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Fin, Humpback, and Minke Whale Foraging Events in the New York Bight as Observed from Aerial Surveys, 2017-2020

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Abstract

The fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*), and minke whale (*Balaenoptera acutorostrata*) are known to occur in the New York Bight (NYB). The primary North Atlantic feeding grounds for these large whale species are commonly recognized to be further north in waters of the Gulf of Maine, eastern Canada, West Greenland, and the eastern North Atlantic (e.g., Iceland, Norway, Ireland, Scotland). Although much is known about their feeding activities in the North Atlantic, relatively little is known about their occurrence and foraging behaviors in mid-Atlantic regions such as the NYB. Understanding how large whales utilize NYB waters is important to evaluate potential impacts from direct (e.g., offshore development, vessel strikes, entanglements) and indirect (e.g., rising ocean temperatures) anthropogenic sources. The New York State Department of Environmental Conservation funded a 3-year baseline monitoring program (2017-2020) which conducted monthly line-transect aerial surveys focused on large whales. Over 3 years, 36 surveys comprised of 263 flights and totaling 688.3 hours of observation time along 140,370 km of over-water flight path were completed. Aerial survey observers documented foraging events for the fin, humpback, and minke whales, including mixed-species aggregations, and analyzed other parameters such as distance from shore, distribution zones, and presence of fish schools. Foraging behavior was observed for 27% of the recorded fin whale sightings, 40% of the recorded humpback whale sightings, and 18% of the recorded minke whale sightings. Sighting rates of foraging whales were highest for humpback whales (4.4 whales/1,000 km of effort), followed by fin whales (0.6 whales/1,000 km effort) and minke whales (0.1 whales/1,000 km of effort), and varied by season, year, and distribution zone. In addition, nearly 5,700 fish schools were recorded with fish presence highest during summer and fall.

Key Words: fin whale, *Balaenoptera physalus*, humpback whale, *Megaptera novaeangliae*, minke whale, *Balaenoptera acutorostrata*, New York Bight, foraging

Introduction

Fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera novaeangliae*), and minke whales (*Balaenoptera acutorostrata*), in general, follow the typical baleen whale migratory pattern consisting of movement between northern feeding grounds during summer and southern breeding and calving grounds during winter (Mackintosh, 1965; Dawbin, 1966; Katona & Beard, 1990; Stevick et al., 1998, 2006; Smith et al., 1999; Risch et al., 2013, 2014; Aguilar & García-Vernet, 2018); however, not all fin whales undergo these seasonal migrations (e.g., Silva et al., 2013; Aguilar & García-Vernet, 2018). The primary North Atlantic feeding grounds for fin, humpback, and minke whales are commonly considered to be in waters such as the Gulf of Maine (Overholtz & Nicolas, 1979; Hain et al., 1982, 1995; Mattila et al., 1987; Weinrich & Kuhlberg, 1991; Weinrich et al., 1998; Clark & Clapham, 2004; Friedlaender et al., 2009; Vu et al., 2012; Waring et al., 2015), eastern Canada (Gaskin, 1983; Johnston et al., 2005; Ingram, 2007), West Greenland, and the eastern North Atlantic (e.g., Iceland, Norway, Ireland, Scotland; Lockyer, 1986; Katona & Beard, 1990; Gill & Fairbainrns, 1995). Fin, humpback, and minke whales are known to be present in the coastal and offshore waters of New York State (Kenney & Winn, 1986; Brown et al., 2018; Muirhead et al., 2018) and the adjacent waters of New Jersey (Whitt et al., 2013, 2015). However, until recently, the biological significance of the mid-Atlantic waters, including waters of the New York Bight (NYB), was relatively unknown for these species. Records of foraging events for these large whales in mid-Atlantic waters were historically reported in unpublished literature (e.g., Cetacean and Turtle Assessment Program [CETAP], 1982; Sadove & Cardinale, 1993) from data collected from the late 1970s to the early 1990s. Foraging events over the last 30 years were seldomly described for these large whale species until quite recently when humpback whale foraging was observed in the NYB (Brown et al., 2018; King et al., 2021; Stepanuk et al., 2021).

The NYB is a section of the northwest Atlantic Ocean that extends between Cape May, New Jersey, in the southwest to Montauk Point, New York, in the northeast (Figure 1). It includes the waters over the continental shelf offshore approximately 160 km to the shelf break and is part of a larger Mid-Atlantic Bight spanning from Cape Hatteras, North Carolina, to Cape Cod, Massachusetts. The NYB has been recognized as an ecologically significant region off the Atlantic coast with high productivity and biodiversity and with habitat complexes important to numerous marine species. The NYB is also economically important for offshore activities such as fishing, shipping, and renewable energy development. Understanding how large whales utilize NYB waters is increasingly critical to evaluate potential impacts from either direct (e.g., offshore development, vessel strikes, entanglements) and indirect (e.g., rising ocean temperatures) anthropogenic threats. Currently, vessel strikes and entanglement are the leading causes of anthropogenic mortality for large whales. Incidences of ship strikes and entanglement in fishing gear in the NYB have been reported for fin, humpback, and minke whales (Jensen & Silber, 2004; Brown et al., 2019; Stepanuk et al., 2021), and humpback and minke whales are currently designated as being in Unusual Mortality Events (UMEs; National Oceanic and Atmospheric Administration [NOAA] Fisheries, 2021a, 2021b). Similarly, these large whales have died from entanglement-related mortalities in the Northeast (NOAA Fisheries, 2018).

The fin whale occurs year-round along the Atlantic coast and is the most commonly documented large whale species in U.S. East Coast waters, though residency periods of individuals are not well known (Whitt et al., 2015; Hayes et al., 2020). The Gulf of Maine, including Cape Cod, Stellwagen Bank, and the Bay of Fundy, are considered the primary spring–fall feeding grounds for fin whales in the western North Atlantic (Arnold & Gaskin, 1972; Gaskin, 1983; Woodley & Gaskin, 1996; Ingram, 2007; Hayes et al., 2020). Humpback whales are

