can have a higher rate of predation than those in open territories (Prindiville Gaines and Ryan 1988). Selection for wide backshores suggests that piping plovers maintained a large buffer from their nests to dunes and vegetation so they could readily see approaching predators.

Piping plovers used, and continue to colonize, Hurricane Sandy-created habitat. New habitat wasn't occupied immediately, possibly, because of low local and regional reproductive output in 2012-2013 (USFWS unpublished), and low local reproductive output in 2015 (Part II, Objective 4). In addition, it is possible that time was needed for development of adequate prey, for plover's acquisition of knowledge about the new habitat, and for locally hatched birds to return to the site and occupy new territories (Catlin et al. 2015). VT expects the piping plover density in these areas to continue to increase as long as there is sufficient reproduction and survival and until the population reaches carrying capacity.

The ability of the 2015 model to predict 2010 nest sites was poor, indicating that piping plovers were selecting nest sites differently in 2010 than they were in 2015. The amount of bay access that drove the 2015 model was not available to plovers before Hurricane Sandy. The low predictive ability of the 2015 model on a pre-Sandy year shows the contrast between nest selection before and after the hurricane. Piping plovers of Fire Island were in the midst of a decline before Hurricane Sandy, with pairs of 52, 31, and 25 in 2009, 2010, and 2011, respectively (USFWS unpublished). Yet, pair numbers showed a general increasing trend in years following the storm (2014 on), perhaps due to the new habitat that was colonized in years after the storm.

The amount of natural- and human-created habitat on Fire Island and Cupsogue Beach County Park demonstrates the importance of these areas as probable piping plover nesting locations in the future. Human-created habitat on Fire Island can be suitable for piping plover nesting. Yet, the amount of piping plover habitat created by natural processes and re-nourishment efforts is prominent. VT should continue to view storm habitat creation as a critical component of piping plover conservation. Barrier island ecosystems like Fire Island are susceptible to constant changes in island morphology and therefore should be modeled often to account for temporal changes and subsequent behavioral responses. As conservation efforts continue, habitat selection should continue to be addressed, especially with regard to storm-induced habitat change.

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PART II: MONITORING OF PIPING PLOVER ON FIRE ISLAND AND WESTHAMPTON ISLAND

2016 EXECUTIVE SUMMARY

During the 2016 piping plover nesting season, VT banded 41 adult plovers. VT banded 101 of 105 chicks that hatched. VT located 43 nests. Thirty-three of those nests hatched, which represented a 77.7% probability of surviving to hatching for exclosed nests, and 64.2% probability of surviving to hatching for unexclosed nests. Of the 105 chicks that hatched, 63 of them fledged, resulting in a reproductive output of 1.75 fledges/pair for the entire study area. When compared by management area, Robert Moses State Park productivity was 1.11 fledges/pair, Fire Island National Seashore productivity was 2.00 fledges/pair, Smith Point County Park productivity was 2.38 fledges/pair, and Cupsogue Beach County Park productivity was 1.00 fledges/pair.

INTRODUCTION

Piping plover populations often increase following habitat creation, while nesting distribution shifts to the newly created habitat (Wilcox 1959, Cohen et al. 2009, Catlin et al. 2015). These increases in population size have been attributed to higher rates of immigration (Cohen et al. 2009, Catlin et al. 2015), increased access to foraging habitat (Cohen et al. 2009), and to lower rates of predation (Catlin et al. 2015) at relatively low densities. Given that piping plovers exhibit high site fidelity (Friedrich et al. 2015), one might expect population increases to be associated with young birds establishing their first nests, but piping plover dispersal does increase immediately following a habitat creation event (Catlin et al. 2016). To accurately assess the effects of habitat creation, an accounting of the sources of population growth are necessary.

In addition to habitat quantity, habitat quality can have a profound effect on piping plover nesting densities (Cohen et al. 2009) and their long-term fitness (Catlin et al. 2014). Past studies have found that piping plovers may travel large distances to forage in optimal habitats (Cohen et al. 2009) and that birds with access to better foraging habitat may produce more massive clutches and hatchlings (Catlin et al. 2014). Piping plovers forage on both terrestrial invertebrates, such as insects, and marine invertebrates (Shaffer and Laporte 1994, Cuthbert et al. 1999, Majka and Shaffer 2008, Cisek 2013). However, prey selection could be further investigated by analyzing fecal samples. Moreover, the variety of prey sources are found on the sand and just below the surface of the sand, thus using multiple methods of prey sampling can be helpful in understanding the overall prey available for these birds. As food abundance and location could drive the entire life cycle, a solid link between forage and habitat changes will be an important step in understanding the impact of Hurricane Sandy and other recent habitat alterations.

Predation and human disturbance can negatively affect plover demography and potentially site selection as well (Cohen et al. 2009). For example, density-dependent predation, related to habitat availability affected reproductive output of plovers on the Missouri River (Catlin et al. 2015). Great horned owls (*Bubo virginianus*) were the key predators in most of the Missouri river studies. There are now cats, foxes, and coyotes on the sandbars and mink only at Lewis and Clark Lake. Human disturbance on Fire Island had negative impacts on plover nest and chick survival (DeRose-Wilson et al. in prep). A full understanding of the effects of Hurricane Sandy on piping plovers should account for the effects of predation and human disturbance.

In addition to monitoring breeding piping plovers, a key goal of VT study was to band piping plover adults and chicks, to compare the relative contribution of local recruitment versus immigration to population growth in the storm-created habitat and artificially closed breaches in subsequent years of the study. Here VT present the results of their banding efforts, data on piping plover reproductive output in various habitats, clutch quality, chick behavior and responses to disturbance in different management units, and information on invertebrate prey abundance in different habitats for April through August 2014–2016.

FIELD METHODS

Habitat and Tide Mapping

In 2015 and 2016 VT used a Trimble Geo7X (Trimble Navigation, Ltd., Sunnyvale, California, USA), to map the spring high and low tides along both the bay and ocean shorelines (Figure 12). In 2013 and 2014, VT used a Garmin 78 to conduct all mapping. In 2016, spring high tides were mapped during May and June. Low tides of the mudflats and sandbars that VT surveyed were mapped during mid-September. VT also mapped the snow fencing and symbolic fencing during late-July and August. In 2015, the spring high tide was mapped during mid-May and early June while all other mapping (wrack line, subsites) were mapped during late-July and early-August. In 2013 and 2014, mapping was done when it could be fit into the schedule throughout the entire season; most was finished by August.



Figure 12. Using a Trimble Geo7X to map the high tide line.

Adult Survey

Throughout the entire monitoring season (April–September) VT surveyed adult piping plovers every 1–3 days in each subsite. VT walked along the shoreline and symbolic fencing areas. VT also drove a UTV along the ocean shoreline in certain subsites. During the nesting period (April–July), VT conducted walking surveys at least twice per week in search of plover tracks, scrapes, and nests. These surveys were done inside and outside of the symbolic fencing in areas of good nesting habitat. Observers spread 50–100 meters apart (depending on number of observers, size of the area, conditions, topography, etc.) in a line and walked the length of the area. If VT could not survey a whole area in one pass, VT completed the remaining area in

another transect. Observers carried spotting scopes (20 x 60, 80 mm) to resight piping plovers (Figure 13), and surveyors recorded banded and unbanded plovers that were encountered. While resighting a plover, VT attempted to read the band combination and note the bird's habitat and behavior. In 2014 and 2015, VT recorded the location of individuals with a Garmin GPS unit. In 2016, VT used a Trimble GPS unit and Nikon laser range finder to record the location of plovers.



Figure 13. Resighting piping plovers using spotting scopes on Democrat Point. View facing east, spotters facing northwest.

Nest Location

VT searched all possible plover nesting habitat within their subsites, including backshore, overwashes, and sparsely vegetated areas. When a nest was found, its location was collected using a Trimble GPS unit or a Garmin GPS unit (Figure 14). If a nest was found at with 4 eggs, VT estimated the nest age and potential hatch date by floating eggs (Alberico 1995). Eggs were not floated in the western wilderness of Fire Island National Seashore after the 2014 season.



Figure 14. Using a Trimble Geo7X to map the location of a piping plover nest.

Location, Elevation and Vegetation Data at Nests (Objective 8)

Since October 2014, VT has contributed to a large-scale study of piping plover habitat use along the Atlantic Coast of the United States, led by the US Geological Survey and Virginia Tech. VT used the mobile smartphone application “iPlover” to characterize the geomorphic setting, vegetation type and density, and substrate type at nesting locations and at random locations throughout Fire Island as per USGS study protocols (Thieler et al. 2016).

Egg Masses

Ideally a nest was found before completion (typically 4 eggs) and checked every 1–2 days to monitor the clutch size. Once a nest reached four eggs, VT weighed the eggs using a digital pocket scale (American Weigh, Norcross, GA, USA, Figure 15). VT only weighed eggs in nests that were found before reaching a full clutch. Nests in the western wilderness of Fire Island National Seashore were not weighed after the 2014 season.



Figure 15. Using a digital pocket scale to weigh piping plover eggs.

Nest Checks

After nests were found, VT checked them every 1–3 days until they hatched or failed. As the hatching date approached, the nests were checked approximately every day for signs of hatching (Figure 16). VT determined the nest fate by the signs that were seen around the nest and in the nest bowl.



Figure 16. Piping plover chick found in nest bowl during a nest check at Robert Moses State Park.

Trapping and Banding

VT captured adult piping plovers on nests while they were incubating a full clutch. VT trapped adults using a drop trap or shoo-in funnel trap. Once the first adult was removed from the trap, VT re-set it to attempt to trap the second adult if there was time remaining and they had been previously trapped that season. Traps were set for a maximum of 20 minutes. If no adults entered the trap in those 20 minutes, VT removed the trap from the nest. Once captured, plovers were banded, weighed, and morphometric measurements (wing length,

culmen length, and tarsus length) were collected (Figure 17). If plovers were banded in a previous year, VT attempted to re-capture them to assess physiological condition and leg health.

Piping plover chicks were captured as close to hatch day as possible. Chicks were banded, weighed, and measured in the same fashion as the adults (Figure 17). VT allowed chicks to be in a hand for a total of 20 minutes for the entire brood every 72 hours. If a whole brood was not captured the first day, a second attempt was done the next day depending on the amount of time left available. If enough time was not available, the second attempt was done 72 hours later, allowing us to have 20 minutes again.



Figure 17. Banding a piping plover adult and measurements of piping plover chick.

Banding Schemes

In 2015 and 2016, all adults and chicks were banded with dark green flags with unique three-digit alphanumeric combinations etched in white on the upper left leg. VT placed an orange band with a three-digit numeric combination on the upper right leg (Figure 18). In previous years, in addition to the current banding schemes, some birds received two color bands on each upper leg, or green flags with alphanumeric combinations with a yellow band on the opposite leg (DeRose-Wilson et al. 2013, DeRose-Wilson et al. 2014).



Figure 18. Band placement on both a piping plover adult and chick.

Brood Observations

After hatch, VT observed the chicks at least every other day, weather permitting, for 30 days regardless of brood fate. On all post-banding visits to the brood, VT attempted to resight all chicks present and conducted a behavioral observation. VT used a randomly generated number (1–5) to select a chick (odd = farthest left, even = farthest right). VT also used the randomly generated number to determine the time before beginning the behavioral observation on the selected chick. Every 10 seconds for 5 minutes, VT recorded the behavior of the chick (forage, run/walk, stand, sit, out of sight, encounter (≤ 10 meters), chase, flee, brood, crouch, preen) and the habitat it was using (wet sand, dry sand, wet vegetation, dry vegetation, wrack). VT recorded all potential disturbances, including humans, vehicles, predators, and other plovers, within 100 meters of the observers' location (Figure 19). If there was only one observer present, the disturbance count was completed immediately following the behavioral observation. A second observation was completed if the brood moved more than 100 meters during the initial observation, or the observed chick went out of sight for ≥ 40 seconds.



Figure 19. Observers collecting data on a brood. Left: Disturbance count, Middle: Recording data given, Right: Observer watching chick behaviors.

Invertebrate Sampling

VT sampled terrestrial invertebrates from 2014–2016 in various habitat types (backshore, overwash, breach fill, restoration zone, intertidal), from the time that the first chicks hatched until the time the last chicks fledged. During each invertebrate sampling set, VT collected four samples, two on the shoreline and two random locations. For the shoreline samples, VT followed a transect perpendicular to the shoreline at the upper edge of the intertidal zone. Using a GPS unit, VT navigated to the last shoreline data point collected during the previous sample in the subsite and continued a random distance, in meters, using a randomly generated number 1–50, for the first sample of the current sampling. VT walked 50 m along the shoreline for the subsequent sample. The third and fourth samples for the set were selected from a predetermined random selection of point, selecting a random point within 100 m of the previous sample.

VT sampled invertebrates on two paint stirrers coated with Tanglefoot tree Insect Barrier (Tanglefoot Company, Grand Rapids, Michigan). One stick had one side coated with Tanglefoot, and was placed horizontally in the sand with the Tanglefoot side facing up. The second stick was coated on both sides, and placed vertically in the sand (Figure 20). VT placed a cage over the trapping station to prevent birds from getting stuck to the Tanglefoot. VT returned to each sample location after 30 minutes and counted, measured (± 1 mm), and identified arthropods to order.



Figure 20. Invertebrate sampling stations in two different habitat types, wet sand and dry vegetation.

Core Sampling

VT collected core samples (2013: June and July, 2015: April) to obtain an index to the amount of marine invertebrates in piping plover habitats. In 2013, VT collected core samples at Old Inlet West, Old Inlet East, Flood Shoals, Bridge Overwash, Pattersquash Overwash, Narrow Bay West, Cupsogue West, and Cupsogue East. In 2015, VT collected samples at Cupsogue Mud Flats, Cupsogue Sandbar, Flood Shoals, two areas of Narrow Bay West (one section was classified as a filled breach while the other was classified as an overwash), and Pattersquash Overwash.

VT collected core samples within an hour of low tide coincident with piping plover surveys and nest searches. Sample stations (2013: 10, 2015: 30) were located along the intertidal zone of each subsite at the water's edge. Samples were placed 10 meters apart, and the locations of each site were recorded with a GPS. At each station VT collected a substrate prey core (7.6 cm diameter, 10 cm deep) and a sediment core (2.6 cm diameter, 10 cm deep). The samples were sieved with a 0.5 mm mesh sieve to discard any fine grain sand. The contents of the sample were preserved in 10% formalin and Rose Bengal. The prey organisms were sorted from the solution under a magnifying lens and stored in alcohol.

VT transported samples to the Marine Resources Institute at the Department of Natural Resources in South Carolina (MRI) where organisms were identified. There, the samples were examined in batches of ten. A random sample in each batch was re-processed by an experienced SCDNR staff member for QAQC. All of the specimens were identified to the family level except for organisms in classes of Insecta and Ostracoda, the order of Antinaria (sea anemones), and the phylum Platyhelminthes (flatworms; Appendix B: Response of Piping Plover Prey to Habitats Created by Hurricane Sandy).

Fecal Sampling

During adult surveys, VT collected fecal samples opportunistically from piping plovers. After observing a plover defecating, VT located the sample and collected it, with as little sand as possible, using needle nose tweezers (Figure 21). The sample was placed in a vial and marked with individual plover, the date, and the subsite in which it was collected. In 2016, the vials were stored in the shade or inside a backpack until they were placed in the freezer until the end of the season. In 2013 and 2014, the samples were stored in alcohol at room temperature. Thirty-nine samples were collected across the study site in 2016, 7 were collected in 2013, and 37 in 2014. In 2013 and 2014, fecal samples were transported to the MRI, where organisms were counted and identified. In 2016, samples were transported to contractors at Jonah Ventures in Boulder, Colorado for metabarcoding DNA analysis. VT did not collect fecal samples in 2015.



Figure 21. Collection of piping plover fecal sample, using needle nose tweezers.

ANALYTICAL METHODS

Objective 1: Compare changes in numbers, density, and distribution of piping plovers in various habitats on Fire Island

VT compared the number of pairs that used the various habitats from 2013–2016. The various habitats compared were backshore, restoration area, unfilled breach/overwash and filled breach/stabilized overwash. Restoration areas are areas of dune or dredge spoil habitats artificially levelled and filled with sand to create piping plover nesting habitat. The filled and stabilized breaches were considered the breach fills at Narrow Bay West and Cupsogue West. Using the GPS locations for each nest, VT assigned each nest a discrete habitat type, and compared the proportion of nests in each habitat type. For the number of nests in each habitat type, VT only included renests of stable pairs (same male and female) in the count if their new nest was in a different subsite and different habitat class. VT assumed that if a male renested in the same subsite and habitat type, the location of the renest was not independent of the first nest.

Pair counts within the study area were estimated using numbers of males within study areas. For pairs that included unbanded individuals, VT use initiation and failure dates to try and determine if the pairs were

independent from individuals banded later in the season. Overall, VT used the most conservative pair counts for comparison purposes.

Objective 2: Estimate the “effect distance” of artificially created habitat at New Made and Great Gun Beach

To estimate the “effect distance” (the distance which birds traveled to use the habitat) of newly created habitats, VT compiled all adult locations from 2014 to 2016, and divided them into two sets. The first set contained all of the points of banded individuals that nested within the study area, during the time that they had an active nest. The second set of points contained all of the points of banded individuals while they did not have a known active nest or brood, including both before and after nest initiation. Before nest initiation, VT used their first nest location for distance calculations, and if a nest failed and a bird renested, VT used the second nest location starting the estimated nest initiation date. Using ArcGIS 10.3, VT calculated the distance of each location from their nest location. If a bird had multiple nests within a given year, VT calculated the distance from each location to the nest that was active closest in time to the location. Similar to adult locations, VT compiled all of the fledgling locations from 2014 to 2016 and calculated the distance from each location to the nest from which the fledgling hatched.

VT joined all three of the point location datasets with a habitat GIS layer, including the flood shoals of Old Inlet and Moriches Inlet, overwashes and restoration areas. VT summarized the distance that birds moved to each of the newly created habitats during the different biological periods.

In addition, to assess the importance of bayside foraging habitat to nesting piping plovers, VT used a Kruskal-Wallis test to compare the distance adults moved from active nests with direct bay access and nests without bay access. Direct bay access included any area where a plover could walk to the bay intertidal area within the subsite of the nest location without encountering a solid line of vegetation within the habitat classification, or water.

Objective 3: Compare egg weights of birds with access to bay side intertidal flats with egg weights of birds without such access

To determine if clutch masses differed in piping plovers that nested where they had direct bay access compared to those that did not have bay access, VT used the Wilcoxon Rank Sum Test. VT considered a nest to have bay access if a chick could walk from the nest to bayside intertidal habitat without encountering a subsite-long line of vegetation, because adults do not encounter barriers to movement between habitat types. Areas with nests that had bay access include Narrow Bay West, Pattersquash Overwash, Cupsogue West, New Made, and Democrat Point. Areas with nests that did not have bay access include Old Inlet East, Great Gun, Smith Point West, Ocean South Side, and Fire Island Lighthouse. VT also used the Wilcoxon Rank Sum Test to determine if clutch masses from 2013-2016 differed in piping plovers that nested where with direct access to the bay versus those that did not.

Objective 4: Compare piping plover nest and chick survival rates in various habitats across Fire Island

VT used a logistic exposure model (Rotella et al. 2004, Shaffer 2004) to estimate the daily survival rates of exclosed nests and nests without exclosures. A nest was considered exclosed only during the period when the exclosure was present. In this model, hatch date was set at 34 days from initiation date (Heisey et al. 2007).

VT calculated annual pair counts using the males within pairs. VT used males for pair counts and productivity estimates because when pairs separate, the males often keep their territory when they partner with a new female. Additionally, males are the primary territory holders and defenders. Using banded adult information and nest date overlaps, VT used the highest number of male territories per management unit as an estimate of the number of pairs in that unit. VT used this estimate so as to not double count any male that nested more than once in a management unit.

To estimate chick survival, VT used the young survival from marked adults model, implemented in Program Mark (Lukacs et al. 2004). VT modeled chick survival for each year from 2014 and 2016 ($n = 61$ broods). VT estimated daily survival over a 31-day period. VT ran two model sets. The first model set included management unit and year. Due to sample size, VT held detection probability constant, and ran a single model with all years and all management units. The second included year and habitat. VT ran all subsets of models including year and habitat terms for both apparent survival and detection probability. To estimate the probability of survival to fledge, VT exponentiated the daily survival estimate to 25 days, and used the delta method to obtain variance estimates (Powell 2014).

VT estimated brood home ranges for 2016 by creating minimum convex polygons around all brood locations in ArcGIS. VT only calculated home range size for broods that had ≥ 10 points available, to control for broods that had smaller sample size due to early chick mortality. A Wilcoxon Rank Sum test was used to compare brood home ranges between broods that had bay foraging habitat and those that foraged on the ocean habitat. VT also used a mixed-design ANOVA to compare fledgling mass at 20–22 days between fledglings that had access to bay foraging habitat and those that did not have such access.

Objective 5: Compare the relative contribution of local growth (local recruitment) vs immigration in population growth associated with new habitats

Using banded and known age birds, VT estimated immigration and local recruitment for 2014, 2015, and 2016. VT estimated immigration rate using a Pradel (1996) model. The parameters estimated from the Pradel model are apparent survival, resight rate and fecundity rate. VT used the fecundity rate as an estimate of the immigration rate (# immigrants in $t+1$ per individual in year t), and ran a single model holding apparent survival and resight rate constant, to estimate annual immigration rates (Catlin et al. 2015). VT also estimated local recruitment as the number of individuals banded as chicks the year prior that returned to breed for the first time in the population in a given year. VT separated Robert Moses from the eastern barrier island study area, as this area was not added to the study until 2015, and thus would have falsely inflated the number of newly banded individuals in 2015. For Robert Moses, the immigration rate was an estimate of the number of unbanded individuals in 2016, divided by the number of individuals in 2015.

Objective 9: Compare prey densities at several habitat types

To assess the difference in the mean number of terrestrial invertebrates collected using sticky sticks on bay shorelines, ocean shorelines, and island interior VT performed an ANOVA using the invertebrate transects from 2016. VT also used a negative binomial mixed model to predict the mean invertebrate catch over a three-hour period in each of four habitat types (bay intertidal, ephemeral pool, ocean intertidal, island interior) and each of three treatment levels (overwash, breach fill, restoration zone) with the combined invertebrate data from 2014–2016. For the grouping variables within the analysis, habitat type was assigned

for each individual invertebrate sample, at the time of data collection. Treatment level was assigned based on the joining of a point file of all invertebrate sample locations with shapefiles of the overwashes, breach fills and restoration zones. Results were extrapolated to three-hour periods to compare to past studies.

At the lab at the Marine Resources Institute at the Department of Natural Resources in South Carolina, the contents of core samples from 2015 were compared among subsites (Appendix B: Response of Piping Plover Prey to Habitats Created by Hurricane Sandy). The MRI also used piping plover fecal samples collected in 2013 and 2014 to understand piping plover prey relative to what was found in the core samples.

In 2016, DNA from fecal samples was extracted, amplified using polymerase chain reaction (PCR), and sequenced using Next Generation Sequencing techniques by Jonah Ventures in Boulder, CO. For these analyses, numerous invertebrate primers were used to identify the invertebrates found within fecal samples to evaluate the proportion of fecal samples which contain each taxonomic group.

RESULTS

Objective 1: Compare changes in numbers, density, and distribution of piping plovers in various habitats on Fire Island

From April–August 2016, VT banded 41 adult piping plovers and 101 chicks (Table 6). Four chicks that hatched were not banded, two chicks from one brood from Smith Point County Park, one from Cupsogue Beach County Park, and one from Fire Island National Seashore. None of these unbanded chicks survived to fledgling. The remaining chicks in 2016 were banded between 0 and 13 days old. VT recaptured 19 adult piping plovers that were banded during previous years, three were banded as chicks on Fire Island, one was banded as a chick in New Jersey, and 15 were banded as adults on Fire Island.

From 2013–2016, VT banded 115 adult piping plovers (60 females and 55 males) and 223 chicks (Table 7). All chicks were banded between 0 and 13 days old. In 2013 and 2014, 8 nests were found at Watch Hill. Five adults and three chicks from those nests were banded. VT did not monitor nests at Watch Hill in 2015 or 2016. VT did not band any birds at Robert Moses State Park or the Lighthouse Tract in 2013 and 2014 as VT did not begin any work at those sites until 2015. Of all of the years that VT have been banding chicks, 45.3% of them were banded in the 2016 season, 19.2% in 2015, 18.3% in 2014 and 15.2% in 2013.

Table 6. Piping plover adults and chicks banded on Fire Island and Westhampton Island from April to August 2016 per management unit. Subsites within each management unit are abbreviated in parentheses. See Table 1 for a detailed description of these subsites.

Management Unit	Adults		Chicks
	Females	Males	
Cupsogue Beach County Park (CSE, CSW, CMF, CSB)	3	3	20
Smith Point County Park (BRE, PSO, PSE, NBW, MWPF, NBE, SPTW, SPTE)	6	6	36
Fire Island National Seashore - east of breach (OIE, BRW, BRO)	3	2	18
Fire Island National Seashore - west of breach (OIW, OIWR)	1	1	3
Fire Island National Seashore - Lighthouse Tract (FIL)	0	1	0
Robert Moses State Park (FLD5, FLD4, FLD3, OSS, STP, DMP, GOLF)	9	6	24
Total	22	19	101

Table 7. Piping plover adults and chicks banded on Fire Island and Westhampton Island from 2013–2016 per management unit. Subsites within each management unit are abbreviated in parentheses. See Table 1 for a detailed description of these subsites.

Management Unit	Adults		Chicks
	Females	Males	
Cupsogue Beach County Park (CSE, CSW, CMF, CSB)	11	9	65
Smith Point County Park (BRE, PSO, PSE, NBW, MWPF, NBE, SPTW, SPTE)	19	18	64
Fire Island National Seashore - east of breach (OIE, BRW, BRO)	8	9	38
Fire Island National Seashore - west of breach (OIW, OIWR)	1	3	14
Fire Island National Seashore - Lighthouse Tract (FIL)	0	1	0
Robert Moses State Park (FLD5, FLD4, FLD3, OSS, STP, DMP, GOLF) ^a	19	12	39
Off Site – Bellport to Watch Hill ^b	2	3	3
Total	60	55	223

^a Birds were only banded here from 2015–2016

^b Birds were only banded here from 2013–2014

VT found 43 nests in 2016, 33 of which survived to hatching and 10 failed (Table 8). Of the 10 that failed, three were abandoned and two were depredated (Table 8). The two nests depredated in 2016 were both suspected as gull predation. From 2013–2016, VT located and monitored 140 nests. Of these nests, 75 of them hatched, and 65 of them failed (Table 9). The most common reason for nest failure was depredation (Table 10).

Table 8. Piping plover nest distributions and fates at Fire Island and Westhampton Island, in various habitats of each management unit, April–August 2016. Nest numbers include renests of some pairs.

Management Unit	Habitat	Nests			Reason for loss
		Found	Hatched	Failed	
Fire Island National Seashore - Lighthouse Tract	Backshore	1	0	1	Abandoned
Robert Moses State Park	Mature dune/sand flat	12	8	4	Abandoned
Cupsogue Beach County Park	Filled breach/stabilized overwash	3	3	0	
Cupsogue Beach County Park	Backshore	3	3	0	
Fire Island National Seashore - east of breach	Natural breach/overwash	7	6	1	Predated
Fire Island National Seashore - west of breach	Natural breach/overwash	1	1	0	
Smith Point County Park	Backshore	2	1	1	Predated
Smith Point County Park	New Made restoration area	1	1	0	
Smith Point County Park	Great Gun restoration area	3	2	1	Unknown
Smith Point County Park	Filled breach/stabilized overwash	10	8	2	Abandoned (1), Unknown (1)
Total		43	33	10	

Table 9. Piping plover nest distributions and status at Fire Island and Westhampton Island, in various habitats of each management unit, 2013–2016. Nest numbers include renests of some pairs.

Management Unit	Habitat	Found	Hatched	Failed	Hatched %	Failed %
Fire Island National Seashore - Lighthouse Tract ^a	Backshore	1	0	1	0.0	100.0
Robert Moses State Park ^a	Mature dune/sand flat	22	13	9	59.1	40.9

Cupsogue Beach County Park	Filled breach/stabilized overwash	18	14	4	77.8	22.2
Cupsogue Beach County Park ^b	Backshore	8	6	2	75.0	25.0
Fire Island National Seashore - east of breach	Natural breach/overwash	21	13	8	61.9	38.1
Fire Island National Seashore - west of breach	Natural breach/overwash	5	4	1	80.0	20.0
Smith Point County Park	Backshore	10	4	6	40.0	60.0
Smith Point County Park ^a	New Made	7	1	6	14.3	85.7
Smith Point County Park ^a	Great Gun	5	2	3	40.0	60.0
Smith Point County Park	Filled breach/stabilized overwash	35	14	21	40.0	60.0
Off Site – Bellport to Watch Hill ^c	Backshore	8	4	4	50.0	50.0
Total		140	75	65	53.6	46.4

^a Not monitored 2013–2014

^b Not monitored in 2013

^c Bellport Beach to Watch Hill only monitored 2013–2014

Table 10. Fate of nests on Fire Island and Westhampton Island, by year, in each management unit, 2013–2016.

Year	Management	Total Nests	Successful	Failed			
				Abandoned	Depredated	Overwash/Flood	Unknown
2013	Fire Island National Seashore	8	5 (63%)	1 (13%)	-	1 (13%)	1 (13%)
	Smith Point County Park	9	3 (33%)	-	4 (44%)	1 (11%)	1 (11%)
	Cupsogue Beach County Park	4	3 (75%)	-	-	-	1 (25%)
2014	Fire Island National Seashore	10	4 (40%)	4 (40%)	2 (20%)	-	-
	Smith Point County Park	9	3 (33%)	-	5 (56%)	-	1 (11%)
	Cupsogue Beach County Park	5	4 (80%)	-	1 (20%)	-	-
2015	Robert Moses State Park	10	5 (50%)	5 (50%)	-	-	-
	Fire Island National Seashore	4	2 (50%)	-	2 (50%)	-	-
	Smith Point County Park	23	2 (9%)	1 (4%)	16 (70%)	-	4 (17%)
	Cupsogue Beach County Park	11	7 (64%)	-	3 (27%)	1 (9%)	-
2016	Robert Moses State Park	12	8 (67%)	4 (33%)	-	-	-
	Fire Island National Seashore	9	7 (78%)	1 (11%)	1 (11%)	-	-
	Smith Point County Park	15	11 (73%)	1 (7%)	1 (7%)	-	2 (13%)
	Cupsogue Beach County Park	6	6 (100%)	-	-	-	-
Total		135	70 (52%)	17 (13%)	35 (26%)	3 (2%)	10 (7%)

The number of pairs Virginia Tech monitored increased from 19 in 2013 to 37 in 2016, however study area boundaries changed across the years of the study (Table 11). The majority of piping plovers nested in backshore and overwash habitat. Restoration areas were not created until after the 2014 nesting season, but they were used by piping plovers thereafter (Table 11). Using their pair counts and extra information from USFWS and NPS, VT were able to estimate pair counts for the entire study area (Robert Moses State Park to Cupsogue Beach County Park) for all four years of the monitoring effort. Pair counts were variable, but the

overall numbers of pairs have slightly increased since Hurricane Sandy in 2012, though there was fluctuation within sites (Table 12).

Table 11. Number of nesting piping plover pairs in each of the various habitats. Restoration areas were not created until after the 2014 nesting season. Numbers increased in the “backshore” habitat in 2015 due to the addition of the Robert Moses State Park study area. Some pairs had more than one nest per year. Footnotes to table indicate changes in monitoring area among years.

Habitat	Year			
	2013 ^a	2014 ^a	2015 ^b	2016 ^b
Overwash	11	17	15	14
Breach Fill	1	1	3	3
Restoration	N/A	N/A	5	4
Backshore	7	3	12	16
Total	19	21	35	37

^a Includes Watch Hill nests, only monitored 2013–2014

^b Includes Robert Moses and the Lighthouse Tract, only monitored 2015–2016

Table 12. Number of pairs nesting at each management unit. Pair counts for areas not monitored by Virginia Tech in a given year (e.g. Robert Moses State Park in 2013–2014) were obtained from USFWS and NPS correspondence and annual reports. Some pairs had more than one nest per year.

Management Unit	Year			
	2013	2014	2015	2016
Robert Moses State Park	12	10	10	9
Fire Island Lighthouse	1	1	0	1
Fire Island National Seashore West	6	4	1	1
Fire Island National Seashore East	4	4	2	6
Smith Point County Park	6	8	13	13
Cupsogue County Park	3	5	7	6
Total	32	32	33	36

Objective 2: Estimate the “effect distance” of artificially created habitat at New Made and Great Gun Beach

Adult Movement

The greatest distance that an adult with an active nest was observed from its nest within a breeding season was 7412m; in 2014, an adult with a nest at Narrow Bay East was observed at Old Inlet East. The greatest distance an adult was observed from an inactive nest was 33km; an adult that nested in Field 3 of Robert Moses State Park was observed foraging at the Old Inlet Flood Shoals after brood loss.

In 2014, the average distance that birds with active nests were observed from their nest was 236 m (SE = 39), and the average distance that birds without active nests (i.e., pre- or post-nesting) were observed from their nests was 536 m (SE = 110). In 2015, the average distance that birds with active nests were observed from their nest was 350 m (SE = 54), and the average distance that birds without active nests (i.e., pre- or post-nesting) were observed from their nests was 873 m (SE = 106). In 2016, the average distance that birds with active nests were observed from their nests was 106 m (SE = 15.1), and the average distance that birds without active nests (i.e., pre- or post-nesting) were observed from their nest was 537 m (SE = 110.4).

During the time that birds had active nests, VT only recorded one location at the Old Inlet Flood Shoal, and it was the location of female nesting 150 m from the resight location. VT recorded six locations of non-nesting adults at the Old Inlet Flood Shoal. The greatest of these non-nesting movements was 33km from Robert Moses State Park, though all observed movements to this area were greater than 1000m (Table 14).

VT observed 18 individuals with active nests and 71 individuals without active nests using the Cupsogue sandbar over the three years of the study. The greatest distance that an individual with a nest moved to the Cupsogue sandbar was 2141 m from the Great Gun restoration area. All of the observations of nesting individuals using the Cupsogue sandbar were nesting either at Cupsogue Beach County Park or Great Gun/Smith Point East. Of the 71 instances of individuals using the sand bar that were not actively nesting, the greatest observed distance was 8.3 km and was an individual who had nested at Pattersquash Overwash earlier in the season. This bird from Pattersquash was observed foraging at the Cupsogue Sand Bar both before and after nest initiation.

At the Cupsogue mud flat, VT observed 8 individuals with active nests foraging at this location. Similar to the sandbar, all of these individuals were nesting either at Cupsogue Beach County Park or the Great Gun Restoration Area. The greatest distance for these observations was 2.5km from an individual nesting at Great Gun. VT recorded 7 pre- or post- nesting individuals foraging at the Cupsogue Mud Flat, with the greatest distance from their nest of 6km, and was an individual that had previously nested at Narrow Bay East.

During both the time that nests were active and the time that nests were inactive, individuals used all of the overwashes within the study area (Table 13, Table 14). VT observed 36 individuals in locations other than the overwash they were nesting in, 16 of which were foraging. Most (N = 13) of these locations were individuals foraging at Narrow Bay West at the bayside mudflat, and the birds moved from Narrow Bay East and the New Made restoration area. Individuals also moved from Narrow Bay East and New Made to Old Inlet East. While many of the observations of piping plovers at the overwashes were observations of birds that had a nest within the overwash, but birds with active nests elsewhere did use the overwashes. Specifically, the greatest distance moved while birds were actively nesting was to the Old Inlet Overwash, adjacent to the Old Inlet Breach—a new habitat created by Hurricane Sandy.

Table 13. Distance from nest for piping plovers with active nests observed in Hurricane Sandy created habitats and the Cupsogue sandbar and mudflat, Fire Island and Westhampton Island, 2014-2016.

Habitat	Distance from Nest (m)			95% Confidence Interval		
	N	Max	Mean	SE	Lower	Upper
OIE Overwash	198	7412.7	296.2	994.7	82.6	163.3
Great Gun	7	3466.1	644.6	1254.4	474.1	1160.1
NBE Overwash	123	3466.1	199.7	461.5	52.9	105.5
Cupsogue Mud Flat	8	2537.2	1174.4	747.6	305.2	784.5
New Made	4	2453.5	695.9	1173.9	586.9	1867.9
Cupsogue Sand Bar	18	2141.2	905.7	444.7	111.2	237
NBW Overwash	129	2006.2	148.4	217.4	22.8	45.3
PSO Overwash	140	1751.9	148.8	191.6	18.2	36
Cupsogue Overwash	207	1419.8	117.3	171.7	13.8	27.3
Bridge Overwash	7	1326.7	404.8	616.7	233.1	570.4
Old Inlet Flood Shoal	1	150.4	150.4	-	-	-
OIWR Overwash	8	87.9	61	7.5	43.3	78.6

Table 14. Distance from nest to Hurricane Sandy-created habitats and the Cupsogue sandbar and mudflat, for adult plovers before or after (but not during) nesting, Fire Island and Westhampton Island, 2014-2016.

Habitat	Distance from Nest (m)			95% Confidence Interval		
	N	Max	Mean	SE	Lower	Upper
Old Inlet Flood Shoal	6	33079.4	12425.1	4495.8	868.3	23981.8
NBE Overwash	120	12426.0	1118.2	254.6	614.0	1622.3
OIE Overwash	175	10870.0	325.0	89.7	147.9	502.1
Cupsogue Sand Bar	71	8326.3	2171.2	301.9	1569.0	2773.3
OIWR Overwash	19	8097.0	2309.3	381.8	1507.2	3111.3
Cupsogue Overwash	234	7762.2	609.7	87.8	436.8	782.6
Cupsogue Mud Flat	7	6070.8	2194.9	695.0	494.2	3895.6
PSO Overwash	172	5797.9	266.0	38.8	189.4	342.5
New Made	11	2505.2	331.8	218.1	0.0	817.8
NBW Overwash	65	2084.2	226.4	38.9	148.7	304.2
Great Gun	3	1251.4	1075.2	173.3	329.7	1820.8
BRO Overwash	2	1048.8	1044.8	4.1	993.2	1096.4

In 2016, adult plovers with an active nest and direct bay access were seen closer to their nests than plovers ($\bar{x}$ = 154.96, SE $\pm$ 19.63) that had no direct bay access ($\bar{x}$ = 155.86, SE $\pm$ 28.6; df = 1, P = 0.036, Figure 22). However, the mean movement distance between the two groups was only .9 m, so a statistical difference between the two groups is unlikely to be biologically relevant (Figure 22). The difference in observed movement from nesting locations was more pronounced in 2014 and 2015 (DeRose-Wilson et al. 2014, Monk et al. 2015).

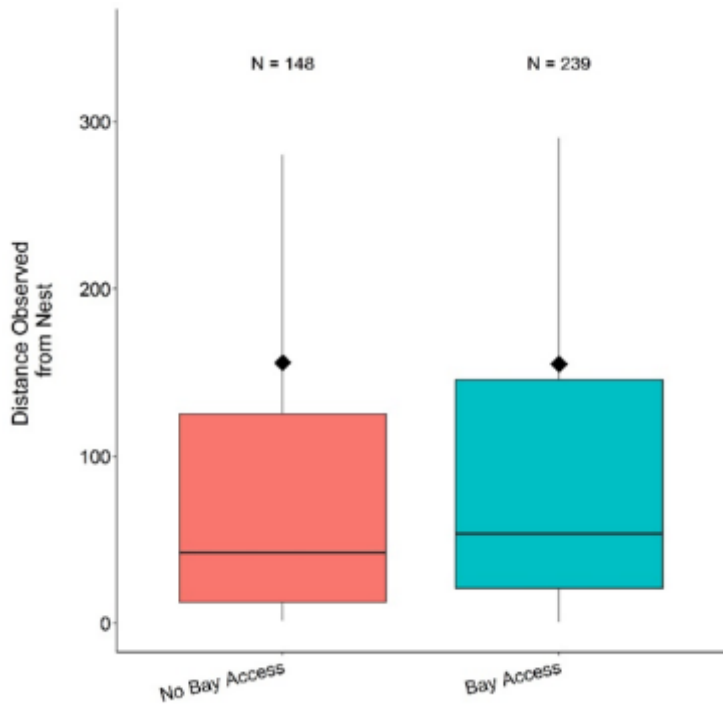


Figure 22. The average distance adult plovers were observed from their nest in 2016. The line within the boxplot indicates the median, and the black diamond indicates the mean. Outliers were removed for interpretability, but the maximum distance for adult plovers with bay access was 2453.5 m and the maximum distance for adult plovers without bay access was 1952.8 m.

Fledgling Movement

VT assessed the use of newly created habitats and other habitats of interest by fledgling piping plovers relative to their nest location. From 2014 to 2016, VT recorded 356 observations of fledglings from the study area. On average, those individuals were observed 2,373m (SE = 239) from the location of their nest. The maximum distance observed was 42,607m; a chick from Pattersquash overwash was observed foraging at tip of Robert Moses State Park in 2016 (Table 15). On average, fledglings moved farthest to Old Inlet Flood Shoals, Cupsogue mud flat, and Cupsogue sandbar. VT did not observe any fledglings in the New Made or Great Gun restoration areas after their creation in 2015. From 2014–2016, VT observed two fledglings return to nest within a subsite where they had been observed in the year prior.

Table 15. Distance moved by fledgling piping plovers; from their nest location

Habitat	Distance from Nest (m)				95% Confidence Interval	
	N	Max	Mean	SE	Lower	Upper
Old Inlet Flood Shoal	21	35841.9	5176.0	1656.3	1721.0	8630.9
Cupsogue Mud Flat	10	13703.0	6680.5	1633.2	2986.0	10374.9
Cupsogue Sand Bar	34	12927.2	3133.1	627.0	1857.5	4408.7
OIE Overwash	46	12644.6	2156.6	483.9	1182.0	3131.1
Cupsogue Overwash	58	12410.7	1452.6	425.0	601.6	2303.6
Bridge Overwash	13	10815.6	1931.5	760.0	275.6	3587.5
PSO Overwash	71	7421.8	2031.8	308.0	1417.6	2646.0
NBW Overwash	17	6714.7	2198.5	624.9	873.8	3523.3
NBE Overwash	9	1108.2	379.7	93.4	164.3	595.2

Objective 3: Compare egg weights of birds with access to bay side intertidal flats with egg weights of birds without such access

In 2016, there was no difference in the clutch masses of piping plovers that had bay access as opposed to those that did not have bay access ($Z = -1.40$, $df = 1$, $P = 0.16$, median = 39.2, $\bar{x} = 38.88$). Similarly, between 2013–2016, there was no difference in the clutch masses of piping plovers that had bay access versus those that did not have bay access ($Z = 0.26$, $df = 1$, $P = 0.79$, median = 39.15, $\bar{x} = 39.08$).

Objective 4: Compare piping plover nest and chick survival rates in various habitats across Fire Island

In 2016, nests that were exclosed during laying or after clutch completion had an 82.2% predicted probability of surviving to hatching. Nests that were never exclosed had a 70.1% predicted probability of surviving to hatching (Table 16). The daily survival rate for exclosed and unexclosed nests was 0.995 and 0.989, respectively. Nests that were exclosed had a lower abandonment rate (12.5%) than nests that did not have exclosures (25%, Table 17)

When comparing among years, the probability of surviving to hatching varied (Table 16). In 2015, midway through the nesting season, exclosures were removed from all of the Smith Point County Parks nests (approximately 15 days after clutch completion) due to a high incidence of fox harassment at exclosed nests. The nests in 2015 that were “previously exclosed” had a 0% probability of surviving to hatching (Monk et al. 2015). Overall, the probability of nest survival increased in for all management units from 2015 to 2016, during the years of the concurrent fox study, however small sample sizes resulted in overlapping confidence intervals among all sites between years.

Table 16. The probability of piping plover nests surviving to hatching with an exclosure and without an exclosure on Fire Island and Westhampton Island, 2013–2016.

Year	Caged	Number of Nests	Failed	Hatched	Apparent Survival	Probability of surviving to hatching	Standard error	Daily Survival	Standard Error
2013	N	6	5	1	0.17	0.271	0.130	0.961	0.014
2013	Y	15	4	11	0.73	0.485	0.118	0.982	0.006
2014	N	9	6	3	0.33	0.339	0.108	0.968	0.009
2014	Y	16	7	9	0.56	0.549	0.096	0.985	0.005
2015	N	25	20	5	0.20	0.270	0.077	0.961	0.008
2015	Y	23 ^a	12	11	0.48	0.484	0.076	0.982	0.005
2016	N	8	6	5	0.63	0.701	0.100	0.989	0.004
2016	Y	32	4	28	0.88	0.822	0.062	0.995	0.002
2015	Removed ^b	5	5	0	0.00	0.000	0.000	0.474	0.247

^a Includes the 5 nests that had exclosures removed due to concerns of fox depredation

^b Probability of survival once exclosures have been removed from a previously exclosed nest

Table 17. Abandonment rate of piping plover nests with exclosures and without exclosures from Fire Island and West Hampton Island 2013–2016.

Year	Caged	# of Nests	Failed	Hatched	Abandoned	Abandonment ^a Rate
2013	N	6	5	1	0	0.000
2013	Y	15	4	11	1	0.067
2014	N	9	6	3	0	0.000
2014	Y	16	7	9	5	0.313
2015	N	25	20	5	2	0.080
2015	Y	23	12	11	5	0.217
2016	N	8	6	5	2	0.250
2016	Y	32	4	28	4	0.125
2015	Removed	5	5	0	0	0.000

^a Calculated as the # of abandoned nests / total nests

Table 18. Predicted probability of surviving to hatch (33 days from incubation) for all four management units, during the years of the concurrent fox study.

Year	Management Unit	Survival Estimate	SE
2015	Robert Moses State Park	0.47	0.31
	Fire Island National Seashore	0.39	0.30
	Smth Point County Park	0.20	0.26
	Cupsogue County Park	0.61	0.25
2016	Robert Moses State Park	0.86	0.12
	Fire Island National Seashore	0.82	0.13
	Smth Point County Park	0.72	0.20
	Cupsogue County Park	0.90	0.08

Daily survival rates for chicks and probability to fledging varied among years and among management units (Table 19). At Smith Point and Cupsogue, survival probability increased from 2015 to 2016. Low nest survival rates in 2015 (Table 18), resulted in few broods for the year, making survival rates difficult to estimate. Causes of chick survival are challenging to identify, however in 2015 and 2016, VT had observations of chicks getting eaten by gulls (Herring and Great Black-Backed) at Robert Moses State Park.

Table 19. Daily survival rate and probability of fledgling for chicks in all management units and years, estimated from Lukacs young survival model in Program MARK. Probability of surviving to fledging represents the probability of surviving to 25 days old.

