ASSESSING THE STATUS AND DISTRIBUTION OF FISH-EATING SEABIRDS ALONG THE COAST OF NORTH CAROLINA, FINAL REPORT

THE CENTER FOR CONSERVATION BIOLOGY

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Assessing the status and distribution of fish-eating seabirds along the coast of North Carolina, Final report

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Recommended Citation:

Watts, B. D., B. J. Paxton, and C. H. Hines. 2021. Assessing the status and distribution of fish-eating seabirds along the coast of North Carolina, Final report. Center for Biology Technical Report Series, CCBTR-21-11. William & Mary. 49 pp.

Project Partners:

North Carolina Wildlife Resource Commission
United States Fish and Wildlife Service
The Center for Conservation Biology
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Front Cover: Double-crested cormorant. Photo by Bryan Watts.

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EXECUTIVE SUMMARY

The double-crested cormorant (*Phalacrocorax auritus*) population has grown exponentially during the post-DDT era recolonizing historic nesting areas and expanding its range. Coastal North Carolina has emerged as a significant migration and winter site for the northeastern subspecies (*P. a. auritus*). Growing numbers within this area have prompted concerns about potential impacts to commercially important fish stocks. However, information is not available to assess potential impacts of cormorants on fish stocks or to inform possible management.

We estimated the population of cormorants (and other fish-eating seabirds) along the Outer Banks of North Carolina including near-shore (1 km seaward of beach) waters and sounds (Currituck, Albemarle, Pamlico, Core) during the fall passage and winter period (October through April). We used aerial transect (650 km) surveys and distance sampling to estimate the number of seabirds using near-shore and sound areas. We identified a network of communal night roosts and surveyed the network by air throughout the study period. We used survey results to estimate the number of bird days, the energy demand of the sea-bird community, and the fish demand in menhaden equivalents.

We estimated 642,043 seabirds were present during surveys within the near-shore and sound study areas between 20 November 2019 and 24 March 2020 while 765,636 seabirds were present during surveys within the near-shore and sound study areas between 04 November 2020 and 21 April 2021. Double-crested cormorants and northern gannets accounted for 88% of the total with brown pelicans, red-breasted mergansers, red-throated loons, common loons, and razorbills accounting for less than 12%, collectively.

The near-shore area accounted for 72% of the total estimate despite the fact that this area represented only 35% of the water surface within the study area. Seabird activity along the near-shore transect was concentrated around major inlets including Oregon, Hatteras, Ocracoke, and Core. Within sounds, seabirds had a southern distribution with Pamlico Sound accounting for >89% of the total estimate. We identified 25 communal night roosts during the study period. These roosts supported a total of 412,459 double-crested cormorants and brown pelicans during the five surveys between 4 November 2019 and 19 March 2020 and a total of 429,126 double-crested cormorants and brown pelicans during five surveys between 15 Oct 2020 and 19 May 2021. Cormorants dominated the roost count with pelicans accounting for only 6% of the total.

We estimated that the study area supported 18,333,709 bird days annually between 04 November and 21 April, with cormorants (76%) accounting for the majority. We estimated that the metabolic demand for the seabird community during the study period was more than 41 billion kilojoules. The menhaden equivalent of this demand is 10,502 metric tons (23.2 million pounds). Cormorants accounted for 67% of this demand. During the study period, the total demand of the community exceeded 60 metric tons per day in the fall, declined to a low of 16 metric tons per day in late February, then rebounded to 26 metric tons per day in April.

BACKGROUND

The double-crested cormorant (*Phalacrocorax auritus*) is a fish obligate that is endemic to North America and the western Caribbean with five described subspecies that are associated with large bodies of water with adequate prey populations (Hatch and Weseloh 1999). All subspecies have experienced wide population swings reaching a low in the early 1900s associated with persecution, exploitation, and habitat loss followed by a recovery that peaked in the 1950s and a subsequent decline attributed to pesticides (Wires et al. 2001). Since 1975, populations have exhibited explosive population growth that has included range expansions back into historic breeding/winter areas and extensions into new territories (Hatch 1995). The northeastern population (*P. a. auritus*) breeds in the upper Midwest, through the Great Lakes, and along the coast from the Canadian Maritimes to the mid-Atlantic and is highly migratory. Breeding populations west of Lake Huron migrate west of the Appalachians and primarily winter along the Mississippi River and upper Gulf Coast. Breeding populations east of Lake Huron migrate east of the Appalachians and winter throughout the Southeast from the Chesapeake Bay to Florida.

The increase in cormorant numbers over the past four decades has led to concerns about impacts to fish stocks throughout primary breeding and winter areas by the recreational and commercial fishing industries (e.g., Wires et al. 2001, Dorr et al. 2012). Double-crested cormorants are efficient predators capable of exploiting a wide range of fish taxa (Hatch and Weseloh 1999, Wires et al. 2001). Constituents have sought regulatory relief to reduce perceived depredation of targeted stocks. However, aside from the aquaculture industry, little information is currently available on 1) the number of cormorants within specific locations or 2) the threat that these populations pose to natural fish stocks.

As breeding populations within the Northeast have reached record highs, coastal North Carolina has emerged as a significant migration and wintering site (Wires et al. 2001). The population appears to be concentrated within the Sounds and associated near-shore waters. In particular, inlets that provide both foraging areas and substrates such as offshore spoil islands, bars and spits for communal roosts and loafing areas appear to be focal sites. Coincident with the increase in the population of cormorants over-wintering in coastal North Carolina has been an increase in public concern about potential impact of birds to fish stocks that are important to local economies.

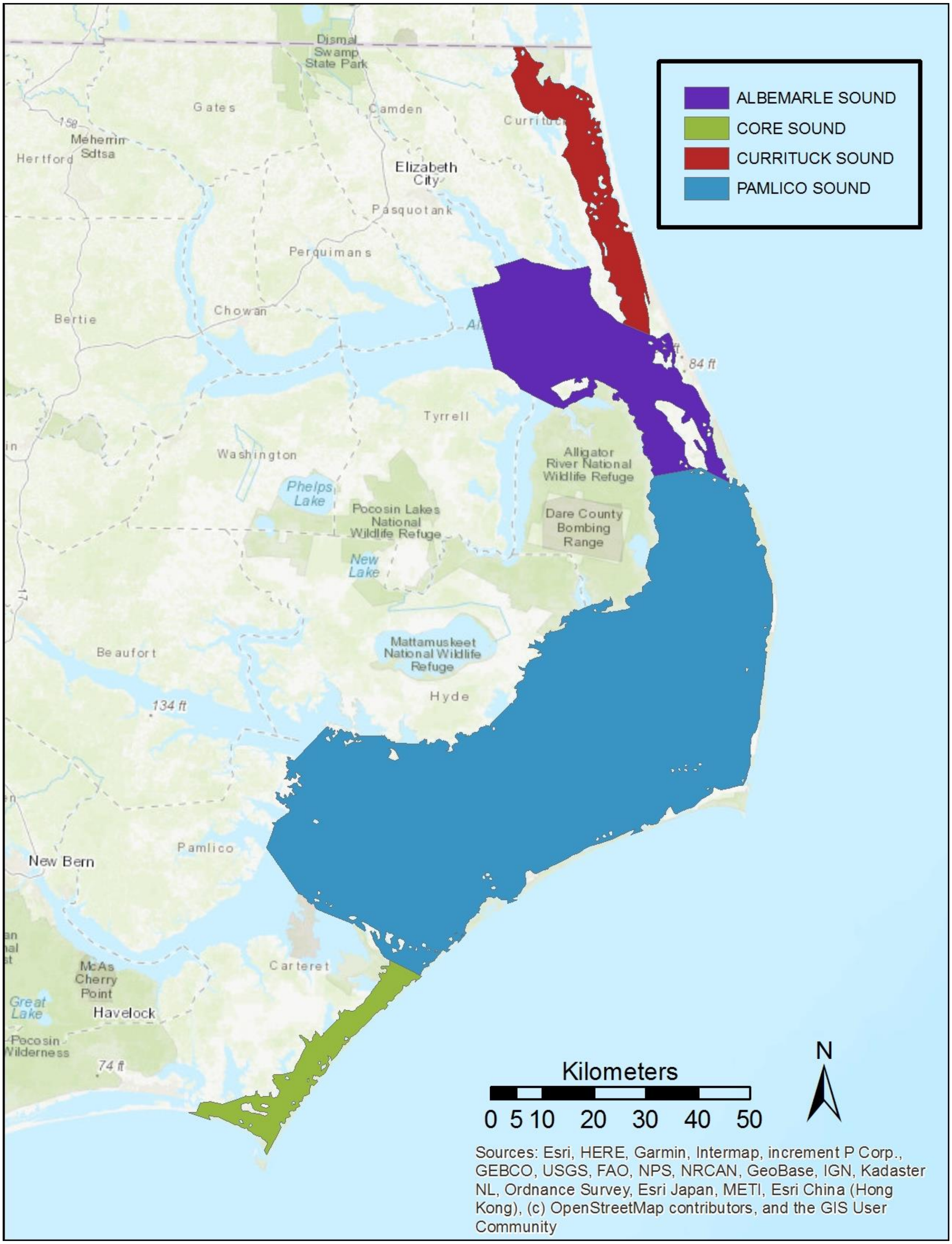
OBJECTIVES

Baseline information on the status, distribution, and seasonality of double-crested cormorants in coastal North Carolina is currently inadequate to assess potential impacts of this consumer population on fish stocks or to inform possible management scenarios. Our objectives with fieldwork include 1) to estimate the status, seasonality, and distribution of seabirds (with an emphasis on double-crested cormorants) using the coastal North Carolina study area during the non-breeding season (October – March, 2019-2020 and October – May, 2020-2021), 2) to identify the network of communal roosts used by the population, and 3) to estimate seasonal fish consumption by the seabird community.

STUDY AREA

The study area included the Atlantic Coast of North Carolina from the North Carolina/Virginia border south to Beaufort Inlet near Morehead City. This includes a 1-km band seaward from the outer coastal beaches and Currituck (361 km^2), Albemarle (854 km^2: including Roanoke and Croatan Sounds), Pamlico (4103 km^2), and Core Sounds (255 km^2) to the mouths of their major tributaries (Figure 1). This area includes 300 km of active beach and 5,582 km^2 of open water within sounds.

Figure 1. Map of study area showing the westward extent of sounds used during this study.