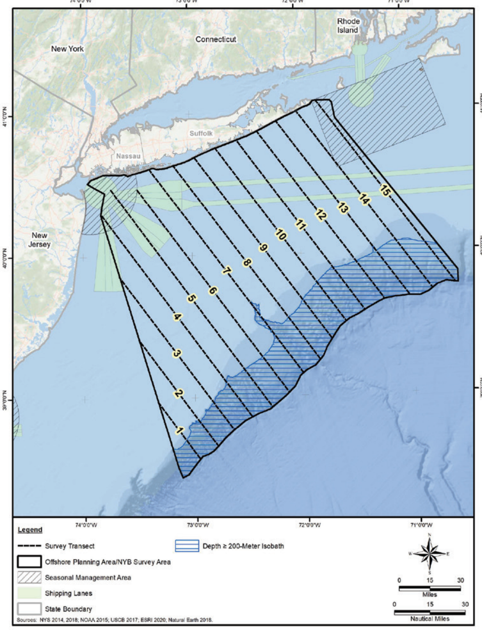

Figure 1. New York Bight (NYB) survey area including 15 transect lines

known to feed and migrate during spring, summer, and fall along the U.S. East Coast, with most animals migrating south to more tropical waters (e.g., the West Indies) during winter for breeding and calving (Katona & Beard, 1990; Stevick et al., 1998, 2006; Hayes et al., 2020). Humpback whales have also been documented with extended seasonal or year-round occurrence in waters off the U.S. East Coast (Clapham et al., 1993; Swingle et al., 1993; Clark & Clapham, 2004; Vu et al., 2012; Murray et al., 2014). Katona & Beard (1990) defined five primary feeding subregions for humpback whales in the North Atlantic: (1) Iceland, (2) Greenland, (3) Newfoundland, (4) Gulf of St. Lawrence, and (5) Gulf of Maine/Scotian Shelf. Similarly, Stevick et al. (2006) identified four summer feeding aggregations: (1) Gulf of Maine, (2) eastern Canada, (3) West Greenland, and (4) the eastern North Atlantic. Similar to fin and humpback whales, waters in the North Atlantic, such as the Gulf of Maine, Cape Cod, Stellwagen Bank, and the Bay of Fundy, are considered the main spring–fall feeding grounds for minke whales (Gaskin, 1983; Ingram, 2007). Minke whales are widespread throughout U.S. waters, but their occurrence in U.S. mid- and North Atlantic waters increases during spring and summer, peaking in July through September (Sadove & Cardinale, 1993; Murphy, 1996; Risch et al., 2013, 2014; Waring et al., 2015). Prey for these three large whale species consists of a variety of small schooling fish (e.g., herring [*Clupea* spp.], sand lance [*Ammodytes* spp.], euphausiid spp., capelin [*Mallotus villosus*], and Atlantic menhaden [*Brevoortia tyrannus*]; Jonsgård, 1966; Overholtz & Nicolas, 1979; Hain et al., 1995; Woodley & Gaskin, 1996; Víkingsson, 1997; Aschettino et al., 2020).

A current paucity of information on large whale occurrence and behaviors in the NYB has resulted in a deficient understanding of these species' use of the region for management and conservation planning at the state and federal levels. To address data gaps and meet monitoring needs, the New York State Department of Environmental Conservation (NYSDEC) funded a 3-year aerial baseline monitoring program focused on large whales in the NYB. This multi-year study collected visual line-transect survey data and provided estimates of large whale density, abundance, and distribution in the NYB (Zoidis et al., 2021). In addition, the distribution of and behaviors during apparent foraging events of fin, humpback, and minke whales were documented and investigated. Herein, we provide information on the occurrence and foraging activities of these species in the NYB from a multi-year systematic aerial survey. Our study offers insight into the interannual, seasonal, and spatial trends of large whale foraging behaviors and supports growing evidence that the NYB region and mid-Atlantic waters serve as a supplemental foraging area for these three species.

Methods

Data were collected during 36 monthly systematic aerial surveys from March 2017 through February 2020 following line-transect distance sampling methods (Buckland et al., 2001). Surveys were flown using a twin-engine aircraft (Partenavia P68C). Fifteen parallel transect lines spaced 16.7 km apart were established to provide appropriate coverage of the NYB survey area of 43,449 km^2 (Figure 1). The position and orientation of the transect lines were based on the local coastline configuration, an assessment of predicted species distributions in the region, and estimated minimum sample size requirements for distance sampling (Palka, 2005; Thomas et al., 2010; Kraus et al., 2016; NOAA Fisheries, 2016). Total transect length was approximately 2,514 km, and the total survey distance (including connector lines) was approximately 2,843 km. Surveys along transect lines were conducted at a target altitude of approximately 305 m and groundspeed of 100 to 110 kts. Flights were conducted when the Sea State (SS) was 5 or lower to ensure that large whales could be detected. When SS 6 or higher was encountered for more than approximately 10 minutes, the survey route was aborted and another region with better SS conditions was surveyed, or the flight was terminated or postponed.

Sighting and environmental data were collected using *Mysticetus*™ software. *Mysticetus*™ displayed and logged positions of marine mammal sightings based on the timestamp, bearing, and declination angle, measured with a Suunto™ handheld clinometer (Suunto Oy, Vantaa, Finland) when the sighting was perpendicular to the aircraft. Whales were identified to the lowest possible taxonomic designation. A digital voice recorder with time-stamp capability recorded all voices on the plane's audio system. Observers also used binoculars (7 × 50) as needed to identify species, group size, behaviors, etc., from the aircraft. A Canon EOS 7D still camera with a Canon EF 100-400 mm f/4.55.6L IS USM lens (Canon, Ota City, Tokyo, Japan) was used to take photographs to confirm species, group size, and calf presence. Environmental variables collected included SS, glare location and intensity, lateral visibility distance from the aircraft, seawater turbidity, cloud cover, precipitation, and overall sighting condition rating. *Mysticetus*™ calculated depth and distance to shore based on the latitude and longitude of the whales' recorded position.

Two observers, one on each side of the aircraft, searched continuously less the viewing conditions precluded observations (SS ≤ 5; unobstructed visibility [e.g., no low clouds or rain blocking or obscuring the water]). Observation effort was divided into the following five categories similar to other line-transect survey studies (Jefferson et al., 2014): (1) transect effort (along primary transects), (2) cross-leg effort (along shorter connector lines), (3) transit effort (while flying to and from transect lines and the shoreline), (4) circling effort (when the aircraft circled back to confirm species, estimate group size, gather behavioral data, and photograph animals), and (5) overland effort. For this study, all effort that occurred over water (i.e., transect, cross-leg, transit, circling, and random) were included in the analyses. Sighting data collected included location and time of the sighting, species (to the lowest taxonomic level possible), number of animals, group size and/or group composition, number of calves, group behavior state, direction of travel, and length of the observation period. A group was defined as individuals up to 100 body lengths apart within visual range of observers with > 50% of individuals within the group engaged in the same behavioral state (after Norris & Schilt, 1988; Baird & Dill, 1996; Smultea et al., 2018). The location and number of fish schools were recorded routinely and to an extent that did not detract from potential large whale detections. Atlantic menhaden were assumed in certain sightings from variables that included schooling behavior or fish size and color.

Foraging events were defined as one or more animals exhibiting foraging behavior. Foraging behaviors were separated into two foraging types, *lunge feeding* and *bubble net feeding*, as defined by Hain et al. (1982). Lunge feeding involves "an upward rush at the water surface with the longitudinal axis of the body intersecting the plane of the surface at an angle of 30°–90°. As the whale breaks the surface, the mouth is agape, and quite often a greatly distended throat region is seen" (Hain et al., 1982, p. 260; see also Goldbogen et al., 2006, 2007; Shadwick et al., 2017). Bubble net feeding includes any behaviors that involved underwater exhalations or bubbling behaviors consisting of "bubble clouds and bubble column[s]" (Hain et al., 1982, p. 261; see also Wiley et al., 2011).

