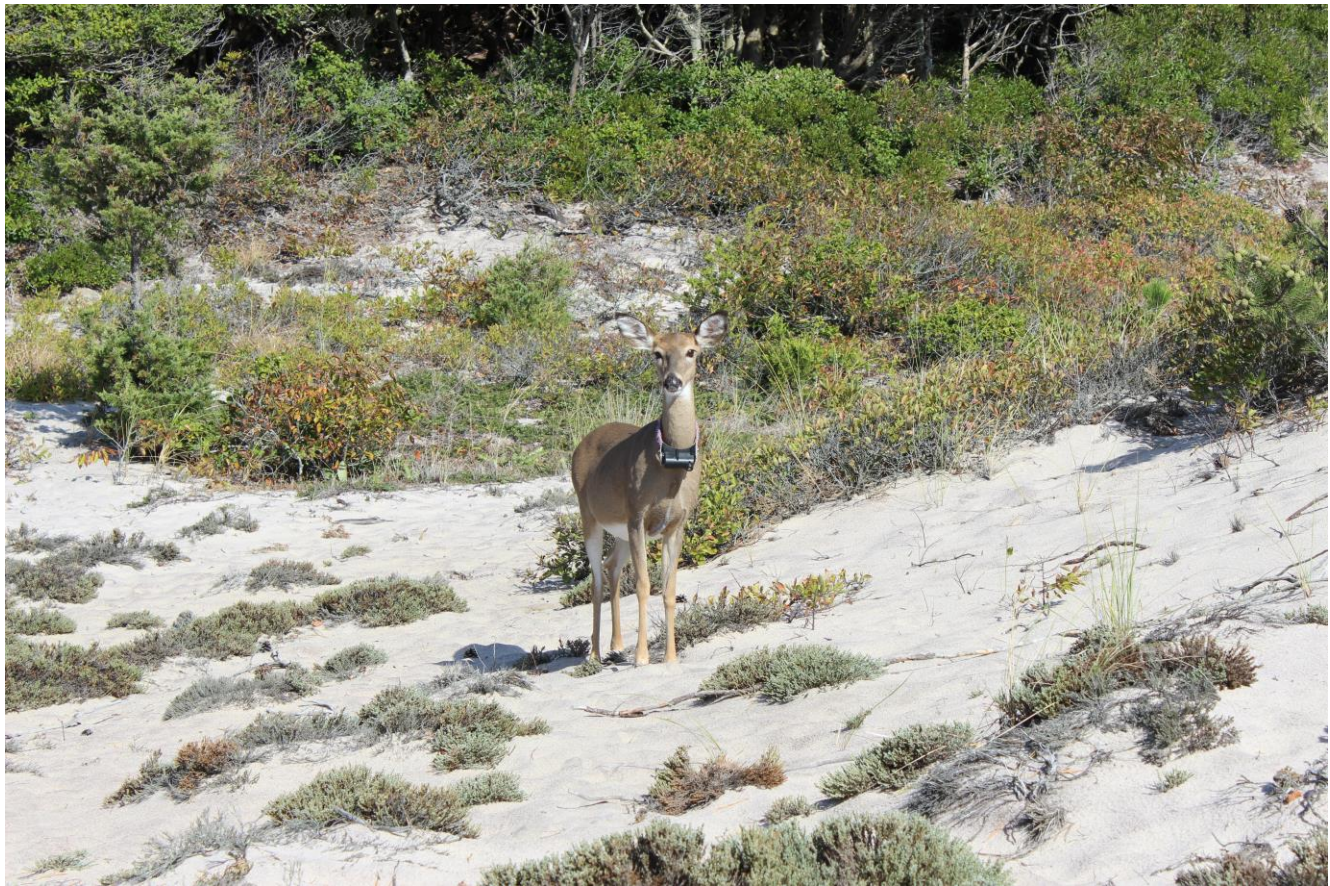




White-tailed deer movements and space use on Fire Island - A four-year radio-telemetry study

2015-2016 Post-Hurricane Sandy Assessment

Natural Resource Report NPS/FIIS/NRR—2019/2038



ON THE COVER

An adult female deer sporting a radio-collar, including Global Positioning System and Very-High Frequency monitoring capabilities, in the Sunken Forest, Fire Island, New York, USA.

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White-tailed deer movements and space use on Fire Island - A four-year radio-telemetry study

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Natural Resource Report NPS/FIIS/NRR—2019/2038

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November 2019

U.S. Department of the Interior
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Fort Collins, Colorado

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Contents

	Page
Figures.....	v
Tables.....	vii
Appendices.....	ix
Executive Summary	xi
Acknowledgments.....	xiii
Introduction.....	1
Methods.....	3
Capturing and Handling White-tailed Deer.....	3
Radio Collar Specifications	5
Identification of Concealment Cover	6
Home Range Estimation.....	6
Daily Movement Rates	7
Results.....	9
Capturing and Handling White-tailed Deer.....	9
Logistical Constraints: Deer Captures and Radio-Collars.....	9
Identification of Concealment Cover	10
Home Range Estimation.....	12
Daily Movement Rates	17
Discussion	19
Conclusions.....	23
Management Implications.....	25
Literature Cited	27

Figures

	Page
Figure 1. Map of Fire Island, New York.....	1
Figure 2. Map of the private communities and natural areas where radio-collared white-tailed deer were frequently observed on Fire Island, New York, USA.	2
Figure 3. A Clover trap placed adjacent to a white-tailed deer trail in the Otis Pike Fire Island High Dune Wilderness Area, New York.....	3
Figure 4. Color combinations used to uniquely identify radio-collared white-tailed deer in the field on Fire Island, New York.	5
Figure 5. Concealment cover polygons delineated for seven radio-collared white-tailed deer in Watch Hill on Fire Island, New York.	11
Figure 6. Concealment cover polygons delineated for three radio-collared white-tailed deer in the western areas of the Otis Pike Fire Island High Dune Wilderness Area, New York.	12
Figure 7. GPS locations from deer collars in Watch Hill and the Otis Pike Fire Island High Dune Wilderness Area (Wilderness Area) west of the post-Hurricane Sandy island breach.....	15
Figure 8. Results of outlier analysis show several outliers in white-tailed deer home range length, 50% home range, and 95% home range among seven study areas on Fire Island, New York.	17

Tables

	Page
Table 1. Concealment cover triangulated for radio-collared white-tailed deer in 2015 and 2016 on Fire Island, New York. Concealment covers (CC) are areas where deer find daytime refuge..	10
Table 2. Information gathered and calculated from radio-collared white-tailed deer in several areas of Fire Island, New York from 2014-2017, including the lighthouse tract (LH), Sailors Haven (SH), and Talisman (T).....	12
Table 3. Information gathered and calculated from radio-collared white-tailed deer in several areas of Fire Island, New York from 2014-2017, including Blue Point (BP), Watch Hill (WH), and the Wilderness Area (WA) east and west of the post-Hurricane Sandy island breach.	14
Table 4. Average home range lengths, 50% home ranges, and 95% home ranges for radio-collared white-tailed deer on Fire Island, New York from 2014 to 2017.	16
Table 5. Data regarding deer collar life, movement seasonality, and step distances by study area pooled among years from radio-collared white-tailed deer on Fire Island, New York..	18
Table B1. Data collected from all adult female white-tailed deer captured on Fire Island, New York between 2014-2017.	37

Appendices

	Page
Appendix A. R code associated with home range analysis of white-tailed deer radio-collar data on Fire Island, New York.	33
Appendix B. Data collected from all adult female white-tailed deer captured on Fire Island, New York between 2014-2017.	37
Appendix C. Concealment cover polygons delineated for collared deer on Fire Island, New York.....	41
Appendix D. GPS locations from deer collars on Fire Island, New York.	45

Executive Summary

This Natural Resource Report is the second of a five-part series in response to Agreement Number P14AC00469, which was awarded to the co-authors in response to Hurricane Sandy. Hurricane Sandy dramatically impacted coastal New England in 2012. Many areas of Fire Island National Seashore, New York (40.669, -73.051) were inundated or eroded, and many primary dunes were overwashed by storm surge. The cooperative agreement aimed to address the following four research tasks: (1) assess effects of white-tailed deer browsing on vegetation establishment, growth, and development in key overwash zones on Fire Island National Seashore, (2) expand vegetation monitoring developed for the Sunken Forest into additional maritime forest zones on Fire Island, (3) document daily, seasonal, and annual movements of white-tailed deer on Fire Island, and (4) explore how access to food, thermal cover, and fresh water affect activity and space use of white-tailed deer between heavily urbanized western communities of Fire Island and the Wilderness Area. This report solely addresses objective (3) listed above. The remaining four reports in this series include three reports addressing each of the remaining objectives and a comprehensive report addressing Fire Island's resilience to future disturbance.

Hurricane Sandy provided a unique opportunity to better understand the movements of Fire Island's dense white-tailed deer (*Odocoileus virginianus borealis*) herds. White-tailed deer inhabit all areas of Fire Island National Seashore and their high densities negatively affect native vegetation in several areas of the island, especially as disturbed areas attempt to recover after a catastrophic storm like Hurricane Sandy. Understanding deer movements and space use helps land managers to prioritize white-tailed deer population size and the health and recovery potential of Fire Island's natural lands according to their management goals. The results of this study will inform Fire Island staff as they prepare to initiate the tasks set forth by the Seashore's approved Deer Management Plan.

We used radio-collars fitted with Very High Frequency (VHF) signal and Global Positioning System (GPS) technology to monitor movements of white-tailed deer for four years after Hurricane Sandy. The greatest movements of Fire Island's adult female white-tailed deer occurred in spring each year. Home range and core area sizes varied among study areas and years, but suggested hierarchical dominance among Fire Island's deer populations. Potentially six distinct populations were delineated through analysis of GPS radio-collar data, though these divisions also reflect the concentrated sampling efforts of deer capture. Nearly all deer monitored shared time between natural and nearby built environments. Since Hurricane Sandy, deer movements in Fire Island's Wilderness are divided by the storm-induced breach. GPS radio-collars provided a wealth of data for analysis of deer movements and space use, and this report is simply a snapshot of the potential information we intend to gain from this study.

Acknowledgments

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Introduction

On October 29, 2012, Hurricane Sandy made landfall off the coast of southern New Jersey. On Fire Island, New York (Figure 1), a barrier island off the southern coast of Long Island, the impacts of Hurricane Sandy on shoreline morphology were dramatic (Hapke et al. 2013). The storm surge produced several overwashed areas of considerable spatial extent, and limbs from large trees in the maritime holly forests were removed, leaving large extent canopy gaps and promoting seedling establishment.

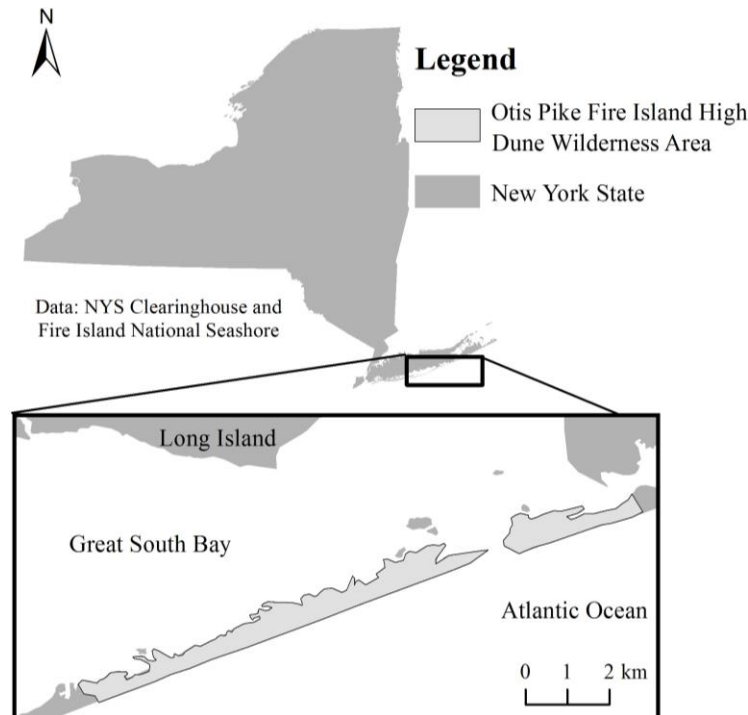


Figure 1. Map of Fire Island, New York.

