

CASE REPORT | Article in Press

First descriptions of common minke whale (*Balaenoptera acutorostrata*) movements off the Eastern Coast of the United States using satellite telemetry

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Abstract

Common minke whales (*Balaenoptera acutorostrata*; hereafter, “minke whales”) are globally distributed, but can exhibit cryptic behavior and sometimes occur in small groups, and are thus challenging to study. Like other baleen whales, this species makes seasonal migrations. However, aspects of their movement and behavioral patterns are not well understood. The Mid-Atlantic Bight (MAB), situated along the eastern coast of the United States, is a known migratory route for minke whales, but earlier observations suggest this area may also serve as foraging grounds despite various natural and anthropogenic stressors. We deployed three satellite tags on minke whales, including two in the New York Bight (NYB) in September 2023 and one off of Virginia (VA) in February 2024, to characterize movement patterns in and around the MAB. These tags yield the first record of minke whale movements in this area and the first dive record for minke whales in the broader northwest Atlantic. The animals showed two types of movement, area restricted search (ARS) and transit, likely reflecting foraging and migratory behavior, respectively. In the NYB, we found evidence of ARS in mid-shelf waters, including in offshore wind lease areas. In VA coastal waters, ARS was documented in and around shipping lanes. We also found evidence of southward migration in the fall, with one animal exhibiting a shift from ARS to sustained transitory movements in late October. In the NYB, the whales exhibited strong diel trends in diving behavior, but this was not observed for the individual off VA. These data provide initial quantification of minke whale behavior and habitat use in the MAB, including in areas that overlap with anthropogenic activities, providing insight for further research, management and conservation.

Keywords Satellite telemetry · Foraging ecology · Anthropogenic activity · Offshore wind · Eiving behavior

Abbreviations

MAB Mid-Atlantic Bight
NYB New York Bight

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OSW	Offshore wind
UME	Unusual mortality event
ARS	Area-restricted search
SST	Sea surface temperature
SSS	Sea surface salinity
SSM	State space model
Chl-a	Shlorophyll-a concentration
SMA	Seasonal management area
LIMPET	Low impact minimally percutaneous electronic transmitter
SI	Straightness index
IQR	Inter-quartile range
VA	Virginia
ERDAPP	Environmental research division data access program

Background

Like many baleen whales, common minke whales (*Balaenoptera acutorostrata*; hereafter, “minke whales”) make annual migrations between feeding grounds in northern latitudes (e.g., Gulf of St. Lawrence; [11, 33]) and breeding grounds in southern latitudes (e.g., the Caribbean; [33]). Seasonal patterns in minke whale occurrence in the northwest Atlantic have been confirmed opportunistically through aerial surveys [23, 27, 29, 42], vessel-based observations [2, 19, 42] and stranding histories [26]. Based on passive acoustic monitoring efforts, a clockwise migration has been suggested for minke whales in the northwest Atlantic, with minke whales travelling northward and closer to shore in spring and summer [32, 33], and southward further offshore in late autumn and early winter, potentially to avoid swimming against the Gulf Stream [33]. Along their migration, minke whales pass through the Mid-Atlantic Bight [2, 5, 19, 23, 33, 36]), a region off the eastern coast of the United States that encompasses the two focal subregions of this study: the New York Bight (NYB) and the coastal waters off of Virginia. Minke whales have occasionally been observed foraging and travelling in the MAB [19, 23], but fine-scale movement patterns of minke whales in the MAB are not well-understood.

While the MAB has not historically been considered a foraging ground, there is a growing body of evidence from visual survey methods suggesting the area may serve as a supplemental foraging ground for baleen whales along their migratory routes [19, 23]. In the NYB, Sadove and Cardinale, [36] found that minke whales often occupy shallow shelf waters individually or in small groups and feed on sand lance (*Ammodytes americanus* or *Ammodytes dubius*, collectively referred to as *Ammodytes spp.*; [38]), Atlantic herring (*Clupea harengus*), and pollock (*Gadus chalcogrammus*; [23, 36]). More recently, minke whales have been observed feeding in the NYB in mid-shelf, multi-species feeding aggregations where sand lance was the primary prey observed [19]. During aerial surveys of the NYB, minke whales were documented foraging in 18% of sightings, which occurred in spring (May) and summer (June and July), and all foraging behavior consisted of lunge feeding [23]. Moreover, minke whale foraging activity overlaps with shipping lanes [23] and offshore wind (OSW) lease areas [19].

Less is known about minke whale habitat use off the coast of Virginia, but there have been observations of foraging in and around shipping lanes (Unpubl. data). Altogether, these observations suggest that, despite heavy anthropogenic activity, minke whales may use areas of the MAB as supplemental foraging grounds along their migratory route. However, little is known about individual behavior and ecology of minke whales in this region, which is concerning given the ongoing Unusual Mortality Event [28] for this species and their overlap with anthropogenic activities during foraging.

Satellite telemetry is an invaluable tool for understanding individual animal movements and habitat use, particularly for highly mobile or cryptic species [18]. Fewer satellite tags have been deployed on minke whales

compared to other baleen whales due to their smaller size, unpredictable surface behavior, and fast swimming speeds, although short-term acoustic and movement tags have provided some fine-scale insights of behavior over periods of hours in other regions (e.g., Kvadsheim et al., [20, 21, 40]). To the best of our knowledge, this is the first attempt to satellite tag minke whales in the MAB. Here, three satellite tags were deployed on minke whales in the MAB, including two in mid-shelf waters in the New York Bight [NYB] and one nearshore off Virginia [VA], to provide insight into minke whale habitat use in high-use areas of the MAB.