Foraging rates were calculated as the number of animals observed exhibiting foraging behavior per 1,000 km of observation effort (including all effort occurring over water). Foraging rates and fish school sighting rates (number of fish schools per 1,000 km of observation effort) were calculated by season, year, and distribution zone. Seasons were defined using calendar months as follows: *Spring:* 1 March to 30 May, *Summer:* 1 June to 31 August, *Fall:* 1 September to 30 November, and *Winter:* 1 December to 28 February. Survey year was defined as the period spanning the first survey in March to the last of the 12 monthly surveys. Year 1 was 1 March 2017 to 28 February 2018, Year 2 was 1 March 2018 to 28 February 2019, and Year 3 was 1 March 2019 to 29 February 2020. Four distribution zones were defined based on distance from shore and standard bathymetric delineations: *Nearshore:* 0 to 25 km from shore, *Shelf:* > 25 km from shore to 200 m water depth, *Slope:* > 200 to 1,000 m water depth, and *Plain:* > 1,000 m water depth (Figure 2). We performed one-way ANOVA and *post-hoc* Tukey HSD (honest significant difference) tests for season and species by mean depth and mean distance to shore for the locations of foraging whales recorded. For humpback whales specifically, we performed an independent *t* test for depth and distance from shore between foraging type (lunge feeding and bubble net feeding), and distance to shore and month for bubble net feeding behaviors. Statistical analyses were performed using *R*, Version 3.4.2, in *RStudio*, Version 1.0.143 (RStudio Team, 2015), at a 0.05 level of significance.

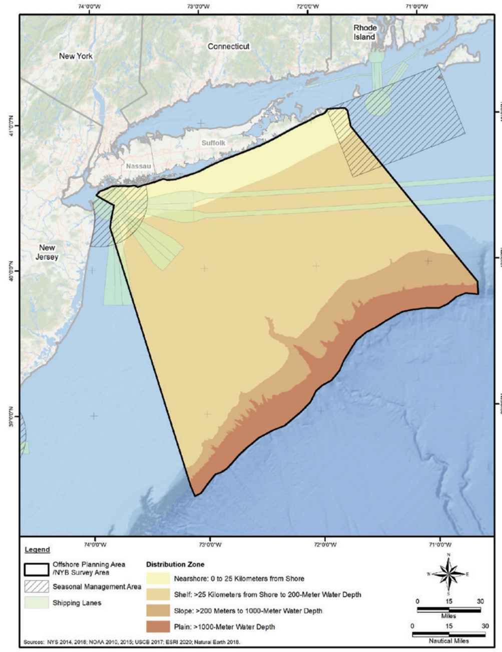

Figure 2. Distribution zones: *Nearshore:* 0 to 25 km from shore, *Shelf:* > 25 km from shore to 200 m water depth, *Slope:* > 200 to 1,000 m water depth, and *Plain:* > 1,000 m water depth.

Results

There were 263 flights completed over 36 survey months with 688.3 hours and 140,370 km of observation effort. The majority of flight time effort consisted of transect (62%), followed by transit (27%), crossleg (5%), and circling (6%) (Figures 3A-C). Observation effort was relatively

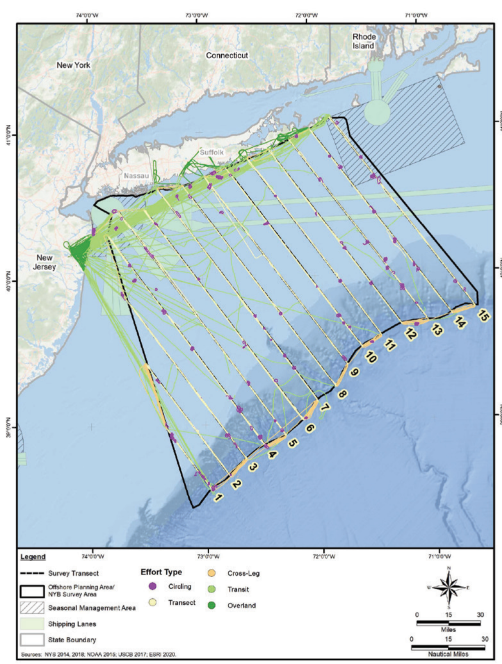

Figure 3A. Survey effort for large whales in the NYB Year 1 (March 2017 to February 2018)

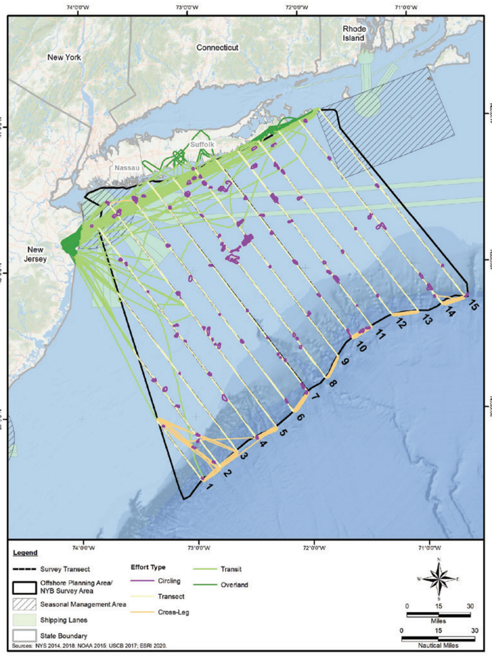

Figure 3B. Survey effort for large whales in the NYB Year 2 (March 2018 to February 2019)

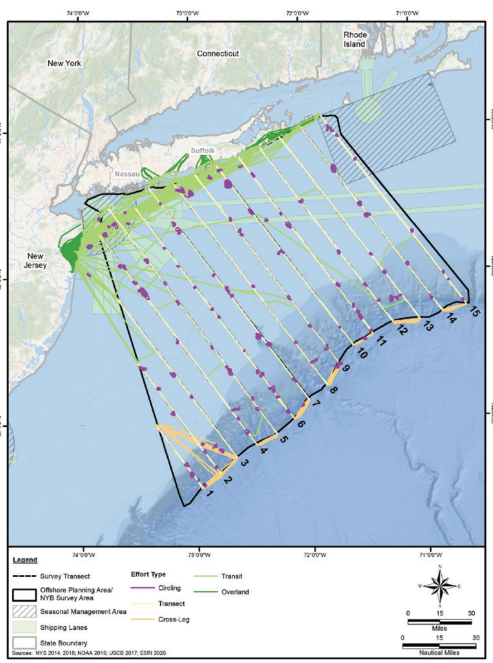

Figure 3C. Survey effort for large whales in the NYB Year 3 (March 2019 to February 2020)

evenly distributed among years (35% in Year 1, 32% in Year 2, and 33% in Year 3) and among seasons (25% occurring in the spring, 24% in the summer, 27% in the fall, and 24% in the winter). Survey effort varied by distribution zone with 28% occurring in the nearshore, 52% in the shelf, 9% in the slope, and 11% in the plain.

In total, 124 groups (207 animals) of fin whales, 111 groups (279 animals) of humpback whales, and 39 groups (45 animals) of minke whales were recorded. Of these, 35 groups (175 animals; 13% of the total group and 33% of total animals) were recorded exhibiting foraging behaviors; 27% (n = 56 whales in 16 groups) of the recorded observations for fin whales, 40% (n = 111 whales in 14 groups) for humpback whales, and 18% (n = 8 whales in groups) for minke whales (Figure 4). Foraging rates were highest for humpback whales (4.4 whales/1,000 km of effort), followed by fin whales (0.6 whales/1,000 km effort) and minke whales (0.1 whales/1,000 km of effort; Table 1).

