

Long-term Coastal Breeding Bird Monitoring in the Boston Harbor Islands, 2007–2019

Carol Lynn Trocki^{1,*}, Aaron S. Weed², Adam Kozlowski³, and Kristin Broms⁴

Abstract - The National Park Service with support from numerous partners and community volunteers, has implemented long-term monitoring of coastal breeding birds in the Boston Harbor Islands since 2007. The objectives of the monitoring are to assess long-term trends in the abundance of priority coastal breeding species among the islands to inform conservation practices and park management. A combination of boat- and ground-based surveys are used to estimate the number of incubating *Larus argentatus* (Herring Gull), *Larus marinus* (Great Black-backed Gull), *Phalacrocorax auritus* (Double-crested Cormorant), *Haematopus palliatus* (American Oystercatcher), *Somateria mollissima* (Common Eider), and tern species annually. Ground-based nest counts are conducted for Common Eider and wading birds (*Plegadis falcinellus* [Glossy Ibis], *Nycticorax nycticorax* [Black-crowned Night Heron], *Ardea alba* [Great Egret] and *Egretta thula* [Snowy Egret]) on a 2–3-year rotation on islands that are accessible for landing by boat. The objectives of this study were to present count data from this monitoring and assess trends in annual counts of cormorants, gulls, and eiders estimated during boat-based surveys from 2007 to 2019. Changes in annual nesting of Double-crested Cormorants, Herring Gulls, and Great Black-backed Gulls estimated by boat-based surveys varied over time and by island, but in the park overall, all 3 species appear to have stable breeding colonies. Boat-based monitoring indicates that counts of tending Common Eider females and ducklings are declining in the areas where they forage near the Outer Islands. Ground-based monitoring has indicated that the largest wading-bird colony has consistently been located on Sarah Island and that Black-crowned Night Herons are the dominant driver in overall numbers and on all islands, except for Sheep Island, where they were overshadowed by an increase in Snowy Egrets in 2016 and 2018. As the long-term monitoring continues, we intend to compare its results to historical and regional data to better understand how populations have and are responding to environmental change in the harbor and to better understand how coastal breeding birds utilize natural communities within the park to inform park management decision-making.

Introduction

Boston Harbor Islands National Recreation Area (BOHA) includes 34 islands and peninsulas situated within the Greater Boston shoreline and provides critical near-shore nesting habitat to many species of birds. In 2002, BOHA was designated a Massachusetts Important Bird Area (IBA) because it provides essential habitat

¹Principal/Conservation Biologist, Mosaic Land Management, LLC, 325 Long Highway, Little Compton, RI 02837. ²Program Manager/Ecologist, Northeast Temperate Inventory and Monitoring Network, National Park Service, 54 Elm Street, Woodstock, VT 05091. ³Data Manager/Wildlife Biologist, Northeast Temperate Inventory and Monitoring Network, National Park Service, 54 Elm Street, Woodstock, VT 05091. ⁴Statistician, Neptune and Company, Inc., 1435 Garrison Street, Suite 201, Lakewood, CO 80215. *Corresponding author - cltrocki@gmail.com.

to one or more species of breeding, wintering, or migrating birds and generally supports high-priority species, large concentrations of birds, exceptional bird habitat, and/or has substantial research or educational value (Massachusetts Audubon Society 2020). The Boston Harbor Islands provide habitat for a significant number of colonially nesting waterbirds, including 2 state-listed *Sterna* spp. (terns; Massachusetts Natural Heritage and Endangered Species Program 2020), *Egretta thula* (Molina) (Snowy Egret), and *Nycticorax nycticorax* L. (Black-crowned Night-Heron) which are, respectively, species of high and moderate continental conservation concern (Kushlan et al. 2002). *Haematopus palliatus* (Temminck) (American Oystercatcher) has expanded its range northward into Massachusetts and now has a substantial breeding population in the Boston Harbor Islands (Paton et al. 2005). The North American population of American Oystercatcher is listed as a high-priority shorebird species with high conservation concern in the US Shorebird Conservation Plan (2004). In addition, BOHA provides critical nesting habitat to other important water birds including *Somateria mollissima* L. (Common Eider), *Phalacrocorax auritus* (Lesson) (Double-crested Cormorant), *Ardea alba* L. (Great Egret), *Plegadis falcinellus* L. (Glossy Ibis), *Larus argentatus* (Pontoppidan) (Herring Gull), and *Larus marinus* L. (Great Black-backed Gull). These species are all classified as species of greatest conservation need in Massachusetts (Massachusetts Division of Fisheries and Wildlife 2015).

Coastal breeding bird populations were identified by the National Park Service as a high-priority monitoring need at BOHA to inform conservation-based strategies such as colony and habitat protection. The need for long-term monitoring to provide consistent estimates of nesting arose because patterns of habitat use for nesting varies among the colonially nesting species as do trends in their abundance (reviewed by Paton et al. 2005). For instance, past surveys have noted significant declines in nesting by wading species on Sarah Island or found that some islands are no longer used for nesting (Parsons et al. 2001). Other surveys suggest that some populations are stable on specific islands in BOHA (e.g., Double-crested Cormorants) yet regionally their populations are either increasing or in decline (e.g., gulls) (Andrews 1990, Hatch 1984). Finally, other species have small, but persistent breeding colonies on specific islands in BOHA (e.g., Common Eider, American Oystercatcher; Hatch 2001, Nove 2001, Veit and Petersen 1993). Given the importance of coastal breeding birds to the BOHA ecosystem, the National Park Service's Northeast Temperate Network Inventory and Monitoring Program (NETN), BOHA, and numerous partners and community volunteers, began implementing long-term monitoring of coastal breeding birds in the Boston Harbor Islands in 2007 (Trocki et al. 2015).

The general objectives of the NETN's coastal breeding bird monitoring effort in Boston Harbor is to provide a consistent index of the nesting population size among islands in BOHA to inform conservation strategies within the park. Specifically, the objectives are to determine long-term trends in species composition and abundance of priority coastal breeding bird species (eiders, cormorants, wading birds, shorebirds, and gulls). In addition, the monitoring seeks to provide information

that will improve our understanding of nesting-habitat relationships in BOHA and the effects of habitat changes and management actions (such as control of invasive plants or predators) on coastal breeding bird nesting and abundance.

In this study, we present monitoring data for gulls, Double-crested Cormorants, Common Eiders, and wading birds from 2007 to 2019 and trend analyses for boat-based counts of gulls, Double-crested Cormorants, and Common Eiders.

Methods

Study site description

BOHA includes 34 islands and peninsulas situated within the Greater Boston shoreline. The islands vary greatly in vegetation cover, geology, history of human use, and level of current human accessibility and activity. Islands included in the coastal breeding bird monitoring program were selected based on either the known presence of nesting waterbirds or the availability of appropriate habitat for potential future colonization, as gleaned from inventory efforts in 2001–2003 and regular surveillance (Paton et al. 2005). Since 2007, we have conducted routine monitoring

Table 1. Coastal breeding bird monitoring schedule by species, survey type (B: boat, G: ground), and sampling frequency (annual or 2–3-year rotation) by island.

Island	Double-crested Cormorants and gulls	Common Eiders	Wading birds
Bumpkin	B - annual	-	-
Button	B - 2-3 y	-	-
Calf	B - annual	B - annual and G - 2-3 y	G - 2-3 y
Gallops	B - 2-3 y	G - 2-3 y	-
Georges	B - 2-3 y	-	-
Grape	B - 2-3 y	-	-
Great Brewster	G - 2-3 y	G - 2-3 y	-
Green	B - annual	B - annual	-
Hangman	G - 2-3 y	G - 2-3 y	-
Langlee	B - 2-3 y	-	-
Little Brewster	B - annual	B - annual	-
Little Calf	B - annual	B - annual	-
Lovells	G - 2-3 y	G - 2-3 y	-
Middle Brewster	B - annual	B - annual and G - 2-3 y	G - 2-3 y
Outer Brewster	B - annual	B - annual and G - 2-3 y	G - 2-3 y
Peddocks	B - 2-3 y	-	-
Ragged	B - 2-3 y	-	-
Rainsford	B - 2-3 y	-	-
Sarah	G - 2-3 y	-	G - 2-3 y
Shag Rocks	B - annual	B - annual	-
Sheep	G - 2-3 y	G - 2-3 y	G - 2-3 y
Slate	B - 2-3 y	-	-
Snake	-	-	-
Spectacle	B - 2-3 y	-	-
Spinnaker Platform	-	-	-
The Graves	B - annual	B - annual	-
Thompson	-	-	-

for coastal breeding bird activity on 26 islands and 1 artificial tern-nesting platform (Spinnaker Platform; Table 1, Fig. 1).

