National Park Service
U.S. Department of the Interior

Northeast Region
Boston, MA

An Inventory of Amphibians, Reptiles, Nonvolant Mammals, and Select Bird Species on Islands in Boston Harbor

Technical Report NPS/NER/NRTR—2007/094

ON THE COVER
Juvenile Black-crowned Night Heron in a mammal box on Sarah Island
Photograph by: Carol Lynn Trocki

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Technical Report NPS/NER/NRTR--2007/094

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U.S. Department of the Interior
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NATIONAL PARK SERVICE
Boston Harbor Islands National Recreation Area
408 Atlantic Avenue, Suite 228
Boston, Massachussets 02110-3349

October 12, 2007

The attached *Inventory of Amphibians, Reptiles, Nonvolant Mammals, and Select Bird Species on Islands in Boston Harbor* is one in a series of inventories that are being completed by the Northeast Temperate Network of the National Park Service's Inventory and Monitoring Program. It is part of a continuing effort by the National Park Service and our many partners to document the biological diversity and natural and cultural resources of the park.

The animal species that live in the park, along with their habitats, are dynamic, and no single 'snapshot' inventory such as the attached report can fully document the distribution and abundance over time of each species. It is certain that there will be additional sightings of animals in locations that are not reported here. In addition, this report focuses on 19 islands of the 34 islands and peninsular properties that comprise the park area. We are developing a process to document ongoing observations of park staff and visitors in order to continually improve our understanding and stewardship of the park.

Thank you for your interest in the biodiversity of the Boston Harbor Islands. We welcome your feedback and hope you will visit the park often to enjoy the scenery, wildlife, and history first hand. For more information on science and stewardship of the park, and to contact us, please see the park website at www.nps.gov/boha and the Northeast Temperate Network website at http://www.nature.nps.gov/im/units/netn/.

Bruce Jacobson
Superintendent

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Introduction

Boston Harbor Islands National Recreational Area (BOHA) consists of over 500 ha of coastal woodlands; dunes; freshwater, estuarine, and marine wetlands; and sandy and rocky beaches scattered over 30 glacial drumlins or bedrock outcrops within the 130 km^2 Boston Harbor (Figure 1). The Boston Harbor Islands became a unit of the national park system in November 1996 by an act of Congress (Public Law 104-333) that contains special provisions that make this a unique unit of the national park system. Rather than having the NPS own and manage lands within the park, Congress designated the NPS as a non-landowning participant in the 13-member Boston Harbor Islands Partnership (Table 1).

The 34 islands and peninsulas that comprise the BOHA are both ecologically and historically diverse. Islands range in size from 0.1 to 104.5 terrestrial hectares (Roman et al. 2005) and vary in their geologic and vegetative composition. Geologists classify many of the islands in Boston Harbor as drumlins that are composed of unconsolidated glacial till with steep cliffs, sand and gravel spits, and beaches (Rosen and Leach 1987). The park includes approximately 55 km of shoreline, most of which is currently relatively undeveloped (Roman et al. 2005).

Most of the islands have a long history of human use, and some (e.g., Thompson, Long Island, Nut Island, Little Brewster and Deer) are still occupied by various institutions. While evidence of anthropogenic alteration is present on all of the islands, the degree of influence varies greatly. Islands like Middle Brewster, Calf, Snake, Sheep, and Langlee contain habitats that have been relatively undisturbed for several decades. Other islands (Georges, Gallops, Peddocks and Lovells) exhibit evidence of historic military use and are managed for large numbers of visiting tourists. Georges Island, in particular, is the site of a historic fort surrounded by extensive lawns and contains little natural vegetation. Spectacle Island is a capped landfill that recently underwent extensive habitat restoration (a combination of grasslands and woodlands), with an emphasis on public access.

Although the BOHA is adjacent to New England's largest urban area, biologists are just beginning to inventory and monitor the flora and fauna of the region. An inventory of vascular flora in the BOHA documented 521 species in 99 plant families, with seven rare species (Elliman 2005). On many of the islands, non-native plants account for more than 50% of the total flora, and 44% of the species documented are classified as exotic (Elliman 2005). Mature forests are rare in the BOHA, and exist only on the largest islands (Peddocks and Thompson) and on Worlds End, which is a peninsula jutting from the mainland. Early successional woodlands are more common, and occur on the interior of many of the islands in the inner harbor (e.g., Grape, Bumpkin, Slate, Langlee, Ragged, Rainsford, and Lovells) as well as sections of Peddocks and Thompson. Maritime shrub communities are the most common habitat type in the park and are present on all but the smallest islands (Elliman 2005). Few freshwater wetlands exist within the park, but occur on Grape, Great Brewster, Long, Lovells, Thompson, and Worlds End.

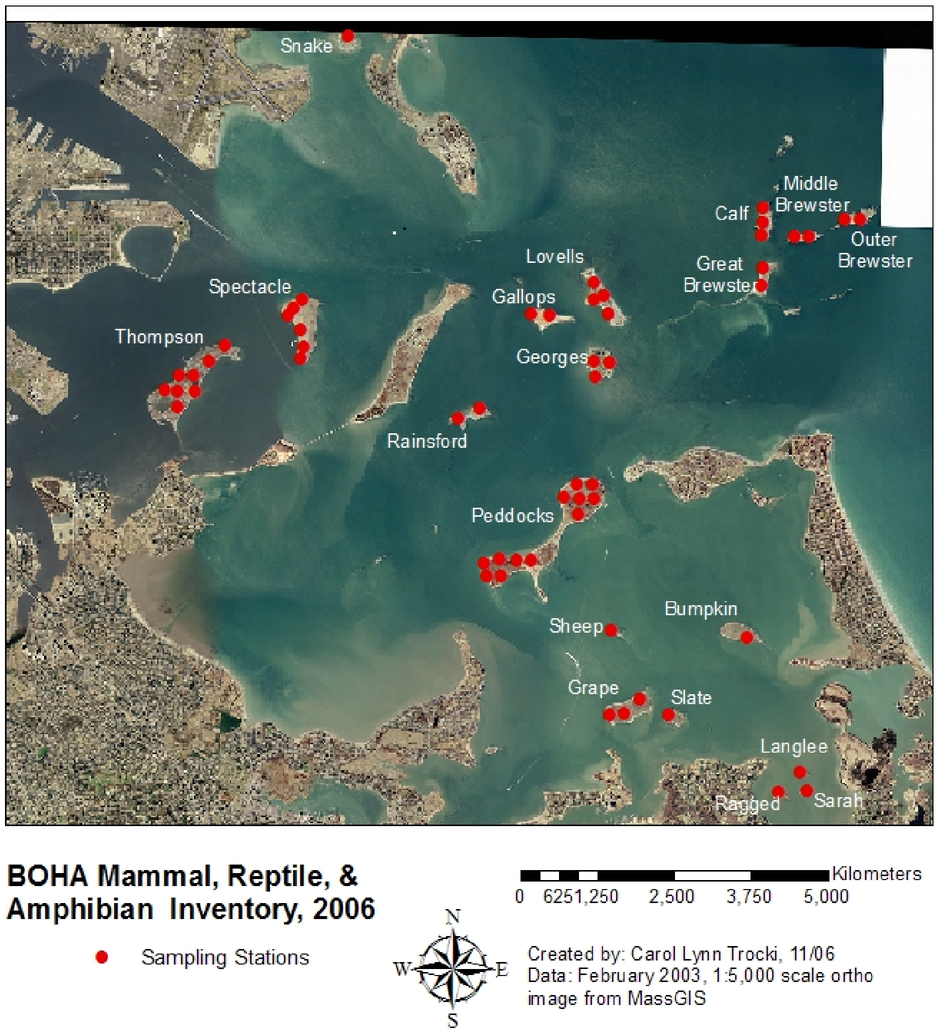

Figure 1. Sampling stations surveyed for nonvolant mammals, reptiles, and amphibians on 19 islands in the BOHA during 2006.

Table 1. Location and ownership of 33 islands within the Boston Harbor Islands National Park Area.

Island	Town	Management
Bumpkin	Hull	Massachusetts Dept. of Conservation & Recreation
Button	Hingham	Town of Hingham
Calf	Hull	Massachusetts Dept. of Conservation & Recreation
Deer	Boston	Massachusetts Water Resources Authority
Gallops	Boston	Massachusetts Dept. of Conservation & Recreation
Georges	Boston	Massachusetts Dept. of Conservation & Recreation
Grape	Weymouth	Massachusetts Dept. of Conservation & Recreation
The Graves	Hull	US Coast Guard
Great Brewster	Hull	Massachusetts Dept. of Conservation & Recreation
Green	Hull	Massachusetts Dept. of Conservation & Recreation
Hangman	Quincy	Massachusetts Dept. of Conservation & Recreation
Langlee	Hingham	Town of Hingham
Little Brewster	Hull	US Coast Guard
Little Calf	Hull	Massachusetts Dept. of Conservation & Recreation
Long	Boston	Boston Public Health Commission
Lovells	Boston	Massachusetts Dept. of Conservation & Recreation
Middle Brewster	Hull	Massachusetts Dept. of Conservation & Recreation
Moon	Quincy	Boston Public Health Commission
Nix's Mate	Boston	US Coast Guard
Nut	Quincy	Massachusetts Water Resources Authority
Outer Brewster	Hull	Massachusetts Dept. of Conservation & Recreation
Peddocks	Hull	Massachusetts Dept. of Conservation & Recreation
Raccoon	Quincy	Massachusetts Dept. of Conservation & Recreation
Ragged	Hingham	Town of Hingham
Rainsford	Boston	City of Boston
Sarah	Hingham	Town of Hingham
Shag Rocks	Hull	US Coast Guard
Sheep	Weymouth	Massachusetts Dept. of Conservation & Recreation
Slate	Weymouth	Massachusetts Dept. of Conservation & Recreation
Snake	Winthrop	Town of Winthrop
Spectacle	Boston	City of Boston / Massachusetts Dept. of Conservation & Recreation
Thompson	Boston	Outward Bound Education Center

To our knowledge, little has been published on the reptiles, amphibians, or mammals of the BOHA. One exception is a report (Cardoza 1989) summarizing the introduction of New England Cottontail (*Sylvilagus transitionalis*) from Cape Cod to Grape Island in 1985. This stocking was at least temporarily successful, as a population was present four years after the initial introduction. Ladd (1971) conducted qualitative surveys of Norway rats (*Rattus novegicus*) on islands in Boston Harbor. We know of no quantitative inventories of mammals, amphibians, or reptiles conducted on islands in Boston Harbor.