Management Unit	Year	N	DSR	S_{fledge}	$SE(S_{\text{fledge}})$
Robert Moses	2015	5	0.955	0.313	0.106
	2016	8	0.959	0.351	0.092
Fire Island National Seashore	2014	3	0.981	0.612	0.164
	2015	2	0.992	0.827	0.155
	2016	7	0.987	0.723	0.095
Smith Point	2014	4	0.993	0.840	0.115
	2015	2	0.974	0.520	0.193
	2016	12	0.991	0.800	0.070
Cupsogue	2014	5	0.956	0.322	0.101
	2015	7	0.898	0.067	0.042
	2016	6	0.932	0.174	0.074

In 2016, chicks had a 60% probability of surviving to fledging. Average productivity was 1.75 fledges/pair. The highest productivity was at Smith Point County Park, whereas the lowest productivity was at Cupsogue Beach County Park (Table 20). When comparing across the study site from 2013–2016, 2016 had the highest rate of productivity and 2015 had the lowest with 0.39 fledges/pair (Table 21).

Table 20. Piping plover productivity (fledges/pair) in four different management units on Fire Island and Westhampton Island, May-August 2016.

Management Unit	# Hatched	# Fledged	# of Territories	Fledges/pair
Robert Moses State Park	24	10	9	1.11
Fire Island National Seashore	22	16	8	2.00
Smith Point County Park	38	31	13	2.38
Cupsogue Beach County Park	21	6	6	1.00
Total	105	63	36	1.75

Table 21. Piping plover productivity (fledges/pair) in four different management units on Fire Island and Westhampton Island, 2013–2016.

Management Unit	2013	2014	2015	2016
Robert Moses State Park	-	-	0.30	1.11
Fire Island National Seashore	0.60	0.75	1.67	2.00
Smith Point County Park	0.50	1.50	0.31	2.38
Cupsogue County Park	0.00	1.20	0.14	1.00
Total	0.47	1.14	0.39	1.75

For daily chick survival among habitat types, VT had two highly-ranked models, both of which included annual differences in daily survival rate. One model considered whether broods had access to bayside foraging habitat, and the second model considered whether broods were present in an overwash. In each year, daily survival probability was higher if chicks had access to bayside foraging habitat, or were present in an overwash. Overall, the predicted probability of a chick surviving to fledging was greatest for chicks in 2016 that had access to bayside foraging habitat (63.9%), and lowest for chicks in 2015 that did not have access to bayside foraging habitat (20.8%; Table 22).

Table 22. Daily survival rate and probability of surviving to fledging of chicks foraging on the bay vs. no bay and overwash vs. no overwash from 2014–2016. Overwashes included both ocean to bay, and oceanside only overwashes, and bayside access indicated that a brood, at some point before fledging, had access to low energy, intertidal bayside habitat.

Year	Habitat	N	DSR	S_{fledge}	$SE(S_{\text{fledge}})$
2014	Bay	7	0.98	0.605	0.078
	No Bay	5	0.969	0.452	0.08
2015	Bay	7	0.961	0.368	0.075
	No Bay	9	0.939	0.208	0.063
2016	Bay	17	0.982	0.639	0.056
	No Bay	16	0.972	0.492	0.06
2014	Overwash	9	0.977	0.554	0.072
	No Overwash	3	0.96	0.36	0.064
2015	Overwash	9	0.962	0.383	0.078
	No Overwash	7	0.936	0.191	0.058
2016	Overwash	19	0.982	0.637	0.056
	No Overwash	14	0.969	0.457	0.056

Broods that had access to the bay intertidal foraging had smaller home ranges than broods that were only able to forage on the ocean (Figure 23, $Z= 2.14$, $df =1$, $P=0.024$). Some broods had no chicks survive to fledging (210, 215, 216, 19, and 25) could have skewed the results slightly since they did not have as much time to expand their home range as broods that survived to fledging, however VT included broods that had no chicks survive to fledging if they had ≥ 10 locations (Figure 24). Some broods moved long distances to reach lower energy foraging habitat (Figure 25 and Figure 26).

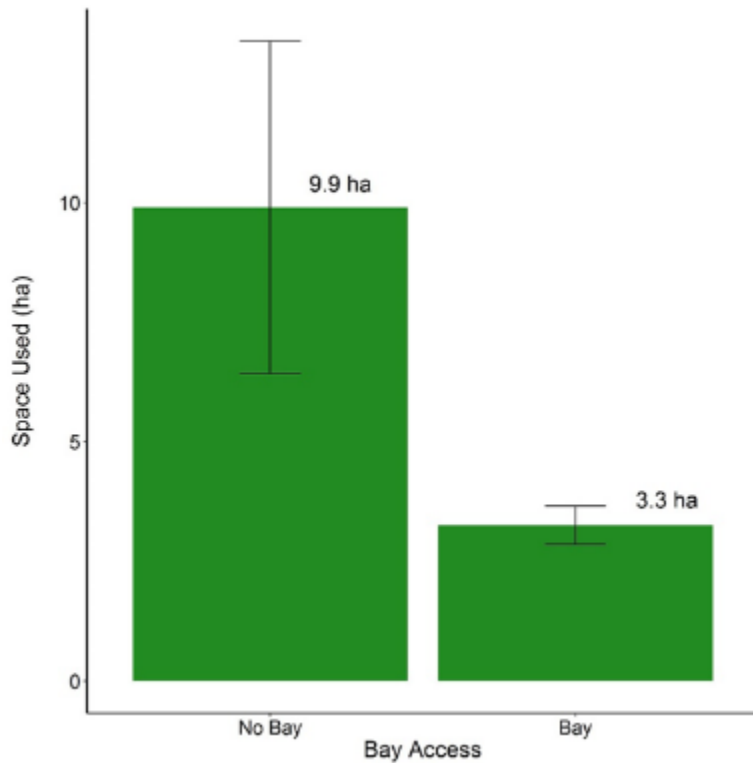


Figure 23. Mean ($\pm$ SE) of 2016 brood home ranges, for broods with at least 10 locations, that had access to bayside foraging habitat and broods that did not have access to bayside foraging habitat. Brood home range size was obtained by creating a minimum convex polygon around all locations for each brood. The numbers above the bar plot indicate the mean territory size for the group.

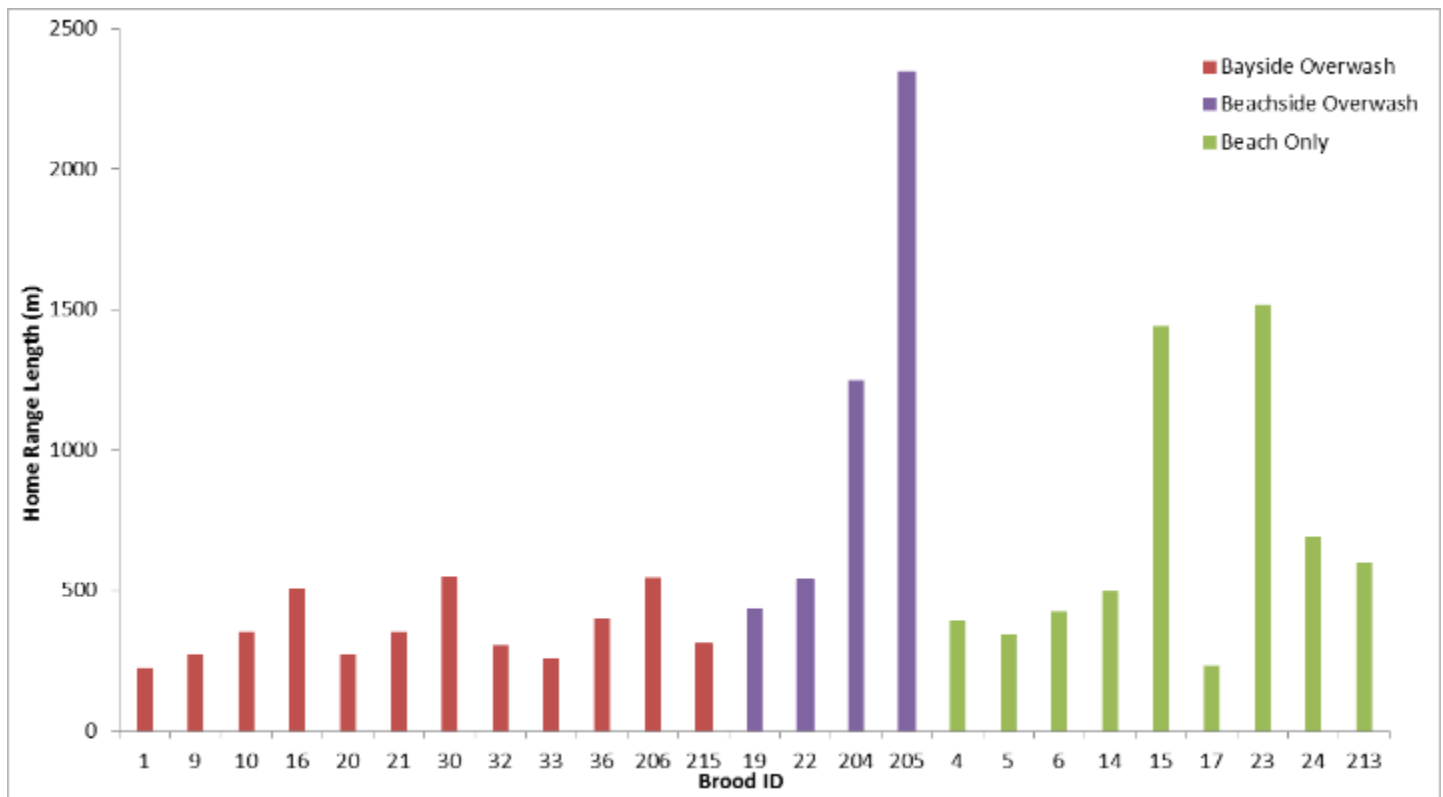


Figure 24. Brood home range lengths of 2016 piping plover broods that foraged on bayside overwashes, beachside overwashes, and ocean beaches. This figure only shows broods that had ≥ 10 location points available.

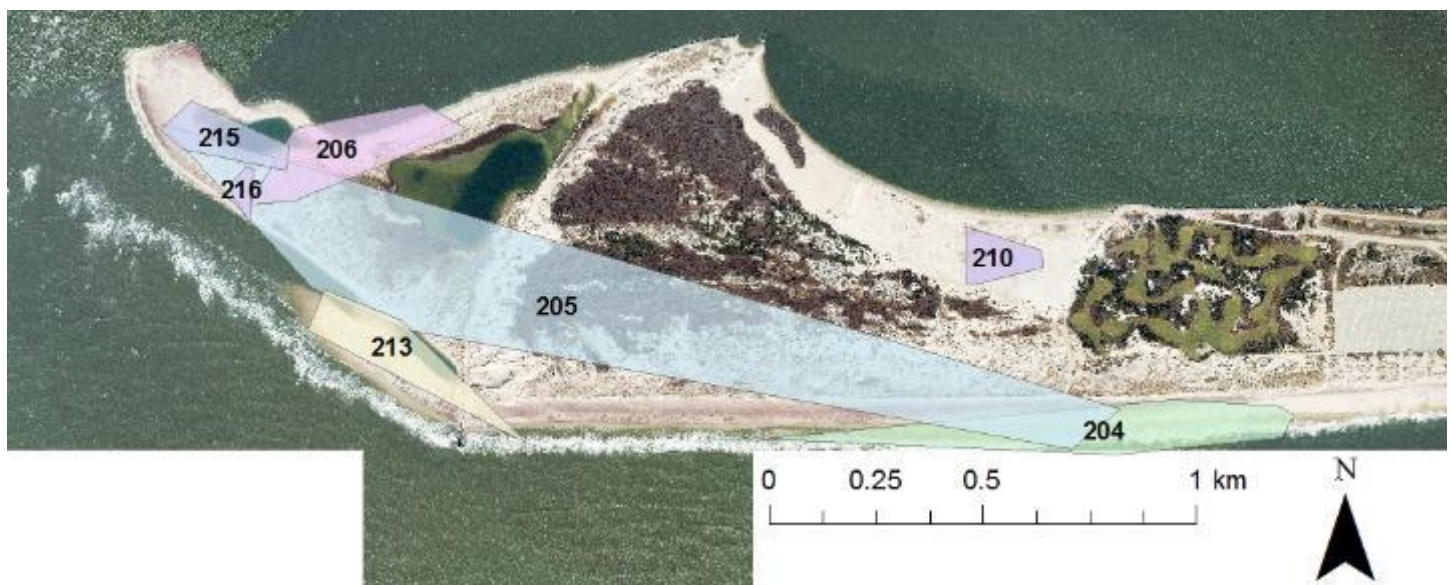


Figure 25. Brood ranges of piping plovers at Democrat Point, May-August 2016. Imagery taken in April, 2016.

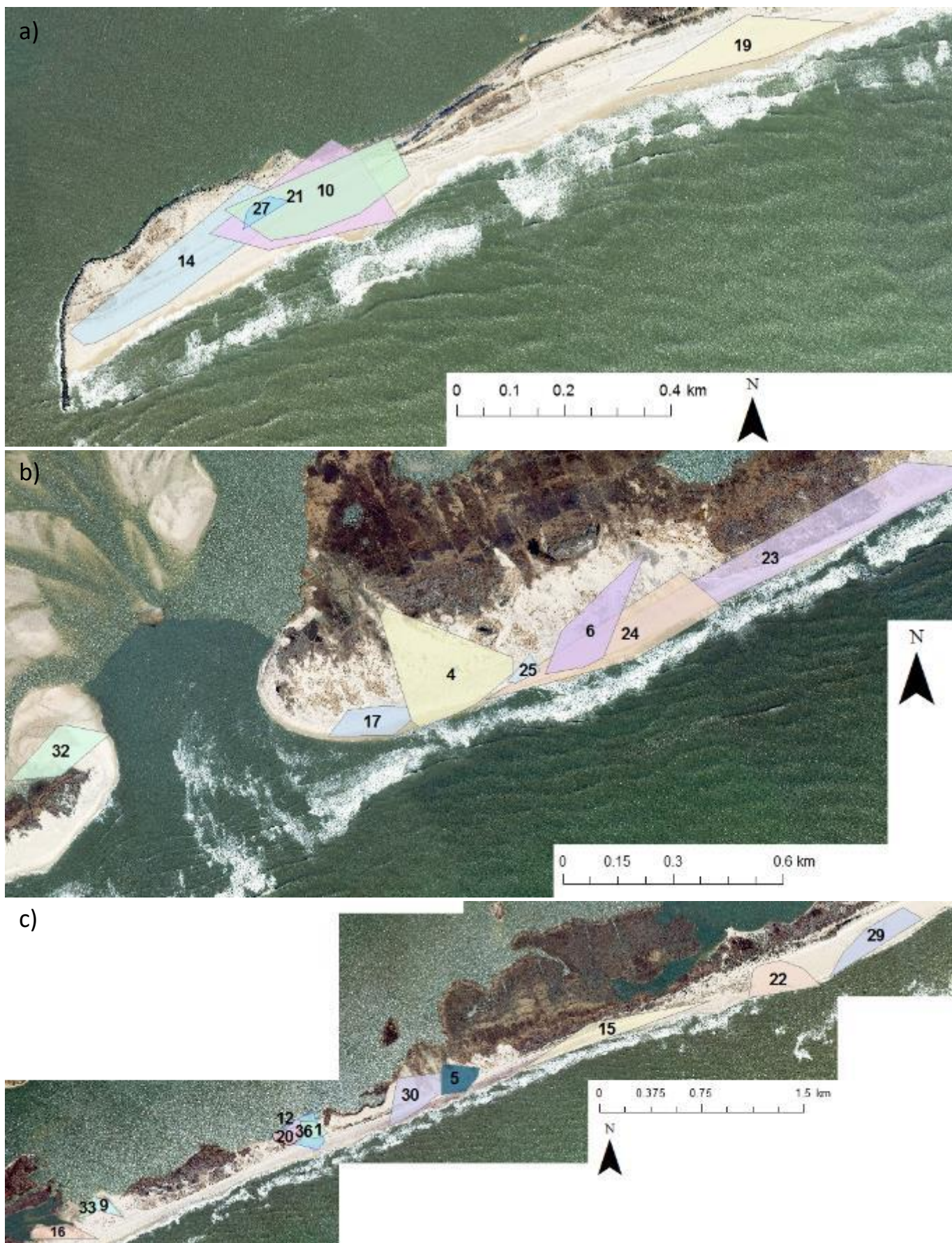


Figure 26. Brood ranges of piping plovers at a) Otis Pike Wilderness Area b) Smith Point County Park and c) Cupsogue Beach County Park, May-August 2016. Imagery taken in April, 2016.

Using a mixed-design ANOVA, VT found that near-fledgling (20–22 days) mass for chicks that had access to bayside foraging habitat ($\bar{x}$ = 34.2 g, Range 25.3–38.6) was greater than near-fledglings that did not have such access ($\bar{x}$ = 33.5 g, Range 21.4–40.3), although the trend was not significant at α = 0.05 (Figure 27, ANOVA, $F_{1,44}=3.34$, $P=0.074$). There were two near-fledgling observations on the bay side that were greater than 10g smaller than the mean, and both were observations from Cupsogue West where previous analyses suggested that human interference with foraging slowed growth.

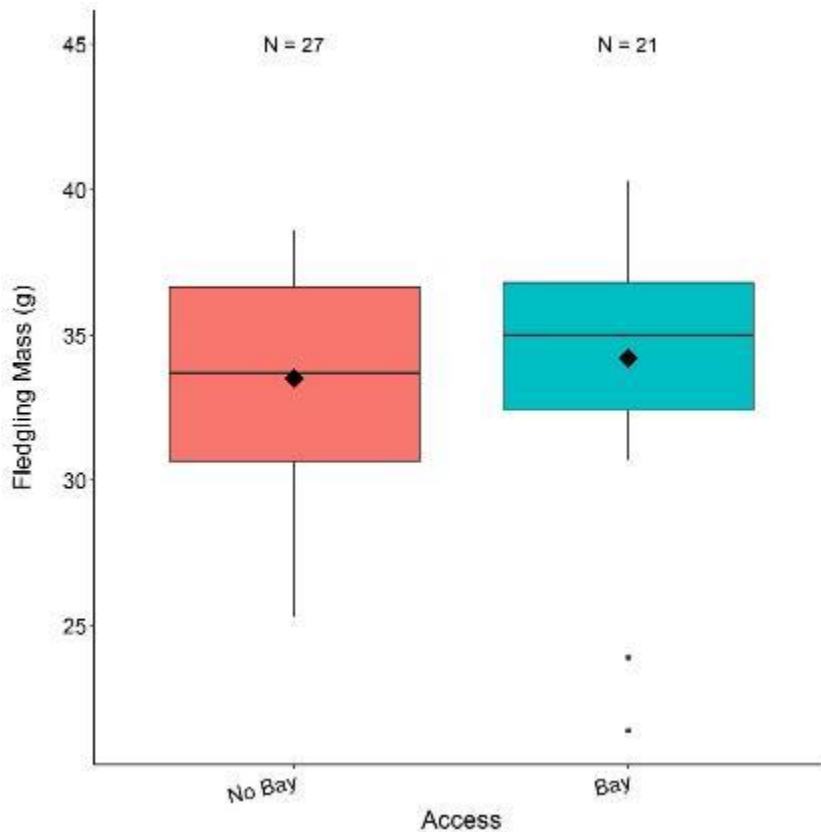


Figure 27. Mass of 2016 chicks between 20–22 days of age relative to bay access (ANOVA, $F_{1,44}=3.34$, $P=0.074$). The box plot includes the mean (diamond), median (solid line in box), 25th and 75th quartile ranges (solid boxes), and the maximum and minimum (error bars). The numbers above the bars are sample sizes of chicks. The two outliers for bay access were chicks from broods at Cupsogue West.

Objective 5: Compare the relative contribution of local growth (recruitment) vs immigration in population growth associated with new habitats

For the eastern barrier islands (NPS Wilderness Area to Cupsogue Beach County Park) 35–54% of the previous year’s breeders returned annually in 2014–2016 (Table 23). The remainder of the birds that nested in the study area hatched in the study area the year before (local recruitment; 8–11%) or were unbanded birds captured during the year (immigrants; 35–54%). The proportion of that population that is represented by immigrants is variable, but makes up less than 60% of the population in any given year. Additionally, the count of immigrants may be a slight over-estimate due to a small number of birds that did not get banded in the year prior. Potential unbanded birds that are not immigrants could include birds that had a nest fail early in incubation so VT did not have a chance to catch and band them, and did not remain in the study area to renest, however, nearly all birds were banded in all years of the study. Estimates from the Pradel model

suggest the highest immigration rate in 2014, and the lowest in 2015, though confidence intervals overlap for all three years, indicating non-significant differences.

In each of the three years, there was at least one locally recruited yearling that nested in an overwash and, in years after restoration zones were created, at least one in a restoration zone (Table 24). The overwashes across the island supported the most immigrant piping plovers across the three years (Table 25). The breach fills supported fewer recruits and immigrants than the overwashes and restoration zones, but the habitat was smaller than the overwashes and the restoration zones.

At the western barrier island, only 3 chicks fledged from Robert Moses in 2015 and none were resighted on the study area in 2016. Only 16% of birds that nested in Robert Moses in 2015 returned in 2016 (Table 26).

Table 23. Eastern study area population (NPS Wilderness Area to Cupsogue Beach County Park) adult piping plovers, broken into categories of number of birds that had nested in the study area previously, the number of recruited young and the number of immigrants.

Year	Returning nesters	Local recruits ^a	Immigrants ^b	Immigration rate ($\pm$ SE) ^c
2014	17 (46%)	2 (8%)	17 (46%)	0.89 (0.27)
2015	20 (54%)	4 (11%)	13 (35%)	0.46 (0.14)
2016	18 (35%)	4 (10%)	26 (54%)	0.80 (0.19)

^a Local recruits are individuals that were hatched as chicks in the study area and returned the year following to nest.

^b Immigrants refers to a count of the individuals that were newly banded in a given year, and any birds that were known to have been hatched outside of the study area and nested on Fire Island or Cupsogue.

^c Immigration rate estimated using a Pradel model in Program MARK.

Table 24. The number of yearlings recruited into the population, that were banded as chicks in the year prior and returned the following year to breed, in new habitats on Fire Island and at Cupsogue following Hurricane Sandy and subsequent habitat alteration. The numbers are the number of recruits that had a nest in that habitat type, with percentage of total yearling recruits that year.

Year	Total # yearling recruits	Overwash	Breach Fill	Restoration Zone
2014	2	1	0	NA
2015	4	2	0	2
2016	4	1	1	1
Total	10	4	1	3

Table 25. The number of individuals that immigrated into the population, divided into the new habitat types on Fire Island following Hurricane Sandy and subsequent habitat alterations. The numbers represented are the number of immigrants that had a nest in that habitat type, with percentage of total immigrants that number represents.

Year	Total # Immigrants	Overwash	Breach Fill	Restoration Zone
2014	17	11 (65%)	2 (12%)	NA
2015	13	6 (46%)	1 (8%)	3 (23%)
2016	26	15 (58%)	1 (4%)	4 (15%)
Total	56	32 (57%)	4 (7%)	7 (13%)

Table 26. Robert Moses State Park subpopulation of adult piping plovers, broken into categories of number of birds that had nested in the study area previously, the number of recruited young and the number of immigrants.

Year	Returning Nesters (percent)	Local Recruits ^a	Immigrants ^b	Immigration Rate (# immigrants in t+1 per individual in year t)
2016	3 (16%)	0	16 (84%)	0.94

^a Local recruits are individuals that were hatched as chicks in the study area and returned the year following to nest.

^b Immigrants refers to a count of the individuals that were newly banded in a given year, and any birds that were known to have been hatched outside of the study area and nested on Fire Island or Cupsogue.

In 2016, VT located two New Jersey banded plovers on Fire Island. The first was first seen at Smith Point County Park on 25 April 2016. The second was seen at Robert Moses State Park on 12 May 2016. The birds were banded as chicks in 2015 at North Brigantine Natural Area and the Holgate Unit of E.B. Forsythe National Wildlife Refuge, respectively.

The first was resighted twenty times from April to September. All twenty of her sightings were at Smith Point County Park, where she had two nests. The first nest was located at Pattersquash Overwash, but was abandoned at 3 eggs. The male associated with the nest was never resighted. She then made a second nesting attempt at the New Made restoration area, with a 2015 chick from OIE. This nest produced 4 chicks that hatched on 2 July 2016 and survived through fledging. The second bird was resighted ten times. All ten of these sightings were at Robert Moses State Park. She did not appear to nest on Fire Island but she was seen with an unbanded male, scraping together in the same area for multiple days.

Objective 8: Location, elevation and vegetation data at nests

During the 2016 breeding season, VT contributed 46 iPlover points, which were added to the 99 points collected in 2014 and 2015.

Objective 9: Compare prey densities at several habitat types

Terrestrial Invertebrates

In 2016, there was no difference in the number of invertebrates collected between the three different locations of bay shoreline, interior, and ocean shoreline (ANOVA, $F_{2,329}=2.217$, $P=0.11$, Table 27).

Table 27. Mean number of invertebrates captured during a 30-minute period at bay shoreline, ocean shoreline, and interior habitats on Fire Island and Westhampton Island, June through August 2016.

Geologic Location	Mean Arthropods/ 30min	SE	N
Bay Shoreline	2.01	0.40	78
Interior	1.41	0.26	186
Ocean Shoreline	0.90	0.15	68

Within habitat types, ephemeral pools and the bay intertidal zone had greater projected invertebrate catches than the ocean intertidal or interior. For the treatment types, overwashes had greater invertebrate catches than the restoration zones and the breach fills (Table 28, Figure 28). Although the invertebrate catch rate was high in ephemeral pools everywhere, ephemeral pools were rare in restoration areas and breach fill areas, as indicated by the small sample sizes (Figure 28).

Table 28. Mean predicted number of invertebrates caught over a three hour period in various habitats from 2014–2016. Actual samples were collected over 30-minute periods and projected over three hours for comparison to past studies.

Habitat	Overwash	SE	Breach Fill	SE	Restoration	SE
Bay Intertidal	19.87	3.16	13.05	3.41	10.00	3.15
Ephemeral Pool	33.15	7.33	21.77	6.36	16.68	5.78
Ocean Intertidal	10.49	1.87	6.88	1.74	5.28	1.67
Interior	5.10	0.71	3.35	0.78	2.56	0.76

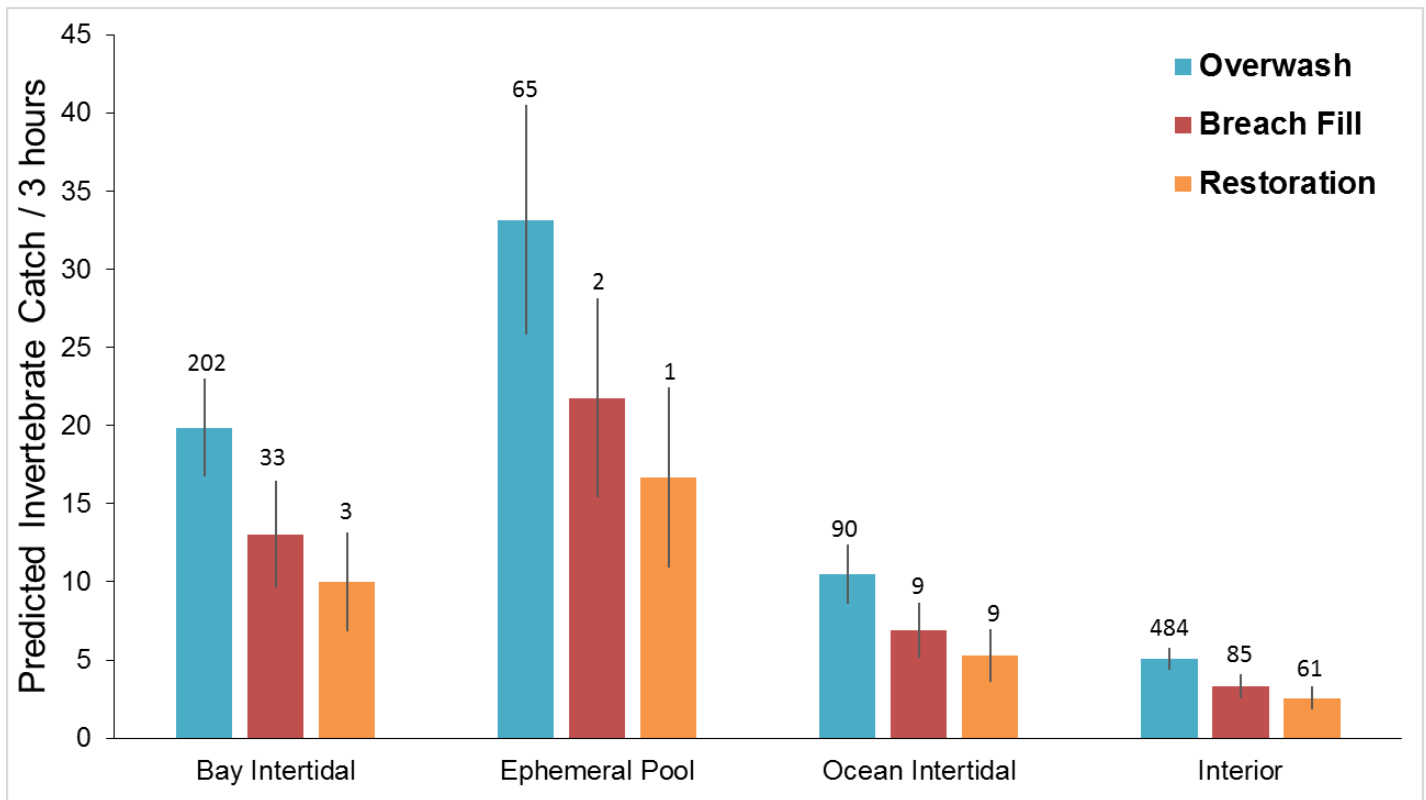


Figure 28. Predicted invertebrates caught over a projected three-hour period in various habitats from 2013-2016. Invertebrate samples were collected over 30-minutes, but projected to 3-hours to facilitate comparison to similar piping plover studies. Numbers above bars indicate sample sizes.

Core Samples

There were 51 microbenthic taxa identified in 198 samples that were collected in 2015. The highest number of taxa was observed in the CMF (Cupsogue mud flats) samples, which contained 38 unique taxa (family/class level). See Appendix B: Response of Piping Plover Prey to Habitats Created by Hurricane Sandy, Report by SC DNR.

Fecal Samples

Diptera was the most common order of invertebrate found in the fecal samples that were collected in 2016 and analyzed with DNA metabarcoding (Figure 29). The second most abundant invertebrate order in fecal samples were Coleopterans.

All fecal samples collected during the 2013 and 2014 field seasons, and analyzed by SCDNR, contained at least one identifiable taxon. Of the 44 samples collected, 22 of them contained invertebrates from the order Coleoptera (beetles) making it the most commonly found identifiable invertebrate in the samples. See Appendix B: Response of Piping Plover Prey to Habitats Created by Hurricane Sandy, Table 2.

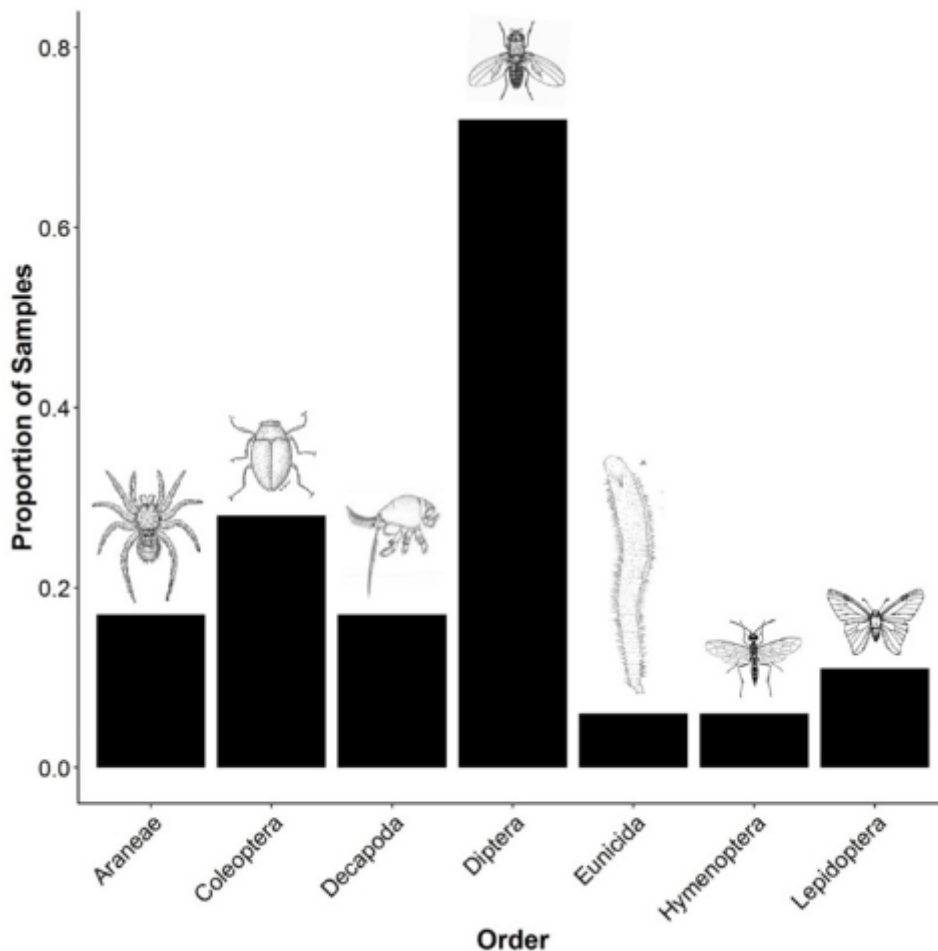


Figure 29. Proportion of invertebrates found in all piping plover fecal samples collected on Fire Island and Westhampton Island, April-August 2016

DISCUSSION

In a highly dynamic system such as barrier islands, changes in habitat distribution and quality can have substantial impacts on the organisms that rely on such systems. Hurricane Sandy caused much habitat change, potentially impacting the nesting piping plovers. VT study focused on the piping plovers on Fire Island and a portion of the nearby Westhampton Island, and VT aimed to assess the overall impacts on piping plovers and their invertebrate prey after Hurricane Sandy made landfall in 2012.

Prey availability in different habitat types likely drives both habitat selection and survival of both adults and chicks. VT collected samples of prey in bay and ocean side intertidal as well as in vegetated areas. VT collected these samples in multiple ways. VT used terrestrial invertebrate transects, core samples to collect marine invertebrate samples, and collected fecal samples to understand actual prey utilization. VT found that in terms of availability of invertebrate prey, bay intertidal and ephemeral pool habitats had greater terrestrial invertebrate availability, and more terrestrial invertebrates were caught in overwashes compared to breach fills and restoration areas. Similarly, the core samples for marine invertebrates found the greatest prey densities in mud-flats, which are intertidal, as well as overwashes. Greater invertebrate abundance and

densities are likely to improve foraging efficiency of both adult plovers and chicks, leading to improved growth rates and eventually survival, and are thus one piece of the puzzle to explain piping plover habitat selection.

The available habitats that plovers select from on Fire Island and Westhampton Island for nesting and brood-rearing territories include overwashes, breach fills, restoration area, and unvegetated backshore areas. The overwashes were created by high waters during Hurricane Sandy, and the breach fills were areas that were breached during the Hurricane and subsequently filled in. The restoration areas include New Made and Great Gun which were created prior to the 2015 nesting season. Each year, young from the previous year nested in areas of overwashes and restoration areas (once available), with overwashes contributing the most to the recruitment and immigration. In each year that the restoration areas were available, at least one new local recruit nested in them. The proportion of the population that is composed of recruits and immigrants make up nearly 50% of the Fire Island plover population in all three of the years represented here, and many of those individuals are using newly created habitat. VT also found that the immigration rate is highest following years of low nest success and chick survival. This could be due to individuals leaving the study area following nest or brood loss, leaving open habitat for dispersing individuals to occupy. Although VT did not see an exponential population increase on Fire Island immediately following Hurricane Sandy, as was seen following past habitat creating events, VT did see a slight pair increase from 2013 to 2016, of 32 to 36 pairs across the study area. VT may not have seen the increase that VT expected following the storm, because reproductive rates were relatively low across Long Island in the years following the storm, so there were fewer birds to occupy the new habitats. However, 2015 was a highly productive season for nearby areas, such as Jones Beach State Park on Jones Island, which may have produced an excess of individuals to colonize open habitats on Fire Island. This is further supported by the large number of second year adults banded within their study area in 2016. With high levels of reproduction in some areas in 2016, the prospects for a population increase in 2017 seem good, although the effects of Hurricane Matthew, which overwashed a key wintering site, remain to be discovered.

Additionally, in their efforts to estimate the effect distance of newly created habitats, VT found that piping plovers traveled great distances to forage along mud flats and habitats created by breaches and overwashes. These distances were determined by calculating the distance traveled from an active or inactive nest. Plovers have been recorded traveling up to 7.4 km when they have an active nest, and 33 km when they are not nesting. Individuals also moved long distances to forage at the overwashes, sand bars and mud flats whether they had an active nest or not. The ocean to bay overwashes often have exposed bayside foraging areas, especially the Pattersquash and Narrow Bay West overwashes, and the sand bar and mud flat at Cupsogue Beach County Park appear to be important to birds preparing to nest and preparing to migrate. Long distance movements by plovers with active nests may be due to birds not having prime access to bayside foraging searching for areas with greater prey abundances. In 2016, however, the distance moved by adults without direct bay access was not much different from that of the adults that did have bay access. The ability for adults with active nests in all habitat types, to travel great distances to access the habitat could be a reason that clutch masses did not differ in piping plovers that had direct access to bayside habitat when compared to those that did not have direct access. Fledglings also were found to fly long distances to Hurricane Sandy created habitats and the Cupsogue sandbar and mudflat, some of which are not protected during migration. A

portion of these movements could be due to prospecting for future nesting sites, adding support for more protection of important plover sites during migration (Davis et al. 2017).

Nests had a higher probability of hatching in 2016 than in the three prior years of the study, which could be related in part to predator densities. In 2015, Smith Point County Park had a high number of foxes, which preyed on some of the nests by climbing into the exclosures. Following these predation events, the exclosures were removed from all other nests at the county park. Once the exclosures were removed, the remaining nests were preyed on. After the 2015 piping plover breeding season and prior to the 2016 breeding season, a mange outbreak left Smith Point County Park and the Wilderness east of Old Inlet without foxes, potentially contributing to the greater nest success of 2016. Foxes were still present west of Old Inlet, where although nest success was high, it was not as high as Smith Point.

Chick survival on Fire Island appeared to be influenced both by the habitat available to the chicks, the predator occupancy of the island and human use of recreational areas. Daily chick survival was highest for chicks that had bayside and overwash habitat available to them. This could be due to the increased prey availability in these habitats, as broods that had access to the bay also had smaller home range size, and thus likely had to move less to forage. VT found a slight difference in near-fledgling mass when VT compared masses of 20-22 day old chicks between birds that had access to bayside foraging or not. While this difference was not statistically significant, two chicks from broods at Cupsogue West, which has some bay access, had masses about 10 g smaller than the mean. Cupsogue traditionally has a more human use than other areas, during the brood rearing period of the season (Monk et al. 2015, DeRose-Wilson et al. *in prep*). High human use could make foraging access challenging for chicks, and result in smaller weights. Additionally, Cupsogue does not have the same wide, low-energy mudflats that some of the overwashes have, so it may be a different type of bay access than for the majority of other fledglings. In 2016, the continued red fox predation pressure in Robert Moses State Park may have contributed to a lower fledge rate where productivity was 1.11 fledges/pair, whereas at Smith Point County Park productivity was 2.38 fledges/pair. There was a higher risk of predation at Robert Moses which may have caused the difference in fledges/pair between the two sites.

With the combined results from chick survival, adult movement, recruitment, immigration and prey availability, it is clear that the overwashes and other habitats created by Hurricane Sandy are important to piping plovers. This is supported by past studies of plovers, that have seen population increases following large habitat creating events, such as past storms in New York in the 1930s' (Wilcox 1959) and 1990s' (Cohen et al. 2009). Initial predator-prey observations on Fire Island suggest that piping plovers in some areas are more productive in years with lower fox densities, but that they are also impacted by their proximity to overwashes and bayside habitat (See Part III). The relationship between plovers and overwashes is likely related to the suppression of vegetation following the storm and the low-energy bayside foraging habitat created by ocean to bay overwash. While studies regarding the impact of habitats created by Hurricane Sandy, and predators on piping plovers are ongoing.

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PART III: RED FOX MOVEMENTS, HABITAT SELECTION, AND DEMOGRAPHY ON FIRE ISLAND, NEW YORK

INTRODUCTION

Many studies have shown that predation is a key determinant of piping plover reproductive output, and predator management often is used to improve piping plover breeding success. The red fox (*Vulpes vulpes*) is a key piping plover predator in a number of areas on the U.S. Atlantic Coast. On Long Island, Cohen et al. (2009), showed that plover reproductive output in West Hampton Dunes was improved when foxes and cats were removed. Their ongoing piping plover monitoring work at Robert Moses State Park, Fire Island National Seashore and Smith Point County Park on Long Island (see Part I of report) showed that foxes were common in all areas, and an important predator of piping plovers on Fire Island with impacts varying across years. Predator management is an important part of piping plover management along the entire U.S. coast, and management of red foxes at these sites on Long Island, whether through lethal removal of adults, destruction of active den sites, or simple nest exclosure, may be important for piping plover populations (USFWS 1996, 2014). Nevertheless, there still are many gaps in their knowledge of the foxes, fox responses to management, and the effects of foxes and fox management on piping plover habitat use and reproductive output.

As part of monitoring in connection with the Fire Island Inlet to Moriches Inlet, Fire Island Stabilization Project (FIMI), VT are collecting data needed to best design and implement predator monitoring and management activities, in particular for the red fox. Specifically, VT report here on the second year, of four planned field work years, to accomplish the following 6 objectives.

Objective 1: Quantify the abundance and occupancy of red foxes and relate changes in these parameters to changes in habitat and predator management activities. (Methods: Camera-trapping, den surveys, habitat assessment, collaboration with predator management partners)

Objective 2: Assess habitat use versus availability by red foxes and any variation in habitat selection related to changing habitat composition and predator management. (Methods: GPS collars, habitat assessment, collaborations with predator management partners)

Objective 3: Quantify home range size, long-range movements, and variation in movement ecology of red foxes and relate to changing habitat composition and predator management. (Methods: GPS collars, habitat assessment, collaboration with predator management partners)

Objective 4: Estimate red fox reproductive success and adult survival, and variation in these population parameters, related to habitat composition and predator management. (Methods: GPS collars, den surveys, habitat assessment, collaboration with predator management partners)

Objective 5: Quantify the interactions of red foxes with shorebird nests and chicks. (Methods: GPS collars, camera traps on shorebird nests, scat collection and diet analysis, collaboration with shorebird management partners)

Objective 6: Utilize information collected in objectives 1-5 to make recommendations on the utility of, and recommended methodologies for, management of red fox populations in the study area and in other coastal habitats.

VT report here on activities related to these objectives that have occurred from August 2015-December 2016.

METHODS

Study Site

VT focused red fox monitoring efforts from Fire Island Inlet to Moriches Inlet on Fire Island, within the administrative boundaries of the National Park Service, the County of Suffolk (Smith Point County Park), and the State of New York (Robert Moses State Park). When conducting red fox monitoring activities during the piping plover nesting and brood-rearing seasons, the red fox research team recorded all activities as they pertained to the sub-sites as described in the “Study Site” section of the introductory information to the overall report. In this section of the overall annual report, VT refer to management units: Robert Moses State Park, Fire Island National Seashore (east or west of Old Inlet), and Smith Point County Park. However, the red fox research efforts were conducted across the entirety of Fire Island as GPS-collared foxes used the entire area.

Sign, scat, and den surveys

Field Methods

VT used ArcMap 10.3 GIS software to create and overlay a grid onto each of the 3 management areas (Robert Moses State Park, Fire Island National Seashore, and Smith Point County Park), subdividing them into 300 m by 300 m cells, and identified the center point of each cell. VT used a 300 m grid cell size, as their work with red foxes at Assateague Island National Seashore (Gieder 2015) showed that foxes rarely moved between camera stations spaced 300 m from each other, except for occasional long distance movements (> 6km), for example to potentially occupy territory available after lethal control efforts. Thus, the goal was to focus survey efforts (for sign, scat, den, abundance, occupancy—see camera trapping design below) such that each potential core range of a fox was sampled with equal probability. Given that foxes rarely moved between camera stations separated by 300 m in the Gieder (2015) study, VT used a 300m spacing of all transects and cameras to approximate equal sampling across potential home ranges. GPS collaring data from foxes monitored in each of the 3 management areas (see GPS tracking results) suggests that this spacing is more than sufficient to cover all potential home ranges, as the smallest observed red fox home range in each area had a radius >300m; thus, there should be no gaps in potential detection based on the overlap of their grid size and the observed movements from Gieder (2015) and their own collars.

VT walked along 96 transects (24 in Robert Moses State Park, 40 in Fire Island National Seashore; and 32 in Smith Point County Park, Figure 30) from the ocean beach high tide line to the bayside high tide approximately once per month in May-July and October-December 2016; these are identical transects to those walked in 2015. The transects connected the center points across the island of the 300 m grid described above. Specifically, VT walked game trails, or in as close to a straight line as possible if no game trails present, between the grid cell center points from ocean beach to bayside as possible on each transect. All red fox scats

located on transects that were estimated to have been deposited within a month of discovery were collected, labeled by transect and GPS coordinates, and frozen for later genetic verification of source species and analysis of prey items (Table 29). All observed red foxes were recorded and GPS locations noted. All inactive and active red fox den sites were also recorded and GPS locations noted. Dens with fresh tracks leading in and out of entrance holes and/or foxes in close proximity were considered “active.”