FIELD METHODS

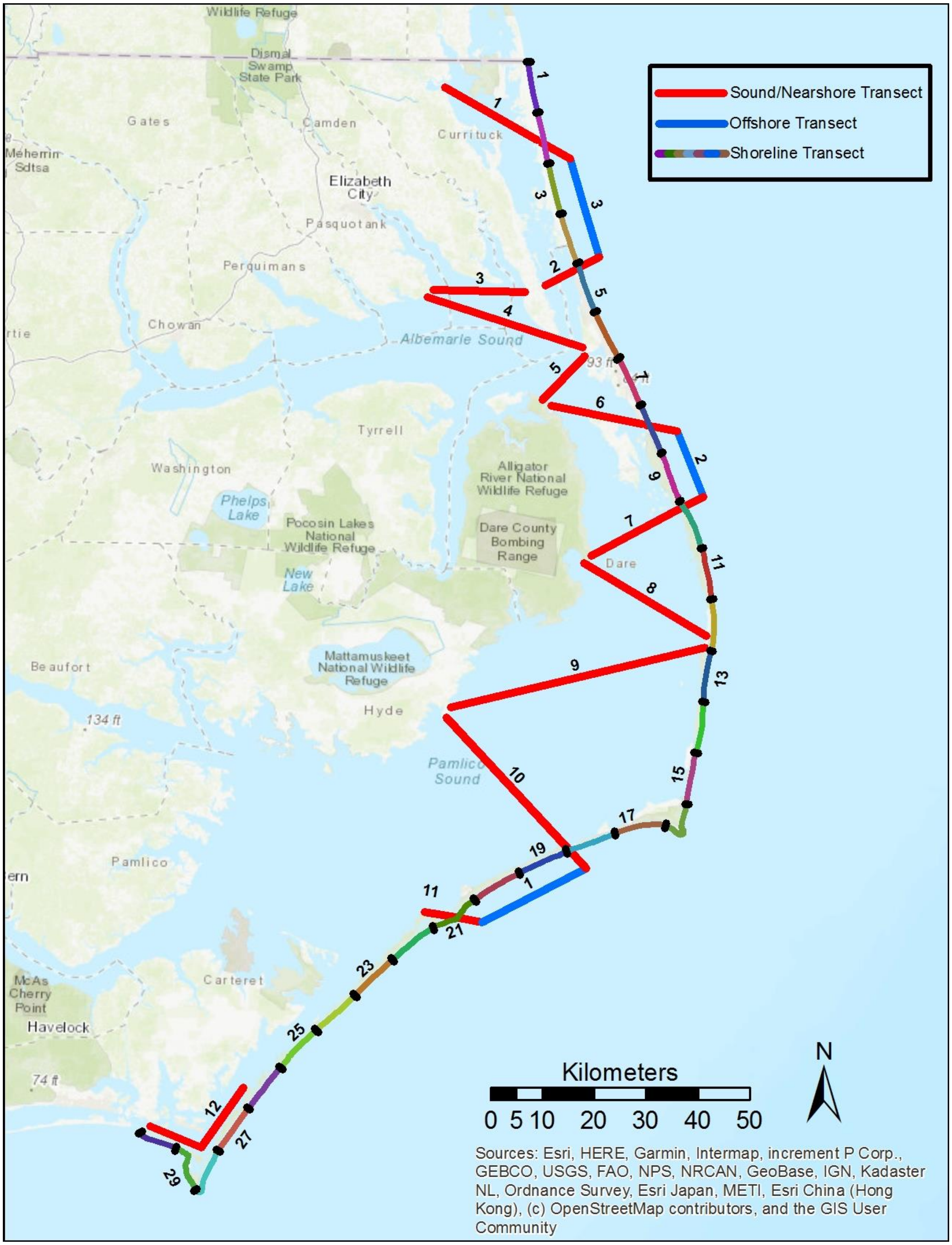
Transect Surveys

We estimated the densities (20 November 2019 to 24 March 2020 and 04 November 2020 to 21 April 2021) of fish-eating seabirds including double-crested cormorants (*Phalacrocorax auritus*), brown pelicans (*Pelecanus occidentalis*), northern gannets (*Morus bassanus*), common loons (*Gavia immer*), red-throated loons (*G. stellata*), red-breasted mergansers (*Mergus serrator*), and razorbills (*Alca torda*) using a network of repeatable aerial transects (Figure 2). The network covered the ocean out to the 3-mile (4.8-km) limit of commercial fishing and all four sounds. Ocean transects included all near-shore waters out to 1 km and three offshore transects (totaling 55.9 km) that followed the 3-mile contour. Sound transects included coverage of Currituck (2 transects totaling 26.4 km), Albemarle (4 transects totaling 78.4 km), Pamlico (4 transects totaling 131.7 km), and Core (2 transects totaling 29.9 km) Sounds. Due to the level of flight training activity and related restrictions on regular access, we excluded the Cherry Point Control Area from the transect footprint.

We surveyed the transect network using a Cessna 172 flying at an altitude of 61 m (200 ft) and a flight speed of 140 km/hr. We followed the outer beach from the Virginia/North Carolina border south to Beaufort Inlet, stopped for refueling in Beaufort and then flew the sound transects from Core Sound to Currituck Sound. For the purpose of aerial surveys and data analyses, we divided the near-shore ocean transect into 30, 10-km segments (Figure 2). All survey information recorded was associated with its respective segment. Sound transects were not subdivided. Transect flights took an average of 6.75 h to complete.

Transect surveys were a collaborative effort between two observers. The lead observer identified birds, recorded all birds detected, estimated the size of flocks encountered, and photographed a subset of flocks. The second observer used a GPS-enabled tablet computer to guide the plane's position along transects and inform the lead observer of segment boundaries. Both flocks and individual birds were encountered during all surveys. Flocks were on the water surface (double-crested cormorants, brown pelicans, northern gannets, red-breasted mergansers), flying (northern gannets) and loafing on the beach or sandbars (double-crested cormorants, brown pelicans). Foraging flocks that were flying or on the water surface could be detected from multiple kilometers away due to the activity and splashing on the water surface. We made a detour to overfly these flocks and estimate size before returning to the transect line. All flocks loafing on the beach could be readily detected from multiple km away and were estimated from the transect line. We stratified near-shore waters into four zones including beach, surf (waves actively breaking), swell (visible non-breaking waves) and beyond swell. All birds detected were placed within these zones.

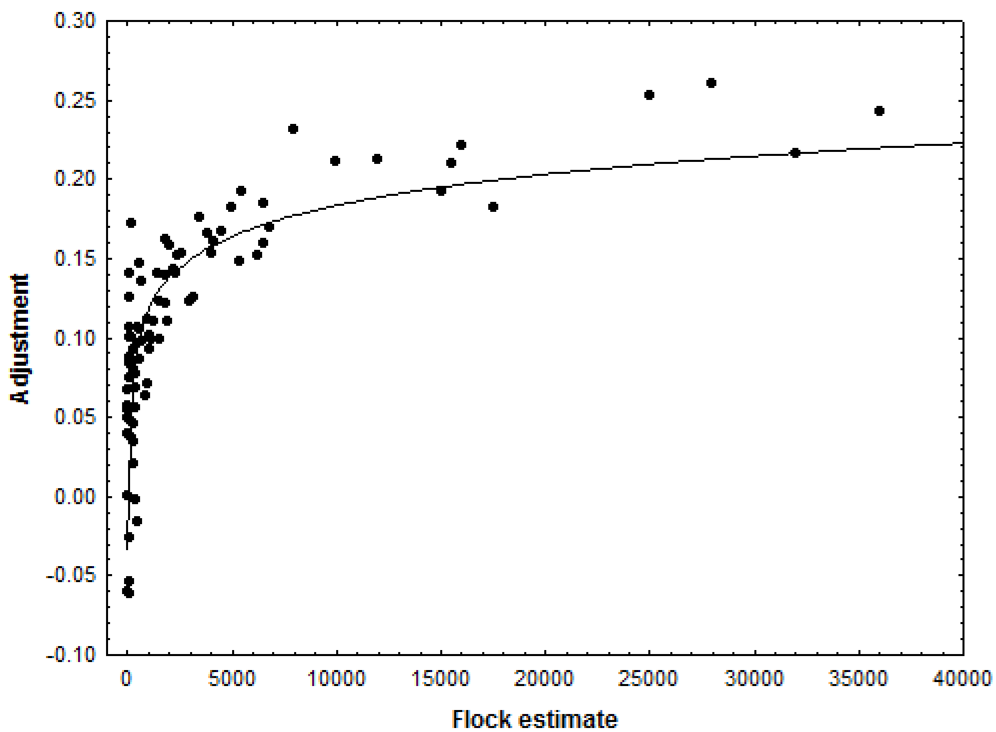
Figure 2. Map of study area showing the transect routes used for aerial surveys. Aerial surveys began on the North Carolina/Virginia border and proceeded south along the near-shore transect to Beaufort Inlet. The survey crew landed on Beaufort Airfield and refueled. Sound and offshore transects were surveyed south to north.



Estimating Seabird Flocks

Flocks encountered during transect surveys were estimated by the lead observer. Small flocks (<50) were enumerated entirely. Larger flocks were estimated using numerical scaling. We photographed a subset of flocks and used photographs to quantify estimation bias by comparing visual estimates to the actual number determined from photographs (N = 100). We overlaid a grid on photographs to facilitate enumeration of all birds within flocks <1,000 birds. We overlaid a grid on photographs of larger flocks and subsampled cells from throughout the flock to estimate a mean density and applied this mean to the number of occupied cells in order to estimate flock size. We evaluated the relationship between estimated and actual flock size by fitting a logistic (Figure 3). We found a systematic underestimate that increased with actual flock size. Small flocks were counted/estimated accurately, medium flocks were underestimated by 8-12% and larger flocks were underestimated by as much as 20%. We derived an equation for the systematic underestimate (Adjustment = -078 + (066*Log10(estimate)) and applied this equation to correct estimated flocks.

Figure 3. Plot of the percent undercount vs flock size. Percent undercount was the difference between the flock size estimated during aerials transect surveys and the actual size determined from photographs of flocks. The relationship was used to adjust flock estimates.



Detection of Birds

We assumed a 100% detection probability for roosting and foraging flocks along survey routes. We used double-observer techniques to estimate detection probabilities for birds that were not associated with flocks. We conducted paired independent surveys on the right side of the plane and recorded results for later comparison. Paired surveys were conducted for 20 seconds. We fit a multinomial-Poisson mixture model (Royle 2004) to the data to estimate the detection probability for the lead observer using the multinomPois function within the 'unmarked' package (Fiske and Chandler 2011) in program R (R Core Team 2020). Because sample size was limited, we grouped red-throated loon, common loon, and razorbills together and derived a common detection probability. Detection probabilities were derived separately for northern gannets, brown pelicans, and double-crested cormorant.

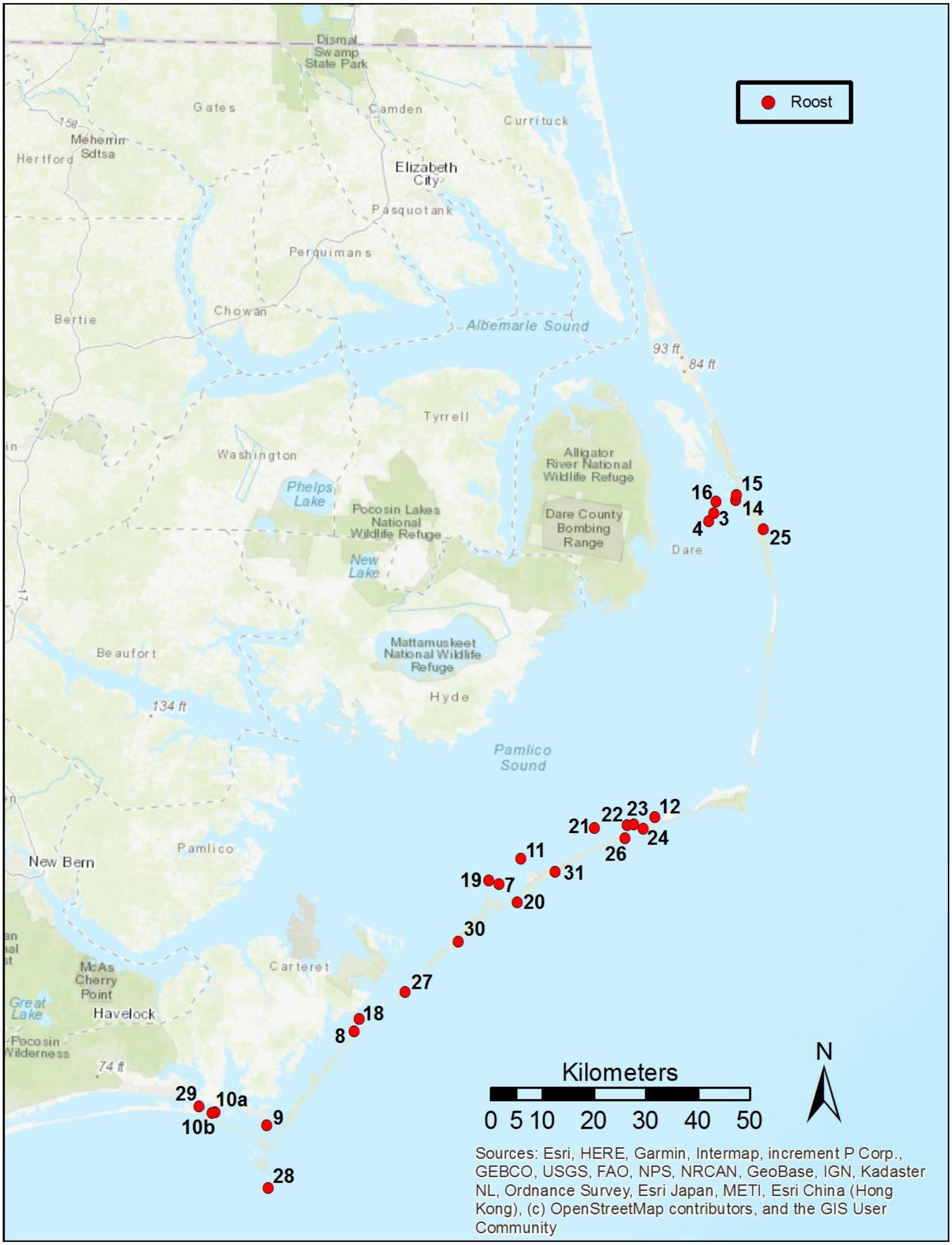
Detection Distance

We measured the distance from the transect line to a subsample of individual birds across species. We recorded altitude from the plane altimeter at the beginning of each transect segment. We used a TruePulse 360R laser rangefinder (Laser Technology) to estimate the declination angle from the plane to an individual bird. Altitude and declination angle were used to triangulate the distance of the bird from the transect line. Because sample size was limited, we grouped red-throated loons, common loons, red-breasted mergansers, and razorbills together. We generated detection distributions for northern gannets, brown pelicans, and double-crested cormorants separately.