By year, number of foraging animals, and subsequently foraging rates, were highest during Years 1 and 2 for fin whales and Years 2 and 3 for humpback and minke whales (Figures 5 & 6). Foraging rates varied by season; during spring, foraging rates were highest for humpback whales (0.35 whales/1,000 km of effort), followed by fin whales (0.26 whales/1,000 km of effort) and minke whales (0.03 whales/1,000 km of effort; Table 1; Figure 7). Similarly, during summer, foraging rates were again highest for humpback whales (2.88 whales/1,000 km of effort), followed by fin whales (1.31 animals/1,000 km of effort) and minke whales (0.20 whales/1,000 km of effort; Table 1; Figure 6). During fall, foraging events were only recorded for fin whales (0.05 whales/1,000 km of effort). Despite the 33,491 km of observation effort flown during winter, no foraging events were recorded for any of these species (Table 1).

Foraging rates varied by distribution zone and were highest in the shelf distribution zone for all three species (0.76, 1.42, and 0.21 whales/1,000 km of effort, respectively; Table 2; Figures 8-10). In the nearshore distribution zone, humpback whale foraging rates were higher than minke whale foraging rates (0.26 and 0.05 whales/1,000 km of effort, respectively; Figures 9 & 10). Only a small number of fin whales were recorded foraging in the nearshore distribution zone (Figure 6). No fin, humpback, or minke whales were recorded foraging in the slope or plain distribution zones, despite 12,111 and 15,564 km of effort, respectively (Table 2; Figures 8-10). All three species and 17% of the total foraging groups (n = 6) were observed foraging in known shipping lanes (Figures 8-10). Foraging activity in the shipping lanes was comprised of one group of fin whales, three groups

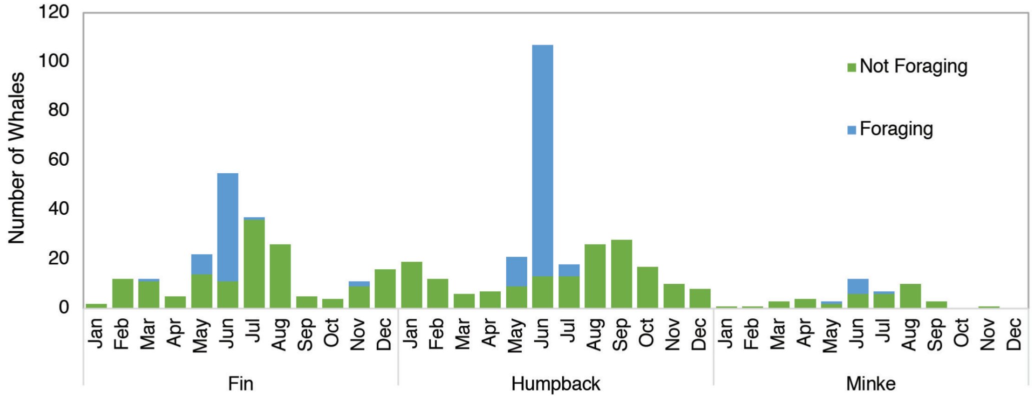

Figure 4. Proportion of whales foraging by month for fin (left), humpback (middle), and minke (right) whales in the NYB

Table 1. Foraging rates (number of animals observed exhibiting foraging behavior per 1,000 km of observation effort) by season

Season	Spring	Summer	Fall	Winter
Total effort (km)	34,534	34,323	38,023	33,491
Fin whale	0.26	1.31	0.05	0.0
Humpback whale	0.35	2.88	0.00	0.0
Minke whale	0.03	0.20	0.00	0.0
All whales	0.64	4.40	0.05	0.0

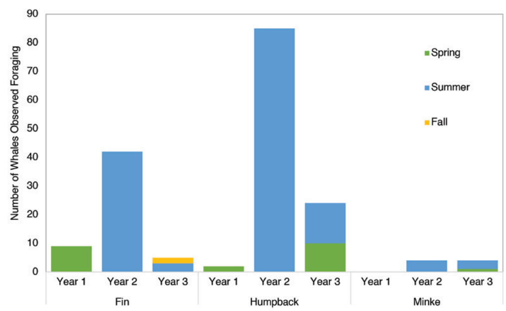

Figure 5. Number of whales observed foraging by season and year for fin (left), humpback (middle), and minke (right) whales in the NYB

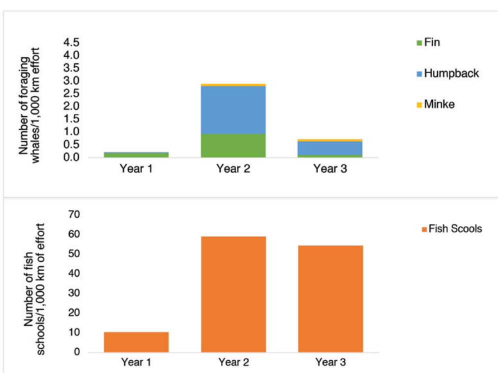

Figure 6. Number of foraging whales/1,000 km of effort for fin, humpback, and minke whales by year (top) and number of fish schools/1,000 km of effort by year (bottom) in the NYB

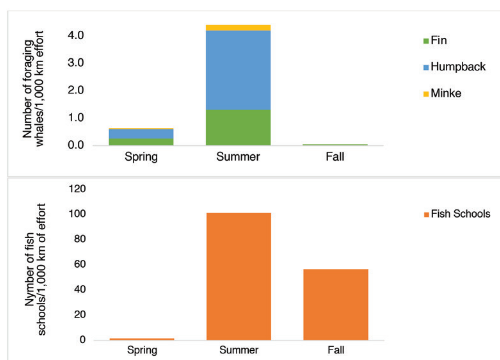

Figure 7. Number of foraging whales/1,000 km of effort for fin, humpback, and minke whales by season (top) and number of fish schools/1,000 km of effort by season (bottom) in the NYB

Table 2. Foraging rates (number of animals observed exhibiting foraging behavior per 1,000 km of observation effort) by distribution zone

Distribution zone	Nearshore	Shelf	Slope	Plain
Total effort (km)	38,975	71,035	12,211	15,564
Fin whale	0.05	0.76	0.0	0.0
Humpback whale	0.26	1.42	0.0	0.0
Minke whale	0.00	0.21	0.0	0.0
All whales	0.51	2.18	0.0	0.0

of humpback whales, and two groups of minke whales, including one group of seven to eight humpback whales engaging in bubble net feeding.