We lacked information regarding impacts of white-tailed deer (*Odocoileus virginianus borealis*) browsing to recovering dune vegetation (Art 1976), though grazing by horses on Assateague Island in Maryland, USA (38.078, -75.206) impacts dune grass recovery (Keiper 1990, Seliskar 2003). We also lacked good predictions of the long-term consequences of chronic herbivory by deer on the conservation status of the mature maritime American holly forest (Forrester et al. 2008: question #5) on Fire Island as it recovers from storm-induced canopy gaps. Hurricane Sandy caused extensive forest canopy gaps in Sailors Haven (i.e., Sunken Forest), Talisman, and Blue Point. In the Otis Pike Fire Island High Dune Wilderness Area (i.e. Wilderness Area, WA) deer densities have remained 25 $\pm$ 8 deer km⁻² since the early 2000s (Underwood 2005). Deer densities in western areas of Fire Island (Figure 2), where natural areas are interspersed between dense residential areas, are 3-4 times greater than in the Wilderness Area (< 75 deer km⁻², Underwood 2005). Of Fire Island's 2,264 ha, approximately 750 ha are managed by the National Park Service's Fire Island National Seashore; the remaining areas include private communities, a state park, and a county park.

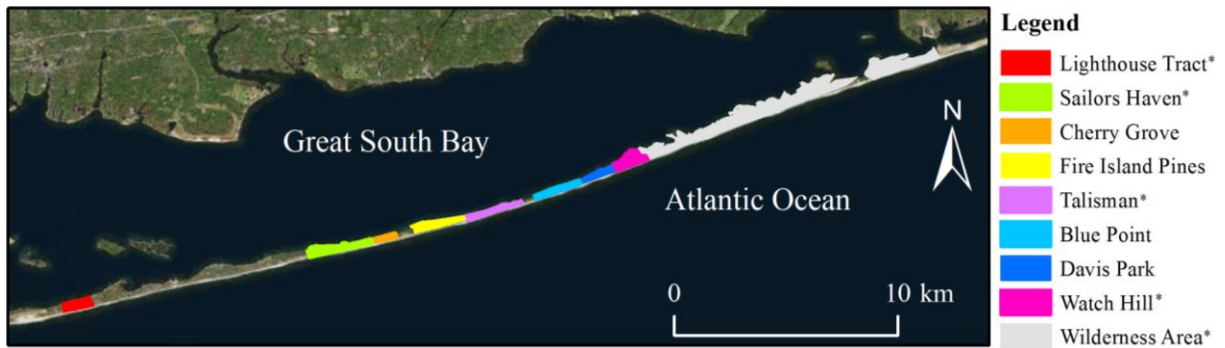


Figure 2. Map of the private communities and natural areas where radio-collared white-tailed deer were frequently observed on Fire Island, New York, USA. Areas delineated with an asterisk (*) are federally managed lands and all others are private communities.

A small sample of deer was captured on Fire Island and radio-collared in the early 1980's (O'Connell and Sayre 1988), but technology of the day prevented precise recording of actual locations and detailed tracking. O'Connell and Sayre (1988) suggested that two discrete populations occurred on Fire Island, with Talisman serving as a possible divide. It is likely that deer in areas with higher deer densities exhibit smaller step distances and home ranges to limit overlap and resource competition (Ellisor 1969, Marchinton and Hirth 1984). We hypothesized that Fire Island's deer populations (Underwood 2005) use space differently in built and natural environments. To test this hypothesis, we monitored white-tailed deer space use on Fire Island using GPS/VHF radio-collars. More precise white-tailed deer movement data and analyses are possible after several years of high-resolution geographic monitoring.

The main objectives of this research were to: (1) monitor annual movements, and (2) assess seasonality in space use of white-tailed deer in natural areas of Fire Island. We aimed to identify resting and foraging areas of deer using GPS and triangulated locations to better understand their daily and seasonal space use on Fire Island, and ultimately their potential impacts to vegetation recovery.

Methods

Capturing and Handling White-tailed Deer

We captured and collared adult female white-tailed deer on Fire Island during the winters of 2014, 2015, 2016, and 2017. Field staff, including summer interns, Biological Science Technicians, and a doctoral student, was trained in proper handling of immobilized animals, including how to assess vital signs, before capturing procedures began. Field staff was also required to read the National Park Service Wildlife Anesthesia's Basic Course workshop materials. Drug administration was only performed by those who were trained by J. Powers, a National Park Service veterinarian, in proper safety procedures and anesthesia protocols (J. Raphael or L. Ries). Each additional field member was assigned a particular task (e.g., breath monitoring, pulse monitoring, measurements of girth and hindfoot) and one person recorded all data and monitored time since immobilization.

In 2014, deer were captured by a remote delivery system (i.e., darting) using DanInject JM Standard rifles and 1.5 cc darts made by Pneudart. In 2015, 2016 and 2017, a combination of darting and Clover traps (Clover 1954) was used to capture deer. Clover traps (Figure 3) were used in an effort to capture deer in Sailors Haven, Watch Hill, and the Wilderness Area that are less habituated to human activity, particularly those who would not come near enough to bait piles to be darted. Clover traps were also used to increase capture efficiency since they did not require constant searches like darting methods.



Figure 3. A Clover trap placed adjacent to a white-tailed deer trail in the Otis Pike Fire Island High Dune Wilderness Area, New York.

For darting each year, we placed small piles of cracked or whole corn (i.e., bait) in each natural area several days before capturing was scheduled to begin to attract deer to the area. We placed corn piles in areas that were relatively inconspicuous to avoid attracting attention from visitors and residents. When an adult female deer arrived to the corn pile and her backside was clearly visible, a biologist

authorized to use the DanInject JM Standard rifle (i.e., J. Raphael, L. Ries, or K. Jackson) shot the deer with a dart containing 1.1 mL BAM (mixture of Butorphanol, Azaperone, and Medetomidine) used as an anesthetic agent (NPS 2015). We remained at the darting location and watched the deer walk or run into nearby wooded areas as the drugs began immobilizing her. After at least 30 minutes, we approached the deer's last known location and searched for the deer until she was found.

In 2015, 2016 and 2017, we placed Clover traps adjacent to deer trails in the Lighthouse Tract, Sailors Haven, Watch Hill, and the Wilderness Area. We staked traps into the ground using rebar (Figure 3) and placed corn in the back of the trap near a trigger string. We set up Clover traps several days before capture was scheduled to begin, tied the doors open, and supplied the traps with corn to habituate deer to the trap. During deer capture nights, we replenished the corn pile and set the traps in the evening. We then checked traps at midnight and again at sunrise the following morning. When a deer was present in the trap, we collapsed the trap onto the deer and hand-injected BAM while the deer was restrained. We held the deer still until she was immobilized by the BAM before gently pulling her from the trap to begin processing.

The handling of captured deer for this study was done according to an approved anesthesia protocol (NPS 2015). We first put a blind fold (i.e., standard knee brace) over the deer's eyes to keep her calm, then began collecting vital signs, including respiration, heartbeat, and internal temperature. We collected vital signs every five minutes throughout the entire processing period. If the deer exhibited any concerning vital signs, we adjusted handling procedures and immediately administered reversal drugs to counteract the immobilization. If all vital signs remained within acceptable ranges according to our protocol, we measured girth and hindfoot using a tape measure, collected two 10-mL vials of blood in red-topped tubes, and collected five fecal pellets (if available) for laboratory analysis. We evaluated the deer's general health, including any visible lacerations or ear damage. We administered an antibiotic, LA 200 (Long-acting oxytetracycline, 7 mL), to minimize post-handling infection. We then used tooth wear to age the deer (Severinghaus 1949). We expected aging to be biased high since sand is likely more abrasive to teeth on Fire Island than in other environments. We verified that the assigned collar was functioning properly using an Advanced Telemetry Systems (ATS) R410 scanning receiver. In 2015, 2016 and 2017, uniquely-identifiable metal ear tags were attached to the deer's ears to identify previously-collared deer in future years. We then administered the BAM-reversal drug Tolazoline and secured the radio collar around the deer's neck. Five minutes after administering Tolazoline, we injected Atipamezole according to approved protocols to complete the reversal process. We moved approximately 30 m from the deer's location and observed the deer as the reversal drug counteracted the immobilization. Only when the deer walked or ran out of view did we return to our vehicle and leave the scene.

Rectal biopsies were conducted on each captured individual in 2014 to test for Chronic Wasting Disease (CWD) and to serve as a baseline for CWD occurrence on Fire Island. Lidocaine gel was used to numb the area prior to conducting the biopsy. J. Raphael and L. Ries collected 1.5 x 1.0 cm strips of mucosal tissue from the wall of the rectum approximately 1 cm cranial to the mucocutaneous junction of the anus using a scalpel. Samples were collected at the 10 and 2 o'clock positions (Wolfe et al 2007).

At the end of each capture day, all data sheets were input into a digital word processor and were verified for accuracy. Any photos captured were labeled and stored for later use.

Radio Collar Specifications

In 2014 and 2015, we used Advanced Telemetry Systems (ATS) G2110D model collars programmed to collect GPS fixes every 30 minutes from 1600 to 0800 and at 1200 each day. Collars emitted VHF signals every day from 0700 to 1900, which we tracked using a scanning receiver and Yagi antenna. Collars were programmed to release from the deer when the main battery died (after approximately 280 days) and to emit a mortality-specific VHF signal if the collar remained in the same location for >8 consecutive hours. In 2015, 2016 and 2017, we used Lotek GPS6000SD model collars programmed to collect GPS fixes every 45 minutes from 1600 to 0800. Collars emitted VHF signal from 0700 to 1900, and were scheduled to release from the deer 365 days after deployment. Lotek collars were also scheduled to emit a mortality-specific VHF signal if the collar remained in the same location for >8 consecutive hours.

To allow for incidental sightings of individual deer without the need for radio-telemetry equipment, we used colored duct tape to uniquely mark each collar before deployment (Figure 4). We used two or three colors for each animal, and taped both sides of the collar so the deer could be identified from either side. We then covered the colored duct tape with clear, extra-strength duct tape to protect the colored tapes from ripping off prematurely.



Figure 4. Color combinations used to uniquely identify radio-collared white-tailed deer in the field on Fire Island, New York.

Weekly, we drove down the beach or central-island access road with the VHF receiver tuned to the frequency of an individual deer until we observed a signal. We recorded the date, observers present, outside temperature, approximate cloud cover, precipitation and overall weather, and categorical wind speed. We then traveled on foot following the signal, using the receiver's "gain" feature to adjust the receiver's sensitivity as we got closer to the collar location. The gain feature is used to refine the search radius and is reduced as the receiver approaches the target collar. We recorded general location of the deer as determined from signal strength and whether or not the animal was seen. If no concerns about the well-being of the animal arose during monitoring (i.e., mortality collar beep, troubling behavior, obvious injury), we changed the VHF receiver to the next deer's frequency. We monitored each deer every week throughout the life of the collar.

Identification of Concealment Cover

Training of field staff in proper triangulation of concealment cover occurred during summer 2014 to ensure accuracy during subsequent seasons. We triangulated daytime deer locations once per week from January 2015 until May 2016. Concealment cover triangulations were not continued in 2017 due to sufficient data obtained in 2015 and 2016. We collected three GPS points surrounding the animal's detected location when gain was low and signal was high (Mech and Barber 2002). If the turn angle between the first two points was approximately 90°, we only collected two GPS locations. At each triangulation point, we recorded time, type of signal detected by the receiver to monitor mortality or battery-health beeps, brief location description (e.g., "between two small pine groves just east of Watch Hill"), percent gain and signal strength from the receiver, compass heading of greatest signal, and if any deer were visible. We often saw a collared deer during triangulations, in which we recorded the observation as a sighting instead of a triangulation. We recorded time, type of signal detected by the receiver, general location of the animal (i.e., crossroad), behavior at time of observation, reaction to our presence (i.e., habituation behavior or flight), GPS coordinates of the animal, sex and age composition of any other deer present, and overall health of the collared deer (i.e., neck abrasion, ear tag irritations). If a collar emitted a mortality signal, we located the collar. If the collar was attached to a deceased deer, we conducted a partial field necropsy, during which we looked for evidence of mortality cause, removed either two front teeth or the entire bottom jaw for analysis, and collected the collar.

All triangulations were used to identify concealment cover. We imported GPS locations into ArcGIS and drew a polyline from the GPS point to the edge of the map using the compass heading collected in the field. After each polyline was drawn for a given triangulation effort, we drew a polygon where the lines intersected, indicating the deer was likely in that location. Larger concealment cover polygons indicate less certainty in the deer's exact location, which resulted from unideal weather conditions and signal distortions when near buildings.

Home Range Estimation

We downloaded GPS data from each collar and imported them into ArcGIS. We projected the collar data into the WGS_1984_UTM_Zone_18N coordinate system and calculated GPS locations in UTM. We manually removed all GPS points collated on mainland Long Island from collar programming and testing. We also removed all GPS points collected outside a 10-m land buffer to avoid inaccurate

home range estimation as a result of collar imprecision. We imported a comma-delimited file into the statistical programming software R, where we used the *mcp* function in the *adehabitatHR* package (Calenge 2006) to calculate minimum convex polygon (MCP) home ranges (95%) and core areas (50%) for each deer. To compare our results to those of previous work on Fire Island, we calculated home range lengths as the farthest distance along Fire Island contained within home ranges. We assessed normality through residuals tests. After removing outliers identified in each study area, we used one-way ANOVA and Tukey's test of significance to assess differences in home range sizes among study areas. All R code is available in Appendix A.