Roost Surveys

We mapped and surveyed a network of communal night roosts using a Cessna 172 aircraft. Double-crested cormorants and brown pelicans move to communal roosts on land during the evening hours. Other seabirds including northern gannets, red-throated loons, common loons, red-breasted mergansers, and razorbills roost on the water and were not included in surveys. We initially overflew the study area on 2 October 2019 to map the network of land roosts (Figure 4). Roosts were then surveyed five evenings between 4 November 2019 to 9 March 2020 and four evenings between 15 October 2020 to 19 May 2021. Roosts were overflown at an altitude of 600-800 ft and a series of photographs was taken with a Canon 1dx camera with a 200-mm lens. The number of cormorants and pelicans using each roost was extracted from photographs. We overlaid a grid on photographs to facilitate enumeration of all birds within roosts with <1,000 birds. We overlaid a grid on photographs of larger roosts and subsampled cells from throughout the roost to estimate a mean density and applied this mean to the number of occupied cells in order to estimate roost size. We flew the roost network in the last 1.5 hours before dusk in order to minimize the number of birds that had not roosted. The network of roosts was trap-lined and the islands were flown between known roosts to survey for additional unknown roosts. Previously unknown roosts were mapped and surveyed.

Figure 4. Map of communal night roosts included within roost network. Roosts were surveyed by air during the last 1.5 hours before dusk.



ANALYTICAL METHODS

Transect Estimates

We handled flock and individual data separately to estimate bird numbers within each transect unit. Flock sizes were adjusted to account for the systematic undercount (see above). Distance sampling was used to estimate densities of birds detected that were not part of flocks. We first adjusted raw numbers by multiplying the reciprocal of detection bias (derived using double-observer techniques) for the lead observer. We applied the distribution of detection distances to the adjusted numbers. We used 200-m bins for all species except northern gannets. We used 500-m bins for gannets to account for greater detection distances. After data adjustments, we fit hierarchical distance sampling models (Royle et al. 2004) using the distsamp function within the 'unmarked' package (Fiske and Chandler 2011) in program R (R Core Team 2020) for all species stratified by all transect segments and surveys. We examined model fit of hazard-rate, half-normal, exponential, and uniform detection distributions and chose hazard-rate for all species. We included a sound parameter (Currituck, Albemarle, Pamlico, Core) for birds observed on sound transects and a segment parameter for birds observed along the near-shore transect. We then used our model results to generate densities of birds in each sound and near-shore segment. We combined flock and distance sampling datasets to estimate the total number of birds using each sound and near-shore transect segment for each survey period.

Fish Demand

We estimated daily and survey-wide fish demand by estimating bird days by species daily field metabolic rates and converting community-wide metabolic demand to fish equivalents. We used the transect survey results to estimate bird days by species. We used total estimates for each bird species from the five survey dates as population benchmarks and interpolated between these dates using a LOESS regression to fit a LOESS curve to the data (Cleveland et al. 1992). We used the LOESS curve to estimate birds by day across the study period and summed these to generate total bird days. Bird days were estimated by species and by geographic area (sounds and near-shore) for the period between 04 November and 21 April.

Many factors (e.g. body size, air temperature, water temperature, movement distances) contribute to an individual's daily energy budget (Ellis and Gabrielsen 2002). Without data on several contributing factors, we are unable to derive site-specific metabolic demand estimates. For this reason, we used published estimates of field metabolic rate (FMS = basal metabolic rate + additional costs of living) for the seabirds considered here (Table 1). We multiplied FMR by the population estimates/day to generate population-wide metabolic demand estimates for all seabird species across the study period. We combined species to generate a community-wide estimate of metabolic demand.

We estimated the fish-equivalents of population and community-wide metabolic demand. We do not know the diet of these seabird species. However, we regularly observed foraging flocks over schools of menhaden. We assume that a significant portion of the fish demand is focused on menhaden. We used the energy density of menhaden (4038 j/g) from Nelson et al. 2006 and calculate the fish-equivalents in metric tons based on menhaden. In the future as more information is available on seabird diet within the study area, we would be able to refine estimates of fish demand.

Table 1. Species, mass, field metabolic rate (FMR), and menhaden equivalent the seabirds included within transect surveys in coastal North Carolina. Mass was taken from Dunning (1993), FMR was taken from Ellis and Gabrielson (2002) and the energy density of menhaden was taken from Nelson et al. (2006).

Species	Mass (kg)	FMR (kJ/d)	Menhaden equivalent (g/d)
Northern Gannet	2,999.5	3,062.07	758.31
Double-crested Cormorant	1,674.0	2,094.70	518.75
Brown Pelican	3,438.0	4,690.15	1,161.50
Red-breasted Merganser	1,021.5	1,518.69	376.10
Red-throated Loon	1,551.0	1,993.17	493.60
Common Loon	4,134.0	3,773.23	934.43

RESULTS

Transect Surveys

We estimated 434,581 seabirds were present within the near-shore and sound study areas during the five survey flights from 20 Novemeber2019 to 24 March 2020 (Table 2) and 783,001 seabirds were present during six flights from 04 November 2020 to 21 April 2021 (Table 3). Numbers varied by geographic area (sound vs near-shore), species and date (Appendix 1-14). The near-shore area accounted for 69% of the total estimate, despite the fact that this area represented only 35% of the water surface within the study area. Double-crested cormorants dominated the seabird community within the study area accounting for 82% of the total estimate. Northern gannets accounted for 6%. No other species exceeded 5% of the total. Species exhibited a range of seasonal patterns. Double-crested cormorants, brown pelicans, common loons, and red-throated loons all exhibited a wave during late fall with numbers reaching their lowest during January. Cormorants and pelicans began to move back through the area during late February and March. Northern gannets and red-breasted mergansers moved into the area, reached a winter peak during January, and then moved out of the area by the end of the survey periods.

Table 2. Total estimates of seabirds within sounds and near-shore portions of the study area. Estimates were derived from transect surveys.

Species by Area	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020	Total
Northern Gannet						
Ocean	6177	4797	7081	4920	47	23,022
Sound	777	252	6,346	748	245	8,368
Total	**3,848**	**2,690**	**9,802**	**3,192**	**281**	**19,815**
Double-crested Cormorant						
Ocean	193382	68626	44840	41397	33054	381,299
Sound	25377	64025	14986	11219	50166	165774
Total	**122,390**	**99,414**	**38,119**	**33,296**	**67,229**	**360,351**
Brown Pelican						
Ocean	10,183	6911	1995	774	307	20172
Sound	920	163	97	319	1484	2981
Total	**6,994**	**4,100**	**1,230**	**842**	**1,717**	**14,878**
Red-breasted Merganser						
Ocean	0	0	503	175	160	838
Sound	0	0	0	0	0	0
Total	**0**	**0**	**487**	**166**	**151**	**805**
Red-throated Loon						
Ocean	680	207	719	1249	322	3178

Species by Area	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020	Total
Sound	0	20316	3089	3454	865	27,726
Total	**650**	**20,513**	**3,762**	**4,631**	**1,172**	**30,732**
Common Loon						
Ocean	201	502	409	730	191	2033
Sound	1,452	3,346	957	287	0	6043
Total	**464**	**1,562**	**285**	**338**	**46**	**2,696**

Table 3. Total estimates of seabirds within sounds and near-shore portions of the study area between 04 Novemeber2020 and 21 April 2021. Estimates were derived from transect surveys.

Species by Area	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021	Total
Northern Gannet							
Ocean	51	20803	2114	50	3098	1	26118
Sound	934	4,462	18,363	1,551	1,342	1,071	27,724
Total	**51**	**25,265**	**20,477**	**1,601**	**7,781**	**1,072**	**56,249**
Double-crested Cormorant							
Ocean	9618	224159	52466	114343	42901	73330	516,817
Sound	26670	27,383	4,397	12,519	12,399	11,738	95,107
Total	**14,876**	**251,541**	**56,863**	**126,862**	**100,761**	**85,068**	**635,974**

Species by Area	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021	Total
Brown Pelican							
Ocean	3762	7251	3902	346	36	1099	16396
Sound	2,777	8,202	1,640	1,551	1,196	3,085	18,452
Total	**3,761**	**15,453**	**5,541**	**1,897**	**1,496**	**4,183**	**33,940**
Red-breasted Merganser							
Ocean	0	0	1538	14938	0	0	16,476
Sound	0	0	0	0	0	0	0
Total	**0**	**0**	**1,537**	**14,723**	**0**	**0**	**8,130**
Red-throated Loon							
Ocean	0	0	85	175	0	0	259
Sound	1,616	1,852	11,411	11,868	1,941	1,164	29,854
Total	**1,616**	**1,852**	**11,495**	**12,042**	**2,078**	**1,163**	**30,250**
Common Loon							
Ocean	0	60	470	420	0	4	953
Sound	1,616	9,182	2,361	1,730	1,200	1,163	17,254
Total	**1,616**	**9,241**	**2,830**	**2,149**	**1,451**	**1,166**	**18,458**

Ocean Surveys

Near Shore Surveys – The 1-km near-shore survey area supported the most dense and diverse seabird community throughout the study area (Table 2). We estimated that 431,262 birds were present during the five transect surveys from 20 November 2019 through 24 March 2020 and 577,245 seabirds were present during the six transect flights from 04 November 2020 through 23 April 2021 (Tables 3-4, Appendices 1-14). Most of these birds were distributed within approximately 300 m of the shoreline. The use of features within this band varied between species (Table 4). Large numbers of cormorants and pelicans were counted loafing on isolated beaches. Large congregations of cormorants would form on beaches near foraging flocks and move back and forth between loafing and foraging. Small numbers of pelicans, cormorants and loons would use the active surf zone around breaking waves. However, the swell zone was the most important water zone within the entire study area supporting more than 99% of the red-throated loons and a significant portion of pelicans, cormorants, and common loons. The zone between the outer boundary of swells and 1 km was dominated by northern gannets and cormorants. Cormorants formed large foraging flocks within the swell zone and east of the swell zone. All flocks observed were within the 1 km outer boundary. Gannets and occasionally pelicans mixed in with these foraging flocks. Gannets extended well out to sea.

Seabirds along the near-shore survey area were concentrated around major inlets including Oregon, Hatteras, Ocracoke, and Core (Appendix 1-14). These inlets account for a significant percentage of the cormorant, gannet, and pelican activity along the shoreline. Loons and mergansers were not associated with these areas. During calm survey days, an obvious plume of water from the sounds ballooned out from the inlet and seabird activity was mostly contained within this plume. During windy days, the plume was often displaced down the shoreline and birds were associated with these areas. Gannets in particular would periodically come from offshore and assemble within the water plume around the inlets.

Table 4. Distribution of seabirds observed along the near-shore transects in coastal North Carolina. Beach refers to birds roosting or loafing on beaches or sandbars, surf refers to the band of actively breaking waves, swell refers to the band of waves that are not breaking and beyond swell is the band of water from the outer boundary of swells out to the 1-km limit of the transect.

Species	Beach	Surf	Swell	Beyond Swell
Northern Gannet	0 (0)	11 (0.02)	4551 (11.3)	35,639 (88.7)
Double-crested Cormorant	167,216 (32.4)	1,983 (0.4)	326,186 (63.2)	20,388 (4)
Brown Pelican	12,636 (66)	1,323 (6.9)	1,633 (8.5)	3,539 (18.5)
Red-breasted Merganser	0 (0)	0 (0)	16,812 (76.3)	5,227 (23.7)
Red-throated Loon	0 (0)	4 (0.3)	1,321 (99.0)	10 (0.7)
Common Loon	0 (0)	0 (0)	913 (78.4)	252 (21.6)
Total	**179,852 (30)**	**3,322 (0.6)**	**351,416 (58.6)**	**65,056 (10.8)**

Offshore Surveys – The seabird community surveyed along the 3-mile contour was less dense and less diverse compared to the near-shore surveys. The offshore community was dominated by northern gannets with low densities of loons. From January through March 2020 and from January through February 2021 razorbills were present within the northern portion of the study area. We did not attempt to extrapolate from the near shore to the offshore surveys to estimate population size within the extensive area between 1 and 4.8 km.

Sound Surveys

We estimated 210,892 seabirds were present within sounds during the five transect surveys from 20 November 2019 through 24 March 2020 and 188,391 seabirds were present during the six transect flights from 04 November 2020 through 23 April 2021 (Table 4, Appendix 15 & 16). The double-crested cormorant was the dominant species (65% of the total) followed by red-throated loon (14% of total) during the study. All remaining species accounted for less than 10%. Seabirds had a southern distribution with Pamlico accounting for 90%, followed by Albemarle at 5%, Core at 4%, and Currituck accounting for <1%. Pamlico Sound was the dominant water body for all seabirds.