Nesting-survey methods

The objective of long-term monitoring of coastal breeding birds at BOHA is to provide a standardized estimate of colony size for each species so that patterns of nesting over time and among islands can be evaluated (Trocki et al. 2015). Following the selection of the 26 islands for monitoring, we delineated standardized survey areas for each species to be monitored by ground-truthing their primary nesting habitats on each island. We estimated nesting areas for each species on each island by creating polygons of suitable habitat from a vegetation map (Largay and Sneddon 2017), correcting the polygons to represent actual survey areas in the field,

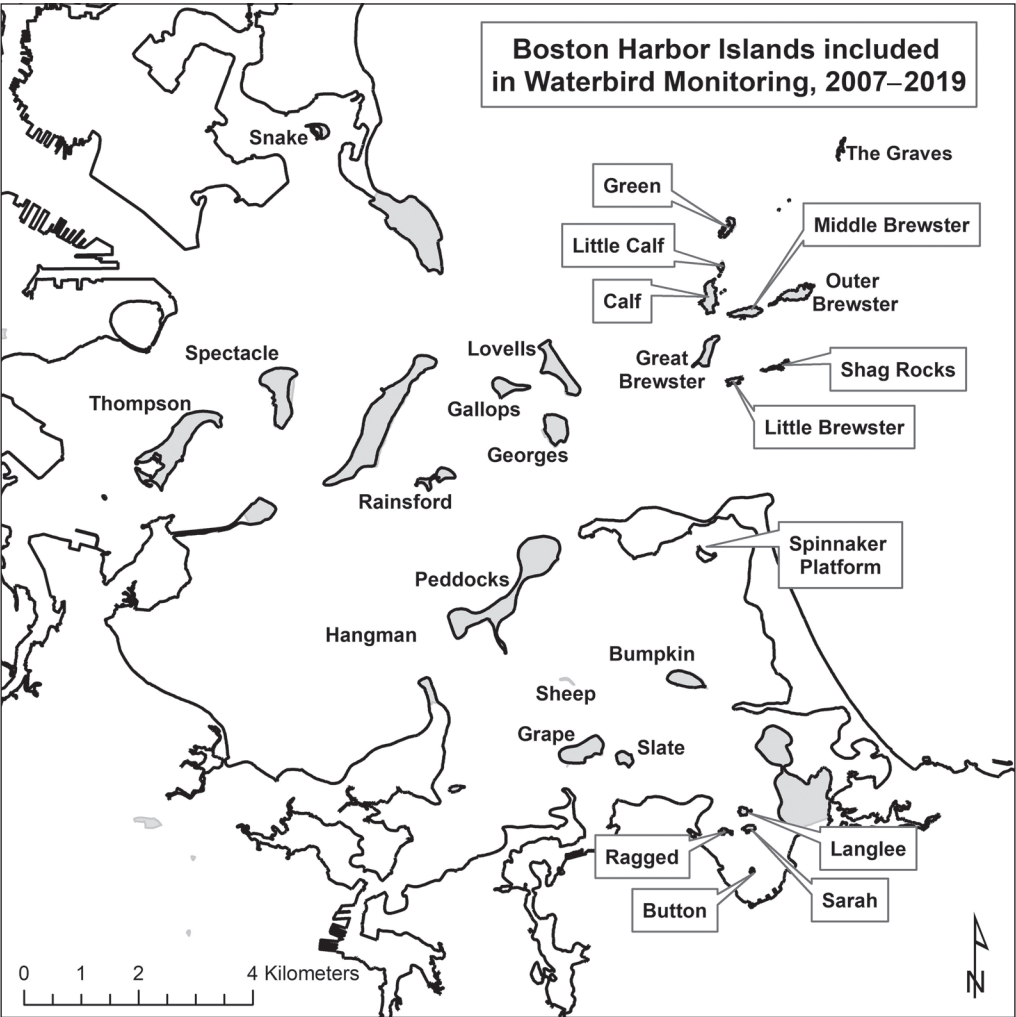


Figure 1. Map of the islands in Boston Harbor that were included in coastal breeding bird surveys from 2007 to 2019. Islands included in the monitoring program are labeled, while the area shaded in gray denotes all park lands.

and summing to generate a total area surveyed. Because many islands are not easy to access and we try to limit colony disturbance as much as possible, we opted to survey some colonies using only boat-based methods. For boat surveys, we further delineated the survey area by clipping the polygon to the approximate area that can be visually surveyed by boat (Table 2). Our boat-based counts likely underestimate the entire nesting colony compared to ground-based methods, but we believe they provide a consistent and logistically feasible index of the nesting population. All survey-area calculations were accomplished using ESRI's ArcMap 10.7.1 (ESRI 2019). A summary of the survey efforts, by method and species group, from 2007 to 2019 can be found in Table 1.

Our survey methods are based on standardized protocols (Erwin et al. 2003, Steinkamp et al. 2003) so that data generated can also be synced with state and regional waterbird survey data, which, for many species, are collected less frequently (~5 years) but provide valuable regional and population-level context. Our survey techniques were designed to: (1) detect changes in species richness, relative abundance of nesting pairs, and nesting locations for each focal species; (2) create minimal disturbance to nesting colonies and/or pairs; (3) be implemented by trained volunteers under the guidance of a lead scientist and with the assistance of park staff; (4) utilize methods that account for imperfect detection (e.g., multiple observers and repeat surveys); and (5) be completed within 10 field days per season (Trocki et al. 2015). Volunteers participating in the program are recruited and screened by the park and attend a training session prior to the start of the field season each year. Although volunteers of all skill levels are welcome to participate, training efforts focus on developing and assessing volunteer capabilities, and individual survey assignments are selected to maximize the accuracy, efficiency, and safety of data collection in the field. Prior to the start of each field survey, we assigned observer experience to 1 of 4 categories: 1 = new observer, 2 = beginner to intermediate, 3 = experienced, and 4 = experienced lead biologist. Volunteer engagement is described below for each survey type.

There are a variety of challenges inherent to monitoring coastal breeding birds in BOHA. Not all islands are easily accessible; many have docking constraints or restricted access during certain tidal stages. Boat size and availability, as well as weather conditions, play a role in which islands can be surveyed, and by which method, on any given day. Generally, we conducted surveys following a rotation that allowed for roughly consistent effort among years, offered flexibility for weather or other unforeseen circumstances that may hinder seasonal timing, and allowed us to coordinate with state or region-wide efforts occurring on a 5- or 10-year basis. A summary of the survey efforts from 2007 to 2019 can be found in Table 1.

During 2007–2019, all NPS surveys were conducted between 7 am and 12 pm during the peak breeding period when temperatures were 10–35° C. Surveys were not conducted when winds were greater than 25 km/h, when boating conditions were deemed unsafe by the boat captain, or when visibility was poor. We conducted all boat-based surveys using a 7.9-m (26-ft) aluminum landing craft chartered from UMass Boston Marine Operations. We conducted ground-based nest surveys only

when winds were below 20 km/hour, temperatures were 16–27° C, and there was no precipitation.

Double-crested Cormorants and gulls

Most Double-crested Cormorants, Herring Gulls, and Great Black-backed Gulls in the park nest on rocky islands in the Outer Harbor (Fig. 1; Paton et al. 2005). The majority of these colonies were surveyed by boat (8 of 9 islands) because landings are challenging and bathymetry allows for consistent circumnavigation regardless of tidal stage (Table 1). In this study, we report nest counts of visible active nests (as evidenced by the presence of an incubating adult or visible chicks) counted by a team of surveyors circling the island survey areas by boat at ~5 km/h from a distance of ~10–45 m offshore (or as close as the boat captain feels safe boat operation is feasible). A standard survey route (“Outer Islands Loop”) that circumnavigates Calf, Little Calf, Green, Middle Brewster, Outer Brewster, and Little Brewster Islands, The Graves and Shag Rocks, was traversed on a date timed to coincide with peak incubation, between 15 May and 1 June, of each year. At the start of each survey, we collected environmental conditions (temperature, wind speed and direction, and cloud cover). We divided each survey route into island segments based on shoreline configuration and the navigable boat track. Although the entire shoreline of boat-surveyed islands was visible by boat, not all islands can be safely circumnavigated independently. The starting and ending points for island segments were defined using fixed, recognizable landforms, and the same survey route was followed in the same order each time a survey was conducted. For each island segment, a paired team of surveyors, with 1 observer and 1 recorder, tallied the number of visible active nests or incubating adults observed for each species, with care taken to avoid counting attending adults.

Common Eiders

We recorded breeding activity by Common Eiders using a combination of ground-based nest counts and boat-based counts. While nesting Common Eiders are not visible from a boat, ducks can be observed rafting in crèches (groups of ducklings communally tended by adult females) offshore near nesting islands beginning shortly after hatching. We surveyed for nesting Common Eiders using ground-based methods on a 2–3 year rotation on 8 islands (Table 1) and report only the raw nest counts from these surveys here. We conducted Common Eider adult and duckling crèche counts annually by boat ~2–3 weeks following peak incubation using the same boat-based Outer Island survey route as for gulls and cormorants. We conducted these surveys between 25 May and 15 July annually as many times as possible to monitor seasonality and estimate the annual number of adult females (those tending ducklings, as well as “lone females”) and ducklings. Surveys were conducted at ~5 km/h from a distance of ~10–45 m offshore (or as close as the boat captain feels safe boat operation is feasible) using a team of 4–6 observers overseen by an experienced lead biologist. At the start of each survey, environmental conditions were recorded as noted above. For each island segment, the number of

females, number of females tending ducklings, and ducklings were recorded with all available surveyors working collaboratively.