Daily Movement Rates

We calculated the number of days each collar actively collected GPS information per season, defined as follows: (1) Winter = 01 December – 29 February, (2) Spring = 01 March – 31 May, (3) Summer = 01 June – 31 August, and (4) Autumn = 01 September – 30 November. We used the following equation to calculate the distance between consecutive GPS fixes for each deer:

$$\text{Distance between } (x_1, y_1) \text{ and } (x_2, y_2) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

We assumed animals moved in a straight line between points (x_1, y_1) and (x_2, y_2) and calculated the mean distance traveled per day as the sum of all between-point distances divided by the total number of days. We used this value as a proxy for average deer movements to compare among individuals. We also calculated mean distances traveled per day among seasons for each individual, and the average distance traveled per day among seasons for all individuals. Lastly, we calculated average distances per day for each study area to compare between years. We removed all deer that died while collared from the study area analysis to avoid biased average step distances.

Results

Capturing and Handling White-tailed Deer

In 2014, 15 adult female deer were captured and collared on Fire Island. One deer, labeled P3, died 38 days after her capture (**Error! Reference source not found.**). We captured and collared 16 adult female deer in 2015. One collared deer, uniquely identified as PY080, showed evidence of a previous collar, including missing hair around the neck and rectal biopsy scar, indicating that she was collared in 2014. When we collared YB060 in 2015, we observed her traveling with O1 (2014), evidenced by a band of missing fur on her neck. In 2016, 18 adult female deer were captured and collared. We darted W2 (2014) and removed her malfunctioning collar in February 2016. We unintentionally captured BO520 (2015) in a Clover trap in February 2016, and released her after collecting vital information. In 2017, we captured and collared 11 adult female deer. WW660 (2016) was collared as PP300 after her capture and subsequent collar switch in 2017. GG400 was collared as BR039 in 2015 and PB460 was collared as YB181 in 2015 as determined through unique ear tags. OB560 could have been a deer collared in 2014 since she has scarring on her neck, no ear tags, and no scarring on the ears to indicate that tags had been removed.

Logistical Constraints: Deer Captures and Radio-Collars

In April 2014, NPS biologists located G1 and removed her collar because of health concerns (i.e., rapid weight loss) and high visibility amongst residents in the Davis Park community. In 2015, WBG120 struggled to stand for 20 minutes after we initiated reversal, attempted to kick/rub off the collar for approximately 10 minutes, and finally walked into nearby woods. WBG120 died 75 days later. One deer (YB181a) slipped out of her collar the evening after we captured her. We did not measure hindfoot or girth nor did we determine age for PB261 because her body temperature remained high while immobilized; we processed her quickly before deploying a collar and administering reversal drugs. In 2016, one deer (BB560a) died seven days after her capture. In 2017, one deer (BB520) died 23 days after her capture; she was previously collared in 2016 as GO500. PP500, who was collared as GG340 in 2016, died 142 days after her capture in 2017.

In 2014, collars only collected data for the first two to six months of deployment due to faulty batteries. In June 2014, the collar on P1 malfunctioned and stopped releasing a VHF signal. P1 was sighted later in 2014, in winter 2016, and in March 2017 with a collar still attached and she appeared to be in good health. In July 2014, the collar from G4 was found on the ground without evidence of collar release. Several other collars failed to detach in 2014, but we were able to dart the deer and remove the collars in winter 2015 (i.e., P2, O2, and O1). All collars deployed in 2015 properly released and were retrieved in winter 2016. Collars on two deer collared in 2016 (WW380, WR580) currently remain on the deer and were not recovered after the VHF signal ceased. An additional collar deployed in 2017 (SS480) remains on the animal after the drop-off mechanism failed, though the collar continues to release VHF signal and Fire Island staff continue to monitor the deer's movements. Park staff intends to capture SS480 in winter 2019 to manually remove the radio-collar. Two collars in 2014 (i.e., O2, W2) collected 5-10% of GPS points in either the Atlantic Ocean or Great South Bay. In 2016, a programming error caused the collars to only collect data at noon daily after the first four months of deployment, though this did not affect the results of this study.

Identification of Concealment Cover

In 2015, we triangulated concealment cover for the entire life of collars, with an average of 26 concealment cover polygons per deer (Table 1). We also triangulated concealment cover from capture date to mid-May in 2016, with an average of nine concealment cover polygons per deer. We estimated concealment cover for five deer in the Lighthouse Tract (Appendix C), six deer in western Sailors Haven, three deer in eastern Sailors Haven and Cherry Grove, two deer in Talisman, four deer in Blue Point, seven deer in Watch Hill (Figure 5), three deer in western Wilderness Area (Figure 6), and two deer in eastern Wilderness Area.

Table 1. Concealment cover triangulated for radio-collared white-tailed deer in 2015 and 2016 on Fire Island, New York. Concealment covers (CC) are areas where deer find daytime refuge. Areas surveyed include the lighthouse tract (LH), Sailors Haven (SH), Cherry Grove (CG), Talisman (T), Blue Point (BP), Watch Hill (WH), and the Wilderness Area (WA) west and east of the post-Hurricane Sandy breach.

Year	Deer ID	Study Area	No. CC	Avg. Area (ha)	Range of Dates Collected	
2015	RYB100	LH	29	0.131	5/13/2015	8/13/2016
2015	PY080	LH	34	0.155	5/4/2015	3/16/2016
2015	BY001	LH	22	0.163	5/4/2015	3/8/2016
2015	RB019	LH	35	0.172	4/29/2015	2/29/2016
2015	PB261	SH	23	0.166	5/8/2015	11/18/2016
2015	WB200	SH	29	0.246	5/5/2015	2/29/2016
2015	WBG120	SH	2	1.400	5/12/2015	5/18/2015
2015	RG160	SH + CG	20	0.103	5/5/2015	3/1/2016
2015	WR140	BP	17	0.070	5/19/2015	12/4/2015
2015	YB181	BP	30	0.192	5/8/2015	3/1/2016
2015	BR039	BP	22	0.233	5/13/2015	3/29/2016
2015	BW400	WH	33	0.416	5/7/2015	3/29/2016
2015	BO520	WH	31	1.395	5/7/2015	3/15/2016
2015	RY680	W WA	33	0.633	5/7/2015	3/29/2016
2015	YB060	E WA	32	0.135	5/22/2015	3/14/2016
2016	PkW640	LH	6	0.209	4/6/2016	5/17/2016
2016	GO500	SH	3	0.174	2/9/2016	3/16/2016
2016	YO420	SH	13	0.387	1/19/2016	5/16/2016
2016	WW380	SH	10	0.665	1/19/2016	5/16/2016
2016	BG600	SH + CG	3	0.136	4/7/2016	5/16/2016
2016	BB560b	SH + CG	3	0.161	4/7/2016	5/16/2016
2016	OO320	Talisman	11	0.383	1/28/2016	5/16/2016
2016	PG540	Talisman	7	0.605	3/1/2016	5/16/2016
2016	PP300	BP	9	0.463	2/18/2016	5/16/2016
2016	WP440	WH	13	0.233	1/28/2016	5/16/2016
2016	YY360	WH	9	0.240	1/20/2016	5/16/2016

Table 1 (continued). Concealment cover triangulated for radio-collared white-tailed deer in 2015 and 2016 on Fire Island, New York. Concealment covers (CC) are areas where deer find daytime refuge. Areas surveyed include the lighthouse tract (LH), Sailors Haven (SH), Cherry Grove (CG), Talisman (T), Blue Point (BP), Watch Hill (WH), and the Wilderness Area (WA) west and east of the post-Hurricane Sandy breach.

Year	Deer ID	Study Area	No. CC	Avg. Area (ha)	Range of Dates Collected	
2016	GG340	WH	8	0.474	1/20/2016	5/16/2016
2016	WW660	WH	7	0.742	3/7/2016	5/16/2016
2016	PB620	WH	8	1.693	3/29/2016	5/16/2016
2016	WR580	W WA	12	0.615	1/19/2016	5/16/2016
2016	OB480	W WA	15	1.913	1/20/2016	5/16/2016
2016	YB460	E WA	11	0.288	3/4/2016	5/17/2016

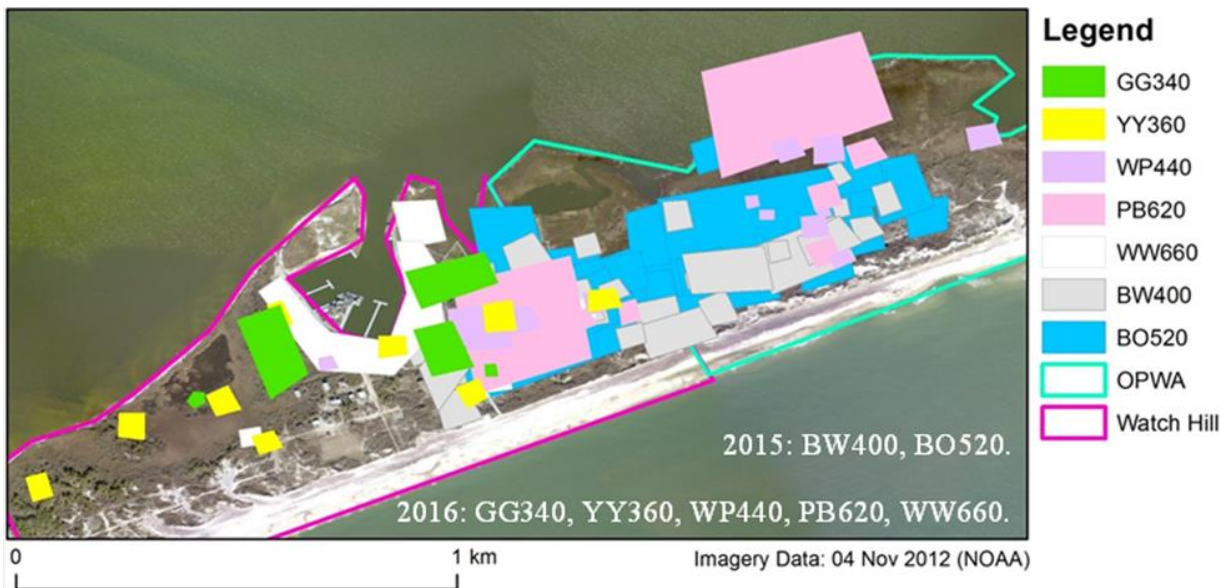


Figure 5. Concealment cover polygons delineated for seven radio-collared white-tailed deer in Watch Hill on Fire Island, New York.

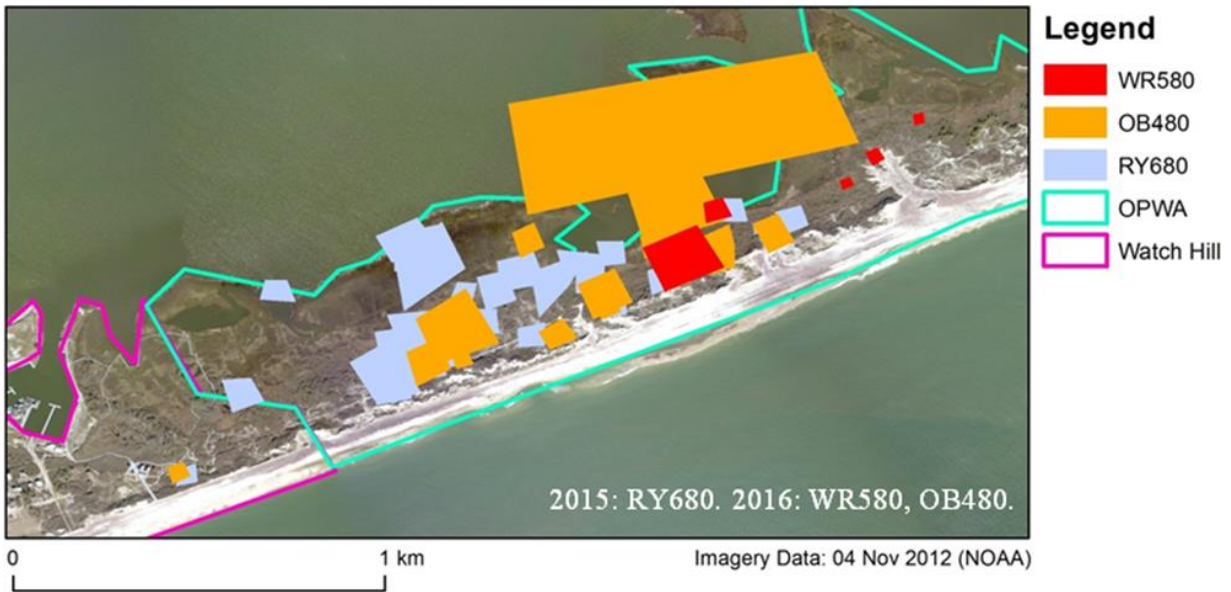


Figure 6. Concealment cover polygons delineated for three radio-collared white-tailed deer in the western areas of the Otis Pike Fire Island High Dune Wilderness Area, New York.