More is known about the spatial distribution and abundance of breeding birds in the BOHA. Hatch (1984) documented an increase in numbers of nesting double-crested cormorants (*Phalacrocorax auritus*) in the outer islands from 1972-1982, and Blodget and Livingston (1996) in 1994 estimated numbers of nesting pairs of coastal waterbirds (cormorants, wading birds, waterfowl, gulls, shorebirds, gulls, and terns). These estimates included 13 pairs of common eiders (*Somateria mollisma*), which were possibly descended from 175 chicks translocated from Portland, Maine to Penikese Island in the Elizabeth Island chain in southern Massachusetts between 1973 and 1976 (Stanton 1977). Alternatively, eiders could have colonized Boston Harbor from coastal Maine. In addition, a comprehensive, long-term survey of birds in Boston Harbor, the Take a Second Look (TASL) program (see http://www.gis.net/~szendeh/tasl.htm), has monitored waterbirds during winter months since 1980. Finally, from 2001-2003, an inventory of breeding landbirds and waterbirds was conducted on 26 islands and one mainland location in BOHA (Paton et al. 2005).

The primary objective of this inventory was to assist the NPS in their effort to document mammal, reptile, and amphibian species expected to be found on islands within BOHA. Due to logistical and budgetary constraints, and the lack of existing data relevant to the islands of Boston Harbor, this project was limited to islands isolated from the mainland, and did not include surveys on peninsulas on the mainland (e.g., World's End, Deer Island).

Based on our knowledge of available habitats on the islands of Boston Harbor, there are no freshwater ponds available as breeding habitat, thus we did not implement surveys designed to inventory pond-breeding amphibians. There are some mapped ponds on some islands, but all of them that we have visited are overwash areas from the Harbor, thus have salinity levels too great to support pond-breeding amphibian larvae. Hence, we conducted terrestrial surveys to assess occupancy rates of northern red-backed salamander *(Plethodon cinereus*), which was the only likely amphibian species to occur on islands in Boston Harbor.

Our inventory excluded bats and most species of small mammals (e.g., shrews, mice, voles). Visiting islands at night to survey bats would have been a logistical challenge and well beyond the financial constraints of this project. Also, more extensive surveys for small mammals were not conducted because current U.S. federal Institutional Animal Care and Use Committee (IACUC) regulations, as implemented at the University of Rhode Island, would have required us to check live traps every evening and morning and wear special protective gear to handle wild small mammals, which again was beyond the financial constraints of this project.

We considered lethal techniques to inventory amphibian, reptiles, and small mammals (snap traps, pitfall traps), but after consultations with park personnel decided non-lethal techniques were preferred. It was a goal of this project to help assist in providing data to develop a statistically sound long-term monitoring program, if park managers decide such a program is necessary. This project will assist managers in developing a better understanding of the spatial distribution patterns of mammal, reptile, and amphibian species on islands in Boston Harbor. In addition, breeding waterbird surveys were conducted in 2005 to supplement data collected during the waterbird inventory work performed by Paton et al. (2005) from 2001-2003. We have included those data here to insure they are included in a public record that will be available to biologists in the future.

Methods

2005 Pilot Study

We initially conducted mammal, reptile, and amphibian sampling on Peddocks, Spectacle, and Great Brewster Islands in June to August 2005 to ascertain the feasibility of several proposed sampling techniques, including the use of enclosed track plates, black plastic tarps, and area-time constrained searches. Based on our experience from this pilot study season, we refined the sampling techniques and conducted species inventories from March to July 2006 on 19 islands in Boston Harbor (Figure 1).

Sampling Design

With minor modifications, we used the same series of sampling points generated by Paton et al. (2005) to inventory landbirds in the BOHA. We used a GIS to overlay a 250-m grid on a map of the islands. We located sampling sites at the confluence of each grid cell and disregarded sampling points located over water. Sampling point allocation followed Geissler and McDonald (2003), which is the methodology specified for use for NPS inventory and monitoring projects (Fancy 2000). We used a systematic sampling design to ensure uniform coverage of the islands, while we introduced randomization to the sampling design so that inventory results would be defensible and statistically valid (Geissler and McDonald 2005). Since the Boston Harbor Islands are relatively small in size, the systematic sampling design we selected spread sampling points over all of the islands. Generally, sites that are distributed throughout the sampling area are more likely to detect rare species with clumped distributions (Thompson 2002).

For this inventory, we modified the landbird sampling scheme by removing sampling locations that were not suited to the mammal, reptile, or amphibian sampling techniques used in this study. In general, we did not sample locations that were within 50 meters of developed areas (e.g., homes, buildings, camp sites) because we did not want to risk vandalization of equipment or attracting domestic animals.

Sampling Sites

We navigated to sampling points using a handheld GPS (Garmin® GPSmap 765; accuracy ± 10-30 m). Once the point was located, we used three different techniques at each sampling location to document the presence of mammals, reptiles, and amphibians. At each sampling location, we established a sampling station consisting of an enclosed track plate in a wooden box (hereafter cubby box), a black plastic tarp, and a plot for area-time constrained searching (TCS). Cubby boxes were positioned at sampling locations, while the black plastic tarps and TCS sites were located 5-15 m away in random directions.

Our selection of these techniques was based on their ability to collect accurate information, their replicability, their ease of implementation, and their low costs. Due to the logistical/financial constraints of needing boats to ferry us to islands, it was critical that we used techniques that could remain in the field unchecked for at least 1 week. We also detected some species incidentally by either direct observation or by observing sign (e.g., tracks, scat) incidentally as we traversed the islands to construct and monitor the sampling stations.

Cubby Boxes

Cubby boxes were based on a design by Zielinski and Kucera (1995). We constructed track plates from 20 x 76 cm aluminum flashing. Wooden boxes were 23 cm tall x 23 cm wide x 81 cm long and made from exterior grade plywood that was held together by wood screws. One end remained open, allowing animals to enter the box, while a wooden cover was screwed to the back end of the box so that animals could access the trap from only one end. Cubby boxes could be unscrewed and collapsed for easy transportation. Track plates were covered along the lower two-thirds of one side with copier toner (Belant 2003). Clear shelf paper (30 x 20 cm) was applied with the adhesive side up to the top third of the plate, leaving about 10 cm of clean plate for the bait. Bait was placed at the end of the plate.

Bait consisted of raw chicken and a "small mammal sachet" made from rolled oats combined with peanut butter and bacon fat and folded into a brown paper towel. Predator 500 lure (Cronk's Outdoor Supplies, Wiscasset, ME) was applied to the chicken before placing it inside the cubby box. The combination of bait and lure were meant to attract as many species of mammals as possible, given the varied diets of different groups of mammals.

Mammals left tracks while accessing the bait at the far side of the cubby box from the opening by stepping on the contact sheet. Sheets were changed during station checks if tracks were present and were collected when we moved cubby boxes. Tracked contact sheets were placed in acetate sheet protectors in the field and archived for later identification. If tracks were present only on the sooted portion of the plate, they were photographed. Tracks were identified primarily using illustrations in Elbroch (2003) and Rezendes (1999).

Many medium-sized mammals have distinct tracks that can be easily identified. Difficulties may arise however within the Order Rodentia, which tend to have similar digit patterns. Species such as eastern gray squirrels and Norway rats can be distinguished by measurements of track length and width. We found the tracks of smaller rodents had a similar structure and similar size, making positive identification of these species unreliable. Based on species accounts and distributions in the region (DeGraaf and Yamasaki 2001), and on the habitat types available in the islands of Boston Harbor, it is likely that the small mammal tracks we observed were either white-footed mice or meadow voles.

Black Plastic Tarps

Cover boards are commonly used to sample snake populations in a repeatable fashion (Kjoss 2000, Kjoss and Litvaitis 2001). Cover boards potentially attract snakes by creating preferred microclimates with increased temperatures and levels of humidity. For this study, we used a modified cover board technique consisting of black plastic tarps staked to the ground (Kjoss 2000, Kjoss and Litvaitis 2001). We cut rolls of black landscape plastic into squares measuring 1.5 m on each side, and then staked corners to the ground using 2-pronged landscape staples.

