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Evaluating Coastal Islands as Potential Translocation Sites for New England Cottontail (*Sylvilagus Transitionalis*)

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EVALUATING COASTAL ISLANDS AS POTENTIAL TRANSLOCATION SITES FOR NEW ENGLAND COTTONTAIL (*SYLVILAGUS TRANSITIONALIS*)

BY

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ABSTRACT

The population of the northeast region's native rabbit, the New England cottontail (*Sylvilagus transitionalis*; NEC), has declined by more than 80% in the last 50 years. In 2006, it was listed as a candidate species for protection under the Endangered Species Act of 1973. In 2010, a captive breeding program was developed to help reverse this trend, and islands were identified as having the potential to serve as ideal release sites for captive-bred NEC. Two islands were chosen as possible release sites: Nomans Land Island National Wildlife Refuge in Chilmark, Massachusetts; and Patience Island, located in Narragansett Bay, Rhode Island. To evaluate their suitability as release sites, an intensive habitat analysis was conducted on each island. The major habitat types on Patience Island also were delineated manually. To inform future releases of NEC on islands, an impact assessment was conducted on Penikese Island, which is known to have hosted previously a population of introduced cottontails. A pilot release of NEC was conducted on Patience Island and the population was monitored using radiotelemetry from April 2012 to February 2013. Rabbit locations were triangulated and home ranges were calculated using an adaptive kernel density estimator. The impact assessment on Penikese Island yielded inconclusive results, but the results of the habitat analysis on Patience Island and Nomans Land Island NWR indicate that both islands are well-suited to support a population of NEC. Survivability was high on Patience Island, and all rabbits spent the majority of their time in bramble-vine thicket and mixed forest habitats. My findings indicate that islands could

play a significant role in the recovery of NEC, and releasing NEC on islands should be strongly considered as a management strategy to help preclude the need for listing under the Endangered Species Act.

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DEDICATION

This thesis is lovingly dedicated to my mother, Linda, whose unwavering support in every aspect of my life has helped me become the person I am today, professionally and personally. I have the utmost gratitude for your guidance, advice, discipline, friendship, and patience along the way, and for giving me the assurance of self I needed to successfully complete this chapter in my life. Thank you for planting the love of nature in my heart.

PREFACE

This thesis was written in manuscript format to be submitted to the journal *Northeastern Naturalist*. It evaluates the suitability of coastal islands as release sites for the New England cottontail (*Sylvilagus transitionalis*; NEC), a candidate species for federal listing under the Endangered Species Act, through a review of historical populations of cottontails on islands, an intensive vegetation analysis on two islands being considered as release sites for NEC, and an investigation of home range size and habitat use by NEC in a pilot island release.

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INTRODUCTION

The population of the northeast region's native rabbit, the New England cottontail (*Sylvilagus transitionalis*; NEC), has declined significantly in the last 50 years (Tash and Litvaitis 2007, Litvaitis *et al.* 2008). As a result, NEC became a candidate for listing under the U.S. Endangered Species Act in 2006 (U.S. Fish and Wildlife Service 2006). Recent studies focusing on the range, distribution, and abundance of NEC have concluded that it has declined significantly and that disjunctive genetic subpopulations may be forming (Livaitis *et al.* 2008, Fenderson *et al*. 2011). Although the precise reasons for this dramatic decline have not been determined, it is clear that NEC is being impacted by habitat loss through human development patterns and forest succession, and also may be affected by the expansion of the introduced eastern cottontail (*Sylvilagus floridanus*; hereafter EC) (Fuller and Tur 2012).

To address the decline of NEC, and prevent it from reaching the status of being a Federally Endangered Species, a conservation strategy was developed in 2012 by the U.S. Fish and Wildlife Service (USFWS) and the Wildlife Management Institute (WMI) outlining research and conservation priorities (Fuller and Tur 2012). Within this conservation strategy, one of the objectives for successful population management is the development of a captive breeding program, which would "…provide a source of individuals for reintroduction to restored habitat to establish new, self-sustaining populations…" (Fuller and Tur 2012). The pilot NEC captive breeding program was initiated in 2010 at the Roger Williams Park Zoo (RWPZ) in Providence, Rhode Island. Initially, RWPZ staff focused on perfecting husbandry techniques to ensure the health of captive rabbits and to establish a successful breeding colony. Using rabbits that were transferred from a genetically robust population in southeastern Connecticut, the first breeding attempts in the summer of 2011 were successful and produced 11 juvenile NEC (Perrotti and McBride 2012).

As the captive breeding program was being implemented, representatives from various agencies and institutions collaborated to form a Captive Breeding Working Group (CBWG) to develop a plan for releasing captive-bred NEC into the wild. The CBWG worked to identify sites, based upon several factors such as known habitat quality criteria, land ownership, presence of competitors, etc., where the reintroduction of NEC would have the greatest probability of success. When all habitat criteria were considered, the CBWG decided that islands may serve as ideal release sites for captive-bred NEC. The group reasoned that islands tend to have low populations of mammalian predators, often have early successional shrub habitats that are maintained naturally by salt spray, and many have no EC present. Islands that met these criteria were considered to have the potential to serve as either temporary breeding colonies, where recruitment and population genetics can be monitored until mainland release sites are restored, or as refuges for self-sustaining permanent populations of NEC. After careful deliberation, the CBWG chose two candidate islands as possible release sites: Nomans Land Island National Wildlife Refuge (hereafter Nomans) in Chilmark, Massachusetts; and Patience Island, located in Narragansett Bay, Rhode Island. My project was conducted to determine the potential of these and possibly other islands to sustain NEC populations; I did so through: 1) an evaluation of previous island introductions of other species of the Family Leporidae; 2) an impact assessment of

Penikese Island, known to have hosted previously a population of introduced cottontails; and 3) intensive habitat analyses of both candidate islands, Patience and Nomans.

When islands were first proposed as potential release sites for NEC, concerns arose regarding the potential for a population of rabbits to decimate the habitat of the island on which they were released. This concern was particularly critical for Nomans, which is designated as wilderness and serves as an important habitat refuge for many species of migratory birds that are of conservation concern (USFWS 2010). To address the potential problem of habitat impacts and possible conflicts of management objectives, I reviewed the literature regarding impacts of members of Family Leporidae on islands and other isolated habitats. I found virtually no information on the impact of *Sylvilagus* on an island habitat after introduction. Historical records of releases of the European rabbit (*Oryctolagus cuniculus*), an invasive species in many parts of the world, have revealed devastating impacts on the habitats of those islands where it was introduced (Thompson 1955; Flux and Fullugar 1992). In contrast, none of the historical island releases of cottontail rabbits exhibited similar outcomes (Peterson 1966, pers. comm. French 2010, Jakubas 2011). On the contrary, island releases of cottontails, NEC in particular, have failed, presumably due to factors such as low recruitment and high levels of depredation (Appendix B). A number of introductions of cottontails to islands have been made in the past (Appendix B). To gain insights into future island introductions, I reviewed the outcomes and lessons learned from those previous introductions. In addition, a pilot release of NEC was conducted on Patience Island and I, with the help of federal and state biologists, monitored the population from April 1, 2012 to February 7, 2013 to gather information regarding survivability, habitat use, and distribution of NEC on the island.

METHODS

Penikese Island Cottontail Impact Assessment

Penikese Island, known to host a cottontail population (presumably EC) (pers. comm. Thomas French 2010 and Carolyn Mostello 2011), was examined for rabbit impact. In addition to this information provided by the Massachusetts Division of Wildlife and Fisheries, Fay and Chandler (1955) refer to the island being used as a "rabbit farm" to stock mainland sites with rabbits for hunting: "An intensively cultivated breeding stock of local and introduced rabbits supplied about 2,000 cottontails of questionable lineage for release in mainland covers." To determine the extent, if any, of the impact cottontail rabbits have had, or are having on the island's vegetation, I conducted a survey on July 14, 2011. The island was surveyed for rabbit browse, other evidence of rabbits (e.g. pellets, burrows), and vegetation characteristics including stem counts, herbaceous cover estimates, and species composition. Twenty sampling points were generated randomly using ArcGIS (Figure 1). Four observers, split into two groups, navigated to these points (representing the center of each plot) using a handheld Garmin GPSmap 60Cx. At each sampling point, a satellite plot design was employed: a 1-m^2 quadrat was placed at the center of the plot, and one quadrat placed in each of the four cardinal directions 10 m from the center point (Figure 2). A documentation photo was taken from the center of the plot in each cardinal direction. Within each of the five 1-m^2 quadrats in each plot, the number of woody stems ≤2.0 cm in diameter that represented available rabbit browse (Todd 1927, Pease *et al.* 1979, Swihart and Yahner 1982) rooted within the quadrat were counted and identified. The overall herbaceous cover within each quadrat was estimated using a Daubenmire (1959) cover class system (Table 1) and the herbaceous species present were recorded in order of dominance. Rabbit impact was assessed by searching within each quadrat for evidence of rabbit browse or other sign such as fecal pellets and burrows. If rabbit browse was observed, the plant species and number of browsed stems were recorded.

Patience Island Habitat Analysis

Patience Island is an 85-ha island located in Narragansett Bay in Portsmouth, Rhode Island. The island is generally categorized as scrub-shrub habitat (RIGIS 2007). Currently, it is owned by the Rhode Island Department of Environmental Management and has no year-round residents. The island is often visited in the summer months by beachgoers who can easily travel by small craft from Prudence Island, a popular summer destination only 0.5 km away. Patience Island has no known resident mammalian predators, but evidence of coyotes has been observed on the island and they may access Patience Island by swimming from Prudence Island. Other predatory species that have been observed include various raptors, gulls (*Larus* spp.), and raccoon (*Procyon lotor*).

The vegetation on Patience Island was examined during the summers of 2011 and 2012 to evaluate its potential as a release site for NEC and to establish a baseline dataset that can be used to monitor the island's habitat after the release of cottontails. A simple random sampling design was employed, with 25 random points on the island being generated using ArcGIS10. The first 18 of these points were navigated to in the field using a handheld Garmin GPS Map60Cx. Each of the points represented the center of a crosshair plot design, with two 50-m transects running perpendicular through the center point in the cardinal directions (one 50-m transect in the North-South direction, the other in the East-West direction). Within each quadrant created by this crosshair design, three 1-m^2 quadrats were placed at random points (Figure 3). The locations of these 12 1-m^2 quadrats were determined using a random number generator in R (version 2.12.2) in association with the numbers on the transect lines bordering each quadrant. Within each of these 12 quadrats, herbaceous cover was measured and stem counts were taken. Herbaceous cover was estimated using a cover classification system described by Daubenmire (1959), and included all plants <0.5 m tall (Table 1). The herbaceous species present within each quadrat were recorded in order of dominance following the taxonomy of Gleason and Cronquist (1991). Woody stems were included in the stem count if they were ≥0.5 m tall and <7.5 cm diameter breast height (dbh), after the methods of Barbour and Litvaitis (1993), and were only counted if they were rooted in the quadrat (Litvaitis *et al.* 1985). The woody species present within the quadrat were recorded in order of dominance, again following the taxonomy of Gleason and Cronquist (1991). Lastly, within four of the 12 quadrats (one in each quadrant of the plot), tree measurements were taken. Canopy cover was measured using a convex spherical densiometer and basal area was measured using a 10-factor prism (20 mm x 40 mm). Along each 50-m transect, the line intercept method (Canfield 1941) was used to estimate shrub cover. I recorded the species intersecting each transect at two heights. Woody vegetation between 0.5 and <1.0 m was considered low shrub and woody vegetation between 1.0 and 2.0 m was considered high shrub. Woody vegetation shorter than 0.5 m was not recorded along the line transect, but was included in the measurements with herbaceous vegetation. All vegetation <0.5 m tall, herbaceous cover, and leaf litter encountered along the line transects was classified as ground cover.

To supplement these fine-scale, on-the-ground measurements, five major habitat types present on Patience Island were delineated manually using ArcGIS10 and a high resolution digital orthophoto provided by RIGIS (2012) (Figure 4). The five major habitat types present on the island were defined as bramble-vine thicket, mixed forest, *Phragmites* meadow, salt marsh, and shoreline. The bramble-vine thicket habitat type has few trees, approximately 50% canopy cover, and is dominated by shrub species such as *Smilax* spp., *Rubus* spp., oriental bittersweet (*Celastrus orbiculatus*), and fox grape (*Vitis labrusca*). The mixed forest habitat type has a higher tree density and canopy cover, dominated by red maple (*Acer rubrum*) and eastern red cedar (*Juniperus virginianaia*), but the understory is still relatively thick with a similar species composition to the bramble-vine thicket habitat. The *Phragmites* meadow is composed entirely of common reed (*Phragmites australis*), the salt marsh is dominated by cordgrasses (*Spartina* spp.), and the shoreline is non-vegetated and is a substrate of rocks, gravel and sand.

The data collected on Patience Island were analyzed using a variety of techniques. First, to ensure sufficient sampling, the variability of each measurement unit (i.e. each 25-m transect and each 1-m^2 quadrat) was contemporaneously monitored during data collection by calculating the mean, standard deviation, and standard error of the shrub cover data. For each variable measured, the standard error was plotted after each sampling episode and examined for plateauing, a sign that sampling error had reached a constant and that an adequate level of sampling had been approached.

For the line intercept data, totals were calculated for each species, in each height category. These totals were used to evaluate the relative dominance of each plant species in each height category. Stem densities were calculated by multiplying the average number of stems per square meter by 10,000 to extrapolate to the number of stems per hectare. Herbaceous cover was characterized by determining the most frequently occurring cover class among all plots and by calculating the mean (±SE) for the midpoints of the range of each cover class reported (Table 1).

Woody and herbaceous species composition was determined by calculating dominance values for all species present by using the frequency of occurrence and the number of times the species ranked first in dominance within the quadrat. An overall dominance value was calculated by dividing the number of times the species ranked first in dominance in each quadrat by the total number of quadrats sampled on the island. A dominance value for when the species was present was obtained by dividing the number of times the species ranked first in dominance by the number of times it occurred. This “dominance when present value” gives some insight into the distribution of the species when it was present at a plot. That is, a high “dominance when present” value indicates a plant species that was not necessarily encountered frequently, but occurred in high abundance when it was present. Canopy cover was calculated by averaging the four densiometer measurements taken at each plot, and the overall average canopy cover for the entire island was estimated by averaging these plot averages. Basal area was calculated per plot (2,500-m^2) and extrapolated to a per hectare basis, and these basal area calculations were averaged to obtain an estimate of basal area for the entire island. Tree density was calculated for each plot by multiplying the number of trees observed within the 2,500-m^2 plot by four to obtain an estimate of trees/ha. Basal area (m^2) was calculated on a per plot basis by summing the basal areas of all trees present within the 2,500-m^2 plot and multiplying the total by four to obtain an estimate of basal area per hectare. The resulting per plot measurements of stem density, basal area, tree density and canopy cover were summarized for each habitat type that was delineated on the island, and these measurements, in addition to the mean stem density estimations for each plot, were weighted by habitat type. The mean of each measurement for all plots within each habitat type were multiplied by the percent cover of that habitat on the island to obtain a more proportionate estimate of whole-island statistics.

Nomans Land Island NWR Habitat Analysis

Nomans Land Island is a 255-ha island located in the town of Chilmark, Massachusetts, and is about 5 km southwest of Martha's Vineyard (USFWS 2010). From 1942 to 1996, the island was owned by the U.S. military and was used as a gunnery target by the Navy during this time. In 1975, the USFWS entered into a joint agreement, taking "overlay" ownership of 1/3 of the island. In 1997 and 1998, a thorough sweep of the island was conducted in an effort to remove any unexploded ordnance and other debris left by the military, and the entire island was transferred to the refuge system as a sanctuary for migratory birds. Although there are various raptor species observed flying over the island from time to time, there are very few trees, and therefore very few perches available on the island, which likely minimizes Nomans use by these species as a prime hunting spot. There are no known mammalian predators present on Nomans, as the only land-dwelling or partially land-dwelling mammals inhabiting the island are muskrat (*Ondatra zibethicus*) and the northern river otter (*Lontra canadensis*) (USFWS 2010). The island and its surrounding waters are now off-limits to public use, and aside from occasional illegal fishing along the perimeter of the island, there is little human disturbance. As a refuge, the island is managed as a part of the USFWS Eastern Massachusetts National Wildlife Refuge Complex, and recently has been designated as wilderness (USFWS 2010). The need to assess the island for its suitability as a release site for NEC was among the refuge's Comprehensive Conservation Plan (CCP) objectives, specifically to: 1) "perpetuate the biological integrity and diversity of coastal island habitats to support native wildlife and plant communities, including species of conservation concern;" and 2) "within 5 years of CCP approval, refuge managers will explore the possibility of introducing NEC on Nomans Land Island NWR" (USFWS 2010).

Nomans was analyzed to assess its suitability as a future release site for NEC August 1-8, 2011. The sampling strategy included stratifying the island based on *a priori* vegetation classifications that were created during a 2010 assessment and provided by the Refuge. This assessment resulted in the island's habitat being divided into 17 distinct vegetation classes (Figure 5). Considering these vegetation classes, a stratified random sampling scheme was developed. First, I used a dataset depicting the existing trails on the island to create a 5-m buffer on either side of the trails. The creation of the 5-m buffer on both sides of the trails was a necessary safety precaution, due to the unexploded ordnance on the island that might be encountered farther off the trail. It is generally considered safe to walk up to 5 m off of the trails, an area that has been thoroughly swept for ordnance, and on the trails themselves. The trails were mowed prior to my fieldwork, but not the 5-m buffer where sampling took place. For the entire 5-m trail buffer across all vegetation classes, I generated 100 random points using ArcGIS (Figure 6). The subsequent habitat classifications that were captured in the 5-m trail buffer and where points were generated were the Maritime Morainal Shrubland (MMS), Northern Tall Maritime Shrubland (TMS), Upland Switchgrass Vegetation (US), Maritime Switchgrass Marsh (MS), and Northern Beachgrass Dune (BD) (Table 2). The Bayberry Shrub Wetland vegetation class is relatively dominant (Figure 5) but was not one of the five habitat types that were sampled. This habitat type was excluded from the sampling scheme because the sampling was limited to <5-m from the trails and none of the points generated within this trail buffer fell in the Bayberry Shrub Wetland classification. Of these 100 random points, 79 were accessible and independent of other points. A point was not considered independent if its transect overlapped with the transect of another point. In such a case, the point was shifted along the trail to the minimum distance necessary to prevent any overlap with another point's transect. If it was not possible to shift the point along the trail without overlapping the transect of yet another point, the transect was laid on the opposite side of the trail or not used if this strategy still resulted in overlap with another transect. Each of these random points was navigated to using a handheld Garmin GPS Map60Cx and represented the center of a 25-m transect. The transect was laid out parallel to one side of the trail as determined by a coin flip, and at a randomly-determined distance from the trail of 1, 2, 3, 4, or 5 m. Along each 25-m transect, shrub cover was determined using a line-intercept method (Canfield 1941). I recorded the species intersecting a transect at two heights: woody vegetation from 0.5 and ≤1.0 m was considered low shrub, whereas woody vegetation >1.0 and ≤2.0 m was considered high shrub. Woody vegetation shorter than 0.5 m was not recorded along the line transect, but was added in the herbaceous vegetation measurements. All vegetation <0.5 m tall, herbaceous cover, and leaf litter encountered along the line transects was classified as ground cover. In addition, 1-m^2 quadrats were placed at the intersection of 4 randomly chosen locations along a transect and a randomly chosen distance from the trail, at 1, 2, 3, 4, or 5 m (Figure 7). Within each of these four quadrats, stem counts were taken for all woody stems ≥0.5 m tall, <7.5 cm diameter breast height (dbh), after the methods of Barbour and Litvaitis (1993), and were only counted if they were rooted in the quadrat (Litvaitis *et al.* 1985). Herbaceous cover was estimated using the cover classification system described by Daubenmire (1959) for all vegetation <0.5 m tall. Woody and herbaceous species present within each quadrat were recorded in order of dominance. All plant identification followed the taxonomy of Gleason and Cronquist (1991). Canopy cover was measured using a convex spherical densitometer and basal area was measured using a 10-factor prism (20 mm x 40 mm) in one of the four quadrats at each plot.