Distribution of species within sounds varied between species. Both loon species occurred in the middle of the large sounds on the water within exploded flocks. Cormorants were distributed throughout the sounds but were concentrated on the sound side of inlets. Northern gannets occurred in low densities throughout the larger sounds. During most surveys, the number of gannets was not significant. The exception to this was on 28 January 2020 during high east winds when a large number of gannets moved from the ocean side through the inlets into the large sounds.

Table 5. Results of seabird transect surveys of sounds in Coastal North Carolina. Numbers (% of total) are estimated totals across ten surveys between (20 November 2019 – 24 March 2020) and 04 Novemeber2020 to 23 April 2021.

Species	Currituck	Albemarle	Pamlico	Core	Total
Northern Gannet	178 (0.5)	2231 (6.2)	33446 (92.7)	236 (0.6)	36,092
Double-crested Cormorant	1,070 (0.4)	10,986 (4.2)	241,016 (92.3)	7,808 (3.0)	260,881
Brown Pelican	198 (0.9)	2,457 (11.5)	11,126 (51.9)	7,652 (35.7)	21,433
Red-throated Loon	233 (0.4)	3,279 (5.7)	53,133 (92.2)	936 (1.6)	57,580
Common Loon	194 (0.8)	2,920 (4.2)	19,733 (84.7)	936 (1.9)	23,297
Total	1,874 (0.5)	21,874 (5.5)	358,454 (89.8)	17,081 (4.3)	**399,283**

Roost Surveys

We identified 25 communal night roosts during the study period. These roosts supported a total of 412,459 double-crested cormorants and brown pelicans during the five surveys between 4 November 2019 and 19 March 2020 and a total of 429,126 double-crested cormorants and brown pelicans during five surveys between 15 Oct 2020 and 19 May 2021 (Table 5 & 6, Appendix 17 & 18). Cormorants dominated the roost counts with pelicans accounting for only 6% of the total. The seasonal pattern of roost use for both cormorants and pelicans was very comparable to the pattern derived from transect surveys (Figures 2 & 3). During individual surveys, the total number of birds detected in roosts was related to the proportion of roosts within the network that was used during both survey seasons. On 6 December 2019 when roosts supported >150,000 birds, 88% of the roosts were occupied. On 17 December 2020 when roost supported >200,000 birds, 86% of roost were occupied. In contrast, on 19 May 2021 roosts supported <20,000 birds and only 24% of roosts were occupied.

Table 6. The number of seabirds counted across the entire network of communal night roosts within the study area during five aerial surveys between 4 November 2019 and 19 March 2020 by species.

Species	11/4 2019	12/6 2019	1/10 2020	2/3 2020	3/19 2020	Total
Double-crested Cormorant	106,334	144,709	45,916	43,666	54,557	395,182
Brown Pelican	7,885	5,861	942	1,080	1,509	17,277
Total	**114,219**	**150,570**	**46,858**	**44,746**	**56,066**	**412,459**

Table 7. The number of seabirds counted across the entire network of communal night roosts within the study area during five aerial surveys between 15 October 2020 and 19 May 2021 by species.

Species	10/15 2020	12/17 2020	3/18 2021	4/22 2021	5/19 2021	Total
Double-crested Cormorant	52,289	194,959	56,156	77,389	12,170	392,953
Brown Pelican	12,992	7,466	795	7,246	7,674	36,173
Total	**65,281**	**202,425**	**56,951**	**84,625**	**19,844**	**429,126**

Figure 2. Estimated number of Double-crested cormorants using roosts during the two survey periods. Dots indicate counts derived from the roost survey flights from November 2019 to 24 March 2020 and 15 Oct 2020 to 19 May 2021. Curves were fit using LOESS regression.

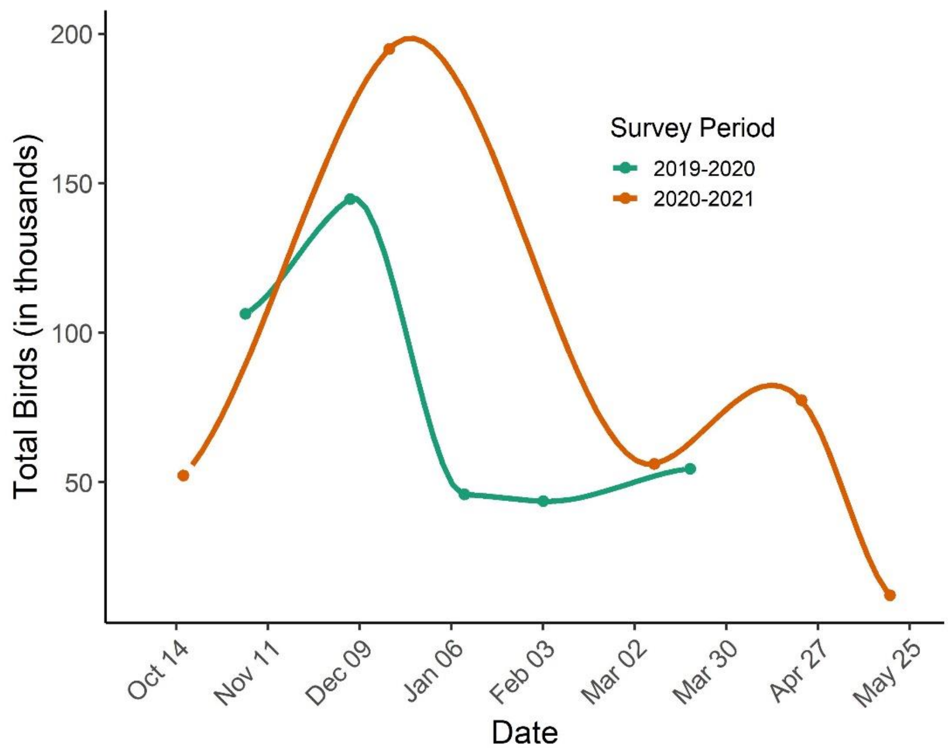
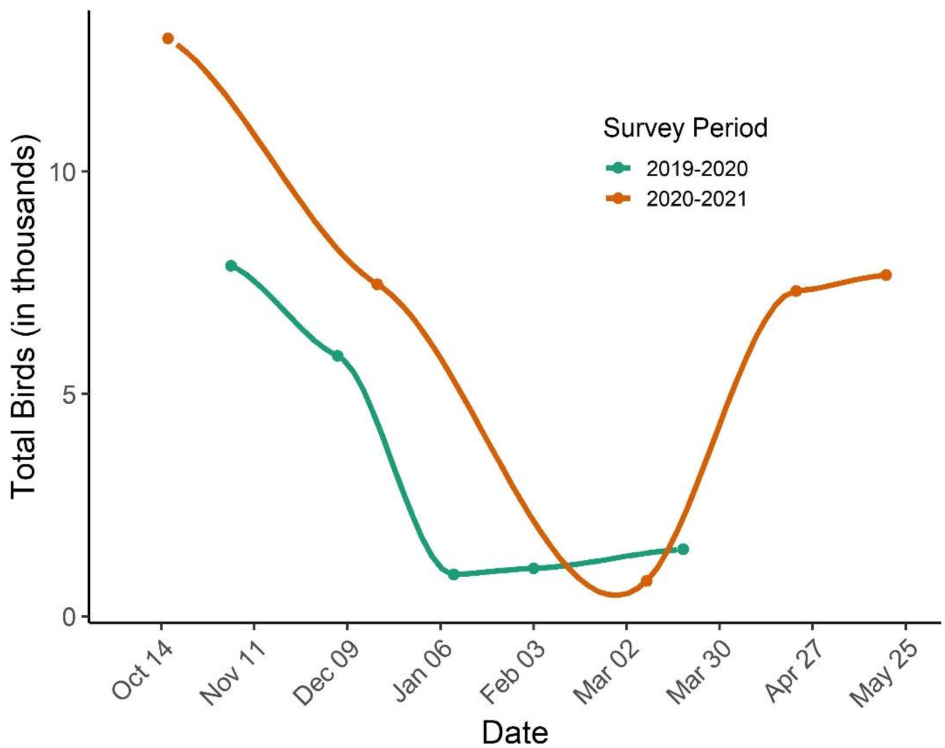


Figure 3. Estimated number of brown pelicans using roosts during the two survey periods. Dots indicate counts derived from the roost survey flights from November 2019 to 24 March 2020 and 15 October 2020 to 19 May 2021. Curves were fit using LOESS regression.



Fish Demand

Bird Days

We estimated that the study area annually supported 18,333,709 bird days between 04 November and 21 April with cormorants (76%) accounting for the majority (Table 6). Numbers varied between geographic areas, season, and species (Figure 5, 6). The greatest number of bird day occurred during December followed by a secondary peak in February. It should be noted that the study period ended before the passage of birds in spring of 2020 effectively truncating the first study season so late-spring estimates are based on data collected only during the second season.

Table 8. Estimated annual bird days (N), energetic demand (Kj) and menhaden equivalents (metric tons between 04 November and 21 April by species.

Species	Total Bird Days	Energy Demand (kJ)	Menhaden Equivalent (metric tons)
Northern Gannet	1,269,625	3,887,763,805	966
Double-crested Cormorant	13,938,970	29,197,913,064	7,231
Brown Pelican	831,838	2,783,749,869	966
Red-breasted Merganser	358,963	545155260	135
Red-throated Loon	1,369,878	2,730401315	676
Common Loon	568,413	2,144,755,857	531
Total	**18,333,709**	**41,289,739171**	**10,502**

Figure 4. Estimated number of birds by species along the near-shore transect. Dots indicate estimates derived from distance sampling along the transect during the survey flights from 04 Novemeber2019 to 24 March 2020 and 04 November 2020 to 21 April 2021. Curves were fit using LOESS regression.

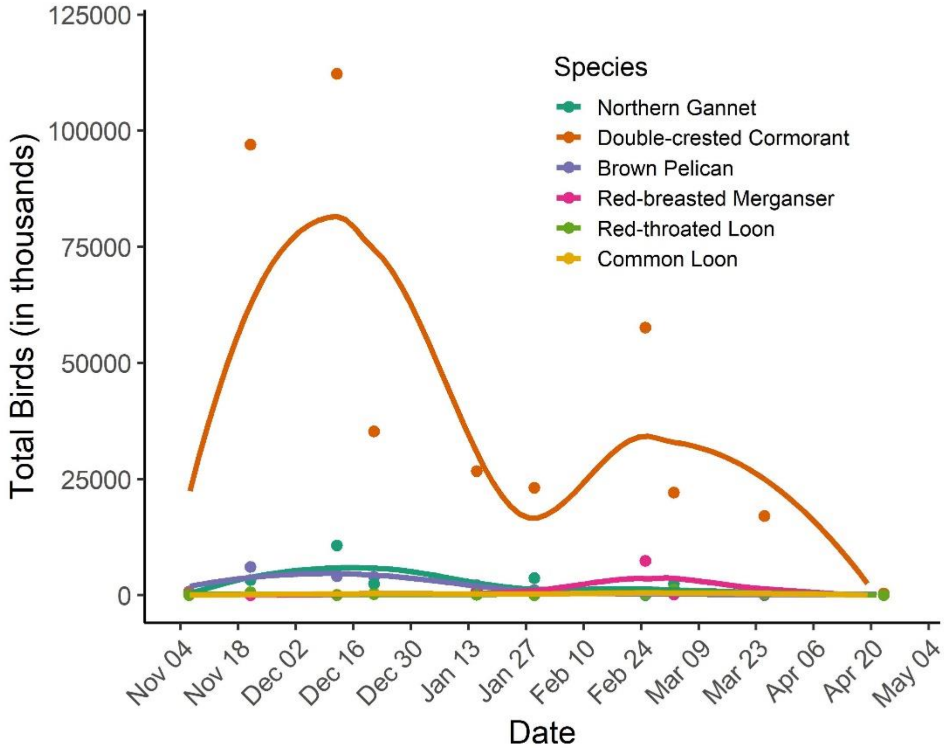
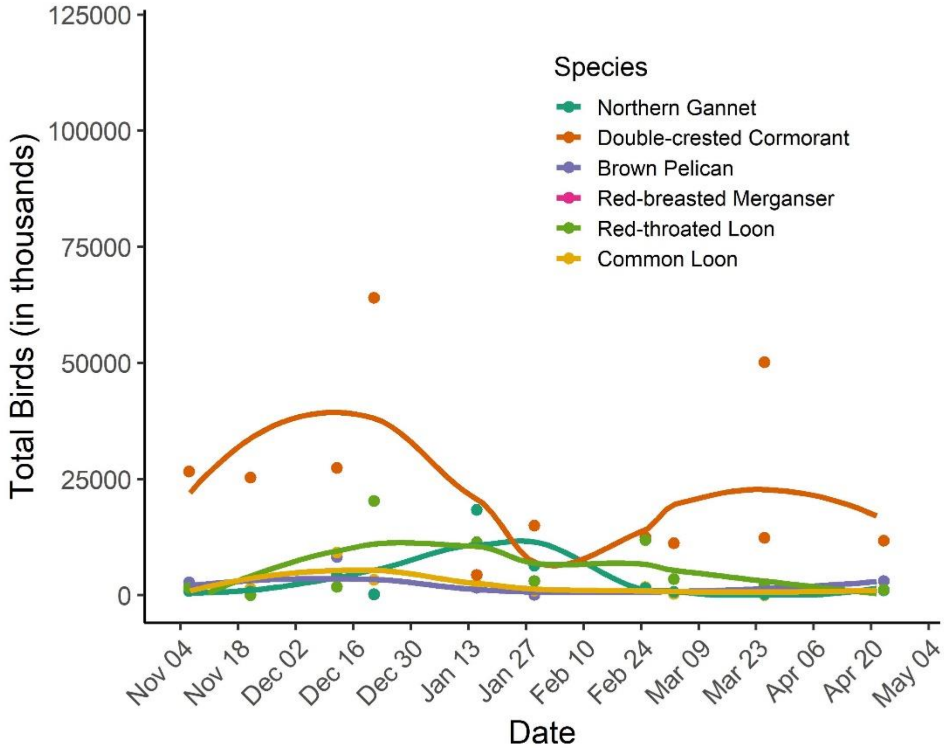