Methods

The Mid-Atlantic Bight (MAB) extends from the eastern coast of the United States to the 150 m isobath, and from Nantucket Shoals to Cape Lookout (Supplemental Fig. 1). Marine mammals use this area for foraging and/or as a migratory corridor, leading to its designation as an Important Marine Mammal Area [16]. This study was conducted in two subregions of the MAB: the New York Bight (NYB) and near the mouth of the Chesapeake Bay in the coastal waters off Virginia (Supplemental Fig. 1). There is growing evidence that the NYB may serve as supplemental foraging grounds for baleen whales from spring to autumn [19, 23]. Off Virginia, the habitat is thought to be used by some baleen whales as an over-winter foraging ground [2]. In both subregions, federally-designated Seasonal Management Areas (SMAs) are active from November 1–April 30, during which all vessels greater than 65 ft travelling through the zone must transit at 10 kn or less to reduce the risk of ship strike, particularly for critically-endangered North Atlantic right whales (*Eubalaena glacialis*).

Within the MAB, satellite-linked depth recording SPLASH10-333 and SPLASH10-333-F (Wildlife Computers, Redmond, WA) low impact minimally percutaneous electronic transmitter (LIMPET) tags were deployed on the dorsal fins of three minke whales following best practice guidelines [1]. Two were deployed in the NYB in September 2023 (hereafter: NYB1 and NYB2 based on timing of deployment) and one was deployed off Virginia in February 2024 (VA1). Two gas-sterilized barbs were attached to the body of the tags, which anchored the device and stabilized the transmitter. Tags were deployed using an airgun rifle (DanInject USA, Austin, TX) from a distance of 5–10 m.

The satellite tags were configured to transmit location and dive data via the Argos satellite system (see Supplemental Materials for details). Correlated random walk state-space models (SSMs) were run using the *aniMotum* package [18, 30] for quality control and to allow for behavioral inferences (see Supplemental Materials for details). Argos location data had six classes of accuracy (B, A, 0, 1, 2, 3, ranging from lowest quality to highest; [6]). Location qualities A and B made up the majority of transmission for NYB1 and NYB2 (75% and 70%, respectively), and made up nearly half of all transmissions for VA1 (48%; Supplemental Table 1). Across the three tag deployments, the mean and max standard error for longitude were 3.6 km and 13.9 and the mean and max standard error for latitude were 2.9 km and 10.6 km. All location qualities were retained in the models because each contributes useful information on animal movement, and positional error is accounted for by the SSMs. The mean gap time between transmissions was 1.04 h for NYB1, 0.87 h for NYB2, and 0.85 for VA1, and gaps were predominantly due to the timing of satellite passes (Supplemental Fig. 2). The optimal model had an hourly interpolation and the estimated hourly locations of the tagged animals were subsequently extracted (see Supplemental Materials for details).

We derived the estimated velocity (m/s) of the animal tracks based on the robust hourly velocity estimates produced by the SSMs, which were then converted from kilometers per hour to meters per second. The mean and standard deviation distance travelled per day were calculated. To evaluate the tortuosity of the animal tracks, which may be used to infer different behaviors, a multi-scale straightness index (SI) was calculated for each hour using the Github version of the *MSSI* package (github.com/pennekampster/MSSI; see Supplemental Materials for details). The multi-scale SI allows the straightness of the animal track to be evaluated over the entire track multiple times and at a range of time scales [31]. The granularity (i.e., the temporal resolution of the data before the SI is calculated) was set to one hour, and the window size (i.e., the length of time used to compute the SI)

was set to 24 h to determine broad-scale behavioral changes. Given the hourly scale of this dataset, we were not able to determine individual feeding bouts; however, this larger window size allows us to infer the predominant behavior over the course of hours to days, which can then be associated with environmental covariates (e.g., Lee et al., [21]). The SI value is bounded between 0 (highly tortuous movements) and 1 (linear movements). When the SI was low (< 0.4) or high (> 0.6), the inferred behavior was area restricted search (ARS) or transit, respectively [21]. Behavioral states for moderate SI values (0.4–0.6) were inconclusive [21]. The proportion of hours spent within OSW lease areas, active SMAs, and shipping lanes was calculated.

Diving behavior was assessed and the thresholds for classifying a qualifying dive varied slightly between the NYB and VA minke whales since the tags were configured to collect different datastreams (see Supplemental Materials for details). For the NYB minke whales, tags were configured to collect time series data for depth at a 75 s sampling interval. Individual dives were determined using the *serseg* function in the *sattagutils* package [7]. For each depth, an associated depth range was provided from the tag to characterize potential error in measurement (Supplemental Fig. 3). Estimated dive depths in deeper waters had greater uncertainty than shallower dives (Supplemental Fig. 4). The 75 s sampling interval increased the risk of aliasing the dive data, thus a segmentation scheme based on inflection points and a 15 m depth threshold was used to classify qualifying dives (see Supplemental Materials for details; Supplemental Fig. 5). We note that this segmentation increases the possibility for outliers, thus dive metrics computed using segmentation should be interpreted cautiously. For VA1, the tag was configured to collect behavioral data with a sampling period of 1 s. The behavior log automatically characterizes the tagged animal's dive behavior into either qualifying dives or surface periods. Surface periods were identified as the time between two qualifying dives (see Supplemental Materials for details) and included times when the whale was beneath the surface but in depths < 2 m or for durations < 2 min. These surface periods were further segregated into shallow (< 2 m) or deep surfacings (when dives were deeper than 2 m but < 2 min) by the behavior log.