The data collected on Nomans Land Island were analyzed using a variety of techniques. First, to ensure sufficient sampling, the variability of each measurement unit (i.e. each 25-m transect and each 1m^2 quadrat) was analyzed continuously for all variables in the same manner used for my analysis on Patience Island. Obvious plateauing occurred in sampling the MMS habitat type and slightly in the TMS habitat type for all measurements. The other three communities were much smaller and were not sampled sufficiently to plateau the measures of variability; the MS habitat type only had one sampling point.

The methods used for analyzing the line intercept, stem density, species composition and herbaceous cover data on Nomans were the same methods used to analyze the data for Patience Island (see page 7). This analysis was applied to each habitat type individually and combined for the island. Basal area was not calculated, as no trees were close enough to any plots to be counted; trees were relatively few in number on the island.

Patience Island Pilot Release

The first attempts at breeding NEC in captivity at RWPZ were successful and produced 11 juveniles; the intention of this effort was to release these offspring onto Patience Island in November 2011. However, due to concerns of harsh weather and monitoring logistics, these juveniles instead spent the winter months in an acclimation pen that was designed and built on a refuge in Charlestown, Rhode Island by the Rhode Island NWR Complex. In March 2012, six penned rabbits were chosen to be released onto Patience Island, and the remaining rabbits were returned to the zoo to continue contributing to the breeding program. On March 28, 2012, six juvenile NEC, four males and two females, were released on Patience Island. Two subsequent releases occurred when rabbits, born in captivity, had grown to an appropriate size to be fitted with radiocollars. Two male NEC were released on July 12, 2012 and seven more NEC, two males and five females, were released on September 20, 2012. The rabbits released onto Patience Island were monitored twice a week for the first 10 weeks, and once or twice per week thereafter, weather permitting. Monitoring responsibilities were divided between myself, with the help of the USFWS Southern New England-New York Bight Coastal Program staff, and RIDEM staff from the time of the initial release until September 2012, when RIDEM assumed full monitoring responsibilities. Monitoring normally occurred during morning hours, once during the beginning of the week and once toward the end of the week, but only when a twice-per-week schedule could be followed. Base stations for collecting telemetry data were established by RIDEM along the eastern shoreline of the island (Figure 8). On each monitoring day, these base stations were used to estimate the locations of the rabbits through radiotelemetry. At each base station, a 3-element Yagi antenna, an ATS model R-2000 receiver (Freq. 150.000 -151.999), and a compass were used to detect the signal and locate its direction for each of the collared rabbits. Compass bearings were taken in the direction of the strongest frequency signal, and the three compass bearings were used to triangulate the position of the rabbit. To minimize the chance of a rabbit's location changing in between bearing readings, the time spent at and between each base station was minimized; our objective was to take all bearings within a 30-minute time period (Saltz 1994). If a mortality signal was detected, the carcass was recovered as soon as possible to determine the potential cause of death. Necropsies were performed by Brian Tefft of RIDEM.

Telemetry data were entered and maintained by both parties in a spreadsheet containing all relevant and up-to-date information on each rabbit. Location estimates were obtained by importing these data into the program Location of a Signal (LOAS), version 4.0.3.8 (Ecological Software Solutions LLC 2010), which triangulated the bearings using the maximum likelihood estimator. The output location estimates and their associated error ellipses were then analyzed, and only location estimates that had small error polygons relative to the size of the island were used. If the location estimate fell on the island, to be counted it must have had: 1) an associated error ellipse ≤10 ha, and 2) ≥50% of the error ellipse falling on the island. If the location estimate did not fall on the island, it was only considered valid if ≥50% of the error ellipse fell on the island. Home ranges were calculated at an 80% contour interval and core use areas were calculated at a 50% contour interval using the kernel density estimation function with a least squares cross validation bandwidth in the program Geospatial Modeling Environment (GME; Beyer 2012) (Worton 1989, Seaman *et al.* 1999, Hemson *et al.* 2005, Kilpatrick *et al.* 2011). Home ranges and core use areas were calculated for all individual rabbits with ≥10 valid location estimates. Additionally, home range and core use areas were estimated for the entire population by pooling all valid locations for all individuals, and for each gender by pooling all valid location estimates for all females and for all males.

The home range estimates for each of the five rabbits with suitable sample sizes, for each gender, and for the population were overlaid in ArcGIS10 with the results from my vegetation analysis and habitat delineation on Patience Island. I used the “Intersect” tool to create a database for each core use area and home range area that contained the area of each habitat type within. These data were also available in shapefile format as an interactive method of viewing the relationship between each rabbit's home range and core use areas and the habitat characteristics present. A chi-square analysis was used to determine if there were any significant differences in habitat use by any individual rabbit, either gender, or the population among the bramble-vine thicket, mixed forest, or other habitat types present on the island. The *Phragmites* meadow, salt marsh, and shoreline habitats were pooled for these tests to create the "Other" category, as they each represent a very small proportion of the island and, in most cases, there were no observations made in these habitat types. For these tests, the 80% home range area was considered available habitat, as opposed to the entire island, to account for the bias associated with all rabbits being released at the same location on the island. The area surrounding the release point was considered "more available" than areas on the island further away from the release point. Observed values for this test were obtained by counting the number of locations within the 80% home range area that fell in each habitat type. Expected values were calculated by multiplying the total number of observed locations within the home range area by the proportion of each habitat type present in the home range area. A paired t-test was used to further examine preference between the two dominant habitat types, the bramble-vine thicket and the mixed forest.

RESULTS

Penikese Island Cottontail Impact Assessment

Of the 12 plots surveyed on Penikese Island, no browsed stems were observed. The only evidence of cottontails on the island was a group of pellets observed on the western side of the island along the rocky perimeter of the grassy habitat bordering the beach. While no browse was observed, the habitat on the island appeared to be suitable for cottontails. Historical records and regular observations by managers working on the island indicate that there is likely a population of eastern cottontails there (Fay and Chandler 1955, pers. comm. Thomas French [2010] and Carolyn Mostello [2011]), but they are either having a very minimal impact on the island and/or my sampling did not encompass enough of the island to capture evidence of impact. My analysis of the habitat resulted in an average stem density of 263,276 ± 45,844 stems/ha. The graph of variability (SE) as plots were sampled did not flatten out, as might be expected if a sufficient number of samples had been taken. Thus, the magnitude in variability in stem density made it difficult to estimate accurately the average stem density across the entire island. The most frequently occurring woody species were *Rubus* spp. (blackberries and raspberries) (Figure 9) and the most frequently occurring non-woody plants were various grasses (Figure 10).

Patience Island Habitat Analysis

A total of 18 plots were surveyed on Patience Island, with 11 plots surveyed in the first year of sampling (June-July 2011) and 7 plots in the second year (June-August 2012). Stem density and herbaceous cover were not included in the analysis for two plots, and basal area was not taken into account for one plot due to quadrat inaccessibility. The running standard error for measurements showed, however, that a sufficient number of samples were taken for both the quadrat and line intercept data.

The average percent cover of shrubs along transects in all 18 plots, regardless of height or species, was 51 ± 3%. The average high shrub percent cover was 52 ± 4% and the average low shrub percent cover was 50 ± 4%. The five dominant species contributing to overall cover (i.e. across all plots and regardless of height class) were oriental bittersweet (23%), blackberry and raspberry (*Rubus* spp.; 20%), briars (*Smilax* spp.; 18%), arrowwood (*Viburnum dentatum*; 10%), and fox grape (*Vitis labrusca*;7%) (Figure 11). The average stem density in all plots combined was 124,948 ± 8,142 stems/ha (n=16), but varied among the habitat types sampled (Table 5). The five woody species with the highest overall dominance values observed during the stem counts were briars, *Rubus* spp., oriental bittersweet, wineberry (*Rubus phoenicolasius*), and arrowwood. When present, the five most dominant woody species were *Amelanchier* spp., alder (*Alnus* spp.), wineberry, briar, and Japanese barberry (*Berberis thunbergii*) (Table 3). The most frequently occurring herbaceous cover class among the 16 plots was one, indicating that most plots contained 0-5% herbaceous cover. However, the mean of the midpoints of the cover class ranges was 23.2 ± 0.4%, and is likely a more accurate representation of herbaceous cover. The most commonly occurring species (i.e. had the highest overall dominance values) in the herbaceous layer, which includes all vegetation < 0.5 m tall, were poison ivy (*Toxicodendron radicans*), Virginia creeper (*Parthenocissus quinquefolia*), *Rubus* spp., cordgrass (*Spartina* spp.), and various grass species (Table 4). The average canopy cover across all plots in which it was measured was 70.3 ± 7.4% (n=17). The average tree density among all plots in which it was measured was 69 ± 11 trees/ha (n=17). Average basal area among all plots in which it was measured was 4.6 ± 1.1 m^2/ha (n=17). These habitat measurements varied among the five habitat types delineated on the island (Tables 7 and 8). The bramble-vine thicket habitat type had a higher mean stem density than the mixed forest habitat type, but the mixed forest habitat type had higher estimates of mean basal area, tree density, and canopy cover (Table 5).

Nomans Land Island NWR Habitat Analysis

The dominant shrub species, for both the low and high shrub categories along the transects on Nomans were northern bayberry (*Myrica pensylvanica*; 44%), winged sumac (*Rhus copallinum*; 30%), blackberry and raspberry (10%), staghorn sumac (*Rhus typhina*; 5%), and arrowwood (4%). The most frequently occurring dominant shrub in both height classes among all habitat types was northern bayberry (Table 8). The average overall shrub cover in this habitat type, regardless of height, was 28% (Figure 12). The total low shrub cover in the dominant MMS habitat type was 40% and the total high shrub cover was 17% (Figure 13a and 13b; Table 7). The Beachgrass Dune habitat type is the only exception to my definition of the ground cover category, as these areas would be more accurately described as bare ground, but no special designation was made for this category. Species comprising less than 1% of the total shrub cover were pooled and classified as other. In the MMS habitat type, the mean stem density was almost double the highest estimate of required stem density of 50,000 stems/ha (Barbour and Litvaitis 1993) (Table 8). Variability among plots was high for all habitat types except MMS. The five woody species with the overall highest dominant values observed during the stem counts in the MMS habitat type were northern bayberry, winged sumac, *Rubus* spp., native roses (*Rosa* spp.), and arrowwood (Table 9). The five woody species with the highest dominance values when present were northern bayberry, rugosa rose (*Rosa rugosa)*, staghorn sumac, winged sumac, and multiflora rose (*Rosa multiflora*) (Table 9). Although the percent cover of herbaceous plants was not captured in the line-intercept method, measurements of herbaceous cover within the quadrats indicated that there was a substantial amount of herbaceous vegetation in most habitat types on the island (Table 10). The variability among quadrats for the MMS habitat type (n=212) indicated that an adequate number of samples were taken for all variables. The most frequently occurring cover class in the MMS habitat type was two and the mean of the midpoints of the cover class ranges was 56.3 ± 0.4%. However, the most frequently occurring cover class for the entire island (all habitat types combined) is six, but at 57.9 ± 2.0%, the midpoint mean was very close the midpoint mean for the MMS habitat type. The five herbaceous species with the highest overall dominance values in this habitat type that were identified were switchgrass (*Panicum* spp.), meadowsweet (*Filipendula ulmaria*), goldenrod (*Solidago* spp.), various unidentified species, and poison ivy (Table 11). Canopy cover estimates indicate a very low percentage of canopy cover on Nomans. Habitat types were pooled for this measurement because the variability among all plots, regardless of habitat type, was low. The average canopy cover for all habitat types combined was 2.8 ± 1.3%; trees were relatively few in number on the island.

Patience Island Pilot Release

A total of 15 NEC have been released onto Patience Island since March 28, 2012, and 12 survived throughout the duration of this project (up to February 7, 2013). Of the initial six NEC released in March of 2012, three had survived. Evidence observed at the sites of carcass recovery and necropsy results indicate that the cause of mortality for the other three rabbits was mammalian depredation, but these results are not conclusive (Table 12). A minimum of 30 valid locations was desired for each individual (Seaman *et. al.* 1999), but logistical constraints, coupled with the geographic constraints inherently encountered when working on an island, led to smaller sample sizes (Table 13). As a result, home range and core use areas were calculated for only five individuals. The number of valid location estimates for the other 10 individuals was not considered to be high enough to estimate a home range. However, the valid locations for all 15 rabbits, all seven females, and all eight males were pooled to estimate a home range and core use area for the population as a whole, and for each gender. The average home range and core use area among the five individual rabbits was 14.6 ± 3.6 ha and 5.8 ± 1.3 ha, respectively. Home range and core use area sizes were very similar between genders (Table 13). The entire population had a home range and core use area of 21.9 ha and 9.0 ha, respectively (Table 13). Overall, the NEC on Patience Island spent the majority of their time in the bramble-vine thicket and mixed forest habitat types (Table 14). A chi-square analysis showed a significant difference among the use of the bramble-vine thicket, mixed forest, and other habitat types by males (n=83; p=0.00) (Table 15), with less observations in habitat types other than bramble-vine thicket or mixed forest than would be expected. A paired t-test comparing the bramble-vine thicket and mixed forest habitats revealed no significant difference between observed and expected values for any individuals, either gender, or the population (Table 16).

DISCUSSION

Coastal islands have many characteristics that make them attractive as release sites for NEC. They often have low predator densities, no other cottontails present, and dense coastal shrubland habitats that are naturally maintained. Unlike the European rabbits that have been released on islands, there is no evidence in the literature that introduced populations of cottontails on islands have any significant negative impacts on the islands' habitats (Peterson 1966, Nowak 1999, Jakubas 2011). My findings on Penikese Island support this conclusion, as historical records and the observations of biologists on the island indicate that there is in fact a population of cottontails present on Penikese Island (pers. comm. Thomas French 2010 and Carolyn Mostello 2011). However, based on the lack of browse and minimal rabbit sign observed in my sampling, it appears that any impact that cottontails are having on the island's habitat is minimal or nonexistent. Additionally, no impacts on other species of conservation concern that inhabit the island (i.e. various tern species) have been observed (pers. comm. Carolyn Mostello 2011). While I do not expect a different conclusion to be drawn, it would be informative to reassess this island for cottontail impact in a few years to see if there is a significant change in the amount of rabbit evidence observed, as the rabbit populations on some of the Boston Harbor islands are suspected to significantly fluctuate in numbers (Trocki *et al.* 2007, pers. comm. Thomas French 2010). It also may be helpful for biologists from Massachusetts Division of Fish and Wildlife to conduct annual cottontail pellet surveys to monitor the relative abundance of the population, and to determine which species of cottontail is/are present on the island. Professional trapping censuses also should be conducted to estimate the population over time to determine if the population's growth pattern is stable, irruptive, or perhaps cyclic. If a pattern does in fact exist, it would be informative to assess the island for impacts from herbivory at a time when the rabbit population is at a peak.

While no negative impacts to the habitat on island release sites are anticipated, it is important to closely evaluate islands that are being considered as release sites for NEC to gather detailed habitat information for the purposes of validating the island's suitability and monitoring the vegetation post-release. Gathering these baseline vegetation data is especially important for islands that are protected as wilderness and/or serve as refuges for other trust resources, such as Nomans. Additionally, although several definitions of suitable NEC habitat have been suggested, gaps remain in the understanding of the specific requirements of NEC that may differ from those of EC and in the role that invasive plant species may be playing in the decline of NEC (Fuller and Tur 2012). Gathering detailed habitat information on candidate islands prior to releasing NEC will not only inform managers on the general suitability of the habitat, but will also provide habitat data that can be used as a tool to help fill in these knowledge gaps in the future if NEC is released there. My analyses of Patience Island and Nomans showed that the habitat on both islands has the potential to support a population of NEC. The estimated stem densities on both islands far surpass all of the minimum suggested requirements described in other NEC habitat studies, and this measurement is often viewed as one of the most important characteristics in NEC habitat (Barbour and Litvaitis 1993, Litvaitis *et. al.* 2003, Tash and Litvaitis 2007). To guide their searches for NEC, Litvaitis and Tash (2006) consider patches of habitat dense enough to be suitable for NEC if they had >9,000 stems/ha of primarily deciduous understory cover. Probert and Litvaitis (1995) created dense patches of habitat of ≥18,000 stems/ha to determine any difference(s) in microhabitat use between NEC and EC. Although their results are inconclusive, they indicate some evidence that EC are more likely to use areas with a lower understory density, and discuss the EC's general ability to exploit a wider range of habitats, further supporting the idea that dense understory cover is particularly important for NEC. Barbour and Litvaitis (1993) report that rabbits used sites with at least 50,000 stems/ha more than sites with sparse understory density in relation to availability. The stem density estimates that I calculated for Patience Island and Nomans are often more than double the highest minimum stem density that is indicated in the literature as necessary to support NEC. In addition, various sites known to be occupied by EC, NEC, or both in eastern Massachusetts by the U.S. Fish and Wildlife Service Eastern Massachusetts NWR Complex have exhibited stem densities similar to or below those on Nomans and Patience Island (Table 17).

In addition to the high stem density measurements, both islands boasted a variety of plant species that are suggested to be suitable components of NEC habitat, both for structural and nutritional purposes (Dalke and Sime 1941, Sweetman 1944; 1949, Reynolds 1975, Litvaitis *et al.* 2006). Although there is not much literature available on the importance of species composition, the structure provided by the dominant shrubs on Nomans and Patience Island indicates that there is sufficient cover available on the islands. On Nomans, the dominant shrub species are also native to the region, and while the role that invasive species play in the context of NEC survival is unknown, it is more likely that NEC will be well supported by habitats that reflect the historical landscape in which they once thrived and to which they are likely adapted. While beyond the scope of this study, the pilot NEC release on Patience Island provides a great opportunity to evaluate the use of invasive-dominated habitats by NEC, and the results provided in my habitat analysis may serve as a baseline for this type of analysis in the future. Although a nutritional analysis of the plants present on the islands was not conducted in this study, communication with professionals in the field and previous studies indicate that the variety of shrub species present on the islands would provide adequate forage in the winter. During a study in Connecticut, Dalke and Sime (1941) report that blackberry (*Rubus allegheniensis*) is one of the most important sources of winter food for cottontails (EC and NEC; results were pooled because food habits observed in this study were nearly identical), in addition to its provision of thick cover. *Rubus* spp. *(R. allegheniensis* and *R. idaeus)* made up the second most dominant plant category on Patience Island, accounting for 20% of the cover observed in the line-intercept analysis and occurring in 14 of the 16 plots where stem counts were taken. Although less prevalent on Nomans, *Rubus* spp. accounted for one of the three shrub species observed in my line-intercept analysis that composed >1% of the cover and occurred in 34% of the plots in the dominant habitat type. Two of the plant species found on Patience Island were included in the forage species used by Litvaitis *et al.* (2006) to help guide NEC pellet surveys in New Hampshire, where particular attention was paid to patches containing *Rubus* spp. (also occurring on Nomans) and red maple. Reynolds (1975) also mentions *Rubus* spp. as dominant in his trapping study of NEC and EC, and states that several of the dominant woody species in his study are known to be food items of both cottontail species. In addition, many of the species found on Patience Island, including red maple, Morrow's honeysuckle (*Lonicera morrowii*), apple (*Malus* spp.), staghorn sumac (*Rhus typhina*), roses (*Rosa* spp.), *Rubus* spp., blueberry (*Vaccinium* spp.), shadbush, black cherry (*Prunus serotina*), arrowwood, and Virginia creeper were found to be moderately or severely browsed by cottontails in the winter by Sweetman (1944; 1949). Eleven of the species considered by Sweetman (1949) as "attractive" to cottontails were found on Patience Island: red maple, Japanese barberry, Morrow's honeysuckle, apple, staghorn sumac, *Rosa* spp., *Rubus* spp., *Vaccinium* spp., shadbush, Virginia creeper, and arrowwood. Several of the woody species present on Patience Island also were accepted as food by the captive NEC at RWPZ. In addition to a diet of commercial rabbit chow and Timothy hay (*Phleum pratense*), captive NEC accepted briar, apple, black cherry, red maple, and various *Rubus* spp. (Perrotti and McBride 2012). Dalke and Sime (1941) also found that sumacs, which are prevalent on Nomans and were observed on Patience, provide a great deal of food for cottontails during the winter. On Nomans, *Rubus* spp. composed 10% and sumacs (*Rhus typhina* and *Rhus copallinum*) 35% of the shrub cover, as measured by the line transects.