We checked the black plastic tarps by lifting 2 corners of the square to check for the presence of reptiles. We captured snakes found under the plastic, identified them in the field based on visual characteristics, and released them on site. Tarps were in place at each sampling station for 2 weeks.

Quadrat-Time Constrained Searches

We primarily used quadrat-time constrained searches (TCS) for amphibian species, although the searches could also detect the presence of reptiles, small mammals, or other animal sign, such as scat, owl pellets, or mammal bones. We used small 4-pronged garden cultivators to search 5 x 5 m sampling plots for up to 15 minutes, with two observers searching each plot simultaneously. We selected an intermediate plot size (25 m^2) because smaller plots (1 X 1 m) were recommended for one of our target species, a plethodon salamander, while larger plots (8 X 8 m) are for larger ranging amphibians (Jaeger and Inger 1994). We used the cultivators by gently raking leaves, sticks, debris, and loose soil to expose amphibians. Species found were identified by sight and photographed if stationary.

After we conducted TCS on a small number of islands, it became apparent that 15 minute sampling intervals were too lengthy. We altered the original protocol by searching until we determined the entire area had been thoroughly searched. Depending on the type of vegetation present in the sampling area, the amount of time necessary for searching could be reduced to < 5 minutes. Sites with thick grasses were the most difficult to search and frequently took up to 15 minutes.

Remote Cameras

We used remote-triggered cameras (DeerCam Model CD300) as an auxiliary method to detect the presence of medium to large mammal species. Cameras were restricted to taking pictures of larger animals (at least as large as skunk) because of the lack of sensitivity of the devices. Cameras were not set up as part of the sampling stations, but rather positioned in areas likely to be used by medium to large mammals. We only used cameras in 2 locations.

Waterbird Monitoring 2005

In 2005, we counted the number of waterbird nests during surveys on 11 islands with known waterbird nesting colonies (Paton et al. 2005). Incubating cormorants and gulls were counted by boat on the outer islands (Calf, Little Calf, Green, Middle Brewster, Outer Brewster, and Shag Rocks), whereas we conducted walking surveys on Calf, Middle Brewster, and Outer Brewster Islands to search for common eider nests. We surveyed nests of wading bird colonies on Sarah, Sheep, Calf, Middle Brewster and Outer Brewster Islands throughout the summer, and also surveyed tern colonies on Rainsford, Lovells, and Snake Islands.

Data Management

All data was stored in a Microsoft Excel workbook that was later imported into a Microsoft Access database. All hard copies of data sheets and contact sheets (with mammal tracks) were retained. Digital photographs were downloaded and labeled by island, station number, and date.

Data Analysis

All analyses were based on records of presence for each species observed, according to the method of observation. Although we collected raw data at individual stations, results were summarized by island for ease of interpretation. For mammals, we present species richness for each island and the park overall. The percentage of stations on each island with detections for each species is also provided. We investigated relationships between island size and species richness with linear regression. Island size was log transformed prior to analysis. This analysis was conducted using SPSS.

For mammals inventoried with cubby boxes, we modeled probability of site occupancy (ψ) while adjusting for imperfect detectability (ρ) using recently developed statistical methods because a species may be present on an island even though it is not detected (MacKenzie et al. 2005). We used site occupancy models for this analysis because incomplete detectability of a species can cause bias using normal logistic regression analysis (Gu and Swihart 2004, Keating and Cherry 2004). Additionally, the estimate of site occupancy (Ψ) can be used as a way to monitor wildlife population trends over time; increases in occupancy rates over time suggest an increase in overall population size (MacKenzie et al. 2005). By removing the bias associated with imperfect detection of a species, the resulting estimates are more accurate and constitute a suitable metric for long-term monitoring.

To estimate the detection probability of a species, ideally one would want to sample the same sites on multiple occasions. During any given sampling occasion, a species could be present at the site and detected (ψ x ρ), present but not detected (ψ x [1-ρ]), or not present (1- ψ). We organized data gathered from the BOHA in 2006 into a capture history matrix that was summarized by island (n =19), where each species could be either detected or not detected on each of 2 site visits. For these analyses, we assumed a closed population, which is feasible given the isolated nature of the islands and the short duration of sampling visits (maximum of 2 weeks at any given station).

In addition to modeling constant site occupancy (Ψ) and detection probability (p) estimates with model $\Psi(.)$ $p(.)$, we included two site covariates to compare models that allowed site occupancy to vary with island area (area) and distance to the mainland (dist). We also included a covariate for trap effort in the models (traps). In these models, we allowed detection probability to vary by the trapping effort to control for variation caused by the unequal number of traps per island.

We created a set of candidate models estimating site occupancy and detection for each species. We used variables representing island area and distance to the mainland included as model covariates to determine the effects of these variables on species occupancy. The candidate set of models also included a covariate for the number of sampling stations on each island, which was used to determine the effects of trapping effort on the probability of detection and control for variation caused by the unequal number of traps per island. We used the information theoretic approach and Akaike's Information Criterion for small sample sizes (AIC_c) to determine the relative support for each model (Burnham and Anderson 2002). All analyses were made using program PRESENCE (J. Hines; http://www.mbr-pwrc.usgs.gov/software/presence.html).

Results

Mammal, Reptile, and Amphibian Inventory

We systematically surveyed 56 sampling stations on 19 islands in the BOHA for the presence of mammals, reptiles, and amphibians between March and July 2006 (Figure 1, Table 2; see Appendix A for detailed information on specific sampling stations). We documented at least 10 species of mammals, 3 species of snakes, and 1 salamander species (Table 3). We detected several small mammal tracks which may have been made by either meadow voles (*Microtus pennsylvanicus*) or white-footed mice (*Peromyscus leucopus*), but we confirmed the presence of white-footed mice during incidental observations on two islands. Given this uncertainty, we only confirmed white-footed mice as present on islands in Boston Harbor, therefore we list 10 confirmed mammals, but include meadow vole as a possible resident in the park.

We detected on average 2.26 ± 1.94 (SD) species per island (which includes nonvolant mammals, reptiles, and amphibians; Table 4). We detected the greatest overall species richness (7 species) on Peddocks Island (Table 4). However, detections of both eastern garter snake (*Thamnophis sirtalis sirtalis*) and northern red-backed salamander (*Plethodon cinereus*) were only made on Peddocks during the pilot study in 2005, when Peddocks was 1 of just 3 islands sampled. Of the islands comparably sampled during the 2006 season, Thompson had the highest species richness with 6 species (all mammals) detected. Of the 19 islands sampled in this inventory, three (Georges, Ragged, and Sarah) had no mammals, reptiles, or amphibians detected.

Mammals

We detected an average of 1.95 ± 1.72 (SD) mammalian taxa per island (Table 4). We detected at least 10 species of mammals in the BOHA (Table 3; Appendix B). No mammals were detected on 5 of the islands we surveyed (Georges, Langlee, Ragged, Sarah, and Slate; Table 4). Mammalian species richness on each island was low, with a mean of 1.95 ± 1.72 (SD) species per island. The greatest species richness was on the largest islands, with 5 species detected on Peddocks (74.6 ha) and 6 species detected on Thompson (54.2 ha, Table 4). The only large mammal we detected was white-tailed deer (*Odocoileus virginianus*) on Grape Island, and this was confirmed by the presence of tracks.

We detected few medium-sized carnivores on the islands: red fox (*Vulpes vulpes*) on Bumpkin and Thompson; raccoons (*Procyon lotor*) on six islands (Grape, Lovells, Peddocks, Snake, Spectacle, and Thompson); and striped skunks (*Mephitis mephitis*) on Thompson and Grape. On Lovells, raccoon prints were incidentally observed while traversing the island, but raccoons were not detected in our cubby boxes. Domestic cats (*Felis silvestris catus*) were only detected on Peddocks, where there is a small community of active homes, and thus the presence of cats was not unexpected.

Table 2. Survey effort, island area, and shortest distance to mainland for islands in the BOHA during 2006 (N=19; see Appendix A for coordinates of sampling stations).

Island	Area (ha)	Distance to Mainland (km)	Number of Stations Surveyed	Techniques[1]		
				BPT	TCS	CB
Bumpkin	12.2	0.67	1	1	1	1
Calf	7.5	3.27	3	3	3	3
Gallops	9.2	2.12	2	2	2	2
Georges	15.8	1.53	3	3	2	3*
Grape	21.9	0.49	3	3	3	3
Great Brewster	7.5	2.35	2	0	2	2
Langlee	1.8	0.53	1	1	1	1
Lovells	19.6	2.22	4	4	4	4
Middle Brewster	5.0	3.2	2	2	2	2
Outer Brewster	7.7	3.4	2	2*	2	2*
Peddocks	74.6	0.47	12	10	11	12
Ragged	1.1	0.39	1	1	1	1
Rainsford	6.6	2.61	2	2*	2	2*
Sarah	1.4	0.48	1	1	1	1
Sheep	0.4	1.89	1	0	0	1
Slate	4.8	0.64	1	1	1	1
Snake	2.9	0.36	1	1	0	1
Spectacle	34.6	1.33	6	6	6	6
Thompson	54.2	0.57	8	8	7	8

[1]BPT: Black Plastic Tarp, TCS: Time-constrained Search, CB: Cubby Box,
Note that on several islands conditions were not appropriate for the use of black tarps and time constrained searches (station fell directly on beach, disappearance of tarps between station checks, etc.), therefore BT and TCS numbers are less than the number of stations surveyed in some cases.
*one of the stations was checked only once, equipment missing.