We assessed mean depth (m) and distance to shore (km) associated with foraging whale locations by species. Mean foraging depth varied by species, however, and was not statistically significant as determined by one-way ANOVA ($F = 1.09$; $p = 0.35$). Foraging fin whales were recorded in the deepest water (mean = 67.1 m; SD = 25.9 m), followed by foraging humpback whales (mean = 57.6 m; SD = 15.2 m) and minke whales (mean = 54.4 m; SD = 17.4 m). Mean foraging distance to shore varied significantly by species as determined by one-way ANOVA ($F = 3.38$; $p < 0.05$). Foraging fin whales were recorded furthest offshore (mean = 85.5 km; SD = 18.6 km), followed by foraging humpback whales (mean = 68.7 km; SD = 22.7 km) and minke whales (mean = 62.4; SD = 26.2 km). For all whales combined, mean distance to shore varied significantly by season as determined by one-way ANOVA ($F = 11.64$; $p < 0.001$), and results of a *post-hoc* Tukey HSD test found a significant difference between spring and summer ($p < 0.01$). Foraging whales were found further from shore during spring (mean = 96.0 km; SD = 11.8 km) and closer to shore during summer (mean = 67.3 km; SD = 19.3 km).

Fin whales were recorded exhibiting foraging events in all 3 years and during spring, summer, and fall. Group size ranged from a single fin whale to a group of 16 animals. All foraging events were recorded as lunge feeding behavior. Fin whales were only recorded foraging in the shelf distribution zone; none were observed foraging in the nearshore, slope, or plain distribution zones (Table 2; Figure 8). Seasonally, foraging sighting rates for fin whales were highest during summer (1.31 whales/1,000 km of effort), followed by spring (0.26 whales/1,000 km of effort) and fall (0.5 whales/1,000 km of effort; Table 1). Interannually, foraging sighting rates were highest during Year 2 (March 2018 to February 2019; 0.9 whales/1,000 km of effort), followed by Year 1 (March 2017 to February 2018; 0.2 whales/1,000 km of effort), and lowest during Year 3 (March 2019 to February 2020; 0.1 whales/1,000 km of effort; Figure 6). On one occasion (May 2017), a group of five fin whales was observed exhibiting expanded throat pleats and lunging at the surface in unison (Figure 11). The largest lunge feeding group was of 16 animals in two subgroups of four and six animals (with the remaining six animals as pairs or singles) as part of a larger mixed-species aggregation comprised of both humpback and minke whales (June 2018). In November 2019, two fin whales were recorded lunge feeding 124 km from shore. This was the furthest offshore and only fall record of foraging behavior for all species.

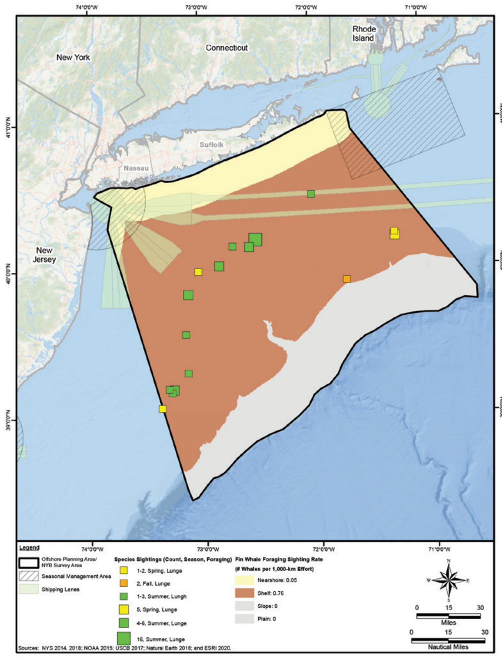

Figure 8. Foraging fin whale sightings by count, season, and distribution zone (*Nearshore:* 0 to 25 km from shore, *Shelf:* > 25 km from shore to 200 m water depth, *Slope:* > 200 to 1,000 m water depth, and *Plain:* > 1,000 m water depth)

Humpback whales were observed foraging during all 3 years and seasonally during spring and summer. Group size of foraging whales ranged from a single humpback whale to a group of 52 animals. Of the 14 groups observed foraging, 10 groups (103 estimated animals) were observed exhibiting bubble net feeding behaviors, and the remaining four groups (8 estimated animals) were observed exhibiting lunge feeding behaviors. The

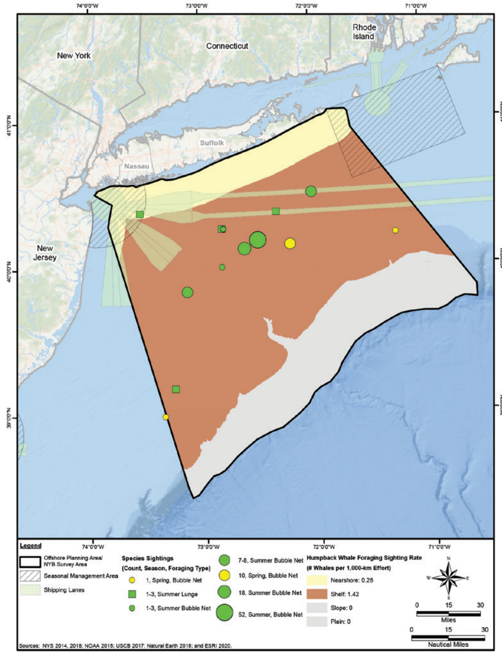

Figure 9. Foraging humpback whales by count, season, and distribution zone (*Nearshore:* 0 to 25 km from shore, *Shelf:* > 25 km from shore to 200 m water depth, *Slope:* > 200 to 1,000 m water depth, and *Plain:* > 1,000 m water depth)

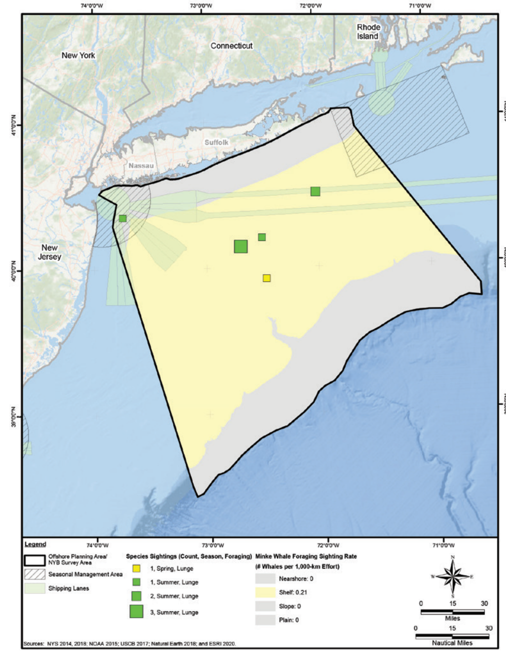

Figure 10. Foraging minke whales by count, season, and distribution zone (*Nearshore:* 0 to 25 km from shore, *Shelf:* > 25 km from shore to 200 m water depth, *Slope:* > 200 to 1,000 m water depth, and *Plain:* > 1,000 m water depth)