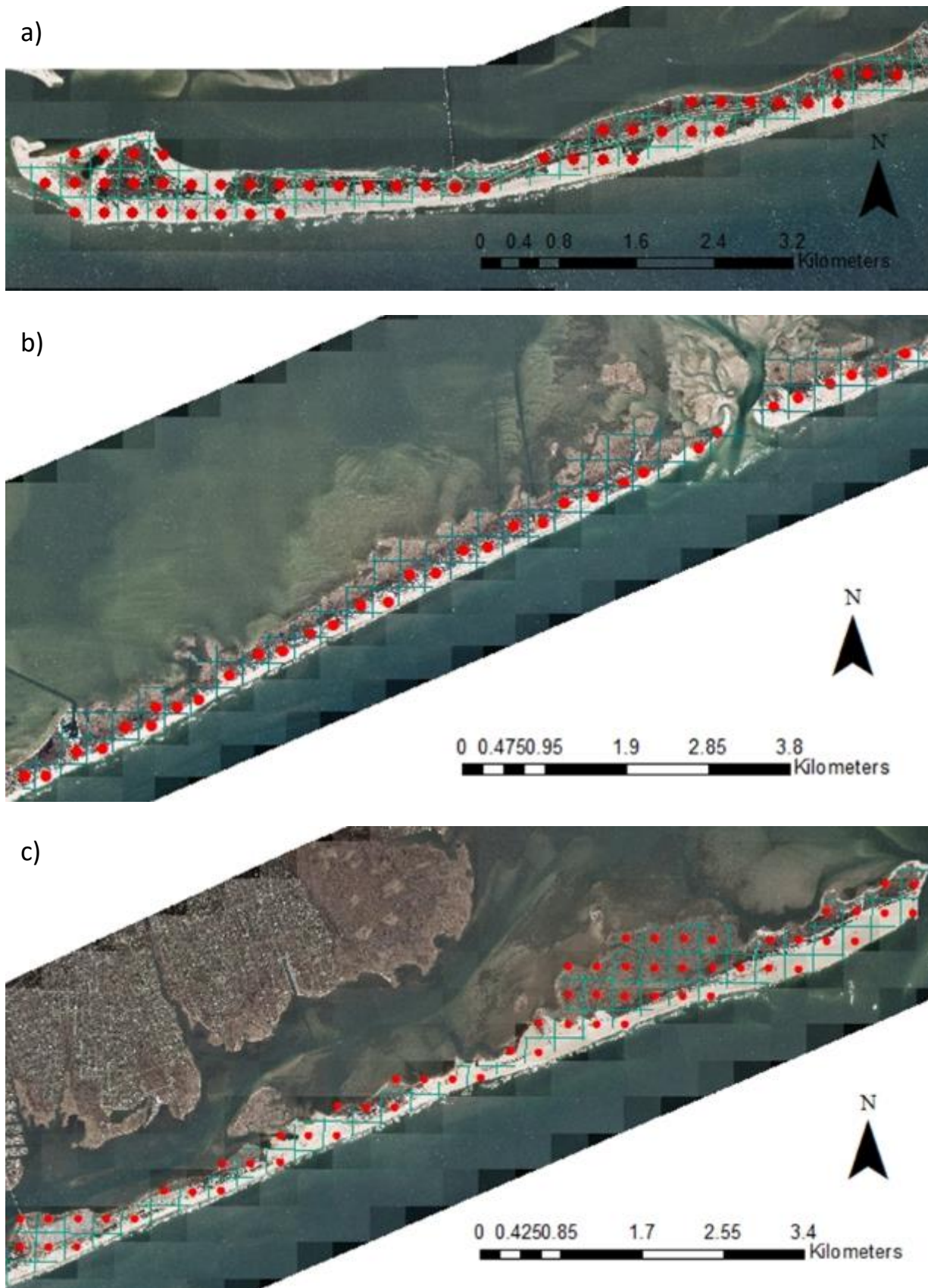


Figure 30. Transect locations in a) Robert Moses State Park and Fire Island National Seashore Lighthouse Tract, b) Fire Island National Seashore, and c) Smith Point County Park. Research technicians walked as close to straight-line transects as possible between grid cell center points, shown here as red dots, from ocean beach high tide line to bayside high tide line to identify fox sign, collect fox scat, and locate fox dens in May-July and October-December 2016.

Lab methods

All collected scat samples were stored in a freezer, then transported on ice back to Virginia Tech's campus and stored in a -20 C walk-in freezer until further laboratory analysis. For each sample, VT separated a small portion (approximately 2mL in volume) of fecal material from the outside edges and tapered ends, and submerged this portion in 95% ethanol for DNA preservation. VT will send these preserved subsamples to the Mammalian Ecology and Conservation Unit in the Veterinary Genetics Lab at UC Davis for mitochondrial DNA sequencing to verify the source species.

VT has begun diet analysis on the remaining portion of each scat sample. Following standard fecal dietary analysis protocols, VT dry the samples and separate out contents by hand (Figure 31), then identify contents to the lowest taxonomic level possible through comparison to reference materials and collections (Reynolds



and Aebischer 1991). VT will calculate percent occurrence and frequency of occurrence for each diet item or group, to assess reliance on different food sources, and compare these results among management areas and among samples collected during months when piping plovers are present vs. absent.

Figure 31. After drying, scat samples are dissected and contents sorted for identification to the lowest taxonomic level possible. Photo: Earle Berge.

Table 29. Scat collection criteria used during sign, scat and den surveys.

Age Category	Color	Moisture	Biodegradation	Notes	Collect?
Super fresh	Varied	Very moist, often steamy	None	Observed a fox depositing the sample	Yes
Fresh	Usually dark	Somewhat moist	None	Did not observe deposition	Yes
Mid	None or minimal, no sun bleaching	May be moist due to recent dew/humidity	None, fecal material intact		Yes
Old	May be sun bleached	Usually dry	Some, fecal material beginning to wear away but still present		Only if fecal material is mostly intact
Very Old	Sun bleached	Very dry	Significant, hardly any fecal material left		No

Den Monitoring

Field Methods

VT monitored all active dens located during den transects, through GPS tracking of breeding foxes, or from opportunistic locations from the time of discovery until at least 2 weeks after the last signs of active den use. All discovered dens were revisited within 1 week and re-assessed to determine the likelihood of current use based on tracks and signs; dens that still appeared active during this secondary assessment were added to their ongoing den monitoring rotation. VT visited active dens once every 2 weeks and collected scats, recorded and photographed prey remains in the immediate area, and recorded other signs of active use, including tracks, new prey remains since the last visit, and foxes observed in the area.

Where surrounding habitat provided sufficient cover and human use was low enough to minimize the likelihood of drawing undue attentions to dens, VT also set up 1 or more remote cameras aimed at the den entrance and/or small clearings directly outside of the den. VT changed memory cards and batteries and adjusted camera angling during den monitoring visits.

Analyses

VT used a combination of remote camera photos, direct observations, and GPS collaring data from breeding foxes to determine the number of adults and kits associated with each den, and when possible, to identify likely family groups and track den relocations during over time. For dens that had no collared adults attending, VT determined likely family groups and den relocations based on the proximity and dates of use of newly active dens relative to previously active dens.

Trapping, ear-tagging, and collaring

VT attempted to capture up to 6 foxes in each management unit to attach GPS collars (Telemetry Solutions, Quantum 4000E, Figure 32), and ear-tags from April-May 2016. In future years, VT will attempt to complete all captures will in February-March of the year so that all captures are completed before piping plovers begin to arrive on site. However, in 2016, the timing of arrival of funding delayed collaring until April in 2016.

VT used capture techniques as recommended by the Association of Fish and Wildlife Agencies Best Management Practices for Trapping Red Foxes in the United States (Updated 2014); specifically, VT used Victor 1 1/2 Soft Catch padded foothold traps (set to 2-lb pressure to avoid capture of lighter animals), Bridger #2 Offset coil spring traps (Figure 33). VT discontinued the use of Tomahawk 2-door fox-size box traps, because no foxes were successfully captured in these traps during last year's capture efforts and there was substantial bycatch of raccoons which were all released in good condition.

Upon capture, VT manually restrained foxes using a catch-pole and attached a muzzle, leg-ties and a blind-fold. No sedatives were used (Figure 34). VT attached the Quantum 4000E collar, the ear-tag in the right ear, and conducted morphometric measurements. VT used serially-numbered/lettered white ear-tags at Robert Moses State Park and small (Approx. size: 1/4" x 5/8") metal ear-tags at Fire Island National Seashore (Figure 35). These metal ear-tags are very inconspicuous, and not likely to be visible in their remote camera photos, but will assist in identifying any individuals recaptured in future years.



Figure 32. Red fox at Robert Moses State Park outfitted with a Quantum 4000E GPS collar and numeric ear-tag.



Figure 33. Setting a padded foothold trap. Photo: Matt Kynoch.



Figure 34. Captured fox being processed. VT manually restrained foxes, and took morphometric measurements before releasing them. Photo: Caitlin Kupferman.



Figure 35. Numeric ear-tags used to mark captured foxes at Robert Moses State Park and Smith Point County Park (left) and small metal ear-tags used to mark captured foxes at Fire Island National Seashore (right) Photos: Premier 1, National Band and Tag

GPS tracking

Field Methods

VT programmed the Quantum 4000E collars to record GPS locations once per hour, every day during the month of May, to allow us to determine which individuals were using areas in the immediate vicinity of piping plover nests, and then once every 2 hours, on every other day until the loss of the collar (originally programmed for the end of August).

Based on nesting information from piping plover field crews, VT determined which individual foxes were using each plover monitoring subsite. As soon as possible after the discovery and planned exclosure of piping plover nests in areas being used by foxes, VT remotely reprogrammed collars to temporarily increase the frequency of location recording, in order to collect fine scale data on fox spatial response to plover nesting activities.

Due to battery life limitations, VT could only sustain this high frequency scheduling for 8 days per collar. VT chose to focus these days around nest establishment, predator exclosure setup (where applicable) and pre-hatching pipping of eggs. Through close collaboration with piping plover field crews and park managers, VT identified expected exclosure setup dates and expected hatch dates, and reprogrammed collars to record locations every 15 minutes for 2 days before and after exclosure setup, and 2 days before and after pre-hatch pipping was estimated to occur. In situations where multiple nests were laid within a given fox's regular use area, VT based their programming on the dates corresponding to the first laid nest. Similarly, for nests laid in areas used by multiple foxes, VT paired nests with foxes based on the proximity of fox locations to nest locations.

VT used Collar SW v 2.09 software (Telemetry Solutions) to remotely download data from each collar every 10-14 days after deployment and to reprogram collars as needed. In order to download the data and reprogram collars remotely, VT relocated the collared fox using the VHF signal on the collar, approached to between 10-50m, connected wirelessly to the collar using the Quantum Base Station, and downloaded the data.

Analyses

VT mapped GPS locations for each individual collared red fox in ArcMap for exploratory analyses, including the determination of fox proximity to nesting areas. VT overlaid these points onto 6- inch resolution orthophotograph imagery taken in April 2016. VT used the "Minimum Bounding Geometry (MBG)" tool in ArcMap to create minimum convex polygons (MCP) using each individual's locations, for a very basic estimate of home range and area used, then used the "Calculate Geometry" tool in ArcMap to estimate polygon area in hectares. These polygons include the minimum area encompassing all locations recorded for each fox that can be contained in a single convex polygon. Due to the nature of this polygon estimation, MCPs can include large areas that may not have actually been used by foxes, but are between two or more locations that were used. VT caution against interpreting these polygons as regularly used home ranges; instead, VT suggest that they be considered as a metric of how far an individual fox might range over the course of the tracking period.

To obtain more refined home range estimates, VT used R package "adehabitatHR" to calculate 50% and 95% kernel density home ranges for each individual, then imported these contours into ArcMap to overlay them on orthophotograph imagery for comparison to recorded locations. VT then used the "Calculate Geometry" tool in ArcMap to estimate the area of each contour in hectares; 50% kernel densities are commonly interpreted as an animal's "core area," or an area of intense use, and 95% kernel densities are commonly interpreted as an individual's larger "home range", which encompasses this core area but is not used as intensively (Laver and Kelly 2008).

Due to the underlying mathematics used to calculate MCPs and kernel densities, both of these descriptors of red fox space use can incorporate areas that are most likely not used, such as deep water, into a polygon or home range contour, if these areas are directly adjacent to areas of intense use. In order to avoid including large amounts of open ocean or bay in their maps and area estimates, VT clipped all polygons and contours to the extent of the island using the "Clip" tool in ArcMap. Similarly, VT clipped the kernel density contours of animals on either side of Old Inlet to the extent of the portion of the island that they were located on as VT did not observe any fox movement across Old Inlet.

As the project progresses, VT will explore a variety of home range estimation techniques, including Brownian bridge estimation (Horne et al. 2007) and biased random bridge estimation (Benhamou 2011) as VT think these additional analyses will allow us to best quantify how red fox movements relate to piping plover nests and brood movements.

VT present results and analyses from GPS collaring data collection that was ongoing at the time of last year's annual report submission. This information was collected on 11 individuals between August 2015 and April 2016 (referred to as Fall/Winter 2015 in this report). VT followed the same protocols described above when capturing capture, ear-tagging, and collaring these foxes in July-November 2015. These captures, GPS data collection schedules, and preliminary findings are described in Part II of the 2015 annual report. Here, VT present the same home range analyses described above based on the final GPS data set collected from individuals tracked during the Fall/Winter 2015 period. This time period includes red fox dispersal season (October-February) and breeding season (January-February) when juveniles and adults will frequently travel long distances in search of vacant territories and/or mates (Ables 1983, Henry 1986). As such, these results are not completely comparable to results from April-August 2016 (referred to as the Spring/Summer 2016 monitoring period in the rest of this report), when red foxes are denning and raising kits, and therefore much more concentrated in their space use.

Remote camera surveys

Field methods

VT used the same 300 m grid cells and center points created in ArcMap to guide camera placement in each of the 3 management areas, as described above for the transect surveys for sign, scat, and dens. Within 50 m of the center point of each grid cell containing suitable sites (i.e., VT excluded hard surface developed areas and inundated marsh from survey grids), VT established an un-baited camera station. Each station consisted of 2 different models of Moultrie game cameras (Pradco Incorporated, Moultrie M880c and M880 Gen2 cameras), each mounted on a plastic t-post and facing towards a game trail, clearing, or other potential wildlife trail (Figure 36). VT set each camera on opposite sides of the game trail, in order to photograph both sides of passing animals (Figure 37), and angled them to be offset from each other.

VT programmed the cameras to take 3 pictures per trigger, with 5 seconds delay after each trigger. VT returned every 10-14 days to switch memory cards, replace batteries as needed, and check each station. VT established 34 stations at Smith Point County Park, and 35 stations at Fire Island National Seashore starting in October 2015 and 2016, and 32 stations at Robert Moses State Park in December 2015 and 2016 (Figure 38). Each grid was or will be operational for a minimum of 1200 trap nights, defined as the number of camera stations * number of nights the cameras are in operation.



Figure 36. Cameras were mounted on plastic t-posts along game trails and wildlife travelways.



Figure 37. VT set one camera on each side of game trails and wildlife travelways in order to photograph both sides of passing animals.



Figure 38. Camera station locations at Robert Moses State Park (top), Fire Island National Seashore between Watch Hill and Old Inlet (middle), and Fire Island National Seashore east of Old Inlet and Smith Point County Park (bottom).

Analyses

In this report, VT presents results and analyses from remote camera data collection that was ongoing at the time of last year's annual report submission. This information was collected in October 2015-January 2016 (referred to as Fall-Winter 2015 in the rest of this report). VT followed the same protocols described above for these camera surveys, which are described in Part II of the 2015 annual report. Data collection is ongoing for their second season. VT have completed entering all 2015 photo data, and completed preliminary occupancy analyses for each management area. VT are in the process of further examining photos in order to determine whether individual red foxes can be identified in photos using ear-tags, GPS collars, and variation in pelage in order to estimate abundance and density in each management area. As this research continues, VT also plan to explore the use of abundance modeling approaches for animals that cannot be individually identified, such as mark-resight modeling. Based on their observed GPS collaring data and camera spacing, VT likely had multiple camera stations within each potential home range, which will greatly assist in their efforts to model abundance and density. Because GPS collared foxes at Fire Island National Seashore west of Old Inlet were geographically isolated from the rest of the national park area but regularly used Smith Point County Park, VT combined detection data from the Old Inlet East portion of Fire Island National Seashore with data from Smith Point County Park in their analyses.

VT used a single species, single season framework in Program PRESENCE to estimate occupancy ψ (i.e., the probability that a site is occupied by red fox) and detection probability p (i.e., the probability of detecting a red fox during a given survey, provided it is present). Occupancy is an index of relative abundance that accounts for detection probability. It does not translate directly to abundance, as it does not yield an estimate of individuals detected, just the probability of presence.

VT used the null model, where no covariates affected occupancy (ψ) or detection (p), and the survey-specific detection model, where no covariates affected occupancy (ψ) but detection (p) varied by day, and used Akaike's Information Criterion to select the model that best fit the observed data. VT did not collapse data, but rather each day was counted as a survey period, thus their estimated occupancy relates to the whole survey period, while detection rates are interpreted as detection by day. VT will model habitat covariates in future analyses and annual reports.

RESULTS AND DISCUSSION

VT results and discussion are organized by objective to better reflect progress towards completion. The relationship between shared methods and objectives are noted in the introduction.

Objective 1 and 2: Quantify the abundance and occupancy of red foxes, and habitat use vs. availability, and relate changes in these parameters to changes in habitat and predator management activities

VT assessed abundance and occupancy of foxes using remote camera surveys, walking transects, and den cameras. In the next phase of the project, and in the next annual report, VT will begin to extrapolate home range size and distribution quantified from GPS collars (see next objective) to get at an additional metric of abundance. VT has not yet begun to relate these metrics to habitat use, but VT will be using the habitat classification maps described in Part I to do so as VT moves forward.

Abundance estimates from den surveys and transect monitoring

VT combined the remote camera data gathered from each den, with GPS collar data of known individuals, to estimate abundance at each management area (Robert Moses State Park, Fire Island National Seashore from Watch Hill to Old Inlet, Fire Island National Seashore east of Old Inlet + Smith Point County Park). VT assumed that each den had 2 adults associated with it, VT suspect that this assumption leads to a conservative estimate of population size as their observations suggest that there may be helper, non-breeding foxes in the population. For example, during their den monitoring, VT observed 3 adult foxes attending the same den, via remote camera photos. In another case, VT observed an adult female fox attending the den of a breeding pair, via direct observation during a monitoring visit to the den. Both breeding adult foxes at this den were GPS collared and ear-tagged this year, while the other attending female was collared and ear-tagged last year, and thus identifiable as a second adult female.

VT monitored 10 breeding dens at Robert Moses State Park during April-September 2016 and estimate that there were at least 12 adults and 16 kits inhabiting Robert Moses State Park during the monitoring period. VT monitored 7 breeding dens at Fire Island National Seashore between Watch Hill and Old Inlet and estimate that there were at least 8 adults and 14 kits inhabiting this area between Watch Hill and Old Inlet during the monitoring period.

The sarcoptic mange outbreak that VT observed beginning in summer-fall 2015 appears to have spread throughout the Old Inlet East area of Fire Island National Seashore and Smith Point County Park, leading to a large-scale die-off. Their observations of foxes during field activities decreased substantially in September-October 2015, and many of the foxes that VT did observe showed the hair loss and skin problems often associated with the *Sarcoptes scabiei* mite infestation that causes sarcoptic mange. The only signs of foxes anywhere east of the inlet during any of their surveys, or at any other time that VT were in these areas after April 2016, were 2 very old red fox den holes observed during their transects at Smith Point County Park. Both dens had partially caved in, and showed no signs of recent use. Thus, VT estimate no red fox were present in Smith Point County Park or the Old Inlet East area of Fire Island National Seashore between April – September 2016.

VT estimates a minimum red fox density of 3.05 adults/km² and 4.07 kits/km² at Robert Moses State Park and of 1.69 adult/km² and 2.95 kits/km² between Watch Hill and Old Inlet at Fire Island National Seashore. VT found no red foxes at Smith Point County Park or Old Inlet East in Fire Island National Seashore during this reporting period. Averaging these densities, and extrapolating to the available area between Fire Island Inlet and Old Inlet, VT estimates a red fox population density of 2.37 adults/km² and 3.51 kits/km², a total available area of 16.18 km² and a total red fox population size of 39 adults and 57 kits between April – September 2016.



Figure 39. Two kits at the entrance of one of the dens that VT monitored at Fire Island National Seashore. Photo: Matt Kynoch.

Occupancy estimates from remote camera monitoring

VT reports here their remote camera survey findings from Fall-Winter 2015; their 2016 camera surveys are ongoing and will be reported in the next annual report.

In each of their management areas, VT found that red fox occupancy was best modeled as constant whereas red fox detection varied by day of the survey period (Table 30).

Red foxes were photographed at least once at every camera station in Robert Moses State Park and Fire Island National Seashore west of Old Inlet in Fall-Winter 2015, resulting in an occupancy of 1; detection varied by day between 0.03-0.72 at Robert Moses State Park and 0.11-0.61 at Fire Island National Seashore. At Smith Point County Park and the Old Inlet East portion of Fire Island National Seashore, VT found red fox occupancy was 0.86 ± 0.06 (SE) and detection varied from 0.03-0.25 by day (Table 31). Given that their remote camera surveys were operating during the end of the mange outbreak at Smith Point County Park, mortalities were occurring during the survey period which violates the assumption of a closed population. Thus, these results should be interpreted and compared to other sites with caution.

In summary, VT found red foxes were present at a majority of camera sites at Smith Point County Park and Old Inlet East, and were present at every camera station at Robert Moses State Park and Fire Island National Seashore west of Old Inlet during the Fall-Winter 2015-2016 survey. These findings are in agreement with their abundance estimates (above) and home range analyses (see below, Objective 3).

Table 30. Model selection table from PRESENCE output for occupancy modeling using Fall-Winter 2015 remote camera detection data. In each area, the model that allowed detection probability to vary by day had the lowest AIC value, signifying a better fit between the model and the observed data.

Management area	Model ^a	AIC	ΔAIC	AIC weight	Model Likelihood	# of Parameters
Robert Moses State Park	$\psi(.)$ p(day)	1953.57	0	1	1	53
	$\psi(.)$ p(.)	2021.14	67.57	0	0	2
Fire Island National Seashore (w of inlet)	$\psi(.)$ p(day)	1985.15	0	1	1	62
	$\psi(.)$ p(.)	2000.6	15.45	0	0	2
Smith Point County Park+OIE	$\psi(.)$ p(day)	1098.5	0	1	1	47
	$\psi(.)$ p(.)	1124.24	25.74	0	0	2

^a ψ =Occupancy, p= detection probability, (.)= constant/no covariates

Table 31. Occupancy (ψ) and detection probability (p) and estimates from the top model for each study area.

Management area	Top Model	ψ (SE)	p ^a
Robert Moses State Park	$\psi(.)$ p(day)	1 (0)	0.03-0.72
Fire Island National Seashore (w of inlet)	$\psi(.)$ p(day)	1 (0)	0.11-0.61
Smith Point County Park+OIE	$\psi(.)$ p(day)	0.86 (0.06)	0.03-0.25

^a Estimated detection probability (p) varies by day; the range of values is reported here.

Objective 3: Quantify home range size, long-range movements, and variation in movement ecology of red foxes and relate to changing habitat composition and predator management.

VT are using GPS-collared foxes to quantify home range size and long-range movements; VT will relate to habitat composition and predator management in future reporting periods.

VT trapped 21 foxes from July- November 2015 over 15 trap nights at Robert Moses State Park, 14 trap nights in Fire Island National Seashore, and 14 nights in Smith Point County Park (Table 32). VT trapped 12 foxes from April through May 2016 over 6 nights at Robert Moses State Park and 7 nights at Fire Island National Seashore (Table 33). VT did not attempt to trap any foxes at Smith Point County Park and Old Inlet East in 2016, due to the lack of fox sign east of the inlet.

In Fall-Winter 2015, VT successfully collected data on 2 males and 3 females at Robert Moses State Park, 2 males and no females at Fire Island National Seashore (1 male was captured east of Old Inlet, the other was west of Old Inlet), and 1 male and 1 female at Smith Point County Park. The download mechanism failed on two collars on male red foxes at Fire Island National Seashore. VT later recovered data from one of these collars after the fox died and VT retrieved the carcass and collar (east of the inlet, due to complications of mange). The download mechanism on another collar on a female red fox at Robert Moses State Park stopped working partway through the tracking period, cutting their data collection short. In Spring-Summer 2016, VT successfully collected on 4 males and 2 females at Robert Moses State Park, and 2 males and 3 females at Fire Island National Seashore (all west of Old Inlet). The download mechanism failed on one collar at Robert Moses State Park on a male red fox 9 days after collaring; VT were able to maintain VHF contact on this fox to track den associations only. A second collar on a red fox male failed and dropped off at Fire Island National Seashore, near Watch Hill, within hours of deployment, resulting in no usable location data for this fox.

Home range estimates: MCPs, 50% and 95% kernel density contours

In this section of the report, VT show home range maps for one male and one female fox from each tracking period. Home range maps from all foxes are shown in Appendix C: Fox Home Range Maps.

Fall-Winter 2015

VT found that fall-winter home range estimates, whether MCP, 50% and 95% kernel density areas, varied widely among individual foxes (Table 34), with an average of 945.9ha for males and 200.7ha for females using MCPs, 223.3ha for males and 80.8ha for females using 50% kernel density estimation, and 796.3ha for males and 142.1ha for females using 95% kernel density estimation, across all management areas (Table 35). Across all three home range estimators, average home range and core areas of males were much larger than those of females, likely due to long distance movements among 3 collared males (see Figure 40 for an example comparison, and “Long distance movements” below).

Average home range sizes varied among management areas, with the largest average male home range observed at Robert Moses State Park and the largest average female home range observed at Smith Point County Park. VT suspects that the mange outbreak and subsequent die-off at Smith Point County Park and Old Inlet East may have allowed foxes there to take over recently vacated home ranges, leading to larger areas for each fox east of the inlet compared to those west of the inlet (excluding the 3 long-distance traveling males).

Despite the relatively large home ranges of some individuals relative to others, the average home range sizes in each management unit are small compared to the results of studies of red fox spatial ecology conducted in other geographic and ecosystem settings, suggesting that red foxes on the island are persisting at relatively high population densities given sufficient resources. For example, different reviews of red fox home range studies report home ranges from a few dozen hectares up to 2000-3000 ha (Goszczyński 2002). Previous studies in coastal habitats also report varying home range sizes, but within a narrower and overall lower range. For example, Dekker et al. (2001) observed home ranges between <50 and 650ha in Dutch coastal dune habitat, with roughly half of the observed home ranges falling under 100ha.

When the 50% and 95% kernel density areas of all GPS-collared foxes are overlaid, the resulting contours encompass the entire area of the island that is dry land, suggesting that red foxes were ubiquitous throughout all management areas during the Fall-Winter 2015 tracking period (Figure 41).

Spring-Summer 2016

VT found that spring-summer home range estimates, whether MCP, 50% and 95% kernel density areas, varied widely among individual foxes (Table 34), with an average of 607.6ha for males and 105.7ha for females using MCPs, 166.7ha for males and 17.7ha for females using 50% kernel density estimation, and 510.1ha for males and 71.1ha for females using 95% kernel density estimation, across all management areas (Table 35).

Similar to the observations during the Fall-Winter season, VT found that females had smaller home range estimates, using all three estimators, than males (Figure 42), due to the long distance movements of 2 males during the tracking period (See “Long distance movements” below). VT hypothesizes that the 2 males that exhibited these inlet-to-inlet movements did not breed this year, as VT never tracked them to a den, but likely were transient individuals with no defined territory (Dekker et al. 2001).

Average home range sizes varied among management areas, with the largest average male home range observed at Robert Moses State Park and the largest average female home range observed at Fire Island National Seashore.

Four sets of 2 collared red foxes (2 sets at Robert Moses State Park and 2 at Fire Island National Seashore) exhibited a high degree of overlap in home range. Two of these sets were known to be breeding pairs, based on their den monitoring observations, while the other 2 were not believed to be breeding pairs. These non-breeding pair sets of foxes could be part of the same family group, sharing one group territory among several individuals. If this is the case, it would suggest that a given area on the island may be regularly and intensively used by multiple foxes, contrary to the common misconception that foxes are solitary animals. Similar red fox social dynamics have been observed previously in urban fox studies (Soulsbury et al. 2010), and are thought to contribute to very high population densities within those study areas. Aside from these overlapping home ranges, resident individuals appeared to use distinct sections of the island spanning from the bay to ocean as their home ranges, as opposed to using long sections spanning only a narrow portion of the bay or ocean sides of the island.

Breeding individuals, particularly females, used very small areas during the beginning of the Spring-Summer 2016 monitoring period, when their locations were mostly near dens. They expanded their use areas throughout the spring and summer, becoming less restricted to den areas as time progressed.

When the 50% and 95% kernel density areas of all GPS-collared foxes are overlaid, the resulting contours encompass the entire area of the island west of Old Inlet that is dry land, suggesting that red foxes were ubiquitous throughout all management areas west of the inlet during the Spring-Summer 2016 tracking period (Figure 43).

Long distance movements

All 3 GPS-collared male foxes that made long distance movements between Fire Island Inlet and Old Inlet during the Fall-Winter 2015 tracking period continued to do so until their collars dropped off in the late winter (See Figure 44 for an example home range map from one of these foxes). Similarly, VT observed 1 GPS-collared male fox making long distance, inlet-to inlet movements throughout the Spring-Summer 2016 tracking period and another GPS-collared male fox making long distance movements between the westernmost end of Fire Island and the villages (See Figure 45 for an example home range map from one of these foxes). Both were initially captured at Robert Moses State Park, and moved regularly between the park, the villages, and (1 fox only) Old Inlet until the end of the tracking period.

Table 32. Foxes ear-tagged and GPS collared in August-November 2015. Dashes indicate areas where foxes were not ear-tagged, in accordance with permits.

Management area	Foxes ear-tagged		Foxes collared	
	Females	Males	Females	Males
Smith Point County Park	2	1	1	1
Fire Island National Seashore – east of breach	-	-	0	1
Fire Island National Seashore – west of breach	-	-	0	3
Robert Moses State Park	5	4	3	2
Total	7	5	4	7

Table 33 Foxes ear-tagged and GPS collared in April-May 2016

Management area	2016	2016
	Males	Females
Smith Point County Park	0	0
Fire Island National Seashore- east of inlet	0	0
Fire Island National Seashore – west of inlet	3	3
Robert Moses State Park	4	2
Total	7	5

Table 34. Home range area estimates (ha) using three methods of analysis (50% and 95% kernel density areas, and MCP) for individual red foxes tracked in Fall 2015-Winter 2016 and Spring-Summer 2016.

Management area	ID	50% kernel area	95% kernel area	MCP area
Fall 2015-Winter 2016				
RMSP	F-01	8.9	39.3	72.7
RMSP	M-01	383.0	1397.0	1440.2
RMSP	F-02	25.1	72.6	122.3
RMSP	M-02	231.2	833.8	1406.8
RMSP	F-03	18.8	80.0	170.8
FINS	M-03	210.4	1202.5	1405.1
FINS	M-05	48.9	155.9	425.2
FINS	M-06	269.8	594.3	469.0
SPCP	M-07	196.2	594.3	528.9
SPCP	F-04	270.5	376.5	437.0
Spring-Summer 2016				
RMSP	M-08	11.8	53.5	84.6
RMSP	F-05	16.0	53.5	158.8
RMSP	M-09	n/a	n/a	n/a
RMSP	M-10	108.7	698.8	976.3
RMSP	F-06	15.5	56.8	74.2
RMSP	M-11	664.2	1617.9	1586.0
FINS	M-13	11.6	39.3	42.0
FINS	M-14	37.4	140.9	348.8
FINS	F-07	13.1	57.0	65.3
FINS	F-08	17.5	91.0	112.8
FINS	F-09	26.4	97.2	117.5

Table 35. Average home range estimates (ha) by method, tracking period, management area, and sex.

Management area	Sex	50% kernel area	95% kernel area	MCP area
Fall 2015-Winter 2016				
RMSP	M	307.1	1115.4	1423.5
	F	17.6	64.0	121.9
FINS (w of inlet)	M	129.6	679.2	915.1
	F	n/a	n/a	n/a
SPCP+FINS (e of inlet)	M	233.0	594.3	499.0
	F	270.5	376.5	437.0
All areas	M	223.3	796.3	945.9
	F	80.8	142.1	200.7
Spring-Summer 2016				
RMSP	M	261.6	790.1	882.3
	F	15.7	55.1	116.5
FINS (w of inlet)	M	24.5	90.1	195.4
	F	19.0	81.7	98.5
All areas	M	166.7	510.1	607.6
	F	17.7	71.1	105.7

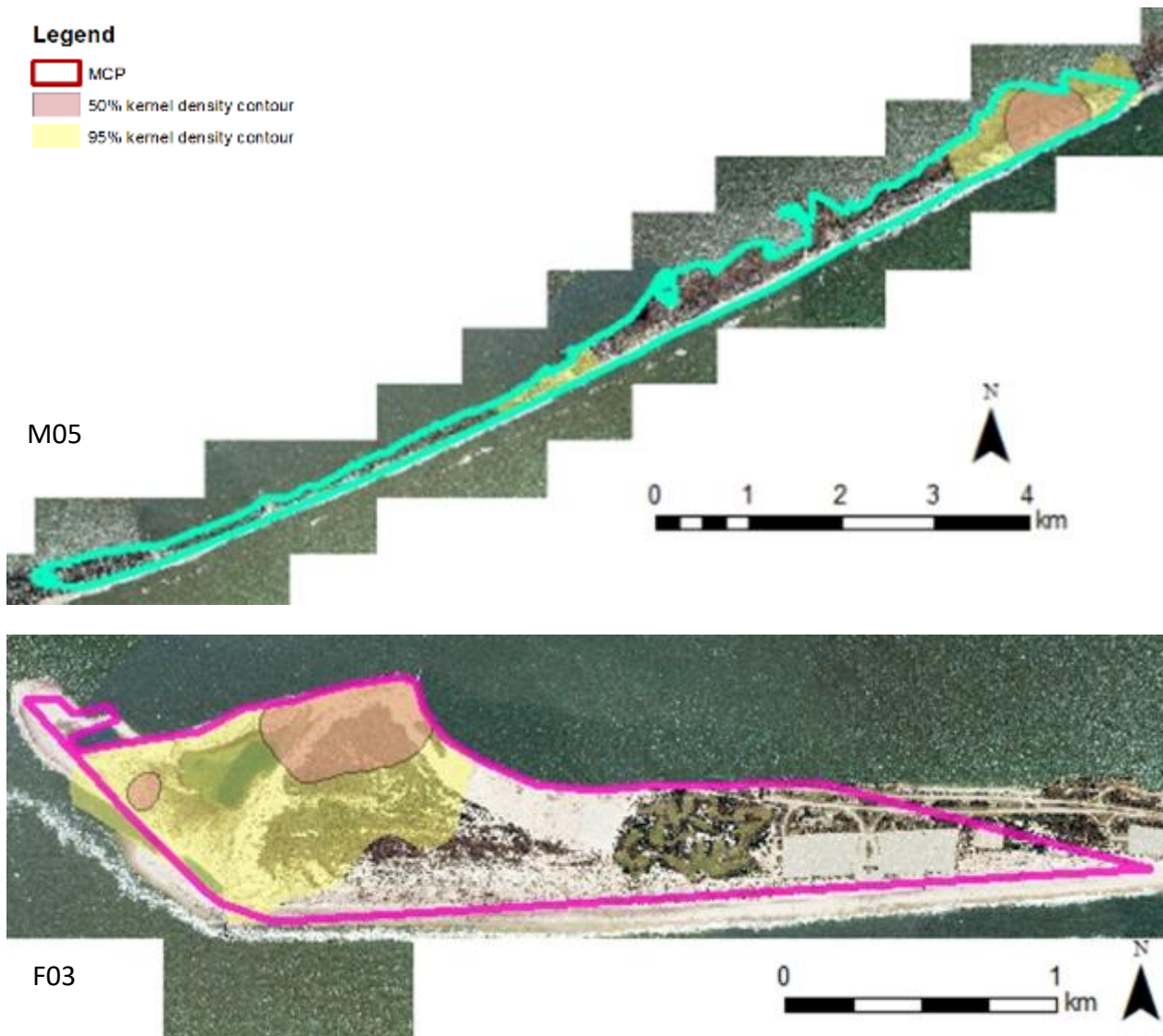


Figure 40. MCPs (outlined in different colors for different foxes), 50%, and 95% kernel density contours for a male red fox at Fire Island National Seashore (top) and a female red fox at Robert Moses State Park (bottom), Fall-Winter 2015.

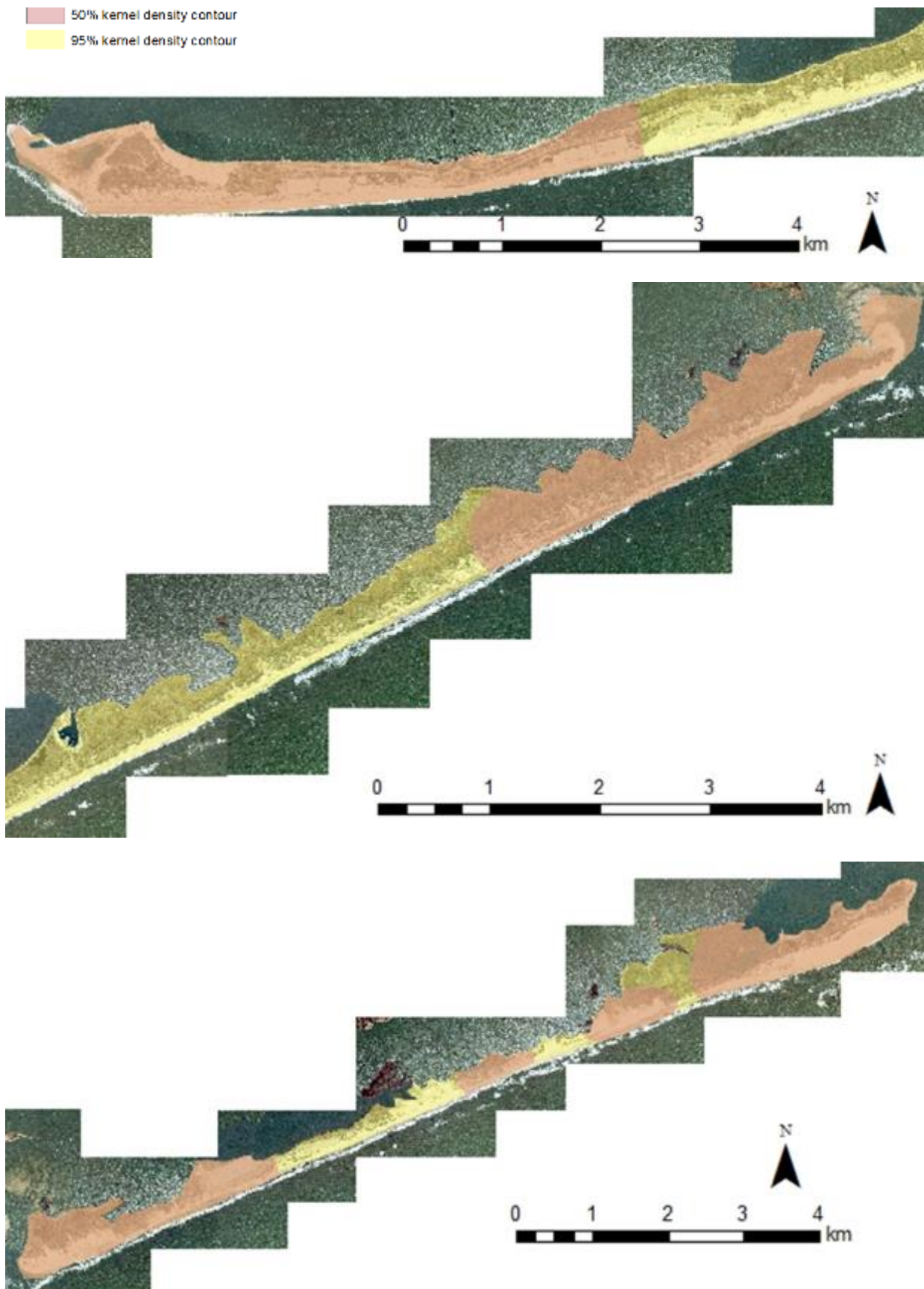


Figure 41. 50% and 95% kernel density contours for all GPS-collared red foxes in Fall-Winter 2015 at Robert Moses State Park (top), Fire Island National Seashore (west of Old Inlet, middle), and Fire Island National Seashore (east of Old Inlet) and Smith Point County Park (bottom) overlaid on top of each other.



Figure 42. MCPs (outlined in different colors for different foxes), 50% and 95% kernel density contours for 1 male red fox (top) and 1 female red fox (bottom) at Fire Island National Seashore, Spring-Summer 2016.

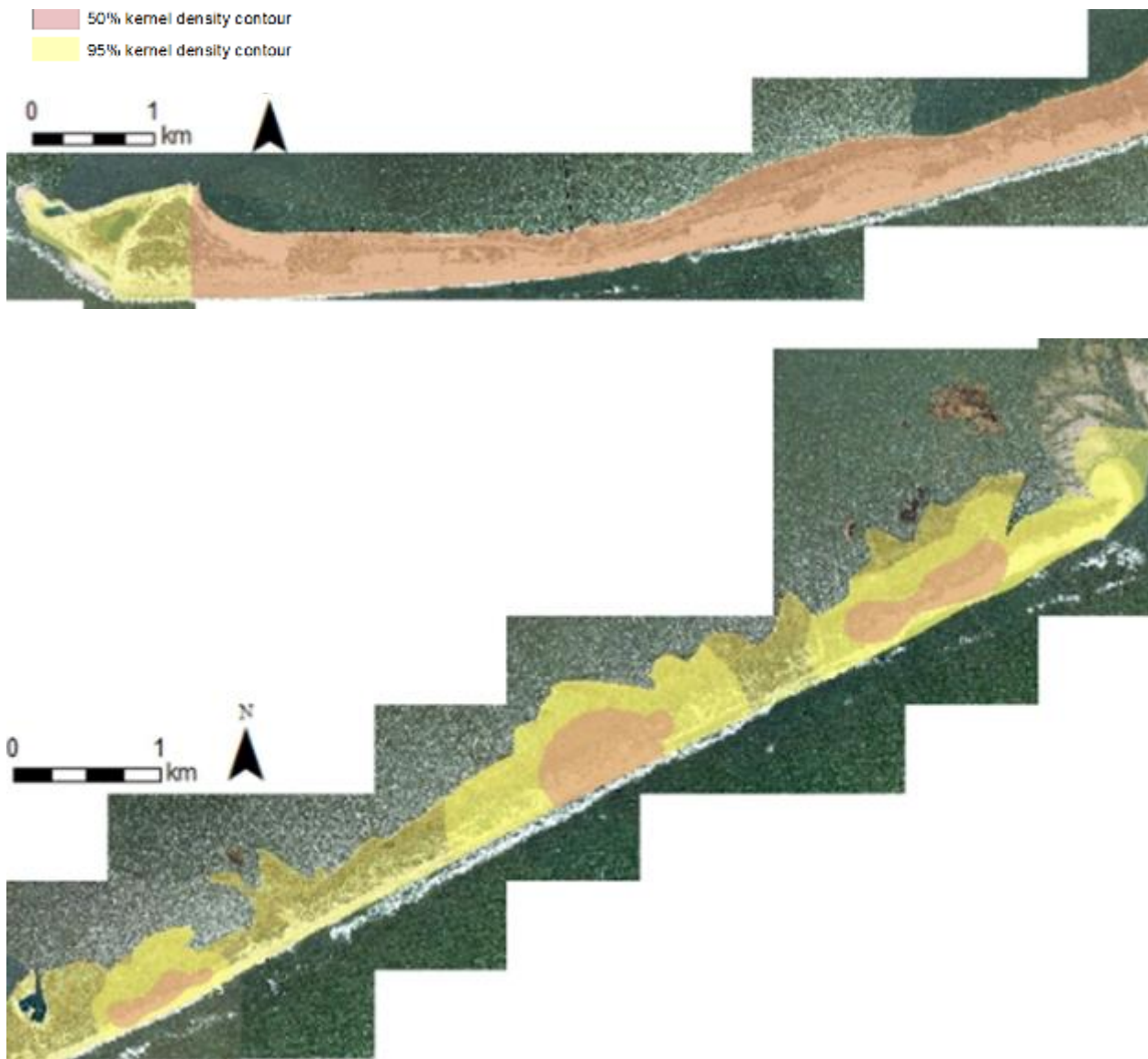


Figure 43. 50% and 95% kernel density contours for all GPS-collared red foxes in Spring-Summer 2016 at Robert Moses State Park (top) and Fire Island National Seashore (west of Old Inlet, bottom) overlaid on top of each other.

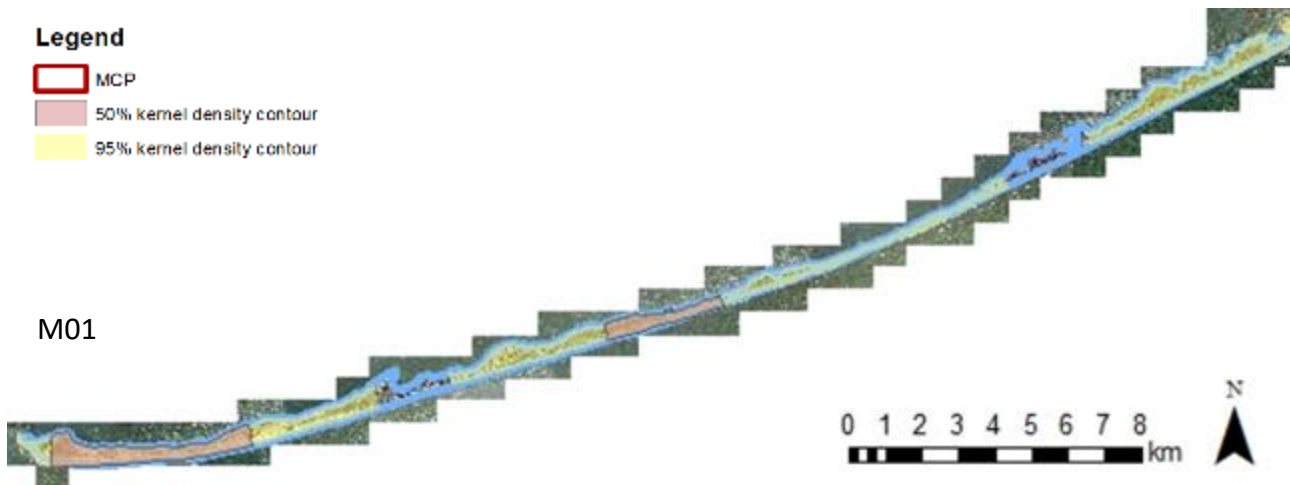


Figure 44. MCP (outlined in different colors for different foxes), 50% and 95% kernel density contours for 1 male red fox originally captured at Robert Moses State Park, who regularly traveled from inlet to inlet during Fall-Winter 2015.

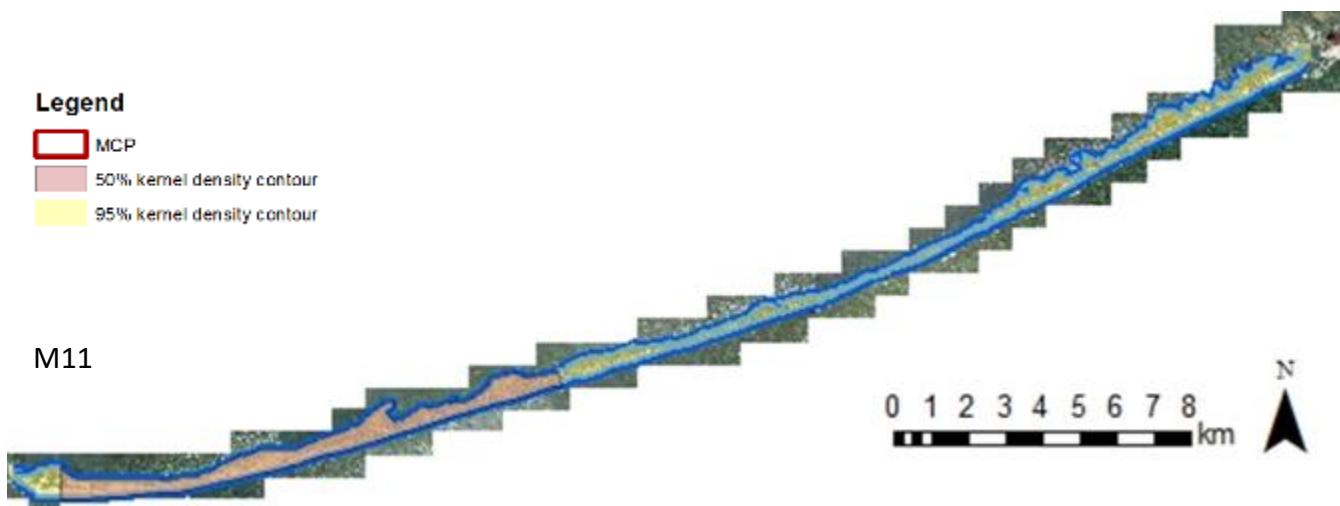


Figure 45. MCP (outlined in different colors for different foxes), 50% and 95% kernel density contours for 1 male red fox originally captured at Robert Moses State Park, who regularly traveled inlet to inlet during Spring-Summer 2016.