Home Range Estimation

Radio collars collected an average of 6,316 GPS fixes in 2014, 6,712 GPS fixes in 2015, 2,272 GPS fixes in 2016, and 6,698 GPS fixes in 2017. In the lighthouse tract, two of eight collared deer took exploratory trips to other areas of the island over the four year study (Table 2). In Sailors Haven, fifteen deer were collared, two of which died during the study and four explored other areas. None of the five deer monitored in Talisman left Talisman during the study. In Blue Point, four of nine collared deer took exploratory trips to other areas of the island (Table 3). Deer in Watch Hill exhibited the greatest proportion and number of explorations; among ten individuals, 23 independent trips occurred. Two deer in the western Wilderness Area and one in eastern Wilderness Area explored into other areas. Maps of GPS locations in each study area also revealed space use overlap by most deer (Figure 7, Appendix D), a seasonal migration for one individual, and a potential dispersal for another individual. GG340/PP500 migrated from western Wilderness Area to Watch Hill in January 2016 and back to the western Wilderness Area in December 2016. G4 dispersed from FI Pines to Watch Hill in April 2014.

Table 2. Information gathered and calculated from radio-collared white-tailed deer in several areas of Fire Island, New York from 2014-2017, including the lighthouse tract (LH), Sailors Haven (SH), and Talisman (T). “HR Len” = home range length, “CA” = core area (50% minimum convex polygon, MCP), and “HR” = home range (95% MCP).

Year	Deer ID	Location	Capture Date	End Date	Days Active	GPS Fixes	Trips	HR Len (km)	CA (ha)	HR (ha)
2014	W1	LH	2/25/14	8/26/14	182	8185	–	2.0	16.4	72.2
2014	W2	LH	2/25/14	8/29/14	185	7439	2W	1.1	15.6	135.8
2014	W3	LH	2/28/14	8/19/14	172	8182	–	0.9	9.3	28.8

Table 2 (continued). Information gathered and calculated from radio-collared white-tailed deer in several areas of Fire Island, New York from 2014-2017, including the lighthouse tract (LH), Sailors Haven (SH), and Talisman (T). “HR Len” = home range length, “CA” = core area (50% minimum convex polygon, MCP), and “HR” = home range (95% MCP).

Year	Deer ID	Location	Capture Date	End Date	Days Active	GPS Fixes	Trips	HR Len (km)	CA (ha)	HR (ha)
2015	BY001	LH	3/12/15	3/11/16	365	7360	–	0.8	4.3	28.4
2015	RB019	LH	3/12/15	3/17/16	371	7404	–	1.6	13.1	40.2
2015	PY080	LH	3/19/15	3/29/16	376	7664	–	0.8	10.5	30.1
2015	RYB100	LH	3/25/15	1/28/16	309	4929	1E	0.9	8.6	23.9
2016	PkW640	LH	3/31/16	4/03/17	368	1825	–	0.9	5.1	23.5
2014	P1	SH	2/27/14	–	–	–	–	–	–	–
2014	P2	SH	3/4/14	9/11/14	191	7973	1W, 1E	1.1	7.7	27.8
2014	P3	SH	3/4/14	4/11/14	38	1806	–	0.5	0.9	4.6
2015	WBG120	SH	3/12/15	5/26/15	75	1589	–	0.7	4.7	14.2
2015	RG160	SH	3/10/15	3/10/16	366	7338	1W, 1E	1.7	10.7	30.6
2015	WB200	SH	3/9/15	3/09/16	366	7643	–	1.2	5.2	20.1
2015	PB261	SH	3/13/15	1/19/16	312	5732	–	0.8	6.8	18.3
2016	WW380	SH	1/13/16	–	–	–	–	–	–	–
2016	YO420	SH	1/13/16	2/06/18	755	4678	–	0.7	3.5	13.4
2016	GO500	SH	2/03/16	3/29/16	55	1340	–	0.5	3.3	11.1
2016	BB560b	SH	4/02/16	10/20/16	201	715	1W, 1E	0.8	5.9	10.1
2016	BG600	SH	3/30/16	10/19/16	203	1128	1W	0.8	2.0	9.0
2017	PB340	SH	3/21/17	3/26/18	370	8064	–	0.6	4.2	12.9
2017	BB520	SH	3/27/17	4/19/17	23	505	–	0.0	0.0	0.0
2017	SB540	SH	3/30/17	3/30/18	366	7962	–	0.9	5.3	19.5
2014	G3	T	2/25/14	8/19/14	175	8188	–	0.9	3.6	29.0
2014	G4	T	3/18/14	7/02/14	106	2117	–	1.2	7.0	204.2
2016	OO320	T	1/12/16	1/12/17	366	3348	–	1.9	6.5	21.8
2016	PG540	T	2/25/16	2/28/17	369	2394	–	6.9	101	237.2
2017	OB560	T	3/23/17	3/26/18	368	7954	–	1.5	3.1	13.8

Table 3. Information gathered and calculated from radio-collared white-tailed deer in several areas of Fire Island, New York from 2014-2017, including Blue Point (BP), Watch Hill (WH), and the Wilderness Area (WA) east and west of the post-Hurricane Sandy island breach. “HR Len” = home range length, “CA” = core area (50% minimum convex polygon, MCP), and “HR” = home range (95% MCP).

Year	Deer ID	Location	Capture Date	End Date	Days Active	GPS Fixes	Trips	HR Len (km)	CA (ha)	HR (ha)
2014	G1	BP	2/24/14	4/28/14	63	2664	–	3.5	4.3	12.2
2014	G2	BP	2/25/14	8/16/14	172	8156	2W	8.6	6.4	14.7
2015	BR039	BP	3/31/15	3/31/16	366	6756	–	1.0	7.8	18.0
2015	WR140	BP	3/12/15	12/11/15	274	4086	3E	0.9	4.6	12.9
2015	YB181	BP	3/11/15	3/09/16	364	7435	2W	1.5	6.4	20.2
2016	PP300	BP	2/02/16	11/17/16	289	2627	–	1.1	3.8	17.2
2017	GG400	BP	3/22/17	3/26/18	369	7707	1W, 1E	1.2	3.9	14.7
2017	BB660	BP	3/27/17	3/28/18	366	7937	–	0.9	4.9	11.3
2017	PB460	BP	3/27/17	3/28/18	366	7905	–	1.2	3.8	14.9
2014	Y1	WH	3/14/14	9/02/14	172	8183	1W	0.7	4.8	16.9
2014	Y2	WH	3/18/14	7/10/14	114	5327	2W	0.9	3.6	25.4
2014	Y3	WH	3/17/14	9/04/14	171	8184	–	0.7	4.1	17.7
2015	BW400	WH	4/01/15	4/05/16	370	9138	2W, 2E	1.4	13.4	50.4
2015	BO520	WH	4/02/15	4/05/16	369	9188	3W	1.2	9.5	38.2
2016	PB620	WH	3/22/16	3/21/17	364	1918	3E	0.8	7.8	26.0
2016	WW660	WH	2/26/16	1/31/17	340	2429	1E	0.9	7.1	21.5
2016	YY360	WH	1/07/16	2/08/18	763	5058	4E	1.2	11.1	32.6
2016	WP440	WH	1/07/16	2/05/18	760	4976	2E	0.9	4.9	22.9
2017	PP300	WH	1/25/17	1/26/18	366	7841	2E	4.4	13.8	110.1
2017	OO320	WH	1/29/17	3/31/18	367	7985	1E	1.3	4.6	25.8
2017	SS480	WH	3/21/17	–	–	–	–	–	–	–
2015	RY680	W WA	4/03/15	12/5/15	246	6152	–	1.0	6.4	26.8
2016	BB560a	W WA	1/14/16	1/20/16	6	145	–	0.2	0.1	0.4
2016	WR580	W WA	1/07/16	–	–	–	–	–	–	–
2016	GG340	W WA	1/14/16	11/16/16	307	3194	–	4.3	32.4	124.3
2016	OB480	W WA	1/07/16	1/06/17	365	3606	1W, 1E	0.9	6.0	25.5
2017	PP500	W WA	11/16/16	4/07/17	142	3105	2W, 2E	4.7	121.0	135.6
2014	O1	E WA	4/01/14	10/6/14	188	8183	–	0.8	0.7	14.7
2014	O2	E WA	4/01/14	7/29/14	119	3846	–	1.0	5.3	145.2

Table 3 (continued). Information gathered and calculated from radio-collared white-tailed deer in several areas of Fire Island, New York from 2014-2017, including Blue Point (BP), Watch Hill (WH), and the Wilderness Area (WA) east and west of the post-Hurricane Sandy island breach. “HR Len” = home range length, “CA” = core area (50% minimum convex polygon, MCP), and “HR” = home range (95% MCP).

Year	Deer ID	Location	Capture Date	End Date	Days Active	GPS Fixes	Trips	HR Len (km)	CA (ha)	HR (ha)
2015	YB060	E WA	3/19/15	3/20/16	367	8005	1E	1.6	8.3	55.9
2016	YB460	E WA	2/10/16	2/14/17	370	2897	–	1.6	4.8	47.9

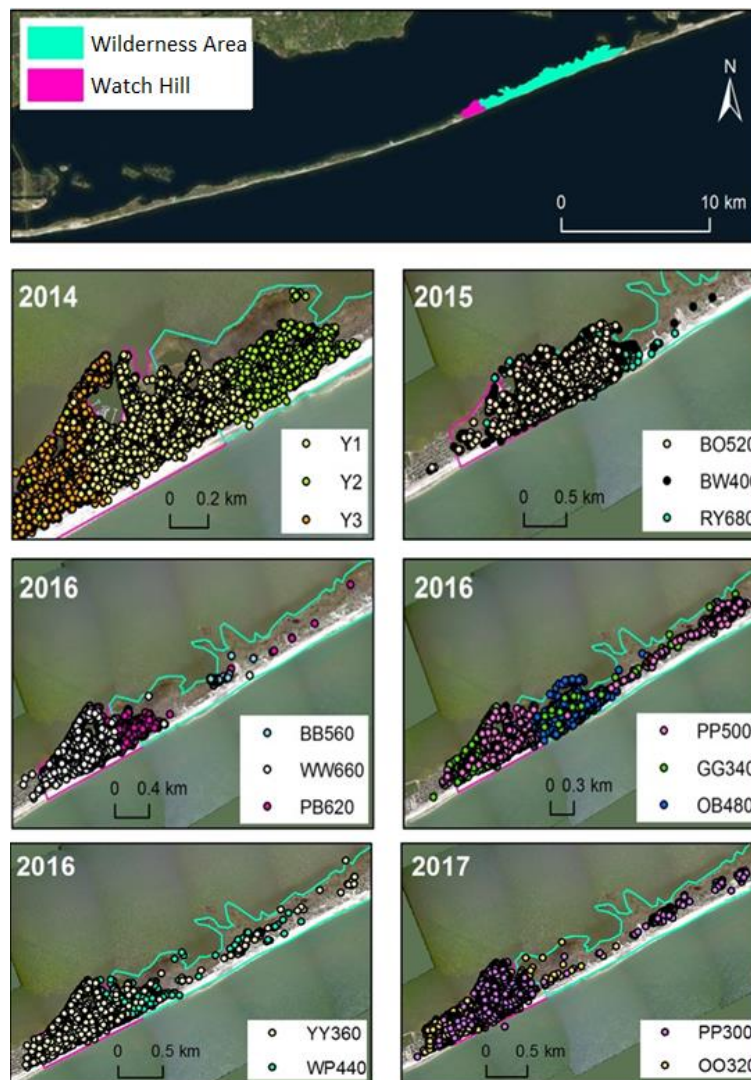


Figure 7. GPS locations from deer collars in Watch Hill and the Otis Pike Fire Island High Dune Wilderness Area (Wilderness Area) west of the post-Hurricane Sandy island breach.