These considerations led to the conclusion that both Nomans and Patience Island provide suitable habitat for NEC and should be considered as release sites. My conclusion regarding Patience Island was supported by the success of the pilot release initiated in 2012. NEC are unlikely to live longer than two to three years in the wild (Fuller and Tur 2012) but 80% of the rabbits released on Patience Island survived at least 10 months, despite being bred in captivity, undergoing multiple translocations between the zoo, the pen, and the island, and having limited exposure to mammalian predators while protected in the pen. Although the monitoring of these rabbits on Patience Island was sometimes limited due to logistical constraints, the data collected during this pilot release will be valuable in informing future releases of NEC on Patience Island and on other coastal islands, such as Nomans, that are also deemed to be suitable for this purpose. At this time, home range estimates could only be calculated for five of the 15 rabbits released on the island, but the habitat use by these individuals and by the population as a whole gives some indication of habitat preference on the island, but continued monitoring will increase the sample sizes for this analysis and can provide more robust home range estimates. All rabbits were released at the same location in the east-central area of the island, and this coincides with the epicenter for home range estimates for all individuals and for the population (Appendix C). This bias was accounted for in my analysis by considering the 80% home range area as the "available" habitat, but it is recommended that this bias be removed in future analyses, and that other release points are considered in future releases if information on habitat preference across the entire island is desired. If rabbits are randomly distributed and released onto different parts of the island and within various habitat types, the results may be more accurate in depicting any true preference in habitat use being exhibited. It is also important to note that the five rabbits for which home ranges were calculated still had relatively low sample sizes compared to most home range studies, and a sample size of ≥50 will likely produce more accurate results, particularly when using an adaptive kernel density estimator with an LSCV smoothing parameter (Horne and Garton 2006). It is likely that the home ranges that I calculated with these small sample sizes have overestimated the actual home ranges of the individual rabbits (Seaman *et al.* 1999, Horne and Garton 2006). Therefore, the home range estimate obtained for the entire population may have greater implications for habitat use and preference by NEC on Patience Island. The likelihood of overestimation in my home range and core use area calculations is further supported by the comparison of my findings to those in the literature (Allen 1939, Schwartz 1941, Haugen 1942, Kilpatrick *et al.* 2011) (Table 18). With the exception of two individuals, all of the home range estimates that I calculated were significantly larger than those described by previous researchers. However, it is worth noting that there is variation among these studies, in that many historical studies of cottontail home range were based on trapping and the use of the minimum convex polygon to estimate home range size (Allen 1939, Schwartz 1941, Haugen 1942), which is now generally considered a less robust technique in the estimation of home ranges (Downs and Horner 2008). In addition, no distinction is made between the two cottontail species in these earlier studies, and it is possible that NEC and EC do not have the same home range sizes. The findings of Kilpatrick *et al.* (2011) provide some support for this theory, reporting home range estimates specifically for NEC that are larger than most home ranges estimates obtained during studies that did not differentiate between the two cottontail species (Table 18). Lastly, the home ranges and core use areas calculated in my study do not differentiate among seasons, as it was not possible to calculate seasonal home ranges with the low number of locations that I was able to obtain.

The results of my study support the objectives outlined in the Conservation Strategy for NEC (Fuller and Turn 2012), which identifies the need to explore the use of islands as a tool in precluding the need to list NEC under the Endangered Species Act. I found no evidence that a population of NEC on an island would have significant negative impacts on the vegetation or on other wildlife, and the use of islands as release sites for NEC should be strongly considered. While some difficulty has been observed in establishing a population of NEC on Stage Island in Maine (Jakubas 2011), a detailed evaluation of the habitat suitability on the candidate island combined with the release of a significant number of cottontails, low predator densities, and the conduction of regular monitoring, it may be possible. One similarity among previous island releases of cottontails that have been unsuccessful is the small number of rabbits released, and the effects of these small founder populations may have been confounded by the lack of subsequent releases and the presence of various predator species (Peterson 1966, pers. comm. Thomas French 2010, Jakubas 2011). Often in previous instances of island releases, the true reason(s) for failure were undetermined. Regular monitoring will be necessary to help ensure the success of future releases and document the cause(s) of a population's failure to become established. Patience and Nomans both exhibit characteristics that make them well suited for introductions, including low levels of predation pressure, the absence of EC, and an abundance of dense cover that is composed of plant species evidenced to be important to NEC. I recommend that the release of NEC on any island is precluded by an intensive vegetation analysis and is followed by the close monitoring of the population as well as the habitat, particularly on an island such as Nomans where there is interest in preserving the wild character of the island's flora and fauna, to ensure genetic variability, track survival and recruitment, and although it may be unlikely to occur, account for any significant impacts that the rabbits may have on the vegetation.

Table 1. Cover classes (after Daubenmire 1959) used to estimate herbaceous cover within 1-m^2 quadrats during a cottontail impact assessment vegetation survey on Penikese Island on July 14, 2011 and during vegetation surveys on Patience Island and Nomans Land Island NWR during the summers of 2011 and 2012. Midpoints of each range were used to estimate mean herbaceous cover.

Cover Class	% Cover Range	Midpoint
1	0-5%	2.5
2	6-25%	15.5
3	26-50%	38
4	51-75%	63
5	76-95%	85.5
6	>95%	98

Table 2. Number of sampling points assigned to each of the habitat classification types on Nomans Land Island NWR during a 2011 vegetation survey to assess the suitability of the island as a release site for NEC. The area of each habitat type is given for the entire island and within the 5-m buffer in which sampling took place. The five habitat types captured in my sampling account for 67% of the island's total area of 255 ha.

Column	A	B (=A/255)	C	D (=C/7.0)	E (= n/79)
Habitat Type	**Area (ha)**	**% of Island**	**Area in Buffer (ha)**	**% of Sampling Area**	**% of Sampling Points**
Maritime Morainal Shrubland (n=53)	101.7	40%	4.6	65%	67%
Tall Maritime Shrubland (n=13)	54.3	21%	1.1	15%	16%
Upland Switchgrass (n=9)	7.2	3%	1.0	14%	9%
Beachgrass Dune (n=3)	4.7	2%	0.2	3%	4%
Maritime Switchgrass (n=1)	3.5	1%	0.2	3%	1%
Total	171.4	67%	7.0	97%	97%

Table 3. Woody species observed during stem counts taken in 192 1-m^2 quadrats on Patience Island during a vegetation survey conducted from 2011 to 2012.

A	B	C	D	E	F
Species	Occurrences	Frequency (=B/192)	No. Times Ranked #1	Dominance Value When Present (=D/B)	Overall Dominance Value (=D/192)
Smilax spp.	115	0.60	82	0.71	0.43
Rubus spp.	69	0.36	28	0.41	0.15
Celastrus orbiculatus	51	0.27	16	0.31	0.08
Rubus phoenicoloasius	16	0.08	12	0.75	0.06
Viburnum dentatum	14	0.07	6	0.43	0.03
Rosa multiflora	11	0.06	5	0.46	0.03
Amelanchier spp.	3	0.02	3	1.00	0.02
Vitis labrusca	6	0.03	2	0.33	0.01
Lonicera morrowii	10	0.05	2	0.20	0.01
Myrica pensylvanica	8	0.04	2	0.25	0.01
Berberis thunbergii	4	0.02	2	0.50	0.01
Parthenocissus quinquefolia	11	0.06	1	0.09	0.01
Toxicodendron radicans	13	0.07	1	0.08	0.01
Acer rubrum	4	0.02	1	0.25	0.01
Alnus spp.	1	0.01	1	1.00	0.01
Vaccinium spp.	2	0.01	1	0.50	0.01
Rhus typhina	1	0.01	0	0.00	0.00
Lonicera japonica	2	0.01	0	0.00	0.00
Juniperus virginiana	2	0.01	0	0.00	0.00
All Unknown	1	0.01	0	0.00	0.00

Table 4. Herbaceous species observed in 192 1m^2 quadrats on Patience Island during a vegetation survey conducted from 2011 to 2012 (n=192).

A Species	B No. Occurrences	C Frequency (=B/192)	D No. Time Rank #1	E Dominance Value When Present (=D/B)	F Overall Dominance Value (=D/192)
Toxicodendron radicans	58	0.62	36	0.62	0.19
Parthenocissus quinquefolia	48	0.46	22	0.46	0.12
Rubus spp.	48	0.38	18	0.38	0.09
Spartina spp.	6	1.00	6	1.00	0.03
Grass spp.	11	0.55	6	0.55	0.03
Celastrus orbiculatus	13	0.46	6	0.46	0.03
Rubus phoenicolasius	5	1.00	5	1.00	0.03
Viola spp.	8	0.63	5	0.63	0.03
Amelanchier spp.	3	1.00	3	1.00	0.02
Moss spp.	3	1.00	3	1.00	0.02
Athyrium filix-femina	4	0.75	3	0.75	0.02
Onoclea sensibilis	5	0.60	3	0.60	0.02
Viburnum dentatum	6	0.50	3	0.50	0.02
Acer rubrum	12	0.25	3	0.25	0.02
Myrica pensylvanica	6	0.33	2	0.33	0.01
Areolata petiolata	1	1.00	1	1.00	0.01
Glyceria spp.	1	1.00	1	1.00	0.01
Arisaema triphyllum	1	1.00	1	1.00	0.01
Unknown	1	1.00	1	1.00	0.01
Ailanthus altissima	1	1.00	1	1.00	0.01
Asclepias spp.	1	1.00	1	1.00	0.01
Carex spp.	2	0.50	1	0.50	0.01
Lonicera morrowii	7	0.14	1	0.14	0.01
Rosa multiflora	4	0.00	0	0.00	0.00
Smilax spp.	8	0.00	0	0.00	0.00
Lonicera. japonica	1	0.00	0	0.00	0.00
Vitis labrusca	2	0.00	0	0.00	0.00
Rubus hispidus	1	0.00	0	0.00	0.00
Clethera alnifolia	3	0.00	0	0.00	0.00
Woodwardia spp.	2	0.00	0	0.00	0.00
Vaccinium spp.	1	0.00	0	0.00	0.00
Simplocarpus foetidus	1	0.00	0	0.00	0.00
Impatiens capensis	1	0.00	0	0.00	0.00
Alnus spp.	1	0.00	0	0.00	0.00
Prunus serotina	1	0.00	0	0.00	0.00
Berberis thunbergii	1	0.00	0	0.00	0.00
Sassafrass albidum	1	0.00	0	0.00	0.00

Table 5. Mean stem density, herbaceous cover, basal area, tree density, and canopy cover estimates across all plots in which each was measured in the a) Bramble-Vine Thicket, b) Mixed Forest habitat types on Patience Island during a 2011 to 2012 vegetation survey.

a) Bramble-Vine Thicket

Plot ID	Stem Density/ha	% Herbaceous Cover	Basal Area (m^2/ha)	Tree Density/ha	% Canopy Cover
12	219,000	3.6	1.5	12	66.5
14	NR[1]	NR	NR	NR	18.4
7	84,000	60.5	11.3	84	83.5
15	NR	NR	2.4	44	75.2
11	132,500	9.0	5.5	60	67
9	145,000	2.5	0.3	4	11.7
24	202,500	2.5	1.5	48	NR
Mean	156,667	15.6	3.8	42.0	53.7
SE	24,478	11.3	1.7	12.2	12.5

b) Mixed Forest

Plot	Stem Density/ha	% Herbaceous Cover	Basal Area (m^2/ha)	Tree Density/ha	% Canopy Cover
13	149,167	23.9	7.0	64.0	85.0
2	110,000	13.8	2.8	60.0	80.9
21	145,833	4.7	13.2	144.0	99.6
16	175,833	3.6	6.5	92.0	98.9
5	80,000	45.5	4.2	68.0	86.3
18	72,500	36.8	11.7	148.0	90.1
19	121,667	52.4	17.9	104.0	88.8
1	174,167	20.0	2.4	36.0	75.8
25	80,833	33.7	6.5	96.0	74.5
4	105,833	15.9	7.7	112.0	93.4
Mean	121,583	25.0	8.0	92.4	87.3
SE	12,128	5.3	1.6	11.5	2.7

[1] Not recorded.

Table 6. Dominant shrub species present in each habitat classification sampled on Nomans Land Island NWR in August 2011 based on the line-intercept method.

Habitat Type (n = # plots sampled)	Dominant Low Shrub	Dominant High Shrub	Dominant Shrub Combined
Maritime Morainal Shrubland (n=53)	*Myrica pensylvanica*	*Myrica pensylvanica*	*Myrica pensylvanica*
Tall Maritime Shrubland (n=13)	*Myrica pensylvanica*	*Myrica pensylvanica*	*Myrica pensylvanica*
Upland Switchgrass (n=9)	*Myrica pensylvanica*	*Rhus typhina*	*Myrica pensylvanica*
Beachgrass Dune (n=3)	*Rosa rugosa*	*Rosa rugosa*	*Rosa rugosa*
Maritime Switchgrass (n=1)	*Rhus copallinum*	*Rhus copallinum*	*Rhus copallinum*

Table 7. Total percent shrub cover along all transects in each habitat classification type sampled using the line-intercept method on Nomans Land Island NWR in August 2011. Measurements of cover at each plot within each habitat type were totaled and divided by the total possible cover in the habitat type (i.e. length of transect multiplied by the number of plots sampled) to obtain the total percent cover.

Habitat Type (# of plots sampled)	Low Shrub Cover	High Shrub Cover	Cover (All Heights)	Ground Cover
Maritime Morainal Shrubland (n=53)	40%	17%	28%	72%
Tall Maritime Shrubland (n=13)	44%	40%	41%	59%
Upland Switchgrass (n=9)	34%	3%	19%	81%
Beachgrass Dune (n=3)	25%	0%	13%	87%
Maritime Switchgrass (n=1)	77%	17%	47%	53%

Table 8. Average stem density (± standard error) in each vegetation community type on Nomans Land Island NWR in August 2011.

Vegetation Community	Mean stems/ha ± SE
Maritime Morainal Shrubland (n=53)	96,038 ± 5,367
Northern Tall Maritime Shrubland (n=13)	180,000 ± 21,544
Upland Switchgrass Vegetation (n=9)	72,500 ± 10,338
Northern Beachgrass Dune (n=1)	106,667 ± 38,145
Maritime Switchgrass Marsh (n=3)	177,500 ± 30,652
Combined (n=79)	107,931 ± 5,634

Table 9. Woody species observed during stems counts in 212 1-m^2 quadrats in the Maritime Morainal Shrubland habitat on Nomans Land Island NWR during a vegetation survey conducted in August 2012.

A	B	C	D	E	F
Species	No. Occurrences	Frequency (=B/212)	No. times Ranked #1	Dominance Value When Present (=D/B)	Overall Dominance Value (=D/212)
Myrica pensylvanica	138	0.65	94	0.68	0.44
Rhus copallinum	92	0.43	49	0.53	0.23
Rubus spp.	73	0.34	25	0.34	0.12
Rosa spp.	50	0.24	14	0.28	0.07
Viburnum dentatum	9	0.04	4	0.44	0.02
Rhus typhina	7	0.03	4	0.57	0.02
Toxicodendron radicans	6	0.03	2	0.33	0.01
Rosa rugosa	3	0.01	2	0.67	0.01
Rosa multiflora	2	0.01	1	0.50	0.01
All Unknown	5	0.02	0	0.00	0.00
Smilax spp.	1	0.01	0	0.00	0.00
Gaylussacia baccata	1	0.01	0	0.00	0.00

Table 10. Average and most frequently occurring herbaceous cover classes present in each vegetation classification type on Nomans Land Island NWR in August 2011.

Habitat Type (# quadrats sampled)	Midpoint Mean ± SE	Mode Cover Class
Maritime Morainal Shrubland (n=212)	56.3 ± 0.4%	2
Tall Maritime Shrubland (n=52)	57.5 ± 1.9%	6
Upland Switchgrass (n=40)	79.7 ± 3.6%	6
Beachgrass Dune (n=12)	27.4 ± 8.0%	1
Maritime Switchgrass (n=4)	21.1 ± 5.6%	2
Combined (n=320)	57.9 ± 2.0%	6

Table 11. Herbaceous species observed in 212 1-m^2 quadrats in the Maritime Morainal Shrubland habitat on Nomans Land Island NWR during a vegetation survey conducted in August 2012.

A	B	C	D	E	F
Species	No. Occurrences	Frequency (=B/212)	No. Times Ranked #1	Dominance Value When Present (=D/B)	Overall Dominance Value (=C/212)
Panicum spp.	159	0.75	103	0.65	0.49
Filipendula ulmaria	110	0.52	38	0.35	0.18
Solidago spp.	120	0.57	22	0.18	0.10
All Unknown	70	0.33	8	0.11	0.04
Toxicodendron radicans	37	0.18	8	0.22	0.04
Achillia millefolium	38	0.18	7	0.18	0.03
Grass spp.	12	0.06	4	0.33	0.02
Rubus spp.	28	0.13	3	0.11	0.01
Parthenocissus quinquefolia	19	0.09	3	0.16	0.01
Rubus hispidus	17	0.08	3	0.18	0.01
Lonicera japonica	11	0.05	3	0.27	0.01
Phragmites australis	4	0.02	3	0.75	0.01
Potentilla recta	12	0.06	1	0.08	0.01
Rhus copallinum	1	0.01	1	1.00	0.01
Unknown fern	1	0.01	1	1.00	0.01
Osmunda cinnamomea	1	0.01	1	1.00	0.01
Cirsium spp.	6	0.03	0	0.00	0.00
Rosa spp.	5	0.02	0	0.00	0.00
Triadenum spp.	2	0.01	0	0.00	0.00
Rumex acetosella	2	0.01	0	0.00	0.00
Trifolium spp.	2	0.01	0	0.00	0.00
Pteridium aquilinum	1	0.01	0	0.00	0.00
Eupatorium perfoliatum	1	0.01	0	0.00	0.00
Viburnum dentatum	1	0.01	0	0.00	0.00
Verbascum thapsus	1	0.01	0	0.00	0.00
Asclepias spp.	1	0.01	0	0.00	0.00

Table 12. Summary of NEC released onto Patience Island during a pilot study from April 1, 2012 to February 7, 2013.

Rabbit ID (Frequency)	Gender	Date of Release	Current Status (as of 2/7/13)	Date of Mortality (Observed)	Cause of Death
151.1032	M	3/28/2012	Alive	-	-
151.1052	M	3/28/2012	Alive	-	-
151.1093	F	3/28/2012	Dead	5/11/2012	Mammalian predator
151.1153	F	3/28/2012	Alive	-	-
151.1173	M	3/28/2012	Dead	5/29/2012	Mammalian predator
151.1195	M	3/28/2012	Dead	6/7/2012	Mammalian predator
151.1012	M	7/12/2012	Alive	-	-
151.1135	M	7/12/2012	Alive	-	-
151.1093	M	9/20/2012	Alive	-	-
151.1114	M	9/20/2012	Alive	-	-
151.1563	F	9/20/2012	Alive	-	-
151.1602	F	9/20/2012	Alive	-	-
151.1654	F	9/20/2012	Alive	-	-
151.1663	F	9/20/2012	Alive	-	-
151.1742	F	9/20/2012	Alive	-	-

Table 13. The number of locations collected for each rabbit released on Patience Island from April 1, 2012 to February 7, 2013, the number of locations deemed suitable for use in home range analysis, and home range and core use area estimates for five individuals and the population.