Objective 4: Estimate red fox reproductive success and adult survival, and variation in these population parameters, related to habitat composition and predator management.

VT is quantifying reproductive success and adult survival through the use of their den monitoring and GPS collar protocols. Here VT reports their initial findings of reproductive success and survival of collared adults. VT will relate these findings to habitat and predator management activities as the project continues.

Reproductive success

For all foxes captured for GPS collaring (see Objective 3 and Table 33), VT recorded physical and morphological data, and noted its overall physical condition. Two of the female foxes captured at Robert Moses State Park were visibly lactating; VT later used GPS tracking data from these females to locate active dens. Coincidentally, the males associated with these dens were also collared, which assisted in monitoring den relocations through the summer. None of the collared individuals at Fire Island National Seashore were visibly lactating, or appeared to be associated with breeding dens, although VT located one active breeding den during trapping activities there. VT avoided setting any traps within 400m of the den to minimize the risk of catching fox kits, which had already emerged from the den based on tracks in the area. In the future, VT aims to have

completed all trapping activities no later than the end of March in 2017, to avoid unnecessary risks associated with keeping lactating females away from their dens for extended time periods, and to minimize the possibility of capturing and potentially injuring newly emerged kits.

VT monitored 10 breeding dens at Robert Moses State Park and 7 breeding dens at Fire Island National Seashore (between Watch Hill and Old Inlet) during April-September 2016 (Table 36). No fox activity, nor active dens, were detected at Smith Point County Park during this time period.

Red foxes at all management areas used multiple den sites within a breeding season, and moved between dens as the season progressed. At Robert Moses State Park, 4 of the 10 breeding dens were active in April 2016, and had high amounts of activity recorded by remote cameras and via observations of signs and scat. In mid-June, activity began to taper off at these 4 dens, and new dens were discovered in nearby locations (e.g., within 800 meters) that had previously shown no signs of denning activity. Given that VT had some breeding foxes GPS collared (see Objective 3: Quantify home range size, long-range movements, and variation in movement ecology of red foxes and relate to changing habitat composition and predator management.), VT were able to track 2 of these 4 family groups to new active dens within the breeding pair's home range using GPS location data, and determined that the other 2 family groups (without any collared adults) had also relocated to other newly active sites. Based on remote camera photos, timing of use, and amounts of activity observed, 4 of the 10 breeding dens at Robert Moses State Park appeared to be natal dens, and the remaining 6 appeared to be relocations later in the season. It is unclear what drove the family groups to shift their activities from the natal dens to these new locations, but VT observed similar patterns across the island, suggesting that this may be a regular part of red fox denning ecology across all management areas. VT observed similar behavior at Fire Island National Seashore, where 4 of the breeding dens appeared to be natal dens, and the remaining 3 appeared to be relocations later in the season. VT is in the process of fully reviewing the literature, but their findings so far suggest that these mid-season sequential relocations may be a novel finding compared to other studies of red fox denning and breeding ecology.

VT located additional dens during their transect surveys in Robert Moses State Park and Fire Island National Seashore between Watch Hill and Old Inlet. These dens did not appear to be breeding dens, and likely served as thermal refugia from the summertime heat and/or daytime underground resting sites used by adults. VT did not find any signs of kits at these dens, and most were only temporarily active, and were not monitored beyond 2 weeks past the last signs of activity.

At Robert Moses State Park, 16 kits were observed at breeding dens among 4 likely family groups, for an average of 4 kits per pair. At Fire Island National Seashore, between Watch Hill and Old Inlet, 14 kits were monitored among 4 likely family groups, for an average of 3.5 kits per pair, although 7 of these kits were observed at a single den. These numbers are similar to average litter sizes reported in other fox studies (Soulsbury et al. 2010). No active dens were detected in Old Inlet East of FINS or Smith Point County Park.

Adult Survival

All 11 foxes that were GPS collared at Robert Moses State Park and all 9 foxes at Fire Island National Seashore (between Watch Hill and Old Inlet), in 2015 and 2016 were alive at the time their collars dropped off or failed. VT ear-tagged and collared 2 foxes and ear-tagged but did not collar 1 fox at Smith Point County Park, and collared 1 fox at Old Inlet East in the Seashore in 2015; all of these foxes were found dead between December

7th and April 11th, 2016. Of these foxes, 3 appeared to have died from complications of mange, and 1 appeared to have died of severe leg injuries of unknown cause. With the assistance of park managers and plover crew members, VT collected all 4 carcasses. Thus, adult survival during their monitoring periods was 100% west of the inlet, and 0% east of the inlet. VT anticipates that continued data collection and analysis will allow us to estimate survival between monitoring periods, based on remote camera detections, potential recaptures, and field observations in future reports.

Table 36. Dens located on transect surveys, through GPS tracking, and opportunistically in April-July 2016.

Management area	Breeding	Non-breeding ^a	Inactive	Unknown ^b	Total
Smith Point County Park	0	0	2	0	0
Fire Island National Seashore – east of inlet	0	0	0	0	0
Fire Island National Seashore – west of inlet	7	8	11	6	32
Fire Island National Seashore – Lighthouse Tract	0	0	0	0	0
Robert Moses State Park	10	0	10	1	16
Total	17	8	21	7	53

^aDens with signs of recent activity but no signs of kits during the monitoring period, including daytime underground resting sites

^bDens that could not be confidently classified as breeding, non-breeding, or inactive

Objective 5: Quantify the interactions of red foxes with shorebird nests and chicks.

VT quantified the interactions of red foxes with shorebird nests and chicks, in particular piping plover nests and chicks, through diet analyses (i.e., recording prey items observed at dens and scat collection on transects) and analyses of spatial overlap of GPS-collared foxes and plover nests and broods.

Diet analyses

VT collected 101 scat samples during their transect surveys, den monitoring, and opportunistically (Table 37). In addition, VT recorded a wide variety of prey remains outside of den entrances and in the immediate vicinity during their monitoring activities, including remains from little skates (*Leucoraja erinacea*), spiny dogfish (*Squalus acanthias*), assorted other fish, soft-shell clams (*Mya arenaria*), white-tailed deer (*Odocoileus virginianus*), a duck, a gull, a gray squirrel (*Sciurus carolinensis*), and a diamondback terrapin (*Malaclemys terrapin*). VT also observed a variety of anthropogenic food waste, including a cat food tin, various snack and chip bags, jerky wrappers, and a large Ziploc bag containing toiletries and eating utensils that appeared to have been stolen from a nearby campsite.

Although VT have only just begun their fecal dietary analyses, VT have already observed a wide variety of prey item remains in scat samples, including insect, fish, bird, small mammal, and plant remains. In addition, VT have observed plastic, tin foil, and other anthropogenic food waste in several samples.

Table 37. Scat samples collected during transect surveys, den monitoring, and opportunistically in April-August 2016.

Management area	Scats
Smith Point County Park	0
Fire Island National Seashore – east of breach	0
Fire Island National Seashore – west of breach	54
Fire Island National Seashore – Lighthouse Tract	5
Robert Moses State Park	42
Total	101

Spatial overlap with piping plover nests and locations

VT used two sets of data from their Spring-Summer 2016 GPS collared foxes to explore spatial interactions between red foxes and piping plovers: the hourly/every two-hour data set collected throughout the season and the 15-minute high frequency sampling conducted around exclosure setup and hatching periods.

Hourly/Every Two Hour Location Data

For the first more coarse dataset by hour/every two hours, VT first found that, as noted above, when one considers the 50% and 95% kernel density contours from all GPS-collared individuals, all dry land area in Robert Moses State Park and Fire Island National Seashore west of Old Inlet was within the home range of at least one collared red fox (see Objective 3, Figure 43). There were many more foxes on the island beyond those VT had collared; these results only describe home ranges and overlap among collared foxes and piping plovers. All piping plover nests in Robert Moses State Park and Fire Island National Seashore west of Old Inlet were located within the 95% kernel density home range of at least one fox, and 6 were located within the 50% kernel density core area of at least one fox (Figure 46). Eight nests located within the 95% kernel density home range of at least one GPS-collared fox hatched successfully, and 4 were abandoned. Four nests located within the 50% kernel density core area of at least one GPS-collared fox hatched successfully, and 2 were abandoned. Additionally, one of the dens that VT monitored at Robert Moses State Park, which was not associated with any of their GPS-collared red foxes, was located within 300m of 3 piping plover nests within the Democrat Point (DMP) plover monitoring subsite. 1 of these nests hatched, and the other 2 were abandoned.

All piping plover adult and brood locations west of Old Inlet were also located within the 95% kernel density home range of at least one fox, and roughly half of the monitored piping plover brood locations were located within the 50% kernel density core area of at least one fox (Figure 47, Figure 48).

During Spring-Summer 2016, no red foxes were collared, nor observed, at Smith Point County Park nor the Old Inlet East unit of Fire Island National Seashore, thus no nests in those areas were overlapping with red fox territories.

High frequency (15-min) Location Data

VT were able to reprogram collars and collect data on high frequency sampling schedules for 5 GPS collared foxes surrounding nest discovery and exclosure, and for 3 of these foxes surrounding expected pipping and hatch dates (Figure 49, Figure 50). These foxes were selected for reprogramming based on the amounts of observed and anticipated potential overlap with nesting areas. Other foxes did not exhibit substantial overlap with any nesting areas, and were not selected for reprogramming. In some cases, planned reprogramming was prevented or delayed by malfunctioning remote connection mechanisms, avoidance behavior by foxes, temporary absence of foxes from the study area, or the use of daytime resting sites in areas that VT could not access due to thick vegetation and/or marsh.

Reprogramming the collars required approaching to within approximately 10m of the target individual and establishing and maintaining a remote connection long enough to upload a new sampling schedule. VT were not always able to do this on the desired dates, and were unsure whether VT would be able to again to reprogram surrounding estimated hatch dates, so when VT did successfully connect to a collar, VT uploaded a new schedule that included high frequency sampling dates surrounding pipping and hatch dates as a precaution. When reprogramming their collars to high frequency sampling, VT used the best information available to us, through communication with park managers and plover field crews, regarding exclosure setup plans and estimated hatch dates to determine which days to switch to the 15-minute location sampling schedule. For various logistical reasons and biological reasons, the estimated dates of these events were not always the same as the actual dates on which they occurred, particularly surrounding pipping and hatch dates that had been estimated several weeks in advance. Therefore, their high frequency data collection at some nests did not line up exactly with the events that VT had scheduled them around. VT used the highest location frequency collected surrounding the actual dates, using 2 days of location data before and after the target event to examine fine-scale spatial response. The collection frequency of location data presented in each of the following maps is noted in the map legends; “High freq” denotes time periods where locations were recorded every 15 minutes, “Partial high freq” denotes time periods where locations were collected every 15 minutes for more than half, but not all, of that time period, and “Reg freq” denotes time periods where locations were collected every 2 hours, on every other day. When only regular frequency data was available, VT used data from the 2 full days of data collection closest to the target event.

Based on GPS locations collected during these focal sampling periods, collared foxes did not exhibit a clear spatial response to nest exclosure, pipping, or hatching. Fox locations appeared to be correlated to den sites for breeding individuals, and resting sites for nonbreeding individuals, with little to no visible shift in locations before vs. after target events. However, this is only preliminary information, based on data from only a few individuals, and more information is needed to assess whether their observations are representative of the larger fox population’s response to target events. VT shows one set of maps with fox locations relative to plover nests before vs. after exclosure setup and before vs. after nest pipping and hatching in the figures below (Figure 49, Figure 50); All maps for high frequency location sampling are included in Appendix D: Spatial response of red foxes to nest exclosure setup, pipping, and hatching.

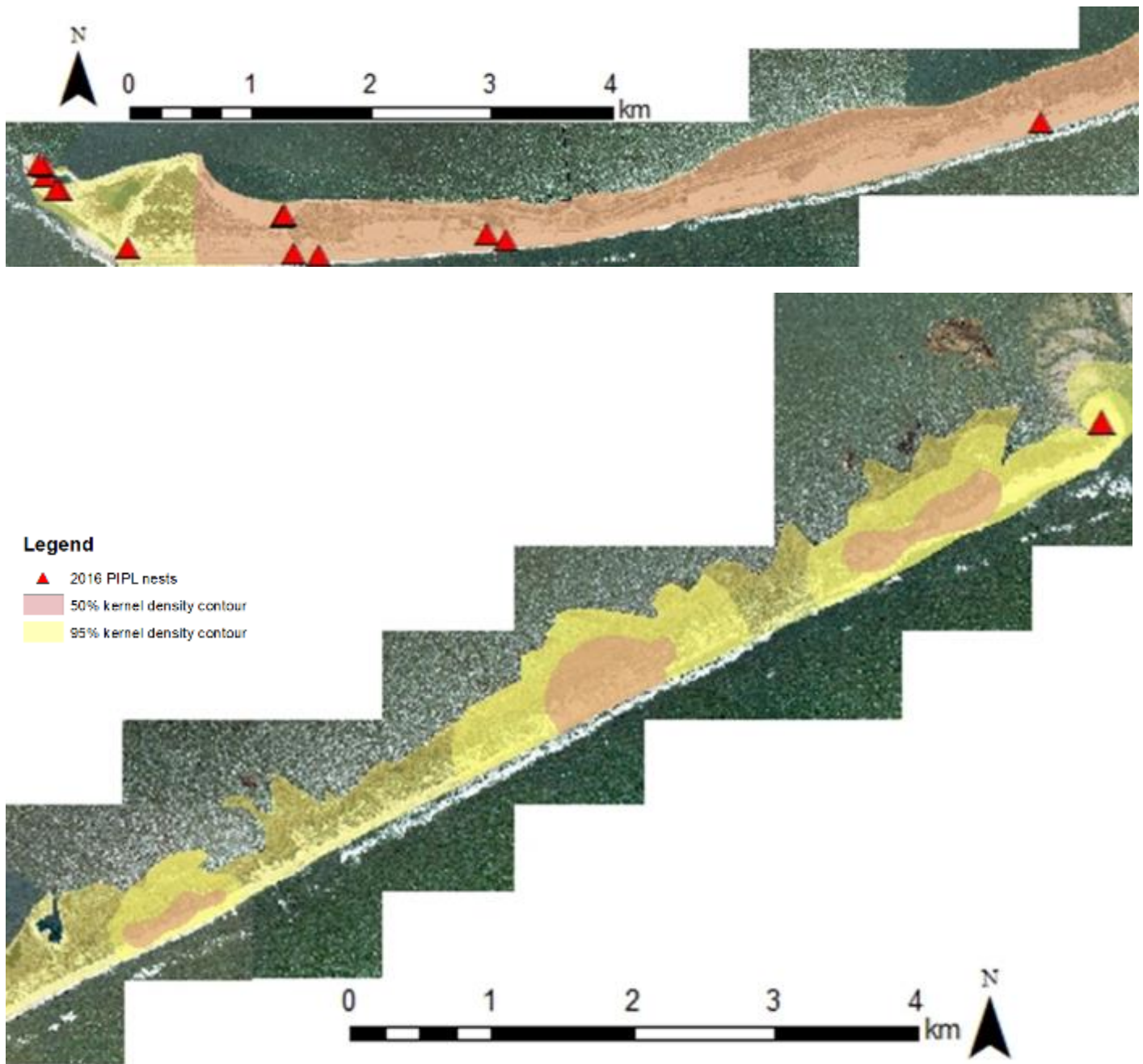


Figure 46. Plover nest locations, 50% and 95% kernel density contours for all GPS-collared red foxes in Spring-Summer 2016 at Robert Moses State Park (top) and Fire Island National Seashore (west of inlet, bottom) overlaid on top of each other.

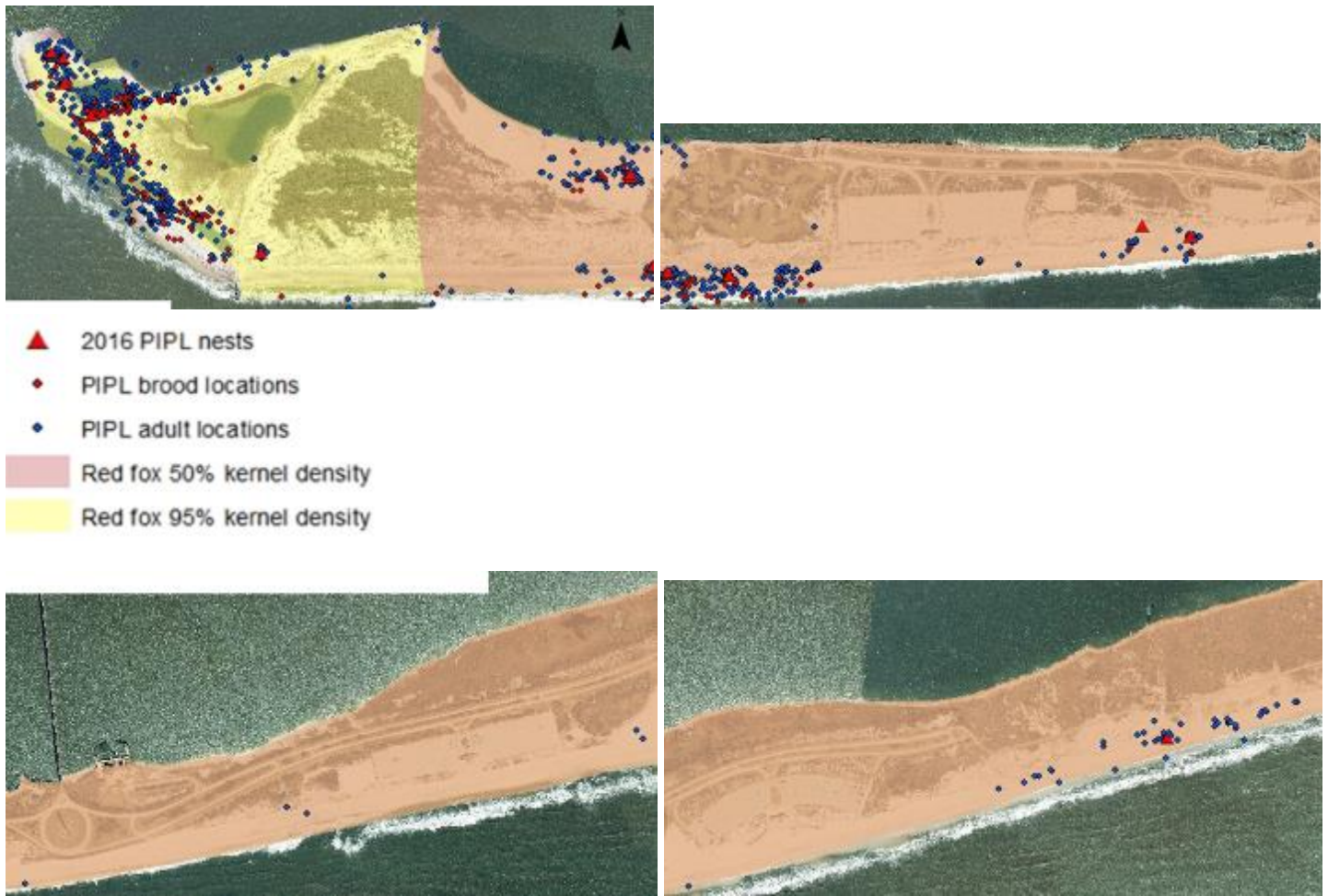


Figure 47. Piping plover nest, brood, and adult locations overlaid onto overall red fox kernel density contours at Robert Moses State Park. Note-maps of each portion have been enlarged to show detail, and are not shown on the same spatial scale among maps.

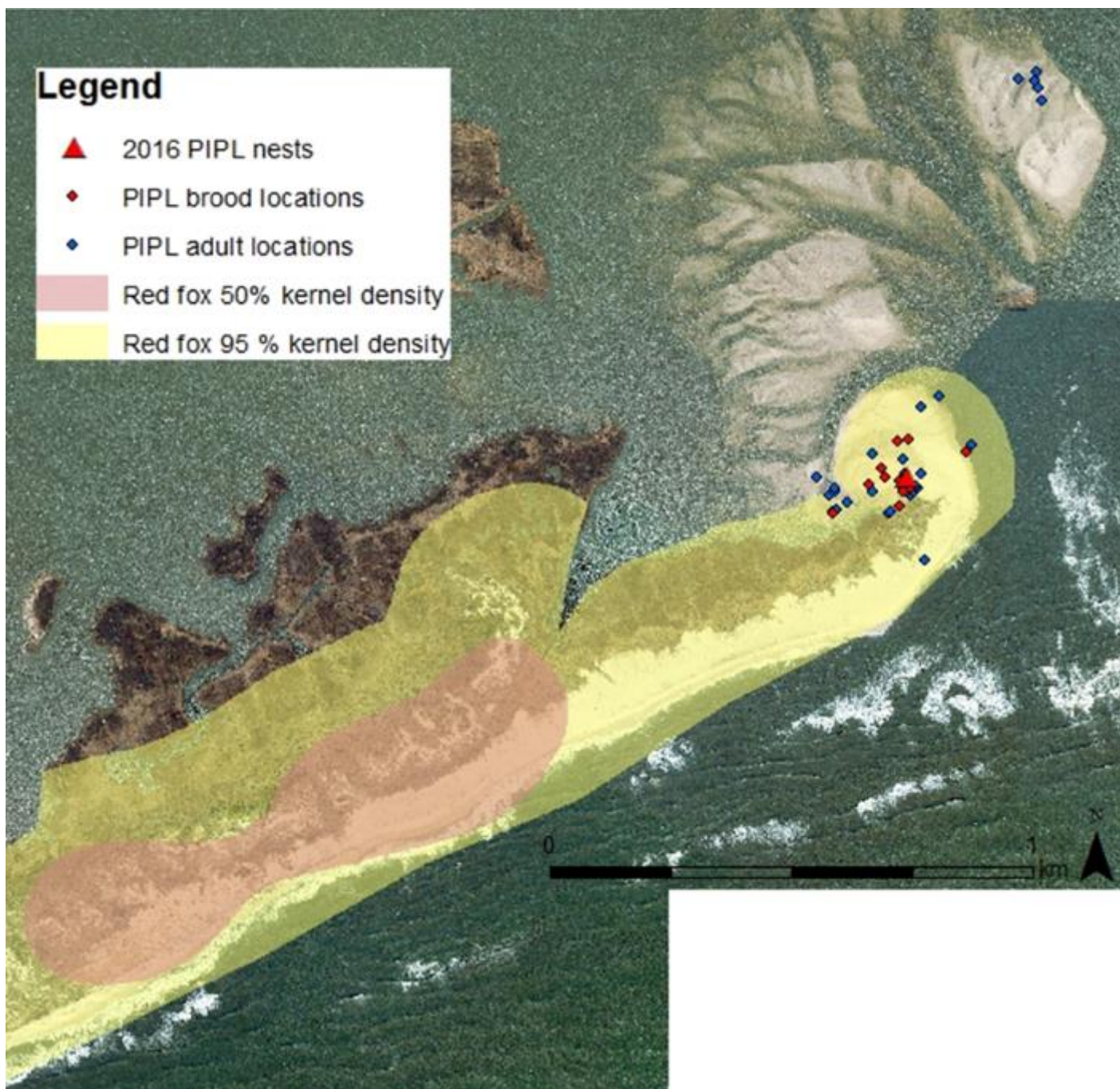


Figure 48. Piping plover nest, brood, and adult locations overlaid onto overall red fox kernel density contours at Fire Island National Seashore (Old Inlet West). This nest hatched successfully.

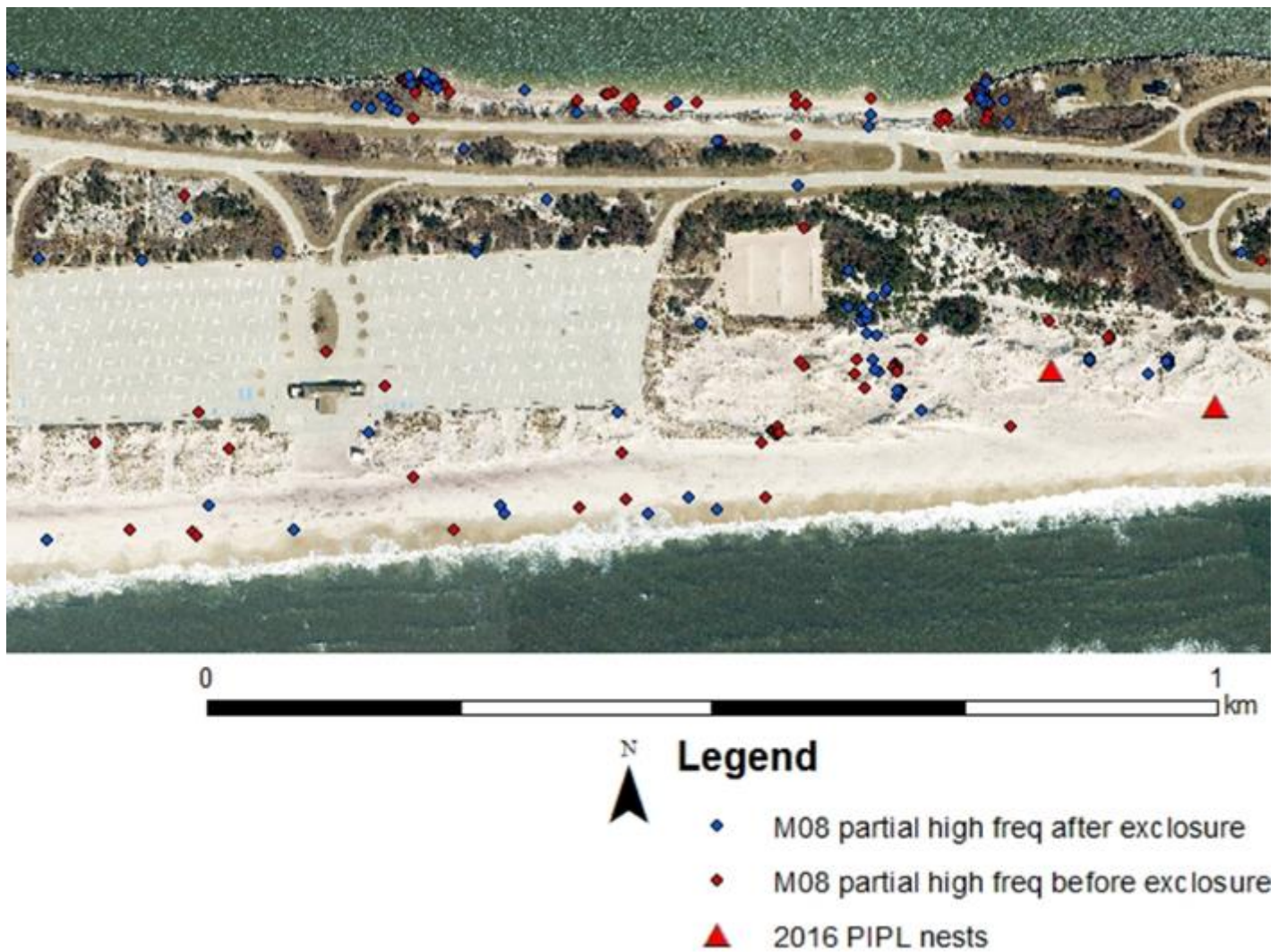
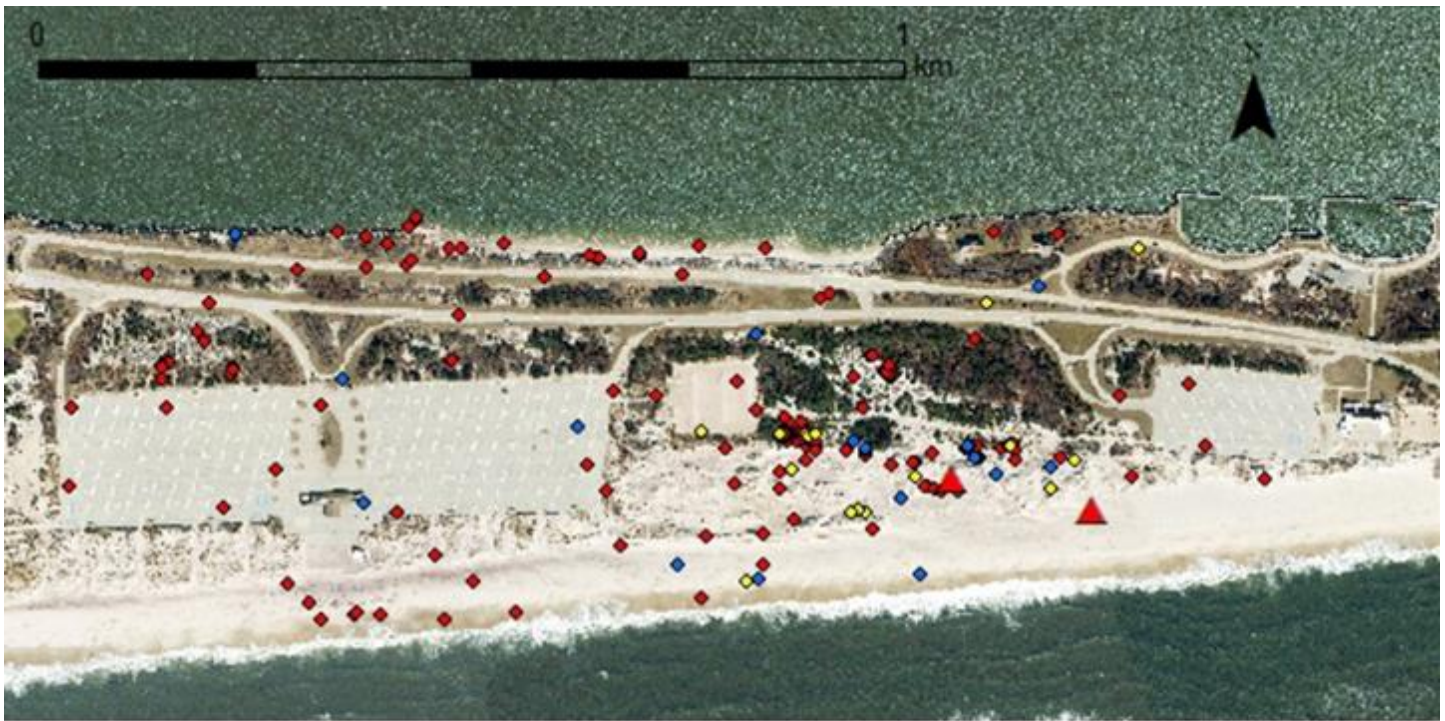


Figure 49. Locations for M08 before and after nest enclosure at Robert Moses State Park, PIPL nest 211 (SE beachfront on map).



Legend

- ▲ 2016 PIPL nests
- ◆ M08 reg freq after hatch
- ◆ M08 reg freq during pip/hatch
- ◆ M08 partial high freq pre-pip/hatch

Figure 50. Locations for M08 before, during, and after nest pipping/hatching at Robert Moses State Park, PIPL nest 211 (See beachfront on map).

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PART IV: MONITORING OF SHOREBIRDS ON FIRE ISLAND AND WESTHAMPTON ISLAND

INTRODUCTION

As shorebird numbers decline throughout the world, the conservation of resident and migratory shorebird populations has become a high priority for scientists and land managers in the North Atlantic (Bart et al. 2007; Clark and Niles 2000). Habitat degradation and development in coastal areas is a significant threat to shorebirds, and the preservation of breeding and staging habitats is a key focus of shorebird conservation efforts (Colwell 2010). Barrier islands and their associated sandbars and mudflats serve as important nesting and foraging habitat for breeding and migratory shorebirds.

In New York, the Fire Island National Seashore and neighboring state and county parks comprise an extensive network of public barrier island habitats managed for both recreation and conservation of coastal wildlife, including shorebirds. Specifically, the federally threatened piping plover (*Charadrius melodus*), which nests on beaches and barrier islands along the northern Atlantic Coast, is the focus of extensive research and management efforts by government agencies, nonprofits, and other land managers in the region (USFWS 1996).

As declining populations of many species, including migratory shorebirds, necessitate increased conservation efforts, the U.S. Fish and Wildlife Service (FWS) has prioritized the use of the ‘surrogate species’ approach to landscape conservation to maximize the effects of management on species of conservation concern. FWS (2015) defines ‘surrogate species’ as ‘subsets of species which are representative of multiple species or aspects of the environment.’ Surrogate species also is defined as ‘a species that is used to represent or serve as a proxy for additional species in conservation management’ (Caro and O’Doherty 1999; Wiens et al. 2008). The surrogate species approach can be used to identify areas of conservation priority, evaluate the effects of environmental change or management activities, or attract public support for conservation endeavors (Caro and O’Doherty 1999; USFWS 2015). However, there are several different types of surrogate species that are used to achieve different objectives. ‘Umbrella species’ have habitat requirements or geographic ranges that broadly represent the habitat requirements and ranges of a host of other species, such that habitat conservation measures implemented for the umbrella species will also protect vital habitat for the beneficiary species (Caro and O’Doherty 1999; Roberge and Angestam 2004). Similar to umbrella species, ‘focal species’ are not one but a suite of species whose habitat or resource requirements are representative of a larger subset of species of concern (Lambeck 1997). ‘Indicator species’ are species that exhibit sensitivity to environmental conditions or marked responses to management activities, and can thus indicate the presence of species with similar constraints or the likely responses of similar species to changes in environment or management (Caro and O’Doherty 1999; Butler et al. 2012). Finally, ‘flagship species’ are charismatic species that can be effectively used as a publicity tool to raise funds and bolster public opinion in favor of conservation, and thus enable conservation action that will benefit additional species in the region (Caro and O’Doherty 1999; Bowen-Jones and Entwistle 2002).

Given the high number of shorebird species that use New York barrier islands, and the challenges associated with collecting data and developing individualized management strategies for each species, the use of one or more surrogate species could be a valuable tool for preserving key shorebird habitat along an important

flyway. From a logistical perspective, the piping plover would be an ideal surrogate species, as the species is already the subject of extensive research, monitoring, and conservation efforts due to its listing under the Endangered Species Act (ESA). However, research is necessary to determine whether piping plovers meet the ecological criteria necessary to serve as a potential surrogate species for resident and migratory shorebirds on New York barrier islands. Furthermore, the literature is divided as to the efficacy of individual surrogate species in achieving tangible conservation outcomes for beneficiary species, and continued monitoring and adaptive management is necessary to determine whether the surrogate species approach is useful in a given system (Roberge and Anglestam 2004; Favreau et al. 2006; Heino 2010).

Therefore, the objectives of this study were:

- a) To determine migratory shorebird numbers and habitat use on Fire Island and Westhampton Island
- b) To evaluate the degree of both spatial and temporal overlap between piping plovers and other migratory shorebirds in the region, and thus evaluate the potential for the piping plover to serve as an effective surrogate species for shorebird conservation on New York barrier islands
- c) To determine whether current management regimes allow for the realization of the potential benefits of the surrogate species approach to shorebird conservation.

STUDY SITE

VT sampling efforts were focused on a 17.3-km stretch of barrier islands on Fire Island and Westhampton Island. The study area encompassed land managed by the National Park Service (5.8 km of the Otis Pike High Dunes Wilderness) and Suffolk County Parks (Smith Point County Park and Cupsogue Beach County Park). It included three inlets (Old Inlet, which was opened by a breach during Hurricane Sandy, Moriches Inlet, and the east side of Fire Island Inlet) and the flood shoals that formed in the Great South Bay behind the inlets (Figure 2). Additionally, in 2015 and 2016 their study area included a 9.8-km stretch of Fire Island at Democrat Point in Robert Moses State Park, managed by New York State Parks (Figure 1).

VT divided the study site into units of habitat small enough that monitoring activities could be completed throughout the entire unit on each visit (Table 2). Subsites generally corresponded to broad habitat categories such as filled breaches or natural overwashes. At subsites with both bay and ocean access, VT surveyed two transects, one along the entire span of bayside intertidal zone and the other on the entire span of ocean-side beach (Table 38). When the subsite included significant backshore habitat, an additional transect was walked along the backshore habitat parallel to both bay ITZ and ocean transects. At few subsites (SPTW, PSE, BRE, OIWR, MTP), only one transect was surveyed due to limited accessibility (Table 38). At few other subsites which formed a mud flat or a sandbar, VT surveyed the entire area and the perimeter of the subsite was considered as the length of the transect (Table 38).

Table 38. Attributes of survey transects set for 21 subsites in four management units on Fire Island and Westhampton Island during 2014–2016. Two transects were set out on the bayside and the oceanside of a subsite when accessible

Management unit	Subsite	Habitat type	Transect	Transect length (m)
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N/A	CMF	Mud flat	mudflat	2837.1
	CSB	Sandbar	sandbar	1629.2
Cupsoque county park	CSE	Beach	bay	906.8
			ocean	1340.8
	CSW	Filled breach	bay	427.6
			ocean	737.0
Smith Point County Park	SPTE	Filled dredge spoil	bay	1980.9
			ocean	1850.1
	SPTW	Beach	ocean	1544.1
	NBE	Overwash	bay	593.8
			ocean	803.8
	MWPF	Filled dredge spoil	bay	165.5
			ocean	670.9
	NBW	Overwash and filled breach	bay	506.6
			ocean	608.7
	PSE	Beach	ocean	773.9
PSO	Overwash	bay	1876.0	
		ocean	1036.0	
BRE	Beach	ocean	2785.0	
Otis Pike Wilderness Area	BRO	Overwash	bay	317.3
			ocean	689.2
	BRW	Beach	ocean	592.2
	OIE	Overwash and inlet	bay	243.8
			ocean	1217.4
	OIW	Overwash and inlet	bay	674.8
			ocean	603.2
FS	Flood shoals	sandbar	2259.2	
OIWR	Beach and overwash	ocean	2418.6	
Robert Moses State Park	MTP	Sand stock pile	bay	1045.2
	THL	Mature dunes and inlet	bay	1959.6
			ocean	1307.3
	HOOK	Inlet	bay	635.8
ocean			451.7	

CAUTION WITH INTERPRETING SHOREBIRD COUNTS

None of the shorebird species was individually marked with field-readable identifiers on their sites except for piping plovers. Since VT knew the number of banded piping plovers for any given day during the survey, VT estimated the daily total counts of piping plovers in a different way from all the other shorebird species. Two different methods of counting shorebirds are described below in the 'Field Methods' section. However, with either method, their daily counts of shorebirds most likely included same individual birds detected over multiple days. Besides, VT did not account for the probability of detecting a shorebird which likely varied across different surveys in relation to time of the day, duration of the survey, weather condition, tidal cycle, and habitat types. Thereby, VT state that the counts of shorebirds VT reported here were not independent

among surveys, hence likely be an overestimate of the true population size, and should be used with a limited interpretation.

FIELD METHODS

Counting the number of piping plovers

Piping plovers on their sites were banded and resighted throughout the breeding season and during both spring and fall migrations. As part of the daily field routine, whenever VT sighted one or more piping plovers, VT recorded the ID of the banded birds and also recorded the number of unbanded birds. VT then tallied up the number of uniquely banded piping plovers present for any given day with the number of unbanded piping plovers counted for each day on each of the subsites.

Shorebird Surveys

VT surveyed the entire study area for shorebirds once per week from April through mid-August and roughly every three days between mid-August and September for fall migration in 2014–2016. As VT walked or drove each transect, VT counted all shorebirds by species using handheld tally counters and recorded whether shorebirds were observed on ocean, bay, or backshore habitats. When more than one person surveyed a transect together, VT combined counts at the end of each survey to reach a final tally for the transect. On the barrier islands, shorebird surveys were conducted at any point during the tide cycle as surveys had to be completed early in the morning to avoid beach use by the public. However, surveys at the flood shoals were always conducted at low tide. Total length of each transect as well as the amount of time taken to survey each transect varied by transects and surveys. Detailed methods of accessing different subsites and subsite-specific survey protocols are described below.

Cupsogue flood shoals were accessed by boats. Once on the Cupsogue Sand Bar (CSB), VT visually divided the sand bar into manageable survey sections, and each team member counted all shorebirds within a section from a fixed point. On the Cupsoque Mud Flats (CMF), one transect was located at the northern edge of the mud flats and the other transect was at the southern edge of the mud flats encompassing the large tidal creek and pond. In 2014, surveys of the Old Inlet Flood Shoals (FS) were conducted from Old Inlet West, using scopes to view and count shorebirds on the small flood shoals. In 2015 and 2016, the flood shoals had enlarged and teams boated to each sand bar to count all shorebirds when boating conditions allowed. At Smith Point County Park, ocean surveys were conducted by UTV. Teams drove a UTV eastward along the ocean shoreline all the way to Moriches Inlet. Surveyors were careful to drive far enough from the ocean shoreline to avoid flushing shorebirds. Once teams reached the inlet, they walked west along the bay shoreline and backshore areas of each subsite to survey bay/backshore habitats for shorebirds. Similarly, in the Otis Pike Wilderness, east of Old Inlet (BRO, BRW, OIE), teams surveyed the ocean by UTV, driving west along the ocean shoreline from the Wilderness Visitor's Center to Old Inlet, and walked back along the bay/backshore to survey for shorebirds in those habitats. At the Otis Pike Wilderness west of Old Inlet, surveyors were dropped off by boat at Old Inlet and walked west to the end of the study area at Bellport Beach. Because the beach was so narrow on this part of the island, teams could survey both the ocean shoreline and bay/backshore habitat in a single transect. At two subsites, STP and DMP, at Robert Moses State

Park (STP, DMP), teams surveyed on foot, walking west along the ocean shoreline, around the inlet, and back along the bay shoreline.

DATA ANALYSIS

Shorebird abundance and diversity on Fire Island

To account for varying length of transects at different subsites, VT calculated the counts of shorebirds detected per 100 m for each day, year, and species for different habitat types and subsites. When more than one survey count was recorded in the same day for a given species at a site, VT chose the maximum count for the day. VT excluded non-shorebird species, such as Black Skimmer and Clapper Rail, as well as tern spp., (e.g., Common Tern, Least Tern, and Royal Tern) from their analyses. VT described the total number of shorebirds counted and the number of species detected at each of the four management units, and each of the five habitat types where transects were set up (ocean, bay ITZ, backshore, Old Inlet Flood Shoals, and Moriches Flood Shoals). Using the total number of shorebirds counted per 100 m, VT described different migration phenologies among four management units and among different shorebird species.

Temporal overlap between beach closure for piping plovers and migration window of shorebirds

VT then fit a smoothing curve to the daily total counts of all shorebird species combined for fall migration during 2014–2016 at Smith Point County Park to compare fall migration phenology to when the park was closed to recreational off-road-vehicle traffic to protect breeding piping plovers.

Space-use overlap between piping plovers and migratory shorebirds

To examine the similarity within the temporal and spatial distributions of piping plovers and other migrating shorebirds during fall and spring migrations, VT used a multivariate ordination analysis called Canonical Correspondence Analysis (CCA; R package ‘vegan’, Oksanen et al. 2015). CCA summarizes measured environmental variables into fewer synthetic gradients (ordination axes) that maximize the niche separation among species (Braak and Verdonschot 1995). Using CCA, VT can identify biological assemblages indicated as a set of species whose relative abundance is greater at certain range of the multi-dimensional habitat space. In this report, VT examined if the relative abundance of shorebirds surveyed for different survey period/year were more similar for certain types of habitats than others. VT also examined if the relative abundance of certain species among different habitat/survey period/year were more similar to that of piping plovers than others.

To use CCA, VT created a matrix with total counts of each species for each year/habitat/survey period combination (**Figure 51**). As not all sites could be surveyed in the same day, VT tallied daily counts from 4 April to 24 September for each year into 30 survey periods, so that each subsite was surveyed only once per survey period (Table 39). Survey counts were summed by species and five habitat types (ocean, bay ITZ, backshore, Old Inlet Flood Shoals, and Moriches Flood Shoals) for each survey period. If not all transects were surveyed for any given year/survey period/habitat combination, VT omitted the counts for that combination from their analysis.

Table 39. Temporal window of 30 survey periods during 2014–2016. Surveys 1 through 10 were considered as spring migration, and surveys 14 through 30 were considered as fall migration. Shorebird counts from survey 11–13 were omitted from the canonical correspondence analysis.

Migration	Survey	2014	2015	2016
Spring migration	1	Apr 6 – Apr 11	Apr 6 – Apr 12	Apr 6 – Apr 12
	2	Apr 14 – Apr 18	Apr 16 – Apr 23	Apr 14 – Apr 21
	3	Apr 22 – Apr 28	Apr 25 – Apr 29	Apr 23 – Apr 29
	4	May 1 – May 7	May 3 – May 4	May 1 – May 7
	5	May 9 – May 12	May 9 – May 12	May 9 – May 12
	6	May 13 – May 21	May 16 – May 21	May 13 – May 21
	7	May 23 – May 25	May 23 – May 27	May 23 – May 27
	8	May 30 – Jun 4	May 28 – May 30	May 29 – Jun 3
	9	Jun 6 – Jun 8	Jun 4 – Jun 8	Jun 4 – Jun 8
	10	Jun 13 – Jun 20	Jun 10 – Jun 17	Jun 10 – Jun 17
Surveys omitted from analyses	11	Jun 21 – Jun 27	Jun 19 – Jun 25	Jun 21 – Jun 25
	12	Jun 28 – Jun 29	Jun 26 – Jun 29	Jun 26 – Jun 30
	13	Jul 5 – Jul 7	Jul 2 – Jul 6	Jul 2 – Jul 7
Fall migration	14	Jul 10 – Jul 14	Jul 8 – Jul 13	Jul 8 – Jul 14
	15	Jul 15 – Jul 22	Jul 16 – Jul 20	Jul 15 – Jul 22
	16	Jul 23 – Jul 29	Jul 23 – Jul 28	Jul 23 – Jul 29
	17	no survey	Jul 30 – Jul 31	Jul 30 – Aug 1
	18	Aug 4 – Aug 6	no survey	Aug 2 – Aug 6
	19	7-Aug	Aug 3 – Aug 6	Aug 7 – Aug 9
	20	Aug 8 – Aug 12	no survey	Aug 10 – Aug 12
	21	Aug 14 – Aug 15	Aug 10 – Aug 16	Aug 13 – Aug 16
	22	Aug 18 – Aug 20	Aug 17 – Aug 19	Aug 17 – Aug 20
	23	Aug 21 – Aug 25	Aug 20 – Aug 25	Aug 21 – Aug 25
	24	Aug 26 – Aug 27	Aug 26 – Aug 28	Aug 26 – Aug 28
	25	Aug 28 – Sep 1	Aug 31 – Sep 2	Aug 29 – Sep 1
	26	Sep 2 - Sep 4	Sep 3 - Sep 8	Sep 2 - Sep 7
	27	Sep 8 - Sep 11	Sep 9 - Sep 14	Sep 8 - Sep 14
	28	Sep 15 - Sep 19	Sep 15 - Sep 17	Sep 15 - Sep 19
	29	Sep 22 - Sep 26	Sep 21 - Sep 23	Sep 20 - Sep 23
	30	no survey	Sep 24 - Sep 25	Sep 24 - Sep 30
Total number of surveys		28	28	30

VT analyzed spring and fall migrations separately to avoid a bimodal effect of time on shorebird abundance, and also to highlight any differences in arrival time or habitat selection during the different migrations. To separate spring and fall, VT removed survey periods 11–13 from their analyses (Table 39), as those survey

periods had low (<300) counts during all three years of the study, and those numbers mainly consisted of resident breeding birds rather than migrants. VT also eliminated species that accounted for less than 1% of all shorebirds counted within each migration season from their analyses.