Average home range length across all study areas was 1.6 km and the greatest average home range lengths were calculated for Blue Point (2.2 km), Talisman (2.5 km), and western Wilderness Area

(2.2 km, Table 4). Average home range lengths in the Lighthouse Tract (1.1 km), Watch Hill (1.3 km), and eastern Wilderness Area (1.3 km) were comparatively constricted, and the shortest average home range length was calculated in Sailors Haven (0.8 km). The largest core areas were calculated in Talisman and western Wilderness Area. Home range sizes were largest and most variable in the Lighthouse Tract, Talisman and the wilderness areas, as evidenced by standard deviations nearly equal to or greater than averages. Across all years, average home ranges were at least three times larger than core areas for all study areas except the western Wilderness Area. Core areas in the eastern Wilderness Area were only 7% of the size of home ranges, and core areas in the western Wilderness Area were 53% of the size of home ranges.

Table 4. Average home range lengths, 50% home ranges, and 95% home ranges for radio-collared white-tailed deer on Fire Island, New York from 2014 to 2017. Home range calculations were conducted using minimum convex polygons. Values in parentheses indicate standard deviations.

Study Area	Home Range Length (km)	50% Home Range (ha)	95% Home Range (ha)	Percentage of 95% HR captured by 50% HR
Lighthouse	1.1 (0.4)	10.4 (4.5)	47.9 (38.9)	21.7
Sailors Haven	0.8 (0.4)	4.6 (2.9)	14.7 (8.6)	31.4
Talisman	2.5 (2.5)	24.1 (42.7)	101.2 (109.8)	23.9
Blue Point	2.2 (2.5)	5.1 (1.4)	15.1 (2.9)	33.7
Watch Hill	1.3 (1.1)	7.7 (3.7)	35.2 (26.7)	21.9
Western Wilderness Area	2.2 (2.1)	33.1 (50.5)	62.5 (62.6)	53.0
Eastern Wilderness Area	1.3 (0.4)	4.8 (3.1)	65.9 (55.8)	7.2

We identified six outliers in home range length, two outliers in core area size, and two outliers in home range size (Figure 8). After verifying normality and removing outliers, home range length was not significantly different among study areas at the 0.05 level ($F=2.316$; $df=6, 42$; $p=0.050$). Core areas ($F=3.766$; $df=6, 45$; $p=0.004$) and home ranges ($F=3.870$; $df=6, 46$; $p=0.003$) both significantly differed among study areas at the 0.05 significance level. Significant differences in core area size were identified between Lighthouse Tract and Blue Point ($p=0.023$), eastern wilderness area ($p=0.088$), Sailors Haven ($p=0.004$), and western wilderness area ($p=0.086$). Significant differences in 95% home range sizes were identified between Talisman and Blue Point ($p=0.008$), Sailors Haven ($p=0.004$), and Watch Hill ($p=0.030$).

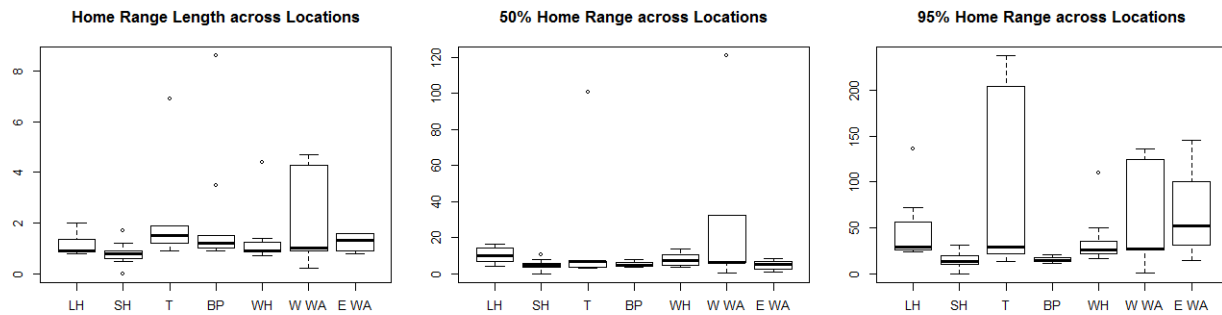


Figure 8. Results of outlier analysis show several outliers in white-tailed deer home range length, 50% home range, and 95% home range among seven study areas (Lighthouse Tract (LH), Sailors Haven (SH), Talisman (T), Blue Point (BP), Watch Hill (WH), and wilderness area (WA) west and east of the post-Hurricane Sandy island breach) on Fire Island, New York. Home ranges were calculated from radio-collars between 2014-2017.

Daily Movement Rates

In 2014, radio collars were active for an average of 146 days (range: 38-188 days). On average, collars collected GPS data for 2 days in winter, 77 days in spring, 65 days in summer, and 4 days in autumn. Assuming deer moved in a straight line between GPS fixes, individuals moved an average of 2,430 m per day throughout the year. On average, deer moved 2,415 m per day in spring and 2,545 m per day in summer. Using limited available data, deer moved on average 3,204 m per day in autumn and 1,850 m per day in winter.

In 2015, radio collars were active for an average of 327 days. On average, collars collected GPS data for 69 days in winter, 87 days in spring, 86 days in summer, and 85 days in autumn. Assuming deer moved in a straight line between GPS fixes, individuals moved an average of 1,508 m per day throughout the year. On average, collared deer moved 1,302 m per day in winter, 1,614 m per day in spring, 1,517 m per day in summer, and 1,681 m per day in autumn.

In 2016, radio collars were active for an average of 277 days. On average, collars collected GPS data for 56 days in winter, 76 days in spring, 78 days in summer, and 68 days in autumn. Assuming deer moved in a straight line between GPS fixes, individuals moved an average of 1,335 m per day throughout the year. On average, collared deer moved 1,710 m per day in winter, 2,203 m per day in spring, 938 m per day in summer, and 981 m per day in autumn.

In 2017, radio collars were active for an average of 318 days throughout the year. On average, collars collected GPS data for 85 days in winter, 85 days in spring, 74 days in summer, and 74 days in autumn. Assuming deer moved in a straight line between GPS fixes, individuals moved an average of 1,039 m per day throughout the year. On average, collared deer moved 872 m per day in winter, 969 m per day in spring, 1,355 m per day in summer, and 1,339 m per day in autumn.

Among years, deer collars were active most often during the spring and they were least active in winter (Table 5). Among seasons, the largest average daily step distances were observed in spring (2,234 m) and the smallest were observed in autumn (1,484 m). The largest average daily step

distances were observed in the eastern Wilderness Area (3,152 m) and the smallest were observed in the western Wilderness Area (1,101 m).

Table 5. Data regarding deer collar life, movement seasonality, and step distances by study area pooled among years from radio-collared white-tailed deer on Fire Island, New York. W = winter (01 December – 29 February), Sp = spring (01 March – 31 May), Su = summer (01 June – 31 August), Au = autumn (01 September – 30 November).

Study Area	# Deer	Average # Days					Average Step Distance (m/day)				
		Total	W	Sp	Su	Au	Total	W	Sp	Su	Au
Lighthouse Tract	8	290	54	90	89	57	2067	1328	2172	2116	1592
Sailors Haven	10	318	64	88	92	74	1383	1037	1453	1422	1608
Talisman	8	299	59	89	83	68	1438	1382	1757	1182	1220
Blue Point	6	271	51	88	74	58	1968	2001	2066	2056	1103
Watch Hill	11	385	88	110	104	83	1256	978	1299	1261	1624
Western Wilderness Area	4	265	58	70	69	68	1101	1168	1001	1079	1106
Eastern Wilderness Area	4	261	47	77	84	54	3152	2784	4560	2053	2182
Total	51	298	60	87	85	66	1767	1525	2044	1569	1491

Discussion

Home ranges of adult female white-tailed deer on Fire Island varied in size among study areas and years. In all areas of Fire Island, home ranges of multiple white-tailed deer overlapped in space. Several deer occasionally left their normal home ranges for a few days of exploration, but all deer monitored for multiple years exhibited strong home range fidelity. Most monitored deer, except a few in the Wilderness Area, used both natural (i.e., federally-managed) and built (i.e., private, residential) lands regularly and their movement rates were greatest in spring.

Several collars malfunctioned throughout our study, though the proportion of collars that malfunctioned is low (Merrill et al. 1998). Each year, several collars, including those of both manufacturers, failed to release from the deer as scheduled. Similarly to Merrill et al. (1998), condensation from Fire Island's high humidity likely caused release failure for many of the collars in this study. Programming of Lotek and ATS collars include a mask that prevents calculation of GPS locations when PDOP exceeds a threshold value (e.g., ATS: PDOP >12, Lotek: PDOP >10). The dilution of precision (DOP) indices (i.e., horizontal DOP, positional DOP) for water-based locations (i.e., Great South Bay or Atlantic Ocean, see Figure 1) recorded by the two ATS collars from 2014 do not suggest they were erroneous (Moen et al. 1997, D'eon and Delparte 2005). However, the sporadic nature of the GPS locations suggests they were indeed inaccurate (Frair et al. 2010). We occasionally observed adult and juvenile deer in salt marshes and ocean surf, but we never observed deer in open water during this study. Many other factors, including habitat type, weather, and antenna position, affect GPS accuracy of radio collars (Mech and Barber 2002, Di Orio et al. 2003), but were not directly assessed in this report.

Capture myopathy, muscle damage caused by changes to blood flow and oxygen transport in the body due to extreme stress or exertion, can lead to death of animals after live capture (Beringer et al. 1996) and is most prevalent within the first 30 days of capture (Rongstad and McCabe 1984, Jones and Witham 1990). We used darting techniques (i.e., remote drug delivery system) and Clover traps because each elicits a lower stress response than other techniques (i.e., rocket nets; Beringer et al. 1996) for capturing wild deer. During capture and processing, we used blindfolds and limited noise/talking to minimize effects of capture myopathy. Of the five deer that died during our study (9%), two occurred within 30 days. BB560a died seven days after capture and BB520 died 23 days after capture and neither exhibited abnormal signs of capture stress or old age during processing. P3 died 38 days after capture, during which we recorded heavy tooth wear with flat molars and visible dentin, both associated with old age. PP500 and WBG120 died far outside the 30-day capture myopathy window (i.e., 142 and 75 days, respectively). During field necropsies, we looked for signs of capture myopathy (i.e., pallor in skeletal muscles of lumbar area and caudal muscles, presence of hemorrhaging; Beringer et al. 1996) and were unable to definitely isolate a mortality cause for any deceased animal. Isolating capture myopathy as the cause of death is difficult and not certain (Rongstad and McCabe 1984, Jones and Witham 1990, Beringer et al. 1996, DelGuice et al. 2001), though we are confident that the proportion of potentially-myopathic mortality in our study is very low (2%). We do not attribute the deaths of P3, WBG120, BB520, and PP500 to capture myopathy due to (1) observations of normal vital signs during capture and characteristic behavior after capture,

(2) lack of myopathy signs to the body after death, (3) in the cases of P3, WBG120, and PP500, length of time since capture (i.e., >30 days), and (4) in the case of P3, obvious signs of old age. The death of BB560a could have been due to capture myopathy; she died seven days after capture, her post-mortem bone marrow was pink with fat suggesting healthy body condition, and we observed no obvious signs of predation besides post-mortem scavenging.

Strong site fidelity and occasional seasonal migrations among adult female white-tailed deer on Fire Island were also documented in the 1980's (O'Connell and Sayre 1988, O'Connell 1989). Like O'Connell (1989), we observed a westerly dispersal or migration in a very small proportion of the deer monitored throughout the four-year study (i.e., 2 out of 55). Like many other studies of seasonal movements of deer (Byford 1969, Loft et al. 1984, Nixon et al. 1988, Beier and McCullough 1990, Long et al. 2008), we observed greatest movement rates in spring compared to other seasons, though our monitoring efforts were comparatively low in winter due to collar deployment and drop-off schedules. We observed deer wading through salt marshes and occasionally in shallow waters of Great South Bay, but we did not observe any dispersals off of Fire Island in our study.

The average home range length of Fire Island deer we observed is nearly 30% shorter than the average home range length reported by O'Connell (1989) for several reasons. Firstly, our study focused on female white-tailed deer only, while O'Connell (1989) captured and monitored both male and female deer. Female deer are known to exhibit shorter and more confined movements than their male counterparts (Rongstad and Tester 1969, Bunnell and Harestad 1983) and females disperse less frequently than males (Kammermeyer and Marchinton 1976, Masters and Sage 1985, Nelson and Mech 1992, Nelson 1993, Lesage et al. 2000). Secondly, technology has greatly improved since O'Connell's study in 1989, and the precision of deer locations in our study no longer relied upon locating the animal using only VHF triangulation. Locating a radio-collar through use of VHF triangulation is much less precise than through GPS information collected consistently by the collars themselves (White and Garrott 1990, Tomkiewicz et al. 2010).