Figure 5. Estimated number of birds by species within sounds. Dots indicate estimates derived from distance sampling along the transects during the survey flights from 20 Novemeber2019 to 24 March 2020 and 04 November 2020 to 21 April 2021. Curves were fit using LOESS regression.



Fish Demand

We estimated that the annual metabolic demand for the seabird community between 04 November and 21 April was more than 41 billion kJ (Table 9). The menhaden equivalent of this demand is 10,502 metric tons (11.6 million pounds). During the study period, the average total demand of the community exceeded 60 metric tons per day in the fall, declined to a low of 16 metric tons per day by February but increased to 26 tons during a secondary peak in early April as loons and cormorants made their way northward (Figure 6).

Fish demand was higher in the near-shore area compared to the sounds (Table 9). The two areas exhibited similar seasonal patterns, though demand was greater in near-shore areas during peak bird densities in December (Figures 8 & 9). During this time, demand topped 45 metric tons along near shore areas (Figure 8) compared to approximately 35 metric tons in the sounds (Figure 9). Within the sound system, fish demand was highest (89%) within Pamlico Sound (Table 10).

Figure 6. Annual total (near-shore + sound) fish demand (menhaden equivalents) for all species between 04 November and 21 April. Fish demand was estimated for each species using the estimate of bird days, field metabolic rate and the energy density of menhaden. The gray shaded area represents standard error for each day.

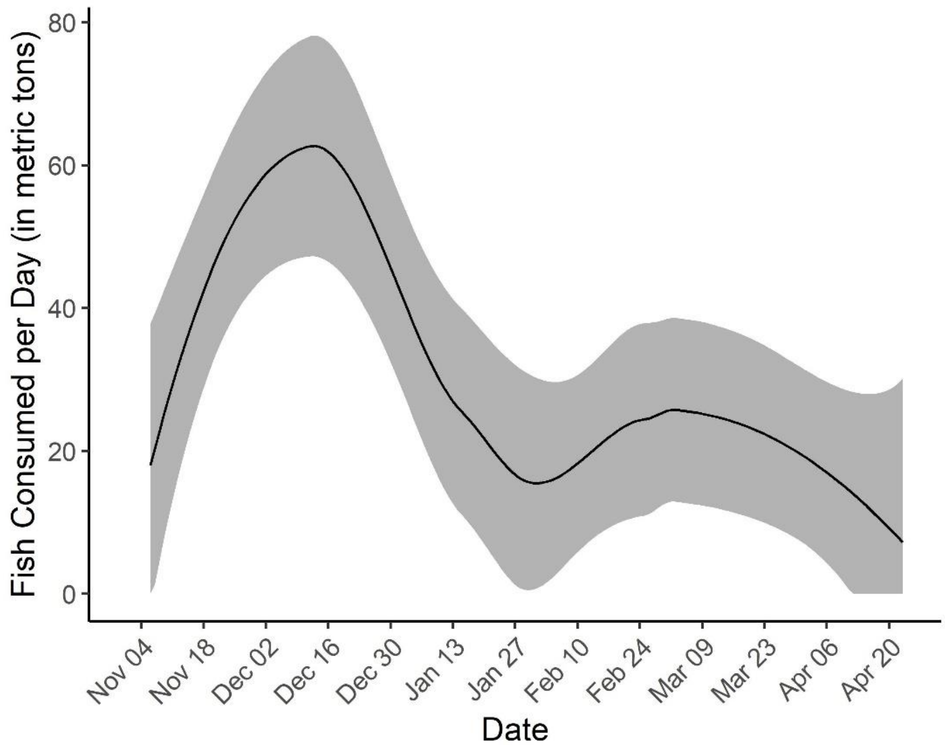


Figure 7. Annual total (near-shore + sound) fish demand (menhaden equivalents) by species between 04 November and 21 April. Fish demand was estimated for each species using the estimate of bird days, field metabolic rate and the energy density of menhaden.

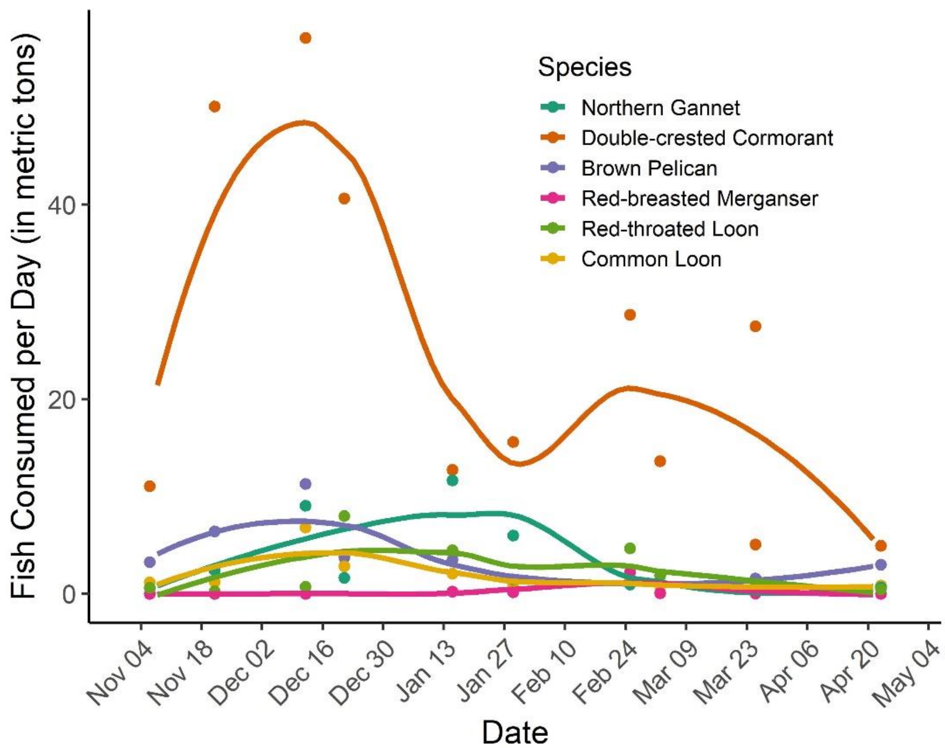


Table 9. Comparison of annual fish demand (metric tons) by geographic region (near-shore ocean, sound) and species between 04 November and 21 April.

Species	Ocean Menhaden Equivalent (metric tons)	Sound Menhaden Equivalent (metric tons)
Northern Gannet	388.6	587.1
Double-crested Cormorant	4,358.3	2,898.6
Brown Pelican	484.1	533.5
Red-breasted Merganser	72.6	0
Red-throated Loon	36.3	609.1
Common Loon	467.3	467.3
Total	5,807.3	5,095.6

Figure 8. Total fish demand (menhaden equivalents) for the near-shore area by species during the study period. Fish demand was estimated for each species using the estimate of bird days, field metabolic rate and the energy density of menhaden.

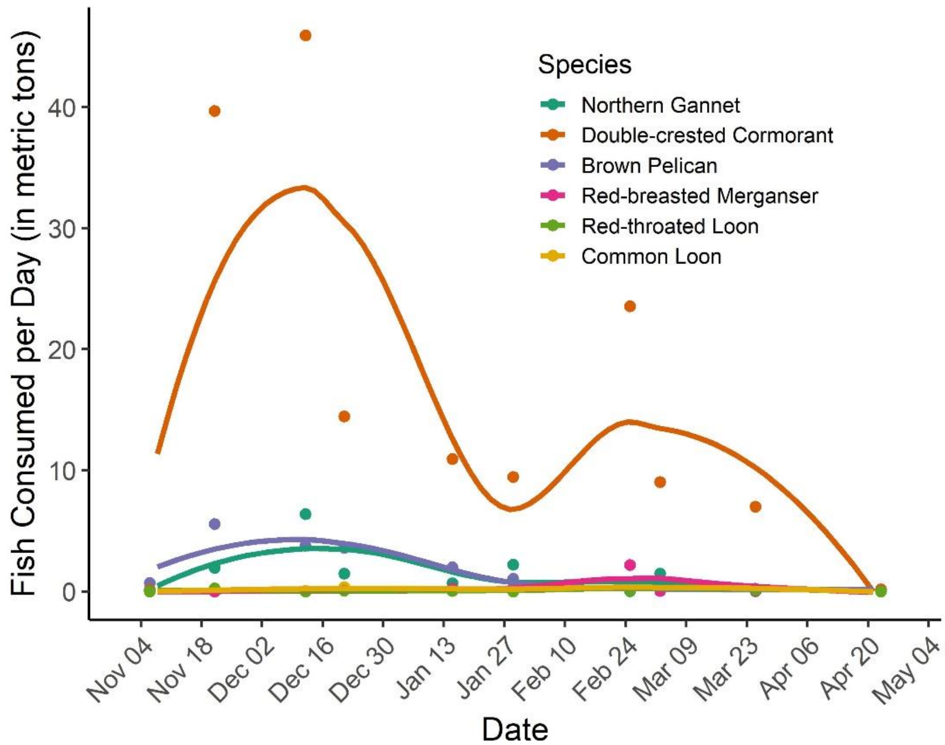


Figure 9. Total fish demand (menhaden equivalents) for the sound area by species during the study periods. Fish demand was estimated for each species using the estimate of bird days, field metabolic rate and the energy density of menhaden.

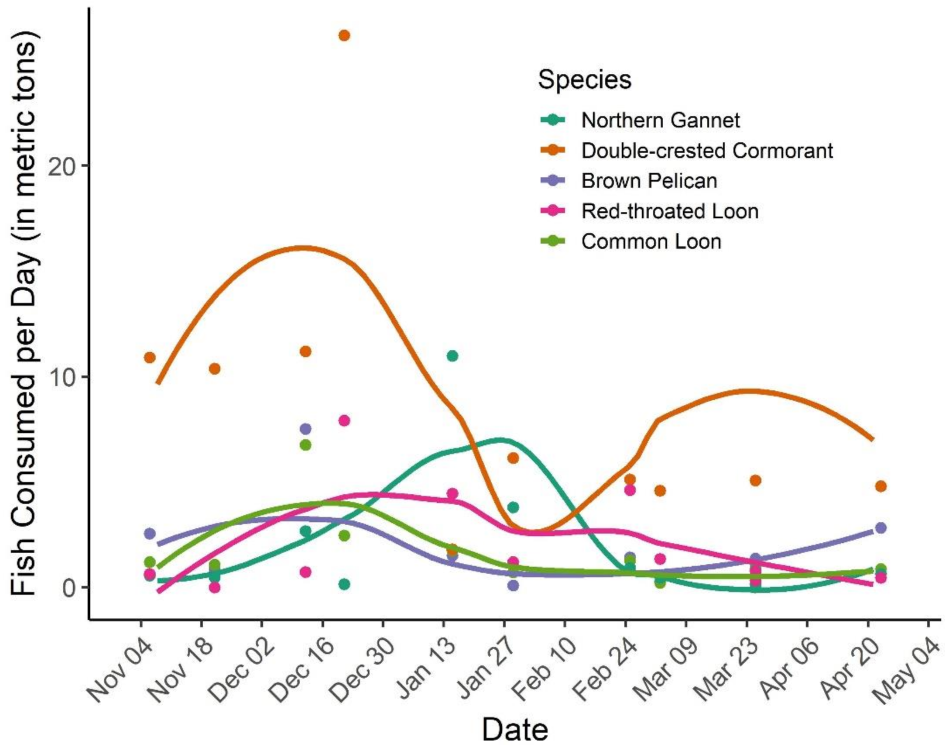


Table 10. Estimated fish demand (metric tons) in menhaden equivalents by sound and species for both study periods between 04 November and 21 April.