Wading birds

Since the early 2000s, Great Egret, Snowy Egret, Black-crowned Night Heron, and Glossy Ibis have commonly nested in vegetation on 5 islands in BOHA. Since this habitat cannot reliably be surveyed by boat, we counted nests using ground-based methods on a 2–3 year rotation across the entire habitat on each island (Table 1). We timed surveys to coincide with peak incubation—between 15 May and 1 June each survey year. At the start of each survey, we recorded environmental conditions. Observers worked in teams of 2–3 people to count nests and their contents when possible (e.g., eggs or chicks), communicating regularly with one another to divide the survey area, ensure complete coverage, and minimize double counting.

While a complete count of actual nests was always attempted, we used adult flush counts to estimate the number of nests on Calf Island in 2016 and 2018, and on Outer Brewster Island in 2007 and 2016, as bowl-shaped topography and especially dense vegetation made complete nest counts untenable. We confirmed actual nesting in all cases and recorded the maximum number of adults flushed from the nesting area from a location along the perimeter of the colony where visibility was maximized. Multiple observers were used to obtain the best possible estimate of the total number of adults present. While adult flush counts are the best available metric for these specific locations and years, they may overrepresent the number of actual nests present since adults share responsibility for incubation and parental care, and the number of non-breeding adults that may be present is unknown.

Weather in 2012 prevented a complete survey of the wading bird colonies from occurring, so islands not surveyed in 2012 were sampled in 2013, and we summarize ground-based nest counts for these species together for 2012 and 2013.

Data analyses

While the long-term monitoring program surveys 11 species annually in BOHA, in this study, our analysis only focused on a subset of the species that we have been monitoring and for which we have the longest survey history. We summarized boat-based counts of Double-crested Cormorants, Herring Gulls, and Great Black-backed Gulls using the maximum count in each year from the most experienced observers (levels 3 and 4) to generate annual counts by island and park-wide of nesting from 2007 to 2019. To generate an annual number of tending females and ducklings observed during boat-based counts of Common Eiders, we took the maximum count per life-stage detected by the most experienced observers between 25 May and 15 July in each year from 2007 to 2019.

We estimated the trend in the raw annual count data of Common Eider crèches, Double-crested Cormorants, Herring Gulls, and Black-backed Gulls using a series of generalized linear models. For each species, we assessed the trend in counts at the park scale and over time by island. Count data for these species were over-dispersed, so we used a negative binomial error distribution to estimate model

coefficients. We derived trend estimates and 95% confidence intervals using bootstrapping based on 200 samples from each model. For all species except Common Eider crèche surveys (which survey the same area each time), we accounted for differences in survey effort among islands by including the approximate area surveyed (log-transformed) per island as described above as an offset in the model (Table 2). We excluded boat-based nesting data for Herring Gulls on Shag Rocks from the trend analysis because of low and infrequent nesting on this island. Preliminary model selection determined that none of the environmental covariates (temperature, wind, or tidal stage) were important in explaining variation of our counts over time, so they were excluded from the models. We accounted for variation in nest counts due to day-of-year or observer skill by taking the maximum counts from surveys repeated over a breeding season (only for Common Eiders) and by only the most experienced observers (level 3 or 4), respectively. For simplicity, we opted to only analyze count data from the most experienced observers, but we have available data for future evaluation of how observer skill may affect our count estimates. All analyses were completed using R software version 3.6 (R Core Team 2020). We present results from all analyses as the raw counts to help interpretation of model results and bird colony sizes among islands and species.

Finally, we present only raw data for the ground-based nest counts of wading birds and Common Eiders and did not conduct trend analyses due to the limited data available to us. We summed nest counts of wading bird species across teams on each island annually to estimate nesting per island by species per year because ground-based nest surveys were split between 2–3 teams, each lead by an experienced observer or the lead scientist. We used adult flush counts to estimate the number of nests on Calf Island in 2016 and 2018, and on Outer Brewster Island in 2007 and 2016.

Results

Boat-based incubation surveys for cormorants and gulls

Boat-based surveys indicate that Double-crested Cormorants were the most frequently observed species during incubation surveys of the Outer Islands of Boston Harbor from 2007 to 2019, averaging 1091 nests·survey⁻¹, with a coefficient of variation (CV) of 11% (*n* = 13; Table 3), followed by Herring Gulls (340; 29%;

Table 2. Approximate area surveyed during annual boat-based incubation surveys of gulls and Double-crested Cormorants on 8 islands in Outer Boston Harbor.

Island	Survey area (m ²)
Calf	41,448
Green	38,024
Little Brewster	8120
Little Calf	10,596
Middle Brewster	34,159
Outer Brewster	56,109
Shag Rocks	9934

$n = 13$; Table 4) and Great Black-backed Gulls (88; 29%; $n = 13$; Table 5) across the 6 islands surveyed. While Double-crested Cormorants were most numerous, they were also the most detectable, as cormorants primarily nest on exposed rock where they are very visible to observers using boat-based methods.

Changes in annual nesting of Double-crested Cormorants in areas visible by boat, varied over time and by island (Fig. 2; for bootstrapped coefficient estimates and 95% CIs, see Supplemental Table 1, available online at <http://www.eaglehill>.

Table 3. Nest counts for Double-crested Cormorant observed during boat-based incubation surveys in the Outer Islands of Boston Harbor from 2007 to 2019. CV = coefficient of variation.

Year	Calf	Green	Little Calf	Middle Brewster	Outer Brewster	Shag Rocks	All islands
2007	153	146	183	530	63	123	1198
2008	111	92	231	564	89	164	1251
2009	59	92	247	453	77	141	1069
2010	70	125	190	620	76	184	1265
2011	54	145	83	416	82	73	853
2012	65	175	147	612	64	118	1181
2013	43	212	107	493	96	93	1044
2014	19	124	160	552	84	123	1062
2015	5	117	149	548	122	95	1036
2016	8	177	121	490	92	104	992
2017	16	152	131	575	107	87	1068
2018	69	113	124	517	70	102	995
2019	34	149	192	596	107	96	1174
Mean	54	140	159	536	87	116	1091
CV	78%	25%	30%	11%	20%	27%	11%

Table 4. Nest counts for Herring Gulls observed during boat-based incubation surveys in the Outer Islands of Boston Harbor from 2007 to 2019.

Year	Calf	Green	Little Calf	Middle Brewster	Outer Brewster	Shag Rocks	All islands
2007	58	21	45	44	127	0	295
2008	118	29	13	80	138	0	378
2009	55	16	2	55	96	0	224
2010	61	20	7	72	93	2	255
2011	44	18	21	34	76	0	193
2012	60	5	2	38	76	1	182
2013	102	27	10	99	159	0	397
2014	122	24	12	112	158	0	428
2015	106	16	4	91	212	0	429
2016	92	24	14	85	131	0	346
2017	99	23	8	105	175	0	410
2018	115	25	8	123	164	2	437
2019	126	26	15	107	165	0	439
Mean	89	21	12	80	136	0.4	339
CV	33%	30%	90%	37%	30%	200%	29%

us/NENAonline/suppl-files/n26-sp9-N1560k-Trocki-s1, and for BioOne subscribers, at <https://dx.doi.org/10.1656/N1560k.s1>). Within the park, mean annual nesting of Double-crested Cormorants was highest in the areas surveyed on Middle Brewster (536 mean nests survey⁻¹; CV = 11%; *n* = 13), Little Calf (159; 30%), and Green (140; 25%) (Table 3, Fig. 2). After accounting for surveyed area among islands, the model estimated a slight, but non-significant decline (trend = -0.02 nests per year; 95% CI = -0.05, 0.01) in Double-crested Cormorant nesting since 2007 across the areas surveyed in BOHA (Fig. 2). While there was evidence for significant declines in nesting on Calf, Little Calf, and Shag Rocks, nesting has increased on Outer Brewster Island over the monitoring period (Fig.2; see Supplemental Table 1).

Our surveys suggest that in areas visible from the boat, nesting by Herring and Great Black-backed Gulls occurs on the same islands, but the amount of nesting per island varies by species. For instance, Herring Gull nesting was highest on Outer Brewster (averaged 136 mean nests·survey⁻¹; CV = 30%), Calf Island (89; 33%), and Middle Brewster Island (80; 37%) (Table 4, Fig. 3), while nesting by Great Black-backed Gulls was highest on Green Island (20; 38%), Calf Island (18; 33%), and Outer Brewster Island (18; 32%) (Table 5, Fig. 4). Shag Rocks supported the lowest numbers of Great Black-backed Gulls (3.3; 86%) and Herring Gulls (0.35; 200%) among the 6 islands surveyed by boat on which nesting occurred (Tables 4, 5; Figs. 3, 4).