location of bubble net feeding events occurred further offshore (mean = 73.5 km; SD = 19.85 km) and in deeper waters (mean = 61.6 m; SD = 13.84 m) than lunge feeding events (mean distance = 56.7 km, SD = 28.01 km; and mean depth = 47.5 m, SD = 15.21 m), although neither were found to be significant (p = 0.33 and p = 0.17, respectively). Bubble net feeding occurred earlier in the season during May and June (median = 21 May), and lunge feeding occurred only during June and July (median = 5 July). Bubble net group size was significantly larger during June (mean = 16.0; SD = 18.13) than May (mean = 4; SD = 5.20; t = -26.806, df = 1, p = 0.023) Groups consisting of greater than three animals exhibiting coordinated bubble net feeding behaviors were recorded on five different occasions: one group (10 animals) during the month of May and four groups (85 animals total) during the month of June 2018 and 2019. The largest foraging event occurred during June 2018 when an estimated 52 animals (spread over 6 km) were observed in 12 subgroups of between three and 10 animals, and nearly all subgroups were bubble net feeding (Figure 12). When assessing foraging distribution, humpback whale sighting rates were higher in the shelf distribution zone (1.4 whales/1,000 km of effort) than the nearshore distribution zone (0.3 whales/1,000 km of effort; Table 2; Figure 9). No humpback whales were observed foraging in the slope or plain distribution zones. Seasonally, foraging sighting rates for humpback whales were highest during summer (2.88 whales/1,000 km of effort), followed by spring (0.35 whales/1,000 km of effort; Table 1). No foraging humpback whales were recorded during fall or winter. Interannually, foraging sighting rates for humpback whales were highest during Year 2 (March 2018 to February 2019; 1.9 whales/1,000 km of effort), followed by Year 3 (March 2019 to February 2020; 0.5 whales/1,000 km of effort), and lowest during Year 1 (March 2017 to February 2018 (0.04 whales/1,000 km of effort; Figure 6).

Minke whales were recorded exhibiting foraging events during Years 2 (March 2018 to February 2019) and 3 (March 2019 to February 2020), and during spring and summer (Figure 4). Group size ranged from a single minke whale to a group of three animals (mean = 1.6; SD = 0.89): three single animals were recorded during May, June, and July, and a group of three and a group of two were recorded during June, with one exhibiting ventral-side-up behaviors. All foraging events were recorded as lunge feeding behavior. Minke whales' sighting rates were higher in the shelf distribution zone (0.8 whales/1,000 km

Figure 11. Four fin whales lunge feeding during large aggregation feeding event, May 2017

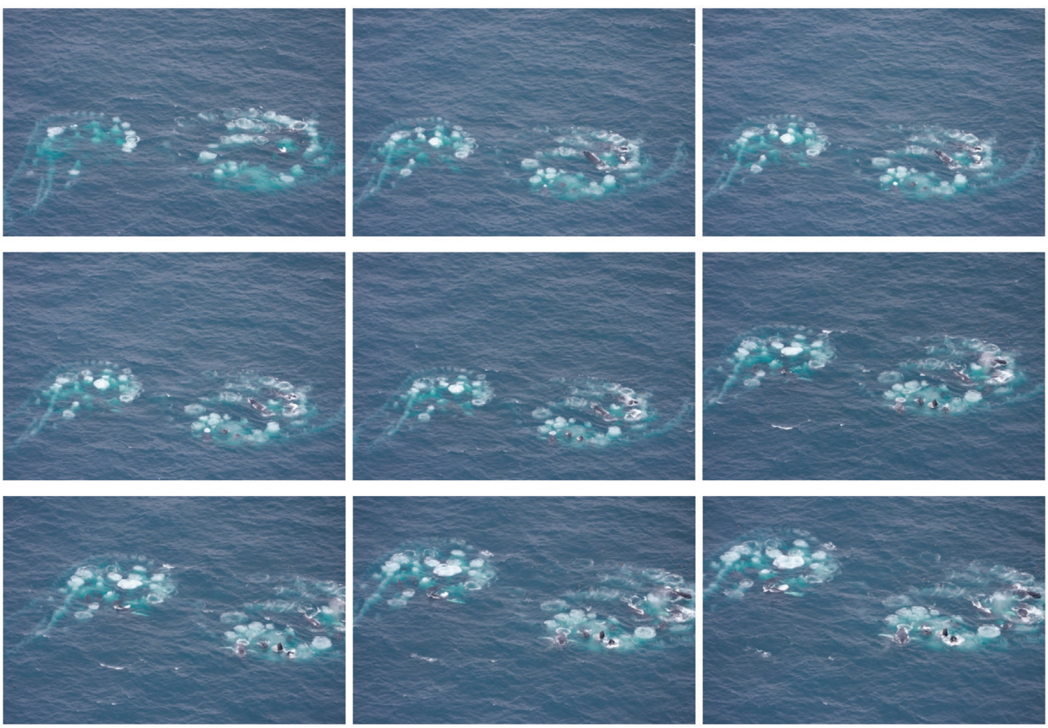

Figure 12. Humpback whale bubble net feeding during large aggregation feeding event, June 2018

of effort) than the nearshore distribution zone (0.1 whales/1,000 km of effort; Table 2; Figure 10). Seasonally, foraging sighting rates for minke whales were highest during summer (0.2 whales/1,000 km of effort), followed by spring (0.03 whales/1,000 km of effort); and none were recorded foraging during fall or winter (Table 1; Figure 7). Interannually, foraging sighting rates for minke whales were the same during Years 2 (March 2018 to February 2019) and 3 (March 2019 to February 2020; 0.1 whales/1,000 km of effort) with none during Year 1 (March 2017 to February 2018; Figure 6).

Mixed-species aggregations between fin, humpback, and minke whales were recorded during four separate events, and common dolphins (*Delphinus delphis*) were recorded during three of these events. For example, on 14 June 2018, over 700 common dolphins were observed in a large feeding aggregation with four fin whales and seven humpback whales. The following day, 15 June 2018, a large aggregation feeding event was observed (spread over 6 km), with an estimated 16 fin whales, 52 humpback whales, and one minke whale along with over 100 common dolphins.

Over the 3-year survey, 5,689 fish schools were observed from the air (Figure 13). Fish school sighting rates were highest during summer (101.2 fish schools/1,000 km of effort), followed by fall (56.6 fish schools/1,000 km of effort), and lowest during spring (1.7 fish schools/1,000 km of effort) and winter (0.2 fish schools/1,000 km of effort; Figure 7). Fish school sighting rates were lowest during Year 1 (10.5 fish schools/1,000 km of effort), increased during Year 2 (59.3 fish schools/1,000 km of effort), and decreased slightly during Year 3 (40.5 fish schools/1,000 km of effort; Figure 6). We assessed fish school sighting rate by distribution zone and found that fish schools were highest in the nearshore distribution zone (135.8 fish schools/1,000 km of effort), followed by the shelf distribution zone (3.8 fish schools/1,000 km of effort), with nearly no fish schools recorded in the slope and plain distribution zones (0.2 and 0.1 fish schools/1,000 km of effort, respectively).