Species	Currituck Menhaden (metric tons)	Albemarle Menhaden (metric tons)	Pamlico Menhaden (metric tons)	Core Menhaden (metric tons)
Northern Gannet	0	7.8	578.5	0
Double-crested Cormorant	11.9	119.0	2,680.8	86.8
Brown Pelican	0.8	41.5	288.5	202.7
Red-breasted Merganser	0	0	0	0
Red-throated Loon	0.6	18.3	582.7	7.4
Common Loon	0.9	49.0	411.4	6.0
Total	**14.2**	**235.8**	**4541.9**	**303.7**

ACKNOWLEDGMENTS

This study was made possible by funding from the North Carolina Wildlife Resources Commission (NCWRC) and the United States Fish and Wildlife Service (USFWS). We thank Scott Anderson, John Carpenter, David Cobb, and the avian committee of the North Carolina Wildlife Resources Commission (NCWRC) for support throughout the project. Laura Duval assisted with initial ground surveys of communal roosts. We thank Captain Fuzzzo Shermer and Matt Crabbe for piloting aerial surveys. Erica Lawler and Marie Pitts provided important administrative support from William & Mary. Kate Pipkin provided administrative support from NCWRC. This work was made possible by funding from NCWRC and The Center for Conservation Biology.

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APPENDICES

Appendix 1. Estimated number (±SE) of northern gannets within near-shore and offshore segments between 11 November 2019 and 24 March 2020.

Location	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020
Segment 1	50±4	1±0	55±0	1±0	1±0
Segment 2	54±4	16±2	62±0	25±0	0
Segment 3	7±1	1,341±0	11±0	7±1	0
Segment 4	7±1	13±0	29±3	2±0	0
Segment 5	15±2	0	21±0	0	0
Segment 6	7±1	3±1	11±1	8±0	0
Segment 7	3±1	59±0	2±0	1±0	0
Segment 8	3±1	10±1	0	1±0	0
Segment 9	0	35±1	2±0	8±1	1±0
Segment 10	2,090±1	10±2	2,096±0	25±0	0
Segment 11	329±1	3±1	331±2	69±0	1±0
Segment 12	0	6±1	0	8±1	0
Segment 13	2±0	4±1	0	1±0	0
Segment 14	59±1	5±1	230±0	611±0	0
Segment 15	10±2	24±0	15±1	7±0	4±0
Segment 16	3±1	0	4±1	15±2	1±0
Segment 17	12±2	13±2	21±0	20±0	1±0
Segment 18	2±0	0	0	0	1±0
Segment 19	351±5	608±1	359±0	12±0	0
Segment 20	0	1±0	0	166±0	0
Segment 21	0	20±1	5±1	1±0	0
Segment 22	0	0	12±2	0	0
Segment 23	0	11±1	16±2	9±1	0
Segment 24	2±0	165±0	7±1	1±0	0
Segment 25	0	0	5±1	0	0
Segment 26	19±2	1±0	27±1	1,353±0	0
Segment 27	6±1	6±1	41±4	12±0	0
Segment 28	4±1	8±1	9±0	7±1	1±0
Segment 29	5±1	1±0	67±5	48±0	1±0
Segment 30	7±2	0	0	0	0
Offshore 1	171±3	18±1	27±2	2±0	3±0
Offshore 2	13±2	5±1	180±8	14±2	2±0
Offshore 3	9±1	12±1	25±2	2±0	3±0
Nearshore	3056±46	2378±31	3444±41	2433±25	14±5
Offshore	193±7	36±4	233±13	19±3	9±1

Appendix 2. Estimated number (±SE) of northern gannets within near-shore and offshore segments between 04 November 2020 and 23 April 2021.

Location	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021
Segment 1	0	0	0	2±0	0	0
Segment 2	0	0	0	2±0	2±0	0
Segment 3	0	3±1	0	6±1	0	0
Segment 4	0	0	0	3±1	0	0
Segment 5	0	2±0	0	4±1	0	0
Segment 6	0	2±0	1±0	1±0	0	0
Segment 7	0	3±1	1±0	1±0	0	0
Segment 8	6±1	3±1	0	0	0	1±0
Segment 9	0	0	0	0	0	0
Segment 10	0	2±0	0	1±0	2±0	0
Segment 11	0	0	0	0	0	0
Segment 12	1±0	532±8	1±0	2±0	0	0
Segment 13	1±0	2,371±6	1±0	1±0	0	0
Segment 14	0	7±1	2±1	1±0	2±0	0
Segment 15	0	4±1	3±1	0	1,059±2	0
Segment 16	0	1,707±4	8±1	0	3,884±0	0
Segment 17	1±0	39±4	2±0	1±0	2±0	0
Segment 18	1±0	36±4	5±1	0	3±1	0
Segment 19	0	12,266±2	2±1	2±0	602±5	0
Segment 20	0	1,048±5	3±1	0	356±4	0
Segment 21	0	24±3	4±1	0	0	0
Segment 22	2±0	4±1	15±2	0	69±5	0
Segment 23	8±1	1,485±4	0	0	4±1	0
Segment 24	11±2	17±2	5±1	0	2±0	0
Segment 25	4±1	0	5±1	0	0	0
Segment 26	0	0	5±1	2±0	0	0
Segment 27	0	3±1	15±2	0	0	0
Segment 28	8±1	1,200±1	2,015±3	2±0	37±4	0
Segment 29	0	0	0	0	0	0
Segment 30	0	0	0	1±0	0	0
Offshore 1	0±0	23±2	0	0	952±0	0
Offshore 2	0	2±0	0	0	0	0
Offshore 3	3±0	9±1	0	0	1±0	0
Nearshore	47±11	20,767±59	2,103±26	28±10	5,485±29	1±0
Offshore	3±1	35±4	10±2	21±3	953±1	0

Appendix 3. Estimated number (±SE) of double-crested cormorants within near-shore and offshore segments between 11 November 2019 and 24 March 2020.

Location	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020
Segment 1	0	283±4	0	26±6	21±5
Segment 2	0	0	0	172±16	14±4
Segment 3	0	0	0	110±13	19±5
Segment 4	0	0	0	33±7	14±4
Segment 5	0	0	13±4	61±9	12±4
Segment 6	16±4	80±10	57±4	400±5	19±5
Segment 7	0	0	13±4	2,507±4	12±4
Segment 8	0	0	0	64±9	17±4
Segment 9	2,148±9	2,111±6	32±4	17±5	0
Segment 10	802±3	2,107±5	8,308±5	5,235±31	3,881±18
Segment 11	63±3	0	18±4	0	702±11
Segment 12	0	0	0	521±14	28±6
Segment 13	0	0	0	228±15	34±6
Segment 14	13±3	87±11	113±4	627±32	32±6
Segment 15	30±6	0	0	87±11	14±4
Segment 16	0	274±11	90±4	505±4	44±7
Segment 17	0	194±6	38±7	452±16	840±4
Segment 18	99±12	4,451±4	238±4	252±5	50±4
Segment 19	935±5	10,443±12	291±4	269±9	88±4
Segment 20	54±8	680±4	547±33	314±22	60±6
Segment 21	90,145±3	6,640±9	6,865±19	14±4	7,192±4
Segment 22	45±6	1,226±17	198±17	111±4	389±5
Segment 23	0	87±11	62±4	394±4	17±4
Segment 24	37±6	19±5	0	16±4	29±4
Segment 25	2,423±8	1,068±5	623±4	28±4	3,087±21
Segment 26	0	4,461±10	321±4	8,887±4	135±6
Segment 27	13±3	75±8	87±11	671±5	75±4
Segment 28	12±3	217±18	2,397±4	17±5	102±4
Segment 29	14±4	615±35	2,681±5	0	92±8
Segment 30	0	18±5	0	0	0
Offshore 1	0	0	0	0	0
Offshore 2	0	0	0	0	0
Offshore 3	0	0	0	0	0
Nearshore	96855±94	35146±206	22997±155	22030±279	17033±182
Offshore	0	0	0	0	0

Appendix 4. Estimated number (±SE) of double-crested cormorants within near-shore and offshore segments between 04 November 2020 and 23 April 2021.

Location	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021
Segment 1	17±4	39±3	12±4	41±7	51±8	31±5
Segment 2	10±3	10±3	24±5	11±3	39±7	45±3
Segment 3	0	9±3	24±5	13±4	17±5	8±2
Segment 4	56±3	9±3	12±4	13±4	30±6	0
Segment 5	23±4	0	0	32±6	14±4	390±2
Segment 6	9±3	33±6	12±4	14±4	20±5	8±2
Segment 7	0	0	24±5	11±3	29±6	12±3
Segment 8	13±3	9±3	12±4	13±4	83±11	8±2
Segment 9	11±3	0	0	7,644±22	26±6	1,044±3
Segment 10	0	461±3	332±4	94±11	156±15	30,050±3
Segment 11	0	0	19±5	11±3	9,805±7	29,337±2
Segment 12	0	0	29±6	11±3	14±4	0
Segment 13	122±13	27±5	12±4	13±4	4,2307±5	8±2
Segment 14	0	0	0	11±3	4,784±8	1,091±10
Segment 15	0	0	191±18	13±4	12,044±4	7,637±2
Segment 16	32±6	21±4	665±9	13±4	11,682±5	9±3
Segment 17	25±5	0	1,228±4	13±4	14±4	0
Segment 18	182±3	6,249±3	637±16	942±3	1,244±12	0
Segment 19	9±3	21±4	25,862±4	0	4,453±26	0
Segment 20	0	0	621±4	13±4	10,181±14	0
Segment 21	2,767±3	136,239±3	592±7	96,717±5	18,981±9	0
Segment 22	2,055±3	9±3	21,712±5	26±5	3,466±4	0
Segment 23	0	52±7	109±12	7,394±4	489±29	8±2
Segment 24	10±3	0	13±4	119±13	801±9	13±3
Segment 25	4,260±3	80,853±6	52±8	17±4	4,299±25	3,567±5
Segment 26	0	36±6	45±7	1,107±3	1,059±17	12±3
Segment 27	10±3	9±3	141±4	11±3	109±7	22±4
Segment 28	0	25±3	20±4	0	17±5	9±3
Segment 29	0	21±4	54±4	11±3	192±4	8±2
Segment 30	0	17±4	0	0	21±6	0
Offshore 1	0	0	0	0	0	31±5
Offshore 2	0	0	0	0	0	45±3
Offshore 3	0	0	0	0	0	8±2
Nearshore	9,617±72	224,158±86	52,466±168	114,343±153	88,362±291	73,330±79
Offshore	0	0	0	0	0	0

Appendix 5. Estimated number (±SE) of brown pelicans within near-shore and offshore segments between 11 November 2019 and 24 March 2020.

Location	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020
Segment 1	135±11	20±4	0	5±1	8±2
Segment 2	258±15	56±7	0	0	4±1
Segment 3	92±5	0	0	0	0
Segment 4	168±10	0	0	0	0
Segment 5	139±7	0	0	0	0
Segment 6	128±11	0	0	0	0
Segment 7	76±6	0	0	0	4±1
Segment 8	78±9	0	0	0	4±1
Segment 9	349±13	11±2	0	0	0
Segment 10	108±3	63±2	0	0	0
Segment 11	10±3	0	0	0	0
Segment 12	38±6	0	0	0	0
Segment 13	30±5	31±4	0	0	4±1
Segment 14	23±2	421±4	0	0	0
Segment 15	10±3	31±2	0	0	0
Segment 16	265±3	309±14	225±1	0	5±1
Segment 17	134±12	18±4	0	44±5	14±2
Segment 18	45±6	65±8	8±2	0	0
Segment 19	923±15	202±6	124±7	0	5±1
Segment 20	83±7	176±9	189±1	9±2	22±1
Segment 21	579±4	921±11	82±4	0	4±1
Segment 22	185±4	356±5	202±2	152±2	7±2
Segment 23	0	17±4	8±2	0	0
Segment 24	61±8	22±2	5±1	0	5±1
Segment 25	1,124±13	0	84±2	0	0
Segment 26	779±11	580±10	76±1	0	6±1
Segment 27	57±7	0	6±2	8±2	16±1
Segment 28	24±5	13±3	6±2	5±1	14±1
Segment 29	8±2	522±5	5±1	5±1	39±2
Segment 30	141±3	0	28±5	0	0
Offshore 1	0	0	0	0	0
Offshore 2	0	0	0	0	0
Offshore 3	0	0	0	0	8±2
Nearshore	6,067±223	3,844±115	1,053±39	231±18	170±30
Offshore	0	0	0	0	0

Appendix 6. Estimated number (±SE) of brown pelicans within near-shore and offshore segments between 04 November 2020 and 23 April 2021.