Rabbit ID (Freq.)	Gender	Date Released	No. Locations Obtained	No. Valid Locations	80% Home Range Area Estimate (ha)	50% Core Use Area Estimate (ha)
151.1032	M	3/28/2012	30	24	25.9	9.3
151.1052	M	3/28/2012	37	22	20.1	8.4
151.1093	F	3/28/2012	6	3	-	-
151.1153	F	3/28/2012	36	20	11.4	5.1
151.1173	M	3/28/2012	12	6	-	-
151.1195	M	3/28/2012	10	4	-	-
151.1012	M	7/12/2012	16	13	9.6	3.6
151.1135	M	7/12/2012	17	14	6.1	2.7
151.1093	M	9/20/2012	6	5	-	-
151.1114	M	9/20/2012	7	6	-	-
151.1563	F	9/20/2012	7	6	-	-
151.1602	F	9/20/2012	7	6	-	-
151.1654	F	9/20/2012	7	7	-	-
151.1663	F	9/20/2012	6	5	-	-
151.1742	F	9/20/2012	6	6	-	-
Total Males	M	-	135	94	23.9	11.4
Total Females	F	-	75	53	23.5	10.1
Population	M+F	-	210	146	21.9	9.0
Mean of individuals ± SE (n=5)	4M, 1F	-	-	-	14.6 ± 3.6	5.8 ± 1.3

Table 14. Summary of habitat type usage by NEC within 50% core use areas (CUA) on Patience Island from April 1, 2012 to February 7, 2013.

		Habitat Type (total area; percent of island)									
		Bramble-Vine (26.2 ha; 30.9%)		Mixed Forest (46.2 ha; 54.5%)		Phragmites Meadow (0.3 ha; 0.3%)		Salt Marsh (3.7 ha; 4.4%)		Shoreline (8.3 ha; 9.8%)	
Rabbit	CUA (ha)	Area (ha)	Percent CUA	Area (ha)	Percent CUA	Area (ha)	Percent CUA	Area (ha)	Percent CUA	Area (ha)	Percent CUA
1.012	3.6	1.6	44%	2.0	56%	0	0%	0	0%	0	0.0%
1.032	9.3	3.5	37%	5.9	63%	0	0%	0	0%	0	0.0%
1.052	8.4	3.7	45%	4.7	55%	0	0%	0	0%	0	0.0%
1.153	5.1	3.7	73%	1.4	28%	0	0%	0	0%	0	0.0%
1.135	2.7	1.6	59%	1.0	39%	0.1	2%	0	0%	0	0.0%
All Rabbits (n=15)	9.0	4.2	47%	4.6	51%	0.2	2%	0	0%	0	0.0%
All Females (n=7)	10.1	5.2	51%	4.2	41%	0.3	3%	0.3	3%	0.2	2%
All Males (n=8)	11.4	5.0	44%	6.2	54%	0.2	2%	0.0	0%	0	0%

Table 15. Chi-square analysis of habitat use for the NEC population on Patience Island from April 1, 2012 to February 7, 2013. Observed values are the number of locations in the home range area observed in each of the habitat types. Expected values were calculated by multiplying the total number of locations within the home range area by the proportion of each habitat type within the area.

Rabbit	Habitat Type	Bramble-Vine Thicket	Mixed Forest	Other (Phragmites Meadow + Salt Marsh + Shoreline)
1.012	Observed	8.00	5.00	0.00
	Expected	6.10	6.00	0.97
	p-value(n=13)	0.42		
1.032	Observed	5.00	17.00	0.00
	Expected	7.74	12.86	1.77
	p-value (n=22)	0.13		
1.052	Observed	10.00	11.00	0.00
	Expected	9.12	10.90	0.98
	p-value (n=21)	0.59		
1.153	Observed	13.00	6.00	0.00
	Expected	9.69	9.27	0.05
	p-value (n=19)	0.31		
1.135	Observed	7.00	7.00	0.00
	Expected	5.50	7.87	0.64
	p-value (n=14)	0.56		
Females	Observed	25.00	21.00	3.00
	Expected	20.59	23.88	4.53
	p-value (n=49)	0.41		
Males*	Observed	40.00	43.00	0.00
	Expected	31.56	41.74	9.72
	p-value (n=83)	**0.00**		
All Rabbits	Observed	63.00	63.00	3.00
	Expected	52.00	69.00	7.81
	p-value (n=129)	0.05		

Table 16. Analysis of preference by NEC between the two dominant habitat types present on Patience Island during a 2012-2013 pilot study. A paired t-test detected no preference by any individual, either gender, or for the entire population of NEC for either bramble-vine thicket or mixed forests habitats.

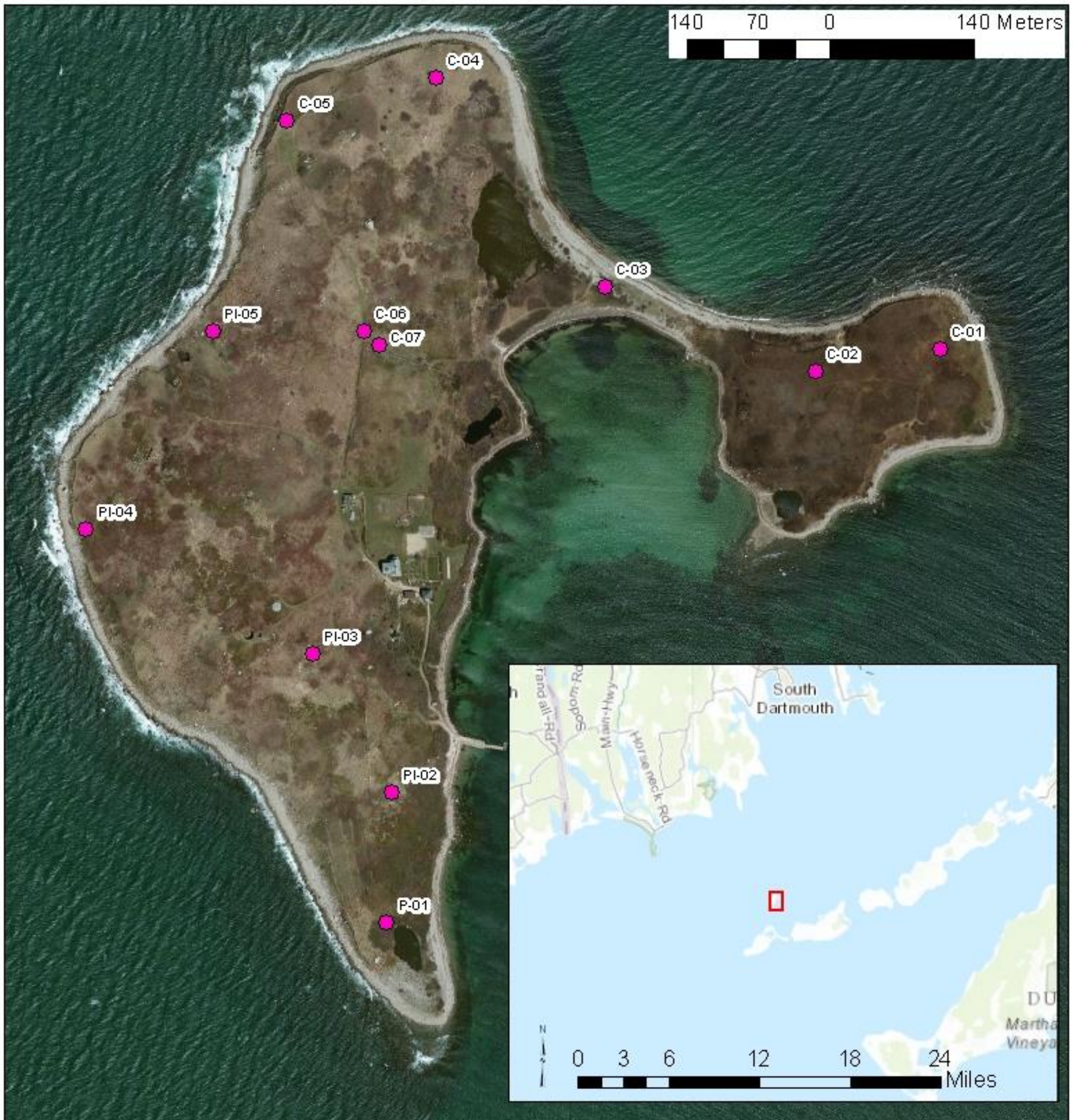
Rabbit	Habitat Type	Bramble	Mixed
1.012	Observed	8.00	5.00
	Expected	6.10	6.00
	p-value (n=13)	0.81	
1.032	Observed	5.00	17.00
	Expected	7.74	12.49
	p-value (n=22)	0.85	
1.052	Observed	10.00	11.00
	Expected	9.11	10.90
	p-value (n= 21)	0.43	
1.153	Observed	13.00	6.00
	Expected	9.68	9.27
	p-value (n=19)	1.00	
1.135	Observed	7.00	7.00
	Expected	5.51	7.87
	p-value (n=14)	0.84	
Females	Observed	25.00	21.00
	Expected	20.60	23.88
	p-value (n=49)	0.87	
Males	Observed	40.00	43.00
	Expected	31.56	41.74
	p-value (n=83)	0.41	
All Rabbits	Observed	63.00	63.00
	Expected	52.00	69.00
	p-value (n=129)	0.82	

Table 17. Stem density estimates on Nomans Land Island NWR measured in August 2011 compared to stem densities estimated by the Eastern Massachusetts National Wildlife Refuge Complex at various mainland sites in 2012.

Site	Mean stem density/m^2 (± SE)	Mean stem density extrapolated to a per ha basis
Nomans (entire island)	10.7 ± 0.6	107,000
Nomans (Maritime Morainal Shrubland habitat only)	9.6 ± 0.5	96,000
Eastern Massachusetts National Wildlife Refuge Complex Sites:		
Quashnet	1.7 ± 0.3	17,000
Orenda	8.0 ± 0.5	80,000
Greenwood	6.5 ± 0.5	65,000
Gravel Pit (pre-burn)	6.7 ± 0.9	67,000
Gravel Pit (post-burn)	4.0 ± 0.5	40,000

Table 18. Summary of cottontail home range estimates from the literature.

Author	Year	Location	Method	Season	Gender/Species	HR (ha)
Haugen	1942	Michigan	Trapping	Winter	F/EC	5.7
				Breeding	F/EC	9.1
Schwartz	1941	Missouri	Trapping	Winter	M/EC	0.6
				Winter	F/EC	0.5
Allen	1939	Michigan	Trapping	Winter	F/EC	0.9
				Winter	M/EC	1.5
Kilpatrick *et al.*	2010	Connecticut	Radiotracking	Winter	Unknown/NEC	2.8
				Breeding	Unknown/NEC	4.3



FID	Shape *	N	Plot_ID	X_UTM	Y_UTM	Stems_m2	Stem_m_SE	Stems_ha	Stems_ha_SE
0	Point	1	C-01	339993	4590698	14.2	4.72	142000	47200
1	Point	2	C-07	339445	4590718	4.8	1.2	48000	12000
2	Point	3	C-06	339431	4590732	14.5	6.14	145000	61400
3	Point	4	C-05	339362	4590939	6	2.07	60000	20700
4	Point	5	C-04	339508	4590977	13	3.71	130000	37100
5	Point	6	C-03	339668	4590768	8	2.53	80000	25300
6	Point	7	C-02	339871	4590680	7.8	5.2	78000	52000
7	Point	8	PI-05	339283	4590736	27.2	13.8	272000	138000
8	Point	9	PI-03	339372	4590418	46.6	1.69	466000	16900
9	Point	10	PI-04	339154	4590546	105	26.2	1050000	262000
10	Point	11	PI-02	339445	4590281	61.4	15.9	614000	159000

Figure 1. Random sampling points generated for the vegetation survey conducted on Penikese Island to assess cottontail impact on July 14, 2011.

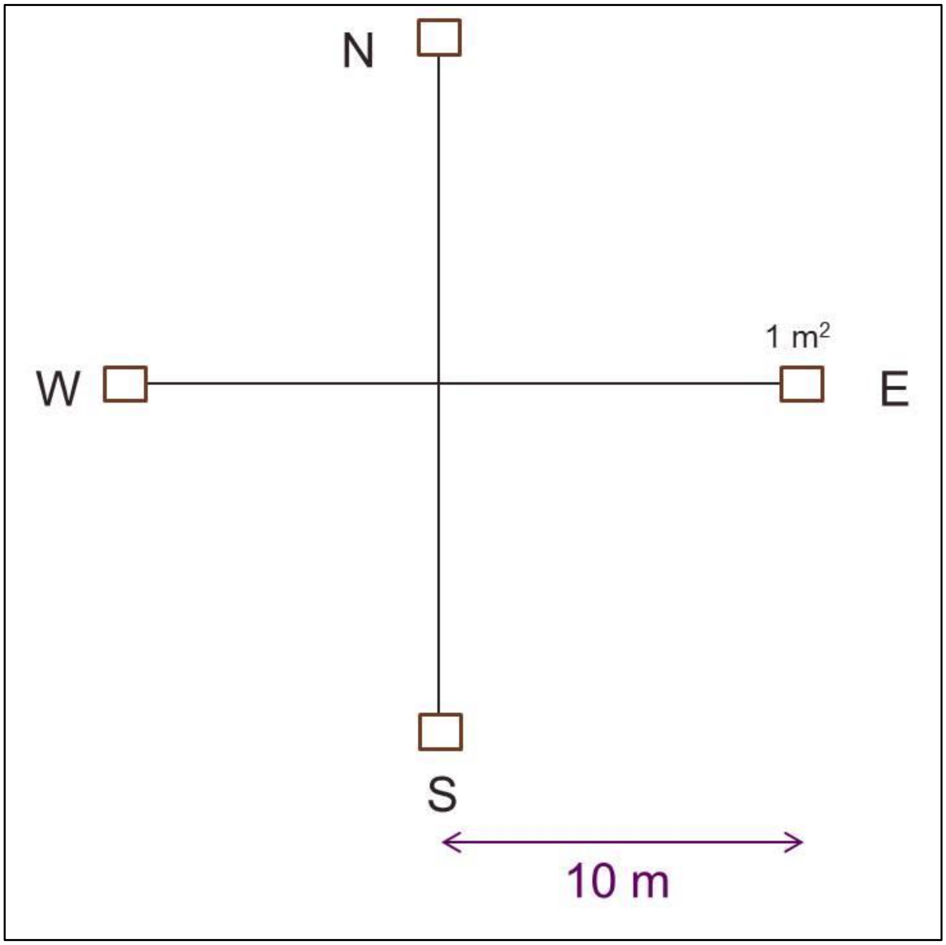


Figure 2. Plot design for vegetation analysis and cottontail impact assessment on Penikese Island conducted on July 14, 2011.

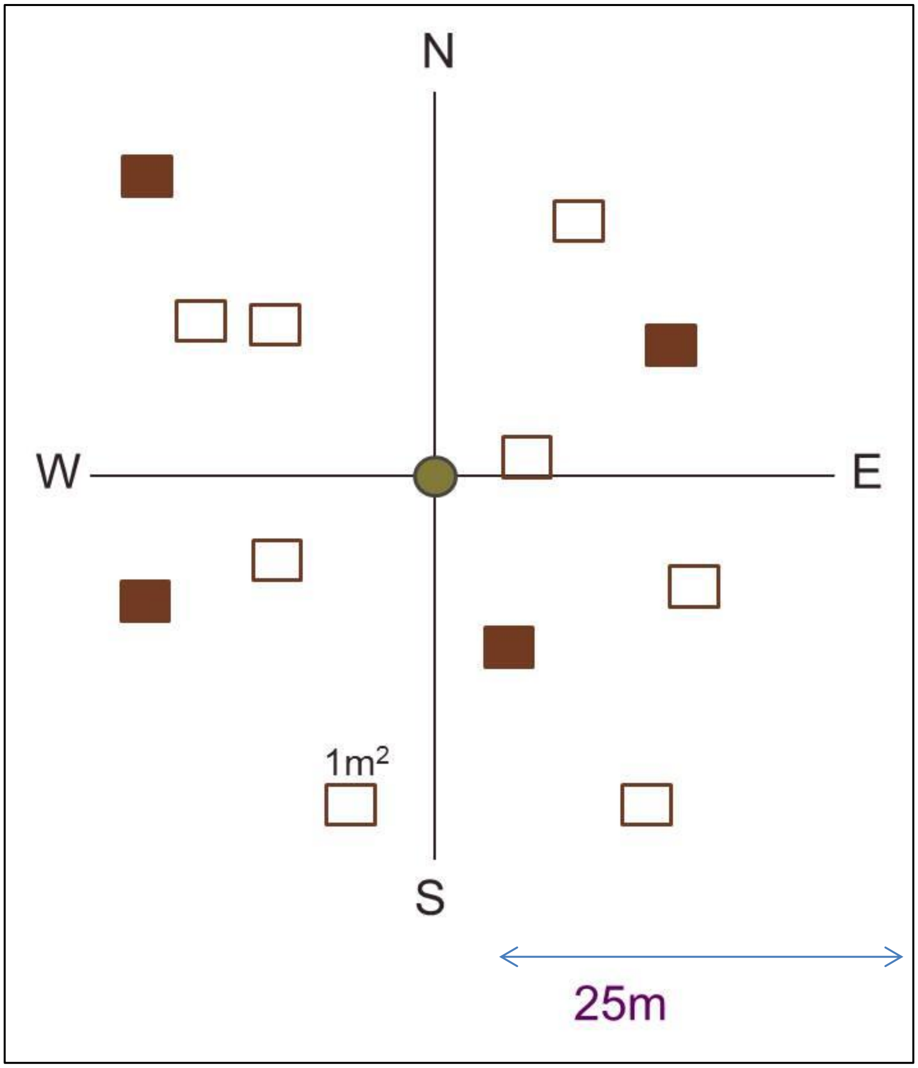


Figure 3. Plot design used for the vegetation survey on Patience Island conducted in the summer months of 2011 and2012. Shrub cover was estimated using the line-intercept method (Canfield 1941) along each of the 25-m transects. Herbaceous cover, stem density, and species composition were measured in each of the 12 randomly placed 1-m^2 quadrats. The quadrats shown in red indicate the randomly chosen quadrats where canopy cover, tree density, and basal area measurements also were taken.