Although our boat-based methods do not sample the entire gull colony on each island, we believe the following results for the gulls are illustrative of the direction of the trends in nesting on each island. Similar to Double-crested Cormorant, annual trends in gull nesting over time in habitats visible from a boat also differ by island and the direction and magnitude of the trends vary by island between species (Figs. 3, 4; for bootstrapped coefficient estimates and 95% CIs see also Supplemental

Table 5. Nest counts for Great Black-backed Gulls observed during boat-based incubation surveys in the Outer Islands of Boston Harbor from 2007 to 2019.

Year	Calf	Green	Little Calf	Middle Brewster	Outer Brewster	Shag Rocks	All islands
2007	23	19	24	53	27	0	146
2008	18	19	6	17	19	3	82
2009	14	19	9	51	26	4	123
2010	17	15	17	4	10	4	67
2011	11	25	9	9	16	1	71
2012	12	15	4	2	12	1	46
2013	17	20	7	27	14	3	88
2014	29	3	11	6	22	2	73
2015	8	18	7	14	16	10	73
2016	22	26	11	13	11	8	91
2017	25	23	13	10	14	3	88
2018	22	36	9	13	24	1	105
2019	20	24	5	14	22	3	88
Mean	18	20	10	18	18	3	88
CV	33%	38%	53%	91%	32%	86%	29%

Tables 2 and 3, both available online at <http://www.eaglehill.us/NENOnline/suppl-files/n26-sp9-N1560k-Trocki-s1>, and for BioOne subscribers, at <https://dx.doi.org/10.1656/N1560k.s1>). Nesting of Herring Gulls in areas visible from the boat increased significantly since monitoring began on Calf, Green, Middle Brewster, and Outer Brewster, and while the colony seems to have declined on Little Calf Island since counts in 2008, the overall trend is not significant (Fig. 3; see also Supplemental Table 2). Nesting of Herring Gulls has increased slightly over time in all areas surveyed across the park (trend = 0.03 nests per year; 95% CI = 0.01, 0.05; Fig. 3). Since 2007, Great Black-backed Gull nesting has declined significantly on Middle Brewster Island but has been increasing in the areas surveyed on Calf, Green, and Shag Rocks (see Supplemental Table 3), while nesting has remained unchanged across all areas surveyed in the park combined (trend = -0.02 nests per year; 95% CI = -0.04, 0.01; Fig. 4).

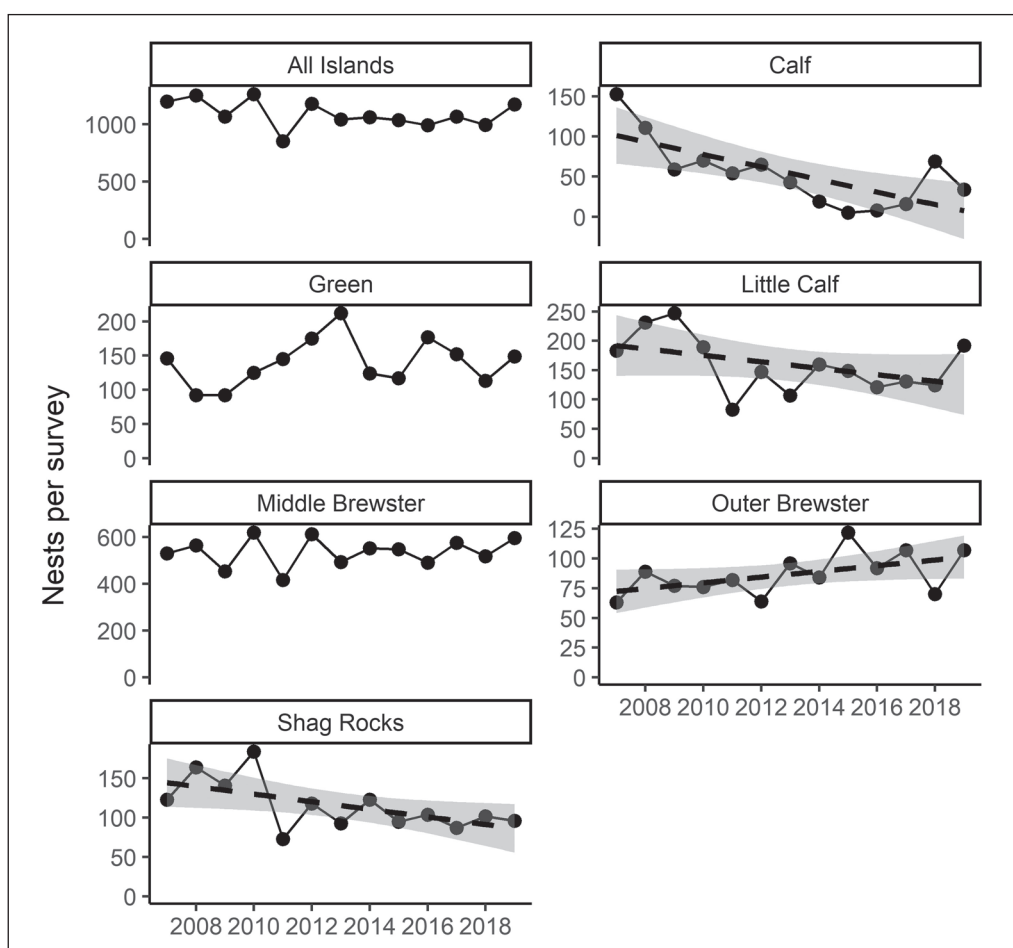


Figure 2. Trends in annual nesting of Double-crested Cormorants surveyed by boat in the Outer Islands of Boston Harbor, 2007–2019. Raw counts are plotted with trend lines (dotted) when $P < 0.05$. Shaded area denotes the 95% confidence interval.

Ground-based nest counts of wading birds

Five surveys were conducted between 2007 to 2018 to estimate wading bird nesting by Great Egret, Snowy Egret, Black-crowned Night Heron, and Glossy Ibis. During this timeframe, wading birds have nested in a total of 5 colony sites in the park. On Sarah Island, nests were in clumps of varying species of trees and shrubs throughout the island. On tiny Sheep Island, the colony site was in a tangled thicket of primarily invasive shrubs and vines in the very center of the island. On both Calf and Outer Brewster Islands, the colony sites were in depressions with sheltering topography and particularly dense vegetation. On Middle Brewster, the few Black-crowned Night Heron nests observed in early years were in an *Ulmus pumila* L. (Siberian Elm) grove.

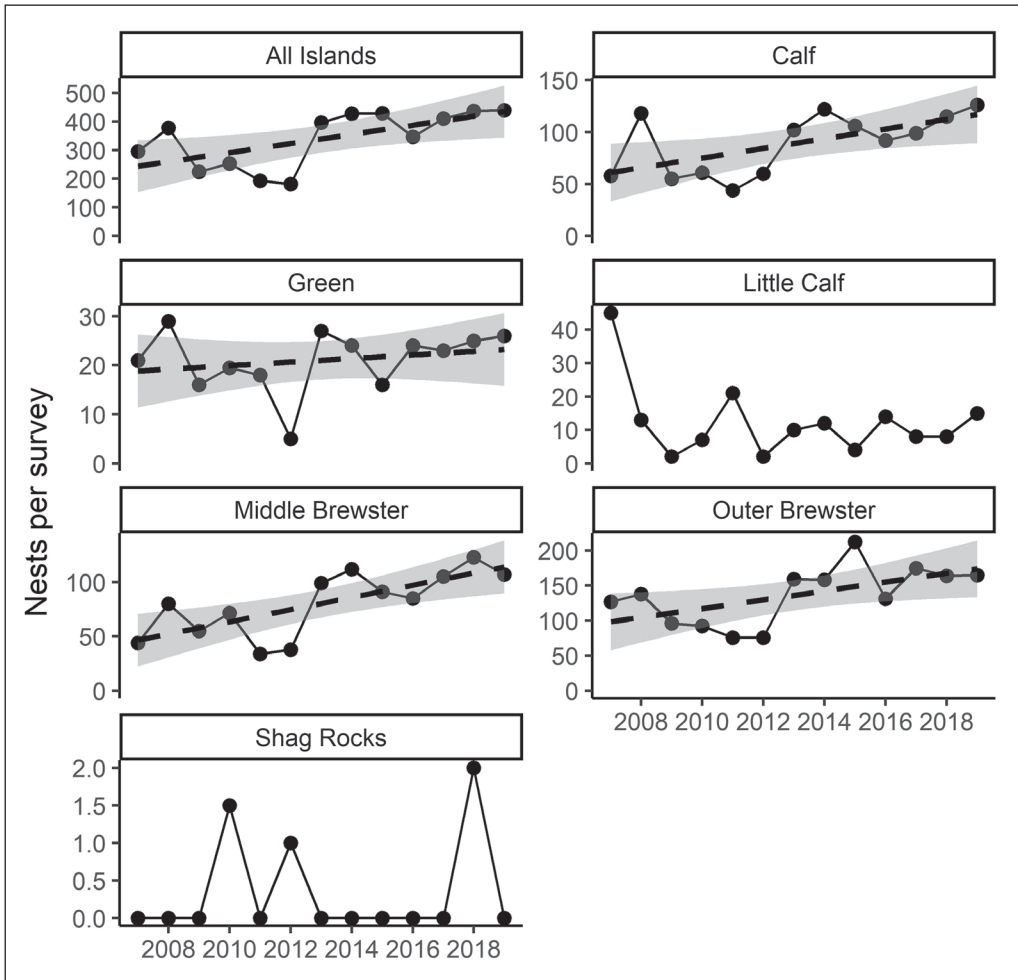


Figure 3. Trends in annual nesting of Herring Gulls surveyed by boat in the Outer Islands of Boston Harbor, 2007–2019. Raw counts are plotted with trend lines (dotted) when significant ($P < 0.05$). Shaded area denotes the 95% confidence interval. Shag Rocks was removed from the trend analysis due to low and infrequent nesting.