Their global CCA model included the effects of survey period, year, and habitat on the relative abundance of shorebirds. VT used stepwise variable selection in both directions with survey period, year, and habitat variables. Variables were not added unless addition decreased the AIC values (Hastie and Pregibon 1992). The variance inflation factors for the variables were all less than 5, suggesting that there was no redundancy in the models (O'Brien 2007). With the best fitting model, VT conducted a permutation test to assess significance of each environmental variable on separating shorebird assemblages.

Total counts of selected species													
1	sample	AMOY	BBPL	DUNL	LESA	REKN	RUTU	SAND	SBDO	SEPL	SESA	WILL	TotalPIPL
2	2014backshore1	2	0	0	0	0	0	0	0	0	0	0	7
3	2014backshore2	0	0	0	0	0	0	0	0	0	0	0	6
4	2014backshore3	0	0	0	0	0	0	0	0	0	0	0	4
12	...												
13	2015backshore1	0	0	0	0	0	0	0	0	0	0	0	4
14	2015backshore2	0	0	0	0	0	0	0	0	0	0	0	2
15	2015backshore3	0	0	0	0	0	0	0	0	0	0	0	2
23	...												
24	2014bay1	2	0	0	0	0	0	0	0	0	0	0	4
25	2014bay2	0	0	0	0	0	0	0	0	0	0	0	1
26	2014bay3	2	8	74	0	0	0	2	0	0	0	0	3
44	...												
45	2014mfs3	4	0	0	0	0	0	0	0	0	0	0	0
46	2014mfs4	4	36	300	0	0	0	200	3	0	0	8	1
47	2014mfs5	2	29	257	0	22	15	190	24	4	0	3	3

Figure 51. Example matrix of total shorebird counts surveyed at Fire Island and Westhampton Island. Columns comprised 12 shorebird species and each row contained counts from each year/habitat/survey period combination assigned as different samples.

RESULTS

Shorebird abundance and diversity on Fire Island

Twenty-eight shorebird species in addition to piping plovers were detected during April–September of 2014–2016 on Fire Island and Westhampton Island (Table 40). Species diversity of shorebirds was similar among Cupsogue County Park, Otis Pike Wilderness Area, and Smith Point County Park, but was lower at the Robert Moses State Park where VT did not survey in 2014. VT counted the highest number of birds (49,371 birds) and the most species (23 species) at Cupsogue flood shoals (Subsites CSB/CMF, Table 40). Two flood shoals at Old Inlet and Moriches Inlet provided habitat where 60,231 birds from 25 species were counted. VT counted 32,565 birds from 18 species on ocean beaches and 12,891 birds from 25 species on bay ITZ (Table 41). Sanderling and semipalmated sandpiper were the most abundant species followed by short-billed dowitcher, black-bellied plover, semipalmated plover, dunlin, willet, ruddy turnstone, and American oystercatcher (Table 40 and Table 41). Among the 28 species VT detected, 12 species were focal species for the Atlantic Flyway

Shorebird working group (Atlantic Flyway Shorebird Business Plan, Andres et al., 2015). The red knots are ‘highly imperiled,’ and the other 11 species were listed as ‘high concern’ in the US Shorebird Conservation Plan (Table 42). Eight species that are either ‘highly imperiled’ or of ‘high concern’ tended to occur with greater frequency at subsites adjacent to Old Inlet and the Moriches Inlet (Figure 52) and at Democrat Point (Figure 53).

Temporal overlap between beach closure for piping plovers and migration window of shorebirds

Accounting for the 29 species of shorebirds detected during the survey across four management units, the period of spring migration spanned from mid-April through early-May, and the fall migration spanned from late-July through early-August (Figure 54). Cupsogue Flood Shoals (CMF/CSB) showed the highest migration peak among four management units, and more birds were detected during the fall migration than during the spring migration (Figure 54). Timing and the height of the fall migration differed among the three years of the study. For eight species that are either highly imperiled or of high conservation concern, VT counted more birds in the fall than spring (Figure 55).

All beaches were open to pedestrians throughout the piping plover breeding season and the migration window of shorebirds. Recreational vehicles were typically permitted to drive on the beach at Smith Point County Park and Robert Moses State Park, however, according to the Biological Opinion, closures may be necessary during the piping plover chick-rearing period if certain conditions are met (USFWS 2014). The closure did not include law enforcement, park staff, and researchers, who continued to drive All-Terrain Vehicles (ATVs) or Utility-Terrain Vehicles (UTVs) throughout the season at Cupsogue Beach County Park and the Otis Pike Wilderness, but recreational driving was not allowed in these areas. Smith Point County Park was closed to recreational off-road-vehicle (ORV) traffic during 9 June – 1 August in 2014 (54 days), 9 July – 13 August in 2015 (35 days), and 22 May – 25 August in 2016 (95 days). In all three years, the Smith Point County Park was closed to ORV traffic at the beginning of fall migration but reopened prior to the peak (Figure 56). Considering the fall migration of 8 focal species, the peak of migration happened during the closed period in only 8 of 18 cases VT observed (Figure 57). The migration peaks observed at the Smith Point County Park generally coincided with migration peaks at other management units (Figure 54). Therefore, VT did not think that the timing of peak migration at Smith Point Count Park was affected by the timing of beach closure for ORVs. Two subsites in Robert Moses State Park (STP and OSS) also were closed to ORV traffic for part of the breeding seasons. Subsite STP was closed during 8 June – 4 August in 2015, and 7 July – 22 July in 2016. Another subsite OSS was closed during 10 July – 4 August in 2015, and 25 June – 5 August in 2016. However, VT counted only 739 birds on these two subsites where beaches were partly closed; the majority of migrating shorebirds counted on Robert Moses State Park used the Democrat Point (Figure 53).

Table 40. Number of shorebirds counted during April–September of 2014–2016 at Fire Island and Westhampton Island shown for four management units and Cupsogue Flood Shoals (CSB and CMF). Species are sorted by the total number of birds counted. All management units were surveyed in 2014–2016 except for Robert Moses State Park which was surveyed in 2015–2016. Each transect was surveyed 28 times in 2014 and 2015, and 30 times in 2016.

	Subsite CSB/ CMF	Cupsogue County Park	Otis Pike Wilderness Area	Smith Point County Park	Robert Moses State Park	Total
Number of transects	2	4	11	16	14	

Sanderling <i>Calidris alba</i> *	12,545	19,937	17,833	5,329	1,104	56,748
Semipalmated sandpiper <i>Calidris pusilla</i> *	7,954	2,778	2,297	66	136	13,231
Short-billed dowitcher <i>Limnodromus griseus</i>	6,605	1,249	351	5	65	8,275
Black-bellied plover <i>Pluvialis squatarola</i>	4,719	844	1,953	73	471	8,060
Semipalmated plover <i>Charadrius semipalmatus</i>	4,329	1,184	1,449	340	198	7,500
Dunlin <i>Calidris alpina</i>	5,189	238	132	2	238	5,799
Ruddy turnstone <i>Arenaria interpres</i> *	1,452	967	610	143	355	3,527
Willet <i>Tringa semipalmata</i>	1,539	859	789	71	187	3,445
American oystercatcher <i>Haematopus palliatus</i> *	2,168	451	321	228	193	3,361
Red knot <i>Calidris canutus</i> *	1,228	461	143	1	28	1,861
Least sandpiper <i>Calidris minutilla</i>	932	184	446	12	27	1,601
Greater yellowlegs <i>Tringa melanoleuca</i> *	367	78	51	3	22	521
Lesser yellowlegs <i>Tringa flavipes</i> *	234	17	47	0	7	305
Spotted sandpiper <i>Actitis macularius</i>	31	38	46	53	40	208
American golden-plover <i>Pluvialis dominica</i> *	26	1	3	0	43	73
Whimbrel <i>Numenius phaeopus</i> *	6	21	3	0	2	32
White-rumped sandpiper <i>Calidris fuscicollis</i>	7	23	1	0	0	31
Pectoral sandpiper <i>Calidris melanotos</i>	13	5	4	7	0	29
Killdeer <i>Charadrius vociferus</i>	9	1	14	2	1	27
Marbled godwit <i>Limosa fedoa</i> *	9	9	0	0	0	18
Stilt sandpiper <i>Calidris himantopus</i>	0	0	12	0	0	12
Western sandpiper <i>Calidris mauri</i>	5	0	5	0	0	10
Long-billed dowitcher <i>Limnodromus scolopaceus</i>	0	0	0	6	0	6
American avocet <i>Recurvirostra americana</i>	0	0	3	0	0	3
Buff-breasted sandpiper <i>Calidris subruficollis</i>	3	0	0	0	0	3
Wilson's plover <i>Charadrius wilsonia</i> *	1	0	0	0	0	1
Red-necked phalarope <i>Phalaropus lobatus</i> *	0	1	0	0	0	1
Solitary sandpiper <i>Tringa solitaria</i>	0	1	0	0	0	1
Number of species	23	22	22	22	16	28
Total counts	49,371	29,347	26,513	6,341	3,117	114,689

* Focal species selected by the Atlantic Flyway Shorebird working group (Atlantic Flyway Shorebird Business Plan, Andres et al., 2015).

Table 41. Number of shorebirds counted during April–September of 2014–2016 at Fire Island and Westhampton Island shown for five habitat types. Species are sorted by the total number of birds counted. Each transect was surveyed 28 times in 2014 and 2015, and 30 times in 2016. Habitat was assigned ‘unknown’ when the habitat the birds were counted in was not recorded.

Habitat type	CSB	CMF	Ocean	Bay ITZ	Old Inlet Flood Shoals	Backshore	Unknown	Total
Number of transects	1	1	18	18	2	21	-	
Sanderling *	11,350	1,195	27,963	4,884	5,412	608	999	52,411
Semipalmated sandpiper *	5,534	2,419	533	2,468	1,180	890	79	13,103
Short-billed dowitcher	4,162	2,443	21	644	716	186	230	8,402
Black-bellied plover	3,494	1,224	1,423	648	578	624	94	8,085
Semipalmated plover	1,604	2,723	750	1,141	970	146	49	7,383
Dunlin	3,240	1,949	78	407	107	12	105	5,898
Ruddy turnstone *	908	544	351	979	494	102	97	3,475
Willet	788	751	812	524	331	86	121	3,413
American oystercatcher *	1,780	388	371	278	306	61	56	3,240
Red knot *	1,154	74	105	122	330	36	0	1,821
Least sandpiper	157	775	20	294	19	298	42	1,605
American avocet	69	31	72	198	14	57	271	712
Greater yellowlegs *	43	324	0	83	32	38	8	528
Lesser yellowlegs *	59	175	0	26	4	41	9	314
Spotted sandpiper	9	22	37	107	0	13	15	203
American golden plover *	23	3	8	39	0	0	0	73
White-rumped sandpiper	5	2	0	10	14	0	1	32
Pectoral sandpiper	3	10	1	10	5	0	2	31
Whimbrel *	2	3	15	5	3	3	0	31
Killdeer	7	2	4	6	0	6	4	29
Marbled godwit *	5	4	0	5	4	0	0	18
Stilt sandpiper	0	0	0	2	0	10	0	12
Western sandpiper	2	3	1	4	0	0	0	10
Long-billed dowitcher	0	0	0	6	0	0	0	6
Buff-breasted sandpiper	0	3	0	0	0	0	0	3
Red-necked phalarope *	0	0	0	0	1	0	0	1
Solitary sandpiper	0	0	0	1	0	0	0	1
Wilson's plover *	1	0	0	0	0	0	0	1
Number of species	23	23	18	25	19	18	17	28
Total counts	34,399	15,067	32,565	12,891	10,520	3,217	2,182	110,841

Table 42. Population status of the focal species selected by the Atlantic Flyway Shorebird working group (Atlantic Flyway Shorebird Business Plan, Andres et al., 2015) and the total number of birds counted during April–September of 2014–2016 at Fire Island and Westhampton Island. Counts for piping plovers are not reported as their total counts for the species was greatly overestimated from their intensive study on the species

Species	USSCP ^a Status	Estimated Population	30-yr population trend	Total counts from their survey			Average Annual Count
				2014	2015	2016	
Sanderling [†]	High Concern	300,000	↓	14,142	14,391	28,215	18,916
Semipalmated sandpiper [†]	High Concern	810,000	↓↓	6,241	2,744	4,246	4,410
Ruddy turnstone [†]	High Concern	180,000	↓↓	1,124	775	1,628	1,176
American oystercatcher [†]	High Concern	11,284	↑	941	839	1,581	1,120
Red knot (<i>rufa</i>) [†]	Highly Imperiled	42,000	↓↓	770	533	558	620
Greater yellowlegs [†]	High Concern	137,000	↑	136	250	135	174
Lesser yellowlegs [†]	High Concern	660,000	↓↓	182	32	91	102
American golden plover	High Concern	500,000	↑↓	67	5	1	24
Whimbrel	High Concern	40,000	↓	4	22	6	11
Marbled godwit	High Concern	2,000	Unknown	12	0	6	6
Wilson's plover	High Concern	8,600	↓	1	0	0	0
Red-necked phalarope	High Concern	250,000	↓↓	0	0	1	0
Purple sandpiper	High Concern	15,000	↓	0	0	0	0
Snowy plover	Highly Imperiled	1,040	↓	0	0	0	0

^a US Shorebird Conservation Plan.

[†] VT described the temporal and spatial variation in daily counts of these seven species surveyed on Fire Island and Westhampton Island in Figure 52, 53, 55, 57.

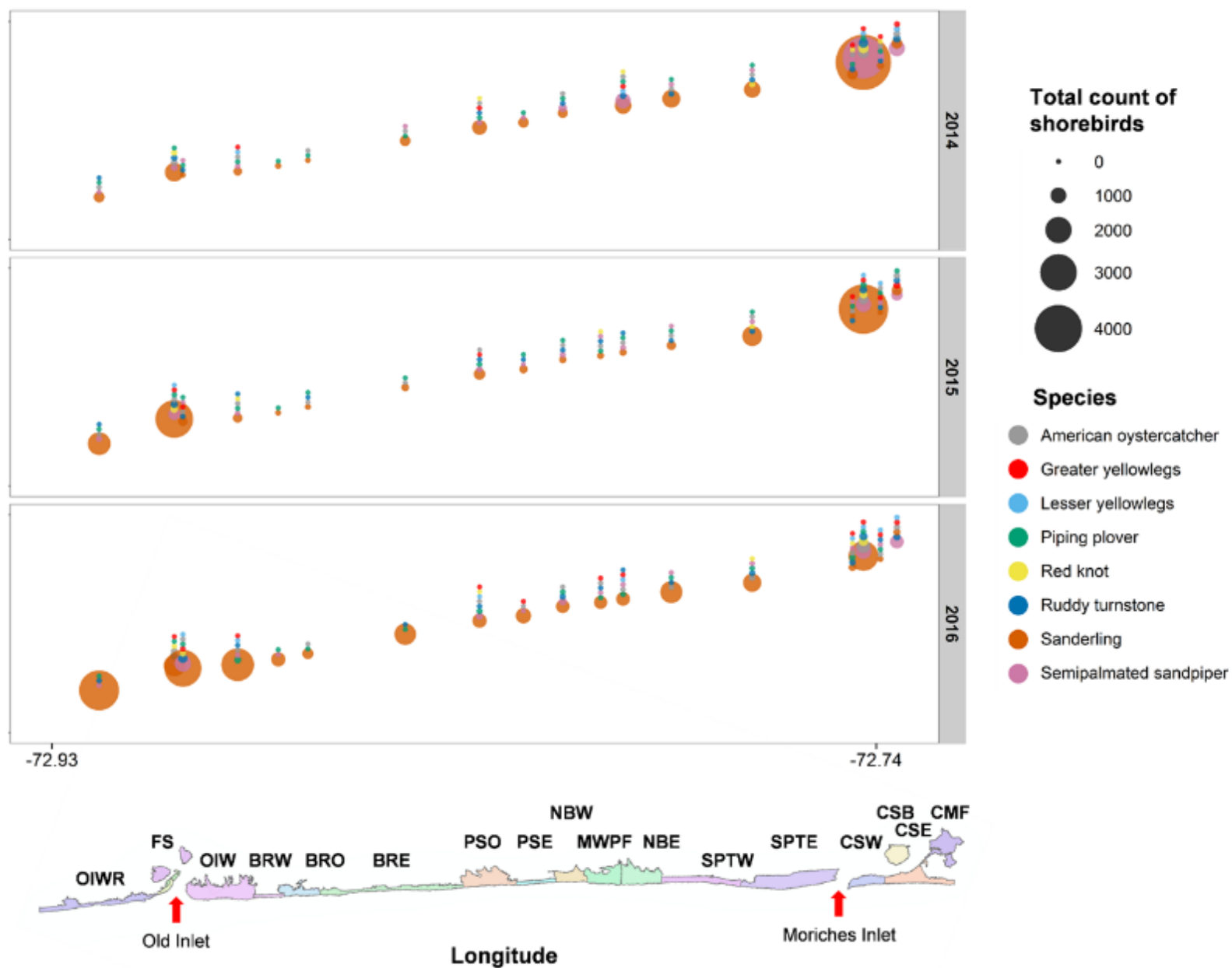


Figure 52. Total annual counts of eight shorebird species that are either ‘highly imperiled’ or of ‘high concern’ surveyed during April–September of 2014–2016 across subsites at Fire Island and Westhampton Island. Points are forced to spread along the y-axis for visibility.

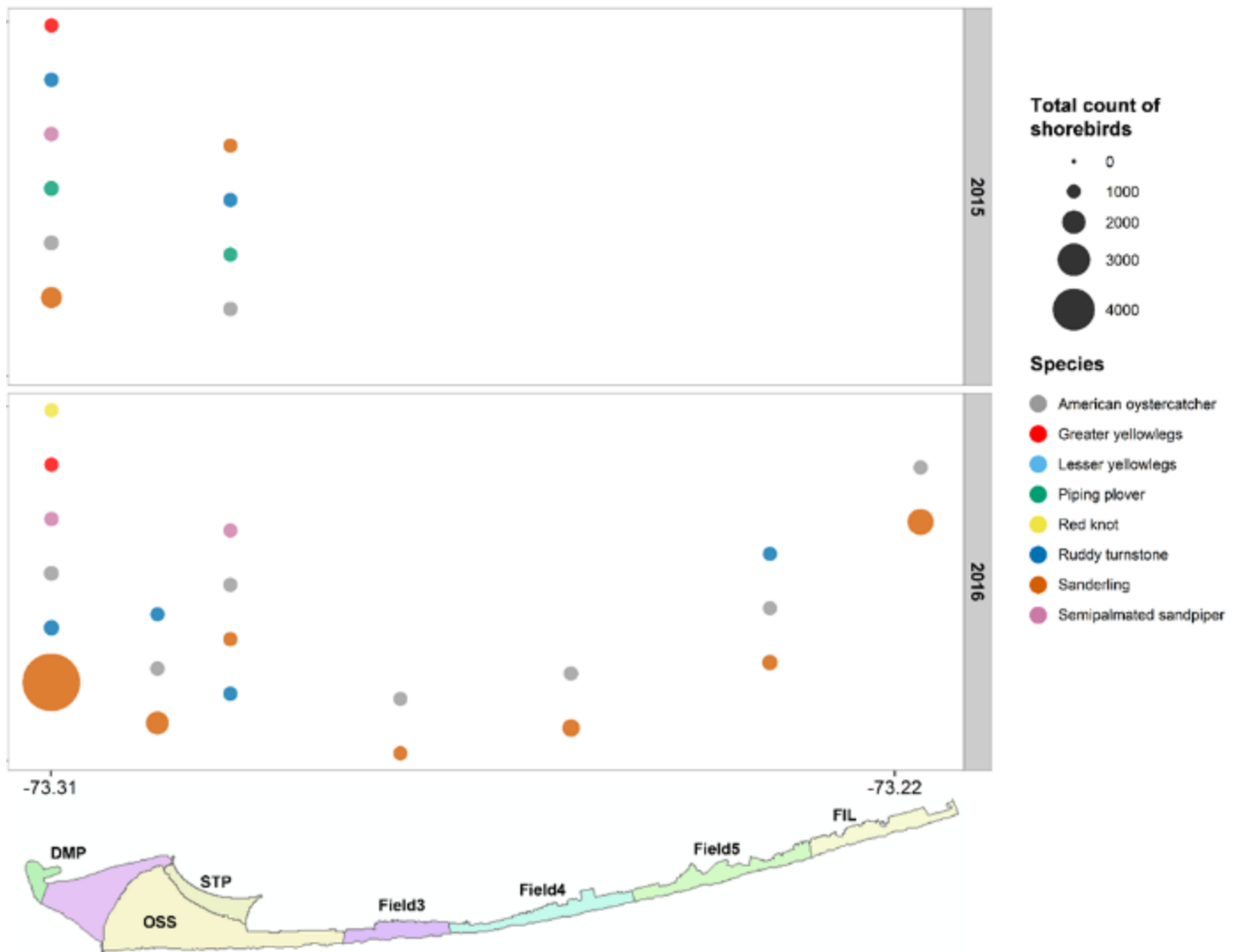


Figure 53. Total annual counts of eight shorebird species that are either ‘highly imperiled’ or of ‘high concern’ surveyed during April–September of 2015–2016 across subsites at Robert Moses State Park. Points are forced to spread along the y-axis for visibility.



Figure 54. Daily total number of all shorebirds counted per 0.1 km surveyed at four management units and Cupsoque flood shoals (CMF/CSB) during the spring and fall migration of 2014–2016.

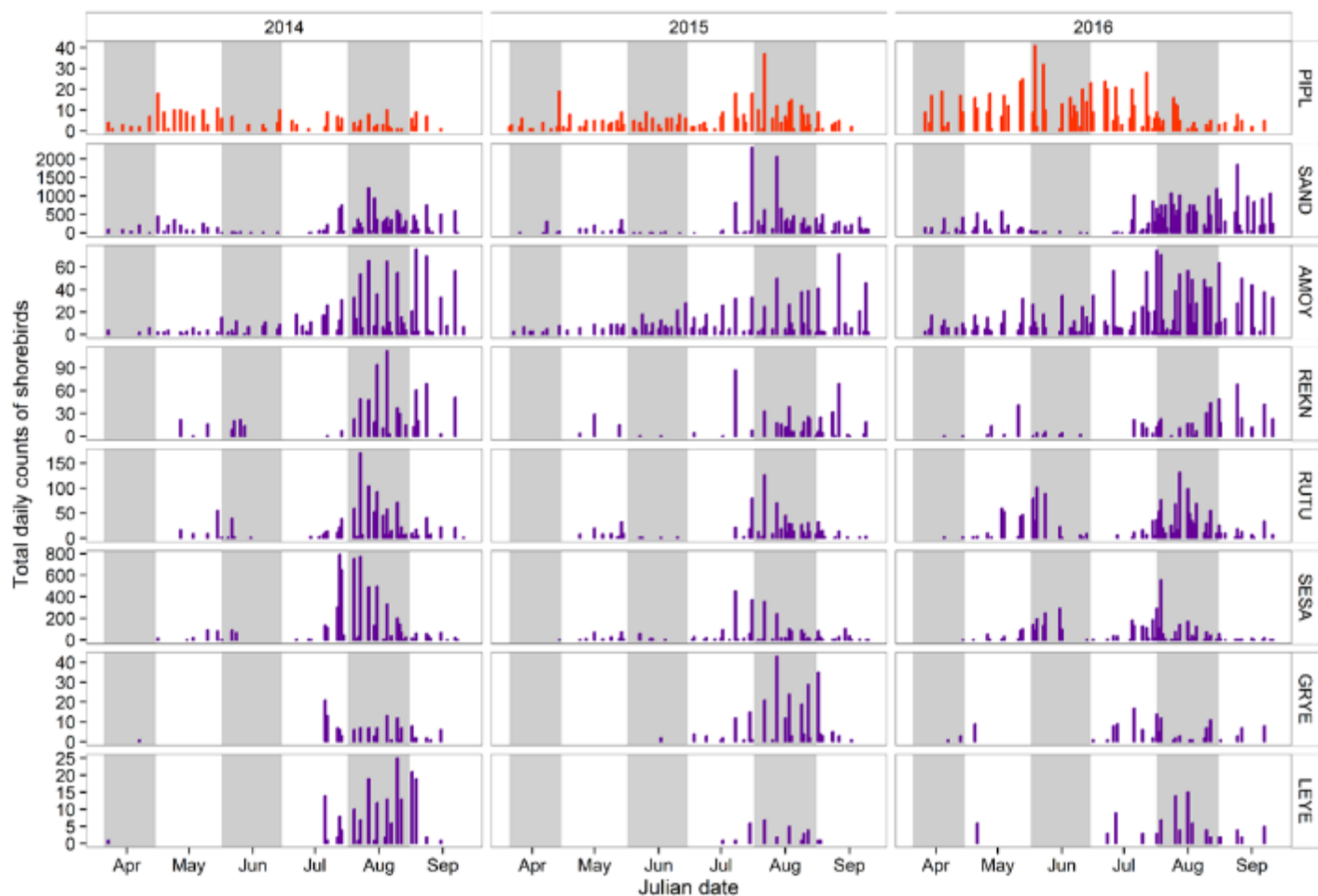


Figure 55. Total daily counts of eight shorebird species surveyed during April–September of 2014–2016 at Fire Island and Westhampton Island. PIPL: piping plover, SAND: sanderling, AMOY: American oystercatcher, REKN: red knot, RUTU: ruddy turnstone, SESA: semipalmated sandpiper, GRYE: greater yellowlegs, LEYE: lesser yellowlegs.

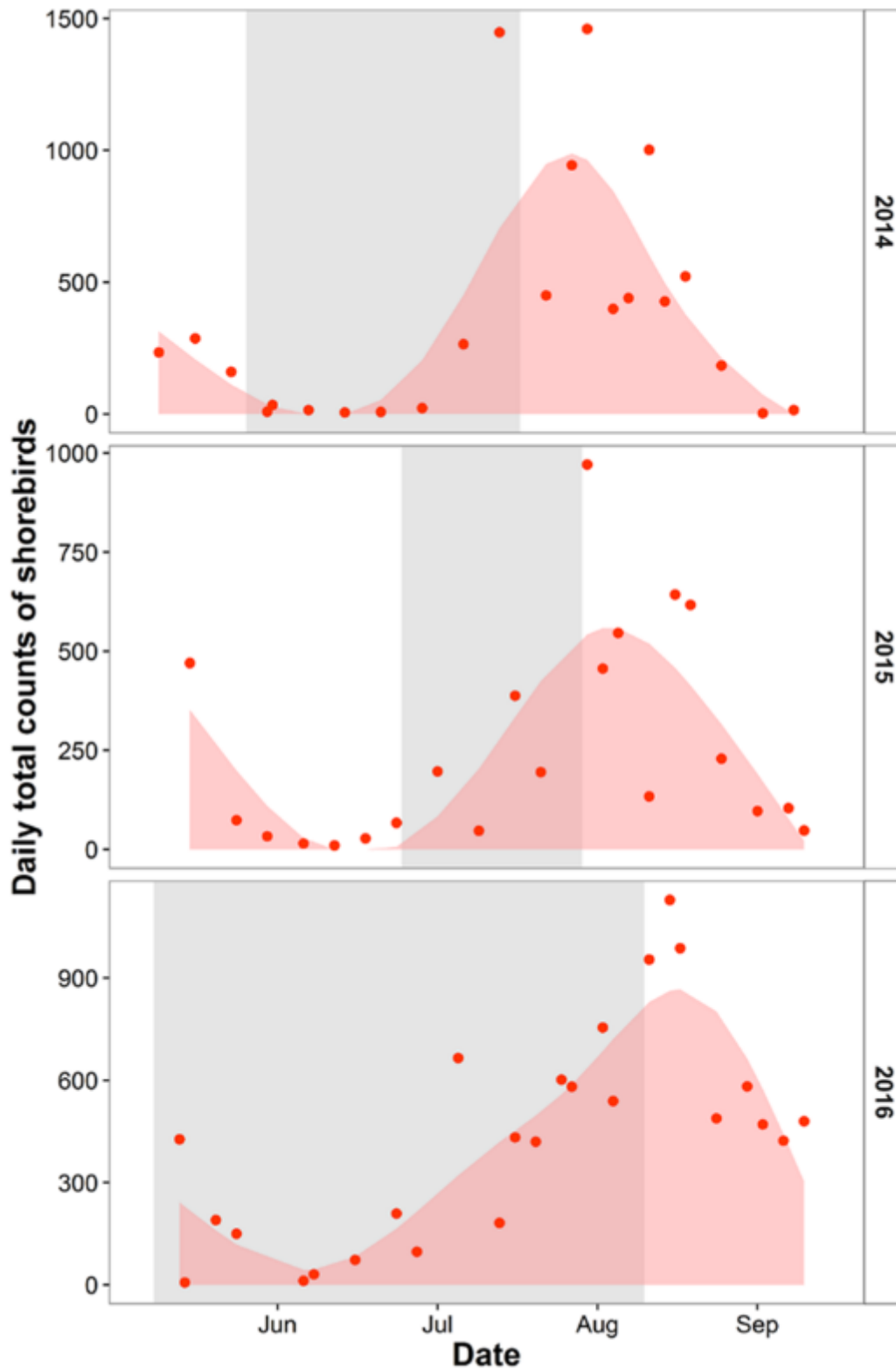


Figure 56. Daily total counts of all shorebird species for fall migration during 2014–2016 at Smith Point County Park. A smoothing curve was fit to the daily total counts for each year, and the area under each curve is shaded with red. Grey bars indicate when the park was closed to recreational off-road-vehicle traffic to protect breeding piping plovers.

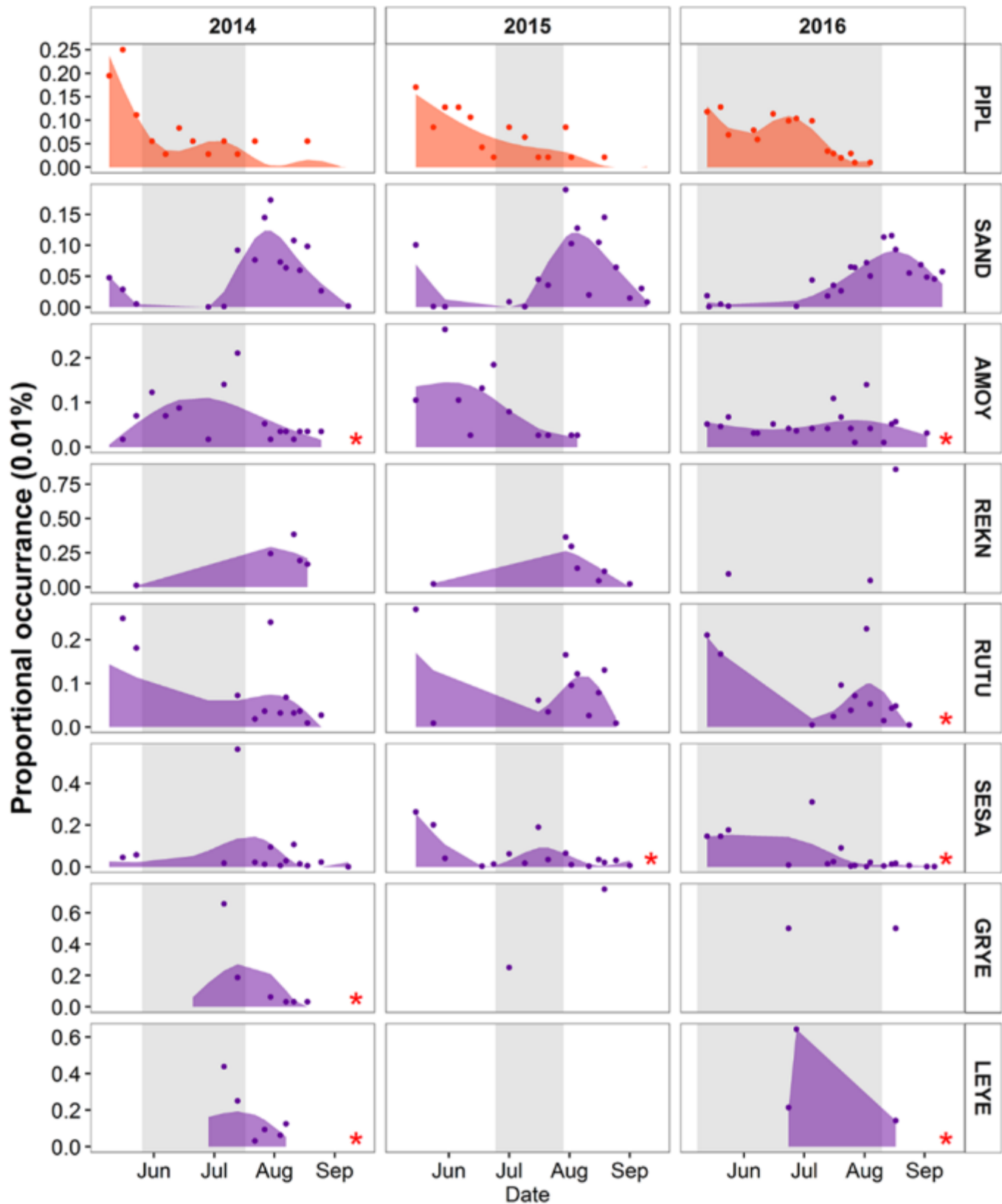


Figure 57. Daily proportion of season total counts of 8 focal species for fall migration during 2014–2016 at Smith Point County Park. Grey bars indicate when the park was closed to recreational off-road-vehicle traffic to protect breeding piping plovers. Red asterisks indicate cases where the beach was closed on the day of peak migration. PIPL: piping plover, SAND: sanderling, AMOY: American oystercatcher, REKN: red knot, RUTU: ruddy turnstone, SESA: semipalmated sandpiper, GRYE: greater yellowlegs, LEYE: lesser yellowlegs.

Space-use overlap between piping plovers and migratory shorebirds

VT chose the eleven most common shorebird species detected during their surveys, and compared the similarity in both spatial and temporal distribution between the eleven species and piping plovers. The eleven species were sanderling, semipalmated sandpiper, short-billed dowitcher, black-bellied plover, semipalmated plover, dunlin, ruddy turnstone, willet, American oystercatcher, red knot, and least sandpiper.

From the Canonical Correspondence Analysis, 31% of variation seen in the relative abundance of shorebirds during spring migration was explained by their three explanatory variables, survey period, year, and habitat type. Of the 31% variation explained, 80% was explained by the first two synthetic gradients (CCA1 and CCA2) VT extracted from three environmental variables. For the Canonical Correspondence Analysis, models are generally considered good if the first two axes explain more than 70% of the variation in the data. For the fall migration, their best model did not include the year effect and explained 25% of variation. Of the 25% variation explained, 77% was explained by the first two gradients (CCA1 and CCA2).

Resulted ordination diagrams from their analyses are shown in Figure 58 from the spring migration and in Figure 59 for the fall migration. In each plot, horizontal and vertical axes represent the two synthetic gradients (CCA1 and CCA2) extracted from their three environmental variables. Two axes can be considered as environmental gradients of different habitat types and seasonal timing. Their first gradient (CCA1) was highly correlated with five different habitat types, and the second gradient (CCA2) was highly correlated with the survey period.

Polygons are given for the categorical explanatory variable (habitat type) and a vector is given for a quantitative variable (survey period). The centroid of each polygon is the weighted average of site points, and the position of a species represents the optimum value (niche) along the first and second environmental gradients (CCA1 and CCA2). The closer a species point is to the habitat point, the more likely that the given species has higher abundance in that habitat type.

For the spring migration, the overlap among habitat polygons in Figure 58a shows that the shorebird communities in ocean, backshore, and bay ITZ habitats were similar, but that they differed from the communities on the two flood shoal habitats (OIFS and MFS). These differences were largely driven by species like red knots, short-billed dowitchers, semipalmated plovers, and dunlins that were detected in higher numbers on the flood shoals than other habitats (Table 41, Figure 58a). For the fall migration, all habitat polygons overlaid to a great extent, hence, indicated that the shorebird communities among habitat types were more similar during the fall migration than the spring migration (Figure 59a).

Survey counts for piping plovers were divided into two categories, counts of piping plovers that were foraging at the time of survey and counts of piping plovers that were showing breeding behaviors (i.e., non-foraging). Both during spring and fall migration, 'Foraging PIPL' was more closely placed with other shorebird species than the 'Non-foraging PIPL' was on their biplot, which indicates that piping plovers found during foraging were likely to be detected in similar habitat types with other shorebirds than plovers found during breeding (Figure 58b and Figure 59b). Non-foraging piping plovers during the spring migration window were counted more on the ocean and backshore habitat than on the flood shoals (Figure 58b), and were counted more on the ocean and bay ITZ habitat during the fall migration window, whereas foraging piping plovers were counted more on diverse habitats including bay ITZ, backshore, and flood shoals with other shorebird species (Figure

58b and Figure 59b). This is likely because the non-foraging piping plovers were detected on or near their nest sites.

In Figure 58b and Figure 59b, an arrow represents a vector for the survey period pointing from earlier to later surveys. During the spring migration, for example, dunlins were detected in high counts earlier in the season followed by black-bellied plover, semipalmated plover, red knot, short-billed dowitcher, ruddy turnstone, and semipalmated sandpipers being the last arrival on the flood shoals (Figure 58b).

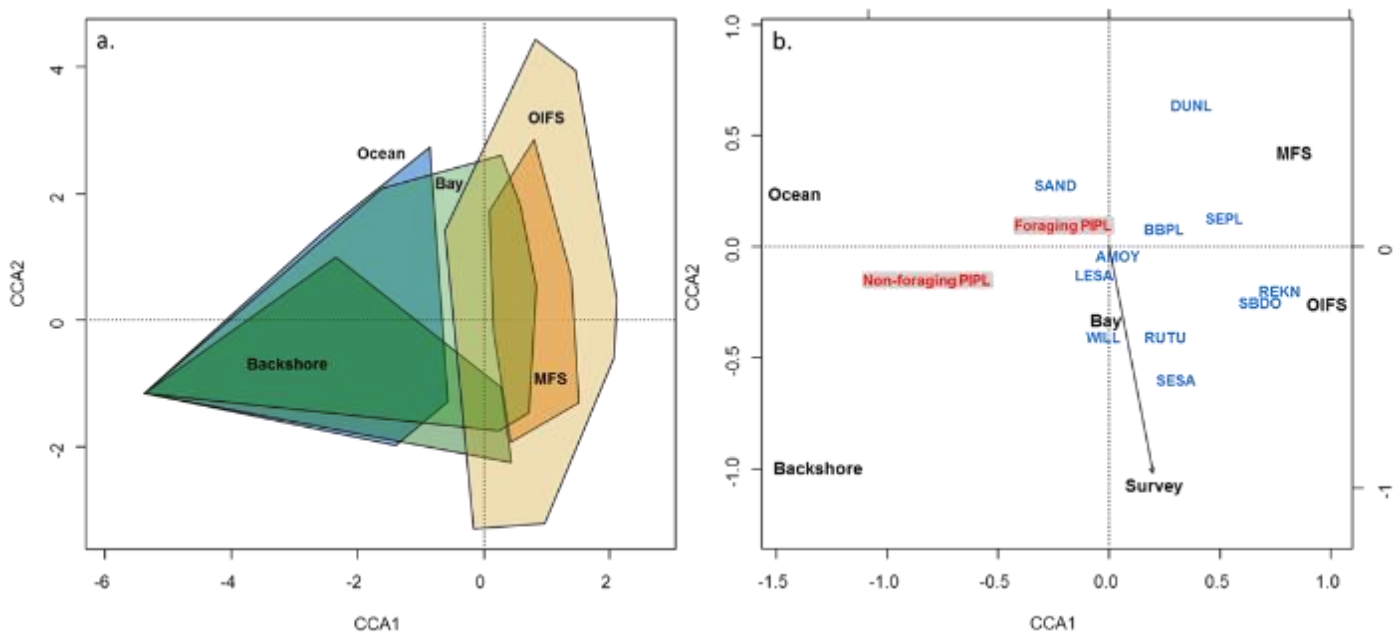


Figure 58. Resulted ordination diagrams from canonical correspondence analysis on survey counts of shorebirds at Fire Island and Westhampton Islands during spring migration of 2014–2016. (a) Biplot of community similarity among five habitat types. Centroid of each polygon indicates the site points weighted by the shorebird abundance at each of five habitat types. Five habitats considered were Ocean, Bay, Backshore, Old inlet flood shoals (OIFS), and Moriches inlet flood shoals (MFS). (b) Triplot of environmental effects on relative abundance of shorebirds. Species points (blue) indicate the relative locations of the species' niches along two axes. Quantitative explanatory variable ('Survey period') is represented by a vector (arrow) pointing in the direction of increase. PIPL: piping plover, SAND: sanderling, AMOY: American oystercatcher, REKN: red knot, RUTU: ruddy turnstone, SESA: semipalmated sandpiper, GRYE: greater yellowlegs, LEYE: lesser yellowlegs.

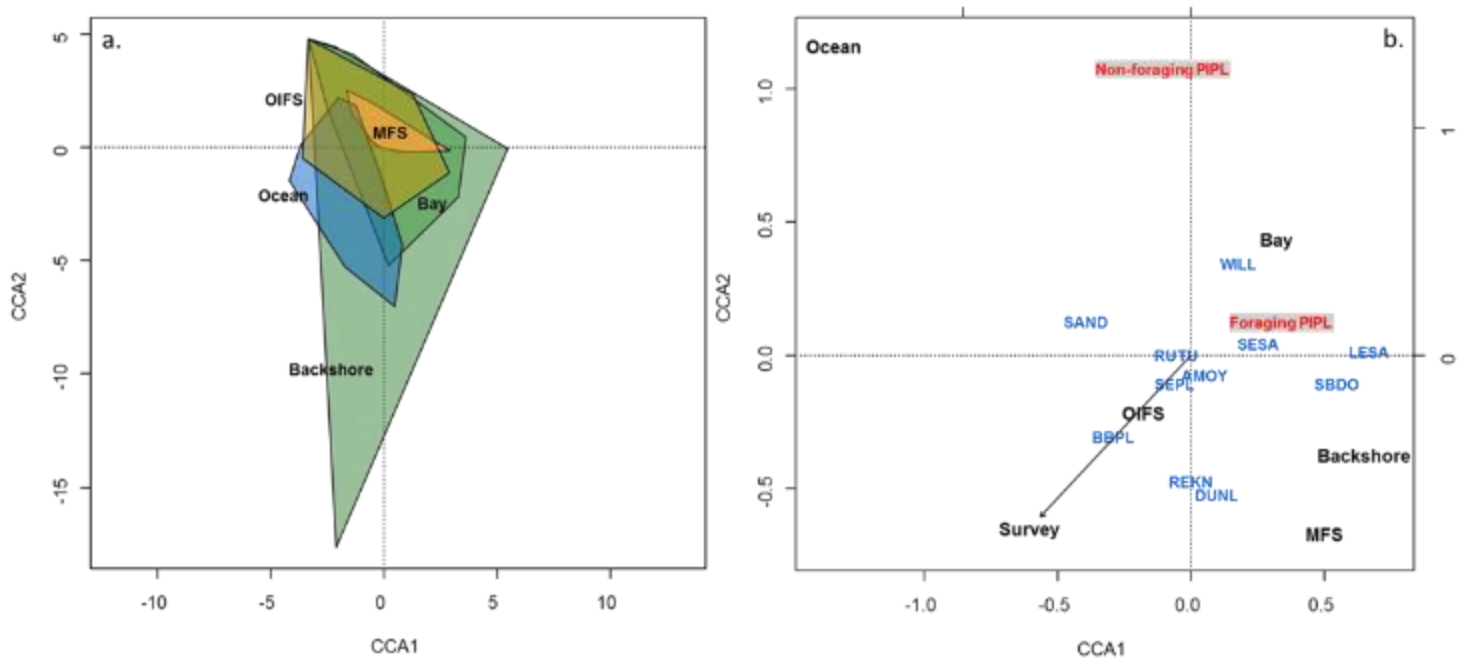


Figure 59. Resulted ordination diagrams from canonical correspondence analysis on survey counts of shorebirds at Fire Island and Westhampton Islands during fall migration of 2014–2016. (a) Biplot of community similarity among five habitat types. Centroid of each polygon indicates the site points weighted by the shorebird abundance at each of five habitat types. Five habitats considered were Ocean, Bay, Backshore, Old inlet flood shoals (OIFS), and Moriches inlet flood shoals (MFS). (b) Triplot of environmental effects on relative abundance of shorebirds. Species points (blue) indicate the relative locations of the species' niches along two axes. Quantitative explanatory variable ('Survey period') is represented by a vector (arrow) pointing in the direction of increase. PIPL: piping plover, SAND: sanderling, AMOY: American oystercatcher, REKN: red knot, RUTU: ruddy turnstone, SEPL: semipalmated sandpiper, GRYE: greater yellowlegs, LEYE: lesser yellowlegs.

CONCLUSIONS

Thirty-seven shorebird species occur in the Northern Atlantic region and use the Atlantic flyway (Clark and Niles 2000). VT detected 29 shorebird species on the Fire Island region during migration, including species that are highly imperiled or of high conservation concern. Adequate management action at Fire Island has great potential to benefit majority of shorebird species that occur on the Atlantic flyway. However, results suggest that piping plover may not provide a good surrogate species for the other migratory shorebirds due to 1) different habitat use between breeding piping plovers and other migratory shorebirds, 2) current plover management limited to their breeding activities, and 3) current beach closures inadequate to cover the migration peaks.

Purpose of using Fire Islands is likely different for piping plovers and other shorebirds that use Fire Island as a stopover site during their annual migration. For example, the counts of breeding piping plovers were greater on ocean-side beaches and backshore habitat where they nest. Other local breeders such as American oystercatcher, sanderling, and willets were abundant on all habitat types representing their broad use of the area. However, other migratory shorebirds that are stopping over at Fire Island were more abundant on bay ITZ and flood shoals, which provide good foraging habitat (Figure 58). Habitat use of different species was

more similar during the fall migration window (shown as more overlap among polygons in Figure 59a). This is likely because local breeders were weakly tied to their nesting site as they move around with their broods in search of good foraging sites. Even during fall migration, however, the breeding piping plovers were counted more on the ocean habitat than any other habitat types. These results showed that the habitat use of breeding piping plovers likely differs from the habitat use of migrating shorebirds on Fire Island.

Current management actions on Fire Island are specifically aimed at reducing impacts of human disturbance to piping plover breeding activities and locations, which entails symbolic fencing around nests and broods and beach closures to the recreational driving during brood-rearing period. Majority of current protective measure is highly localized to locations of breeding activities of piping plovers. Migration peak observed on Fire Island was the highest at Cupsogue Beach County Park and on the adjacent sandbar habitat (Figure 54). A key habitat for many species was the flood shoals at Old Inlet and Moriches Inlet, and three subsites (CSB, CMF, and FS) there in accounted 54% of their total counts of shorebirds. To their knowledge, the three subsites are closed for recreational driving, which can protect foraging migratory shorebirds as well as piping plovers. Although closed to recreational driving, however, the three subsites are open to pedestrians and pets by personal boats. An extension on the current protective measure to cover the flood shoals or a habitat-based management plan to protect the flood shoals would likely benefit the migratory shorebirds the most.

