Acoustic presence and vocal activity of North Atlantic right whales in the New York Bight: Implications for protecting a critically endangered species in a human-dominated environment

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Abstract
North Atlantic right whale (NARW) distribution shifts have led to increased presence in the US mid-Atlantic, which includes the New York Bight (NYB), an area with substantial vessel traffic. NARW vessel strikes are mitigated by a seasonal management area (SMA) that is active November–April. Within the SMA, vessels ≥ 19.8 m must travel at ≤10 knots. However, until recently, surveys of the NYB were not conducted after the NARW distribution shifted. Thus, it was unclear whether the SMA captured NARW presence in the NYB. Outside the SMA, voluntary speed restrictions are implemented over a limited area when NARW calls are acoustically detected; therefore, it was important to quantify NARW vocal activity. Acoustic recordings (2016–2020) were analyzed to determine NARW presence, vocal states, and diel pattern of vocal activity. NARWs were detected outside SMA boundaries, and medium/high vocal states (21–69 calls over 3–6 h) occurred while the SMA was inactive. Therefore, the SMA spatiotemporal boundaries should be revised. Vocal activity was highest at night (22:00–1:00), and NARWs were acoustically detected when they were not detected by aerial surveys, illustrating acoustic detections are a viable method for triggering mitigation measures when NARWs are vocalizing but are not visually observed.

KEYWORDS
dynamic and seasonal management, New York, right whales, vessel strikes

1 | INTRODUCTION

Mysticetes encounter multiple threats to individual survival and fitness (Avila et al., 2018). These threats include human-induced stressors, such as injury or death from vessel strikes (Shoeman et al., 2020), entanglement in fishing gear (Feist et al., 2021), lethal and sublethal effects of anthropogenic noise (Erbe et al., 2018) as well as direct and/or indirect effects of climate change (Tulloch et al., 2018). These stressors are not mutually
exclusive, and may act synergistically or cumulatively (e.g., Arrigo et al., 2020; Maxwell et al., 2013), hindering population growth. Mitigating human-induced stressors is of critical importance to manage these threats, particularly for populations recovering from whaling. A key component of this is identifying when and where mysticetes overlap with human-induced stressors. The ability to mitigate mysticetes’ exposure to human-induced stressors is difficult because of current, or predicted, shifts in whale distributions in response to climate change (e.g., Santora et al., 2020; Silber et al., 2017). This is particularly true for the critically endangered North Atlantic right whales (NARWs; Cooke, 2020), which have shifted their distribution, moving into areas that lack adequate protection from human-induced mortalities.

Historically, NARW habitats included calving grounds in the United States (US), a presumed migration corridor through US mid-Atlantic waters, and foraging grounds in US and Canadian waters within or bordering the Gulf of Maine (GOM; Kenney et al., 2001; Winn et al., 1986). Critical habitats include calving grounds along the coast of northern Florida to South Carolina, and foraging grounds in the Great South Channel (GSC) and GOM (Figure 1; NOAA, 2015). US foraging grounds utilized in the spring consisted of Cape Cod Bay (CCB), Massachusetts Bay, Jeffrey's Ledge, and the GSC (Brillant et al., 2015; Kenney et al., 2001; Weinrich et al., 2000; Winn et al., 1986). Canadian critical habitats utilized in summer and fall consisted of the Grand Manan Basin and Roseway Basin foraging grounds (Figure 1; Brillant et al., 2015; Brown et al., 2009; Davies et al., 2015; Kenney et al., 2001; Winn et al., 1986). Based on NARW timing on calving versus foraging grounds, it was assumed southern migration through the US mid-Atlantic occurred in fall to early winter, and northern migration occurred in late winter to early spring (Kenney et al., 2001; Winn et al., 1986).