O'Connell (1989) observed longer home range lengths in western communities (Lighthouse Tract, Sailors Haven, Fire Island Pines, Talisman) than in the eastern half of Fire Island (Blue Point, Davis Park, Watch Hill, Wilderness Area). Our results suggest shorter home range lengths in western areas than eastern areas using the same dividing line. Sanderson (1966) suggested that if all forage needs are met within a small area, animals will likely respond by using a smaller home range. In western areas of Fire Island, intentional and unintentional supplemental feeding is well-documented (Seimer et al. 2007). In south Texas, deer feeding was concentrated near supplemental feeders, but deer still relied heavily upon natural vegetation and induced habitat degradation (Cooper et al. 2006). When food supplies were removed, daily movements of female white-tailed deer home ranges expanded and were less spatially concentrated (Byford 1969). Plant diversity is also greater in western areas of Fire Island as a result of exotic plantings and residential landscaping (Stalter et al. 1986, Dowhan and Rosza 1989). Similarly in rural California, female black-tailed deer exhibited smaller home ranges in areas with greater habitat diversity (Loft et al. 1984). In the same areas, some deer used large home ranges and others maintained small home ranges, supporting O'Connell's (1989) supposition of hierarchical dominance in Fire Island's deer populations.

Average minimum convex hull home range sizes for deer in our study were small compared to deer studied in inland populations (Byford 1969, Larson et al. 1978, Loft et al. 1984, Hölzenbein and Schwede 1989, Labisky et al. 1999). Small home ranges on Fire Island likely result from several factors, including intentional and unintentional supplemental feeding throughout the year (Siemer et al. 2007), smaller body size and therefore lower energy requirements of island deer compared to mainland deer following the island rule (Raia and Meiri 2006), and high interspersed resources (Gorham and Porter 2011, Quinn et al. 2013, Kilheffer 2014). In addition, the configuration of the relatively narrow barrier island itself could have caused smaller home ranges (O'Connell and Sayre 1988). Unlike the deer movements observed in the 1980s, we observed home ranges covering six relatively distinct areas of the island: (1) the Lighthouse Tract and western island communities, (2) Sailors Haven and adjacent communities, (3) the Pines and Talisman, (4) Blue Point and Davis Park, (5) Watch Hill and western Wilderness Area, and (6) eastern Wilderness Area and neighboring Smith Point County Park. The six populations that we identify likely represent a gradient in movement of Fire Island's white-tailed deer, and are seemingly distinct due to our concentrated sampling efforts in these areas. We hypothesize that the eastern Wilderness Area deer likely intermingled with the western Wilderness Area before the breach occurred in 2012.

Behavioral and preference decisions are made at multiple spatial scales (Boyce et al. 2003, Morales et al. 2004) and differ for each monitored individual. Deer with large home ranges and long daily movement rates likely impact vegetation over a broad extent, but potentially to a lesser degree than those with smaller, more condensed home ranges. While selecting feeding areas, deer may appear to use a large area via GPS locations, but their impacts are much more localized in feeding areas with dense available forage as compared to the surrounding area (Johnson et al. 2002, Frair et al. 2005). Deer which frequently explore other feedings areas may display a large home range, but their foraging impacts likely occur over smaller extents (Senft et al. 1987) where forage preference is high within the extent of the home range.

A Deer Management Plan for Fire Island National Seashore was approved in 2016, the goal of which is to protect cultural and natural resources that are negatively affected by high deer densities by enhancing public outreach and education in western communities and reducing deer densities on federal tracts of land throughout Fire Island (FIIS 2016). In this report, we document the seasonal and annual movements of white-tailed deer along Fire Island, New York. Radio-collars provide a wealth of data, only a fraction of which is presented in this report. In future analyses, we aim to assess diel patterns in movement, including nocturnal space use and compare movement patterns between natural and built areas on Fire Island at finer temporal and spatial scales than those that we present in this report.

Conclusions

We used radio-collars to monitor white-tailed deer on Fire Island from 2014 to 2017 in seven different areas. We assessed step distances and home ranges among study areas and found the greatest movements of Fire Island's adult female white-tailed deer in spring each year. Home range sizes varied among study areas and years and indicated hierarchical dominance among Fire Island's deer populations. Potentially six distinct populations were delineated through analysis of GPS radio-collar data, though these divisions also reflect the concentrated sampling efforts of deer capture. Since Hurricane Sandy, deer movements in Fire Island's Wilderness are divided by the storm-induced breach and nearly all deer monitored shared time between natural and nearby built environments. GPS radio-collars provided a wealth of data for analysis of deer movements and space use, and this report is simply a snapshot of the potential information we intend to gain from this four-year study.

Management Implications

Fire Island National Seashore staff have implemented parts of the Deer Management Plan, such as enhancing public education and outreach, and initiating long-term monitoring plans for deer and vegetation throughout the Seashore. The goal of the Deer Management Plan is to protect natural and cultural resources that are negatively affected by high deer densities. In the near future, the Seashore staff will begin reducing deer densities on federal tracts throughout the Seashore. Because Fire Island's deer exhibit behaviors associated with hierarchical dominance of females, it is likely that the population structure will be disrupted by any lethal management if high ranking (i.e., older; Hall 1983, Aycrigg and Porter 1997, Townsend and Bailey 2004) females are removed from the population. We suggest continued monitoring of deer densities and deer behavior (i.e., habituation, fear response) through non-intrusive methods (i.e., distance sampling) as outlined in the Seashore's monitoring plan for the duration of deer management activities. Monitoring will assess program efficacy and document changes in population size, movements, and behavioral responses to human activity.

White-tailed deer movements in the western, more heavily residential areas of Fire Island suggest that deer respond to supplemental feeding and utilize smaller home ranges, because they do not strictly rely on naturally available forage. Supplemental feeding can be intentional (i.e., human food from direct feeding) or unintentional (i.e., uncontained garbage, ornamental plants, etc). Deer on federal tracts exhibit greater movements as they must search through larger areas as they selectively forage natural vegetation. We suggest continued efforts to educate visitors and residents of the Seashore on the harms of supplementing deer diets with human food, whether intentional or unintentional. For example, supplemental feeding of deer could result in further habituation of deer, causing a greater number of undesirable human-deer interactions as deer congregate nearer to people and homes. In addition, supplemental feeding can cause high deer densities that are not naturally sustainable and lead to subsequent declines in individual deer health conditions.

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Appendix A. R code associated with home range analysis of white-tailed deer radio-collar data on Fire Island, New York.

```
#####  
#####  
### C. Kilheffer et al. 2018 (NPS NRR Task 3)  
### R Version 3.2  
#####  
#####  
  
rm(list = ls()) # clear console memory  
  
#### Home range analysis ####  
install.packages("adehabitatHR") #home range analysis  
library(raster)  
library(rgdal)  
library(ggplot2)  
  
#Set the working directory  
setwd("../")  
  
All_Deer_GPS <- read.csv("All_Deer_GPS.csv", header=TRUE)  
track <- All_Deer_GPS  
summary(track)  
coordinates(track) <- c("UTMX", "UTMY")  
plot(track, col=track$Individual)  
proj4string(track) #currently, no coordinate info in file  
proj4string(track) <- CRS("+init=epsg:32618")  
summary(track)  
clu <- clusthr(track)  
class(clu)  
length(clu)  
windows()  
plot(clu $W1)  
Deer_cp50 <- mcp(track,percent=50)  
Deer_cp95 <- mcp(track,percent=95)  
windows()  
plot(Deer_cp)  
writePolyShape(Deer_cp50, "homerange_Deer_50")  
writePolyShape(Deer_cp95, "homerange_Deer_95")  
  
#### Stat Tests####
```

```

library(lattice)
library(agricolae)
library(stats)

#### Read Data from csv file ####
hr <- read.csv("DeerMvmt_HR.csv")

## Create factor for study area
study <- within(hr, Loc.F <- factor(Location))
Location <- factor(hr$Location, levels=c("LH", "SH", "T", "BP", "WH", "W
WA", "E WA"))

#### Select rows within each study area ####
LH <- hr[hr$Location=="LH",]
SH <- hr[hr$Location=="SH",]
T <- hr[hr$Location=="T",]
BP <- hr[hr$Location=="BP",]
WH <- hr[hr$Location=="WH",]
WWA <- hr[hr$Location=="W WA",]
EWA <- hr[hr$Location=="E WA",]

#### Bivariate outlier tests ####
windows()
par(mfrow=c(1,3))
boxplot(hr$HRL ~ Location, main="Home Range Length across
Locations")
boxplot(hr$HR50 ~ Location, main="50% Home Range across Locations")
boxplot(hr$HR95 ~ Location, main="95% Home Range across Locations")

#### One way ANOVA tests ####
#Remove outliers by data frame row
hr.1 <- hr[-c(25,27,28,46,50,51),]
anova.hrl <- aov(HRL~Location, data=hr.1) #Home Range Length
summary(anova.hrl)
TukeyHSD(anova.hrl)
res.1 <- anova.hrl$residuals
hist(res.1, main="Histogram of standardized residuals",
xlab="Standardized residuals")

hr.50 <- hr[-c(25,50,51),]
anova.hr50 <- aov(HR50~Location, data=hr.50) #Home Range, 50% MCP
summary(anova.hr50)

```

```
TukeyHSD(anova.hr50)
res.50 <- anova.hr50$residuals
hist(res.50, main="Histogram of standardized residuals",
xlab="Standardized residuals")

hr.95 <- hr[-c(46,2),]
anova.hr95 <- aov(HR95~Location, data=hr.95) #Home Range, 95% MCP
summary(anova.hr95)
TukeyHSD(anova.hr95)
res.95 <- anova.hr95$residuals
hist(res.95, main="Histogram of standardized residuals",
xlab="Standardized residuals")
```


Appendix B. Data collected from all adult female white-tailed deer captured on Fire Island, New York between 2014-2017.

Table B1. Data collected from all adult female white-tailed deer captured on Fire Island, New York between 2014-2017.

Year	No.	Deer ID	Location**	Capture Date	Hindfoot (cm)	Girth (cm)	Age (yr)
2014	1	W1	LH	2/25/2014	45.5	90.5	5
2014	2	W2	LH	2/25/2014	43.9	76.7	2
2014	3	W3	LH	2/28/2014	43.0	75.5	4
2014	4	P1	SH	2/27/2014	41.5	65.6	2
2014	5	P2	SH	3/4/2014	38.5	71.4	2
2014	6	P3	SH	3/4/2014	42.0	76.0	3+
2014	7	G3	T	2/25/2014	42.0	74.3	7
2014	8	G4	T	3/18/2014	42.0	78.0	3+
2014	9	G1	BP	2/24/2014	41.5	74.0	8+
2014	10	G2	BP	2/25/2014	43.0	68.8	2
2014	11	Y1	WH	3/14/2014	40.3	77.6	3+
2014	12	Y2	WH	3/18/2014	43.5	83.5	3+
2014	13	Y3	WH	3/17/2014	42.8	77.5	3+
2014	14	O1	E WA	4/1/2014	41.0	73.0	8+
2014	15	O2	E WA	4/1/2014	42.1	74.0	3
2015	16	BY001	LH	3/12/2015	43.0	77.5	6
2015	17*	RB019	LH	3/12/2015	43.7	76.4	4
2015	18*	PY080	LH	3/19/2015	42.1	82.0	3+
2015	19	RYB100	LH	3/25/2015	44.0	76.0	3
2015	20*	YB181a	LH	3/9/2015	42.0	72.5	5
2015	21*	WGB120	SH	3/12/2015	43.6	78.6	3

* Deer captured in a Clover trap. All other deer were captured using the darting technique.

** Locations include Lighthouse Tract (LH), Sailors Haven (SH), Talisman (T), Blue Point (BP), Watch Hill (WH), Otis Pike Fire Island High Dune Wilderness Area west of the post-Hurricane Sandy island breach (W WA), and Otis Pike Fire Island High Dune Wilderness Area east of the breach (E WA).

Table B1 (continued). Data collected from all adult female white-tailed deer captured on Fire Island, New York between 2014-2017.