Table 3. Mammal, reptile, and amphibian species detected on 19 islands in the BOHA during the pilot study in 2005 and inventory conducted in 2006.

Species	Scientific Classification	4-Letter Code
Mammals		
Belgian hare	*Oryctolagus cuniculus*	ORCU
domestic cat	*Felis silvestris catus*	FEDO
eastern gray squirrel	*Sciurus carolinensis*	SCCA
meadow vole[1]	*Microtus pennsylvanicus*	MIPE
Muskrat	*Ondatra zibethicus*	ONZI
Norway rat	*Rattus norvegicus*	RANO
Raccoon	*Procyon lotor*	PRLO
red fox	*Vulpes vulpes*	VUVU
striped skunk	*Mephitis mephitis*	MEME
white-footed mouse	*Peromyscus leucopus*	PELE
white-tailed deer	*Odocoileus virginianus*	ODVI
Reptiles		
eastern smooth green snake	*Liochlorophis vernalis*	LIVE
eastern garter snake	*Thamnophis sirtalis sirtalis*	THSA
northern brown snake	*Storeria dekayi dekayi*	STDE
Amphibians		
northern redbacked salamander	*Plethodon cinereus*	PLCI

[1]small mammal tracks may belong to either *Microtus pennsylvanicus* or *Peromyscus leucopus*; only *Peromyscus leucopus* was confirmed through incidental direct observation

Table 4. Summary of species richness on 19 islands in the BOHA during pilot study in 2005 and inventory in 2006; summary of species[1] detections by station in 2006.

Island	Overall Species Richness 2005-06	Mammal Species Richness 2005-06	Stations Sampled (2006)	Mammals (% stations detected, 2006)											Reptiles (% stations detected)			Amphibians (% stations detected)
				ORCU	FEDO	SCCA	MIPE	ONZI	RANO	PRLO	VUVU	MEME	PELE	ODVI	LIVE	THSA	STDE	PLCI
Bumpkin	3	3	1	-	-	-	100	-	-	-	-	-	100	-	0	0	0	0
Calf	2	2	3	-	-	-	-	-	33	-	-	-	-	-	0	0	0	0
Gallops	1	1	2	100	-	-	-	-	-	-	-	-	-	-	0	0	0	0
Georges	0	0	3	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
Grape	4	3	3	-	-	-	-	-	-	33	-	100	-	-	33	0	0	0
Great Brewster	3	3	2	-	-	-	-	-	50	-	-	-	-	-	0	0	0	0
Langlee	1	0	1	-	-	-	-	-	-	-	-	-	-	-	0	0	0	100
Lovells	3	3	4	25	-	-	-	-	25	-	-	-	-	-	0	0	0	0
Middle Brewster	4	3	2	50	-	-	-	-	50	-	-	-	-	-	0	0	50	0
Outer Brewster	2	2	2	-	-	-	-	-	50	-	-	-	-	-	0	0	0	0
Peddocks	7	5	12	-	8	-	33	-	42	67	-	-	33	-	0	33	0	0
Ragged	0	0	1	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
Rainsford	2	2	2	-	-	-	100	-	-	-	-	-	100	-	0	0	0	0
Sarah	0	0	1	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
Sheep	1	1	1	-	-	-	-	-	100	-	-	-	-	-	0	0	0	0
Slate	1	0	1	-	-	-	-	-	-	-	-	-	-	-	0	100	0	0
Snake	2	2	1	-	-	-	-	-	100	100	-	-	-	-	0	0	0	0
Spectacle	1	1	6	-	-	-	-	-	-	100	-	-	-	-	0	0	0	0
Thompson	6	6	8	-	-	13	13	-	-	50	-	100	13	-	0	0	0	0

[1]unable to discriminate between the tracks of MIPE and PELE

We detected Belgian hares (*Oryctolagus cuniculus*) on Gallops, Lovells, and Middle Brewster Islands by the presence of copious scat and den sites, and through the direct observation of multiple individuals. We examined lagomorph skulls found during time-constrained searches and identified the species as Belgian hare using published keys (Blair et al. 1968, Martin et al. 2001) and comparison to a reference collection. For more information regarding the Belgian hare see Cardoza (1988).

Muskrats (*Ondata zibethicus*) were detected on four of the Outer Islands (Calf, Great Brewster, Middle Brewster, and Outer Brewster) by the observation of scat and den sites. Although we used bait made with peanut butter and oats that we thought might attract herbivores and small mammals, neither Belgian hares nor muskrats were ever detected in cubby boxes.

Norway rats were the most widely distributed species, and were detected with cubby boxes on 8 (42%) of the islands sampled (Table 5). Small mammal tracks belonging to either white-footed mice or meadow voles were detected in cubby boxes on four islands, but white-footed mice were directly observed under black tarps on Peddocks and Great Brewster (Table 5). Eastern gray squirrel tracks (*Sciurus carolinensis*) were observed in a cubby box on Thompson Island.

There was a positive relationship between island area and overall species richness (Overall species richness = 0.383 + 2.182 (log area); $F_{1,17}$ = 13.1, P = 0.002, R^2 = 0.66; Figure 2a) and species richness of mammals (Number of mammal species = 0.283 + 1.931 (log area); $F_{1,17}$ = 13.3, P = 0.002, R^2 = 0.65; Figure 2b; Table 6). Island area appeared to more important than distance from the mainland in predicting species richness patterns, either for overall species richness or mammalian species richness on islands in Boston Harbor.

For raccoons, we found very strong evidence that site occupancy should be modeled to include both distance to the mainland and island area, when detection probability was modeled as a function of number of traps on an island, with the best model at least 13 times more likely than other models, and with the second ranked model having a ΔAIC_c >5 (Table 7). According to the best model, raccoons were much less likely to occur on islands farther from the mainland ($\beta_{\text{distance to mainland}}$ = -6.17; SE = 4.36) and occupancy rates were positively related to island area ($\beta_{\text{island area}}$ = 0.35; SE = 0.24). It was less clear which covariates affected the spatial distribution of Norway rats among islands in Boston Harbor, with 4 models including distance to mainland (modeled averaged: $\beta_{\text{distance to mainland}}$ = -1.46; SE = 4.53), island area (model averaged: $\beta_{\text{island area}}$ = 0.55; SE = 0.70), and constant occupancy probabilities having substantial weight, with constant detection probabilities (Table 7).

Small mammals (either white-footed mice or meadow vole based only on tracks) were different from other groups we detected with cubby boxes; their detection probabilities increased dramatically from the first trapping session (P = 0.08) to second trapping session (0.56; Table 8), which suggests these animals might have become 'trap happy' and learned to find food in the traps. Striped skunks were less likely to occur on islands farther from the mainland, although the relationship was weaker than for raccoons ($\beta_{\text{distance to mainland}}$ = -1.79; SE = 0.68), and as with raccoons, detection probabilities were a function of number of traps on the island. We estimated occupancy rates for these four mammalian taxa on individual islands, with fairly close agreement between models and actual detections (Table 8).

Table 5. Summary of species detections by method[1] on 19 islands in the BOHA during pilot study in 2005 and inventory in 2006.

Island	Mammals											Reptiles			Amphibians
	ORCU[2]	FEDO	SCCA	MIPE	ONZI	RANO	PRLO	VUVU	MEME	PELE	ODVI	LIVE	THSA	STDE	PLCI
Bumpkin	-	-	-	CB[4]	-	-	-	SO?	-	CB[4]	-	-	-	-	-
Calf	-	-	-	-	SO	CB	-	-	-	-	-	-	-	-	-
Gallops	TCS, DO, SO	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Georges	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grape	-	-	-	-	-	-	CB	-	CB	-	SO	BT	-	-	-
Great Brewster	-	-	-	-	SO	CB, SO	-	-	-	DO[3], BT*	-	-	-	-	-
Langlee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	TCS
Lovells	TCS, DO, SO	-	-	-	-	CB	SO	-	-	-	-	-	-	-	-
Middle Brewster	TCS, DO	-	-	-	SO	CB	-	-	-	-	-	-	-	BT, DO	-
Outer Brewster	-	-	-	-	SO	CB	-	-	-	-	-	-	-	-	-
Peddocks	-	CB	-	CB[4]	-	CB	CB, SO	-	-	DO, BT[3], CB[4]	-	-	BT*	-	TCS[3]
Ragged	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rainsford	-	-	-	CB[4]*	-	-	-	-	-	CB[4]	-	-	-	-	-
Sarah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sheep	-	-	-	-	-	CB	-	-	-	-	-	-	-	-	-
Slate	-	-	-	-	-	-	-	-	-	-	-	-	BT	-	-
Snake	-	-	-	-	-	CB	CB	-	-	-	-	-	-	-	-
Spectacle	-	-	-	-	-	-	CB	-	-	-	-	-	-	-	-
Thompson	-	-	CB	CB[4]	-	-	CB	SO	CB, SO	CB[4]	-	-	-	-	-

[1]detection method: DO – incidental direct observation, SO – sign observed, CB – cubby box tracks, BT – black tarps, TCS – time constrained searches
[2]species codes: see Table 3
[3]detection occurred exclusively in 2005
[4]unable to discriminate between the tracks of MIPE and PELE

Table 6. Results of linear regression analyses investigating relationships between species richness and island area and distance to mainland for overall species richness (i.e., number of reptiles, amphibians, and nonvolant mammals) and mammalian species richness on islands in Boston Harbor.