Beginning in 2010, there was an unprecedented large-scale shift in NARW distribution (e.g., Davis et al., 2017). NARW sightings on the calving ground decreased as fewer whales migrated south, likely because of higher female mortality, lower reproduction due to poor health, and individuals overwintering to maximize foraging (Christiansen et al., 2020; Corkeron et al., 2018; Gowan et al., 2019; Meyer-Gutbrod et al., 2015; Moore et al., 2021; Pettis et al., 2021). On foraging grounds, NARW distribution changed in response to prey distribution shifts likely driven by climate change (Meyer-

![Figure 1](image-url)
Gutbrod et al., 2015; Meyer-Gutbrod et al., 2018; Meyer-Gutbrod & Greene, 2018; Record et al., 2019). In Canadian waters, NARWs shifted north to a novel foraging ground in the Gulf of Saint Lawrence (Figure 1; Davies & Brilliant, 2019; Davies et al., 2019; Davis et al., 2017; Record et al., 2019; Simard et al., 2019). In US foraging grounds, detection of NARWs in the GSC decreased while increasing in CCB and Massachusetts Bay, and NARWs shifted to a novel foraging ground in southern New England (Figure 1; Charif et al., 2020; Davis et al., 2017; Ganley et al., 2019; Leiter et al., 2017; Mayo et al., 2018). In the US mid-Atlantic, acoustic presence of NARWs increased, and NARWs were acoustically detected year-round (Davis et al., 2017; Hodge et al., 2015; Salisbury et al., 2015).

With these large-scale shifts, NARWs occupied waters with inadequate protection from human-induced mortalities. The net effect of these distribution shifts is unusual mortality events (UMEs) that began in 2017 and are ongoing (Davies & Brilliant, 2019; Moore et al., 2021; NOAA, 2022a). A UME is defined by the US Marine Mammal Protection Act (MMPA) as “a stranding that is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response.” (NOAA, 2022b). Between 2017 and 2021, there were 50 NARW UMEs (mortalities and serious injuries that eventually result in death) primarily caused by vessel strikes (26%) or entanglement in fishing gear (46%; NOAA, 2022a). Given the 2020 population estimate of 336 individuals, the UMEs equate to 15% of the population, exceeding the Potential Biological Removal (PBR) threshold of <1 whale per year set by the MMPA (Hayes et al., 2019; NOAA, 2022a; Pettis et al., 2022) by a factor of 10 (i.e., 50 mortalities/5 years). This represents only a fraction of the total human-induced mortalities as many go undetected (Pace III et al., 2020). Since NARW extinction could occur in <30 years (Meyer-Gutbrod et al., 2018), the ongoing UMEs indicate an urgent need for management actions that incorporate these large-scale shifts in distribution.

With respect to vessel strikes, management actions include re-routing of shipping lanes to avoid whale aggregations, designating areas with whale aggregations as an area to be avoided (ATBA), and implementing seasonal and/or dynamic speed restrictions (Shoeman et al., 2020).

In Canadian waters, shipping lanes were re-routed to avoid the Grand Manan Basin habitat, and the Roseway Basin habitat is an ATBA (Figure 1; Brown et al., 2009). When NARW distribution shifted to the Gulf of Saint Lawrence (GoSL), whales were not protected from vessel strikes, as management actions were not immediately implemented (Davies & Brilliant, 2019). As a result, 62% of UMEs caused by vessel strikes occurred in the GoSL (NOAA, 2022a). Mandatory seasonal and dynamic speed restrictions were implemented in GoSL, and detected human-induced mortalities decreased (NOAA, 2022a; Transport Canada, 2020).