Year	No.	Deer ID	Location**	Capture Date	Hindfoot (cm)	Girth (cm)	Age (yr)
2015	22	RG160	SH	3/10/2015	42.0	80.5	3
2015	23	WB200	SH	3/9/2015	42.5	85.0	5
2015	24*	PB261	SH	3/13/2015	N/A	N/A	N/A
2015	25	BR039	BP	3/31/2015	43.0	81.5	3+
2015	26	WR140	BP	3/12/2015	42.0	76.5	3
2015	27	YB181	BP	3/11/2015	43.0	73.5	4
2015	28*	BW400	WH	4/2/2015	43.1	64.8	3
2015	29*	BO520	WH	4/2/2015	44.0	80.2	6
2015	30*	RY680	W WA	4/3/2015	42.6	73.5	6
2016	32*	PkW640	LH	3/31/2016	42.0	77.0	5
2016	33	WW380	SH	1/13/2016	42.0	80.0	6
2016	34	YO420	SH	1/13/2016	43.0	81.0	4
2016	35	GO500	SH	2/3/2016	42.0	78.0	6
2016	36	BB560b	SH	4/2/2016	42.5	77.0	8
2016	37	BG600	SH	3/30/2016	42.5	70.5	3
2016	38	OO320	T	1/12/2016	40.5	77.0	8
2016	39	PG540	T	2/25/2016	42.0	81.0	3
2016	40	PP300	BP	2/2/2016	42.0	73.0	6
2016	41*	PB620	WH	3/22/2016	42.0	72.5	6
2016	42*	WW660	WH	2/26/2016	44.0	69.0	5
2016	43	YY360	WH	1/7/2016	43.0	72.0	6
2016	44	WP440	WH	1/7/2016	42.5	79.5	7
2016	45*	BB560a	W WA	1/14/2016	43.0	76.0	8
2016	46*	WR580	W WA	1/7/2016	44.0	76.0	6

* Deer captured in a Clover trap. All other deer were captured using the darting technique.

** Locations include Lighthouse Tract (LH), Sailors Haven (SH), Talisman (T), Blue Point (BP), Watch Hill (WH), Otis Pike Fire Island High Dune Wilderness Area west of the post-Hurricane Sandy island breach (W WA), and Otis Pike Fire Island High Dune Wilderness Area east of the breach (E WA).

Table B1 (continued). Data collected from all adult female white-tailed deer captured on Fire Island, New York between 2014-2017.

Year	No.	Deer ID	Location**	Capture Date	Hindfoot (cm)	Girth (cm)	Age (yr)
2016	47*	GG340	W WA	1/14/2016	42.7	73.0	8
2016	48*	OB480	W WA	1/7/2016	43.5	76.5	4
2016	49	YB460	E WA	2/10/2016	44.0	79.0	5
2017	50	PB340	SH	3/21/2017	43.0	73.0	4
2017	51	SB540	SH	3/30/2017	43.0	71.5	4
2017	52	BB520	SH	3/27/2017	42.5	75.5	7
2017	53	OB560	T	3/23/2017	42.0	71.0	7
2017	54	GG400	BP	3/22/2017	43.0	72.0	7
2017	55	BB660	BP	3/27/2017	42.0	68.0	4
2017	56	PB460	BP	3/27/2017	43.5	68.0	5
2017	57	PP300	WH	1/25/2017	42.5	76.0	7
2017	58	OO320	WH	1/29/2017	43.0	81.0	7
2017	59	SS480	WH	3/21/2017	44.0	73.0	5
2017	60	PP500	W WA	11/16/2016	43.0	80.0	7

* Deer captured in a Clover trap. All other deer were captured using the darting technique.

** Locations include Lighthouse Tract (LH), Sailors Haven (SH), Talisman (T), Blue Point (BP), Watch Hill (WH), Otis Pike Fire Island High Dune Wilderness Area west of the post-Hurricane Sandy island breach (W WA), and Otis Pike Fire Island High Dune Wilderness Area east of the breach (E WA).

Appendix C. Concealment cover polygons delineated for collared deer on Fire Island, New York.

Figures C-1 through C-6 show the concealment cover polygons delineated for collared deer in several areas along Fire Island, New York.

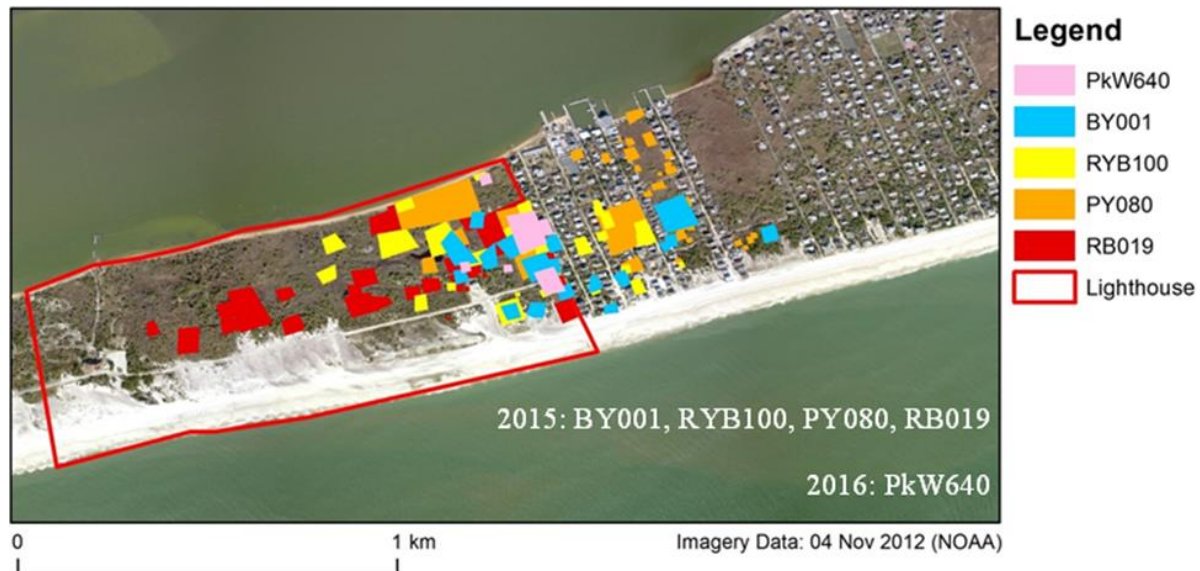


Figure C.1. Concealment cover polygons delineated for collared deer in the Lighthouse Tract on Fire Island, New York.



Figure C.2. Concealment cover polygons delineated for collared deer in Sailors Haven on Fire Island, New York.



Figure C.3. Concealment cover polygons delineated for collared deer in Cherry Grove and Fire Island (FI) Pines on Fire Island, New York.



Figure C.4. Concealment cover polygons delineated for collared deer in Talisman on Fire Island, New York.

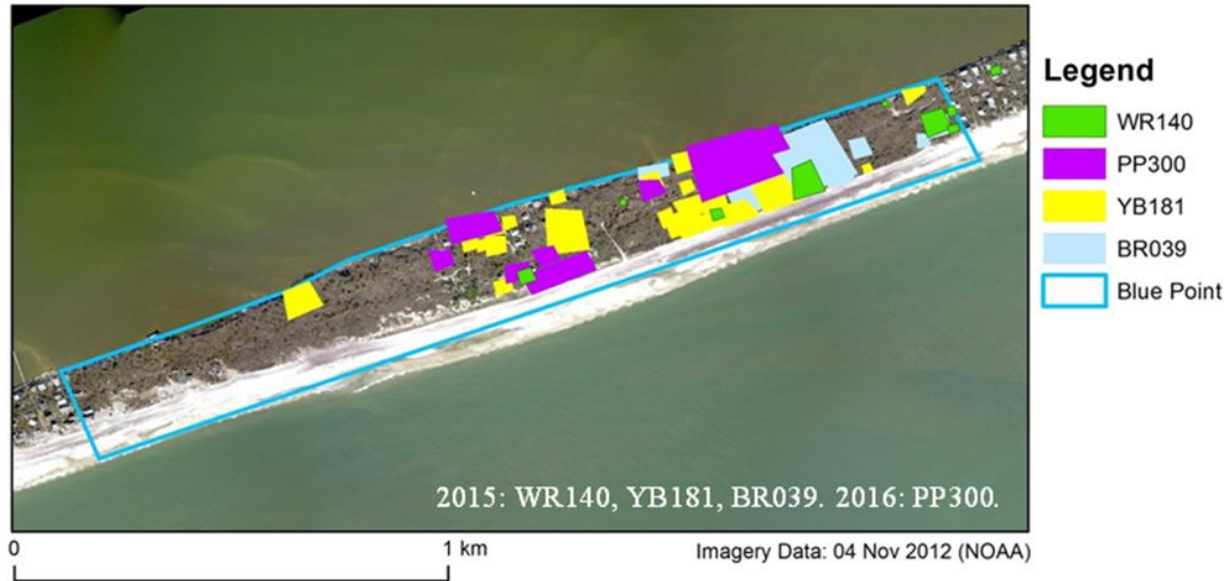


Figure C.5. Concealment cover polygons delineated for collared deer in Blue Point on Fire Island, New York.

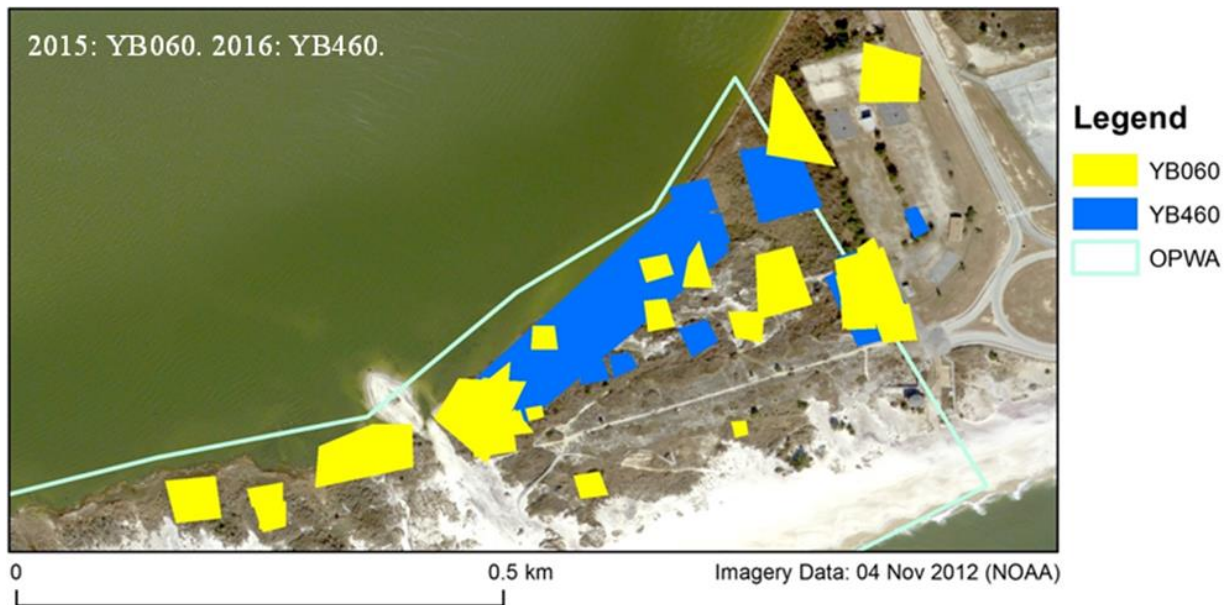


Figure C.6. Concealment cover polygons delineated for collared deer in the Otis Pike Fire Island High Dune Wilderness Area (WA) east of the post-Hurricane Sandy island breach on Fire Island, New York.

Appendix D. GPS locations from deer collars on Fire Island, New York.

Figures D-1 through D-4 show GPS locations from deer collars in several areas on Fire Island, New York.