Protective measure that has broad spatial coverage such as beach closures can protect both breeding piping plovers and migratory shorebirds. On Fire Island, only Smith Point County Park and a small section of Robert Moses State Park were closed to the recreational off-road-vehicle for part of the breeding season to protect breeding piping plovers. VT results showed that the time span of protective closure was not long enough to cover the peak of fall migration in all three years surveyed. Moreover, the duration of the closed time window also varied between 35 to 95 days among the years that VT surveyed depending on the length of the breeding season for piping plovers for the given year. Therefore, not only the timing of beach closure but also the duration of beach closure varied year to year which makes piping plover a less preferable surrogate species for the other shorebird species.

On a short-term, extension of the beach closure to cover the fall migration peaks can reduce potential human disturbance on migratory shorebird flocks. As the foraging piping plovers showed more similar habitat use with other migrating shorebirds, protective measure for not just broods but also for foraging adults of piping plovers would benefit migratory shorebirds via minimizing human disturbances on their foraging habitat. VT have identified flood shoals and sand bars as an important habitat for migrating shorebirds. Formation of flood shoals up and down the coast may be prevented by breach filling, and once formed, the shoals can be damaged by inlet dredging operations, either by piling spoil on the shoals so the shoals lose their intertidal character, or by reducing shoal size. Part II of their report suggested that conserving the breach and overwash processes that help form shoals could improve breeding success of piping plovers. On a longer-term, a habitat-based management action that protects the flood shoals and sand bars where migratory shorebirds tend to congregate foraging would contribute the most to conserve the migratory shorebird population on Fire Island as well as benefiting breeding piping plovers.

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SUMMARY REMARKS

- Based on modelling, VT estimates that there was more than 5 times the amount of suitable piping plover habitat in the study area in 2015 as there was in 2010. In 2010, when many nests were in unsuitable habitat, the Fire Island plover population was declining precipitously.
- As expected based on results of previous studies plovers quickly began using this new habitat, including restoration areas after they were built. The move to different nesting areas was especially pronounced where the beach was widened and where there was access to the bay. Overall, seventy-seven percent of immigrants, and 70% of local recruits nested in newly created habitats (i.e. overwashes, breach fill or restoration zones).
- Despite increased habitat and immigration, the population increase in the study area since the hurricane has been modest (only 12.5 %). Less than anticipated growth may have been related to generally low local and regional reproduction just before and since the storm. Twenty-five percent of adult birds die annually, and there must be enough reproduction to replace those just to maintain a stationary population. Without immigration, the population likely would have decreased as it did elsewhere in the NY-NJ recovery unit in 2012-2014.
- Although not described in this report, the habitat is vegetating in rapidly. It is not clear how much there will be available by 2017. Still local and regional reproduction was good in 2016, so it if unoccupied habitat remains, VT may see an increase in breeding plovers in 2017.
- Adult and fledgling piping plovers moved large distances to access overwash, flood shoal and mudflat habitats, some of which were not protected during migration or otherwise.
- The difference in plover reproductive output on Smith Point before and after the smith point fox die off and between Smith Point and Robert Moses after the die-off is consistent with the hypothesis that foxes have suppressed piping plover reproductive output on Fire Island. However, the relationship between fox predation rates on plovers and habitat remains to be thoroughly explored.
- Broods that had access to the bay had smaller home ranges and higher survival than broods that did not. Similarly, broods that had access to overwash habitat had higher survival, and on average, chicks that are close to fledging (ages 20-23) with access to the bay were heavier than chicks without bay access other than two lighter than average chicks at Cupsogue.
- Chick survival and reproductive output remain low in the high human use areas, Cupsogue County Park and Robert Moses State Park, relative to other areas. However, reproductive output did increase in all sites in good years, such as 2016.
- Breeding piping plovers were overall distinct in habitat use compared to other shorebirds, and foraging piping plovers used habitat similarly with other shorebirds.
- Like piping plovers, other shorebirds in the area used storm created and maintained habitat. Fifty-four percent of shorebirds tallied were on flood shoals in Old Inlet and Moriches Inlet. Birds in these areas get no protection that VT know of, therefore a habitat-based management plan would be more beneficial for migratory shorebird species rather than using piping plovers as a surrogate species.

Predator Management Considerations:

- By extrapolating red fox densities to the area available between Fire Island Inlet and Old Inlet, VT estimates a minimum red fox population size of 39 adults and 57 kits between April – September 2016.
- Red foxes were photographed at least once at every camera station in Robert Moses State Park and Fire Island National Seashore west of Old Inlet in Fall-Winter 2015, resulting in an occupancy of 1 in these two management areas.

- When the home range boundaries of GPS-collared red foxes are overlaid, in both Fall-Winter 2015 and Spring-Summer 2016, the resulting contours encompass the entire area of Fire Island west of Old Inlet, suggesting that red foxes were ubiquitous throughout all management areas during the Fall-Winter 2015 tracking period, and throughout Robert Moses State Park and Fire Island National Seashore, west of Old Inlet in Spring-Summer 2016. Red foxes on Fire Island are persisting at relatively high population densities.
- Red foxes at all management areas used multiple den sites within a breeding season, and moved between dens as the season progressed.
- VT observed 3 GPS-collared males make multiple inlet-to-inlet movements during the Fall-Winter 2015 tracking period and 1 male doing so in Spring-Summer 2016.
- VT observed an average of 4 kits per pair at Robert Moses State Park. At Fire Island National Seashore, between Watch Hill and Old Inlet, VT observed an average of 3.5 kits per pair, although one pair had 7 kits.
- All piping plover adult and brood locations west of Old Inlet in 2016 were located within the 95% kernel density home range of at least one fox, and roughly half of the monitored piping plover brood locations were located within the 50% kernel density core area of at least one fox. Based on GPS locations collected during target periods around nest exclosure and prior to hatching, collared foxes did not exhibit a clear spatial response to nest exclosure, pipping, or hatching. Fox locations appeared to be correlated to den sites for breeding individuals, and resting sites for nonbreeding individuals, with little to no visible shift in locations before vs. after target events.
- The difference in piping plover reproductive output at Smith Point County Park before and after the mange -caused fox die-off east of Old Inlet is consistent with the hypothesis that foxes have suppressed piping plover reproductive output on Fire Island. However, the increase in nest and chick survival at Robert Moses State Park between 2015 and 2016, despite no obvious decrease in fox populations, also supports the hypothesis that red fox are just one driver of plover reproductive output.
- Old Inlet appears to have prevented foxes from immediately recolonizing the Old Inlet east portion of the Seashore and Smith Point County Park, and it also prevented the spread of mange to the west of the inlet.
- The high density, ubiquitous presence to the west of Old Inlet, high reproductive output, high adult survival, presence of non-breeding floater foxes and long distance movements suggests that red fox eradication using normal methods would be difficult (if possible) and expensive.
- Although more work needs to be done, the results to date are consistent with the longstanding understanding that natural processes of overwash and breaching create and maintain piping plover habitat. Not surprisingly other shorebird species also used these habitats. Habitat restoration areas were used by plovers; but the number of breeding pairs that can be supported on these habitats remains to be discovered.

ACKNOWLEDGEMENTS

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APPENDICES

Appendix A: Injured Piping Plover Observations

Table 43. Piping plovers that were seen injured or limping after being banded on Fire Island and Westhampton Island, April - September, 2016.

Flag ID	Age of Banding	Date Banded	Subsite	First Seen Limping	Seen not limping	Comments
GF(E2T)	Second Year	6/20/2016	OIE	7/22/2016	8/3/2016	Seen several times after 8/3 still not limping.
GF(E24)	Chick	6/10/2016	CSW	6/11/2016	6/13/2016	Briefly limping following banding. Fledged ~ 7/16/16
GF(V73)	Chick	6/23/2016	SPT	8/16/2016	N/A	Only observed once so far.
GF(V34)	Chick	6/26/2016	OSS	8/15/2016	N/A	Have a photo and video. Discoloration apparent in the leg. Still at Breezy Point as of November 2016, not using flag leg.
GF(979)	Chick	6/18/2016	SPTW	8/4/2016	N/A	Only observed once.
GF(2AN)	Second Year	6/11/2016	OIW	8/2/2016	11/19/2016	Never got a complete read on this bird, but the crew said they are 90% sure of the read. Seen on Abaco – Bahamas not limping
GF(EVU)	After Second Year	6/20/2016	DMP	7/19/2016	7/20/2016	Leg not swollen and band moving fine when she was seen limping.
GF(4PK)	Chick	6/10/2016	CSW	N/A	N/A	Bird never seen limping but leg was swollen upon recapture. Band was still moving freely
GF(2PP)	Chick	6/26/2016	OSS	7/25/2016	7/26/2016	Leg was swollen upon recapture but the band was still moving freely.

**Response of Piping Plover Prey to Habitats Created by Hurricane Sandy
Final Report for 2015**

Submitted to Virginia Tech
for inclusion in report to US Fish and Wildlife Service

Submitted by
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Introduction

The piping plover (*Charadrius melodus*) is a North American shorebird which is currently federally listed as threatened and endangered (USFWS 1985). Piping plover breeding grounds are distributed along the Atlantic Coast from Canada to North Carolina, the Northern Great Plains, and the Great Lakes (Johnson and Baldassarre 1988). Populations in all breeding regions are affected by a wide range of natural and anthropogenic factors such as habitat loss due to storm activity and coastal development, predation, and human disturbance (Plissner and Haig 2000).

Recent studies have found that physical habitat changes, such as sediment composition and tidal levels, may be associated with changes in infaunal macroinvertebrate distributions and subsequent reductions in shorebird utilization of the affected habitat (Peterson et al. 2006; Spruzen et al. 2008; Bergquist et al. 2011). Some studies have suggested that loss or reductions in the densities of specific prey items can adversely affect the survival of a wide range of foraging shorebirds (Goss-Custard 1995; Stillman et al. 2005; West et al. 2007). Piping plover are visual predators whose dietary prey include infaunal and epifaunal marine invertebrates such as polychaete worms, crustaceans, and bivalve mollusks as well as insects (Nicholls 1989; Staine and Burger 1994; Zonick and Ryan 1996). Bergquist et al. (2011) investigated macroinfaunal invertebrate communities in piping plover foraging overwintering and migratory habitats and determined several organisms that may comprise the specific prey group of piping plover. Little evidence is available to determine the relationships between habitat modification, invertebrate prey communities and piping plover breeding-ground behavior.

In response to breaches created by Hurricane Sandy on Fire Island and Westhampton Island, NY in October 2012, a Breach Contingency Plan (USACE 1996) was implemented by the US Army Corps of Engineers (USACE) to evaluate and/or repair the damaged shoreline. Two of the breaches, one of which included a portion of the Narrow Bay West area, were immediately closed. The beaches of the Fire Island and Westhampton Island, NY

provide critical nesting habitat for the federally threatened/endangered piping plover, *Charadrius melodus* (DeRose-Wilson et al. 2013).

The Virginia Tech Shorebird Project has been studying piping plover populations and their associated nesting/foraging habitat at Fire Island and Westhampton Island for close to 15 years. The goal of the most recent study was to better understand the effects of breaches and breach closures on piping plover populations and the macroinvertebrate prey communities in their feeding habitats. Virginia Tech researchers collaborated with South Carolina Department of Natural Resources' (SCDNR) Environmental Research Section (ERS) on this study due to our previous research investigating the potential prey communities of piping plover in overwintering and migratory habitats in South Carolina (Bergquist et al. 2011, Coastal Eco-Group, Inc. 2014a; 2014b; 2016). This report provides a summary of the Fire Island and Westhampton Island, NY infaunal macrobenthic community, as part of Virginia Tech's larger monitoring and assessment program on piping plover.

Methodology

The study area consisted of a 17.4 km stretch of barrier islands on Fire Island and Westhampton Island, NY. Piping plover nesting and foraging habitat in the area consists of sandy beaches backed by dunes and shoals, as well as habitat created by Hurricane Sandy. Six sites were chosen for sampling: Cupsogue Mud Flats (CMF), Cupsogue Sandbar (CSB), Mussel Shoal (MUS, or Flood Shoals as identified in DeRose-Wilson et al. 2014), Narrow Bay West (NBWT1 and NBWT2), and Pattersquash Overwash (PSO) (Table 1, Figures 1-6). CMF was identified as a mudflat. CSB and MUS were identified as flood shoals. NBWT1 was identified as a filled breach. NBWT2 and PSO were identified as overwash areas (DeRose-Wilson et al. 2013). Sampling occurred within an hour before or after low tide in April of 2015. Invertebrate sampling was conducted concurrently with bird and nest surveys. At each site, thirty sampling stations were established every 10 m along a transect parallel to the water in the intertidal zone. GPS coordinates were obtained for each station. One push core (7.6 cm diameter X 10 cm deep; 0.004536 m² surface area) was collected at each station for characterization of the potential macrobenthic infaunal prey community.

The contents of each macrobenthic community core were washed through a 0.5 mm mesh sieve, and organisms and sediment retained on the sieve were preserved in a buffered solution of 10-20% formalin/seawater containing rose bengal stain. Prey organisms were sorted from retained material under a magnifying lens and stored in alcohol.

In addition, fecal samples were opportunistically collected throughout Fire Island and Westhampton Island in 2013 (n=7) and 2014 (n=37) (Figure 7). GPS coordinates were obtained for most of the fecal sampling sites. Fecal samples were preserved in alcohol.

Potential prey organisms from macrobenthic community sediment cores and fecal samples were identified and enumerated by experienced SCDNR taxonomists. Organisms from sediments were identified to the family level except for organisms from the classes of Insecta and Ostracoda, the order of Actinaria (sea anemones), and the phylum Platyhelminthes (flatworms). Meiofaunal species (such as nematodes and copepods that are not well quantified using a 0.5 mm sieve) were not recorded. Fecal sample identification is very difficult and generally does not result in quantification of the organisms. Every attempt was made to quantify the number

of organisms of each taxa in the fecal samples, if possible, but we have chosen to discuss the results as presence/absence of the taxon. A reference collection was created for the project and maintained by the Environmental Research Section at the SCDNR Marine Resources Research Institute (Charleston, SC).

All sediment benthic samples processed for sorting and taxonomy were subjected to a rigorous quality assurance (QA) process. Samples were processed in batches of ten with one random sample out of every ten samples being re-processed by an experienced SCDNR staff member (10% QA). For sorting and identification, if less than 90% of the organisms were sorted from the sieve-retained material (and more than one organism remained in the sample) or if more than 10% of the specimens in a sample were mis-identified, the entire batch were re-processed until QA was passed.

All data are stored in a Microsoft Access relational database. Multivariate statistics were used to assess the macrobenthic infaunal community. The study dataset was divided into two separate groups for analysis including: (1) total abundance of all organisms collected, and (2) a group of taxa which are thought to be important prey items or resources for piping plover. The prey items for piping plover were selected based on Bergquist et al. (2011), a previous SCDNR study, and expanded to include insects. The prey resources for this study are insects, three large, errant polychaete families (Oeononidae, Glyceridae, Nereididae), Haustoriid amphipods, and the clam *Donax* sp.

Non-metric multidimensional scaling (MDS), hierarchical cluster analysis (CLUSTER), similarity profile permutation tests (SIMPROF), and similarity percentage (SIMPER) were performed using Primer v6.1 (Primer-E Ltd. 2009). All of these tests use the taxonomic composition and relative abundances of macroinvertebrate infauna collected at each sampling event (sediment core) at each site, and then evaluate similarities and differences among these communities. For analyses involving the total macroinvertebrate infaunal community, the species matrix consisted of all taxa identified during the entire study. For analyses only involving taxa considered to serve as prey for piping plover, the species matrix consisted of all taxa listed above. Analyses were performed on site level data: the abundance of each taxa was averaged across stations within each site. Site level data were square-root transformed, a Bray-Curtis similarity resemblance matrix was calculated from the transformed data, and MDS analysis was performed on the resemblance matrix using 50 restarts (Clarke and Gorley 2006). Hierarchical cluster analysis (CLUSTER) was implemented on the same resemblance matrix to identify site community groupings, and CLUSTER similarity results were overlaid on the MDS plot (Clarke and Gorley 2006). In the MDS plots, similar communities appear closer together, while more distinct communities plot farther apart. Points that fall within a specific CLUSTER-based similarity grouping represent site communities that share at least that level of similarity with the other communities in that grouping.

To test for significant differences between the groups of communities identified in a CLUSTER analysis, similarity profile permutation tests (SIMPROF) with 999 simulations were applied (Clarke and Gorley 2006). For the SIMPROF test, the p-value was considered significant at $\alpha=0.05$; groupings of site communities that were determined to be significantly different from others are referred to as “clusters”. SIMPER was used to identify taxa responsible for similarity among samples within groups of sites, as well as taxa responsible for dissimilarity between samples from two different groups of sites.

RESULTS

Fecal samples from Fire Island and Westhampton Island were found to contain representatives from phyla Arthropoda and Annelida (Table 2). Every sample contained an identifiable organism or fragment of an organism with at least one insect taxon observed in all 44 fecal samples. The marine-related taxa were found in only 14 (33%) of the samples. Six identifiable families and one unidentifiable Insecta group were observed in the fecal samples. The Insect unidentifiable group was found in 24 of the 44 samples. The insect families identified included two samples with Formicidae (ants), 22 samples with Coleoptera (beetles), and one each with Lepidoptera (butterflies/moths), Scarabaeidae (scarab beetles), Diptera (true flies), and Curculionidae (true weevils). Other Arthropods found in the fecal samples included Limulidae (horseshoe crab) eggs (7 samples) and larva (1 sample) as well as evidence of Acarina (spider, 1 sample), and Natantia (shrimp-like decapod, 1 sample). Two polychaete families (Nereididae and Sabellidae) and a nondescript polychaete group were also observed in the fecal matter (Table 2). Nereididae is one of the polychaete families previously identified as prey items for piping plover in South Carolina (Bergquist et al. 2011) and was included in the prey items from this study. Worms from the family Sabellidae are relatively small tube-building polychaetes and not likely to be a major food resource. Therefore, they have not been included as a prey resource for this study.

If each piping plover fecal sample is considered separately then 34%, 39%, and 20% of the samples contained evidence of only one, two or three different taxa, respectively. Three fecal samples contained more than three taxa, with a maximum of four, five, and six taxa observed. These results do not comprehensively reflect piping plover prey resources as soft-bodied organisms were likely under-represented due to digestion processes. Sample sizes were different in 2013 and 2014; however, all seven of the samples from 2013 contained at least three taxa including the two samples that contained five and six taxa.

A total of 51 macrobenthic taxa were identified in the 198 samples collected from the six areas in 2015 (Table 3). The sites varied with regard to average density with the lowest values (3,743/m² and 7,216/m²) observed at the two flood shoal sites (CSB and MUS, respectively) and the highest values (24,535/m² and 26,872/m²) observed at the two overwash sites (PSO and NBWT2, respectively) (Table 3, Figure 8). The average densities at the mud flat site (CMF) and the filled breach site (NBWT1) were found to be 17,679/m² and 21,138/m², respectively. The number of taxa was highest at the CMF (mud flat) site, with 38 unique taxa (family/class level) observed, followed by the PSO (overwash) site with 30 unique taxa. NBWT1 and NBWT2 had the same number of unique taxa with 25 each. The number of unique taxa at MUS and CSB (flood shoal) sites was similar with 18 and 19, respectively (Table 3).

The average densities of piping plover prey items ranged from a high at CMF of 802/m² compared to the lowest at CSB and MUS of 33/m² and 79/m², respectively (Table 4, Figure 9). The next highest site was PSO with a value of 441/m², followed by similar densities of 187/m² and 220/m² at NBWT2 and NBWT1, respectively. These sites are adjacent to each other and appear to have similar benthic communities based on April 2015 sampling, approximately two years after NBWT1 was filled. The polychaete family Nereididae comprised the highest proportion of prey taxa, ranging from 85-97% of the abundance for CMF, PSO, NBWT1, and NBWT2 (Figure 9). In comparison, amphipods from the family Haustoriidae represented the highest proportion, ranging from 60-100%, at the two flood shoal sites (CSB and MUS).

The multivariate analysis of the total macroinvertebrate infauna communities at the six sites sampled in April 2015 had a shared similarity of 26.9% (Figure 10A). Hierarchical cluster analysis (CLUSTER) identified three

clusters among the site-specific communities: MUS/CSB, CMF, and NBWT1/NBWT2/PSO (Figure 10). The two flood shoal communities (MUS/CSB) had a shared similarity of 52.9%, and were significantly different (SIMPROF $p = 0.001$) from the other four communities (CMF/NBWT1/NBWT2/PSO), which had a shared similarity of 49.3%. The difference in the community composition of the flood shoal community cluster versus the non-flood-shoal group of communities is represented by their separation from each other in the non-metric multidimensional scaling plot (MDS plot, Figure 10B). Among the non-flood-shoal communities, the mud flat community (CMF) was significantly different (SIMPROF $p = 0.001$) from the filled breach and overwash communities (NBWT1 and NBWT2/PSO, respectively), which had a shared similarity of 69.6% (Figure 10). Based on the MDS plot, no macrobenthic infaunal community groupings were apparent among sites where piping plover were observed, or among sites where piping plover were not observed.

The contribution of individual taxa to the similarity among sites within each primary community cluster (flood shoal versus non-flood-shoal), as well as to the dissimilarity between the two clusters, was determined using the “similarity percentages” (SIMPER) routine (Table 5). SIMPER analysis showed that the bivalve families Mytilidae and Cyrenidae; Orbiniid polychaetes; Tubificid oligochaetes; Ostracoda; and Haustoriid amphipods were among the taxa that typified the flood shoal site communities. The taxa that typified the non-flood-shoal site communities included Cyrenid bivalves; Tubificid oligochaetes; Lumbrinerid, Orbiniid, Syllid, and Nereidid polychaetes; and Corophiid amphipods. The dissimilarity between the flood shoal and non-flood-shoal communities was driven primarily by differences in average abundances of the bivalve families Cyrenidae and Mytilidae; Tubificid and Enchytraeid oligochaetes; Lumbrinerid, Orbiniid, Syllid, and Nereidid polychaetes; and Corophiid amphipods (Table 5).

As observed among the total macroinvertebrate infauna communities, the piping plover prey communities at the flood shoal sites (MUS/CSB) were quite distinct from the piping plover prey communities at the non-flood-shoal sites (NBWT1/NBWT2/CMF/PSO), with a shared similarity of only 5.25% among the six communities (Figure 11A). Despite the low similarity observed between the flood shoal and non-flood-shoal prey communities, the two groups were not significantly different (SIMPROF $p = 0.09$). The piping plover prey subsets of the two flood shoal communities (MUS/CSB) had a shared similarity of 48.1%, and the four non-flood-shoal communities (CMF/NBWT1/NBWT2/PSO) had a shared similarity of 67.0%. Among the non-flood-shoal sites, the piping plover prey communities formed two sub-groups: NBWT1/NBWT2 (filled breach/overwash; 71.7% shared similarity), where piping plover were not observed during April 2015 shorebird surveys, and CMF/PSO (mud flat/overwash; 84.4% shared similarity), where piping plover were observed during surveys (MDS plot, Figure 11B).

Discussion

The macrobenthic infaunal communities at the two flood shoal sites were similar to each other and different from the communities at the non-flood shoal sites. The two flood shoal sites had lower total densities, lower family richness, lower polychaete densities, and higher Haustoriid amphipod densities compared to the non-flood shoal sites. In addition, the piping plover prey resources available at the flood shoal sites were low and consisted primarily of Haustoriid amphipods, in contrast to the polychaete dominated prey resource observed at the non-flood shoal sites.

The two sites with the highest densities of prey resources were also two of the three sites where piping plover were observed during shorebird surveys in April 2015; however, the third site where piping plover were observed in April 2015 was also the site with the lowest observed density of piping plover prey items. Marine macrobenthos along Fire Island and Westhampton Island are likely influenced by location within the intertidal area, sediment composition, perturbation (e.g., wave energy), and predation. Piping plover distribution may be related to parental and social behavior, weather conditions, nesting success, disturbance, predation, and human/dog proximity (DeRose-Wilson et al. 2014; Murchison et al. 2016). Environmental factors that vary among the different habitats include geographical location, exposure, tidal stage and inundation, vegetative cover, surficial sediment characteristics, proximity to structures, and proximity to disturbance. All of these variables are likely influencing both the macrobenthic community and the piping plover usage of an area.

Staine and Burger (1994) found that nocturnal foraging in the intertidal area was explained by tidal stage, year, and breeding cycle stage. They observed the highest feeding rates around low tide and also observed that feeding occurred more frequently in areas with polychaete worms than in other areas where polychaete worms were less abundant. Piping plover have also been observed more frequently in areas with higher polychaete abundance, particularly the Nereididae, Oeonidae, and Glyceridae, on the overwintering grounds of SC (Sanger unpublished data; Coastal Eco-Group, Inc. 2016).

The invertebrates observed in piping plover fecal matter comprised representatives from two phyla, Arthropoda and Annelida. The arthropods were the dominant organisms (or fragments of organisms) observed, with insects being the most numerous type of arthropods. Horseshoe crab eggs and larvae, spiders, and shrimp-like decapods were the other arthropods observed in the fecal samples. Two families of polychaetes, Nereididae and Sabellidae, were also observed in the fecal samples. In general, these organisms have been identified as piping plover prey resources in other studies (e.g., Staine and Burger 1994; Cuthbert et al. 1999; Bergquist et al. 2011; Cisek 2012). Previous studies have generally identified polychaete worms, insects, crustaceans and mollusks as prey resources. No evidence of mollusks was found in the fecal matter of this study; however, evidence of *Donax* sp. have been observed in fecal samples from overwintering and migrating piping plover in SC (Bergquist et al. 2011).

Arthropods, particularly the insect taxa are likely over-represented in comparison to soft-bodied annelid taxa which may be under-represented in this study as many of their identifiable characteristics are destroyed by digestive processing. In addition, avian gizzards likely destroy polychaete setae (the only structures to survive digestion for some polychaete species) and amphipod integument beyond recognition. Future efforts to assess available piping plover stomach contents as well as using new techniques such as DNA barcode sequencing in combination with traditional taxonomic identifications will provide further information about their preferred prey resources and all potential prey resources. This additional information as well as additional supporting information from the scientific literature will allow for a more comprehensive list to be developed in the future.

In addition, future efforts should focus on connecting terrestrial and marine invertebrate sampling to further understand the feeding strategies of piping plover. It is also of interest to assess use of the study areas by other shorebird species to better understand the potential predation of marine macrobenthos and impacts on piping plover prey abundances by other shorebirds. For example, three Dunlin (*Calidris alpina*) stomachs obtained in SC were found to contain a significant number of Nereidid jaws, with 354 and 469 jaw halves

observed in two of the stomachs (Sanders and Levisen unpublished data). This level of predation is significant when considering the findings of this study, which found a high of approximately 776 Nereididae per square meter at the Cupsogue Mud Flats site.

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Table 1. Sampling site name, general habitat description, transect length for macrobenthic sampling, maximum number of piping plover (PIPL), and PIPL survey length for each site sampled in the 2015 macrobenthic study. The number of PIPL represents the maximum number of PIPL observed on any one of the survey days in April, 2015. The maximum number of PIPL for NBWT1 and NBWT2 was based on shorebird surveys for the NBW unit, and for MUS was based on the Flood Shoal area, as identified in DeRose-Wilson et al. (2014).

Name	Subsite Code	Year Sampled	Description	Habitat Type	Habitat Type Year	Transect Length (m)	# PIPL (max)	Survey Length (m)
Cupsogue Mud Flats	CMF	2015	Mud flats north of the Cupsogue parking lot, and south of the high bare island in Moriches Bay.	Mud flat	2001	310	10	2,840
Cupsogue Sandbar	CSB	2015	Large low energy sandbar/shoal north of Cupsogue West Beach and narrow strip of bayside intertidal zone at east end of the Cupsogue Beach County	Flood shoal	2001	333	7	1,630
Mussel Shoal	MUS	2015	Flood shoal just west of the old inlet, on the bay side. A component of the Flood Shoals (FS) system.	Flood shoal	2012	361	0	2,260
Narrow Bay West - Filled Breach	NBWT1	2015	Small breach-fill area west of the Hazardous Area.	Filled breach	2012	322	0	510
Narrow Bay West - Overwash	NBWT2	2015	Overwash west of the Hazardous Area.	Overwash	2012	331	0	510
Pattersquash Overwash	PSO	2015	Overwash west of Pattersquash East, has marshy spots, on the bay side.	Overwash	2012	322	2	1,880

Table 2. The number of fecal samples containing each taxon observed in the fecal samples (n=44).

Category	Phylum	Taxon	# of Fecal Samples Containing Taxon
polychaete	Annelida	Nereididae	3
polychaete	Annelida	Polychaeta	2
polychaete	Annelida	Sabellidae	1
decapod (shrimp-like)	Arthropoda	Natantia (shrimp-like decapod)	1
horseshoe crab	Arthropoda	Limulidae egg	7
horseshoe crab	Arthropoda	Limulidae larva	1
arachnid	Arthropoda	Acarina	1
insect (no distinguishing parts)	Arthropoda	Insecta (insect like)	24
insect (ants)	Arthropoda	Formicidae	2
insect (beetles)	Arthropoda	Coleoptera	22
insect (butterflies/moths)	Arthropoda	Lepidoptera	1
insect (scarab beetles)	Arthropoda	Scarabaeidae	1
insect (true flies)	Arthropoda	Diptera	1
insect (true weevils)	Arthropoda	Curculionidae	1

Table 3. The average density (#/m²) of each macrobenthic taxon collected for each study site. A total of 33 samples were collected from each site in April 2015.

Phylum	Category	Taxonomist Classification	April 2015 Average Density (#/m ²) by Site & Habitat Type					
			CMF	CSB	MUS	NBWT1	NBWT2	PSO
			Mud Flat	Flood Shoal		Filled Breach	Overwash	
Annelida	oligochaete	Enchytraeidae	3,768	154	7	20	33	79
		Tubificidae	280	20	93	4,295	855	2,820
	polychaete	Ampharetidae	66	20	7	0	0	0
		Capitellidae	121	73	66	148	53	154
		Chaetopteridae	7	0	0	7	7	7
		Cirratulidae	187	0	0	128	20	134
		Glyceridae	13	0	0	0	7	13
		Lumbrineridae	2,820	13	0	816	1,116	602
		Maldanidae	1,938	20	0	7	0	0
		Nephtyidae	0	0	26	20	0	0
		Nereididae	776	0	0	187	181	421
		Oeonidae	0	7	0	0	0	0
		Orbiniidae	93	300	73	615	941	128
		Paraonidae	20	66	20	7	7	0
		Pectinariidae	7	0	0	0	0	0
		Phyllodocidae	293	93	0	134	33	134
		Spionidae	734	0	13	106	20	26
		Syllidae	2,518	40	13	842	428	562
Arthropoda	amphipod	Ampeliscidae	20	0	0	0	7	7
		Aoridae	0	0	0	7	13	115
		Corophiidae	60	0	20	4,416	747	2,063
		Haustoriidae	0	20	79	0	0	0
		Liljeborgiidae	13	0	0	0	0	0
		Lysianassidae	7	0	0	7	0	7
		Oedicerotidae	7	0	0	0	0	0
		Phoxocephalidae	40	0	0	0	26	174
	cumacean (hooded shrimp)	Cumacea	0	0	0	0	7	0
		Diastylidae	7	0	0	0	0	0
	decapod (true crab)	Pinnotheridae	7	0	0	0	0	0
	horseshoe crab	Limulidae	7	0	0	7	0	0
	insect	Insecta	7	7	0	26	0	7
	isopod	Idoteidae	20	0	0	0	7	128
		Sphaeromatidae	0	0	0	0	13	2,332
	ostracod (seed shrimp)	Ostracoda	20	26	441	99	73	154
	pycnogonid (sea spider)	Phoxichilidiidae	0	7	0	0	0	93
	tanaid	Leptocheliidae	0	0	0	7	0	981
		Tanaidacea	0	0	0	0	0	7
Cnidaria	cnidarian	Actiniaria	7	0	0	40	0	79
Mollusca	bivalve	Cyrenidae	3,333	915	26	9,173	22,253	13,214
		Mytilidae	93	1,951	6,226	13	7	13
		Pelecypoda	148	0	40	0	0	0
		Solemyidae	7	0	0	0	0	0
		Solenidae	0	0	7	0	0	0
		Tellinidae	13	7	26	0	0	0
	gastropod	Acteonidae	0	0	0	0	7	0
		Crepidulidae	0	0	0	13	0	0
		Hydrobiidae	0	0	0	0	0	7
		Littorinidae	40	0	0	0	0	0
		Nassariidae	60	7	0	0	13	46
Nemertea	nemertean worm	Nemertea	13	0	33	0	0	26
Platyhelminthes	flatworm	Platyhelminthes	115	0	0	0	0	0
Total (#/m ²)			17,679	3,743	7,216	21,138	26,872	24,535
Number of Taxa			38	19	18	25	25	30

Table 4. The average density of each macrobenthic taxon considered to be a Piping Plover prey item, by study site.

Phylum	Category	Taxonomist Classification	April 2015 Average Density (#/m ²) by Site & Habitat Type					
			CMF	CSB	MUS	NBWT1	NBWT2	PSO
			Mud Flat	Flood Shoal		Filled Breach	Overwash	
Annelida	polychaete	Glyceridae	13	0	0	0	7	13
		Nereididae	776	0	0	187	181	421
		Oenonidae	0	7	0	0	0	0
Arthropoda	amphipod	Haustoriidae	0	20	79	0	0	0
	horseshoe crab	Limulidae	7	0	0	7	0	0
	insect	Insecta	7	7	0	26	0	7
Total (#/m²)			802	33	79	220	187	441
Number of Taxa			4	3	1	3	2	3

Table 5. Taxa found, based on SIMPER analysis, to be most responsible for the similarity among flood shoal sites, for the similarity among other sites, and for the dissimilarity between flood shoal sites and other sites. Included is percent contribution of each taxon to overall similarity or dissimilarity; only those taxa contributing 2% or more are shown.

Taxa most characteristic of:				Taxa most responsible for dissimilarity	
Flood Shoal sites		Other sites			
Taxon	% Contr.	Taxon	% Contr.	Taxon	% Contr.
Mytilidae	34.01	Cyrenidae	48.49	Cyrenidae	24.19
Cyrenidae	30.03	Tubificidae	13.98	Tubificidae	10.97
Orbiniidae	16.33	Lumbrineridae	8.78	Mytilidae	8.19
Tubificidae	5.28	Orbiniidae	6.71	Lumbrineridae	7.31
Ostracoda	3.43	Syllidae	5.68	Orbiniidae	5.77
Haustoriidae	2.83	Nereididae	4.17	Syllidae	5.43
		Corophiidae	3.25	Corophiidae	5.41
				Enchytraeidae	4.44
				Nereididae	3.74
				Capitellidae	2.82
				Phyllodocidae	2.80
				Maldanidae	2.79
				Ostracoda	2.50

Average similarity	20.20%	Average similarity	37.61%	Average dissimilarity	85.77%
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Figure 1. Map of the study area and 2015 sampling sites used for this study. Base map source: 2013 NYGIS Orthoimagery.

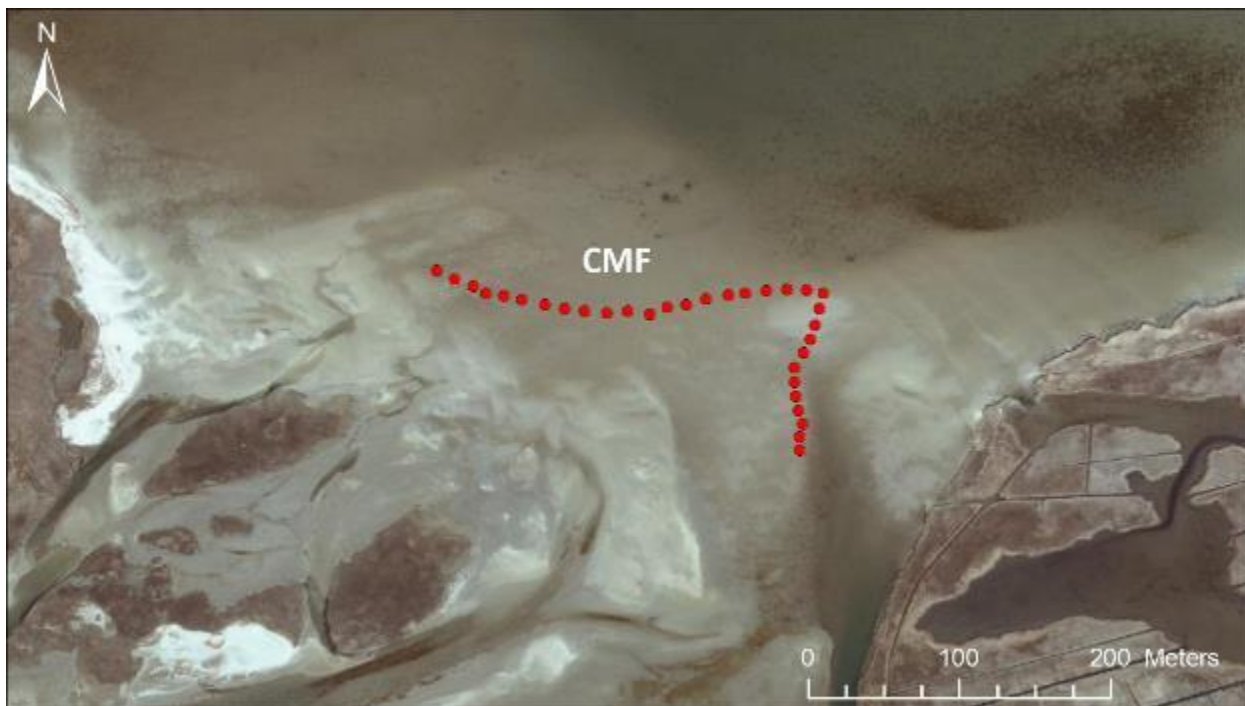


Figure 2. Map of the Cupsogue Mud Flats (CMF) study area and 2015 sampling stations used for this study. Base map source: 2015 NAIP USDA Farm Service Imagery.

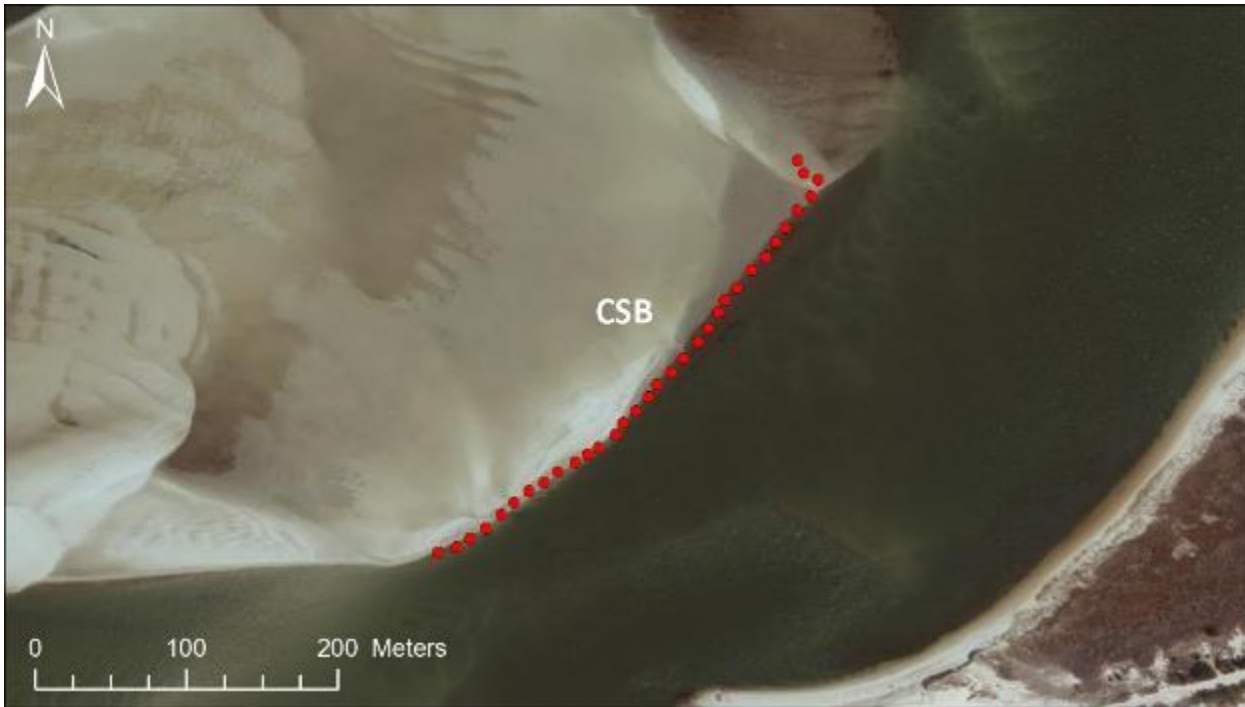


Figure 3. Map of the Cupsogue Sand Flats (CSB) study area and 2015 sampling stations used for this study. Base map source: 2015 NAIP USDA Farm Service Imagery.



Figure 4. Map of the Mussel Shoal (MUS) study area and 2015 sampling stations used for this study. Base map source: 2015 NAIP USDA Farm Service Imagery.



Figure 5. Map of the Narrow Bay West Filled Breach (NBWT1, red circles) and Overwash (NBWT2, blue circles) study area and 2015 sampling stations used for this study. Base map source: 2015 NAIP USDA Farm Service Imagery.

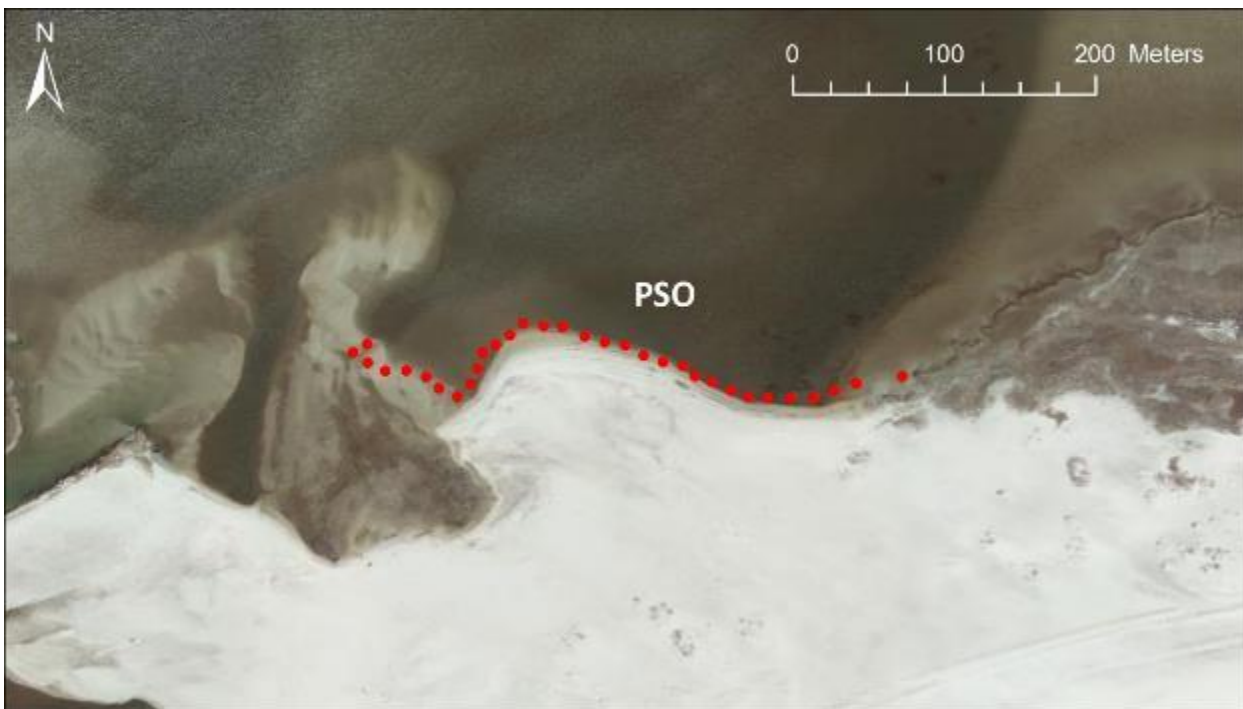


Figure 6. Map of the Pattersquash Overwash (PSO) study area and 2015 sampling stations used for this study. Base map source: 2015 NAIP USDA Farm Service Imagery.



Figure 7. Map of the macrobenthic sampling sites (clusters of white circles) and fecal sampling sites (pink circles) used in this study. Base map source: 2015 NAIP USDA Farm Service Imagery.

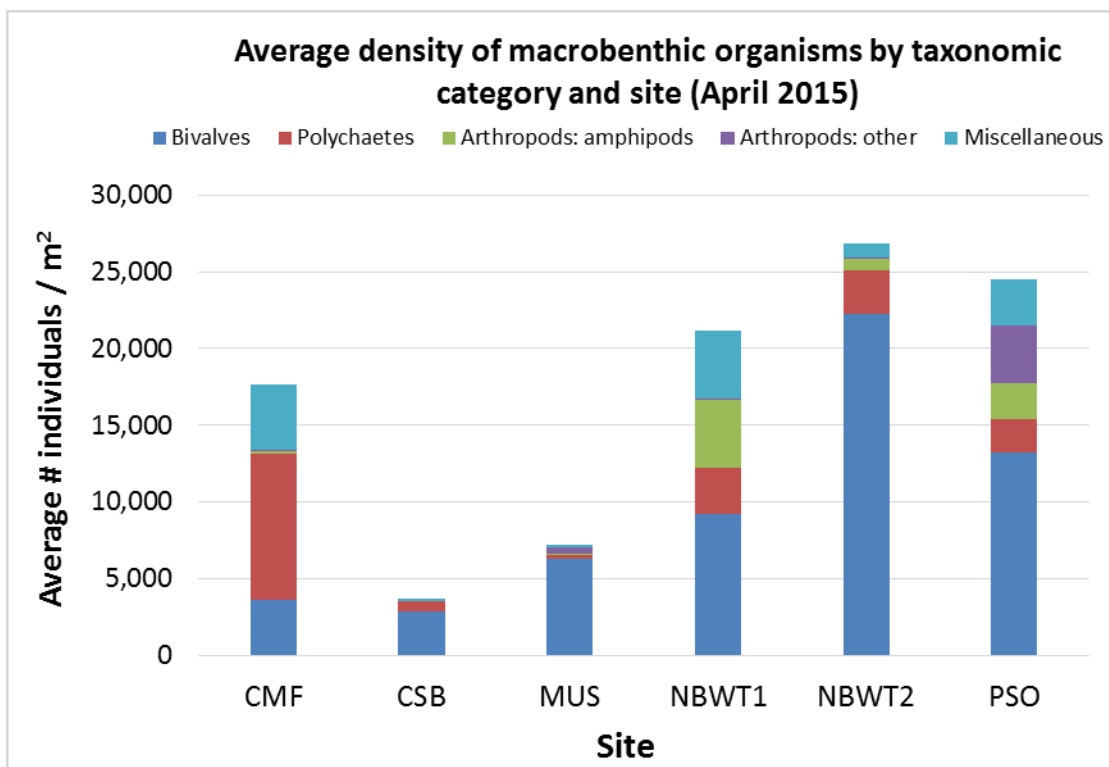


Figure 8. The average density ($\#/m^2$) of macrobenthic taxa by category for the six study sites.