Model	**df**	**F**	***P***	**R^2**	**Adj R^2**
Overall species richness = distance + log area	2,16	12.3	0.001	12.3	0.001
Mammal species richness = distance + log area	2,16	10.3	0.001	10.3	0.001
Coefficients					
Overall species richness = distance + log area	β	SE	t	*P*	
Constant	0.563	0.629	0.89	0.384	
Log Area	0.080	0.016	4.95	<0.001	
Distance	0.324	0.289	1.12	0.280	
Mammal species richness = distance + log area	β	SE	t	*P*	
Constant	0.291	0.586	0.497	0.626	
Log Area	0.068	0.015	4.533	<0.001	
Distance	0.414	0.269	1.536	0.144	

Table 7. Summary of model selection procedures for occupancy (*Ψ*) and detection (*p*) probabilities for the most frequently detected mammal species on 19 islands in the BOHA, 2006.

Raccoon *(Procyon lotor)*

Model[1]	AIC_c	Δ AIC_c	AIC_c Weight	Model Likelihood	No. Parameters
Ψ(distance, area)*p*(traps)	36.1	0.0	0.78	1.00	3
Ψ(distance)*p*(trap)	41.2	5.2	0.06	0.08	2
Ψ(area)*p*(trap)	41.5	5.4	0.05	0.07	2
Ψ(.)*p*(session)	41.7	5.6	0.05	0.06	3
Ψ(.)*p*(traps)	42.9	6.8	0.02	0.03	2
Ψ(.)*p*(.)	43.1	7.1	0.03	0.03	2

Norway rat *(Rattus norvegicus)*

Model	AIC_c	Δ AIC_c	AIC_c Weight	Model Likelihood	No. Parameters
Ψ(distance)*p*(.)	81.8	0.00	0.32	1.00	2
Ψ(.)*p*(.)	82.6	0.82	0.21	0.66	2
Ψ(area)*p*(.)	82.9	1.13	0.18	0.57	2
Ψ(distance, area)*p*(.)	83.5	1.72	0.14	0.42	3
Ψ(.)*p*(session)	84.5	2.71	0.08	0.26	3
Ψ(.)*p*(trap)	85.2	3.42	0.06	0.18	3

Small mammals

Model	AIC_c	Δ AIC_c	AIC_c Weight	Model Likelihood	No. Parameters
Ψ(distance)*p*(session)	52.4	0.00	0.38	1.00	3
Ψ(.)*p*(session)	52.9	0.51	0.30	0.77	3
Ψ(distance, area)*p*(session)	54.3	1.92	0.15	0.38	4
Ψ(area)*p*(session)	54.6	2.26	0.12	0.32	3
Ψ(distance)*p*(traps)	57.9	5.61	0.02	0.06	2
Ψ(.)*p*(.)	59.3	6.95	0.01	0.03	2

Striped Skunk *(Mephitis mephitis)*

Model	AIC_c	Δ AIC_c	AIC_c Weight	Model Likelihood	No. Parameters
Ψ(distance)*p*(.)	67.1	0.00	0.47	1.00	2
Ψ(distance)*p*(trap)	67.5	0.45	0.38	0.80	2
Ψ(distance, area)*p*(trap)	69.5	2.38	0.15	0.30	3
Ψ(.)*p*(trap)	77.6	10.53	0.002	0.005	2
Ψ(.)*p*(.)	78.0	10.9	0.002	0.004	2
Ψ(area)*p*(trap)	85.1	18.0	0.001	0.001	2

[1]Abbreviations for models: dist = distance to mainland; area = area of island; session = first and second trapping session

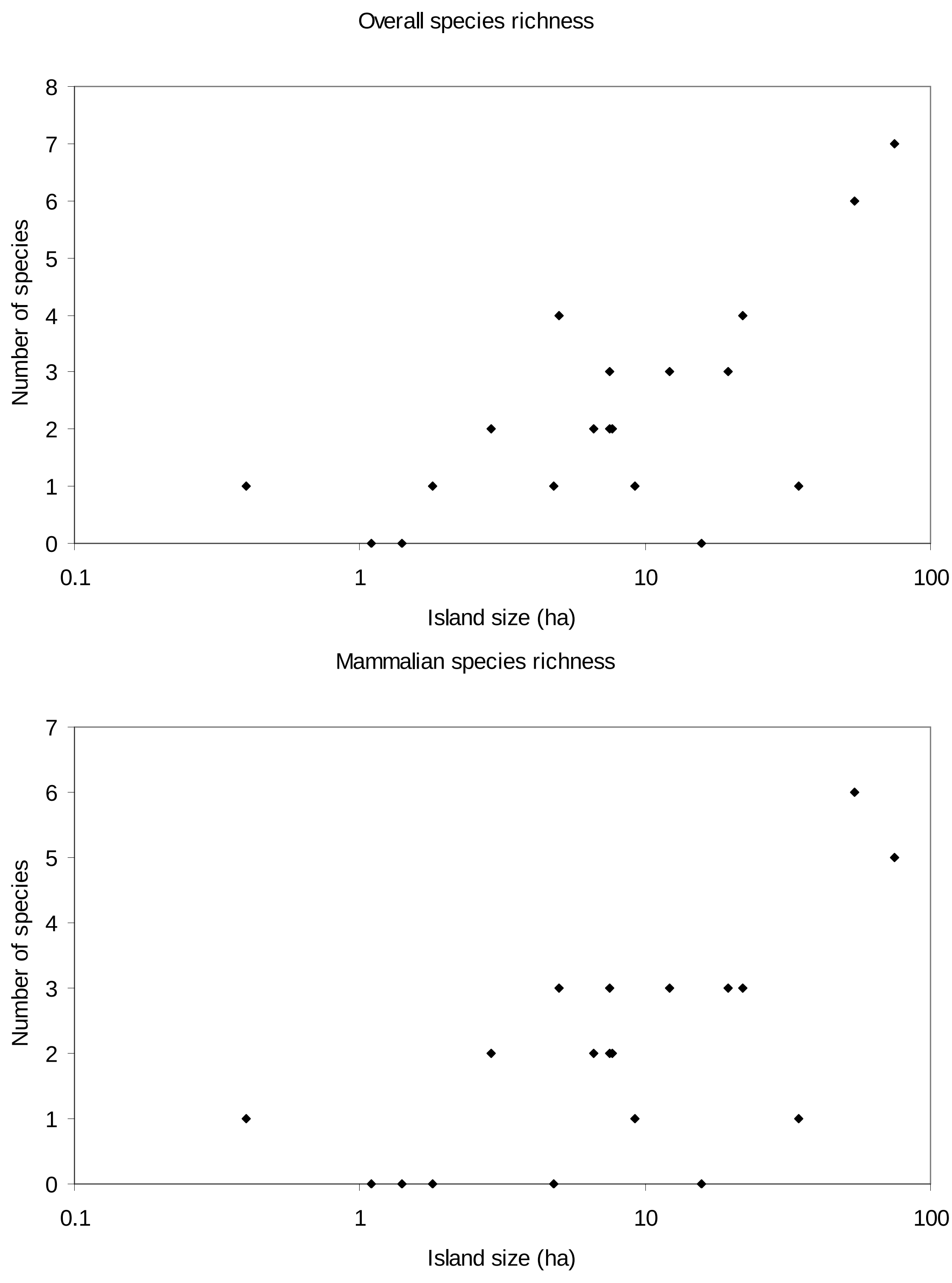

Figure 2. Relationship between species richness and island size on islands in the BOHA; (a) overall species richness of amphibians, reptiles, and nonvolant mammals, and (b) nonvolant mammals.

Table 8. Parameter estimates for occupancy probabilities (*Ψ*) for raccoons, Norway rats, striped skunks, and small mammals on 19 islands in Boston Harbor based on model averaging of best models presented in Table 6. Islands in **boldface** = species was detected on island. Also shown are detection probabilities (p) for either model p(.) or p(session) based on best models in Table 6.