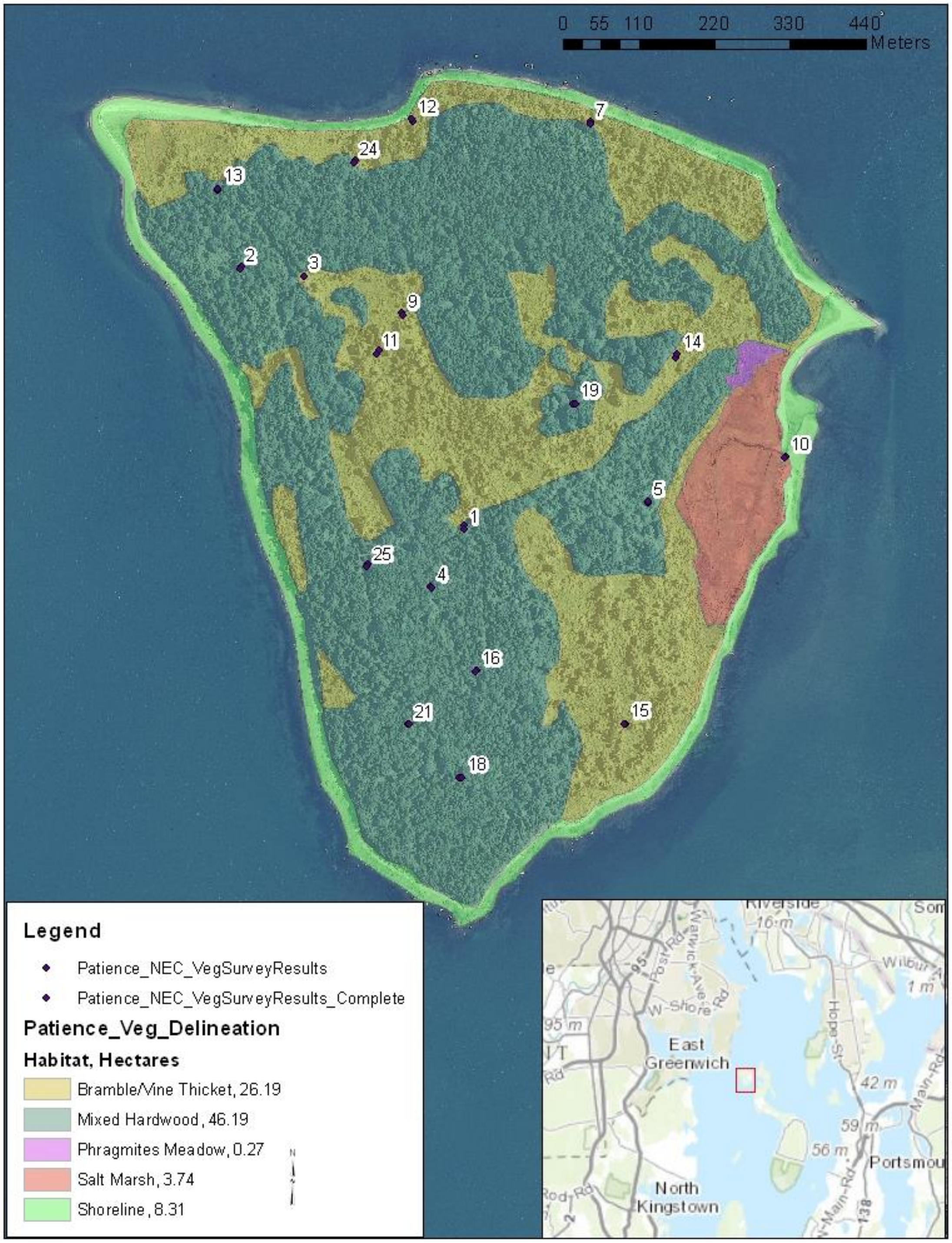


Figure 4. Five major habitat types present on Patience Island and randomly generated sampling points used for a 2011-2012 vegetation survey.

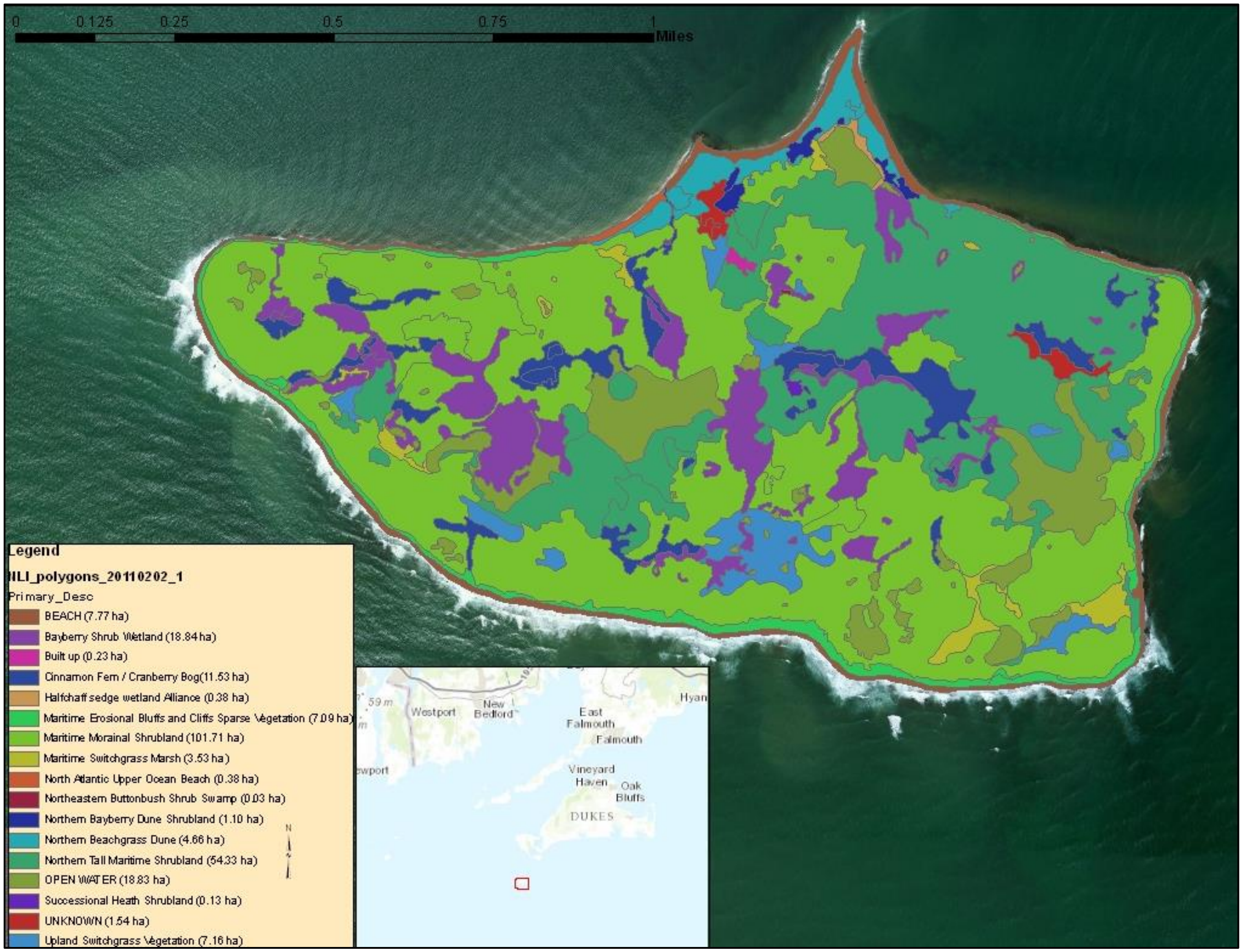


Figure 5. Map of Nomans Land Island NWR showing the 17 habitat classifications provided by the Eastern Massachusetts NWR Complex in 2010.

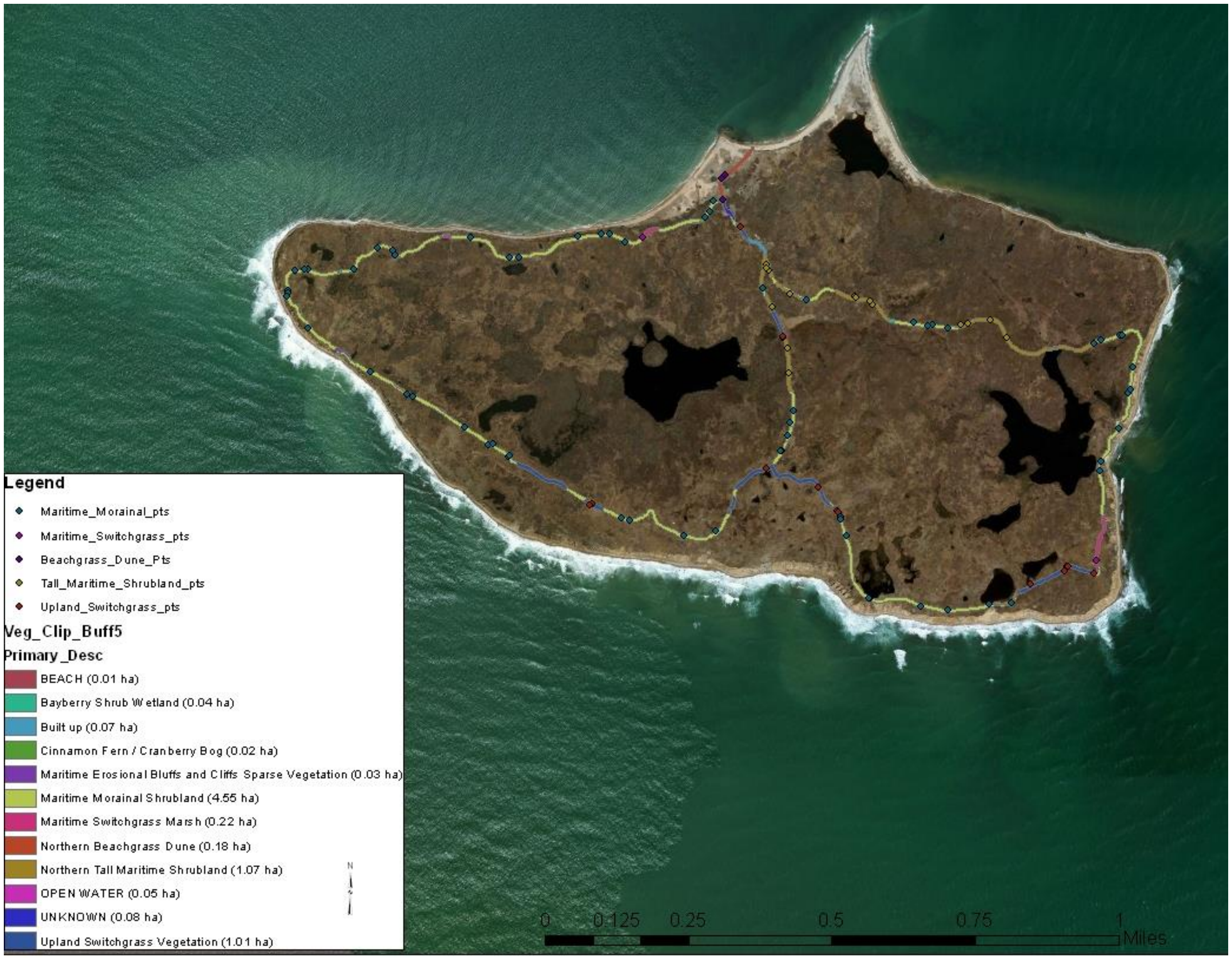


Figure 6. Random sampling points that were generated within the 5-m buffer around mowed trails for a vegetation survey conducted on Nomans Land Island NWR in August 2011. The 5-m buffer captured 12 habitat classifications, and randomly generated points fell in five of these 12 classifications.

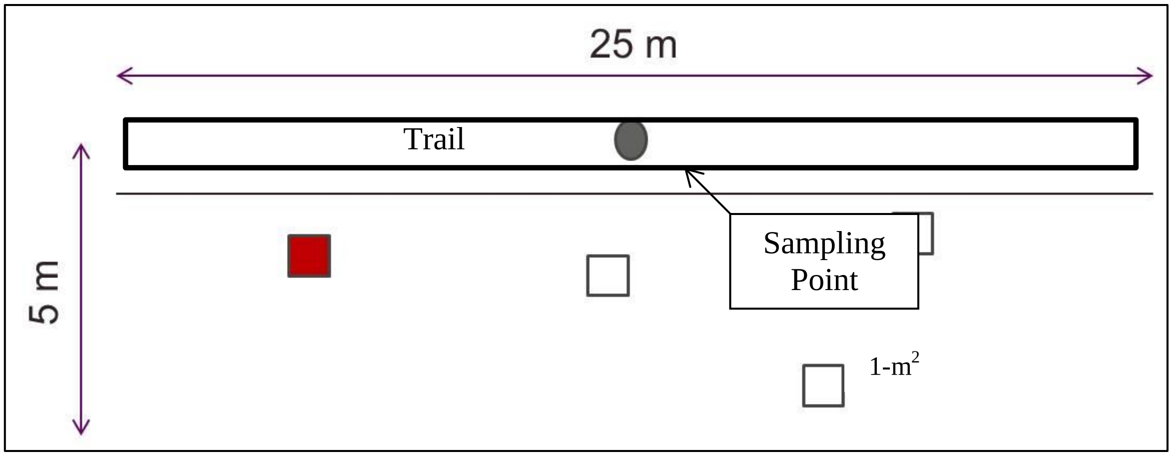
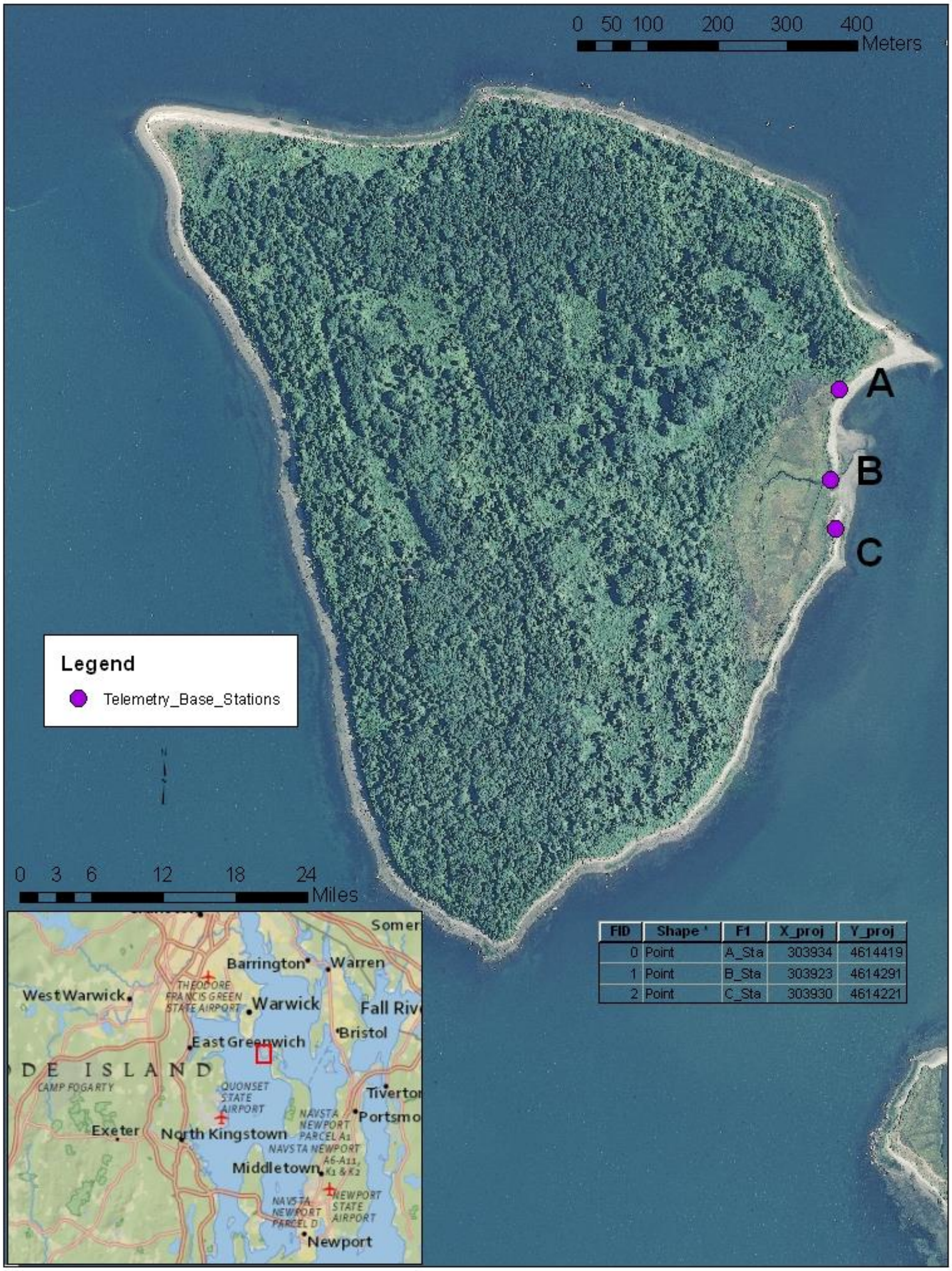


Figure 7. Plot design for the vegetation survey conducted on Nomans Land Island NWR in August 2011. The side of the trail on which the 25-m line-transect was placed was determined randomly by a coin flip at each plot, and was used to estimate shrub cover with the line-intercept method (Canfield 1941). Herbaceous cover, stem density and species composition were measured in each of the four randomly-placed 1-m^2 quadrats. The quadrat shown in red indicates the randomly chosen quadrat where canopy cover and basal area measurements also were taken.



FID	Shape *	F1	X_proj	Y_proj
0	Point	A_Sta	303934	4614419
1	Point	B_Sta	303923	4614291
2	Point	C_Sta	303930	4614221

Figure 8. Locations of the three base stations on Patience Island used to conduct radio telemetry monitoring of NEC released there in 2012.

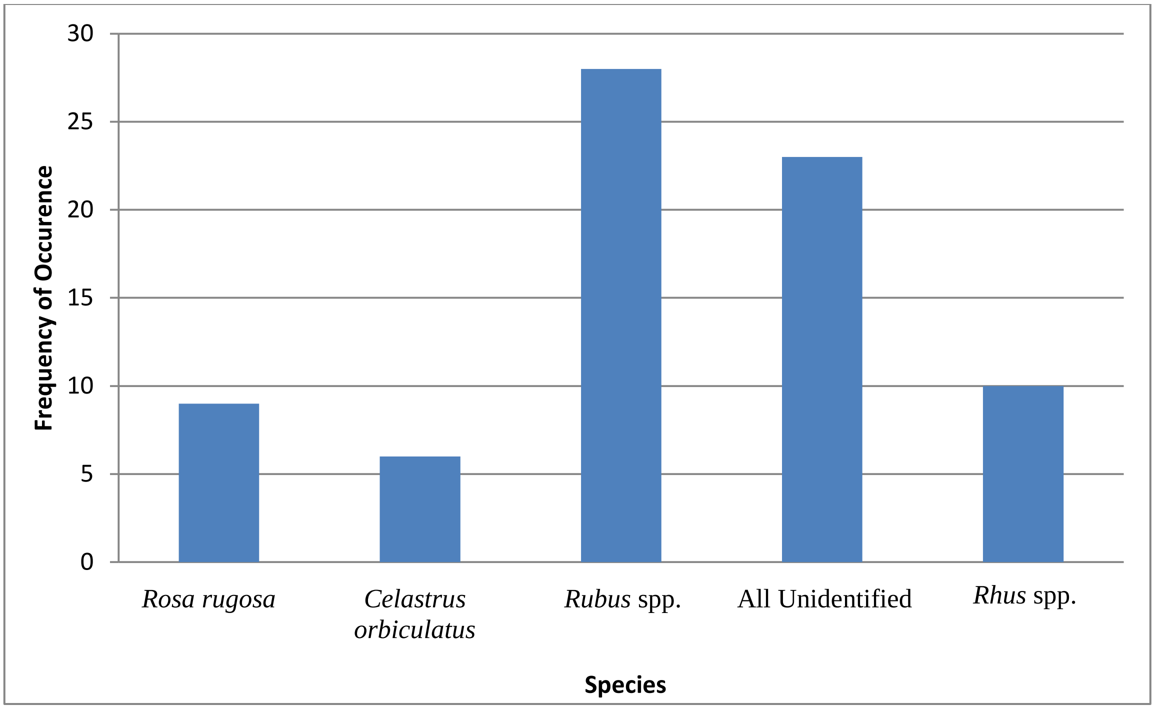


Figure 9. Frequency of woody species present on Penikese Island, Massachusetts, during a cottontail impact assessment vegetation survey on July 14, 2011.