About 38% of UMEs caused by vessel strikes occurred in US waters, but seasonal management areas (SMAs) were not revised. In 2008, the US National Oceanic and Atmospheric Administration (NOAA) implemented SMAs with fixed spatiotemporal boundaries (Figure 1; NOAA, 2008). While traversing an SMA, mariners operating a vessel 19.8 m are required to travel at ≤10 knots. In US mid-Atlantic waters, SMAs are constrained to a 37 km radius around port entrances and are active from November 1 to April 30. Outside SMAs, NOAA implemented dynamic management areas (DMAs) activated in near real-time by NARW visual sightings (Clapham & Pace, 2001; NOAA, 2008). Starting in 2020, NOAA implemented Slow Zones (SZs), which are activated in near real-time by NARW visual sightings or acoustic detections (Baumgartner et al., 2019; Pettis et al., 2021). Whereas SMAs are mandatory, mariner cooperation with the 10-knot speed limit in DMAs/SZs, or avoidance of these areas, is voluntary. Mariner cooperation with DMAs was low, constraining their efficacy (NOAA, 2020; Silber et al., 2012). Limited cooperation with voluntary speed restrictions means SMAs are the primary mitigation measure for vessel strikes. However, incidences of mysticete vessel strikes, including NARWs, were greater in the US mid-Atlantic when compared to foraging or calving grounds before and after the implementation of SMAs (van der Hoop et al., 2013, 2015), thus, the authors of these studies suggested SMA boundaries be revised.

The boundaries of US mid-Atlantic SMAs were derived from incomplete data, predicated on an assumption, and do not encapsulate recent shifts in NARW distribution. The boundaries were initially determined using NARW data collected before the SMAs were first implemented (Knowlton et al., 2002; NOAA, 2004, 2008; Russell et al., 2005). Data from the US mid-Atlantic was sparse due to limited survey effort. Nevertheless, the data were analyzed to identify as best as possible when NARWs were transiting past US mid-Atlantic ports (Knowlton et al., 2002). An underlining assumption of the analysis was that NARW presence in this region was solely a reflection of migrating whales. This assumption may not be accurate. Pregnant females migrate to calving grounds to give birth (Kraus et al., 1986), but whether or not other whales migrate varies annually with age and sex, and may be dependent on prey abundance, thus only a subset of the population undergo an annual migration (Gowan et al., 2019). NARWs may transit through the US mid-Atlantic several times a year, instead of just during a seasonal migration (Brown & Marx, 2000; Knowlton et al., 2002). NARWs were observed feeding and engaging in behavior suggestive of mating in US mid-Atlantic
waters, indicating this region is utilized for more than migration (Sadove & Cardinale, 1993; Tetra Tech & LGL, 2020; Whitt et al., 2013; Zoidis et al., 2021). Year-round acoustic presence in the US mid-Atlantic along with the newly formed southern New England foraging ground (Davis et al., 2017; Hodge et al., 2015; Leiter et al., 2017; Salisbury et al., 2015) suggest the region is more than a migration corridor. The southern New England foraging ground is not protected by an SMA and although DMAs were implemented, low mariner cooperation (NOAA, 2020) suggest NARWs are not adequately protected. Additionally, year-round presence in the US mid-Atlantic mean NARWs are not protected from vessel strikes while SMAs are inactive (May 1 to October 30) further signifying a lack of protection in this region.

Inadequate protection from vessel strikes is problematic for the New York Bight (NYB), which is located within the US mid-Atlantic. There is a significant volume of vessel traffic in these waters, and 20% of the UMEs caused by vessel strikes in US waters occurred in this area (NOAA, 2022a; Port Authority NY NJ, 2022). It is unclear if the Port of NY-NJ SMA captures the entirety of NARW occurrence in the NYB since a complete picture of NARW presence off the NY coast is lacking. Historical data for this area was sparse resulting in an incomplete understanding of NARW occurrence before the Port of NY-NJ SMA was delineated (Knowlton et al., 2002). Systematic surveys were conducted after SMAs were implemented, but before NARW distribution shifts occurred (Muirhead et al., 2018; Whitt et al., 2013). Off the coast of NJ, NARW were visually observed from fall through spring, but acoustically detected in all seasons (Whitt et al., 2013). Off the NY coast, NARW were acoustically detected between February and May and intermittently detected between September and January, but summer months (June–August) were not surveyed (Muirhead et al., 2018). These surveys reported daily presence, but corresponding levels of vocal activity were not quantified, nor was the diel pattern of vocal activity. Since SZs triggered by acoustic detections are an alternative mitigation measure in this area, it is important to characterize NARW vocal activity as this can affect the acoustic detectability of NARWs (e.g., Baumgartner et al., 2019).