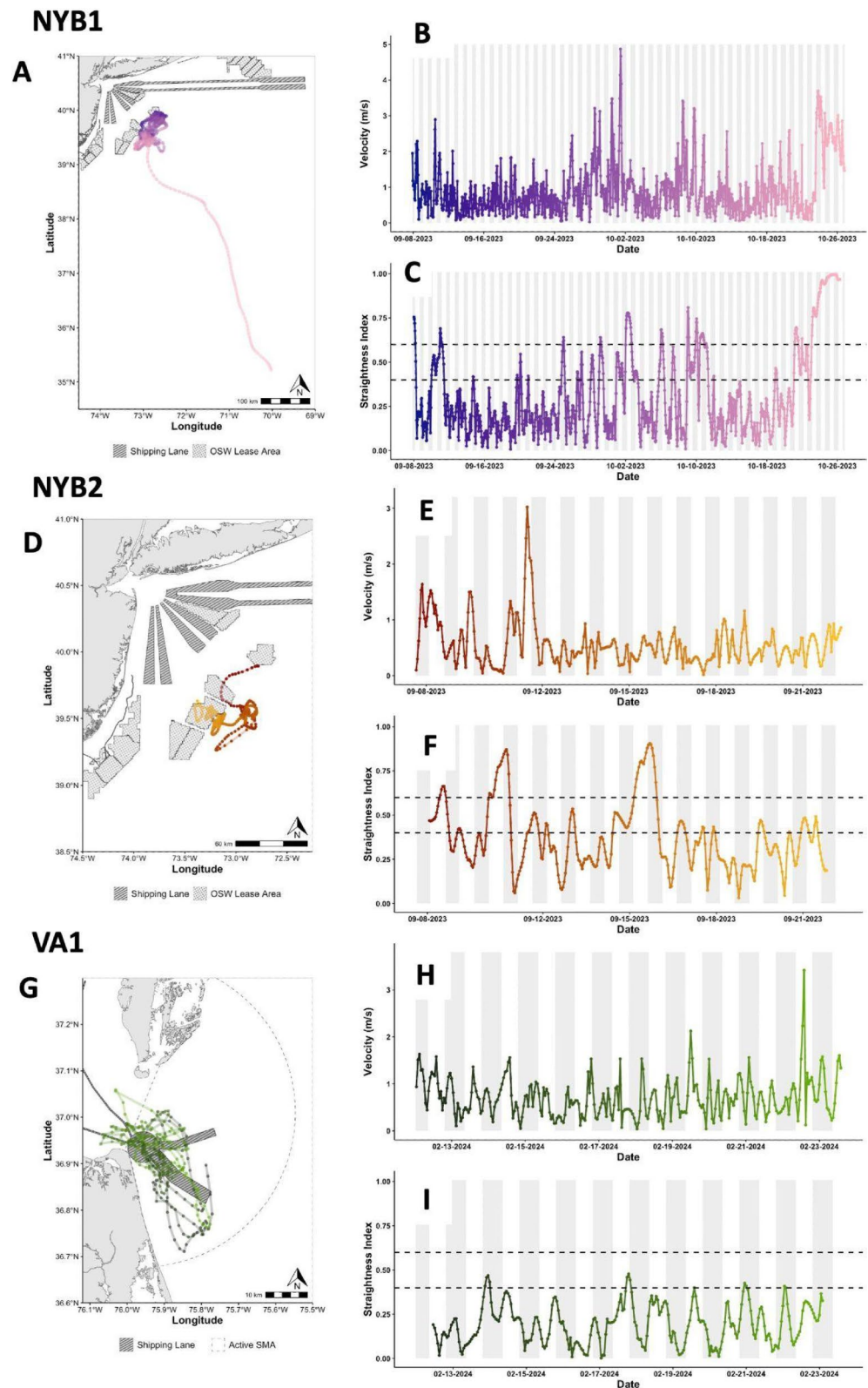
For each tag, dive characteristics, including maximum dive depth (m), dive duration (min), and dive shape (U, V, or square), were calculated from the qualifying dives. Subsequently, the mean and IQR of dive depths (m) and dive durations (min) were calculated. The proportion of dives with each dive shape was calculated out of the total number of qualifying dives. The mean maximum depth was determined during the night and day. A Mann-Whitney U test was performed to evaluate whether there were statistically significant diel differences in mean maximum depths. We calculated the proportion of time spent at/near the surface and at depth for each tag.

To explore the environmental context of the habitat the minke whales moved in and around, we collated relevant environmental variables, including sea surface temperature (SST; °C), chlorophyll-a concentration (chl-a; mg m³), sea surface salinity (SSS; psu), distance to shore (km), seabed sediments, and bathymetric depth (m; see Supplemental Material for details). SST, chl-a, and SSS data had a daily resolution, while distance to shore, seabed sediments and bathymetric depth were available at each estimated hourly position. The mean and range of these environmental variables were calculated across the tag duration for each individual.