Discussion

Our study establishes that fin, humpback, and minke whales seasonally utilize the NYB for foraging purposes. Peak foraging for all three species occurred during summer followed by spring. Spatially, foraging activities were most prevalent in the shelf and nearshore environment, with little foraging activity in the slope and plain. Congruently, seasonal and spatial patterns in fish aggregations corresponded with foraging whale sightings, with higher fish school presence during summer and in the nearshore and shelf distribution zones. Overall, fin whales were

Figure 13. Example of large fish school as observed from the aerial platform, June 2019

observed foraging all 3 years and in all seasons except winter and were only recorded on the shelf distribution zone. During fall, two whales were recorded lunge feeding > 120 km from shore, the furthest offshore and the only fall foraging record for all species. Humpback whales were observed foraging during all 3 years, and nearly half of the total recorded humpback whales were observed foraging. Seasonally, we found peak foraging during summer, particularly during the month of June, followed by spring, as well as foraging occurring in the nearshore and shelf distribution zones. Minke whales were observed foraging during the second 2 years of the survey, in spring and summer, and in the nearshore and shelf distribution zones. All three species were recorded foraging in the shipping lanes. Mixed-species aggregations were observed for all three large whale species; and in multiple events, these observations included common dolphins. Our results indicate the NYB is seasonally a supplemental feeding ground for these three large whale species, and possibly shifting prey availability is linked to increasing foraging activity. Although the NYB was not previously considered a significant feeding ground for large whale species, a handful of recent studies have indicated that the NYB and mid-Atlantic waters are becoming increasingly important ecologically for foraging humpback whales (e.g., Brown et al., 2018; King et al., 2021; Stepanuk et al., 2021). Our observations validate and add to previous findings on humpback whale foraging presence in the NYB and additionally document fin and minke whale foraging activities in the region. Further, our study adds novel finer scale detail across several parameters to illustrate how and when these large whales are utilizing the NYB for foraging, including foraging activity for all three species in the NYB shipping lanes.

Historic accounts of fin, humpback, and minke whale presence in the NYB are provided in a government agency report by Sadove & Cardinale (1993), compiled from over 15 years of marine mammal dedicated surveys and anecdotal accounts. Authors reported that fin and humpback whale foraging was more prevalent during summer months and within 48 km of land. In addition, they state that during the summer, feeding groups often involved aggregations of more than 20 animals, with incidences of over 200 not uncommon. After the fin whale, minke whales were the second most abundant large whale they noted in the NYB, primarily in shallow shelf waters and singly or in small groups (up to 20 individuals); they were also observed feeding on fish (e.g., herring, pollack, sand lance). Humpback whales were reported regularly within the NYB in aggregations of up to 20 animals commonly. Abundance fluctuated, with the greatest numbers occurring from June through September when they were found to be feeding on shoals of small schooling fish thought to be sand lance (Sadove & Cardinale, 1993). An earlier report from the Cetacean and Turtle Assessment Program (CETAP) (1982) also reported observations of feeding behaviors from the NYB, though only in the far northeastern corner. The CETAP ran from 1978 to 1982 and covered Canada to North Carolina from the coastline out to 5 nmi seaward of the 1,000-fathom depth contour; it included both vessel and aerial observations, overlapping with a portion of the NYB survey area lines. Limited observations of fin and humpback whales occurred east and southeast of Long Island, including limited (fewer than 15%) sightings of feeding events noted east of Montauk Point bordering waters near Cape Cod. Most humpback whale feeding sightings were inshore in shallow depths in spring and summer, and the few fin whale feeding observations occurred in spring and summer with more in the summer off Montauk Point. Very limited sightings of minke whale feedings were noted (less than 4%) in spring and summer, with a small number of those east of Montauk Point. During our study, no whales were recorded feeding near Montauk Point; however, the furthest extent (i.e., the most eastern transect line) of our survey area was at Montauk Point.

Since these two reports, over 30 years ago, only a handful of other studies on large whale foraging activities in the NYB and nearby waters have been published (Whitt et al., 2015; Brown et al., 2018, 2019; King et al., 2021; Stepanuk et al., 2021). Whitt et al. (2015) conducted aerial and shipboard surveys during 2008 and 2009 in adjacent nearshore New Jersey waters (coast to ~37 km offshore) and recorded large whale sightings. Possible foraging behaviors were recorded once during August by a fin whale mother–calf pair; the fin whale appeared to be making foraging dives several hundred meters from the calf. Although they could not confirm feeding was occurring, the authors similarly suggested that New Jersey's nearshore waters may serve as additional feeding areas for fin whales. Brown et al. (2018) reported observing 46 humpback whales in Lower New York Bay, Raritan Bay, and Sandy Hook Bay between 2001 and 2016 during an inshore study in the New York-New Jersey Harbor Estuary—area adjacent to the northwest portion of the NY OPA. Half of these sightings ($n = 23$) were of them lunge feeding, and nine sightings were confirmed to be of them feeding on Atlantic menhaden through direct observation or photographs of prey. King et al. (2021) investigated baleen whale behavior from nonsystematic small vessel surveys in the coastal NYB during 2017-2019 and found that in the mid-shelf region (10 to 60 km from shore), whales were spatially concentrated and primarily feeding on sand lance; whereas in the nearshore region (< 10 km from shore), whales were more dispersed and feeding on Atlantic menhaden, and humpback whales were commonly observed lunge feeding on prey patches. Authors additionally state that the presence of foraging behaviors support the hypothesis that the NYB may be a supplementary feeding area for some large whale species. Stepanuk et al. (2021) investigated humpback whale feeding in the NYB in relation to age and reported a total of 24 feeding individuals inshore and offshore in quarterly surveys that spanned from 2018 to 2020 for a total of seven surveys. Authors found that foraging in nearshore waters (< 10 km from shore) were exclusively surface feeding (i.e., lunge feeding) juveniles; whereas in offshore waters (> 40 km from shore), both juveniles and adults were seen foraging cooperatively (i.e., bubble net feeding). Consistent with Stepanuk et al., our results showed humpback whales were engaging in cooperative foraging behaviors further offshore, and lunge feeding by single animals was occurring closer to shore. In addition, we found bubble net feeding was occurring earlier in the season than lunge feeding with a clear peak during June. Further, bubble net feeding group size was larger in June than in May, possibly coinciding with fine-scale escalation in prey availability.

In general, the whale watch industry has reported increasing humpback whale presence off Long Island since 2011; and observations, including local news reports, of humpback whales feeding on large schools of Atlantic menhaden in nearshore waters are increasingly common (Axelrod, 2014; Plautz, 2014; Pierre-Louis, 2017; Hayes et al., 2020). Over the last decade, large schools of Atlantic menhaden have been progressively sighted near New York harbor and nearshore Long Island (SEDAR, 2015, 2020a, 2020b). Although previously considered overfished and depleted, the Atlantic menhaden stock is now considered to be healthy, wide-ranging, and sustainably managed (SEDAR, 2015, 2020a, 2020b). Currently, along the Atlantic coast, Atlantic menhaden constitute the largest fishery landings by volume of any commercial fisheries (SEDAR, 2015). Atlantic menhaden undergo extensive north-south migratory movements and are believed to consist of a single population (Atlantic States Marine Fisheries Commission [ASMFC], 2020). Adults from large, near-surface schools move inshore and northward in the spring. During summer, Atlantic menhaden schools stratify by size and age along the coast, with older and larger Atlantic menhaden found farther north. During fall-early winter, Atlantic menhaden of all sizes and ages migrate south around the North Carolina capes to spawn (ASMFC, 2020).