Island	**Raccoon**		**Norway Rat**		**Striped Skunk**		**Small mammals**	
	Ψ	**SE**	***Ψ***	**SE**	***Ψ***	**SE**	***Ψ***	**SE**
Bumpkin	0.55	0.28	0.63	0.15	0.24	0.07	**0.33**	**0.09**
Calf	0.00	0.00	**0.89**	**0.25**	<0.01	<0.01	0.03	0.06
Gallops	<0.01	<0.01	0.81	0.27	0.02	0.03	0.1	0.12
Georges	0.22	0.08	0.75	0.25	0.06	0.06	0.16	0.13
Grape	**0.99**	**0.03**	0.63	0.16	**0.31**	**0.06**	0.37	0.07
Great Brewster	0.00	<0.01	**0.83**	**0.27**	0.01	0.02	0.08	0.11
Langlee	0.07	0.12	0.59	0.1	0.28	0.07	0.36	0.08
Lovells	<0.01	0.01	**0.83**	**0.27**	0.02	0.03	0.09	0.11
Middle Brewster	0.00	0.00	**0.89**	**0.26**	<0.01	<0.01	0.03	0.06
Outer Brewster	0.00	0.00	**0.90**	**0.24**	<0.01	<0.01	0.03	0.06
Peddocks	**1.00**	**<0.01**	**0.74**	**0.34**	0.38	0.13	**0.38**	**0.07**
Ragged	0.12	0.15	0.56	0.08	0.33	0.06	0.4	0.06
Rainsford	0.00	0.00	0.85	0.27	0.01	0.01	**0.06**	**0.09**
Sarah	0.08	0.13	0.59	0.09	0.30	0.07	0.38	0.07
Sheep	0.00	<0.01	**0.77**	**0.27**	0.03	0.04	0.12	0.13
Slate	0.10	0.16	0.61	0.13	0.24	0.07	0.34	0.09
Snake	**0.24**	**0.17**	**0.56**	**0.07**	0.37	0.05	0.41	0.06
Spectacle	**0.98**	**0.06**	0.77	0.26	0.10	0.07	0.2	0.13
Thompson	**1.00**	**<0.01**	0.71	0.28	**0.32**	**0.09**	**0.35**	**0.08**
p(.) or p(session1)	0.30	0.08	0.17	0.07	0.78	0.10	0.08	0.08
p(session2)	0.63	0.08					0.56	0.28

Reptiles

Mean snake species richness was 0.21 ± 0.42 (SD) snake species per island. Snakes were detected on only four islands (Peddocks, Grape, Slate, and Middle Brewster) and no island had more than one species. Eastern smooth green snake (*Liochlorophis vernalis*) was detected on Grape Island, eastern garter snakes (*Thamnophis sirtalis sirtalis*) were detected on Peddocks and Slate Islands, and northern brown snake (*Storeria dekayi dekayi)* was detected on Middle Brewster Island. In addition, Paton (unpublished data) observed a northern brown snake on Grape in 2003.

Amphibians

We detected only one species of amphibian, the northern red-backed salamander, on only Peddocks and Langlee Islands. Thus overall amphibian species richness averaged 0.11 ± 0.32 (SD) species per island, with islands with amphibians averaging one species.

Comparison of Techniques

Of the survey techniques employed, cubby boxes were productive at detecting mammals, with seven mammal species detected on 13 islands (68%). Black tarps detected three snake species on four islands (21%). Time constrained searches resulted in the detection of northern red-backed salamanders, which were not detected through any other method. Time constrained searches also revealed lagomorph skulls on Gallops and Lovells Islands, which provided the evidence necessary to identify these animals as Belgian hares. No species were detected with remote-triggered cameras on either Thompson or Grape Islands.

Waterbird Monitoring

We detected 13 species of waterbirds on 12 islands in 2005 (Tables 9 and 10). The most abundant species was double-crested cormorant, with approximately 1,000 nesting pairs located on eight islands. Herring gulls (*Larus argentatus*, 213 nests on 6 islands) and great black-backed gulls (*Larus marinus*, 24 nests on 6 islands) were relatively widespread, with many birds nesting on the outer islands. The most abundant and widespread heron we detected was black-crowned night-heron (*Nycticorax nycticorax*) with 50 nesting pairs on 5 islands. However, we did not survey the colony on Sarah Island during the peak of the nesting season, so we possibly underestimated the total number of nests. Least terns (*Sterna antillarum*), a state threatened species, were detected nesting on Rainsford and Lovells, with approximately 90 nesting pairs in 2005.

Table 9. Waterbird species detected during surveys in the BOHA.

Species Name	Scientific Name	4-Letter Code
Double-crested Cormorant	*Phalacrocorax auritus*	DCCO
Great Egret	*Ardea alba*	GREG
Snowy Egret	*Egretta thula*	SNEG
Little Blue Heron	*Egretta caerulea*	LBHE
Black-crowned Night-heron	*Nycticorax nycticorax*	BCNH
Glossy Ibis	*Plegadis falcinellus*	GLIB
Canada Goose	*Branta canadensis*	CAGO
Common Eider	*Somateria mollissima*	COEI
American Oystercatcher	*Haematopus palliatus*	AMOY
Herring Gull	*Larus argentatus*	HERG
Great Black-backed Gull	*Larus marinus*	GBBG
Common Tern	*Sterna hirundo*	COTE
Least Tern	*Sterna antillarum*	LETE

Table 10. Estimated number of nests of waterbirds on select islands in the BOHA in 2005 (Numbers indicate total number of nests; 4-letter species codes given in Table 6).

Island	Survey Type	Species Detected												
		DCCO	**GREG**	**SNEG**	**LBHE**	**BCNH**	**GLIB**	**CAGO**	**COEI**	**AMOY**	**HEGU**	**GBBG**	**COTE**	**LETE**
Calf	walking and boat survey	20	0	0	0	15	2	0	23	1	18	1	0	0
Green	boat survey only	51	0	0	0	0	0	8	0	0	3	7	0	0
Little Brewster	boat survey only	0	0	0	0	0	0	0	0	0	0	0	0	0
Little Calf	boat survey only	185	0	0	0	0	0	0	0	0	11	6	0	0
Lovell's	walking / tern survey	0	0	0	0	0	0	0	0	0	0	0	0	52
Middle Brewster	walking and boat survey	473	0	0	0	21	1	0	8	1	39	1	0	0
Outer Brewster	walking and boat survey	51	0	8	1	3	0	1	0	0	34	6	0	0
Rainsford	walking / tern survey	0	0	0	0	0	0	0	0	1	0	0	0	39
Sarah	walking and boat survey	63	[1]	[1]	[1]	[1]	0	0	0	0	0	0	0	0
Shag Rocks	boat survey only	119	0	0	0	0	0	0	0	0	0	0	0	0
Sheep	walking and boat survey	12	0	19	0	11	5	0	0	2	108	3	0	0
Snake	walking / tern survey	0	0	0	0	0	0	0	0	2	0	0	8	0
	Total number of nests	**974**	**0**	**27**	**1**	**50**	**8**	**9**	**31**	**7**	**213**	**24**	**8**	**91**
	Total number of islands	**8**	**1**	**3**	**2**	**5**	**3**	**2**	**2**	**5**	**6**	**6**	**1**	**2**

[1]Island not sampled for nests of this species in 2005, but adults observed present

Discussion

Our inventory documented relatively few species of mammals (10 species), amphibians (1 species), or reptiles (3 species) on islands in Boston Harbor. This was not unexpected, as all of the islands were small (maximum < 100 ha; Table 1), vegetation was dominated by invasive species, woodlands were relatively young, and there has been considerable human disturbance (Elliman 2005). Species richness of forest-dwelling small mammals generally increases with area and is highest in continuous forest sites (Nupp and Swihart 2000), so we did not expect high diversity in the BOHA.

Mammals

Mammalian communities on islands in Boston Harbor are depauperate compared to the mainland populations. There are approximately 121 mammal species (91 species if you exclude bats) in eastern North America (Whitaker and Hamilton 1998) and 64 mammal species (54 species excluding bats) in New England (DeGraaf and Yamasaki 2001), yet we detected only 10 species on the islands we surveyed. Of the 10 species detected, all but the non-native Belgian hare are common and widespread in the region (DeGraaf and Yamasaki 2001).

Only one large mammal, the white-tailed deer, was detected, and only on Grape Island, which is less that 0.5 km from the mainland. Deer are strong swimmers (Stewart 1971, Schemnitz 1975, Whitaker and Hamilton 1998), thus it is somewhat surprising that this species is not more widespread on the islands. Although our techniques were not specifically targeting deer, in areas where they exist tracks and scat are generally prevalent, so it seems unlikely that deer were using the islands and not detected.

We detected four species of medium-sized carnivore (domestic cat, red fox, striped skunk, and raccoon). Domestic cats are common in areas of human habitation, and would be reasonably expected on any of the islands regularly inhabited by people during the time of sampling. Red fox are omnivorous and use a variety of habitats, but generally occupy territories > 60 ha (Whitaker and Hamilton 1998), making many of the islands in Boston Harbor unsuitable for permanent territories.

We documented skunks at all of the cubby boxes on Grape and Thompson Islands (Table 4), which are both relatively close to the mainland when compared to other islands in the archipelago. Skunks prefer early successional habitat types with fields, forest openings, and habitat edges (Rosatte 1987), which are found on both of these islands. Skunks feed extensively on insects associated with grassland habitats (Rosatte 1987), but population densities can be higher in urban compared to rural areas (Ray 2000). It is unlikely that striped skunks would be able to colonize islands as easily as white-tailed deer, raccoons, or coyotes, which are more efficient swimmers, but skunks are frequently relocated by humans and may have reached the islands in that manner.

Although raccoons are thought to be strong swimmers and widespread throughout the region (Whitaker and Hamilton 1998, Gehrt 2003), they have a somewhat limited distribution on islands in Boston Harbor, with the species primarily found on islands closer to the mainland. Population increases since the 1940's have resulted in 15- to 20-fold increases in abundance in the northeast (Ray 2000). Since raccoons are common to urban areas (Ray 2000, Oehler and Litvaitis 1996) and efficient at exploiting anthropogenic resources (Prange and Gehrt 2004), it is not unusual that they occur on the nearby harbor islands. Raccoons are usually associated with some type of water resource, but are adaptable to a wide variety of conditions (Sanderson 1987). Interestingly, mainland populations of raccoons are most active during the nighttime, but coastal populations tend to become active during low tide and inactive during high tide as receding tidal waters expose food items such as crustaceans and mollusks (Sanderson 1987). Our results suggest it unlikely that raccoons will colonize the outer island, where they could impact waterbird nesting populations. This information could be an aid to managers seeking to promote sensitive avifauna, as raccoons are known to be efficient nest predators (Heske 1995, Chalfoun et al. 2002, Gehrt 2003).