Hence, a modern understanding of NARW occurrence and vocal activity in the NYB is vital to inform vessel strike mitigation.

The aim of our study was to gain a contemporary understanding of NARW presence and vocal activity off the coast of NY to inform management actions that mitigate vessel strikes. The research objectives were as follows: (1) to determine NARW daily presence and concurrent levels of vocal activity, and (2) to determine the diel pattern of NARW vocal activity off the coast of NY. We analyzed acoustic recordings collected via a buoy moored off the coast of NY 28.9 km from the Port of NY-NJ SMA, which is the same buoy system used to activate SZs (Baumgartner et al., 2019; Pettis et al., 2021). We determined the presence of NARWs relative to the Port of NY-NJ SMA as this is the primary mitigation measure for vessel strikes in the NYB. The results are discussed with respect to mitigating vessel strikes via SMAs and dynamic management areas.

## METHODS

### 2.1 Data collection

A buoy moored in the NYB from June 2016 to January 2020 collected acoustic recordings, but only recordings from July 2016 onward were analyzed (Figure 1 and Table S1). The mooring included a surface buoy, the multi-function node (MFN), which is an aluminum structure anchored to the sea floor, and stretch hoses connecting the buoy and MFN. Acoustic recordings were collected with a custom-built hydrophone connected to a digital acoustic monitoring instrument (DMON) that was attached to the MFN. The hydrophone had a flat response at 8–7500 Hz, 36 dB re µPa/√Hz noise floor at 2000 Hz, –203 dB re V/µPa sensitivity, and a total system gain of 33.2 dB (Baumgartner et al., 2013, 2019). Audio from the hydrophone was digitized by the DMON at a 2000 Hz sampling rate and 16 bit-depth using a duty cycle of 30 min every 60 min. Detection data of tonal sounds were transmitted in near real-time to shore via satellite for review (Baumgartner et al., 2019). These near real-time data were not used in the analyses presented here; only the acoustic recordings simultaneously collected by the DMON were analyzed.

### 2.2 Acoustic analysis

Acoustic recordings were analyzed using automatic detection of NARW calls via the low-frequency detection and classification system (LFDCS; Baumgartner & Mussoline, 2011). The LFDCS created a “pitch track” of any tonal sound with an amplitude ≥5 dB higher than background noise. A pitch track traces changes in frequency and amplitude of a tonal sound over time. The LFDCS classified these sounds, or autodetections, using a quadratic discriminate function analysis (QDFA) that compared pitch tracks to a library of exemplar NARW calls. The library was developed by Baumgartner and Mussoline (2011) and augmented by Davis et al. (2017). We focused on the detection of NARW upcalls as this
vocalization is produced by all age classes, sexes, and is a reliable vocalization for detecting NARWs (Clark et al., 2010). The QDFA measured a Mahalanobis distance between autodetections and exemplar calls. Mahalanobis distances ranged from 1 to 13. A distance of 1 indicated an autodetection was well-matched to exemplar vocalizations, whereas a distance of 13 indicated a poor match. Autodetections categorized as NARW calls and assigned a Mahalanobis distance ≤ 6 was reviewed for human verification.

Using Raven Pro 1.6.1 (K. Lisa Yang Center for Conservation Bioacoustics, 2019), an experienced analyst verified which autodetections were NARW calls. Additionally, the acoustic recordings were reviewed to ensure NARW calls missed by the LFDCS were captured. Raven Pro was used to create spectrograms (Hanning window, 512 FFT, and 90% overlap) of the acoustic recordings with a time resolution of 0.03 s (or 51 samples) and a frequency resolution of 3.91 Hz. Spectrograms were reviewed using a frequency range of 10–1000 Hz. Vocalizations missed by the LFDCS were time stamped. In this way, every instance of a NARW call was captured.