Results

Tag deployments for NYB1 and NYB2 lasted for 49.89 and 14.79 days from Sept–Oct 2023. During this time, NYB1 travelled a total of 3250.7 km (mean: 63.1 km/day $\pm$ 33.6 km) and NYB2 travelled 543.5 km (mean: 35.1 km/day $\pm$ 17.4 km), respectively. For NYB1, there was a marked change in the distance travelled each day between the first 46 days (September 7–October 23) and the last three days of the tag deployment (October 24 – October 26), with daily distances travelled for the first 46 days averaging 56.8 km $\pm$ 22.9 km and for the final 3 days averaging 160.0 km $\pm$ 15.1 km (Fig. 2). Through October 23, NYB1 travelled slowly (mean velocity: 0.86 m/s $\pm$ 0.68) and had an SI < 0.4 (mean SI: 0.28 $\pm$ 0.19), consistent with foraging behavior. Their behavior changed from October 24–26, 2023, with faster speeds (mean velocity: 2.4 m/s $\pm$ 0.54), farther transiting distances, and an SI consistently > 0.6 (mean SI: 0.97 $\pm$ 0.03), indicative of migratory behavior (Fig. 1). NYB2

Fig. 1 Minke whales in the MAB predominantly showed movement consistent with foraging, with rarer instances of transit, potentially indicative of migration. The estimated hourly locations of NYB1 (A), NYB2 (E) and VA1 (G) based on the output of the correlated random walk state space model, and overlap with offshore wind (OSW) lease areas, active seasonal management areas (SMAs) and shipping lanes. OSW lease areas and shipping lanes are indicated by the dotted and striped regions on the map, respectively, while the active SMA is outlined by the dashed line. The hourly velocity (m/s) is shown for the tagged animals in Figures B, E, and H and the hourly straightness index is demonstrated in Figures C, F, and I. In graphs C, F, and I, the dashed horizontal lines at 0.4 and 0.6 represent the thresholds for determining different behavioral states (i.e., > 0.6 is associated with transit, < 0.4 is associated with area restricted search (ARS), and $0.4-0.6$ is unspecified). The alternating grey and white shaded regions indicate periods of nighttime and daytime, respectively



mostly maintained an $SI < 0.4$ (mean $SI: 0.37 \pm 0.19$), with several exceptions where the SI exceeded 0.6 (Fig. 1). Generally, NYB2 turned often, moved slowly, and did not travel far (Fig. 1). Between these two animals, 9% ($n = 138$) of hourly estimated locations occurred within OSW lease areas and neither individual overlapped with designated shipping lanes throughout their tag deployments. NYB2 spent more hours in OSW lease areas (21% of hourly estimated locations; $n = 75$) compared to NYB1, (5% of hourly estimated locations; $n = 63$; Fig. 1).

The tag deployed on VA1 lasted for 11.71 days in February 2024. This animal travelled a total of 565.5 km (mean $46.9 \text{ km/day} \pm 12.0 \text{ km}$). Overall, VA1 moved slowly (mean velocity: $0.70 \text{ m/s} \pm 0.43$), with an $SI < 0.4$ (mean $SI: 0.19 \pm 0.11$). This whale was not in OSW lease areas for any part of the tag duration, but overlapped with shipping lanes for 39.1% ($n = 109 \text{ h}$) of the tag deployment. 820.

NYB1 performed 9,457 qualifying dives over 49 days, averaging 202 dives per day (IQR: 158–246). NYB1 typically dove to moderate depths (mean: 21.8 m; IQR: 8–48 m) with an average dive duration of 4.7 min (IQR: 2.5–6.25 min). In comparison, NYB2 performed 3,600 qualifying dives over 14 days, averaging 366 dives per day (IQR: 209–318). The dive behavior of NYB2 was similar to NYB1, with an average dive depth of 19.4 m (IQR: 6–35 m) and average dive duration of 4.4 min (IQR: 2.5–5 min). In contrast, the VA-tagged whale performed 670 qualifying dives over 11 days, with substantially fewer dives per day (mean: 59; IQR: 49–78). This whale also dove to much shallower depths (mean: 8.8 m; IQR: 6–10 m) and for shorter durations (mean: 2.7 min; IQR: 2.25–5.8 min). The NYB-tagged whales demonstrated diel trends in dive behavior, diving deeper during the day (Fig. 2; Supplemental Fig. 6). These trends were not observed for the VA-tagged animal.

For the NYB-tagged whales, the most common dive shape was square, followed by U-shaped, while V-shaped dives were rare (Supplemental Table 2). The majority of sampled depths for the NYB-tagged whales were below the 2 m qualifying depth threshold (87.8% of sampled depths for NYB1 and 83.7% of sampled depths for NYB2). The VA-tagged whale also performed dives that were predominantly square shaped, but both U-shaped and