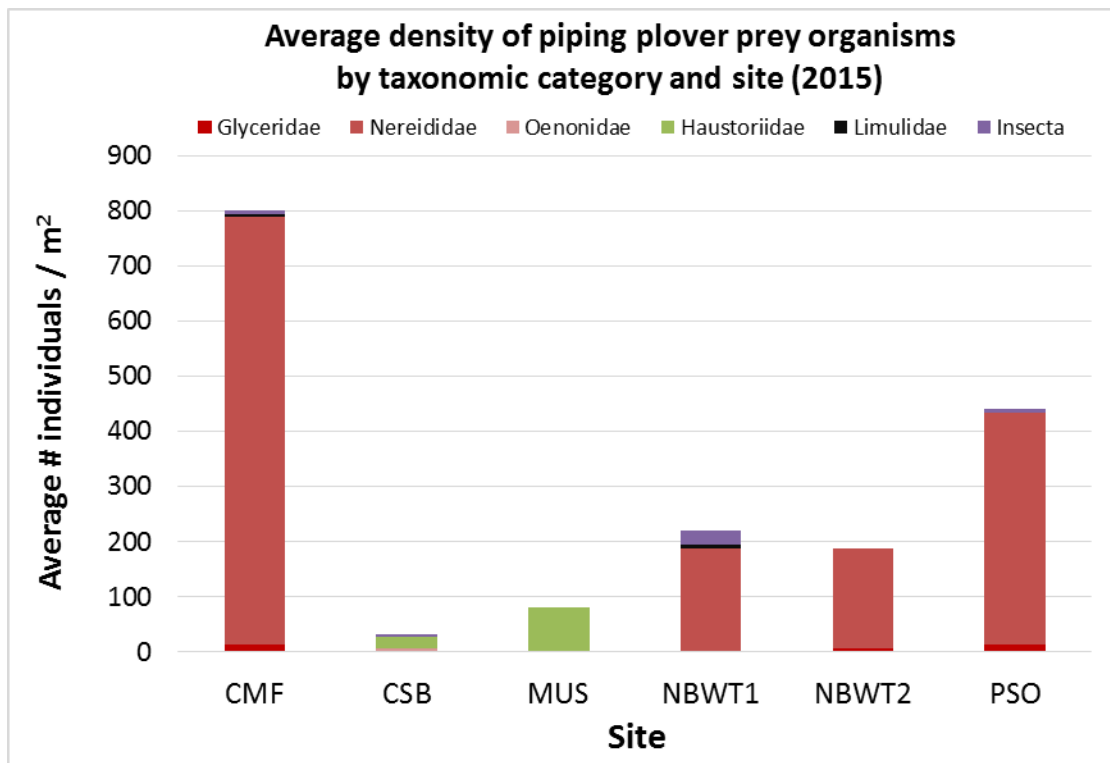
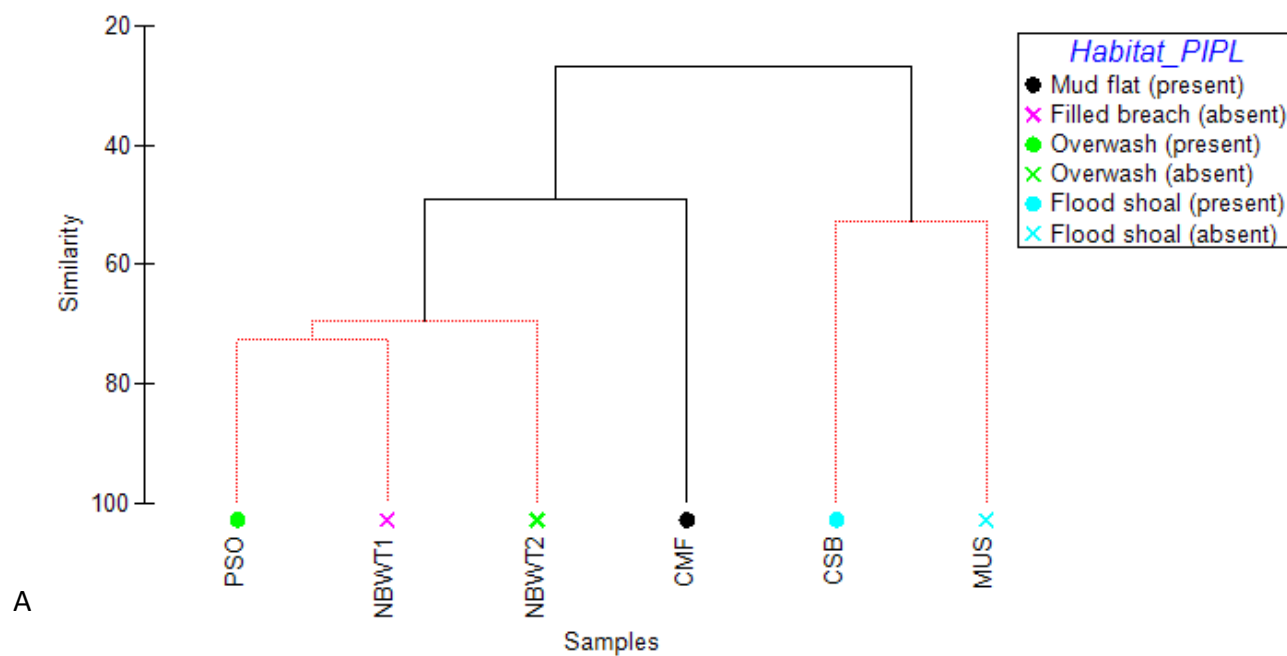


Figure 9. The average density ($\#/m^2$) for each piping plover prey item for the six study sites.



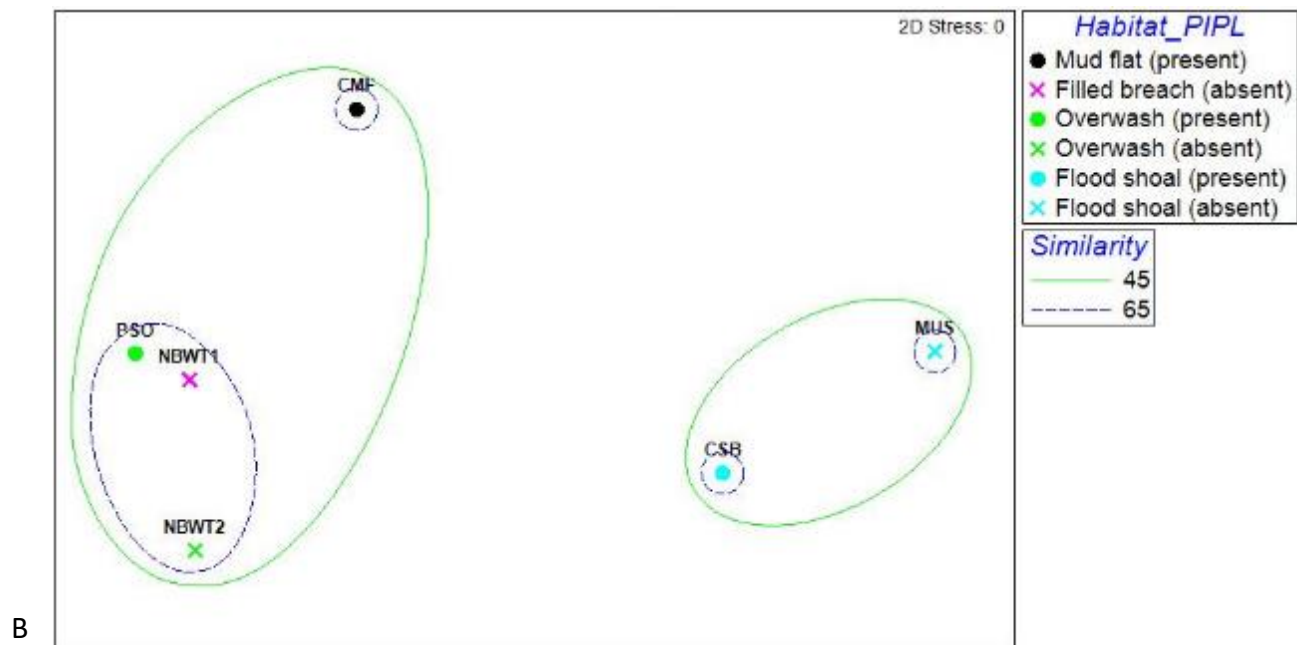
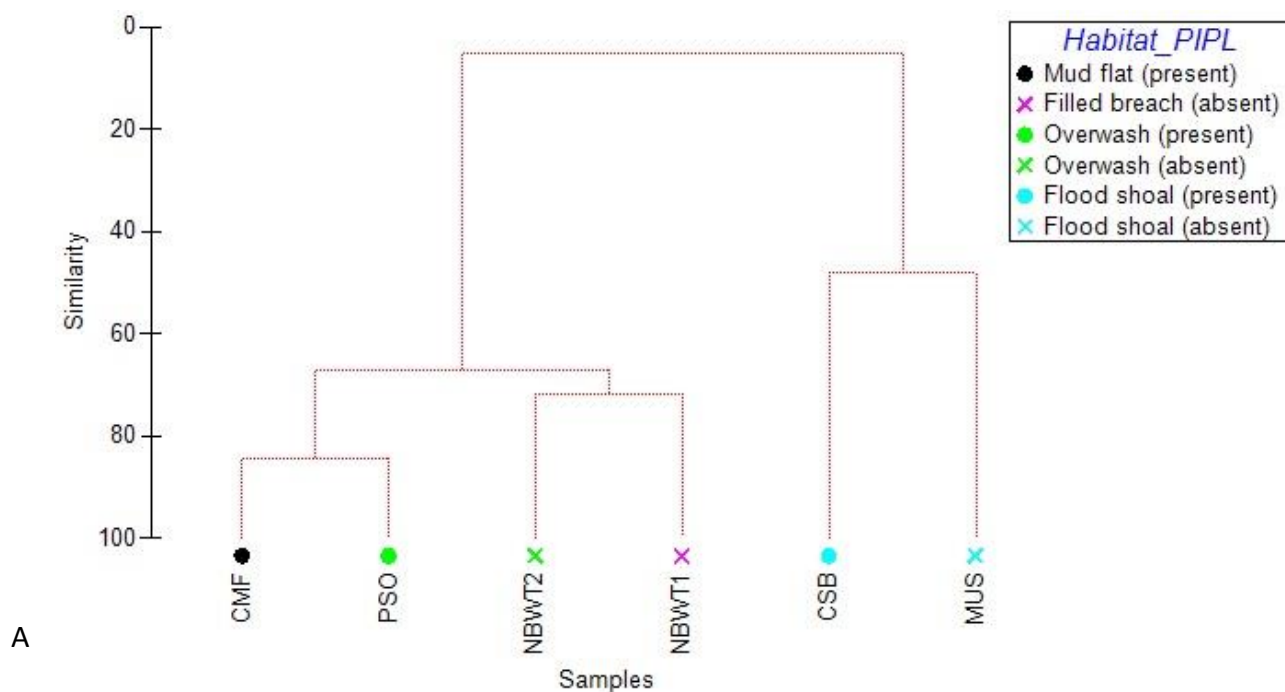


Figure 10. CLUSTER tree (A) and MDS ordination plots (B) of total macroinvertebrate infaunal community structure averaged for each of the six sites sampled in April 2015. MDS similarity lines are based on CLUSTER results. Symbol color represents habitat type, and symbol shape represents whether piping plover were observed (filled circles) or not observed ("X") during April 2015 shorebird surveys.



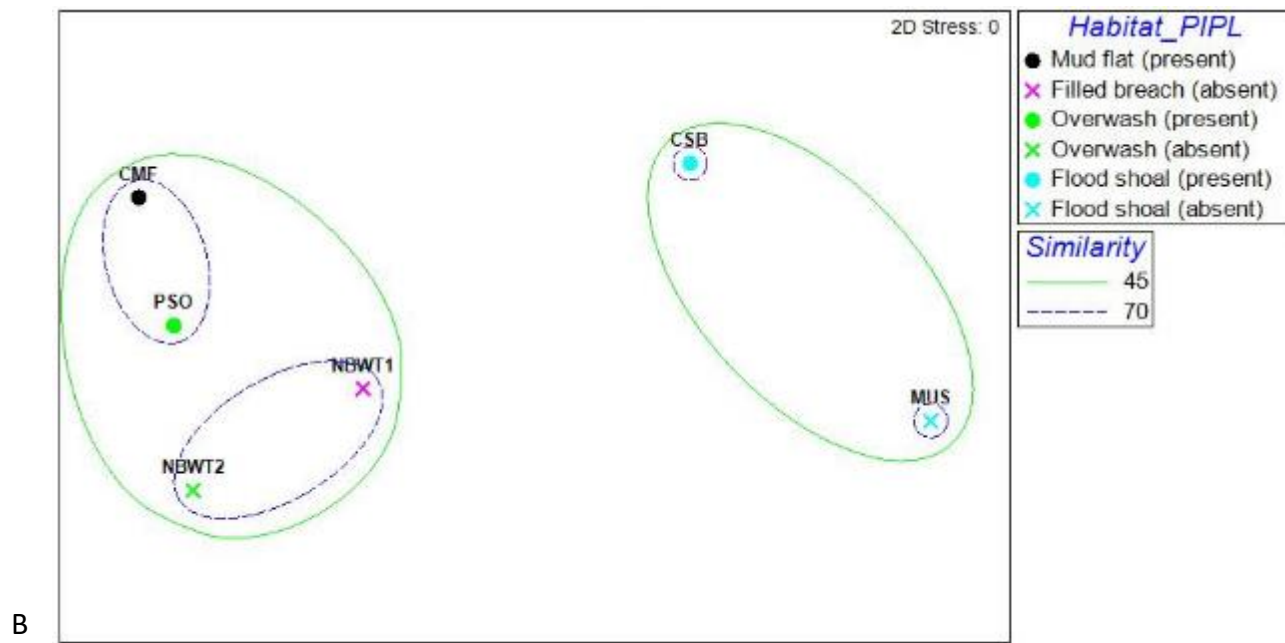


Figure 11. CLUSTER tree (A) and MDS ordination plots (B) of the piping plover prey subset of macroinvertebrate infaunal community structure averaged for each of the six sites sampled in April 2015. MDS similarity lines are based on CLUSTER results. Symbol color represents habitat type, and symbol shape represents whether piping plover were observed (filled circles) or not observed ("X") during April 2015 shorebird surveys.

Appendix C: Fox Home Range Maps

Individual home range maps and for all GPS collared foxes tracked during Fall 2015-Winter 2016 and Spring-Summer 2016 are shown below, grouped by sex and study area. We also show 50% and 95% kernel contours for all tracked foxes in each study area and tracking period overlaid on top of each other, to show broader patterns of area use among the overall sample population.

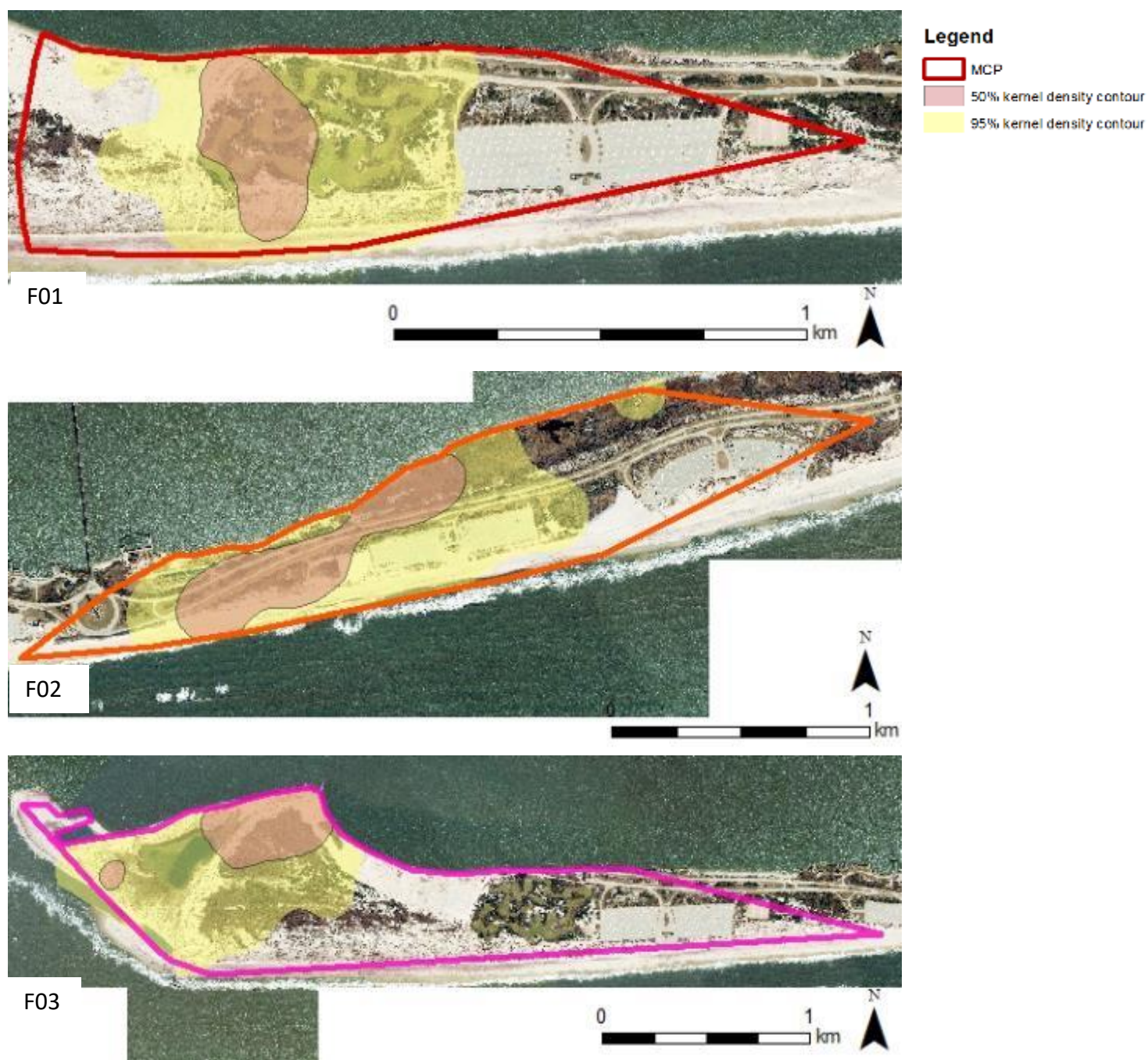
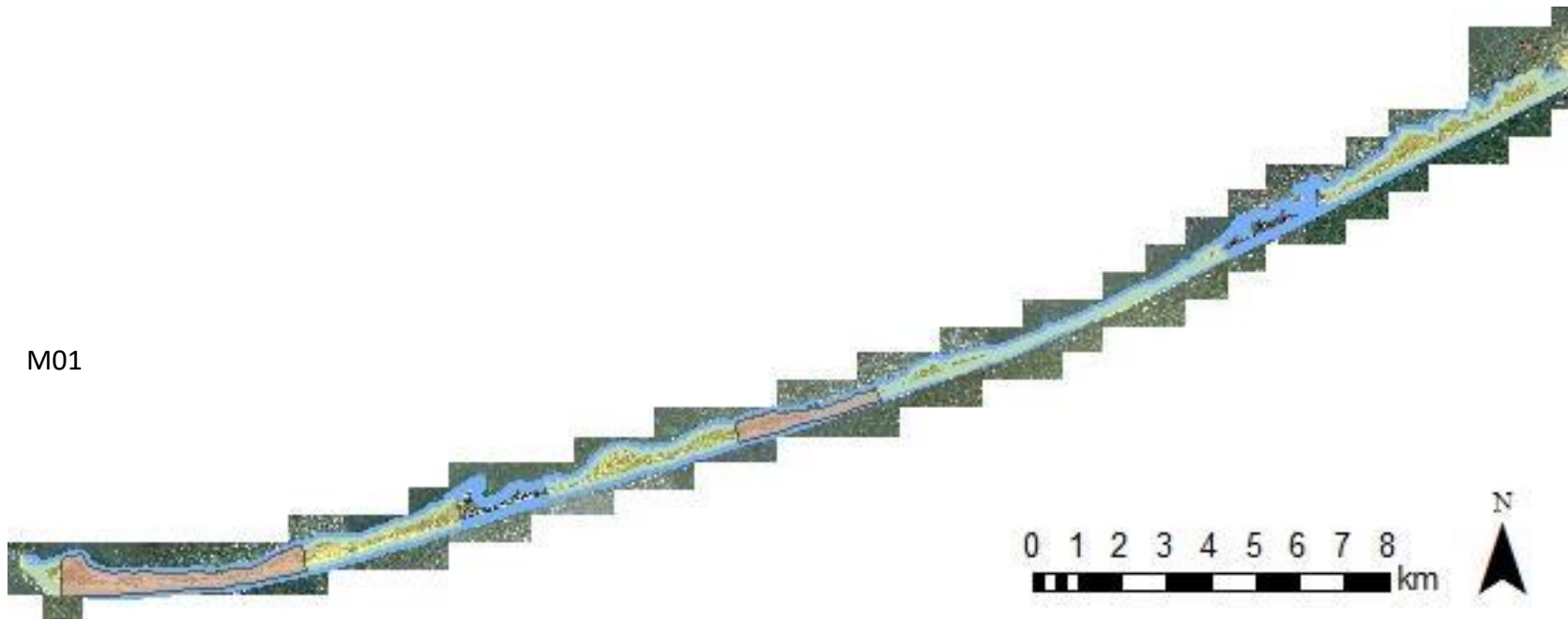


Figure 60. MCPs (outlined in different colors for different foxes), 50% and 95% kernel density contours for 3 female red foxes at Robert Moses State Park, Fall-Winter 2015.

M01



Legend

-  MCP
-  50% kernel density contour
-  95% kernel density contour

M02

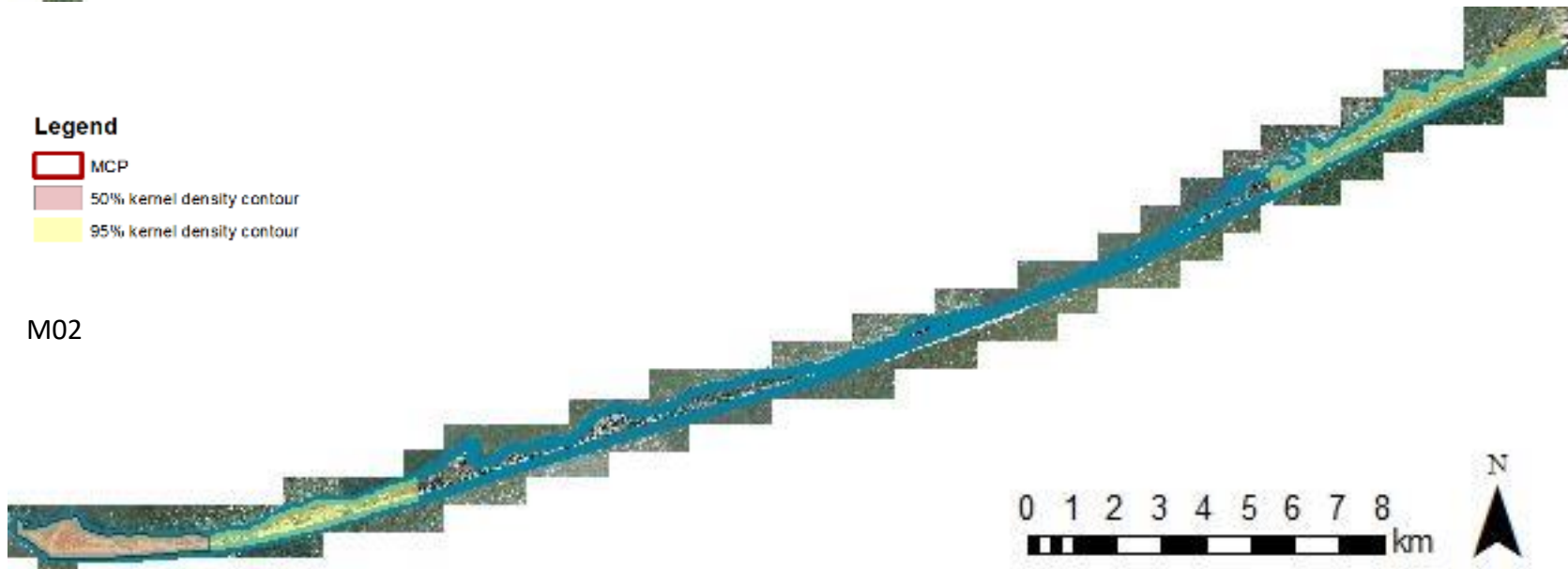


Figure 61. MCPs (outlined in different colors for different foxes), 50% and 95% kernel density contours for 2 male red foxes originally captured at Robert Moses State Park during Fall-Winter 2015.

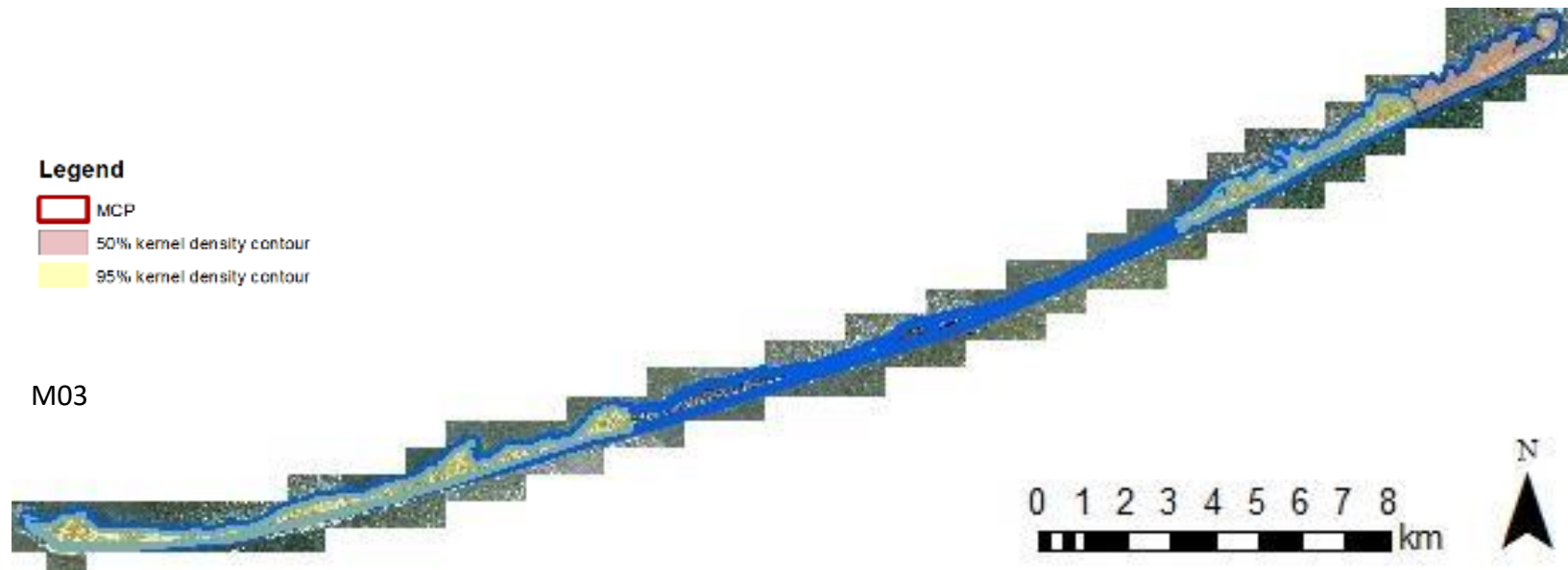


Figure 62. MCP (outlined in different colors for different foxes), 50% and 95% kernel density contour for 1 male red fox originally collared at Fire Island National Seashore in Fall-Winter 2015.

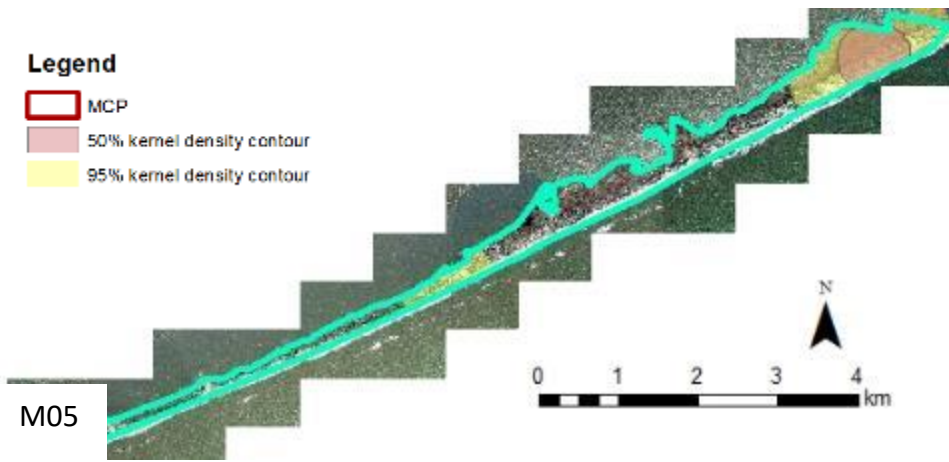


Figure 63. MCP (outlined in different colors for different foxes), 50% and 95% kernel density contour for 1 male red fox at Fire Island National Seashore in Fall-Winter 2015.

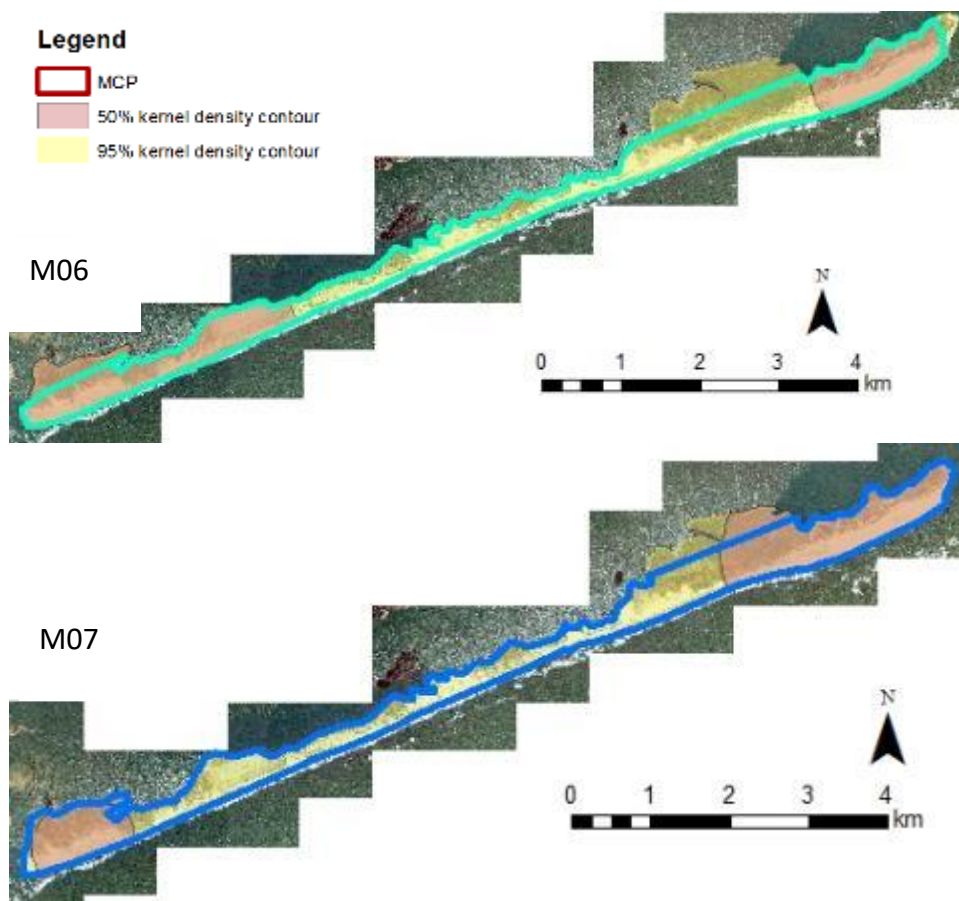


Figure 64. MCPs (outlined in different colors for different foxes), 50% and 95% kernel density contour for 2 male red foxes at Fire Island National Seashore (Old Inlet East) and Smith Point County Park in Fall-Winter 2015

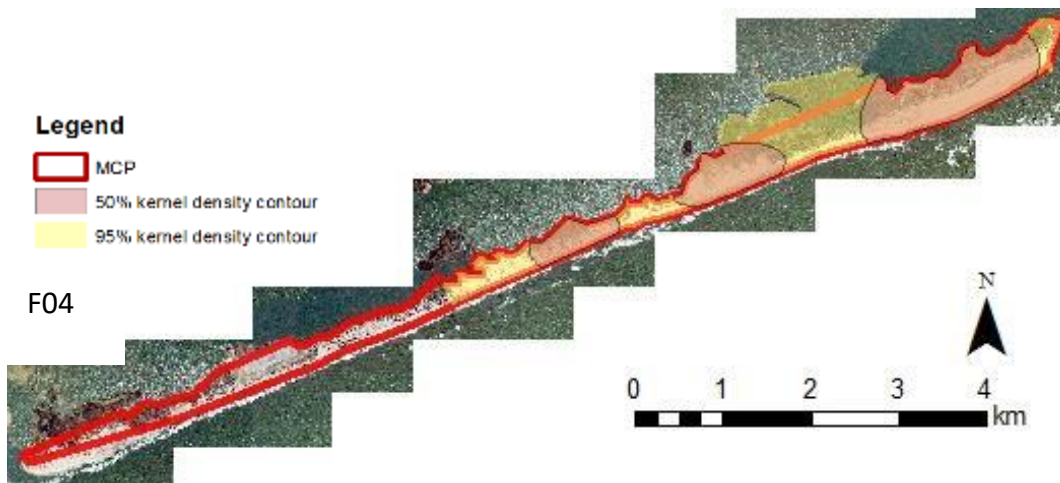


Figure 65. MCP (outlined in different colors for different foxes), 50% and 95% kernel density contour for 1 female red fox at Fire Island National Seashore (Old Inlet East) and Smith Point County Park in Fall-Winter 2015.

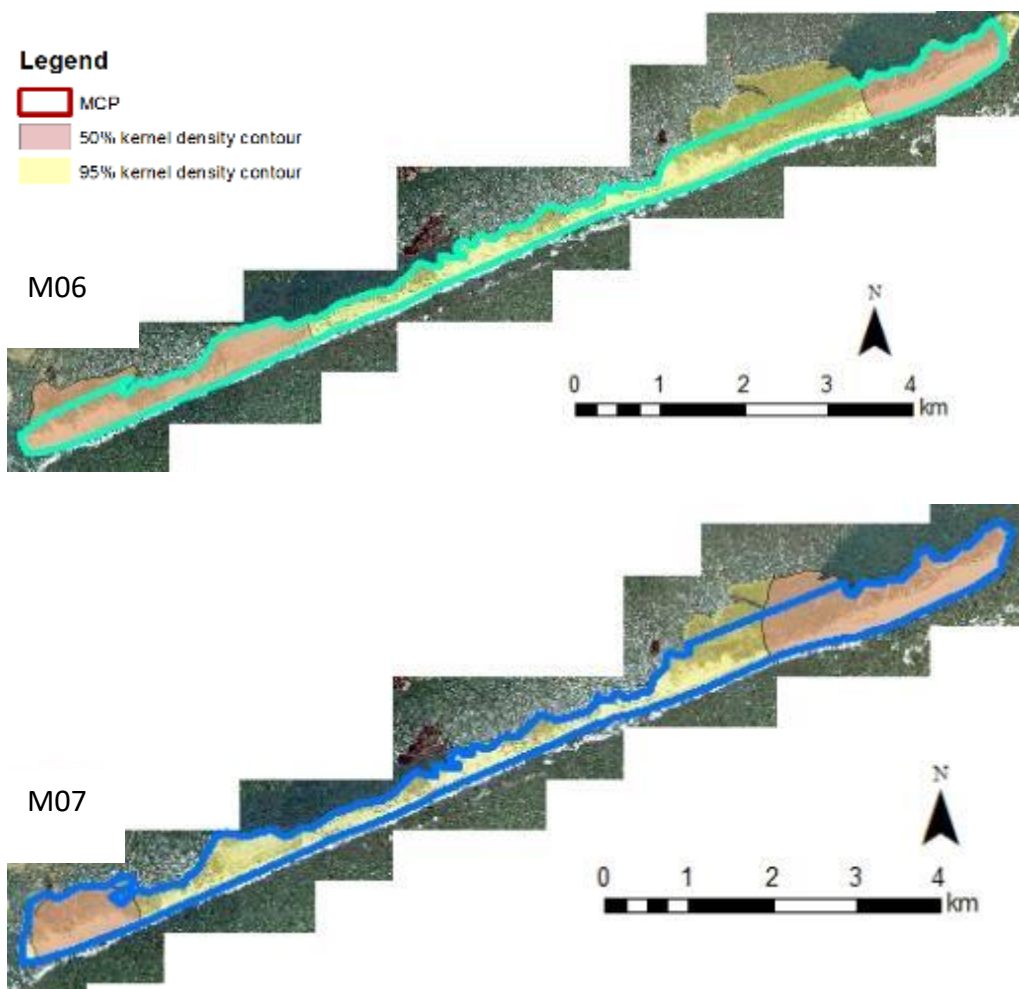


Figure 66. MCPs (outlined in different colors for different foxes), 50% and 95% kernel density contour for 2 male red foxes at Fire Island National Seashore (Old Inlet East) and Smith Point County Park in Fall-Winter 2015.

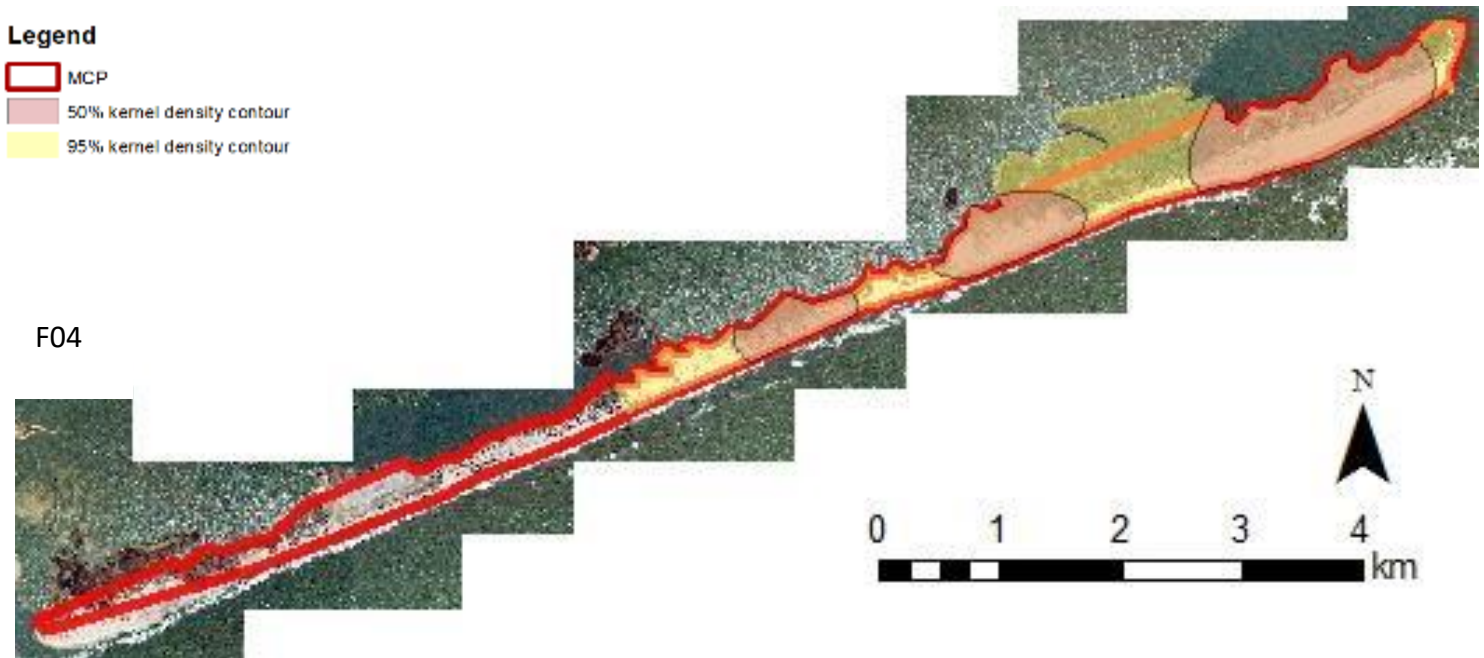


Figure 67. MCP (outlined in different colors for different foxes), 50% and 95% kernel density contour for 1 female red fox at Fire Island National Seashore (Old Inlet East) and Smith Point County Park in Fall-Winter 2015.



Figure 68. 50% and 95% kernel density contours for all GPS-collared red foxes in Fall-Winter 2015 at Robert Moses State Park and Fire Island National Seashore Lighthouse Tract overlaid on top of each other.

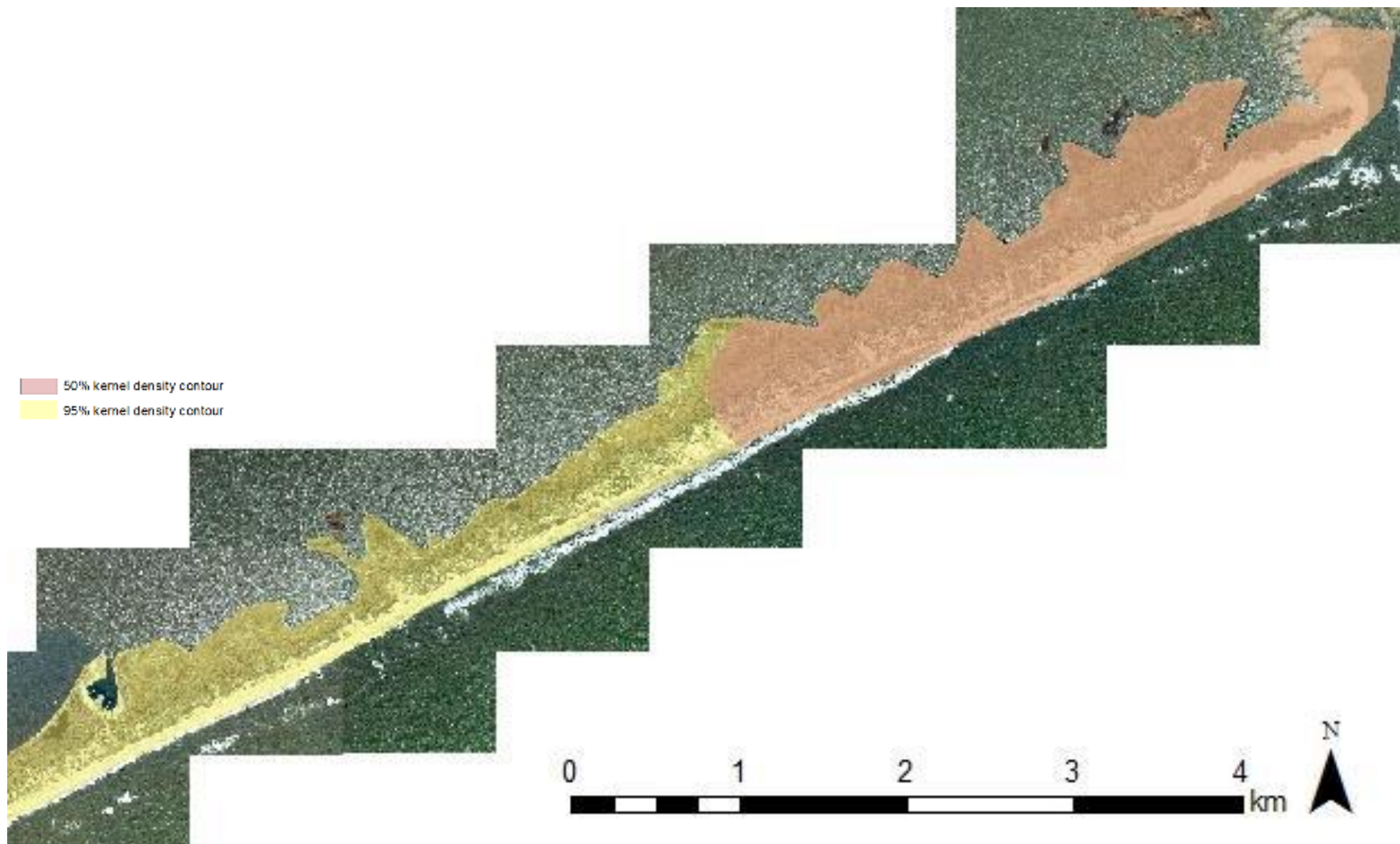


Figure 69. 50% and 95% kernel density contours for all GPS-collared red foxes in Fall-Winter 2015 at Fire Island National Seashore (Watch Hill to inlet) overlaid on top of each other.

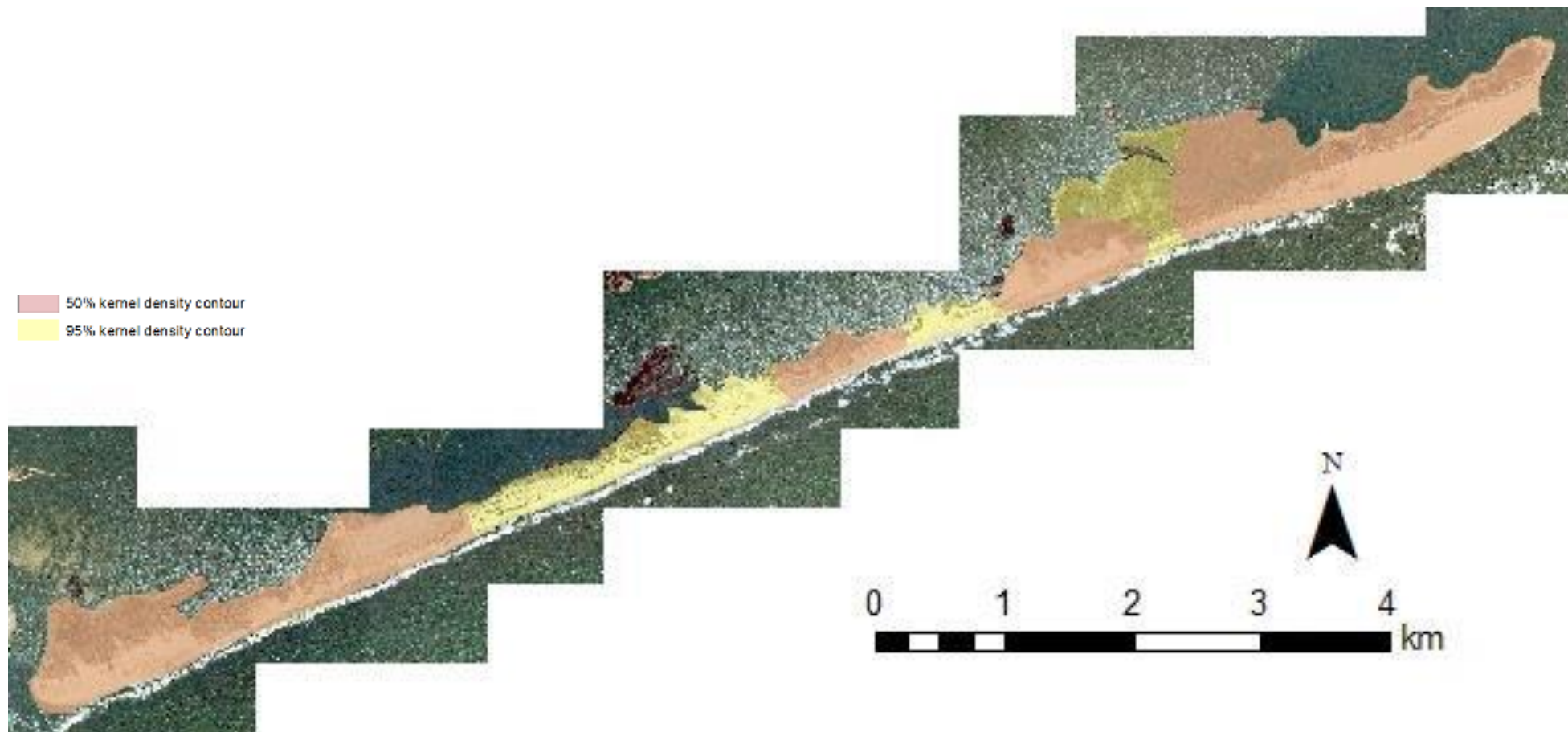


Figure 70. 50% and 95% kernel density contours for all GPS-collared red foxes in Fall-Winter 2015 at Fire Island National Seashore (Old Inlet East) and Smith Point County Park overlaid on top of each other.