The majority of nesting by all wading bird species occurred on Sarah Island, followed by Outer Brewster, Sheep, and Calf islands (Fig. 5, Table 6). The Outer Brewster colony was abandoned in 2018, but breeding activity increased on Calf Island in that same year (Fig. 5, Table 6).

At the island-scale, nesting by Black-crowned Night Herons was the highest on Sarah Island followed by Outer Brewster Island, Calf Island, Sheep Island, and then Middle Brewster Island. Great Egrets also nested primarily on Sarah Island and, to a much lesser extent, on Sheep, Outer Brewster, and Calf islands (Table 6). Most Snowy Egret nesting occurred on Sarah and Sheep islands (Table 6). Unlike the other wading birds, Glossy Ibis nested primarily on Outer Brewster Island until that colony was abandoned in 2018, but activity increased on Calf in that same year (Fig. 5). Glossy Ibis nests have also been detected on Sarah and Sheep islands, but not in every survey (Table 6).

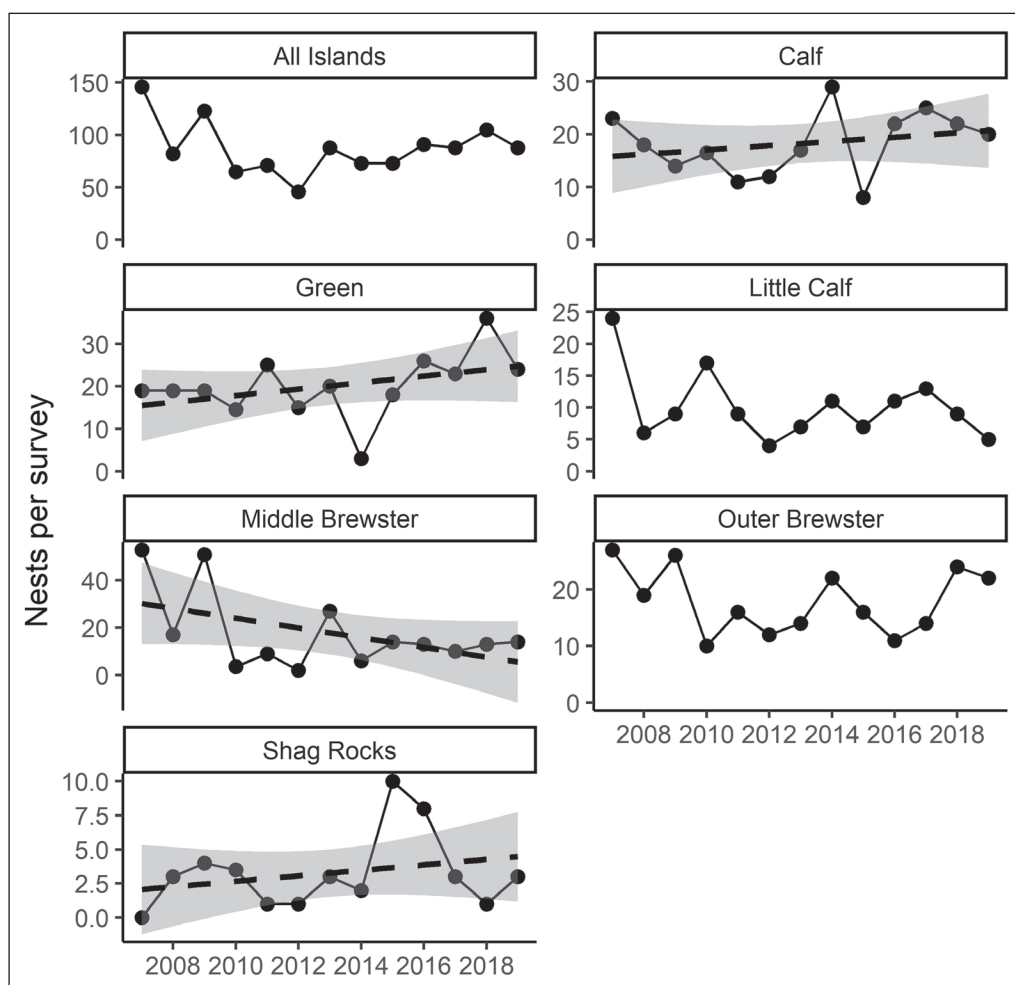


Figure 4. Trends in nesting of Great Black-backed Gulls surveyed by boat in the Outer Islands of Boston Harbor, 2007–2019. Raw counts are plotted with trend lines (dotted) when $P < 0.05$. Shaded area denotes the 95% confidence interval.

Common Eider

Ground-based counts of nesting Common Eiders was the highest on Calf Island (99 nests·survey⁻¹; 28% coefficient of variation; *n* = 4) followed by Outer Brewster Island (75; 19%), and Middle Brewster Island (42; 34%) (Table 7). During a ground-based survey for gulls on Gallops Island in 2012, Common Eider were discovered nesting there as well. Additional nests were found on Gallops in 2015 and 2018 (Table 7).

Since boat-based crèche surveys of Common Eiders began in 2008, observers have detected on average a maximum of 151 females·year⁻¹ (CV = 42%) tending ducklings and 218 ducklings·year⁻¹ (CV = 38%) over the 12-year period, foraging in and around the islands of Outer Boston Harbor (Table 8). As expected, fluctuations in maximum count of females tending ducklings closely mirrored the maximum number of ducklings detected each season (Fig. 6). Since 2008, both female (coefficient: year = -0.03 max count·year⁻¹; 95% CI = -0.05, -0.01) and duckling counts

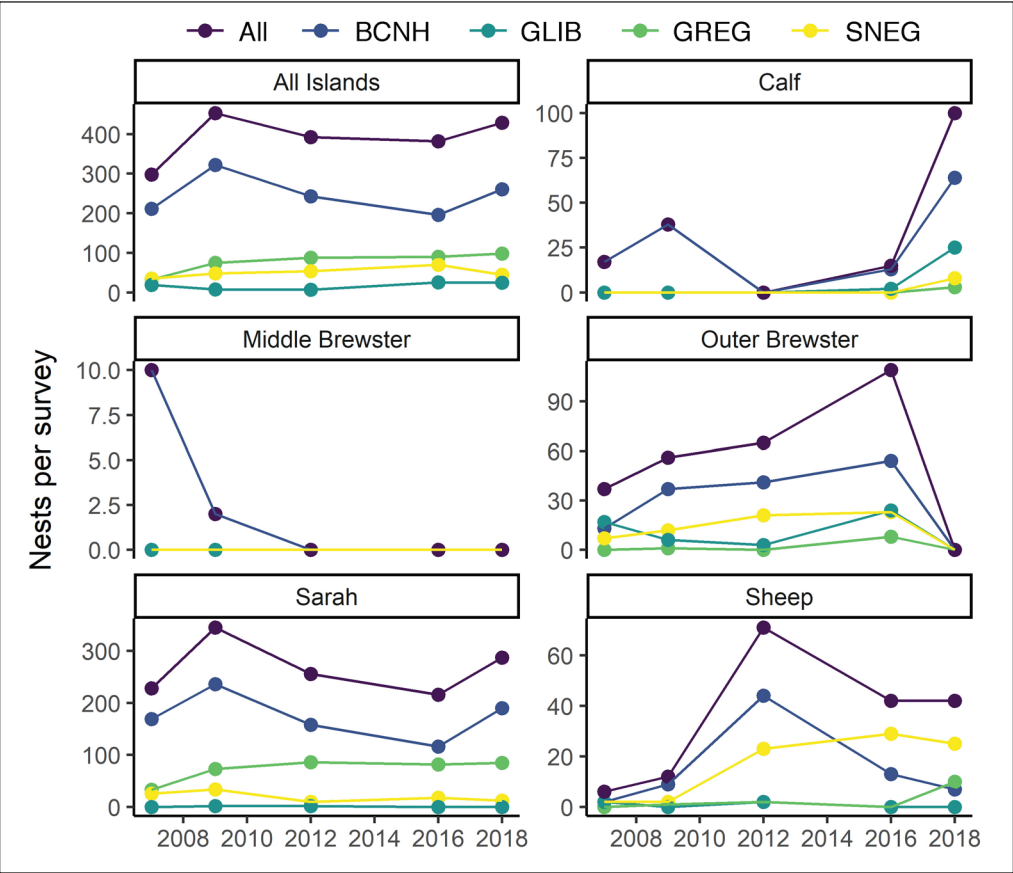


Figure 5. Ground-based nest counts of all wading bird species (All), Black-crowned Night Heron (BCNH), Glossy Ibis (GLIB), Great Egret (GREG) and Snowy Egret (SNEG) on individual islands in the Boston Harbor Islands, 2007–2018. Counts on Outer Brewster in 2007, Calf and Outer Brewster in 2016, and Calf in 2018 are estimates of the total number of flushed adults present only.

have declined over time (coefficient: year = -0.04; 95% CI = -0.06, -0.03) around the Outer Islands (Fig. 6, Table 8).