During our study, nearly 5,700 fish schools were observed from the air, peaking during summer. Fish school sighting rates were highest during Year 2, followed by Year 3, corresponding with foraging sighting rates for humpback whales. Similarly, fish schools were found to be most common in the nearshore and shelf distribution zones as was humpback whale foraging activity. Although it was not possible to identify all fish schools observed from the aerial platform, it was probable that many of the fish schools observed during this survey were Atlantic menhaden. This presumed identification was based on photographic documentation of fish schools' recorded behavior depicting large schools of small, silvery colored fish with individual fish breaking the surface (P. Sieswerda, pers. comm., 3 August 2020), and was additionally based on local observations of Atlantic menhaden schools from other groups in the area which correlated with sightings. It is likely that the increase in large whale, particularly humpback, foraging events in the NYB is linked to the increase of Atlantic menhaden, and possibly other prey species, in the region. Subsequently, the ecologically abundant waters of the NYB are providing supplemental foraging areas for large whale species.

Shifting foraging patterns based on prey availability have been reported for fin whales in the North Atlantic (Coakes et al., 2005), and for humpback whales in South Africa (Findlay et al., 2017), the North Atlantic (Askin et al., 2017), and nearshore Virginia (Swingle et al., 1993). In the waters off Halifax, Nova Scotia, Coakes et al. (2005) reported an unusually high number of fin whales during 1997 when compared to other years of the study: 1996 to 2004. The authors suggested that fin whales migrating into the St. Lawrence Estuary found abnormally high prey availability near Halifax, including herring, sand lance, and euphausiids, and stayed in the region rather than continuing their normal migration into the St. Lawrence Estuary. Findlay et al. (2017) presented evidence of humpback whale expansion into new feeding grounds off the southwest coast of South Africa (and larger than average feeding groups ranging from 20 to 200 animals) during a 2011 to 2015 study. The authors considered this shift unusual since feeding grounds for this population are thought to be off the coast of the southern polar regions of Antarctica, and they further speculated that changes in prey availability, or an increased abundance in the whale population, may have caused the restoration of feeding strategies not previously observed. In the North Atlantic, Askin et al. (2017) reported that during the fall of 2016, humpback whale feeding events were observed in St. Mary's Bay located at the mouth of the

Bay of Fundy, an area that had no reported feeding activity for over 30 years. Authors indicated this regional expansion of foraging humpback whales was related to local water temperature being warmer than usual along with anecdotal evidence of increased numbers of herring in the bay. Humpback whales were observed feeding in the nearshore waters of Virginia for the first time in 1993, apparently due to large aggregations of fish schools (Swingle et al., 1993).

Seasonal distribution variability for foraging baleen whales is known to occur and has been documented in other summer feeding grounds, including in the Atlantic (e.g., Christensen et al., 1992; Visser et al., 2011; Anderwald et al., 2012). Numerous studies indicate that baleen whales can capitalize on food availability and track production in prey blooms which, in turn, affects whale seasonal presence and species-specific patterns of habitat use (e.g., Piatt & Methven, 1992; Laidre et al., 2010; Visser et al., 2011). Behavioral plasticity where whales adapt feeding strategies based on prey movements has been noted with similar patterns of differing habitat use in other areas (e.g., Piatt & Methven, 1992; Hazen et al., 2009; Laidre et al., 2010; Santora et al., 2010; Visser et al., 2011; Anderwald et al., 2012; Silva et al., 2013; Volkenandt et al., 2016; Kirchner et al., 2018) and indicate that whales can respond and even fine tune their responses to prey availability and abundance at scale. It is conceivable that the interannual, seasonal, and spatial variations we found in large whale presence in the NYB are driven by fluctuations in prey availability. This was particularly apparent during the large-scale mixed-species events when large numbers of all three species were observed foraging cooperatively (i.e., humpback whales bubble net feeding and fin whales lunge feeding in unison) and in proximity, coinciding with a higher presence of fish schools.

It is important to highlight some of the limitations of this study. Data are not known for any potential patterns occurring in wider temporal periods between survey periods. Our data represent snapshots over a 3-year period and are consistent. This study could not effectively investigate prey availability, confirm prey type when foraging events were occurring, or identify each individual fish school species. Additional studies that include vessel platforms for concurrent in-water sampling could better investigate prey type and availability. Due to government-designated survey methods, observations were limited to records of large whale feeding behaviors from the aerial platform, and confirming prey species was limited to observations and photographs from the aircraft. The track lines for our study were designed in conjunction with two government agencies (NYSDEC and NOAA Fisheries) and were fixed; thus, not all effort occurred nearshore. However, transit to the survey lines occurred nearshore, and any feeding in nearshore sightings during transit were documented. In addition, since large whales often feed subsurface, this study's foraging data are limited to aerially observed surface foraging behaviors. It is possible that foraging was occurring subsurface and not visible from our aircraft platform. The aerial platform also limits the ability to photo-identify individuals; therefore, it could not be confirmed whether the same individuals were counted more than once during a season or throughout the study period. While these limitations are present, the data presented herein are from extensive survey effort (i.e., 688.3 h and 140,370 km). Further, although results on large whale and fish school variability by season and distribution zone are interesting and noteworthy observations, they should be reported with a measure of uncertainty since data were pooled across years. While 3 years is a relatively short time to draw conclusions about the foraging ecology of these species, clearly foraging is occurring for these species in the NYB. Continued research is needed to determine whether the NYB will remain, diminish, or potentially expand as a supplemental feeding ground for these species.

Understanding on how large whales utilize NYB waters, a region also busy with fishing, shipping, marine tourism, and renewable energy development, is increasingly critical to evaluate potential impacts from direct and indirect anthropogenic threats. Along with vessel strikes and entanglement—currently the leading causes of anthropogenic mortality—and humpback and minke whales designated as being in an UME, our results showing groups of foraging whales from all three species in shipping lanes are significant. Stepanuk et al. (2021) used Automatic Identification System (AIS) data to quantify vessel density in the NYB and found high densities of cargo vessels, tankers, and service and research vessels within shipping lanes in both offshore waters and nearshore waters in the New York Harbor region. Further, the authors speculate that surface behaviors (such as foraging) put large whales at higher risk of vessel strikes due to the amount of time spent at the surface and decreased ability to be detected by vessel operators. Such links to surface activity and the increased risk of vessel strikes have been demonstrated in many other large whale studies (e.g., Silber et al., 2010; Parks et al., 2012; Lomac-MacNair et al., 2018).

Our findings illustrate interannual, seasonal, and spatial trends of large whale foraging behaviors and support growing evidence that the NYB region and mid-Atlantic waters serve as a supplemental foraging area for fin, humpback, and minke whales. This, along with our results depicting foraging activity in NYB shipping lanes, could be used for management and conservation planning at the state and federal levels, especially in an already busy region experiencing potential growth. More studies like this will be needed to continue to inform management and policy decisionmakers and to assist in the development of effective mitigation strategies in the NYB.

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