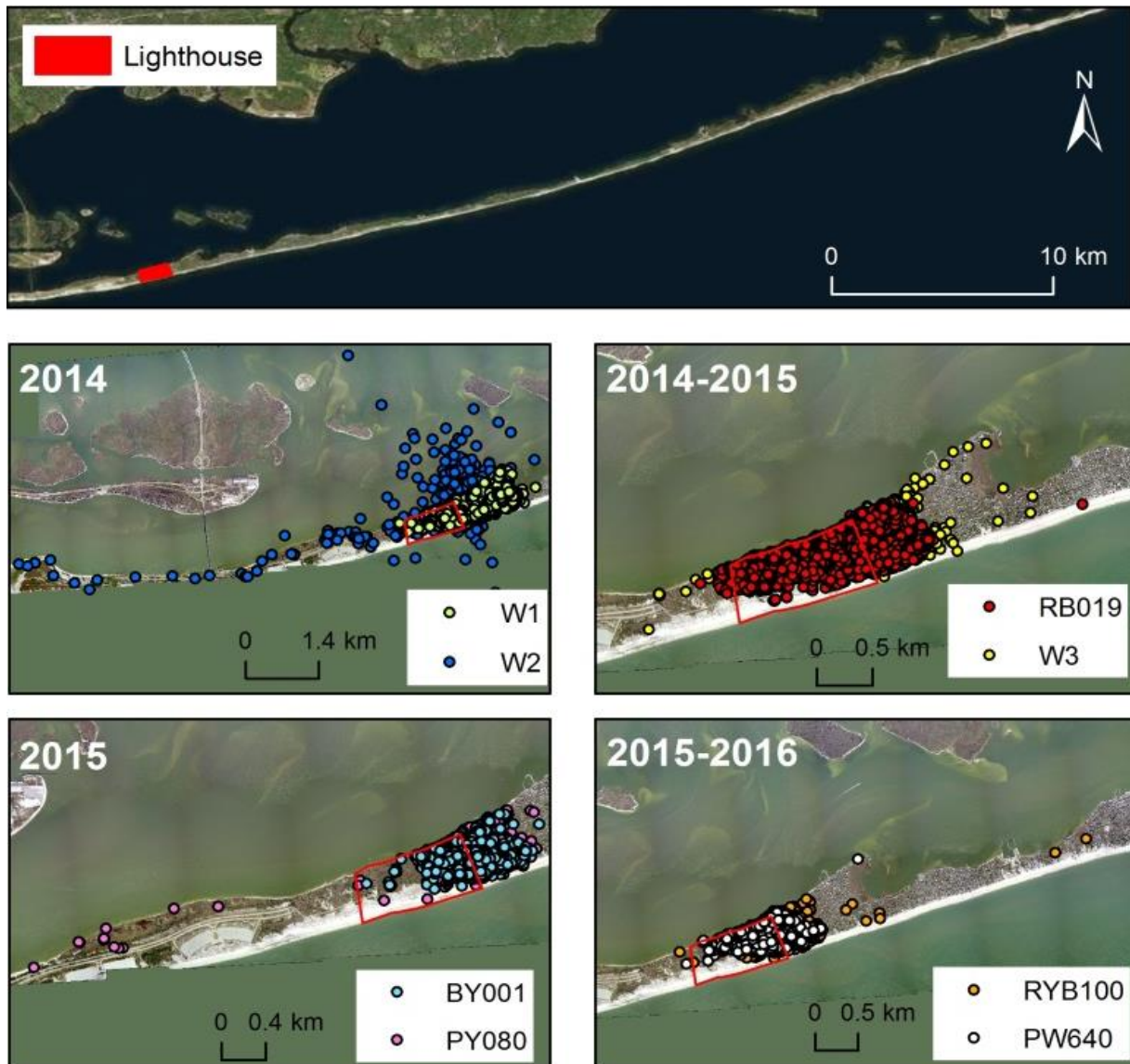


Figure D.1. GPS locations from deer collars in the Lighthouse Tract on Fire Island, New York.

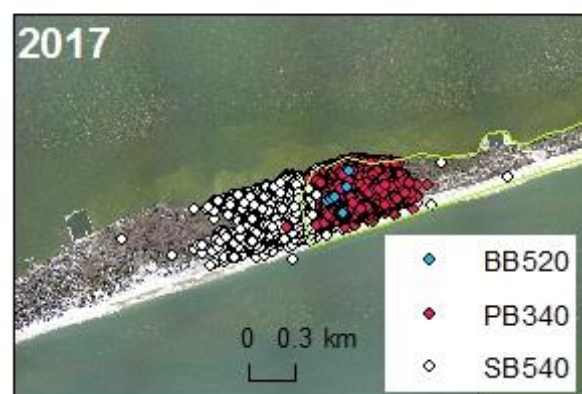
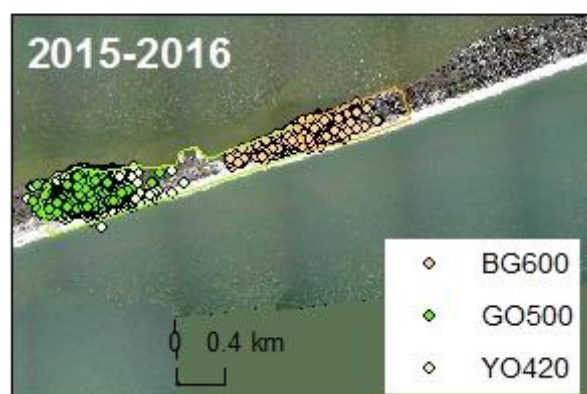
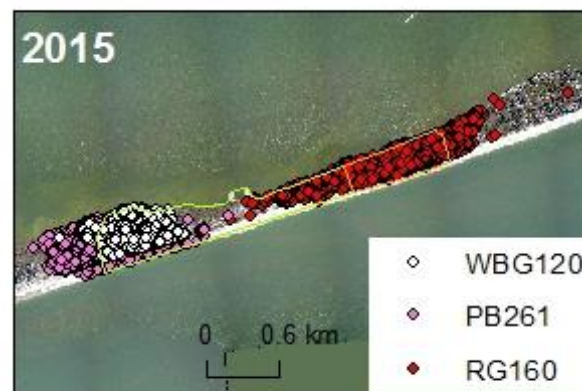
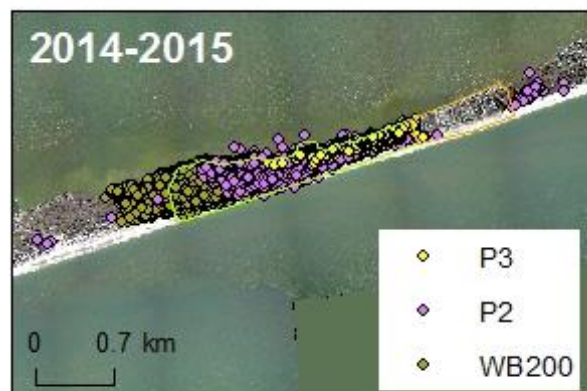


Figure D.2. GPS locations from deer collars in Sailors Haven and Cherry Grove on Fire Island, New York.

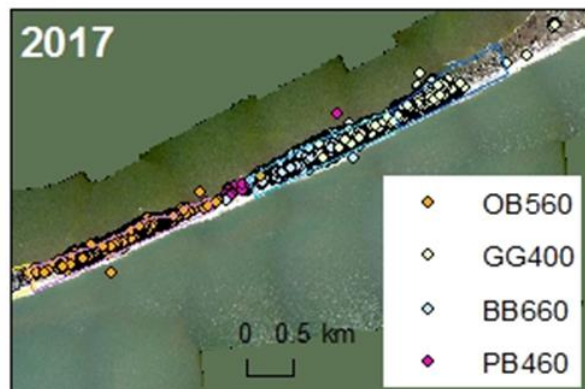
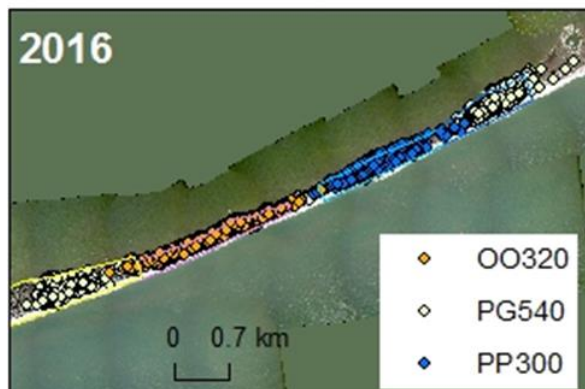
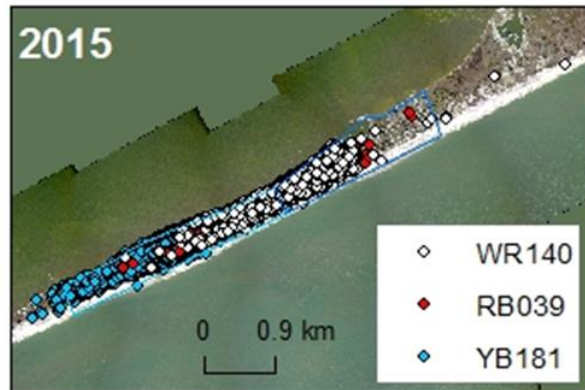
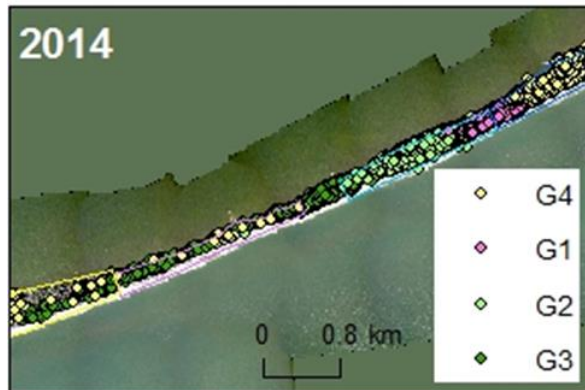
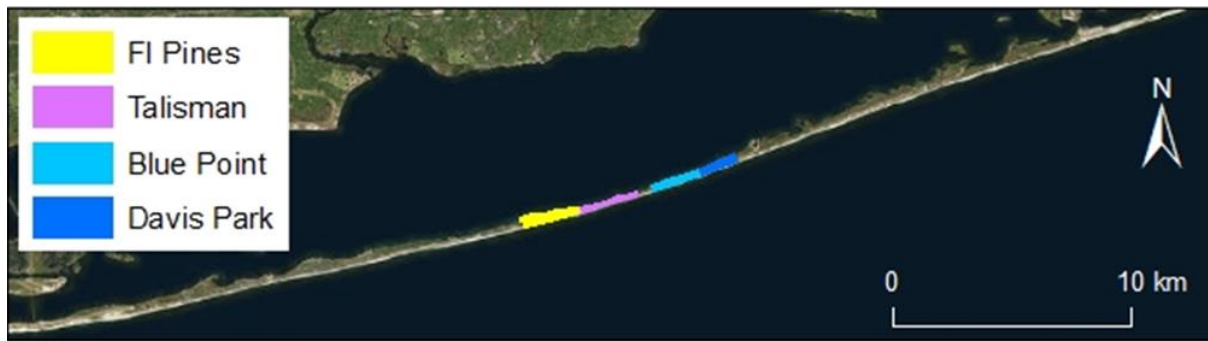


Figure D.3. GPS locations from deer collars in Fire Island (FI) Pines, Talisman, Blue Point, and Davis Park on Fire Island, New York.

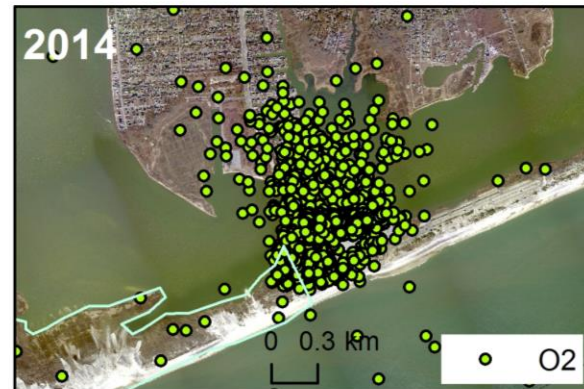
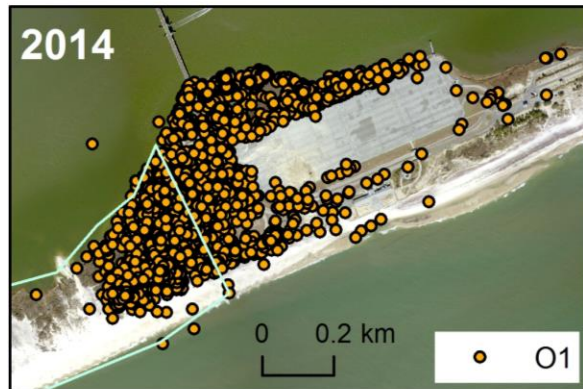
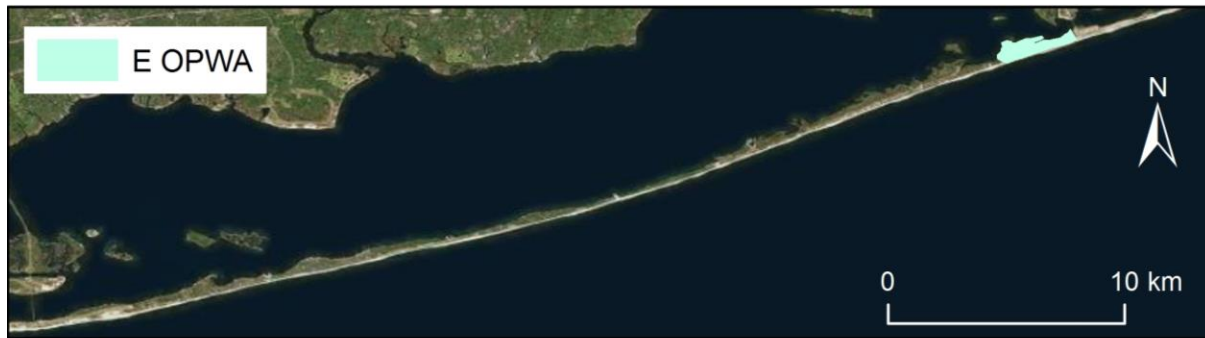


Figure D.4. GPS locations from deer collars in the Otis Pike Fire Island High Dune Wilderness Area east of the post-Hurricane Sandy island breach on Fire Island, New York.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior



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