Table 6. Ground-based nest counts of wading birds in Boston Harbor Island colonies ($n = 5$); adult flush counts are the only available data for surveys marked with an ‘*’.

Birds	Island	2007	2009	2012	2016	2018
All Waders	Calf	17	38	0	15*	100*
	Middle Brewster	10	2	0	0	0
	Outer Brewster	37*	56	65	109*	0
	Sarah	228	345	256	216	287
	Sheep	6	12	71	42	42
	All Islands	298	453	392	382	429
Black-crowned Night Heron	Calf	17	38	0	13*	64*
	Middle Brewster	10	2	0	0	0
	Outer Brewster	13*	37	41	54*	0
	Sarah	169	236	158	116	190
	Sheep	2	9	44	13	7
	All Islands	2	322	243	196	261
Glossy Ibis	Calf	0	0	0	2*	25*
	Middle Brewster	0	0	0	0	0
	Outer Brewster	17*	6	3	24*	0
	Sarah	0	2	2	0	0
	Sheep	2	0	2	0	0
	All Islands	19	8	7	26	25
Great Egret	Calf	0	0	0	0*	3*
	Middle Brewster	0	0	0	0	0
	Outer Brewster	0*	1	0	8*	0
	Sarah	33	73	86	82	85
	Sheep	0	1	2	0	10
	All Islands	33	75	88	90	98
Snowy Egret	Calf	0	0	0	0*	8*
	Middle Brewster	0	0	0	0	0
	Outer Brewster	7*	12	21	23*	0
	Sarah	26	34	10	18	12
	Sheep	2	2	23	29	25
	All Islands	35	48	54	70	45

Table 7. Ground-based nest counts of Common Eiders on islands in Boston Harbor ($n = 4$). CV = coefficient of variation.

Island	2007	2008	2015	2018	Mean	CV
Calf	72	111	132	79	99	28%
Outer Brewster	86	57	69	87	75	19%
Middle Brewster	35	28	61	45	42	34%
Great Brewster	7	4	1	4	4	61%
Gallops	-	-	6	36	-	-
Hangman	0	0	0	2	-	-
Sheep	0	0	4	4	-	-
All Islands	200	200	273	257	23	16%

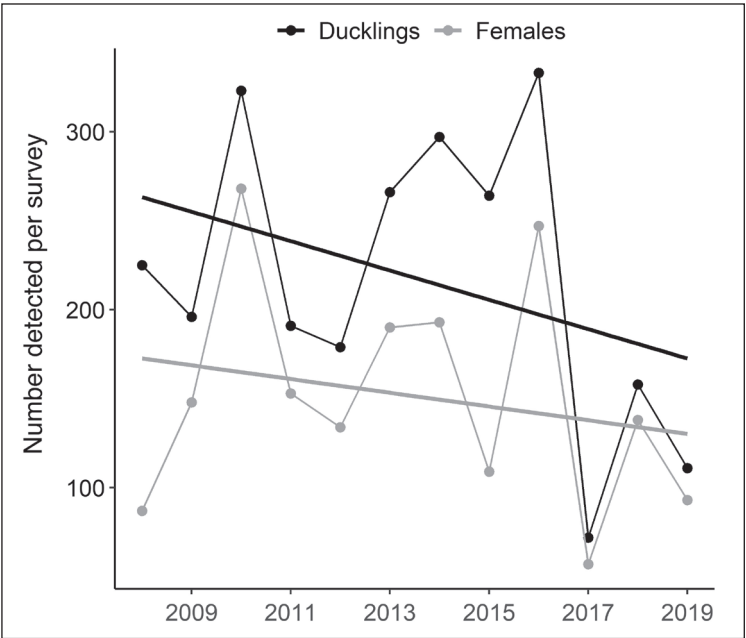
Discussion

The islands of Boston Harbor provide important, perennial nesting habitat for a diversity of coastal breeding bird species. Long-term monitoring of species of high conservation status supported by NPS and its partners is important to understanding their current and future nesting and foraging ecology in the harbor. While long-term monitoring can help us better understand changes in population size, it also can illuminate important patterns of habitat use that can help to better prioritize conservation and other management actions in the harbor as well as indicate how

Table 8. Boat-based crèche surveys of Common Eider in the Outer Island of Boston Harbor, 2009–2019 ($n = 11$). Shown are the maximum ducklings counted and the number of females tending ducklings during the same survey in each year. CV = coefficient of variation.

Year	Tending females	Ducklings
2008	87	225
2009	148	196
2010	268	323
2011	153	191
2012	134	179
2013	190	266
2014	193	297
2015	109	264
2016	247	333
2017	57	72
2018	138	158
2019	93	111
Mean	151	218
CV	42%	38%

Figure 6. Boat-based counts of adult female Common Eider tending ducklings and ducklings in the Outer Islands of Boston Harbor, 2007–2019. Shown are the maximum ducklings counted and the number of females tending ducklings during the same survey in each year. Raw counts are plotted with trend lines when $P < 0.05$.



these birds are responding to local vs regional environmental changes. Continued monitoring is essential in Boston Harbor given that rare and endangered species are re-colonizing the harbor after past extirpation and because we need to better understand how land use and climate change is affecting their populations and nesting habits. Implementing this monitoring program with volunteers has also offered a significant opportunity for engaging the public and other partners in coastal breeding bird ecology in the park. Our high volunteer-retention rates yield improved skill and consistency in data collection, while the diversity of tasks provided by the program supports engagement by volunteers of varying skill levels.

Double-crested Cormorants and gulls

Boat-based surveys were chosen as a method to count nesting gulls and Double-crested Cormorants over ground-based methods to reduce colony disturbance. We know that our boat-based surveys underestimate the actual number of nesting pairs on some islands because the nesting colony may not be entirely visible from the boat and also because of imperfect detection, but we expect that our boat-based methods provide a consistent index of the nesting population. Boat-based counts may especially underestimate total colony size for islands with relatively large cormorant colonies spread over interior areas not visible from the water (Middle Brewster) and for gull species that nest in a wider range of locations that are not limited to the immediate shoreline, and hence not visible from the water.

We researched the availability of comparable ground-based counts that could be used to evaluate the effectiveness of boat-based methods, but available data from periodic state surveys is very limited. Overall, we believe our boat-based counts may more closely approximate ground-based methods if a scaling factor is used that accounts for the proportion of nesting habitat area visibly surveyed by boat. There may also be other factors affecting accuracy of boat-based counts that will need to be considered or improved upon such as inclusion of factors that affect detection (e.g., weather, observer skill). We intend to continue evaluating how boat-based methods relate to true colony nesting size in the future and evaluate how well boat surveys approximate more comprehensive ground-based methods.

Boat-based monitoring demonstrated that in the areas we surveyed, Double-crested Cormorant nesting has significantly declined on Calf Island, Little Calf, and Shag Rocks since 2007, though these sites are the least used by Double-crested Cormorants of the islands in the outer harbor. Shag Rocks and Little Calf Islands are both rocky outcroppings, with little vegetation and comparatively low topography (maximum elevation of 8.2 m [27 ft]). Sea-level rise and increased tidal exposure (Talke et al. 2018) coupled with changes in storm frequency and intensity are likely already impacting the quality and suitability of these nesting locations. Double-crested Cormorants are very flexible in habitat selection (Dorr et al. 2020), and movements away from nesting areas with greater storm exposure could contribute to increases in other places, including the apparent increase in the number of tree-nesting cormorants on islands such as Sheep and Sarah, where they currently overlap with wading birds (C.L. Trocki, pers. observ.). These relationships and movement patterns are deserving of greater study.

Our results indicate the numbers of nesting Great Black-backed and Herring Gulls in the Outer Islands appear stable, which runs contrary to reports of decline in northern portions of these species' ranges (Bond et al. 2016, Mittelhauser et al. 2016), but those trends were examined over longer timeframes. We have not yet had the opportunity to compare our results to historical data, either from park sites or statewide, but similar survey efforts have been conducted for colonial-nesting species in Massachusetts every 10 years since 1984 (Andrews 1990), and this historical context may be very valuable in better understanding the status of the park populations. Unfortunately, a mix of survey methods and effort between years for individual locations makes comparisons challenging, and greater research into historical methods will be needed to untangle population trends from sampling biases.