Gilbert et al. (2007) surveyed medium-sized mammal communities in 10 National Parks throughout northeastern North America. As a collaborative effort, Talancy (2005) modeled occupancy and detection probabilities of 10 mammal species at 8 of these parks against landscape and vegetative characteristics. Raccoons were the most detectable species during Talancy's fieldwork, with raccoon detection probabilities for 3-day sampling intervals equal to 0.41 (95% CI [0.36 – 0.46]). Our estimates of detection probability in the BOHA were similar to Talancy's estimates during the first trapping period (0.30; SE = 0.08; Table 8), while detection probabilities increased during the second trapping session (0.63; SE = 0.8), suggesting that raccoons might have become 'trap happy' on islands in Boston Harbor. A low detection probability means that it is more difficult to estimate species occupancy, and inventory projects that focus on species with low detection probabilities should either sample for longer periods of time or increase the number of sampling locations (MacKenzie and Royle 2005).

The theory of island biogeography predicts that there will be greater species richness on larger islands closer to mainland source populations (MacArthur and Wilson 1967). For a given species, this translates into a hypothesis that distance from the mainland and island area should be important predictors of occupancy. Our modeling results suggest that island area and not distance from the mainland was most important in predicting mammalian species richness on islands in Boston Harbor, although larger islands closer to the mainland had a greater likelihood of occupancy. Lomolino (1994) also reported that island isolation, strong currents, and instability of ice-cover impeded immigration rates of mammals on archipelagoes in Lake Huron, Michigan. Because of the anthropogenic influences in Boston Harbor, some species with inadequate dispersal capabilities may have been transported to islands intentionally or unintentionally, which may explain why distance from the mainland did not appear to be important in explaining the spatial patterns we observed.

Because Norway rats often travel by boat to colonize islands, our results were not surprising, as we had only weak evidence that their distribution was affected by either island area or distance from the mainland (see also Ladd 1971). Human aided dispersal of organisms in Boston Harbor, whether intentional or accidental, could alter the dynamics between island size, distance to the mainland, and species richness.

Both muskrats and Belgian hares were detected on a number of islands in the BOHA by direct observation and the presence of sign. These herbivores were not adequately sampled with the techniques used in this inventory, but we are confident that they were detected on the islands where present in reasonable numbers.

We did not find any evidence of lagomorph species occurring on Grape Island, though New England cottontails have been documented on Grape as recently as 1989 (Cardoza 1989). During each of the visits to Grape we made an attempt to locate and collect lagomorph pellets for fecal DNA analysis. Fecal DNA analysis is an unobstrusive way to separate New England cottontail species from the more common eastern cottontails (*Sylvilagis floridanus*, Litvaitis and Litvaitis 1996). We never found lagomorph pellets to collect, but did not spend much time in the dense early successional vegetation that New England cottontails prefer. Since New England cottontails are being considered for listing under the Endangered Species Act, this species may warrant sampling efforts specifically designed to determine their presence.

Amphibians

Although there are at least 10 species of frogs and 11 species of salamanders on the adjacent mainland (http://www.mass.gov/dfwele/dfw/dfwamph.htm), the scarcity of amphibians on the islands was not surprising. There are no freshwater ponds on any of the islands that we could find that might provide breeding habitat for pond-breeding amphibians. We only detected northern red-backed salamanders on two islands (Langlee and Peddocks) that varied considerably in size, 2 ha and 74 ha, respectively. Northern red-backed salamanders are abundant habitat generalists on the mainland, thus it was surprising that this species was not more widespread on the islands we surveyed. However, we only surveyed a small fraction of each island, and northern red-backed salamanders may be more widespread that our data shows.

It is difficult to ascertain the spatial distribution of northern red-backed salamanders on islands in Boston Harbor with certainty because, although this species is completely terrestrial and common in moist woodlands, they remain buried underground during much of the year (DeGraaf and Yamasaki 2001). Thus soil composition or past land use practices on islands may be important factors determining the current spatial distribution of this species through the archipelago. Seasonal differences may also influence the results of TCS surveys. Our data show that red-backed salamanders were only captured during the summer months. Cold winter temperatures or hot dry conditions could cause populations of salamanders to burrow deeper underground, making detection more difficult (Bailey et al. 2004).

Reptiles

There are 10 species of terrestrial turtles (i.e., excluding sea turtles) and 14 species of snakes documented as occurring in Massachusetts (Degraaf and Yamaski 2001), of which we detected only three species of snakes during fieldwork on the Boston Harbor Islands.

The scarcity of turtles was not surprising. Most turtle species require wetlands for part of their annual cycle (Ernst et al. 1994), yet there are no wetlands with long hydroperiods on any of the islands. We did not detect any species of turtle in the BOHA.

The snake species we detected tend to be habitat generalists that are tolerant of anthropogenic habitat disturbance (Klemens 1993). In particular, the northern brown snake (sometimes referred to as DeKay's brownsnake) and eastern garter snake are widespread and common on the mainland (DeGraaf and Yamaski 2001). The eastern smooth green snake, detected on Grape Island, is common but declining in southern New England (DeGraaf and Yamaski 2001). We did not detect, nor did we hear reports, of any additional snake species occurring on any of the islands.

Comparing Techniques

Efficient inventories of species diversity are, and will remain, a challenge for natural resource managers. It is common for some inventory techniques to be more effective for certain species. The challenge lies in selecting the most appropriate technique or techniques to survey all of the target species. This project directly confronted the issue of balancing inventory objectives with logistical constraints and a finite project budget. We selected techniques that cost little to construct, maintain, and deploy. Each of the three techniques we selected work primarily with one group of target species (i.e., nonvolant mammals, reptiles, or amphibians). In general we were pleased with the results of our efforts; however, we did observe some limitations in the techniques that we used.

We found that cubby boxes were useful and provided valuable information on the distribution of medium-sized mammals and even some smaller species such as the Norway rat. Cubby boxes were not well suited to collecting information on larger species (e.g., coyote, red fox) because their size limits entry to the devices. Distinguishing characteristics of the smallest mammals (e.g., voles, mice) by track also proved difficult, because tracks have fewer distinguishing characteristics and track sizes are similar between species. Live trapping would be a possible alternative for sampling small mammals, but would be very time intensive because as we previously mentioned, IACUC regulations require a dawn and dusk trap check during each 24-hour trapping session.

Pitfall traps would also be a productive alternative for sampling small mammals and amphibian species, though they require intensive effort to set up and are invasive (many animals will would be collected dead) unless monitored several times each day. Placing traps in the earth may also disturb historical artifacts or other archeological items, which can complicate the permit process. Time constrained searches resulted in no additional information in most locations, but were the only effective method for detecting red-backed salamanders. Time constrained searches over a larger search area may prove more fruitful.

The efficiency of using black tarps to sample reptiles in this setting remains somewhat unclear. Although we had seemingly little success capturing snakes with this method, all of the snake species encountered were discovered using the tarps. No additional species were encountered incidentally during our time traversing the islands between stations, although, in passing, we regularly checked areas that appeared to provide suitable habitat (rock walls, moist wooden debris). Sampling conducted in the late summer may improve detection rates for reptiles, as most species tend to be most active during this time.

Remote-triggered cameras might be a useful technique for medium to large mammal species, but implementation in the BOHA would need to be further explored. Our field schedule was designed to sample islands with high human visitation before the onset of the summer season, but some vandalism (on Georges and Rainsford Islands) was still encountered. Although active sensor cameras may be more effective, they are also significantly more costly, and would be a greater financial risk in these environs.

Summary of Management Recommendations

Information provided in this report can be used to help determine needs for long term monitoring in the BOHA, as determined by the specific management objectives for the park. Based on the results of this inventory, it does not appear that the long term monitoring of mammals, reptiles, or amphibians needs to be a priority in the BOHA. Of the 10 mammal species, three snake species, and one amphibian species detected with this inventory, all but one mammal species are common and widespread in the region. The remaining species, Belgian hare, is non-native.

It is reasonable to assume that mammals will move between islands in the future, especially those islands that are relatively close to the mainland. Depending on the management goals for specific islands, it is possible that some management of mammal species may be required in the future (for example, high raccoon activity on Spectacle may present a predation risk to nesting birds). If the restoration of native flora or fauna is undertaken as a management goal, the overabundance of certain non-native species (e.g., Belgian hare, Norway rat) could present a conflict.

Further investigation into the presence of New England cottontails on Grape Island may also be warranted. The New England cottontail is currently a candidate for listing as a federally endangered species and was previously known to occur on Grape Island. Although we did not detect any cottontails on Grape, our techniques did not specifically target this species.

In general, the techniques employed in this inventory were designed to detect as many different species as possible with the resources available. More specialized techniques targeting herbivores, bats, or small mammals could provide additional information. Given the size of islands in the Harbor, the prevalence of exotic vegetation on all islands, and the anthropogenic nature of habitat on the islands, it is unlikely that any rare terrestrial mammals use the islands. It is possible that migratory bats could use the islands, and the Park Service might consider conducting some bats surveys in the future. In addition, a broader distribution of snakes and redbacked salamanders might be expected if time constrained searches were expanded to cover a larger area.

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Appendix A. Mammal, reptile, and amphibian 2006 sampling stations on 19 islands in Boston Harbor (derived from landbird inventory stations, Paton et al. 2005).