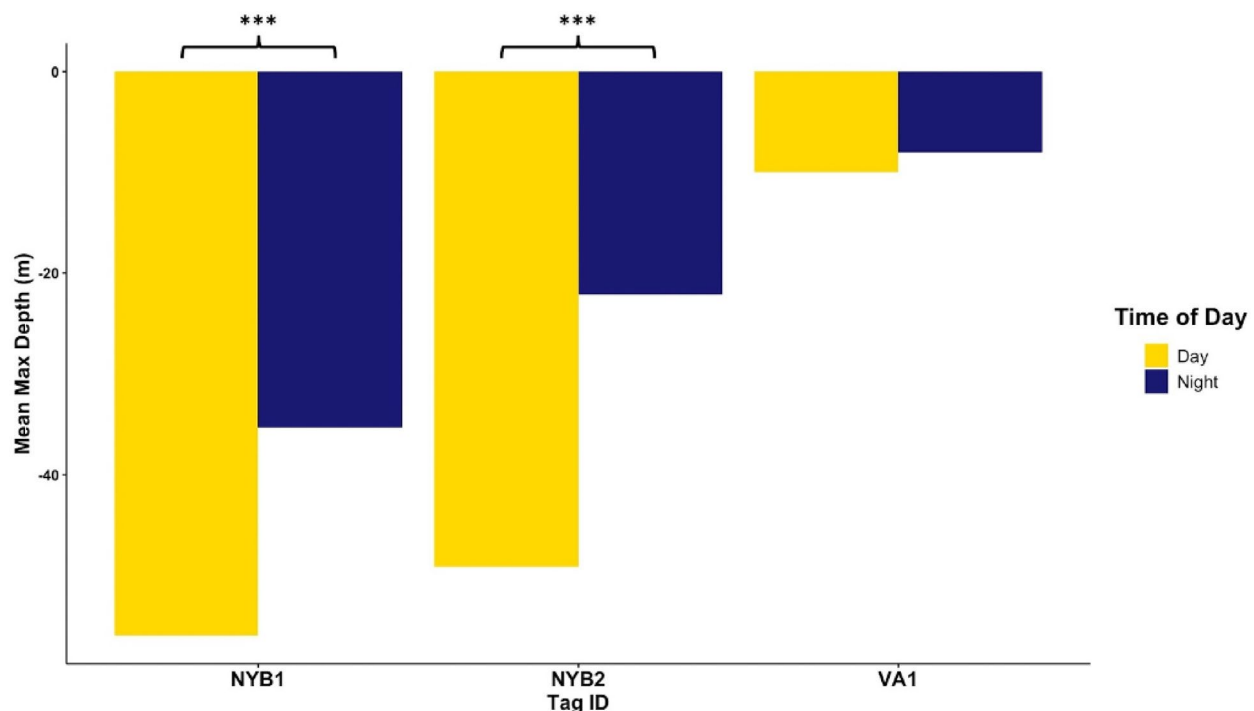


Fig. 2 Mean maximum depths (m) for the three tagged minke whales during the day and night. Statistical significance is indicated by the asterisks (***) $p < 0.05$). The NYB-tagged whales showed strong diel variation in dive depth and typically dove deeper than the VA-tagged whale

V-shaped dives were rare (Supplemental Table 2), and while the NYB whales spent most of their time at depth, VA1 spent 66.5% of the tag deployment hours at or near the surface (Fig. 3).

NYB1 occupied waters ranging from 16.1 to 27.3 °C with salinities of 31.0–35.8 psu and chl-a concentrations of 0.11–0.41 mg m³ (Table 1). This animal moved into substantially deeper waters in the final three days of the tag deployment (October 24–26; Fig. 4). During this transition to deeper waters, NYB1 moved from waters with higher chl-a concentrations (mean: 0.34 mg m³ ± 0.05 mg m³) to lower chl-a concentrations (mean: 0.13 mg m³ ± 0.02 mg m³; Fig. 4). NYB2 remained in warmer waters with SSTs (21.2–25.9 °C) and bathymetric depths