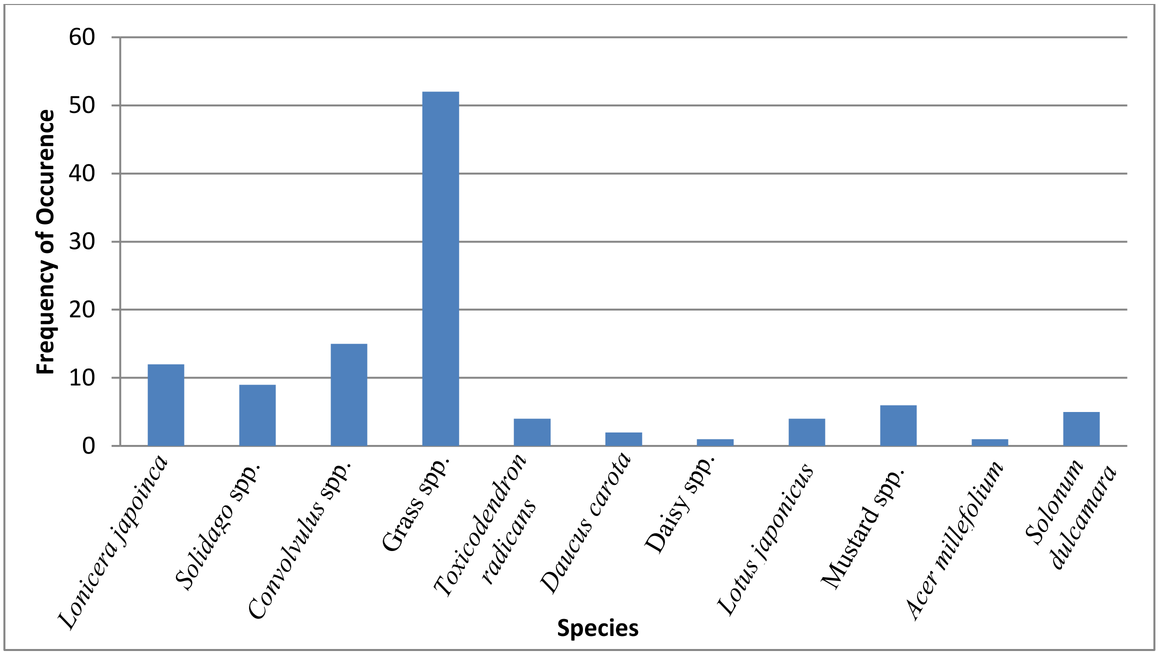


Figure 10. Frequency of herbaceous species present on Penikese Island during a cottontail impact assessment vegetation survey on July 14, 2011.

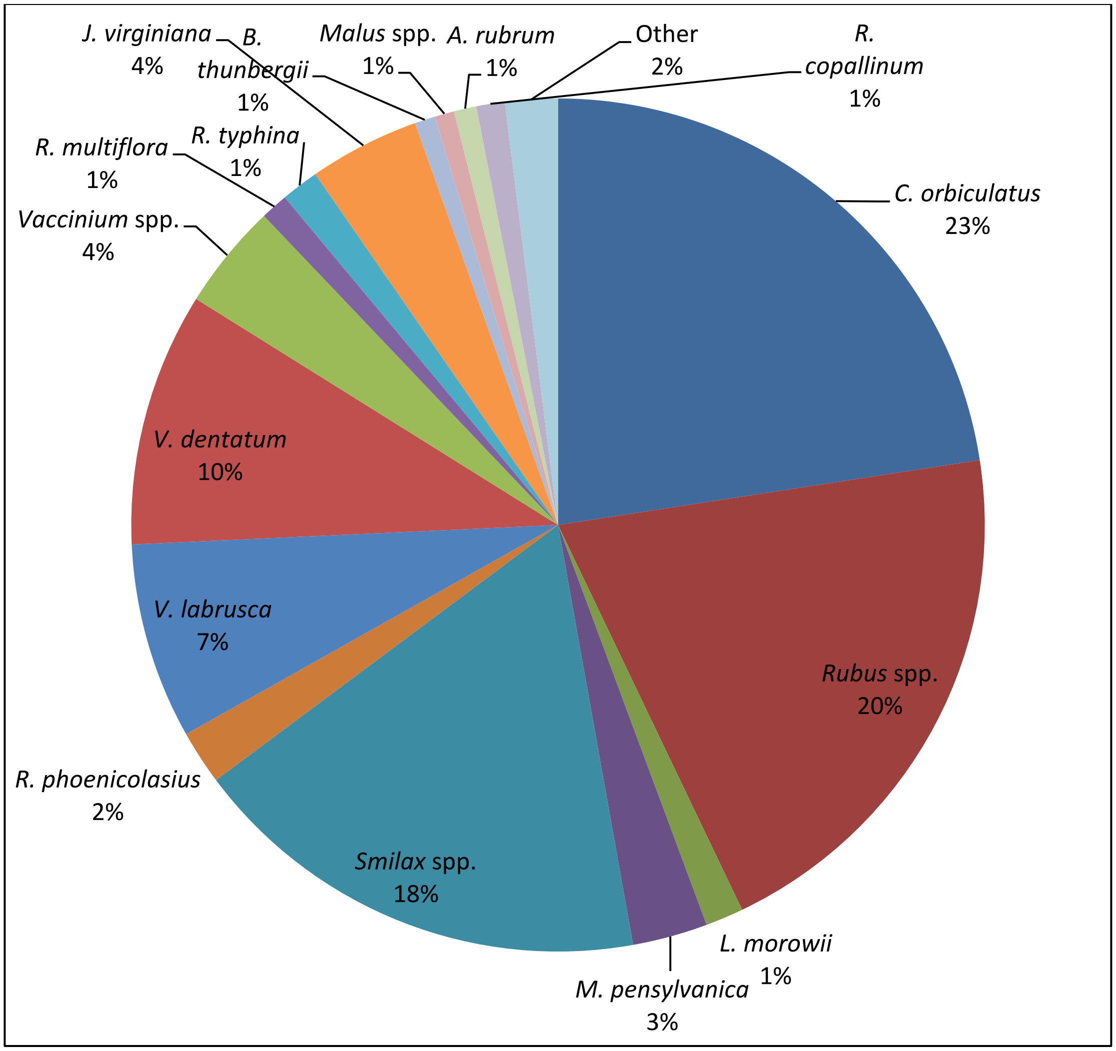


Figure 11. Woody species composition on Patience Island for all height classes recorded during a vegetation survey using the line-intercept method conducted in the summer months of 2011 and 2012 (n=18). “Other” combines all species that individually make up <1% of the total cover.

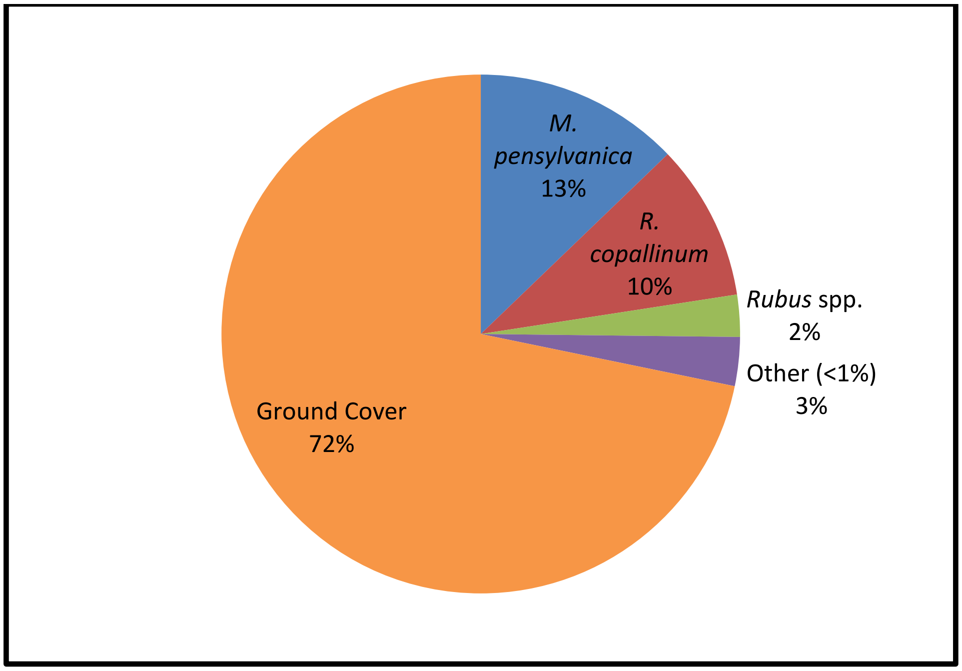
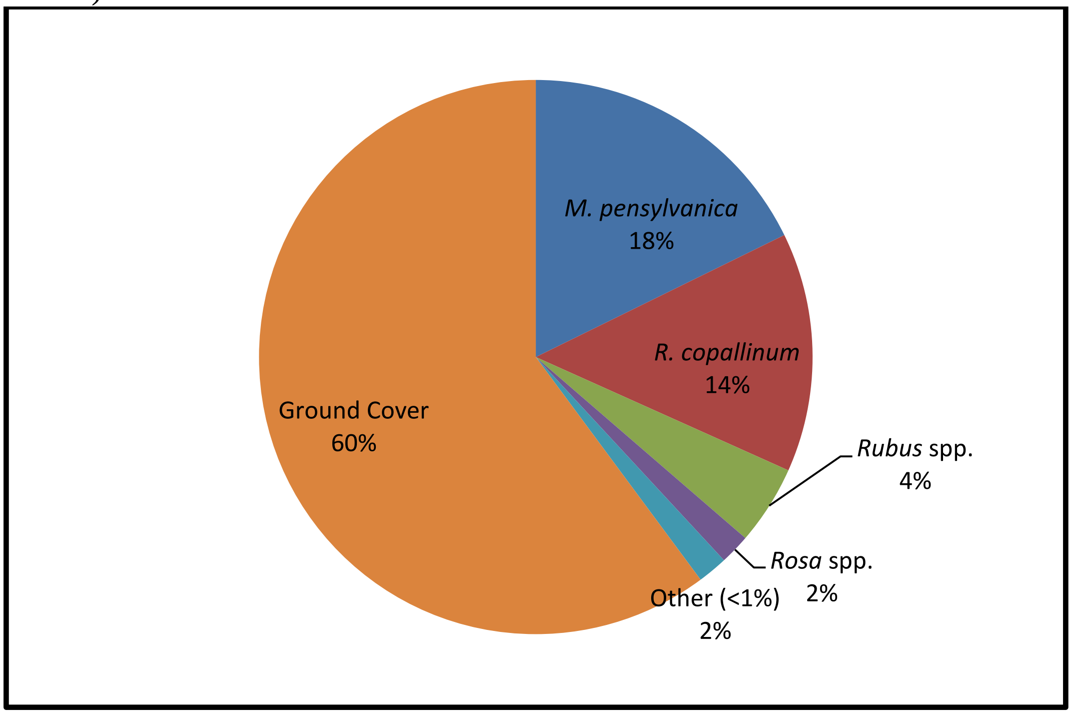


Figure 12. Percent cover of shrubs (0.5-2 m in height) and ground cover (woody vegetation <5 m tall, herbaceous cover, and/or leaf litter) along line transect plots within the Maritime Morainal Shrubland designation on Nomans Land Island NWR in August 2011 (n=53).

a) Low Shrub Cover



b) High Shrub Cover

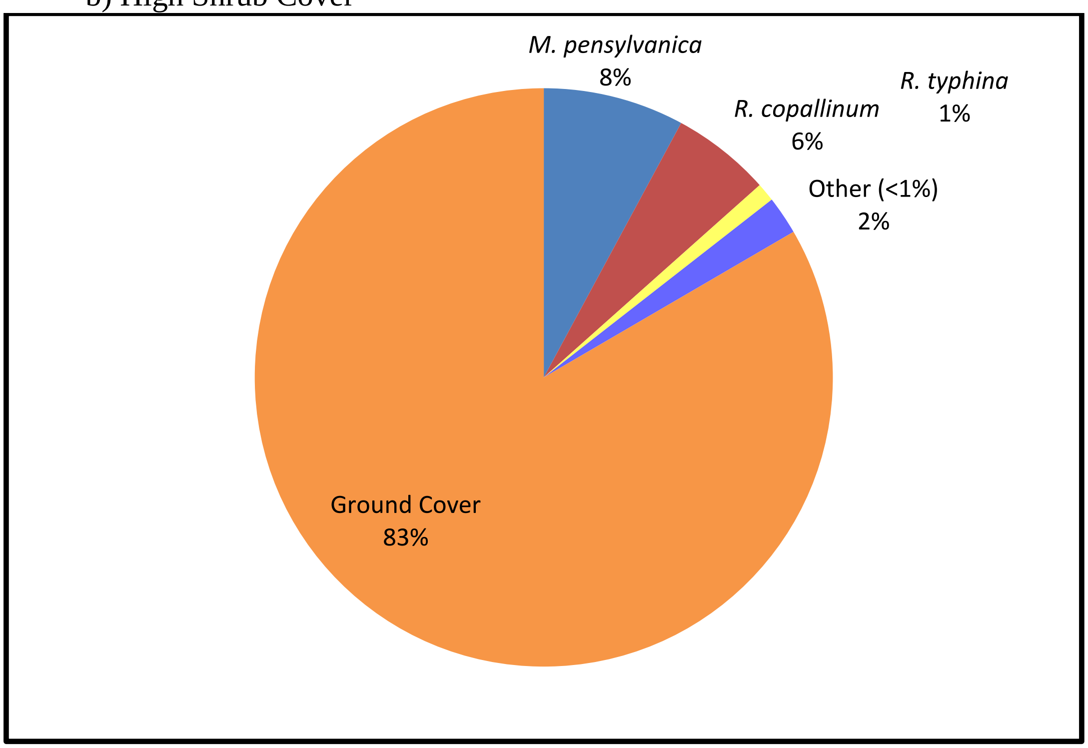


Figure 13. a) Percent cover of low shrubs (0.5m-≤1m in height) and b) high shrubs (>1m-2m in height) and ground cover (woody vegetation <5 m tall, herbaceous cover, and/or leaf litter) along line transect plots within the Maritime Morainal Shrubland designation on Nomans Land Island NWR in August 2011 (n=53).

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APPENDIX A

Literature Review

The New England cottontail (*Sylvilagus transitionalis*; NEC) has become a species of great conservation concern in recent years, and many studies have been conducted in an effort to pinpoint the reason for their decline (Fay and Chandler 1955; Jackson 1973; Litvaitis *et al.* 2003; 2006). While there is not one factor deemed to be the cause of their decline, the two factors most widely believed to affect NEC populations are the introduction of the eastern cottontail (*Sylvilagus floridanus*) to the region in the early 1900s (Reynolds 1975, Fuller and Tur 2012, Litvaitis *et al*. 2006, Probert and Litvaitis 1995) and habitat loss and fragmentation (Barbour and Litvaitis 1993, Litvaitis and Villafuerte 1996, Litvaitis *et al*. 2006, Tash and Litvaitis 2007).

Although the NEC has been well studied in recent years, many questions remain about the true causes of their decline. While there is a focus on identifying these factors, a proactive approach to prevent NEC from becoming a Federally listed species also has been implemented in the form of a captive breeding program (Fuller and Tur 2012). One component of this program involves the use of islands as release sites for captive bred rabbits. Islands have historically been used as release sites for cottontails for both conservation and hunting purposes and have had varying results (Peterson 1966, Jakubas 2011, pers. comm. Thomas French 2010). Historical records of releases of the European rabbit (*Oryctolagus cuniculus*), an invasive species in many parts of the world, have revealed devastating impacts on the habitats of those islands where it was introduced (Thompson 1955, Flux and Fullugar 1992, Litvaitis *et. al* 2006, Bullock *et al.* 2002, Coyne 2010). However, the European hare and cottontail rabbits are very different in their behavior, and it is very unlikely that cottontail rabbits would have these sorts of effects on island habitats (Nowak 1999). While there is no evidence that cottontails would negatively affect an island's habitat, there is the potential for their release to affect other prey species inhabiting the island based on the hyperpredation theory, which predicts that an increase in a prey population, cottontail in this case, will cause an increase in the predator population and will therefore increase the risk of depredation for other prey species (Courchamp *et al.* 2000).

To evaluate potential island release sites for their suitability as cottontail habitat and also to establish baseline data that will allow for monitoring of the habitat in the future, several vegetation analysis methods are available. Stem density and shrub cover are two very important characteristics in cottontail habitat (Tash and Litvaitis 2007; Barbour and Litvaitis 1993; Litvaitis *et. al.* 2003) and a variety of techniques to quantify these measurements exist. Shrub cover can be estimated using a line-intercept method (Canfield 1941) and recent studies characterizing NEC habitat estimate stem density based on counting stems that are ≥0.5 m tall and <7.5 cm diameter breast height (dbh) (Barbour and Litvaitis 1993), and only if they are rooted in the sample quadrat (Fuller and Tur 2012). Several studies have used these or similar methods to determine the minimum stem density required by NEC. To guide their searches for NEC, Litvaitis and Tash (2006) considered patches of habitat to be suitable if they had >9,000 stems/ha of primarily deciduous understory cover. Probert and Litvaitis (1995) created dense patches of habitat of at least 18,000 stems/ha to determine any difference(s) in microhabitat use between NEC and EC. Although their results were inconclusive, they found some evidence that EC are more likely to use areas with a lower understory density, and discuss the EC's general ability to exploit a wider range of habitats, further supporting the idea that dense understory cover is particularly important for NEC. Barbour and Litvaitis (1993) examined patch use versus availability, based on fecal pellet distribution in relation to understory density, and report that NEC show a significant preference for sites with ≥50,000 stems/ha. In addition to the significance of high stem densities, several researchers have explored the importance of species composition in terms of structure and nutritive value. During a study in Connecticut, Dalke and Sime (1941) found that blackberry (*Rubus allegheniensis*) is one of the most important sources of winter food for cottontails, in addition to its provision of thick cover. Litvaitis *et al.* (2006) also mentions *Rubus* spp. as an indicator to help guide NEC pellet surveys in New Hampshire. They suggest that particular attention should be paid to patches containing *Rubus* spp. and other favored browse species including willow (*Salix* spp.), aspen (*Populus tremuloides*), and red maple (*Acer rubrum*). Browse species accepted by NEC in captivity also have been documented by the staff at the captive breeding facility at the Roger Williams Park Zoo in Providence, RI. In addition to a diet of commercial rabbit chow and Timothy hay (*Phleum pratense*), captive NEC accepted briar (*Smilax* spp.), apple (*Malus* spp.), black cherry (*Prunus serotina*), red maple, and various *Rubus* spp. (Perrotti and McBride 2012).

Many studies have evaluated the use of these habitat characteristics by cottontails in various landscapes using estimating home range and core use area size. Prior to the use of radiotelemetry and GPS technology, trapping was used to estimate home range sizes of cottontails, sometimes among seasons, gender, and age (Haugen 1942, Allen 1939, Schwartz 1941). More recent studies have employed radio collared rabbits to calculate home range estimates (Kilpatrick 2010 [unpublished data], Trent and Rongstad 1972). Many software programs exist to calculate home range estimates, but one common technique that is shared by most and used often is the kernel density estimator (KDE) (Kilpatrick *et al.* 2011, Worton 1989, Seaman *et al.* 1999). While the standard contours most often used to describe home range and core use areas are 95% and 50%, some have suggested that the outer contours, particularly those greater than 80%, often have significantly greater bias than those between 50% and 80% (Seaman *et al.* 1999, Anderson 1982). In general, the two most important factors affecting the accuracy of a KDE home range is the sample size and the smoothing parameter or bandwidth that is chosen (Horne and Garton 2006, Seaman *et al.* 1999). The preferred smoothing method is the least squares cross validation, but this method has a tendency to overestimate home range size when the sample size is not large enough (Horne and Garton 2006, Seaman *et al.* 1999).