Location	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021
Segment 1	105±6	7±2	16±2	0	7±2	0
Segment 2	98±7	9±3	8±2	0	8±2	5±1
Segment 3	237±7	31±5	8±2	0	5±1	7±2
Segment 4	1,113±6	0	769±2	0	11±2	0
Segment 5	18±4	94±4	13±3	0	25±4	4±1
Segment 6	31±5	15±3	38±5	0	0	0
Segment 7	87±7	0	769±2	0	6±2	0
Segment 8	143±7	0	628±9	25±2	13±2	0
Segment 9	9±3	7±2	19±4	272±3	16±3	4±1
Segment 10	22±2	11±3	284±2	8±2	5±1	36±1
Segment 11	24±4	9±3	8±2	4±1	0	552±2
Segment 12	14±3	13±3	0	0	0	4±1
Segment 13	0	91±9	0	0	7±2	5±1
Segment 14	7±2	83±9	0	0	5±1	4±1
Segment 15	9±3	94±9	0	0	6±2	42±2
Segment 16	18±4	452±10	65±3	10±2	0	0
Segment 17	58±6	7±2	0	4±1	5±1	12±2
Segment 18	82±6	1,508±8	24±4	0	6±2	5±1
Segment 19	9±3	184±9	6±2	0	5±1	9±2
Segment 20	25±5	60±3	0	0	0	4±1
Segment 21	268±2	1,929±6	100±2	0	0	0
Segment 22	855±6	16±4	782±2	0	15±3	5±1
Segment 23	55±6	83±9	0	6±1	5±1	9±2
Segment 24	906±4	48±6	24±4	4±1	6±2	10±2
Segment 25	38±5	21±4	27±3	0	0	26±3
Segment 26	14±3	20±4	21±4	0	21±3	10±2
Segment 27	9±3	23±2	47±5	4±1	29±4	8±2
Segment 28	279±6	61±2	191±7	0	0	6±1
Segment 29	15±3	2,321±5	42±2	4±1	76±1	309±1
Segment 30	15±4	37±7	0	0	9±2	12±3
Offshore 1	0	0	0	0	0	0
Offshore 2	0	0	0	214±0	0	0
Offshore 3	0	0	0	0	0	0
Nearshore	3,761±143	7,251±151	3,902±85	570±20	300±55	1,098±49
Offshore	0	0	0	0	0	0

Appendix 7. Estimated number (±SE) of red-breasted merganser within near-shore and offshore segments between 11 November 2019 and 24 March 2020.

Location	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020
Segment 1	0	0	0	0	0
Segment 2	0	0	216±20	0	0
Segment 3	0	0	0	7±2	0
Segment 4	0	0	0	0	0
Segment 5	0	0	0	0	0
Segment 6	0	0	0	0	0
Segment 7	0	0	0	0	0
Segment 8	0	0	0	0	0
Segment 9	0	0	0	14±2	6±1
Segment 10	0	0	0	0	0
Segment 11	0	0	0	0	0
Segment 12	0	0	0	0	0
Segment 13	0	0	0	0	0
Segment 14	0	0	0	0	0
Segment 15	0	0	0	0	0
Segment 16	0	0	0	0	0
Segment 17	0	0	0	0	0
Segment 18	0	0	0	0	0
Segment 19	0	0	0	0	0
Segment 20	0	0	0	0	0
Segment 21	0	0	0	0	0
Segment 22	0	0	0	0	0
Segment 23	0	0	0	0	0
Segment 24	0	0	0	0	0
Segment 25	0	0	0	0	0
Segment 26	0	0	0	0	0
Segment 27	0	0	0	0	0
Segment 28	0	0	0	0	0
Segment 29	0	0	0	0	0
Segment 30	0	0	0	0	0
Offshore 1	0	0	0	0	0
Offshore 2	0	0	0	0	0
Offshore 3	0	0	0	0	0
Nearshore	0	0	216±20	22±4	6±1
Offshore	0	0	0	0	0

Appendix 8. Estimated number (±SE) of red-breasted merganser within near-shore and offshore segments between 04 November 2020 and 23 April 2021.

Location	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021
Segment 1	0	0	935±1	537±1	0	0
Segment 2	0	0	602±1	2,708±1	0	0
Segment 3	0	0	0	8,742±1	0	0
Segment 4	0	0	0	333±1	0	0
Segment 5	0	0	0	237±1	0	0
Segment 6	0	0	0	335±1	0	0
Segment 7	0	0	0	610±1	0	0
Segment 8	0	0	0	886±1	0	0
Segment 9	0	0	0	297±1	0	0
Segment 10	0	0	0	0	0	0
Segment 11	0	0	0	0	0	0
Segment 12	0	0	0	0	0	0
Segment 13	0	0	0	34±1	0	0
Segment 14	0	0	0	0	0	0
Segment 15	0	0	0	0	0	0
Segment 16	0	0	0	0	0	0
Segment 17	0	0	0	0	0	0
Segment 18	0	0	0	0	0	0
Segment 19	0	0	0	0	0	0
Segment 20	0	0	0	0	0	0
Segment 21	0	0	0	0	0	0
Segment 22	0	0	0	0	0	0
Segment 23	0	0	0	0	0	0
Segment 24	0	0	0	0	0	0
Segment 25	0	0	0	0	0	0
Segment 26	0	0	0	0	0	0
Segment 27	0	0	0	0	0	0
Segment 28	0	0	0	0	0	0
Segment 29	0	0	0	0	0	0
Segment 30	0	0	0	0	0	0
Offshore 1	0	0	0	0	0	0
Offshore 2	0	0	0	0	0	0
Offshore 3	0	0	0	0	0	0
Nearshore	0	0	1,537±3	14,723±15	0	0
Offshore	0	0	0	0	0	0

Appendix 9. Estimated number (±SE) of red-throated loons within near-shore and offshore segments between 11 November 2019 and 24 March 2020.

Location	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020
Segment 1	0	0	0	0	0
Segment 2	0	0	160±17	119±14	9±3
Segment 3	0	0	0	100±13	9±3
Segment 4	0	0	200±20	95±13	7±2
Segment 5	0	0	0	27±6	7±2
Segment 6	0	8±2	0	203±20	0
Segment 7	0	7±2	0	119±14	8±3
Segment 8	0	0	105±3	142±16	23±5
Segment 9	0	0	0	13±4	30±6
Segment 10	0	0	0	0	0
Segment 11	0	0	0	54±9	7±2
Segment 12	0	0	0	19±5	12±3
Segment 13	25±6	0	12±4	11±4	12±3
Segment 14	0	0	0	22±6	23±5
Segment 15	0	0	0	14±4	207±4
Segment 16	0	0	12±4	0	0
Segment 17	0	0	0	0	0
Segment 18	0	0	0	0	0
Segment 19	76±11	0	0	0	0
Segment 20	124±15	6±2	0	0	0
Segment 21	19±5	0	0	0	0
Segment 22	107±13	20±4	18±5	0	0
Segment 23	0	0	17±5	0	0
Segment 24	18±5	0	11±4	0	7±2
Segment 25	0	0	0	0	0
Segment 26	0	0	12±4	0	0
Segment 27	0	0	11±4	0	0
Segment 28	45±8	0	0	44±8	0
Segment 29	0	0	105±3	0	0
Segment 30	0	0	0	0	0
Offshore 1	17±3	0	0	0	0
Offshore 2	0	0	0	0	0
Offshore 3	0	0	34±5	57±7	5±1
Nearshore	418±65	42±12	479±77	980±140	179±50
Offshore	17±3	0	34±5	57±7	5. 87±1

Appendix 10. Estimated number (±SE) of red-throated loons within near-shore and offshore segments between 04 November 2020 and 23 April 2021.

Location	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021
Segment 1	0	0	0	0	0	0
Segment 2	0	0	0	8±3	0	0
Segment 3	0	0	0	6±2	13±3	0
Segment 4	0	0	7±2	18±4	12±3	0
Segment 5	0	0	12±3	15±4	12±3	0
Segment 6	0	0	12±3	6±2	8±3	0
Segment 7	0	0	7±2	0	11±3	0
Segment 8	0	0	0	0	32±6	0
Segment 9	0	0	6±2	12±3	16±4	0
Segment 10	0	0	0	13±3	6±2	0
Segment 11	0	0	7±2	6±2	6±2	0
Segment 12	0	0	6±2	7±2	0	0
Segment 13	0	0	0	14±4	0	0
Segment 14	0	0	0	8±3	0	0
Segment 15	0	0	6±2	7±2	7±2	0
Segment 16	0	0	0	6±2	0	0
Segment 17	0	0	0	0	6±2	0
Segment 18	0	0	0	0	0	0
Segment 19	0	0	0	6±2	0	0
Segment 20	0	0	9±2	0	0	0
Segment 21	0	0	0	0	0	0
Segment 22	0	0	0	0	0	0
Segment 23	0	0	0	0	0	0
Segment 24	0	0	0	8±3	0	0
Segment 25	0	0	0	0	0	0
Segment 26	0	0	0	0	0	0
Segment 27	0	0	0	0	0	0
Segment 28	0	0	0	0	0	0
Segment 29	0	0	7±2	6±2	0	0
Segment 30	0	0	0	0	0	0
Offshore 1	0	0	0	0	0	0
Offshore 2	0	0	0	5±2	0	0
Offshore 3	0	0	0	7±2	0	0
Nearshore	0	0	84±27	161±51	137±38	0
Offshore	0	0	0	13±4	0	0

Appendix 11. Estimated number (±SE) of common loons within near-shore and offshore segments between 11 November 2019 and 24 March 2020.

Location	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020
Segment 1	0	9±3	0	0	7±2
Segment 2	0	144±16	67±109	116±14	6±2
Segment 3	0	0	0	66±10	6±2
Segment 4	0	26±6	47±8	0	0
Segment 5	0	0	0	14±4	6±2
Segment 6	0	0	0	0	0
Segment 7	0	11±3	9±3	14±4	6±2
Segment 8	0	0	0	0	7±2
Segment 9	0	0	0	10±3	0
Segment 10	0	9±3	0	154±17	0
Segment 11	0	0	0	27±6	7±2
Segment 12	0	11±3	0	18±5	0
Segment 13	0	0	10±3	21±5	7±2
Segment 14	0	9±3	0	37±7	7±2
Segment 15	0	106±4	8±3	13±4	0
Segment 16	0	53±9	0	0	0
Segment 17	0	0	31±6	0	0
Segment 18	6±2	0	0	0	0
Segment 19	0	0	0	0	0
Segment 20	0	0	8±3	0	0
Segment 21	22±4	0	0	0	0
Segment 22	0	0	0	0	0
Segment 23	0	0	17±5	0	0
Segment 24	0	0	8±3	0	0
Segment 25	0	0	0	0	0
Segment 26	0	0	9±3	0	0
Segment 27	0	0	0	0	0
Segment 28	0	0	8±3	13 ±4	0
Segment 29	0	0	9±3	0	0
Segment 30	8±3	28±7	11±4	0	0
Offshore 1	0	0	0	0	0
Offshore 2	0	0	0	8±23	0
Offshore 3	0	0	13±3	0	3±1
Nearshore	35±10	311±60	246±60	509±90	61±21
Offshore	0	0	13±3	8±3	1±0

Appendix 12. Estimated number (±SE) of common loons within near-shore and offshore segments between 04 November 2020 and 23 April 2021.