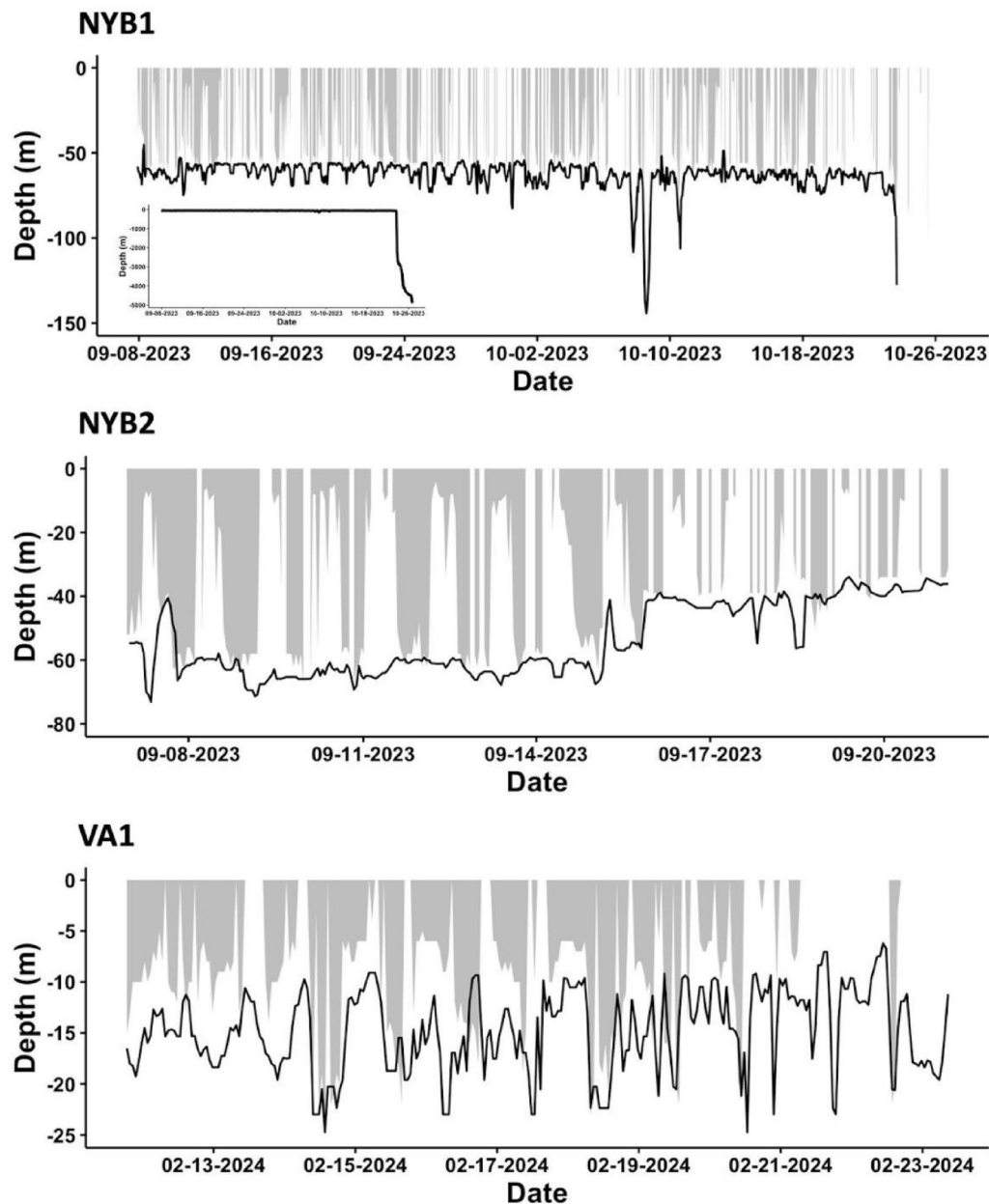


Fig. 3 The range of hourly dive depths (from the surface to the maximum dive depth recorded within each hour) for the tagged minke whales in relation to the bathymetric depth at the estimated hourly location. Shaded regions indicate water column usage from the water surface to the max dive depths (m) for each hour. The black line is the bathymetric depth at the estimated location of the minke at each hour. NYB1 travelled to substantially deeper waters after October 23, 2023 (see inset)

Table 1 Mean (range) of the environmental conditions experienced by the tagged minke whales throughout their tag deployments

Environmental covariate	NYB1	NYB2	VA1
SST (°C)	20.3 (16.1–27.3)	23.3 (21.2–25.9)	7.0 (6.7–7.2)
SSS (psu)	33.2 (31.0–35.8)	32.0 (30.0–33.0)	32.63 (30.1–34.6)
Chl-a (mg m ³)	0.33 (0.11–0.41)	0.41 (0.28–0.58)	3.55 (2.52–4.62)
Distance to shore (km)	117.5 (83.1–491.7)	92.8 (61.1–115.8)	7.52 (0.89–17.1)
Bathymetric depth (m)	314.9 (57.5–4558.2)	52.5 (35.3–65.6)	15.1 (11.4–17.9)
Seabed sediment (type and percent of tag deployment hours)	Majority sand (63.3%) Sand with some mud and gravel (27.3%) Sand with some gravel (6.5%) Majority mud (1.8%) Sand with some mud (0.8%) Mud with some gravel (0.2%) Mix of sand and mud (0.1%)	Majority sand (76.1%) Sand with some mud and gravel (13.5%) Sand with some gravel (10.4%)	Majority Sand (75.5%) Sand with some mud and gravel (19.0%) Sand with some gravel (5.4%) Sand with some mud (1.1%)

(35.3–65.6 m) for the entire tag deployment, but moved into waters with higher chl-a concentration halfway through the deployment (Fig. 4). In contrast, the VA whale occupied much shallower (11.4–17.9 m) and colder (6.7–7.2 °C) waters, with much higher chl-a concentrations (2.52–4.62 mg m³). This animal stayed closer to shore throughout the tag deployment, staying within 20 km of the coast, whereas the other two animals were never closer than 60 km from shore (Table 1). All three minke whales tended to inhabit areas with similar salinities (30–35.8 psu). The whales inhabited waters that had mostly sandy bottoms or sand with some mud and/or some gravel, while NYB1 moved into areas with more mud and gravel in the last several days of the tag deployment (Table 1).