Common Eiders

Though our sample sizes were limited, nest-count trends indicate the breeding-season eider population in BOHA is increasing slightly, while counts of females in the area during June and the first half of July have been stable over time. A mark-and-recapture experiment conducted on Calf Island in 2008 indicated a 72% detection probability for eider nest searches on the north end of Calf Island, where eider nest most densely (Trocki 2009). When applied to the total nest count in the park during the most recent survey in 2018, the estimated number of nests increased from 257 to 357. In addition, we know there may be some eider nesting on islands that are not accessible for ground-based counts, such as Green or Little Calf, and we have observed an increase in the number of islands on which nesting Common Eiders have been detected during the study period, if in relatively low numbers, all of which suggests eider breeding effort may be expanding in the park.

In a recent publication, Heusmann and Trocki (2020) speculate that the Boston Harbor eider population is likely derived from birds translocated from Casco Bay, ME, to the Elizabeth Islands (just south of Cape Cod Canal) by Philip Stanton in the 1970s, given the lack of historical reference to nesting eider as far south as Massachusetts. Regardless of origin, Common Eider numbers are believed to be declining in the southern portion of their North American range generally (Bowman et al. 2015), and Boston Harbor birds comprised 41% of the total number of eider nesting in Massachusetts in 2018 (Heusmann and Trocki 2020), making Boston Harbor an important area of their southern range extension, even if this area is only a very small portion of the entire population. With a circumpolar range distribution, the worldwide population of Common Eider (estimated at 3.3-4 million individuals; Wetlands International 2012) is also declining, and the species has now been listed as near threatened by Birdlife International (2015) in Europe, as well as appearing on the North American Bird Conservation Initiative's (2016) watchlist.

A number of factors are at play in determining the stability and future of the North Atlantic population of Common Eider, and concerns about uncertainties have led resource agencies in Canada and the US to undertake more detailed assessments (Sea Duck Joint Venture 2015). While harvest undoubtedly plays an important role in the size of Common Eider populations (Rothe et al. 2015), other factors also contribute to fluctuations. During the course of the monitoring period reported here, a unique

viral pathogen affecting Common Eider, Wellfleet Bay virus, was discovered, and the epicenter of exposure appears to be Massachusetts (Allison et al. 2015, Ballard et al. 2017). Irregular outbreaks of avian cholera also occur across the southern portion of this species' North Atlantic range and can have devastating consequences (Descamps et al. 2012), though this has not been detected in Boston Harbor.

In addition, low rates of duckling survival have been identified as one of the greatest limiting factors for Common Eider recruitment (Sea Duck Joint Venture 2015), a trend that would appear to be supported by our crèche-survey data to date. Crèche-monitoring data collected annually in Boston Harbor may prove useful for understanding population demographics. Common Eider ducklings are at great risk from gull predation (Donewater and Bird 2008) and also impacted by the availability of benthic food resources during brood-rearing periods (Diéval et al. 2011, Hamilton 2001). While the availability and spatial distribution of benthic resources in Boston Harbor are not well known, these resources are likely to be impacted by changes in sea temperature (Pershing et al. 2015), which could in turn have an impact on eider recruitment (Mallory et al. 2020). A better understanding of the relationship between nesting and brooding areas and benthic food resources in Boston Harbor would be helpful in determining the likely future of breeding Common Eiders at the southern edge of their current breeding range.

Wading birds

Black-crowned Night Herons and Snowy Egrets both appear to have maintained fairly stable nesting populations in the park during this study period (2007–2018), though these species have been shown to be declining range-wide over a broader time period (Kushlen et al. 2002). With the limited data available, we can't know with confidence that these local populations are secure. In 1994, Parsons et al. (2001) tallied 550 Black-crowned Night Heron nests and 148 Snowy Egret nests on Sarah Island, compared to 190 and 12 nests, respectively, found on Sarah in 2018. A closer investigation of all available historical wading-bird data from BOHA and the surrounding areas (Andrews 1990, Blodget and Livingston 1996, Melvin 2010, Paton et al. 2005) is warranted to better understand the pace at which these changes have occurred, especially in the context of the statewide population change. Monitoring data showed an increase in the population of Great Egrets nesting in the park, which mirrors a region-wide trend for this species (Kushlan et al. 2002). Glossy Ibis is a notoriously nomadic species (Davis and Kricher 2020) and nests in low numbers in the park, making trends difficult to assess, especially with such a limited sample size and full nest counts available from only 6 of the 10 colony surveys for which adults were present.

While the overall total number of wading birds nesting in the park appeared fairly stable during the study period, movement between colonies was evident, driving home the importance of managing multiple colony sites, even in years where they are not used. For example, Middle Brewster Island hosted a significant wading bird colony in 1994 (425 nests; Blodget and Livingston 1996), and still has seemingly appropriate habitat available, though it was used little for nesting during this study period.

Predation, disturbance, and changes in vegetation can all impact the suitability of nesting habitat (Kushlan and Hafner 2000). For example, the number of Double-crested Cormorants nesting on Sarah and Sheep islands has increased over time, which could have an impact on habitat suitability for wading birds in these locations in the future as cormorants' negative impact on vegetation can be substantial (Dorr et al. 2020). Habitat availability on Sheep Island is very limited, elevation is minimal, and the island is already subject to storm inundation, leaving the future of this location as a viable colony site in question. The cause of colony abandonment on Outer Brewster is unknown, but predation seems likely as this island receives very limited human traffic, and habitat was unchanged throughout the study period.

As with the other colonial-nesting species, we welcome the opportunity to more closely examine how our results fit within the larger spatial and temporal context of existing data, but will face similar challenges in making comparisons among surveys where methods and effort levels have varied over time. In addition, another area of significant interest is the current unknown carrying capacity for wading birds breeding in the park ecosystem overall. A sustainable breeding population requires not only suitable nesting habitat, but also adequate foraging habitat within a reasonable commuting distance (Gibbs 1991). Given the location of the Boston Harbor colonies within a highly urbanized metro area, examining all the factors affecting carrying capacity would also be an interesting area of further exploration for which long-term monitoring data could be applied.

Conclusions

Long-term monitoring of coastal breeding birds in BOHA has been successfully implemented since 2007 with the assistance of citizen scientists and local partners. As we begin to learn more about the patterns of nesting within the harbor from our monitoring data, we hope this program will provide helpful information to support coordinated management and outreach to maintain and improve nesting habitat for these species in BOHA and provide a perspective on the relative status of these populations compared to the broader region. We intend to continue evaluating our methods so that monitoring provides information that will permit assessing trends of the nesting populations and improve a harbor-wide understanding of nesting-habitat relationships so that the effects of climate change, land use, and management actions (such as invasive plant control or predator control) on coastal breeding bird nesting and abundance can be better evaluated.

Acknowledgments

Thanks to the 103 incredible volunteers and staff who have participated in this program since 2007! Thank you also to National Park Service staff who have supported the effort and assisted in recruiting and coordinating volunteers: Marc Albert, Rachel Vincent, Bonnie Schwartz, and Mary Raczko. We greatly appreciate Captain Russ Bowles and his capable and professional staff at UMass Boston Marine Operations for providing transportation on the water. Thanks to Dr. Brian Mitchell and Dr. Peter Paton for their earlier support in program

development. This project was supported and funded by the Northeast Temperate Network Inventory and Monitoring Program of the National Park Service.