2.3 Determining daily presence and vocal states

Our first research objective was to determine NARW daily presence and concurrent levels of vocal activity in relation to the Port of NY-NJ SMA. Daily presence was represented as a 1 to indicate NARW were present and vocalizing, or 0 to indicate NARW were truly absent or present but undetected (i.e., present but not vocalizing, or present and producing vocalizations that were not detected). Since, daily presence does not capture vocal activity levels; we used three variables to quantify concurrent levels of daily vocal activity, number of calls, hours of vocal activity, and period of vocal activity. Number of calls was the total number of calls per day. Hours of vocal activity was the total number of hours per day with NARW calls. Both variables captured daily fluctuations in NARW vocal activity, providing information on not only the sum calling activity per day, but also the number of hours over which that activity occurred. The period of vocal activity, was the number of days over which daily presence was continuous. Each day was assigned a value equal to the duration of consecutive daily presence that day fell within. This variable indicated whether daily vocal activity occurred in isolation (i.e., period of vocal activity was 1 day), or occurred during a time of sustained vocal activity over multiple days. The resulting data were chronological sequences of daily vocal activity that were a multivariate time series as each day of vocal activity was quantified by three variables. Since these days occurred in chronological order, there was a lack of independence between consecutive days or temporal autocorrelation between days. We, therefore, conducted a hidden Markov model (HMM; Zucchini et al., 2016) analysis to categorize daily vocal activity into vocal states. The HMM analysis was a statistical means of segmenting the multivariate time series into discrete categories (or vocal states) while considering the values of...
all three variables simultaneously and accounting for temporal autocorrelation between days. The HMM analysis was conducted in RStudio (RStudio Team, 2020) using the `depmixS4` package (Visser & Speekenbrink, 2010). Further details about the HMM analysis are in Appendix S1.

### 2.4 Characterizing the diel pattern of vocal activity

Our second research objective was to determine the diel pattern of NARW vocal activity. A scatter plot of the number of calls versus hour of the day indicated a non-linear relationship between variables, thus, a generalized additive model (GAM) was fitted to the data. The GAM analysis was performed in RStudio using the `mgcv` R package (Wood, 2021). The response variable was number of calls and predictor variable was hour. The response variable was modeled using a Poisson distribution and log link function since number of calls was a discrete variable of count data (Evans et al., 1993). A thin plate regression spline was used for the predictor smooth function and restricted maximum likelihood was used to estimate the intercept, number of basis functions and smoothness parameter. Diagnostic plots were created, using `gam.check` function in `mgcv` package, to confirm the model did not violate any assumptions.

### 3 RESULTS

A review of acoustic recordings from 1185 deployment days, yielded 3835 NARW calls within 131 days or 509 h. The LFDCS automatically detected 86.9% of these calls, and 13.1% were manually annotated.

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**FIGURE 3** North Atlantic right whale (NARW) daily presence and concurrent vocal states. Periods when the Port of New York-New Jersey seasonal management area (SMA) was active are labeled on the x-axis. The y-axis includes daily presence (presence), and the three variables quantified to characterize concurrent vocal states; number of calls (no. of calls), hours of vocal activity (hours of VA), and period of vocal activity (period of VA). Periods when the buoy was not deployed are grayed out. NARW was present from November to April while the SMA was active. NARW was also present when the SMA was inactive in October, May, June, and/or July depending on the year. While the SMA was active, peak and high vocal states only occurred from November to February. Medium or low vocal states occurred throughout the SMA timeframe; however, vocal activity from March to April was only categorized as medium or low vocal states. High, medium, and low vocal states occurred while the SMA was inactive; May–October.
3.1 Daily presence and vocal states