Figure 71. MCP (outlined in different colors for different foxes), 50% and 95% kernel density contours for 1 male red fox at Robert Moses State Park in Spring-Summer 2016.

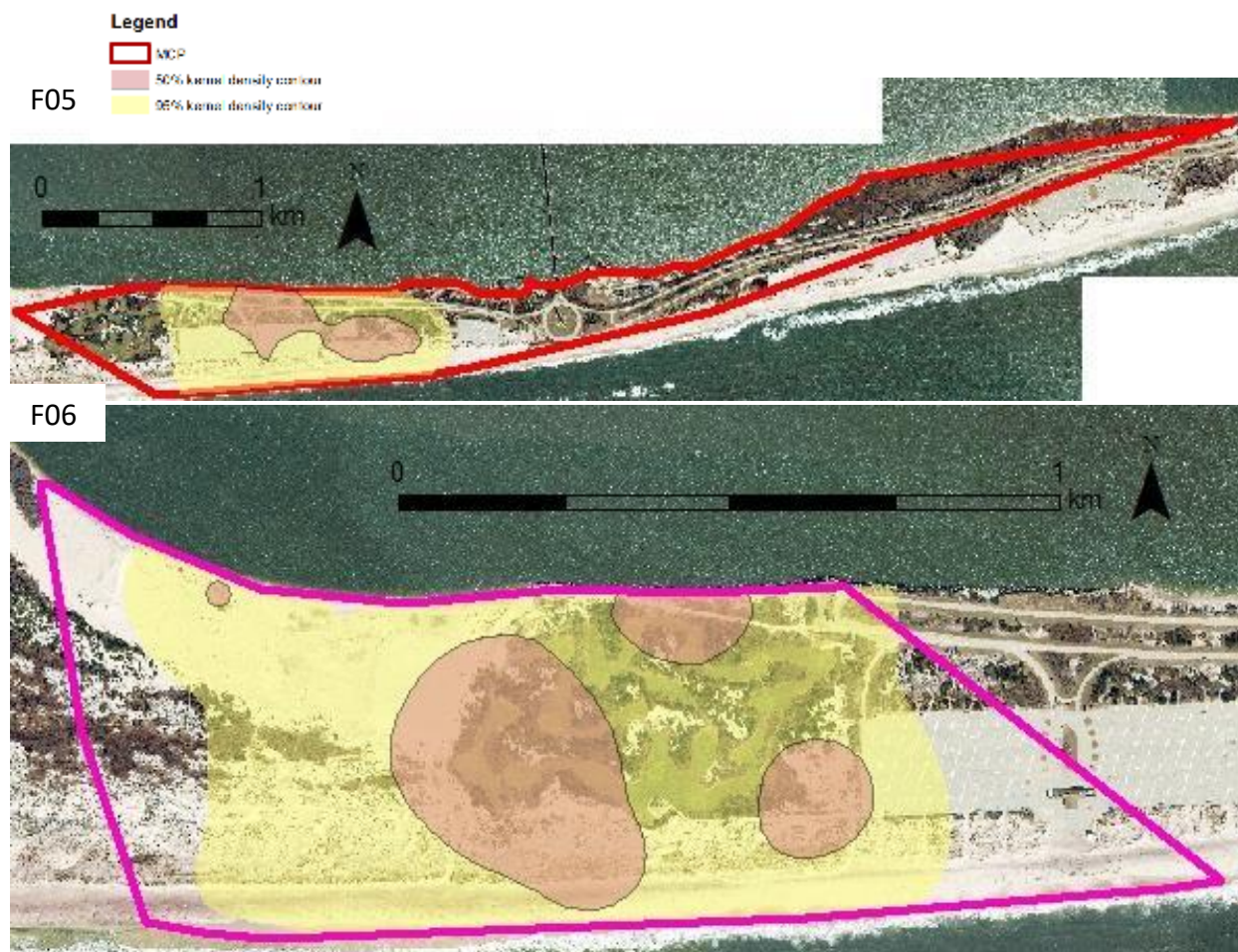


Figure 72. MCPs (outlined in different colors for different foxes), 50% and 95% kernel density contours for 2 female red foxes at Robert Moses State Park in Spring-Summer 2016.

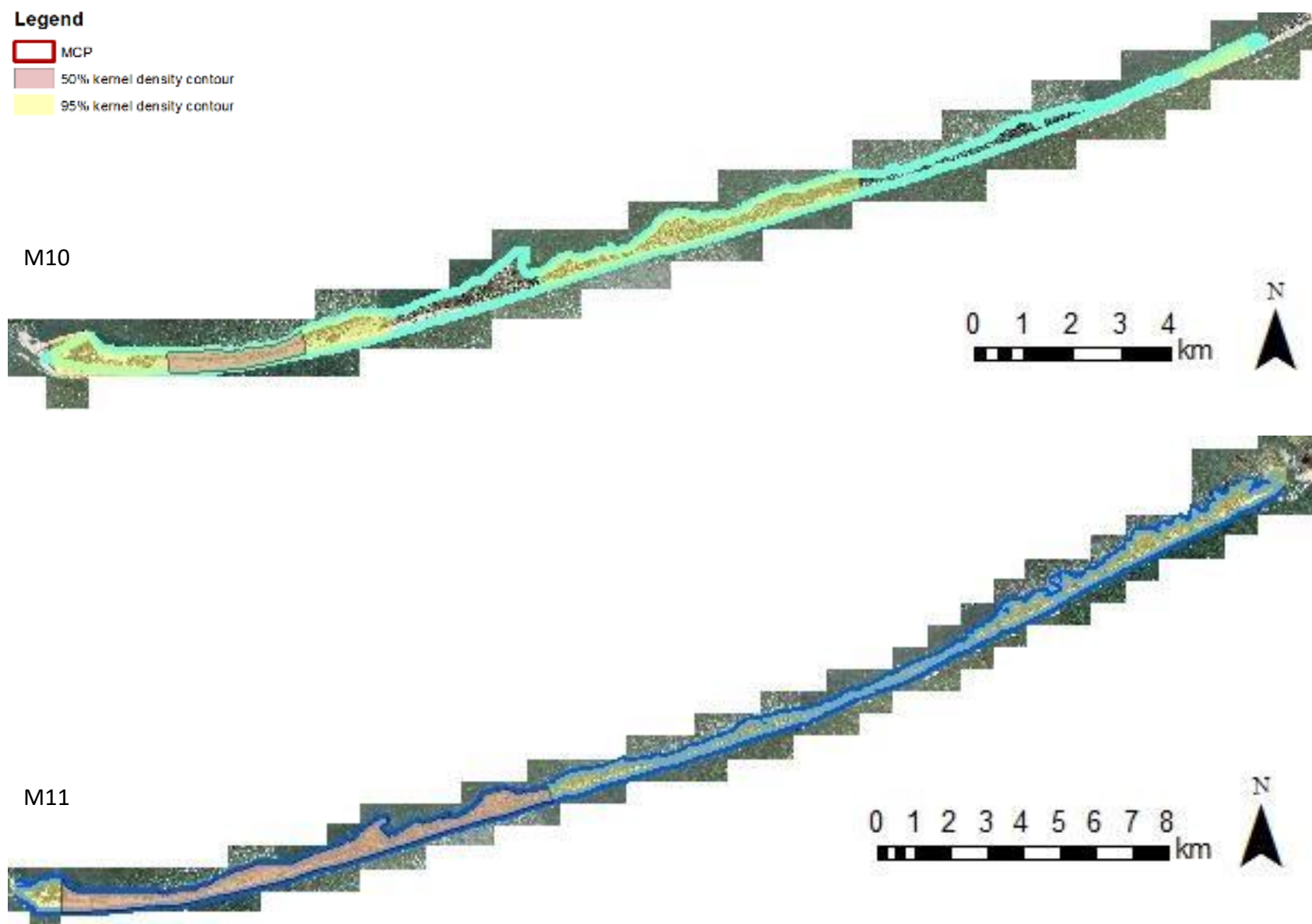


Figure 73. MCPs (outlined in different colors for different foxes), 50% and 95% kernel density contours for 2 male red foxes originally captured at Robert Moses State Park during Spring-Summer 2016.

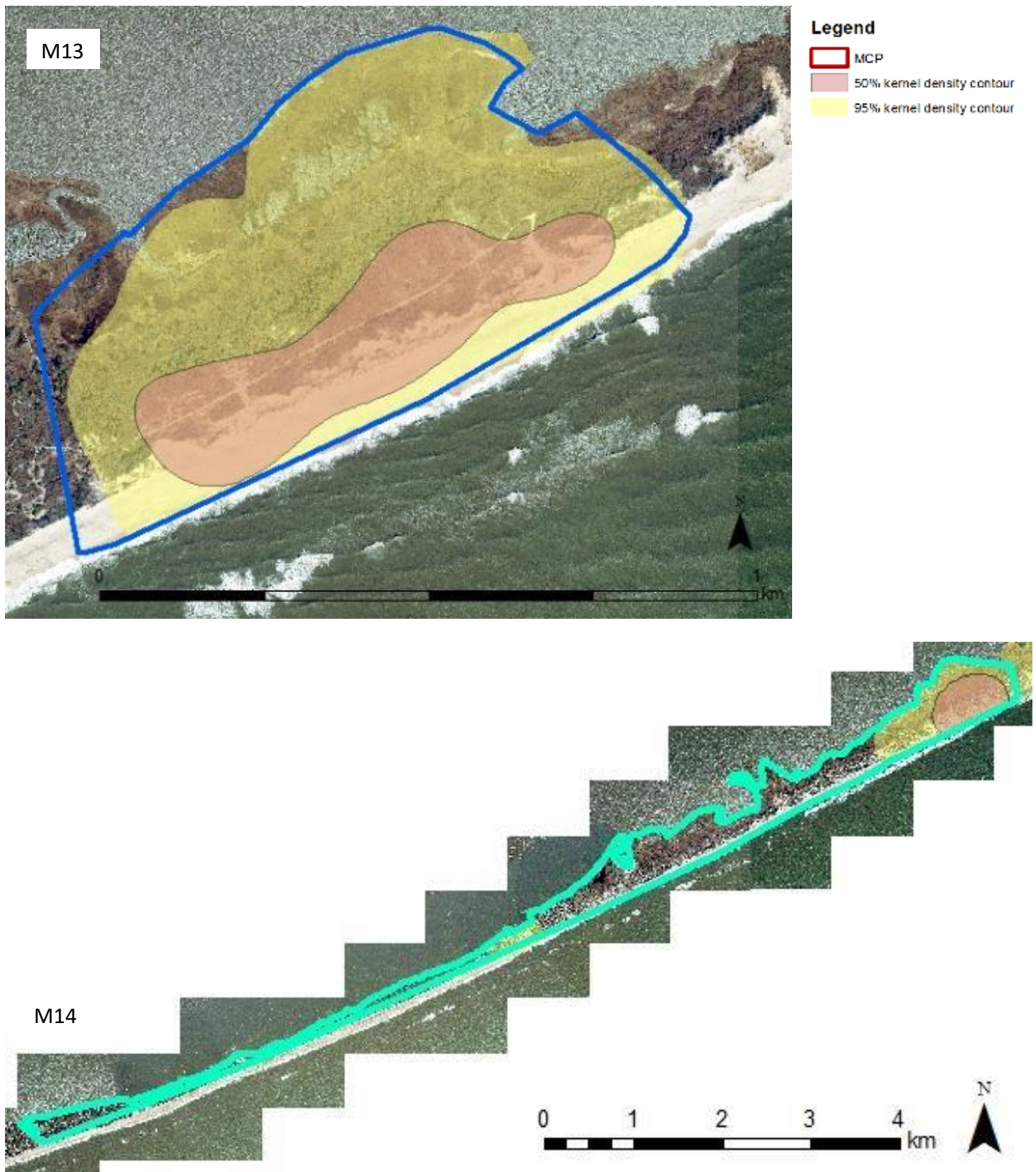
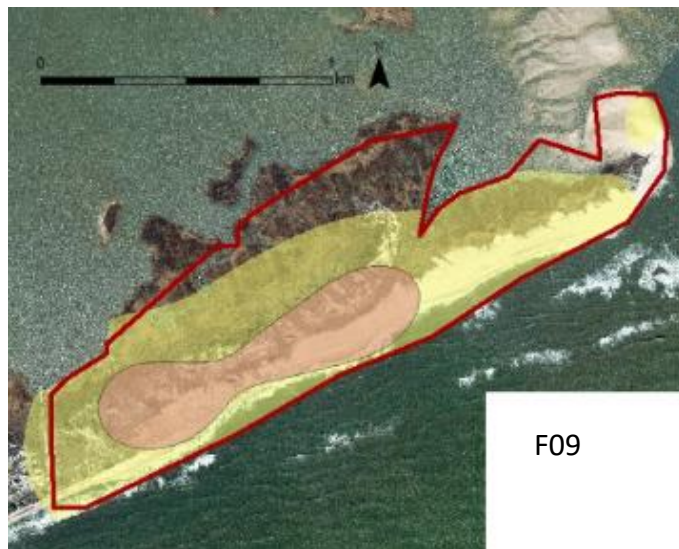
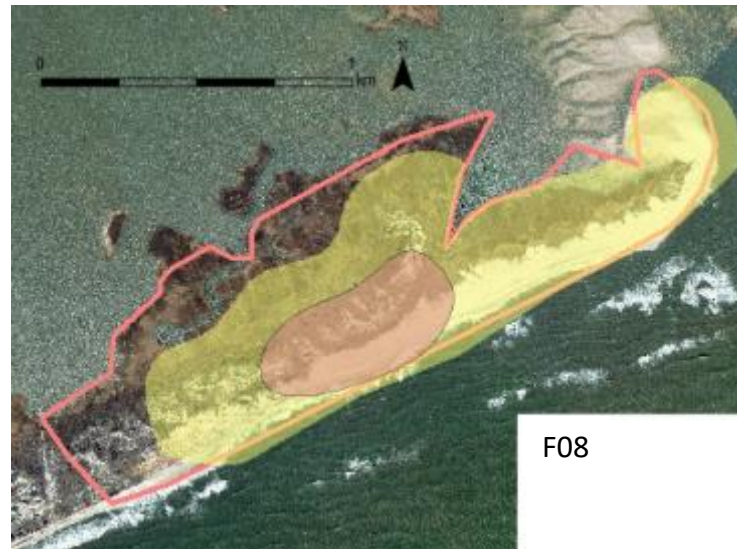


Figure 74. MCPs (outlined in different colors for different foxes), 50% and 95% kernel density contours for 2 male red foxes at Fire Island National Seashore in Spring-Summer 2016.



Legend

- MCP
- 50% kernel density contour
- 95% kernel density contour

Figure 75. MCPs (outlined in different colors for different foxes), 50% and 95% kernel density contours for 3 female red foxes at Fire Island National Seashore in Spring-Summer 2016.

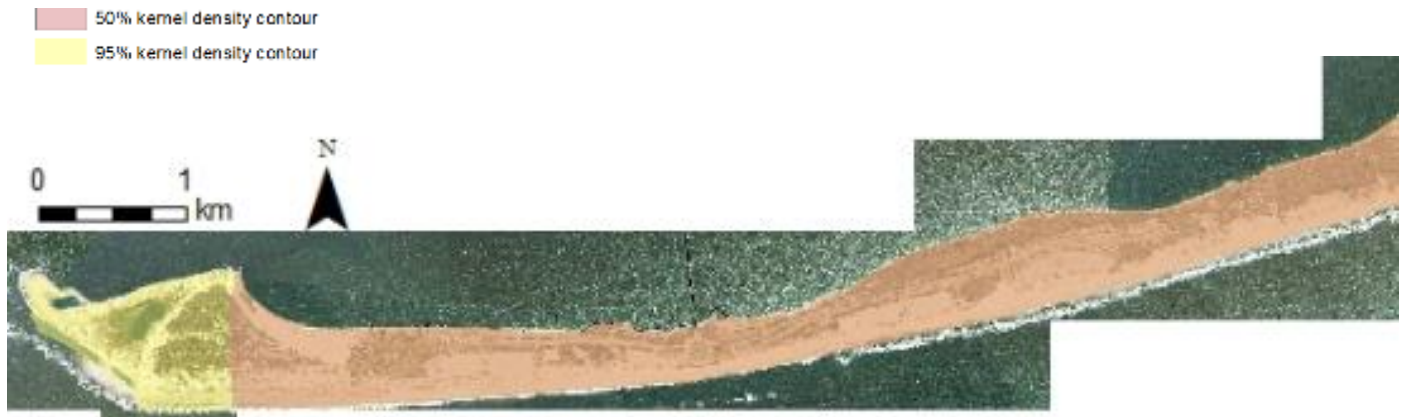


Figure 76. 50% and 95% kernel density contours for all GPS-collared red foxes in Spring-Summer 2016 at Robert Moses State Park overlaid on top of each other.

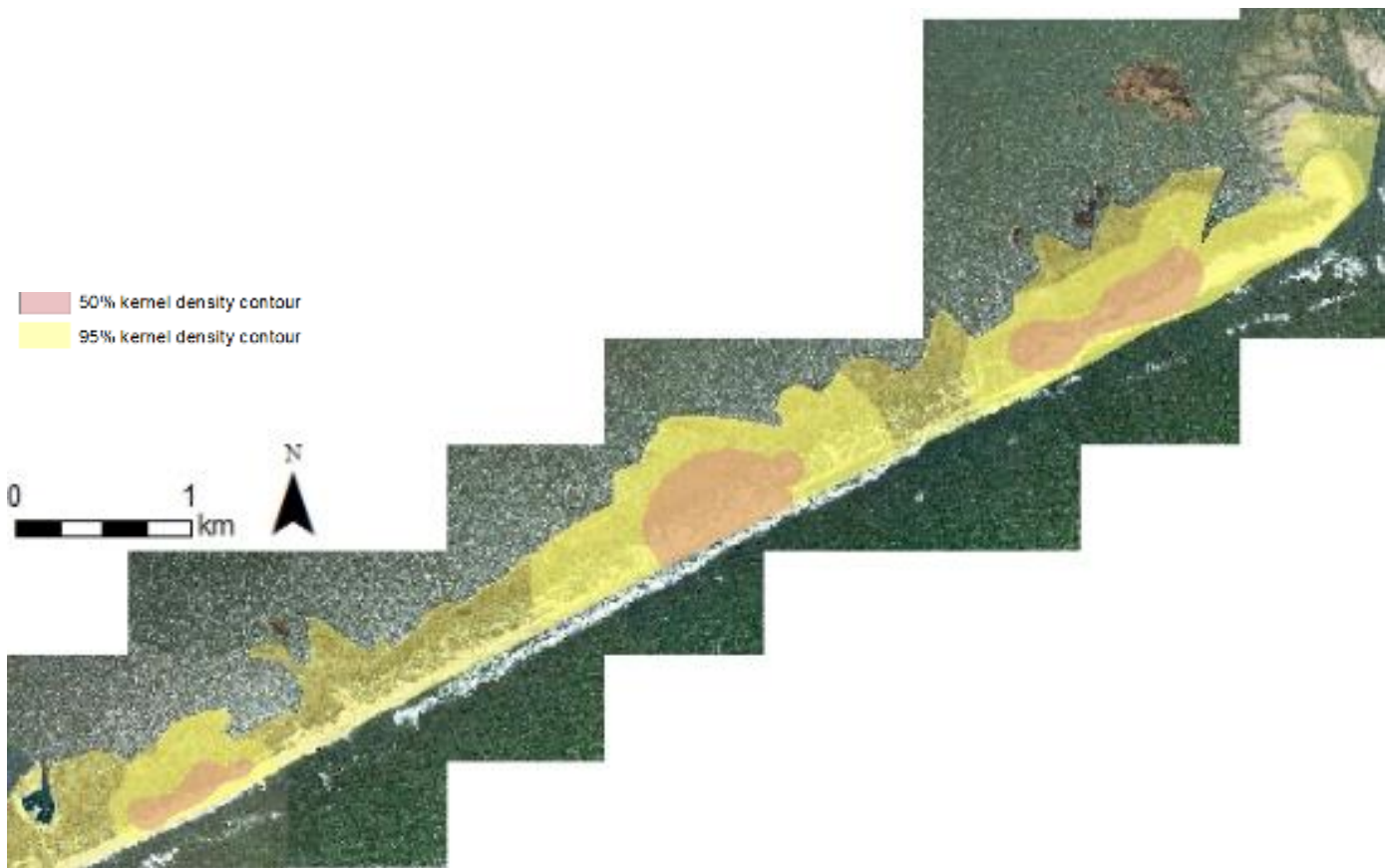


Figure 77. 50% and 95% kernel density contours for all GPS-collared red foxes in Spring-Summer 2016 at Fire Island National Seashore (west of Old Inlet) overlaid on top of each other.

Appendix D: Spatial response of red foxes to nest exclosure setup, pipping, and hatching

Maps of fox locations during high frequency location sampling surrounding nest exclosure set-up and estimated nest pipping and hatching dates are shown below. For various logistical and biological reasons described in the report, our high frequency data collection periods at some nests did not line up exactly with

the events that we had scheduled them around. We used the highest location frequency collected surrounding the actual dates, using 2 days of location data before and after the target event to examine fine-scale spatial response. The collection frequency of location data presented in each of the following maps is noted in the map legends; “High freq” denotes time periods where locations were recorded every 15 minutes, “Partial high freq” denotes time periods where locations were collected every 15 minutes for more than half, but not all, of that time period, and “Reg freq” denotes time periods where locations were collected every 2 hours, on every other day. When only regular frequency data was available, we used data from the 2 full days of data collection closest to the target event.

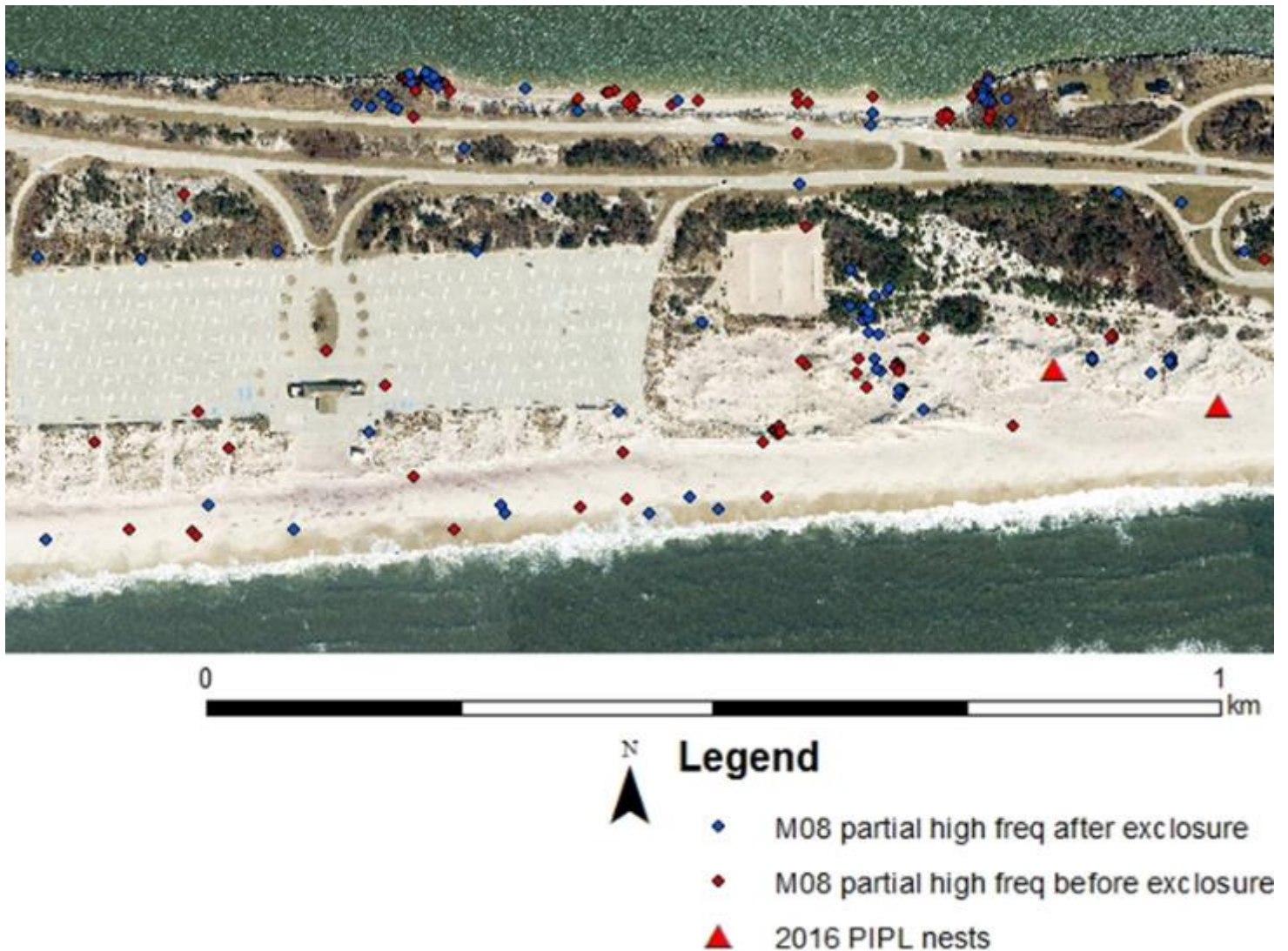
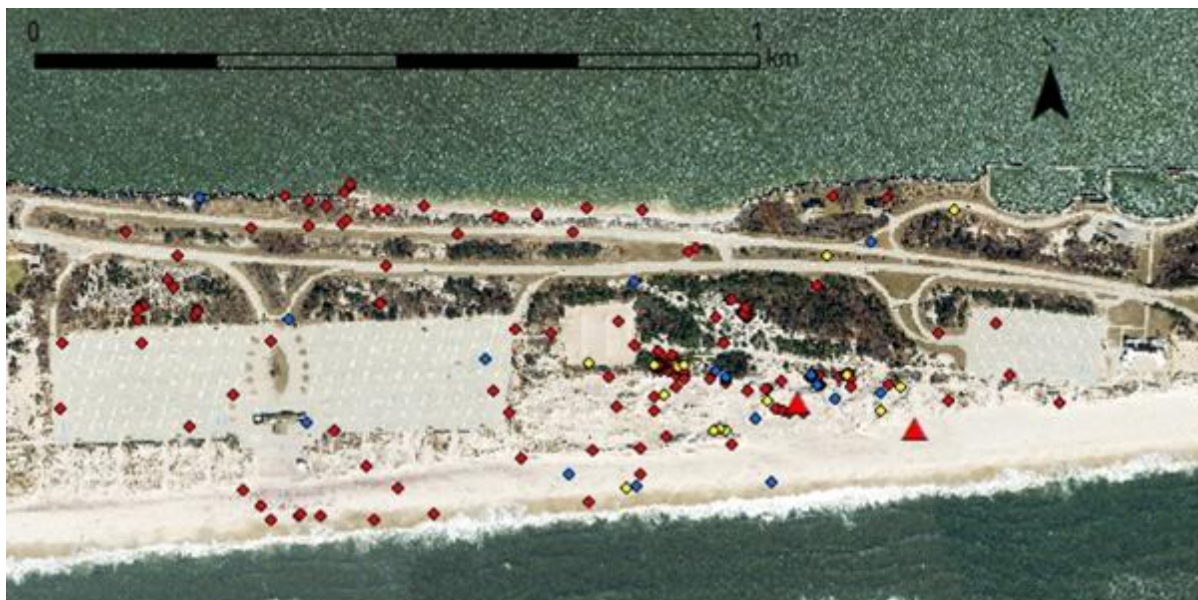


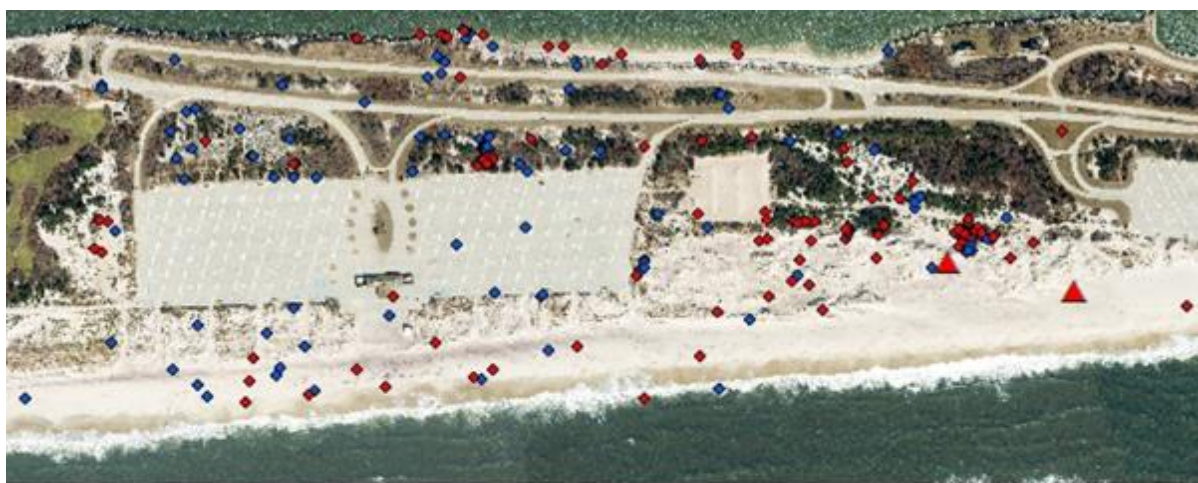
Figure 78. Locations for fox M08 before and after nest exclosure at Robert Moses State Park, PIPL nest 211.



Legend

- ▲ 2016 PIPL nests
- ◆ M08 reg freq after hatch
- ◆ M08 reg freq during pip/hatch
- ◆ M08 partial high freq pre-pip/hatch

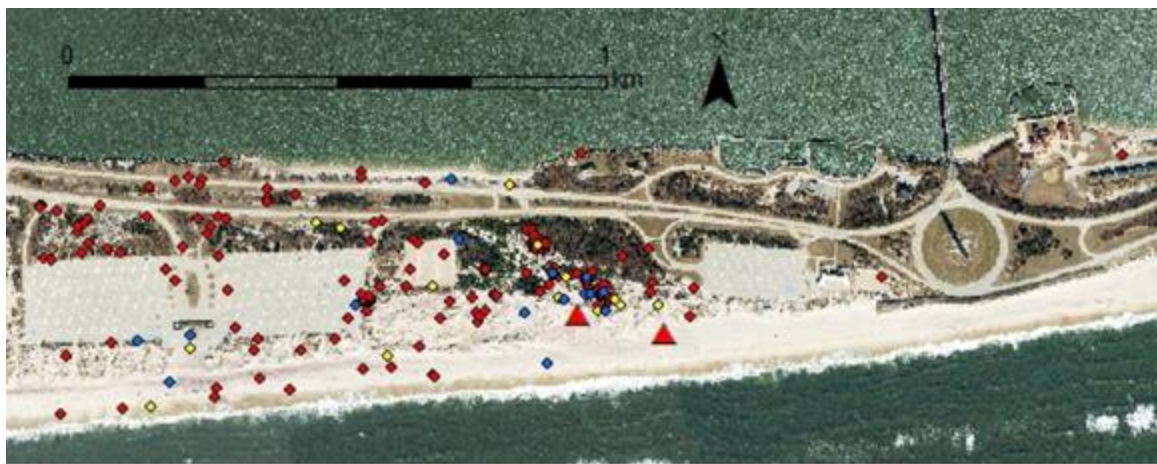
Figure 79. Locations for fox M08 before, during, and after nest pipping/hatching at Robert Moses State Park, PIPL nest 211.



Legend

- ◆ F05 partial high freq before enclosure
- ◆ F05 partial high freq after enclosure
- ▲ 2016 PIPL nests

Figure 80. Locations for fox F05 before and after nest enclosure at Robert Moses State Park, PIPL nest 211.



Legend

- ▲ 2016 PIPL nests
- ◆ F05 reg freq after hatch
- ◆ F05 reg freq during pip/hatch
- ◆ F05 partial high freq pre-pip/hatch

Figure 81. Locations for fox F05 before, during, and after nest pipping/hatching at Robert Moses State Park, PIPL nest 211.



Legend

- ▲ 2016 PIPL nests
- ◆ F06 partial high freq before exclosure
- ◆ F06 high freq after exclosure

Figure 82. Locations for fox F06 before and after nest exclosure at Robert Moses State Park, PIPL nests 204 and 205 (on southern beachfront).



Figure 83. Locations for fox F06 before, during, and after nest pipping/hatching at Robert Moses State Park, PIPL nests 204 and 205 (on southern beachfront).

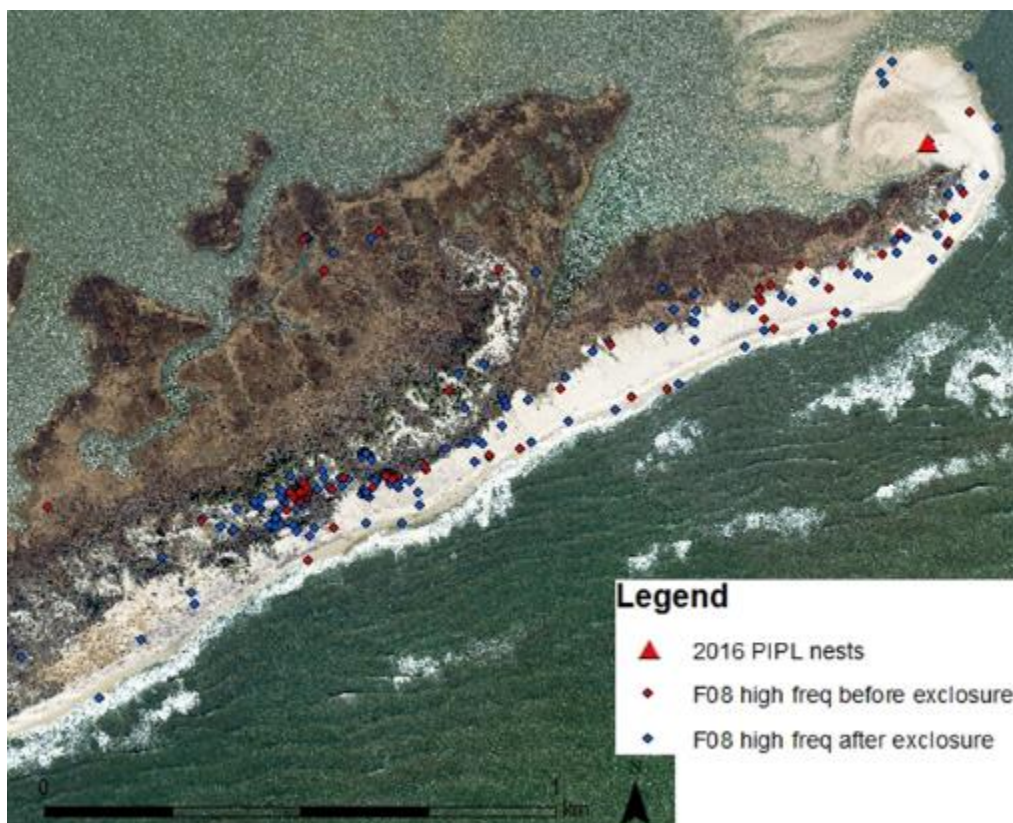


Figure 84. Locations for fox F08 before and after nest exclosure at Fire Island National Seashore, PIPL nest 32.

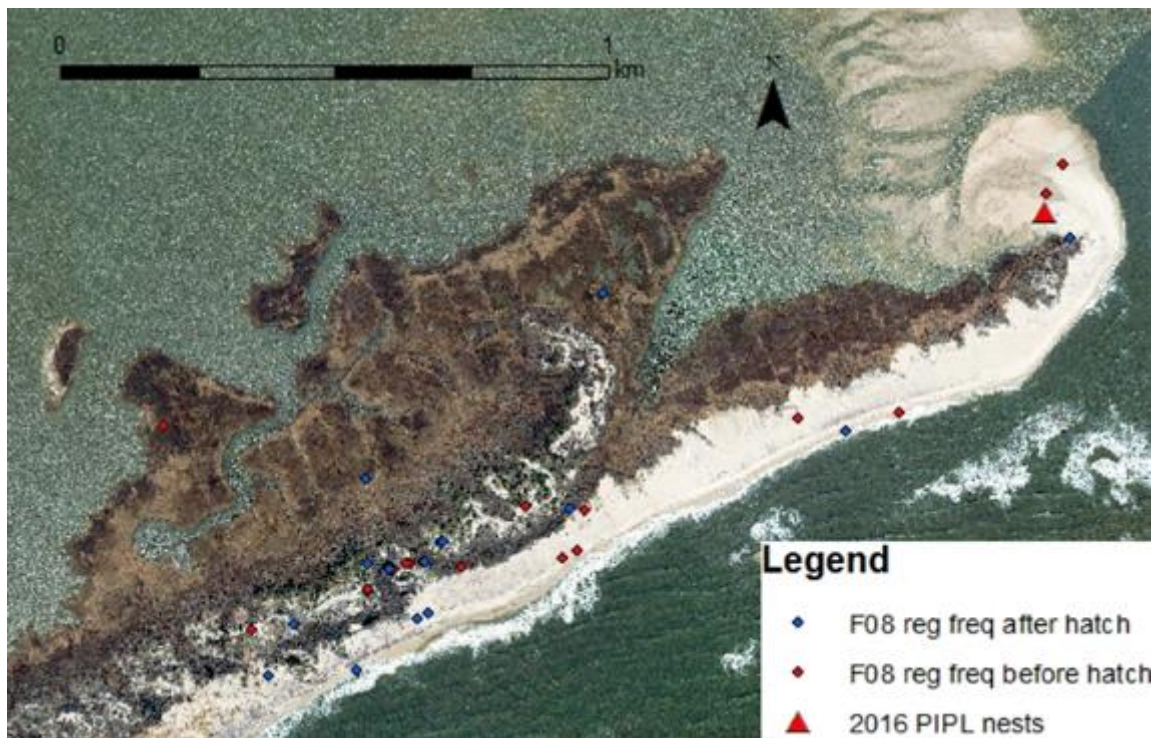


Figure 85. Locations for fox F08 before and after nest hatching at Fire Island National Seashore, PIPL nest 32.

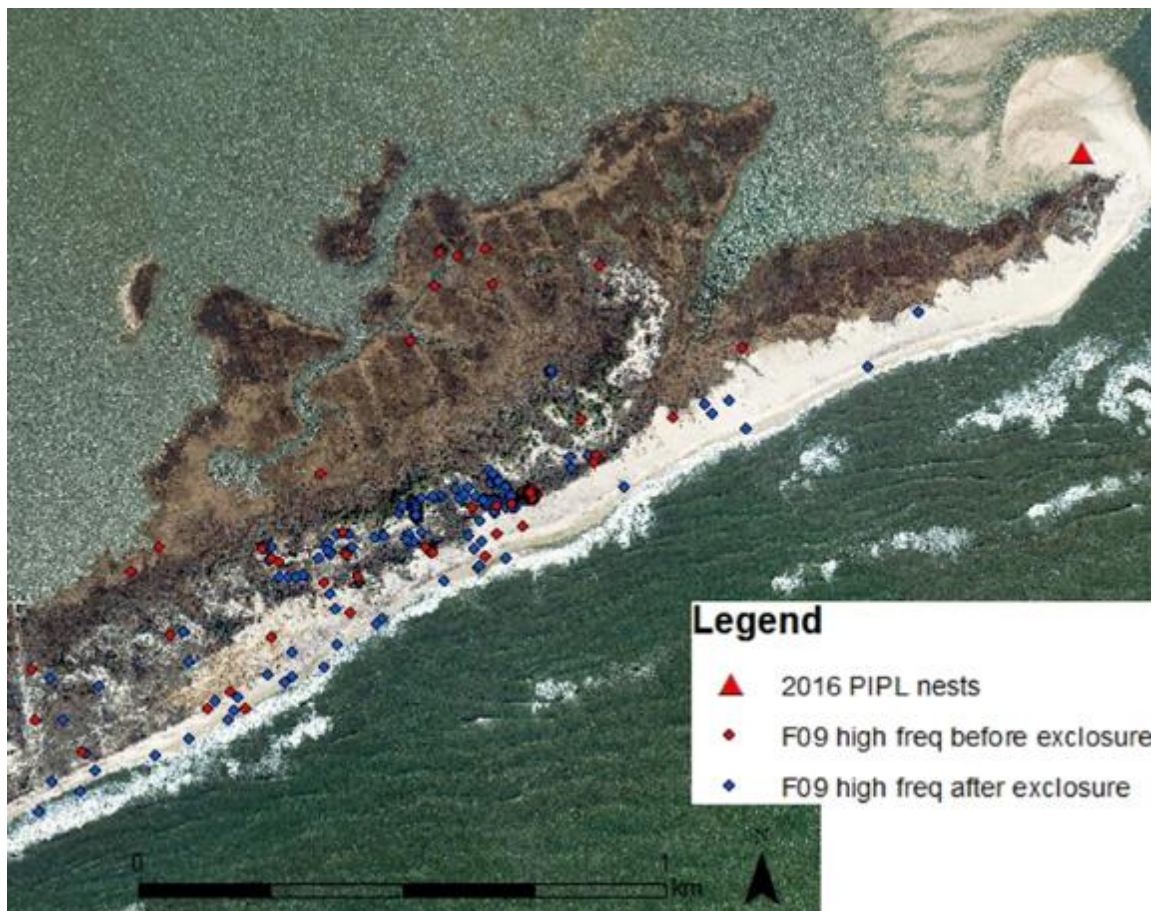


Figure 86. Locations for fox F09 before and after nest exclosure at Fire Island National Seashore, PIPL nest 32.

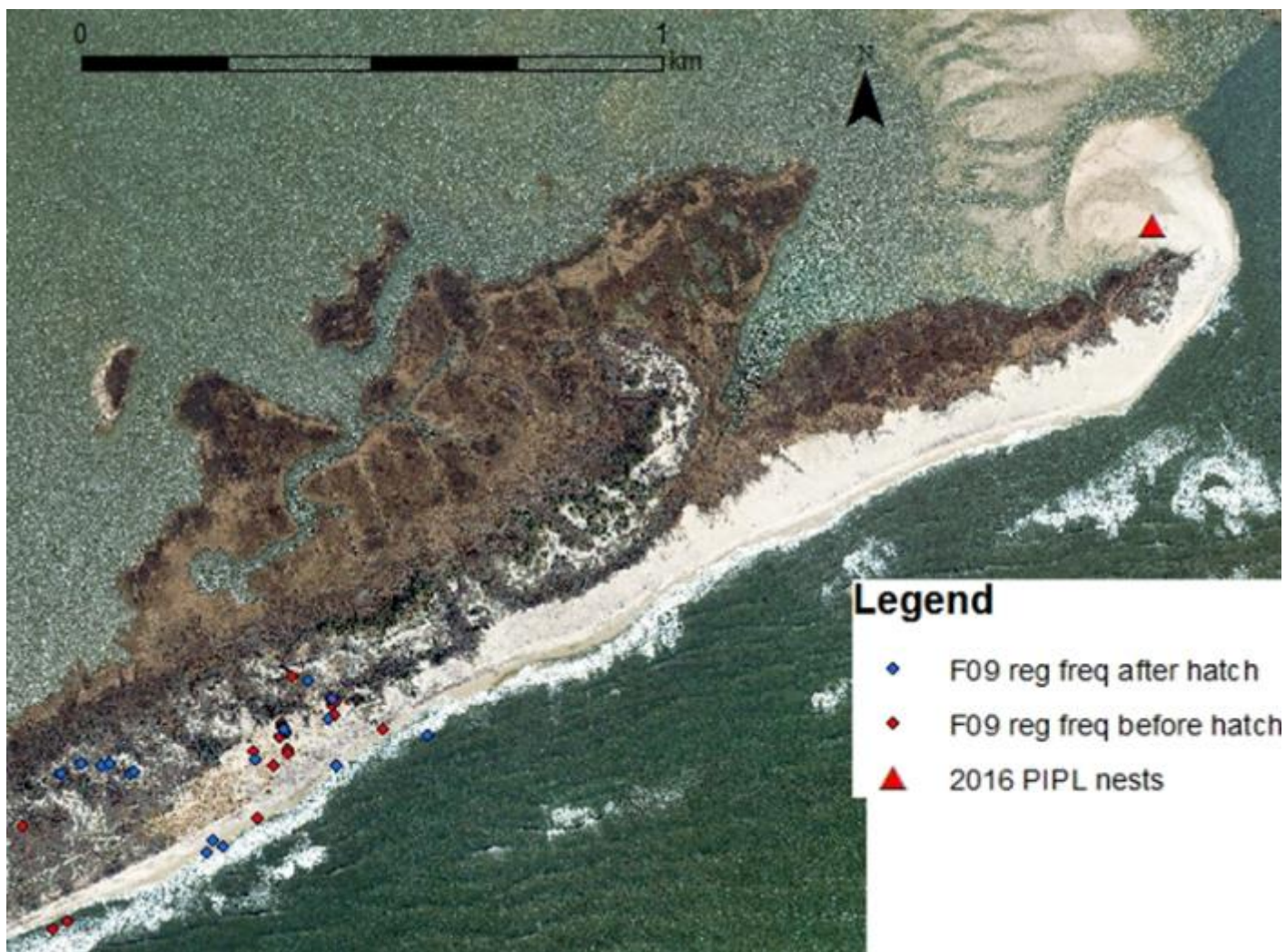


Figure 87. Locations for fox F09 before and after nest hatching at Fire Island National Seashore, PIPL nest 32.