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APPENDIX B

Record of Introductions of Cottontails on Island Habitats

Quabbin Reservoir. The oldest recorded experimental release of cottontail rabbits was implemented by the Massachusetts Cooperative Wildlife Research Unit in the 1960s (Peterson 1966). To expand knowledge of the basic biology, population dynamics, and interactions between the two *Sylvilagus* species, six NEC and five EC were released onto a 10.5-ha island in the Quabbin Reservoir in February and March of 1963. Due to concerns of rabbits traveling back to the mainland during the ice-over of the reservoir, 12 more rabbits (six of each species) were subsequently released in April and May of that year. It is important to note that species identification at this time was based solely on physical characteristics as guided by McDonough and Hames (1953). However, as modern molecular evidence has demonstrated (Sullivan *et al*. 2013), there is great potential for misidentification using morphological methods of identification. A resident population of snowshoe hares (*Lepus americanus*) was extant on this island, but an effort was made prior to the release of cottontails to trap and remove all hares. Trap censuses were conducted from September 24 to October 3, 1963, and from November 20 to November 25, 1963. Each census included the use of 20 wooden box traps located at 61-m intervals in addition to observations made by driving through the area. Twelve imprint plots and driving also were used for indirect censusing. Trapping efforts to document the post-release status of cottontails did not result in high enough numbers to estimate a population size, but due to the general low recapture rate of cottontails, it was assumed that the population was larger than the trapping rates indicated. The first trap census in September included 139 trap nights and resulted in 23 captures of five rabbits (one juvenile and two adult EC and one juvenile and one adult NEC). The second trap census in October included 100 trap nights and resulted in only nine captures of three juvenile cottontails (one EC and two NEC, with one only one recapture from the first census). Recruitment was low, with only five juveniles from at least four different litters surviving until the fall census, indicating a ratio below the expected of three or four juveniles to one adult in the fall. By December 31, 1963, no evidence of cottontails was observed (i.e. no tracks or sign could be observed on a nine day old powder snow) and the Peterson concluded there were no live cottontails remaining on the island. There are many factors that may have contributed to the low success of this island release of cottontails. First, the ice-over during the winter may have allowed mammalian predators to immigrate to the island or for rabbits to emigrate to the mainland. Additionally, the presence and behavior of a flock of crows observed on the island during the summer of 1963 may support the findings of Kalmbach (1918) and Kirkpatrick (1950) who suggest that crows can efficiently locate and depredate young cottontails. In the final analysis, the reasons for the failure of the cottontail populations introduced to this island remain unknown.

Grape Island. Grape Island is a 22-ha island located in Boston Harbor (Elliman 2005). Personal communication with Tom French (2010) describes the following history of cottontails on Grape Island. In 1985, 16 NEC were transported from Sandwich, Massachusetts to Grape Island, which had European hares present, but no cottontails. In 1986, 10 NEC were captured during a trapping census, four of which were juveniles. In 1987, a similar census yielded 14 NEC, seven of which were juveniles. Formal trapping censuses did not occur after this, but cottontails were observed during trips to the island in 1989 and 1998. A rabbit skull, identified as NEC, was recovered during the 1998 visit. During an extensive search of the island in 2009, no pellets or other rabbit sign were observed. A survey of the mammals of the Boston Harbor Islands in 2005 and 2006 resulted in similar findings for Grape Island, with no evidence of any lagomorph species being detected (Trocki and Paton 2007).

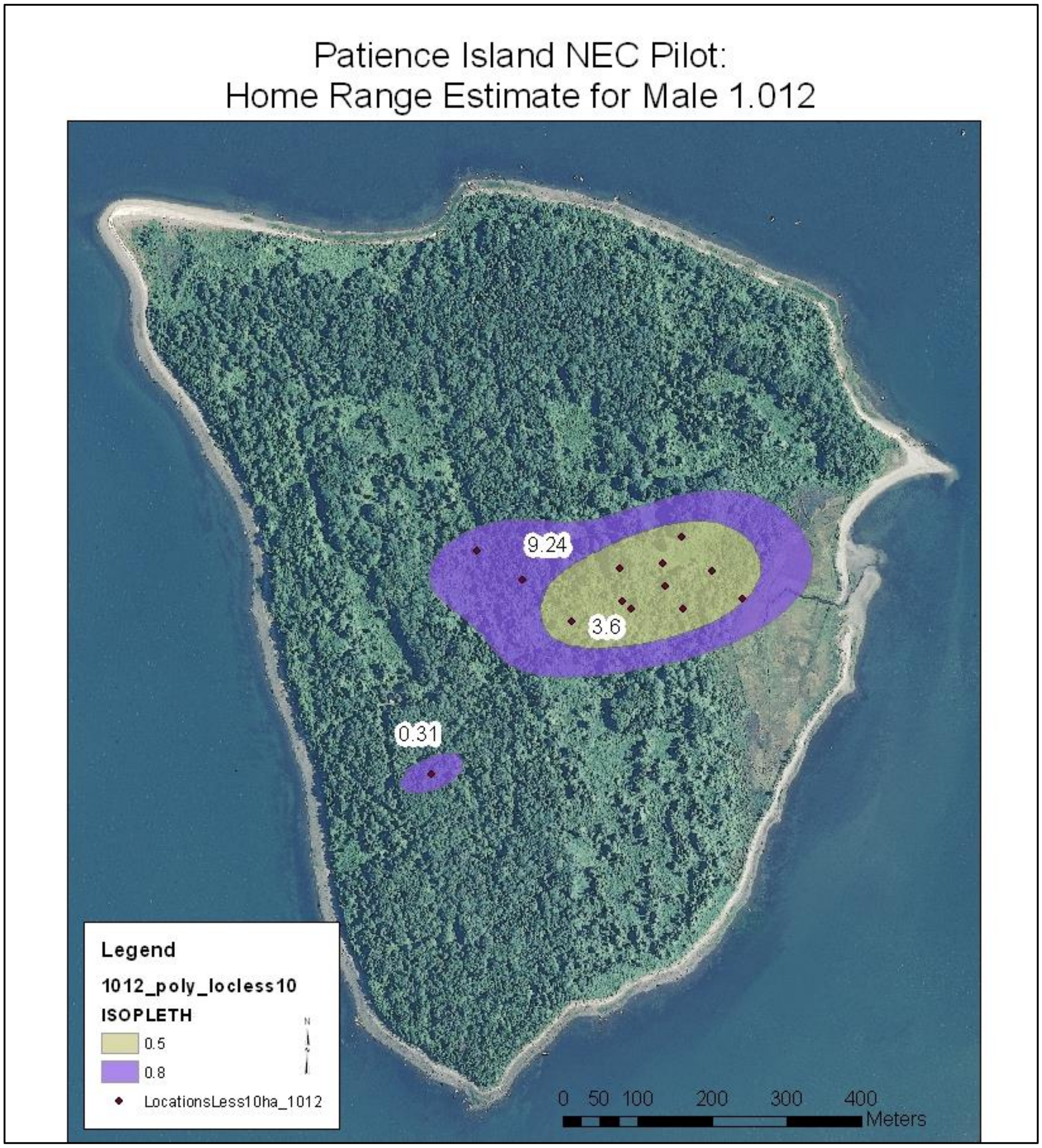
Stage Island. According to Jakubas (2011), Stage Island is a 12-ha island located approximately 0.5 km off the coast of Cape Porpoise, Maine and is owned by the Kennebunkport Conservation Trust. Sixteen NEC were transported from the Portland and South Portland, Maine to Stage Island in March of 2010. Eleven of the 16 rabbits were fitted with radiocollars. These rabbits were monitored using radiotelemetry twice per week. Their documented activity indicated that they spent much of their time on the western side of the island, near where most of the rabbits were released. The mortality rate for these 11 rabbits from March to September 30 was 73%, with four rabbits being killed by predators, four with unknown sources of mortality, and three remaining alive. Three of the four predation mortalities were documented to be the result of a long-tailed weasel (*Mustela frenata*), and the fourth was the result of an unidentified predator. Although the habitat on the island seemed to provide good cover (i.e. apparent high stem densities and a thick understory), pellets and tracks were often observed on open shore areas and on a rock pile with no overhead cover, areas where predation may have been a greater factor. A professional trapper was hired to remove any long-tailed weasels after the first mortality was documented, but this effort was unsuccessful. During winter months, some mammalian predators may have taken advantage of the ice-over, or at other times, were able to make the short swim from the mainland. In addition to the long-tailed weasel, other potential predators present on the island include short tailed weasel (*Mustela erminea*), mink (*Mustela vison*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), bald eagle (*Haliaeetus leucocephalus*), northern harrier (*Circus cyaneus*), and various gulls (*Larus* spp.). Trapping in November indicated that only the three known, collared rabbits were present on the island. Twelve rabbits were captured over six days (237 trap nights), with the same three rabbits being repeatedly captured. Images from trail cameras coincided with these findings, with only collared rabbits being detected. These results indicate that there was no evidence of recruitment, however, the two females remaining on the island showed signs of having nursed young. Jakubas (2011) provides two hypotheses to explain the failure of this translocation: 1) "The plants available on the island provided inadequate nutrition making the rabbits and offspring more susceptible to predation"; and 2) "Habitat and environmental differences between the initial capture site and the release site increased the vulnerability of NEC to predation." Strategies such as supplemental feeding and the implementation of artificial, above-ground burrows were employed in an attempt to mitigate these effects, but the effectiveness of these strategies were not evaluated. In the end, they were clearly not adequate to support NEC.

Penikese Island. Penikese Island is a 30-ha island located in Buzzards Bay and, according to personal communications with Thomas French (2010), was acquired by the Massachusetts Division of Fisheries and Wildlife in 1924. In March 1925, 79 cottontails were released onto the island with the intention of allowing them to breed and provide a source of rabbits that could be trapped and transported back to the mainland to enhance populations at low points or at sites made depauperate by heavy hunting. By early fall, about 200 rabbits were estimated to be on the island, and by 1926 there were “hundreds.” Releases continued on Penikese Island from 1925 to 1939, with a total of 369 cottontails from Massachusetts and Vermont being transported to the island during this time period to add vigor to the population. The species of cottontails introduced were not specified, but based on the historic range of NEC in New England, it is likely that there were some NEC included in these releases (Litvaitis *et. al.* 2008, Litvaitis *et. al.* 2006). During this same time period, French reports a record of 3,792 cottontails were trapped on Penikese and transported to the mainland. In subsequent translocations about 4,300 cottontails were trapped and moved to the mainland. Also, from the 1920s to the 1940s, about 16,200 ECs were transported to Penikese from other states including Kansas, Missouri and other Midwestern states, and a number of cottontails, likely NEC, were transported from Vermont. The population on Penikese Island continues to exist, although rabbits may not be easily observed for two or three years at a time (pers. comm. French 2010). Approximately 20 skulls have been collected on the island since 1985 and all have been identified as EC.

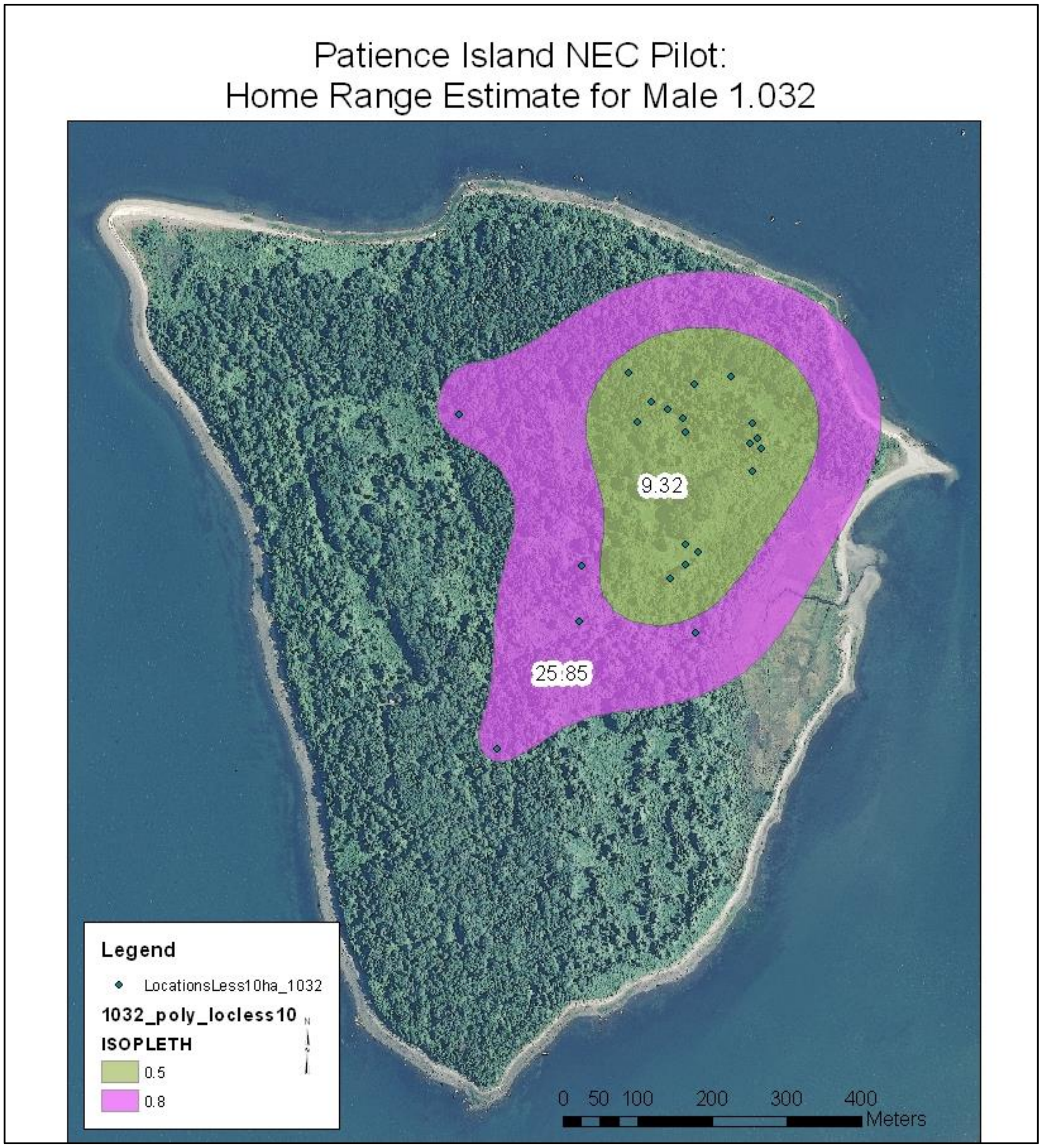
These case studies give some insight into the potential outcomes of releasing cottontails on coastal islands. There is one glaring difference between Penikese Island, which seems to have a self-regulating population of cottontails, and the other islands where cottontails were introduced, which is simply the initial number of rabbits that were released onto the island. Thousands of rabbits were brought to Penikese Island within a 20 to 30 year time period, which likely ensured a genetically robust island population. Penikese is also the largest of the islands overviewed here, but is small compared to the islands being evaluated in my study. This indicates that it is possible that a relatively small coastal island can sustain a population of cottontails on a long-term basis. However, it seems likely that the population on Penikese is currently only composed of eastern cottontails, so the question of whether or not a population of only NEC would have the same success remains. Another concern that is not addressed in the history of cottontail releases on these islands is the effects, if any, that the cottontails may have had on the habitat. Penikese Island, because of the substantial number of cottontails believed to inhabit the island, was chosen for an assessment of the long-term impact of cottontails on an island habitat.

APPENDIX C

Home Range Maps for NEC on Patience Island

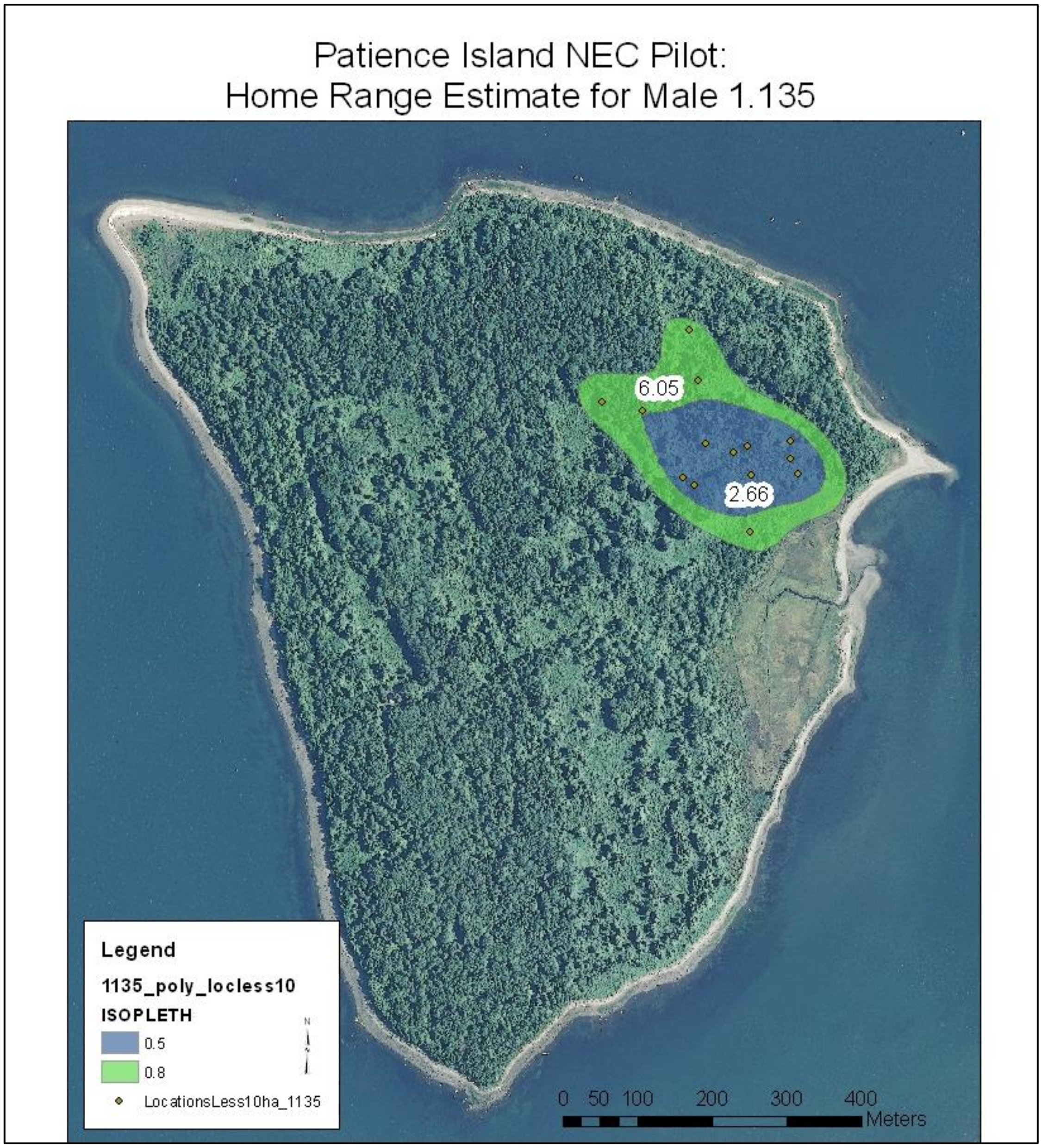


Appendix C1. Home range estimate (80% contour) and core use area estimate (50% contour) for a male NEC with radio frequency 1.012 from 17 July, 2012 to 7 February, 2013 (n=13). Areas are shown in hectares.