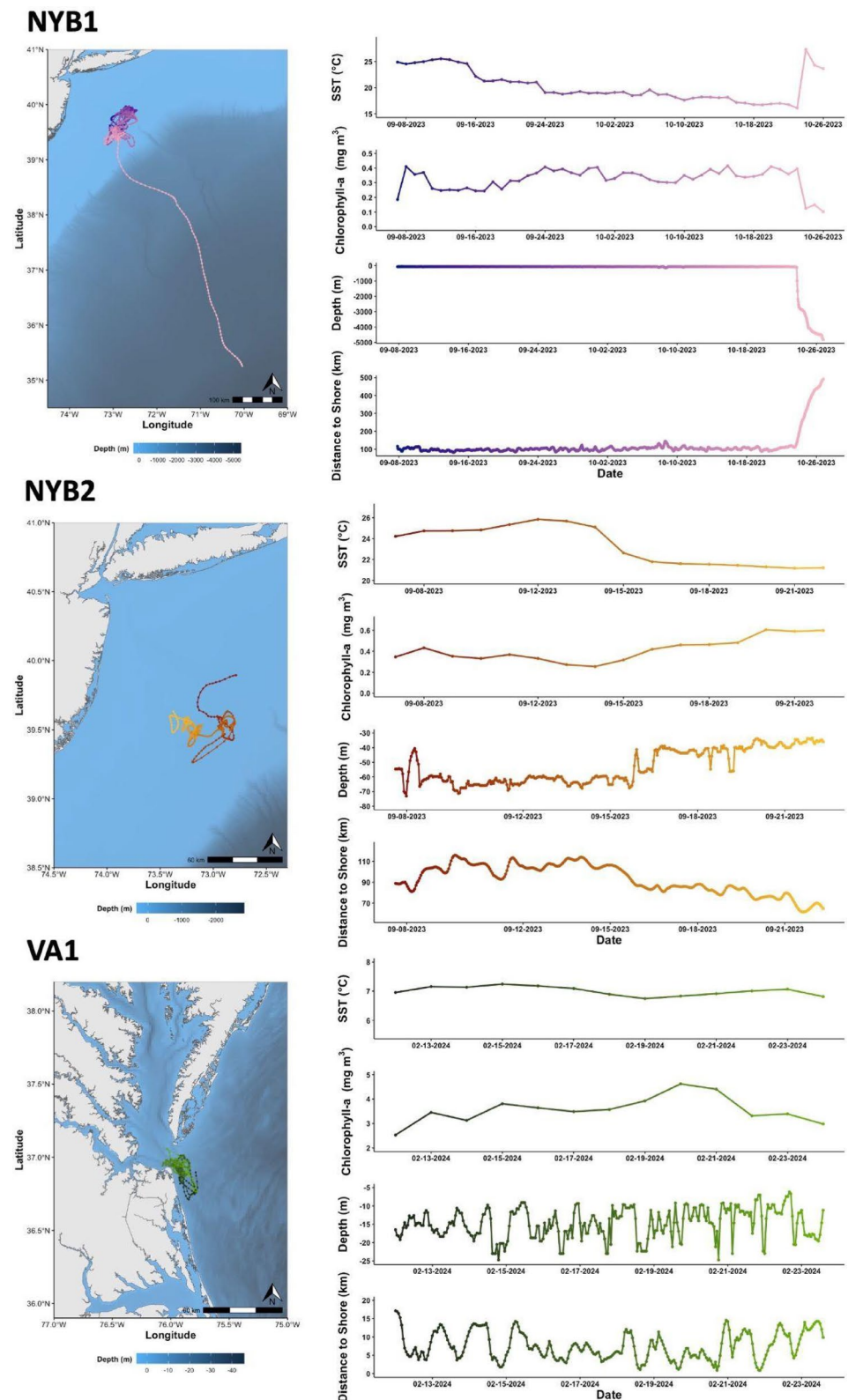
Discussion

These results comprise the first description of satellite-tagged minke whale movements in the MAB and minke whale diving behavior in the broader northwest Atlantic. The number of dives and duration of continuous movement patterns provide a snapshot of minke whale habitat use and behavior in a high-use area, despite the small number of individuals tagged. Our results provide context for minke whale habitat use in and around current OSW lease areas and shipping lanes and provide additional evidence that the MAB is a foraging ground for this species.

Both ARS and transit were documented in the MAB during tag deployments. During ARS, individuals travelled more slowly and often made turns, increasing the chances of foraging success by maintaining proximity to prey patches [17, 35]. For the NYB-tagged animals, movements from early September through mid-October were characterized by frequent turning, slower travel speeds (< 1 m/s), and shorter distances (< 10 km) per day compared to movements in late October (for NYB1). During ARS, the two NYB whales overlapped with OSW lease areas, indicative of foraging in these areas in the late summer and autumn.

Similarly, throughout the tag deployment for the Virginia-tagged minke, movements were indicative of foraging behavior in and around shipping lanes off Virginia in winter, corroborating vessel-based sightings of this animal during the tag deployment (Unpubl. Data). Moreover, ships do not always stay within the narrow bounds of the designated shipping lanes off Virginia, such that vessel traffic is also elevated adjacent to the shipping lanes (Unpubl. Data). Therefore, even when the VA1 was not within the defined shipping lanes, they still may have an increased risk of interacting with vessels. Surface foraging behavior has been documented for minke whales in the MAB in spring (in April off Virginia and May in the NYB; Unpubl. Data; [23]) and summer (June, July, and August in the NYB; [19, 23]). However, this is the first evidence of minke whale foraging behavior later in the summer and into autumn (September and October, in the NYB) and in winter (February, in coastal waters off Virginia).

Fig. 4 The estimated hourly locations of the tagged minke whales in the context of bathymetric depth. Mean daily sea surface temperature (SST; °C) and chlorophyll-a concentration (chl-a; mg m³) are shown in addition to the hourly bathymetric depth (m) and distance to shore (km)



During ARS, all three animals favored areas with sandy seafloors (Supplemental Fig. 7), in either mid-shelf (NYB1 and NYB2) or nearshore (VA1) waters. In other areas, minke whales show similar preferences, presumably because these areas are the preferred habitat of minke whale prey [34, 35]. There is no one species that dominates the prey supply for minke whales [37]. In the NYB, minke foraging behavior has primarily been documented in mid-shelf waters, where they forage on sand lance, pollock, and herring [19, 23]. Another less well-known prey species of minke whales are Atlantic menhaden (*Brevoortia tyrannus*), which tend to occupy waters closer to shore with sandy bottoms [22, 41]. For example, in the nearshore waters of Maine, minke whales have been increasing in the area, presumably due to increased menhaden abundance locally [4]. Menhaden are known to be important prey for other cetaceans in the nearshore waters of the NYB [19] and Virginia [2], and in December 2024 a stranded minke whale in Sore Thumb Beach, New York had the remains of menhaden in its stomach, indicating that it had recently been feeding on menhaden in the NYB.

For the NYB-tagged minke whales, ARS was documented in areas that overlap most heavily with the habitat preferences of sand lance (35–96 m depths, 61–180 km from shore, and majority sand seabeds), suggesting sand lance may have been the targeted prey species for these two animals (see Supplemental Materials for details; Supplemental Fig. 8). In contrast, the VA-tagged animal may have targeted menhaden as this individual overlapped most heavily with menhaden habitat, in shallower waters (11–18 m) closer to shore (1–17 km from shore; Supplemental Fig. 8). This inference is corroborated by visual observations of menhaden in the area where VA1 was observed foraging (Unpubl. Data).