Literature Cited

- Allison, A.B., J.E. Ballard, R.B. Tesh, J.D. Brown, and M.G. Ruder. 2015. Cyclic avian mass mortality in the northeastern United States is associated with a novel orthomyxovirus. *Journal of Virology* 89:1389–1403.
- Andrews, R. (Compiler). 1990. Coastal waterbird colonies: Maine to Virginia 1984–85. US Fish and Wildlife Service, Newton Corner, MA. 807 pp.
- Ballard J.R., R.M. Mickley, S.E.J. Gibbs, C.P. Dwyer, C. Soos. 2017. Prevalence and distribution of Wellfleet Bay virus exposure in the Common Eider (*Somateria mollissima*). *Journal of Wildlife Diseases* 53:81–90.
- BirdLife International. 2015. European red list of birds. Office for Official Publications of the European Communities, Luxembourg City, Luxembourg.
- Blodget, B.G., and J.E. Livingston. 1996. Coastal colony-nesting waterbirds: The Massachusetts status report 1994–1995. *Massachusetts Wildlife* 4:10–20.
- Blodget, B.G., and S.M. Melvin. 1996. Massachusetts Tern and Piping Plover Handbook: A Manual for Stewards. Massachusetts Division of Fisheries and Wildlife, Westborough, MA. 82 pp.
- Bond, A.L., S.I. Wilhelm, G.J. Robertson, and S. Avery-Gomm. 2016. Differential Declines among Nesting Habitats of Breeding Herring Gulls (*Larus argentatus*) and Great Black-Backed Gulls (*Larus marinus*) in Witless Bay, Newfoundland and Labrador, Canada. *Waterbirds* 39(sp1):143–151.
- Bowman, T.D., E.D. Silverman, S.G. Gilliland, and J.B. Leirness. 2015. Status and trends of North American sea ducks: Reinforcing the need for better monitoring. Pp. 1–28, *In* J.P.L. Savard, D.V. Derksen, D. Esler and J.M. Eadie (Eds.). *Ecology and Conservation of North American Sea Ducks*. Studies in Avian Biology. CRC Press, New York, NY. 610 pp.
- Davis, W.E., Jr., and J.C. Kricher. 2020. Glossy Ibis (*Plegadis falcinellus*), version 1.0. *In* S.M. Billerman (Ed.). *Birds of the World*. Cornell Lab of Ornithology, Ithaca, NY.
- Descamps, S., S. Jenouvrier, H.G. Gilchrist and M.R. Forbes. 2012. Avian cholera, a threat to the viability of an Arctic seabird colony? *PLoS One* 7(2):e29659.
- Dieval, H., J.F. Giroux and J.-P.L. Savard. 2011. Distribution of Common Eiders, *Somateria mollissima*, during the brood-rearing and moulting periods in the St. Lawrence Estuary, Canada. *Wildlife Biology* 17(2):124–134.
- Donehower, C.E., and D.M. Bird. 2008. Gull predation and breeding success of Common Eiders on Stratton Island, Maine. *Waterbirds* 31(3):454–462.
- Dorr, B.S., J.J. Hatch, and D. . Weseloh. 2020. Double-crested Cormorant (*Phalacrocorax auritus*), version 2.0. *In* A.F. Poole (Ed.). *Birds of the World*. Cornell Lab of Ornithology, Ithaca, NY. Available online at <https://doi.org/10.2173/bow.doccor.01>. Date Accessed: September 14, 2020.
- Erwin, R.M., C.J. Conway, S.W. Hadden, J.S. Hatfield, and S.M. Melvin. 2003. Waterbird-monitoring protocol for Cape Cod National Seashore and other coastal parks, refuges, and protected areas. Long-Term Coastal Ecosystem Monitoring Program, Cape Cod National Seashore, Wellfleet, MA. 97 pp.
- Environmental Systems Research Institute (ESRI). 2019. ArcGIS Desktop: Release 10.7.1. Redlands, CA.

- Gibbs, J.P. 1991. Spatial relationships between nesting colonies and foraging areas of Great Blue Herons. *The Auk* 108(4):764–770.
- Hamilton, D.J. 2001. Feeding behavior of Common Eider ducklings in relation to availability of rockweed habitat and duckling age. *Waterbirds* 233–241.
- Hatch, J.J. 1984. Rapid increase of Double-crested Cormorants nesting in southern New England. *American Birds* 1984:984–988.
- Hatch, J.J. 2001. Tern nesting in Boston Harbor: The importance of artificial sites. *Bird Observer* 29:187–193.
- Heusmann, H.W., and C.L. Trocki. 2020. Expanded Common Eider (*Somateria mollissima dresseri*) breeding range in Massachusetts is likely the result of transplants. *Wilson Journal of Ornithology* 132(1):176–183.
- Kushlan, J.A., and H. Hafner (Eds.). 2000. *Heron Conservation*. Academic Press, Cambridge, MA. 496 pp.
- Kushlan, J.A., M.J. Steinkamp, K.C. Parsons, J. Capp, M.A. Cruz, M. Coulter, I. Davidson, L. Dickson, et al. 2002. *Waterbird Conservation for the Americas – The North American waterbird conservation plan, Version 1*. Waterbird Conservation for the Americas, Washington, DC. 78 pp.
- Largay, E.F., and L.A. Sneddon. 2017. Vegetation inventory project: Boston Harbor Islands National Recreation Area, Massachusetts. Natural Resource Report. NPS/NETN/NRR—2017/1529. National Park Service. Fort Collins, CO. 396 pp.
- Mallory, M.L., R.A. Ronconi, R.B. Allen, C. Dwyer, S. Lair, C.D. Mallory, N.R. McLellan, G.R. Milton, G.J. Parsons, L. Savoy, and M.D. Tomlik. 2020. Annual movement patterns of American Common Eiders, *Somateria mollissima dresseri*. *Wildlife Biology* 2020(2). <https://doi.org/10.2081/wlb.00665>.
- Massachusetts Audubon Society. 2020. Important Bird Area Program. Available online at <https://www.massaudubon.org/our-conservation-work/wildlife-research-conservation/statewide-bird-monitoring/massachusetts-important-bird-areas-iba>. Accessed 14 September 2020.
- Massachusetts Division of Fisheries and Wildlife. 2015. 2015 Massachusetts State Wildlife Action Plan. Westborough, MA. 13 pp.
- Massachusetts Natural Heritage and Endangered Species Program. 2020. As listed in 321 CMR 10.90. Available online at <https://casetext.com/regulation/code-of-massachusetts-regulations/departments-321-cmr-division-of-fisheries-and-wildlife/title-321-cmr-1000-massachusetts-endangered-species-act-regulations/part-v-lists-designated-significant-habitats/section-1090-list-of-endangered-threatened-and-special-concern-species>. Accessed 10 January 2020.
- Melvin, S.M. 2010. Survey of coastal nesting colonies of cormorants, gulls, night-herons, egrets and ibises in Massachusetts, 2006–2008. Final Report. Natural Heritage and Endangered Species Program, Massachusetts Division of Fisheries and Wildlife, Westborough, MA. 48 pp.
- Mittelhauser, G.H., R.B. Allen, J. Chalfant, R.P. Schauffler, and L.J. Welch. 2016. Trends in the nesting populations of Herring Gulls (*Larus argentatus*) and Great Black-Backed Gulls (*Larus marinus*) in Maine, USA, 1977–2013. *Waterbirds* 39(sp1):57–67. <https://doi.org/10.1675/063.039.sp112>.
- North American Bird Conservation Initiative. 2016. *The State of North America's Birds 2016*. Environment and Climate Change Canada, Ottawa, ON, Canada. 8 pp. Available online at <https://www.stateofthebirds.org>.
- Nove, J. 2001. Birding the Boston Harbor Islands. *Bird Observer* 29:173–186.

- Parsons, K.C., S.R. Schmidt, and A.C. Matz. 2001. Regional patterns of wading bird productivity in Northeastern US estuaries. *Waterbirds* 24:323–330.
- Paton, P.W.C, R.J. Harris, and C.L. Trocki. 2005. Distribution and abundance of breeding birds in Boston Harbor. *Northeastern Naturalist* 12:145–168.
- Pershing, A.J., M.A. Alexander, C.M. Hernandez, L.A. Kerr, A. Le Bris, K.E. Mills, J.A. Nye, N.R. Record, H.A. Scannell, J.D. Scott, G.D. Sherwood, and A.C. Thomas. 2015. Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery. *Science* 350(6262):809–812.
- R Core Team. 2020. R: A language and environment for statistical computing. Version 3.6. R Foundation for Statistical Computing, Vienna, Austria. Available online at <https://www.R-project.org/>.
- Rothe, T.C., P.I. Padding, L.C. Naves, and G.J. Robertson. 2015. Harvest of sea ducks in North America: A Contemporary Summary. Pp.419–469, *In* J.P.L. Savard, D.V. Derksen, D. Esler, and J.M. Eadie (Eds.). *Ecology and Conservation of North American Sea Ducks*. Studies in Avian Biology. CRC Press, New York, NY. 610 pp.
- Sea Duck Joint Venture. 2015. Sea Duck Joint Venture species status summary and information needs: Common Eider, American Race. 7 pp. Available online at <https://seaduckjv.org/wp-content/uploads/2014/08/AM-COEI-status-March-2015-FINAL.pdf>. Accessed 14 September 2020.
- Steinkamp, M., B. Peterjohn, V. Byrd, H. Carter, and R. Lowe. 2003. DRAFT Breeding season survey techniques for seabirds and colonial waterbirds throughout North America. USGS Waterbird Monitoring Partnership, Laurel, MD. 81 pp.
- Talke, S.A., A.C. Kemp, and J. Woodruff. 2018. Relative sea levels, tides, and extreme water levels in Boston Harbor from 1825 to 2018. *JGR Oceans* Volume 123(6):3895–3914.
- Trocki CL. 2009. Boston Harbor Islands coastal breeding bird monitoring: 2008 field season summary. National Park Service, Natural Resource Technical Report NPS/NETN/NRTR – 2009/209. Fort Collins, CO. 20 pp.
- Trocki, C.L., B.R. Mitchell, and P.W.C. Paton. 2015. Coastal breeding bird monitoring protocol for Boston Harbor Islands National Recreation Area: 2015 revision. Natural Resource Report NPS/NETN/NRR—2015/954. National Park Service, Fort Collins, CO. 168 pp.
- US Shorebird Conservation Plan. 2004. High Priority Shorebirds — 2004. Unpublished Report, US Fish and Wildlife Service, Arlington, VA. 5 pp.
- Wetlands International. 2012. Waterbird population estimates, Fifth Edition. Summary Report. Wetlands International, Wageningen, The Netherlands. 28 pp.