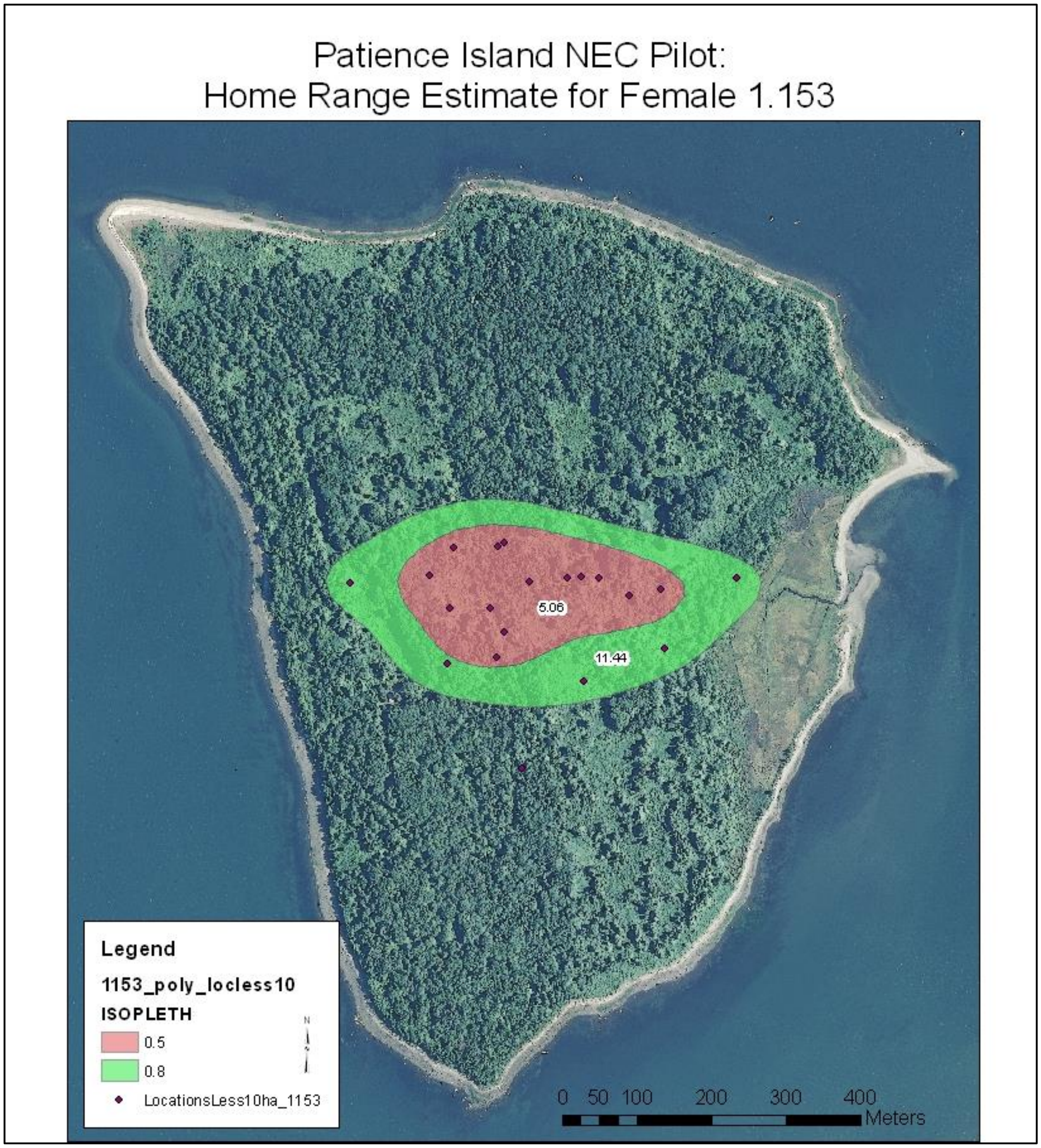


Appendix C2. Home range estimate (80% contour) and core use area estimate (50% contour) for a male NEC with radio frequency 1.032 from 1 April, 2012 to 7 February, 2013 (n=24). Areas are shown in hectares.

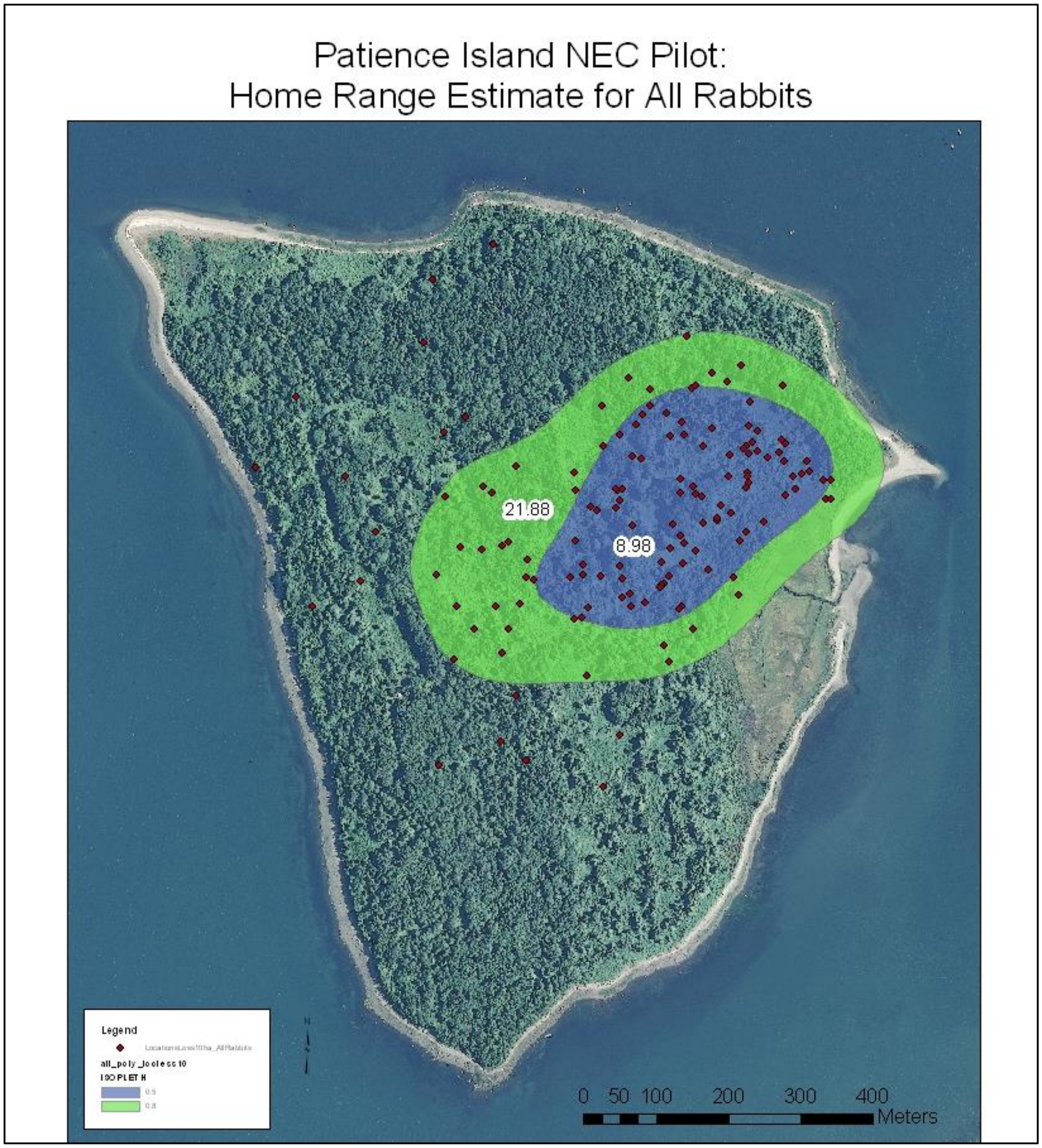
Appendix C3. Home range estimate (80% contour) and core use area estimate (50% contour) for a male NEC with radio frequency 1.052 from 1 April, 2012 to 7 February, 2013 (n=22). Areas are shown in hectares.



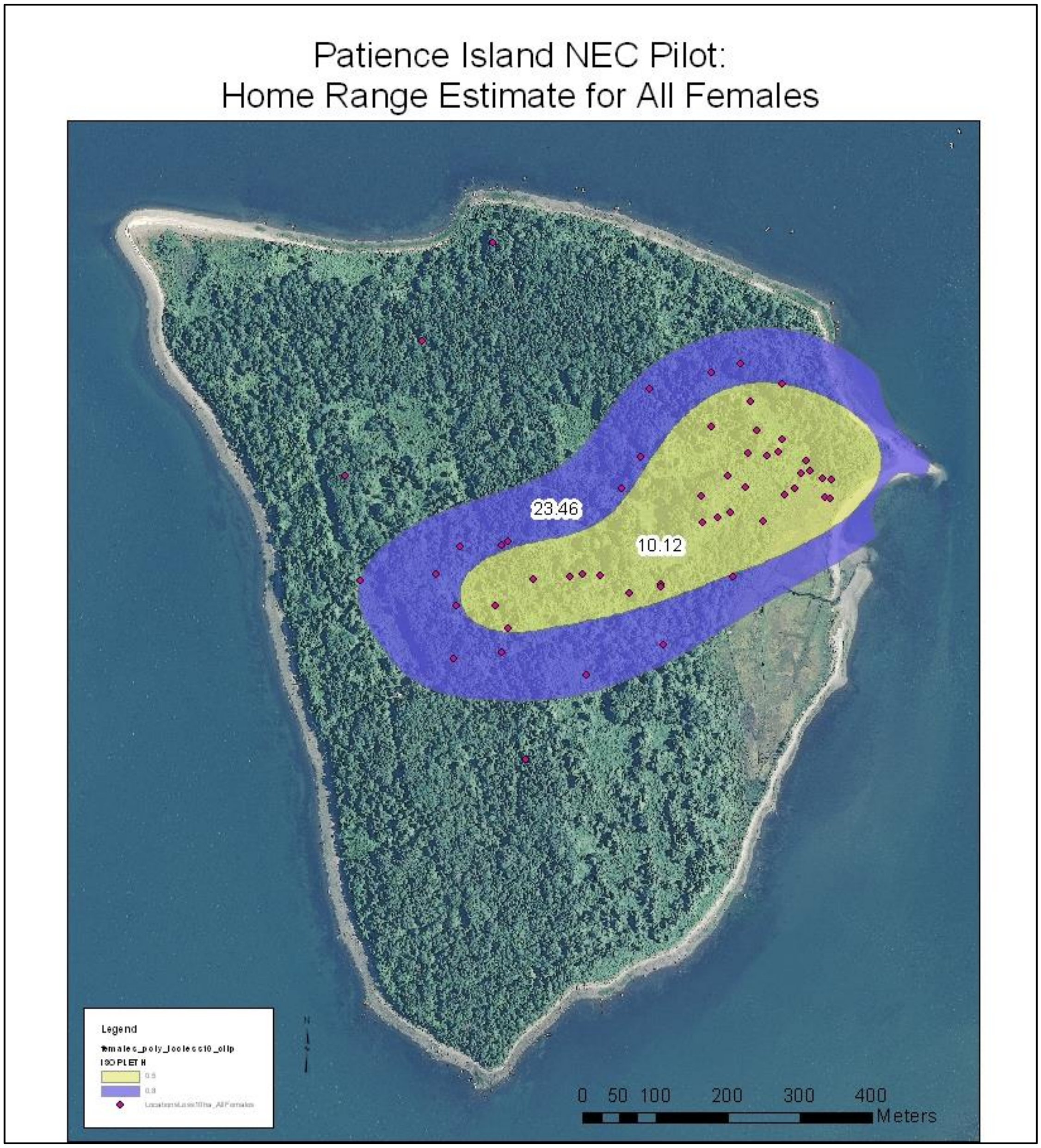
Appendix C4. Home range estimate (80% contour) and core use area estimate (50% contour) for a male NEC with radio frequency 1.135 from 5 October, 2012 to 7 February, 2013 (n=14). Areas are shown in hectares.



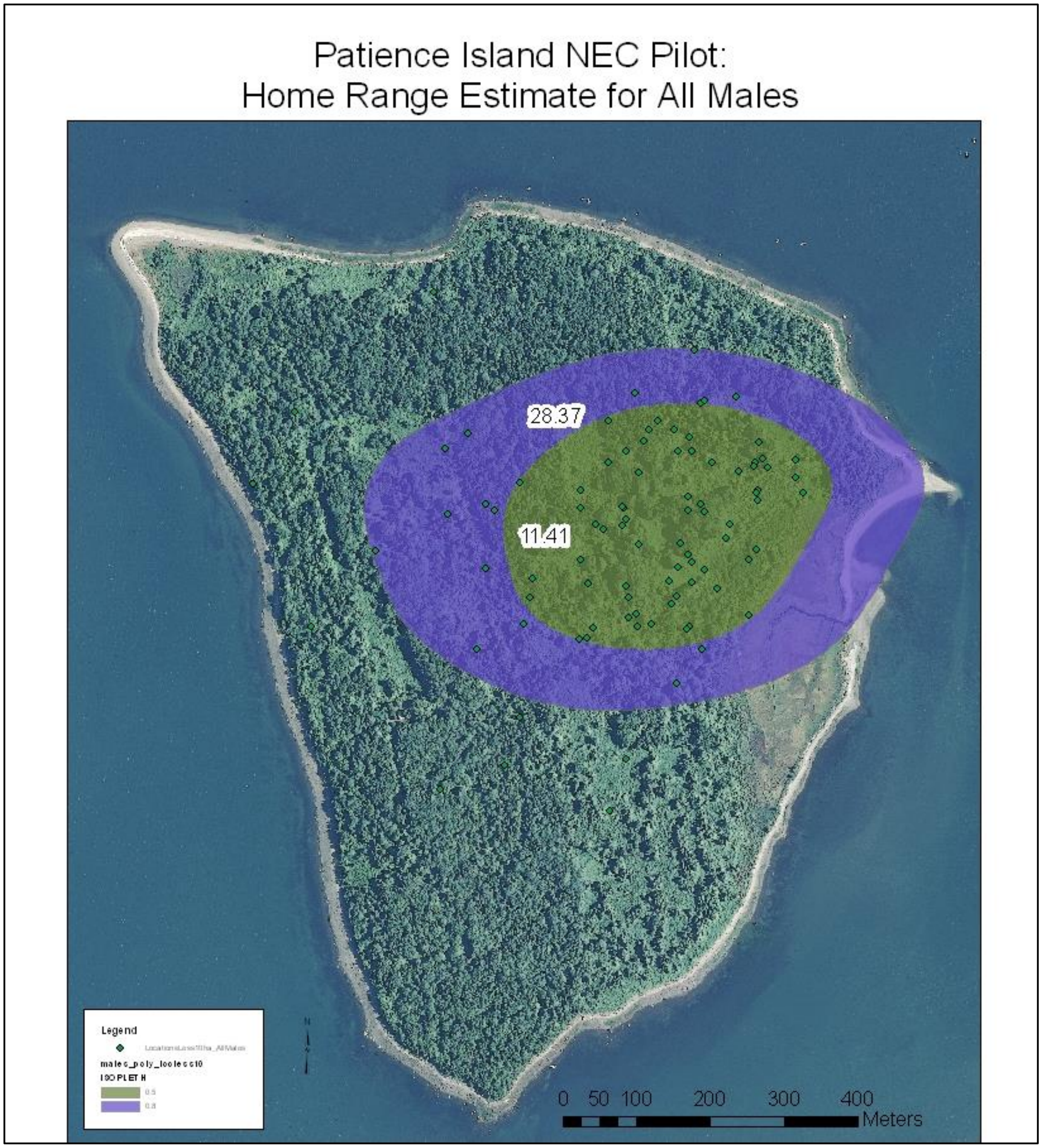
Appendix C5. Home range estimate (80% contour) and core use area estimate (50% contour) for a female NEC with radio frequency 1.153 from 1 April, 2012 to 7 February, 2013 (n=20). Areas are shown in hectares.



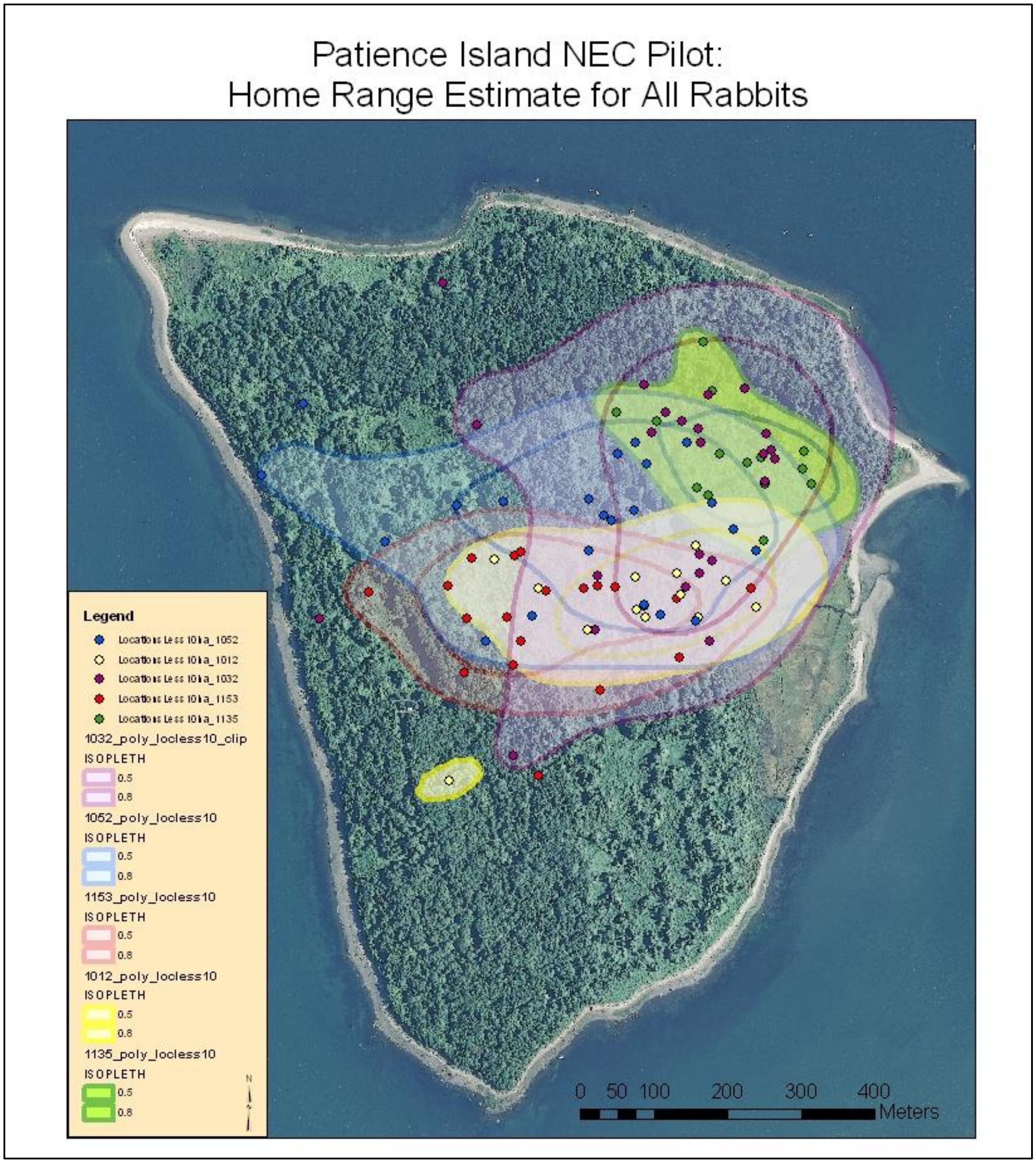
Appendix C6. Home range estimate (80% contour) and core use area estimate (50% contour) for all NEC released on Patience Island from 1 April, 2012 to 7 February, 2013 (n=146). Areas are shown in hectares.



Appendix C7. Home range estimate (80% contour) and core use area estimate (50% contour) for all female NEC released on Patience Island from 1 April, 2012 to 7 February, 2013 (n=53). Areas are shown in hectares. Home range polygon is clipped to the outline of the island provided by RIGIS.



Appendix C8. Home range estimate (80% contour) and core use area estimate (50% contour) for all male NEC released on Patience Island from 1 April, 2012 to 7 February, 2013 (n=94). Areas are shown in hectares.



Appendix C9. Home range estimates (80% contour) and core use area estimates (50% contour) for all five NEC released on Patience Island from 1 April, 2012 to 7 February, 2013.

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