Location	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021
Segment 1	0	5±2	76±11	25.±6	8±3	0
Segment 2	0	0	86±12	12±4	13±4	0
Segment 3	0	0	11±4	17±5	7±3	0
Segment 4	0	5±2	31±7	43±8	10±3	0
Segment 5	0	6±2	17±5	46±8	9±3	0
Segment 6	0	5±2	22±6	20±5	12±4	0
Segment 7	0	5±2	27±6	0	78±3	0
Segment 8	0	5±2	21±6	156±5	29±6	0
Segment 9	0	5±2	14±5	21±5	8±3	0
Segment 10	0	5±2	0	22±6	8±3	0
Segment 11	0	5±2	14±5	25±6	13±4	0
Segment 12	0	0	27±6	12±4	0	0
Segment 13	0	0	10±4	18±5	9±3	0
Segment 14	0	0	13±4	29±6	0	0
Segment 15	0	0	14±5	12±4	9±3	0
Segment 16	0	5±2	11±4	10±4	41±7	0
Segment 17	0	0	0	10±4	0	0
Segment 18	0	0	0	0	8±3	0
Segment 19	0	0	0	10±4	0	0
Segment 20	0	5±2	10±4	0	0	0
Segment 21	0	0	0	10±4	0	0
Segment 22	0	0	0	0	0	0
Segment 23	0	0	0	10±4	0	0
Segment 24	0	0	10±4	14±4	8±3	0
Segment 25	0	0	0	0	0	0
Segment 26	0	0	0	11±4	8±3	0
Segment 27	0	0	10±4	0	0	0
Segment 28	0	0	0	0	8±3	0
Segment 29	0	0	0	12±4	31±6	0
Segment 30	0	0	0	0	0	0
Offshore 1	0	0	0	0	0	0
Offshore 2	0	0	9.34±3	0	5.57±2	4±4
Offshore 3	0	0	37.61±6	18±4	4±1	0
Nearshore	0	60±23	42±101	402±108	242±70	0
Offshore	0	0	47±9	18±4	9 ±4	4±4

Appendix 13. Estimated number (±SE) of razorbills within near-shore and offshore segments between 11 November 2019 and 24 March 2020.

Location	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020
Segment 1	0	0	0	0	0
Segment 2	0	0	0	0	0
Segment 3	0	0	0	0	0
Segment 4	0	0	0	0	0
Segment 5	0	0	0	0	0
Segment 6	0	0	0	0	0
Segment 7	0	0	0	0	0
Segment 8	0	0	0	0	0
Segment 9	0	0	0	0	0
Segment 10	0	0	0	0	0
Segment 11	0	0	0	0	0
Segment 12	0	0	0	0	0
Segment 13	0	0	0	0	0
Segment 14	0	0	0	0	0
Segment 15	0	0	0	0	0
Segment 16	0	0	0	0	0
Segment 17	0	0	0	0	0
Segment 18	0	0	0	0	0
Segment 19	0	0	0	0	0
Segment 20	0	0	0	0	0
Segment 21	0	0	0	0	0
Segment 22	0	0	0	0	0
Segment 23	0	0	0	0	0
Segment 24	0	0	0	0	0
Segment 25	0	0	0	0	0
Segment 26	0	0	0	0	0
Segment 27	0	0	0	0	0
Segment 28	0	0	0	0	0
Segment 29	0	0	0	0	0
Segment 30	0	0	0	0	0
Offshore 1	0	0	0	0	0
Offshore 2	0	0	35	10±2	0
Offshore 3	0	0	103	5±1	0
Nearshore	0	0	0	0	0
Offshore	0	0	138.1±15.4	15±3	0

Appendix 14. Estimated number (±SE) of razorbills within near-shore and offshore segments between 04 November 2020 and 23 April 2021.

Location	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021
Segment 1	0	0	0	0	0	0
Segment 2	0	0	0	0	0	0
Segment 3	0	0	0	0	0	0
Segment 4	0	0	0	0	0	0
Segment 5	0	0	0	0	0	0
Segment 6	0	0	10±3	0	0	0
Segment 7	0	0	0	0	0	0
Segment 8	0	0	0	0	0	0
Segment 9	0	0	0	0	0	0
Segment 10	0	0	0	0	0	0
Segment 11	0	0	0	0	0	0
Segment 12	0	0	0	0	0	0
Segment 13	0	0	0	0	0	0
Segment 14	0	0	0	0	0	0
Segment 15	0	0	0	0	0	0
Segment 16	0	0	0	0	0	0
Segment 17	0	0	0	0	0	0
Segment 18	0	0	0	0	0	0
Segment 19	0	0	0	0	0	0
Segment 20	0	0	0	0	0	0
Segment 21	0	0	0	0	0	0
Segment 22	0	0	0	0	0	0
Segment 23	0	0	0	0	0	0
Segment 24	0	0	0	0	0	0
Segment 25	0	0	0	0	0	0
Segment 26	0	0	0	0	0	0
Segment 27	0	0	0	0	0	0
Segment 28	0	0	0	0	0	0
Segment 29	0	0	0	0	0	0
Segment 30	0	0	0	0	0	0
Offshore 1	0	0	0	0	0	0
Offshore 2	0	0	7±2	99±11	0	0
Offshore 3	0	0	94±9	16±3	0	0
Nearshore	0	0	10±3	0	0	0
Offshore	0	0	101±11	115±13	0	0

Appendix 15. Estimated number of individuals by seabird species within specific sounds between 20 November 2019 and 24 March 2020.

Sound	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020
Northern Gannet					
Currituck	0	0	0	0	0
Albemarle	84±2	0	110.30±3	0	0
Pamlico	693±18	252±3	6,235.20±527	748.41±20.12	245±2
Core	-	0	0	0	0
Total	777±20	252±3	1,586.4±530	748.41±20.12	245±2
Double-crested Corm					
Currituck	64±9	61±9	62±9	208±80	197±72
Albemarle	402±28	1,140±201	1,022±178	1,030±182	3,3306±1,064
Pamlico	24,912±592	61,371±41,529	12,862±3,754	9,981±2,188	46,453±15,295
Core	-	1,453±108	1,040±134	0	186±39
Total	**25,378±629**	**64,025±41846**	**14,986±4075**	**11,219±2450**	**50,166±16470**
Brown Pelican					
Currituck	0	0	28.31±2.38	0	0
Albemarle	0	0	0	226.89±10.87	237.01±12
Pamlico	920±29	0	0	0	899.70±28
Core	-	163±20	68.39±5.33	91.64±8.30	347.02±63
Total	**920±29**	**163±20**	**96.7±7.7**	**318.5±19.2**	**1,483.7±102**
Red-throated Loon					
Currituck	0	0	53±10	0	0
Albemarle	0	667±99	424±47	0	0
Pamlico	0	19,309±6,650	2,405±243	3,351.78±425	865.53±36
Core	-	341±107	208±46	103±15	0

Sound	11/20/2019	12/20/2019	1/28/2020	3/2/2020	3/24/2020
Total	0	**5,079.2±6856**	**3,089±87**	**3,455±440**	866±36
Common Loon					
Currituck	38±5	0	0	0	0
Albemarle	303±24	444±51	0	287±20	0
Pamlico	1,112±58	2,790±314	866±37	0	0
Core	-	111±17	91±10	0	0
Total	**1453±88**	**3345±382**	**957±47**	**287±21**	0

Appendix 16. Estimated number of individuals by seabird species within specific sounds between 04 October 2020 and 23 April 2021.

Sound	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021
Northern Gannet						
Currituck	0	0	0	0	0	0
Albemarle	0	0	0	248±12	0	0
Pamlico	674±16	3,987±6378	17,6281±6999	1261±60	986±34	0
Core	0	41	0	0	0	0
Total	6734±16	**4,028±640**	**17,627±6998**	**9,537±1679**	**1509±17**	**0±0**
Double-crested Corm						
Currituck	89±19	97.24±18.33	18.60±1.00	46.65±5.73	125.91±38.44	101±26
Albemarle	761±121	856.74±134	0	599.27±77.36	837.07±142.89	723±103
Pamlico	25,227±580	23,909±5491	3,977±171	11,597±1756	10138±344	10,589±1,864
Core	592±285	2,520±6	118±1	276±48	1298±405	325±89
Total	**26,670±1646**	**27,383±5650**	**4,113±173**	**12,519±1886**	**12,399±5650**	**11,738±2082**
Brown Pelican						
Currituck	0	0	0	0	0	0
Albemarle	0±14	533±66	245.70±12.29	0	252±13	0
Pamlico	1,576±62	2969±367	1225.12±55	1261±59	0	1,538.60±106.34
Core	924±3	4668±69	0	0	0	1,035.24±210.47
Total	**2500±1006**	**8170±501**	**1470.8±64**	**1261.4±60**	**252±5**	**2079.8±316.8**
Red-throated Loon						
Currituck	0	0	0	0	0	0
Albemarle	0	0	516±65	0	0	0
Pamlico	0	1,525±111	10,809±3486	11,269±36454	1,493.34±102.	0

Sound	11/04/2020	12/10/2020	1/14/2021	2/24/2021	3/25/2021	4/21/2021
Core	0	0	0	0	0	0
Total	**0**	**1,525±111**	**11,325.0±3551.5**	**11,269±36445**	**1,493.3±102**	**0**
Common Loon						
Currituck	0	0	0	0	0	0
Albemarle	0	489±60	305.37±24	273±19	0	0
Pamlico	0	8,611.00±2411.59	2,005±188	1411±95	832±33	0
Core	0	0	0	0	55.96±4	0
Total	**0**	**9,100±2471**	**2,310±212**	**1684.8±115.1**	**888±38**	**0**

Appendix 17. Number of double-crested cormorants counted within communal night roosts during five survey flights from 04 November 2019 to 19 March2020 and from 15 October 2020 to 19 May 2021.

Roost	11/4/2019	12/6/2019	1/10/2020	2/3/2020	3/19/2020	10/15/2020	12/17/2020	3/8/2021	4/22/2021	5/19/2021
3	1,880	855	23,550	14,225	178	300	4100	36,485	3300	0
4	4,350	17,450	13	2,670	244	750	0	350	4,3178	7,565
7	385	1,865	639	0	30	7,956	0	3,656	0	0
8	57,235	435	983	2,326	19,865	12,374	28,388	0	0	0
9	4,730	168	75	0	0	375	835	0	410	43
10a	46	43	67	105	125	0	15	0	0	0
10b	489	12	17	17	0	0	48	0	655	0
11	1,850	7,465	0	2,080	2,260	0	93,477	6,824	23,822	4,562
12	425	1,271	173	0	282	0	2,964	45	55	0
14	13,580	0	0	0	0	0	0	0	0	0
15	3,655	485	5,390	545	1,260	420	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
18	0	0	172	0	96	55	650	8,733	0	0
19	94	64	78	0	0	2,666	0	0	75	0
20	15,450	6,685	0	0	0	0	51,842	0	0	0
21	1,080	350	0	0	185	22,795	0	0	0	0
22	980	10,838	0	0	3,540	1825	8,585	55	35	0
23	0	481	535	0	0	2,417	0	8	0	0
24	105	10,230	555	3185	67	0	0	0	5,849	0
25	0	0	0	0	4,252	0	0	0	0	0
26	0	35,570	0	0	8,250	0	0	0	0	0
27	0	24,550	13,625	1563	1,028	0	0	0	0	0
28	0	656	44	0	9,720	0	3,865	0	0	0
29	0	178	0	0	15	0	75	6	0	0
30	0	25,058	0	16950	3,160	356	115	0	0	0
Total	**106,334**	**144,709**	**45,916**	**43,666**	**54,557**	**52,289**	**194,959**	**56,156**	**77,379**	**12,170**

Appendix 18. Number of brown pelicans counted within communal night roosts during five survey flights.

Roost	11/4/2019	12/6/2019	1/10/2020	2/3/2020	3/19/2020	10/15/2020	12/17/2020	3/8/2021	4/22/2021	5/19/2021
3	0	425	62	0	0	0	450	15	65	0
4	685	350	32	0	0	0	312	0	15	0
7	12	7	40	275	0	1645	175	0	0	0
8	0	96	207	45	0	885	110	0	0	0
9	4,310	1663	0	51	49	3,268	2,844	110	2,865	2,948
10a	61	65	49	72	6	0	0	0	0	0
10b	172	3	0	0	2	355	85	0	0	0
11	55	0	0	0	0	455	0	135	126	28
12	875	1,808	264	445	80	3,035	115	85	10	226
14	250	0	0	0	6	0	0	0	0	0
15	385	325	0	0	0	0	710	0	0	0
16	0	0	0	0	902	0	55	0	0	0
18	520	52	178	0	241	1,244	553	170	1,865	1,885
19	410	233	28	51	207	0	475	65	2,250	2,587
20	25	118	0	0	0	150	0	0	0	0
21	0	0	0	0	0	0	0	70	0	0
22	23	0	0	0	0	0	1,567	80	39	0
23	102	23	0	0	14	0	0	0	11	0
24	0	178	10	0	0	0	15	65	0	0
25	0	0	15	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	53	48	0	0	0	0	0	0
28	0	469	0	93	0	1,565	0	0	0	0
29	0	46	4	0	2	35	0	0	0	0
30	0	0	0	0	0	355	0	0	65	0
Total	**7,885**	**5861**	**942**	**1,080**	**1509**	**12,992**	**7,466**	**795**	**7,246**	**7,674**