Island	Station #	Setup Date	X	Y	GPS Accuracy (m)	Habitat Type	Substrate
Calf	1	6/14/2006	343797	4689598	11	Maritime Shrub	Grass
Calf	2	6/14/2006	343810	4689371	11	Maritime Shrub	Grass
Calf	3	6/14/2006	343780	4689153	5	Maritime Shrub, Grass	Grass
Outer Brewster	4	6/28/2006	345138	4689408	12	Grassland, Maritime Shrub	Grass
Outer Brewster	5	6/28/2006	345385	4689426	6	Grassland	Grass
Great Brewster	6	6/14/2006	343794	4688627	16	Erosional Cliff	Cobble
Great Brewster	7	6/14/2006	343771	4688341	8	Maritime Scrub-Shrub, Marsh	Grass
Sarah	23	6/12/2006	344515	4680139	10	Maritime Scrub-Shrub, Rock	Pokeweed
Bumpkin	24	5/22/2006	343548	4682625	7	Maritime Shrub	Leaf Litter
Slate	25	5/22/2006	342270	4681359	9	Pioneer Forest	Leaf Litter, Ferns
Grape	26	5/22/2006	341791	4681631	7	Maritime Shrub	Leaf Litter
Grape	27	5/22/2006	341544	4681379	14	Pioneer Forest	Leaf Litter
Grape	28	5/22/2006	341302	4681360	8	Maritime Shrub	Leaf Litter
Peddocks	29	3/22/2006	no satellite reception	no satellite reception	no satellite reception	Maritime Forest	Leaf Litter, Woody Debris
Peddocks	30	3/27/2006	341039	4685104	10	Maritime Forest	Cement Battery
Peddocks	31	3/27/2006	340561	4684895	9	Maritime Forest	Leaf Litter, Woody Debris

Island	Station #	Setup Date	X	Y	GPS Accuracy (m)	Habitat Type	Substrate
Peddocks	32	3/22/2006	340826	4684873	17	Maritime Forest	Leaf Litter, Woody Debris
Peddocks	33	3/27/2006	341053	4684870	14	Developed Edge, Maritime Forest	Leaf Litter, Bare
Peddocks	35	3/22/2006	340803	4684622	16	Maritime Forest, Path Edge	Path, Grass
Peddocks	38	3/22/2006	340039	4683881	7	Developed Edge, Maritime Shrub	Grass
Peddocks	39	3/22/2006	339802	4683867	12	Maritime Scrub-Shrub	Sand, Leaf Litter
Peddocks	40	3/22/2006	339528	4683891	14	Pioneer Forest	Leaf Litter, Woody Debris
Peddocks	41	3/20/2006	339258	4683832	12	Pioneer Forest	Leaf Litter
Peddocks	42	3/20/2006	339303	4683621	9	Maritime Shrub, Beach	Rocky / Shell Shore, Leaf Litter
Peddocks	43	3/20/2006	339546	4683613	6	Maritime Shrub, Pioneer Forest	Rocky / Shell Shore
Georges	45	4/12/2006	341048	4687109	13	Developed Edge, Maritime Shrub	Grass
Georges	46	4/12/2006	341309	4687099	8	Developed Edge, Maritime Shrub	Grass
Georges	47	4/12/2006	341090	4686847	6	Developed	Grass
Lovells	48	4/12/2006	341046	4688394	13	Marsh, Maritime Shrub	Grass

Island	Station #	Setup Date	X	Y	GPS Accuracy (m)	Habitat Type	Substrate
Lovells	49	4/12/2006	341045	4688122	8	Developed, Maritime Forest	Bare Ground
Lovells	50	4/12/2006	341226	4688188	14	Maritime Shrub, Beach	Grass, Sand
Lovells	51	4/12/2006	341299	4687872	17	Developed, Dune	Sand, Cement
Gallops	52	4/3/2006	340042	4687881	10	Maritime Shrub	Grass
Gallops	53	4/3/2006	340331	4687858	8	Maritime Shrub, Pioneer Forest	Grass, Leaf Litter
Spectacle	69	5/1/2006	336302	4688122	7	Grassland	Grass
Spectacle	70	5/1/2006	336084	4687853	6	Grassland	Grass
Spectacle	71	5/1/2006	336168	4687961	6	Grassland	Grass
Spectacle	72	5/1/2006	336297	468730	7	Grassland	Grass
Spectacle	73	5/1/2006	336326	4687354	7	Grassland	Grass
Spectacle	74	5/1/2006	336289	4687150	8	Dune, Beach	Sand
Thompson	76	5/17/2006	335042	4687361	7	Grassland Edge, Erosional Cliff Edge	Grass
Thompson	78	5/17/2006	334796	4687108	33	Maritime Forest, Grassland Edge	Leaf Litter, Grass
Thompson	79	5/17/2006	334304	4686873	7	Maritime Shrub, Freshwater Wetland	Grass, Woody Debris
Thompson	80	5/17/2006	334538	4686875	11	Grassland / Orchard, Maritime Shrub	Grass
Thompson	81	5/17/2006	334067	4686654	6	Maritime Shrub, Salt Marsh	Grass, Leaf Litter
Thompson	82	5/17/2006	334296	4686633	9	Grassland, Barren	Grass

Island	Station #	Setup Date	X	Y	GPS Accuracy (m)	Habitat Type	Substrate
Thompson	83	5/17/2006	334562	4686623	6	Dune, Maritime Shrub	Sand, Grass
Thompson	86	5/17/2006	334296	4686364	6	Pioneer Forest, Grassland	Blackberry
Rainsford	87	6/19/2006	338849	4686184	11	Maritime Scrub-Shrub	Cobble, Sand
Rainsford	88	6/19/2006	339184	4686350	12	Maritime Shrub	Grass
Sheep	89	5/22/2006	341336	4682731	9	Maritime Shrub	Shell, Stone
Langlee	90	6/12/2006	344396	4680427	13	Maritime Forest	Leaf Litter, Rock, Woody Debris
Ragged	91	6/12/2006	344050	4680107	12	Maritime Forest	Leaf Litter, Woody Debris
Middle Brewster	93	6/21/2006	344545	4689128	6	Maritime Scrub, Marsh	Grass, Rock
Middle Brewster	94	6/21/2006	344302	4689140	6	Maritime Scrub-Shrub, Grass	Grass, Rock
Snake	95	6/12/2006	337057	4692395	8	Pioneer Woodland	Grass

Appendix B. Summary of capture histories of cubby boxes on 19 islands in Boston Harbor.

Island	Station	Birds		Domestic cat		Striped Skunk		Small mammals		Raccoon		Norway rat		E. Gray Squirrel	
		1	2	1	2	1	2	1	2	1	2	1	2	1	2
Bumpkin	24	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Calf	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Gallops	52	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	53	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Georges	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	46[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	47	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Grape	26	1	0	0	0	1	0	0	0	1	0	0	0	0	0
	27	0	0	0	0	1	1	0	0	0	0	0	0	0	0
	28	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Great Brewster	6	0	1	0	0	0	0	0	0	0	0	0	1	0	0
	7[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Langlee	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lovells	48	1	0	0	0	0	0	0	0	0	0	0	1	0	0
	49	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	50	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	51	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Middle Brewster	93	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	94	0	0	0	0	0	0	0	0	0	0	1	1	0	0

Island	Station	Birds		Domestic cat		Striped Skunk		Small mammals		Raccoon		Norway rat		E. Gray Squirrel	
		1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Outer Brewster	4	0	1	0	0	0	0	0	0	0	0	0	1	0	0
	5	0		0		0		0		0		0		0	
Peddocks	29	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	30	0	0	0	0	0	0	0	1	0	0	1	0	0	0
	31	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	32	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	33	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	35	0	0	1	0	0	0	0	0	0	1	0	0	0	0
	38	0	0	0	0	0	0	0	0	0	1	1	0	0	0
	39	0	0	0	0	0	0	0	1	0	0	1	0	0	0
	40	0	0	0	0	0	0	0	1	1	1	0	0	0	0
	41	0	0	0	0	0	0	0	1	0	1	0	0	0	0
	42	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	43	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Ragged	91	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rainsford	87[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	88	0	1	0	0	0	0	0	1	0	0	0	0	0	0
Sarah	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sheep	89	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Slate	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Snake	95	0	0	0	0	0	0	0	0	0	1	0	1	0	0
Spectacle	69	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	70	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	71	0	0	0	0	0	0	0	0	1	1	0	0	0	0

Island	Station	Birds		Domestic cat		Striped Skunk		Small mammals		Raccoon		Norway rat		E. Gray Squirrel	
		1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Spectacle	72	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	73	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	74	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Thompson	76	0	0	0	0	1	1	0	1	0	0	0	0	0	0
	78	0	0	0	0	1	1	0	0	0	1	0	0	0	1
	79	0	0	0	0	1	1	0	0	0	0	0	0	0	0
	80	0	0	0	0	1	1	0	0	1	1	0	0	0	0
	81	0	0	0	0	1	1	0	0	0	0	0	0	0	0
	82	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	83	0	0	0	0	1	0	0	0	0	1	0	0	0	0
	86	0	0	0	0	1	0	0	0	0	1	0	0	0	0

[1]Traps were missing, thus no data could be collected

As the nation's primary conservation agency, the Department of the Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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National Park Service
U.S. Department of the Interior

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