Dive behavior, movement patterns, environmental, and seasonal context indicate potential differences in foraging strategies between the minke whales tagged in the NYB and the individual tagged off Virginia, which is likely related to the distribution and behavior of their prey (e.g., [24]). Preferred prey can vary across age class and sex of the animals (e.g., Robinson et al., [35]; however, while all three tagged minke whales in this study were sub-adults/adults, the sex is unknown for NYB-tagged whales and VA1 was a female. For the NYB-tagged whales, diel trends in diving behavior, ARS movement patterns, and association with sand lance habitat may reflect daytime pelagic foraging on sand lance, which has been documented in the Northeast Atlantic [10, 35, 39]. Sand lance are more generally available in the water column during the daytime, though Freeman et al., [12] found that some schools of sand lance stay close to the seabed or even stay buried in the sand during daylight hours. This may explain why the minke whales dove down to the seabed during the daytime and tended to stay near the seabed throughout their dives, constituting the high proportion of square and U-shaped dives reported here. In other baleen whales, sand lance behavior has been shown to influence diving behavior (e.g., humpback whales in Stellwagen Bank, United States; [13]). In contrast, the VA-tagged whale lacked a strong diel pattern in dive behavior, demonstrated ARS movement patterns in nearshore, shallow waters and spent the majority of the tag duration near the surface of the water, which is consistent with surface foraging (i.e., lunge feeding) on Atlantic menhaden off Virginia. Atlantic menhaden tend to school and feed in near-surface waters and do not show strong diel patterns in their vertical distribution in the water column [14]. Further research is needed to better understand the diet composition of minke whales in the MAB. However, the patterns in the movements and diving behavior of these minke whales provide novel insights into their seasonal habitat use in the MAB, and provide a foundation for further research.

In addition to movement patterns associated with ARS, one of the minke whales also demonstrated a prolonged period of transit. We observed evidence of migratory behavior from NYB1, from October 23, 2023 until the end of the tag deployment on October 26, 2023. This whale's movements became more directional (mean SI=0.99) and faster (mean velocity=2.36 m/s), resulting in an increase in the distance travelled per day (mean: 101.6 km per day). During this time, NYB1 moved southward into deeper waters further from shore and into areas with lower chl-a concentrations and majority mud seabed sediments. Similar results were found in Icelandic waters, where the daily traveling speeds for satellite-tagged minke whales were substantially faster when they moved into offshore waters, as they began their southward migration [40]. The clear contrast between ARS and transit documented here provides further evidence that the MAB may be used as a foraging ground for minke whales along their migratory route.

Together, these results suggest that minke whales are likely foraging in MAB, including in areas overlapping with anthropogenic activities. In the NYB, tagged minke whales appeared to be foraging in and around OSW lease areas and may be exposed to or potentially impacted by some activities related to offshore wind development. While the NYB minke whales spent more time at depth than VA1, they performed shallower dives at night when visibility is limited. Increased near-surface behavior at night may lead to increased risk of vessel strike during periods when visual mitigation is challenging and other mitigation strategies (e.g., vessel speed reductions) may be more effective. The tagged minke whale off Virginia spent the majority of the tag deployment in near-surface waters, likely engaging in surface active foraging behavior, such as lunge feeding [23] on Atlantic menhaden. Similarly, humpback whales have previously been documented in this area lunge feeding on Atlantic menhaden [2]. Occupying near-surface waters, particularly in shipping lanes, may increase the likelihood of vessel strike (e.g., Crum et al., [9], and evidence of vessel strikes have been documented for humpback whales in coastal waters off Virginia [2]. While VA1 spent the majority of the tag deployment within an active SMA, which reduces the likelihood of a lethal collision with a ship, this animal also spent time foraging outside of the SMA, where they were more at risk. Moreover, in August 2025, a vessel strike of a minke whale in Barnegat, New Jersey was videotaped [15] demonstrating that small recreational vessels can also pose risks to minke whales, particularly in shallow waters.

Given these concerns, understanding the baseline habitat use of these animals in the MAB is imperative for being able to measure changes in behavior relative to forthcoming developments and changes in the environment. This information can also be used to inform updates to best practices and/or management regulations aimed at reducing potential impacts to whales in high use areas, such as extending the spatial boundaries of the SMA in Virginia's coastal waters to reduce ship strike risk to North Atlantic right whales, with benefits for other baleen whale species that forage in this area (e.g., [2]). Although the sample size of this study is small ($n = 3$), it provides valuable insight into minke whale habitat use by describing trends in diving behavior and characterizing movements throughout the MAB for the first time using satellite telemetry, and within the context of offshore wind development and shipping activity. These findings are consistent with other studies of minke whale behavior in the North Atlantic, highlighting the importance of the MAB for this species, and helping inform future research, management, and conservation efforts for this species.

Full legal disclaimer

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate All research activities were carried out under NOAA/NMFS Scientific Research Permits 17086 and 20605 issued to Robin Baird; NOAA/NMFS permit 14809-03, issued to Doug Nowacek; and NOAA General Authorization 16185, issued to Andrew Read, in accordance with the relevant guidelines and regulations on the ethical use of animals as experimental subjects. Tagging procedures were reviewed and approved by the Institutional Animal Care and Use Committee of Duke University.

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