The 5-state HMM had the lowest AIC and BIC values indicating this model fit the data best (Table S2). Parameters of the 5-state HMM are reported in Tables S3–S5. The averages for each variable decreased across the five states (Figure 2). Therefore, we labeled the states as peak, high, medium, low, or none to reflect the decrease in vocal activity that occurred across states. The peak vocal state was characterized by the largest average values for all three variables; average number of calls per day (±standard deviation) was 207 (±84.5) calls, average hours of vocal activity was 13 (±3.5) h, and average period of vocal activity was 8 (±2.7) days. The high vocal state had the second greatest average values; average number of calls was 69 (±28.2) calls, average hours of vocal activity was 6 (±2.7) h, and average period of vocal activity was 5 (±3.1) days. Followed by the medium vocal state, which had smaller average values for each variable; average number of calls per day was 21 (±8.9) calls, average hours of vocal activity was 3 (±1.9) h, and average period of vocal activity was 4 (±2.3) days. The low vocal state had the smallest average values; average number of calls was 3 (±1.7) calls, average hours of vocal activity was 1 (±0.7) h, and average period of vocal activity was 3 (±2.9) days. The none vocal state reflected days with no vocal activity. All of the vocal states were distinct from one another with respect to the number of calls, but there was some overlap between states in terms of hours of vocal activity and period of vocal activity (Figure 2; see Appendix S1 for further details).

NARW were present from November to April each year while the Port of NY-NJ SMA was active; however, NARW were also detected when this SMA was inactive in October, May, June, and/or July depending on the year (Figure 3). A majority of vocal activity (120 days or 91.6%) occurred from late fall through mid-spring while this SMA was active (November 1 to April 30). During this time period, days with vocal activity categorized as peak (9.2%) or high (19.2%) vocal states only occurred in late fall through winter (November–February). Days with vocal activity categorized as medium (30%) or low (41.7%) vocal states occurred throughout this time, but vocal activity in early to mid-spring (March–April) was only categorized as medium or low vocal states. During these months, the period of vocal activity was limited to 1, 2, or 3 days. There were 11 days (8.4%) of vocal activity while the Port of NY-NJ SMA was inactive from late spring through mid-fall (May 1 to October 31). Five of these days (45.5%) had vocal activity categorized as medium or high vocal states, and these days occurred in fall, late spring, or summer (October 2016, May 2017, June 2017, and July 2018). The remaining days (54.5%) were categorized as a low vocal state, and these occurred in fall or summer (October 2016, June 2017, July 2019, and October 2019). Vocal activity during this time was intermittent as the period of vocal activity was 1 or 2 days.

3.2 Diel pattern of vocal activity

NARW vocal behavior followed a bimodal diel pattern with two peaks in calling activity, one at night and the other mid-day (Figure 4). The equation, estimated degrees of freedom, Chi-squared statistic, p values, and goodness of fit indices for the GAM are reported in Table S6. The highest peak was at night between 22:00 and 01:00 followed by a minimum in calling activity, after which the number of calls increased to the maximum.

4 DISCUSSION

Systematic surveys of the NYB were not conducted before the US mid-Atlantic SMAs were implemented. Therefore, the Port of NY-NJ SMA spatiotemporal boundaries were derived from a sparse dataset that did not produce a clear understanding of NARW presence in the NYB (Knowlton et al., 2002). Systematic surveys of the NYB were conducted after the SMAs were implemented (Muirhead et al., 2018; Whitt et al., 2013). However, these surveys
occurred before NARW presence in the US mid-Atlantic, which includes the NYB, increased as part of a widespread shift in distribution (Davis et al., 2017). Consequently, a contemporary understanding of NARW presence and vocal activity in the NYB was lacking. The results of our study, in conjunction with other surveys conducted between 2017 and 2020 (Estabrook et al., 2019, 2020; Zoidis et al., 2021) provide a modern-day understanding of NARW presence in the NYB. When data from our study were pooled across years, we acoustically detected NARWs in every month except August and September. A concurrent study involving a greater number of acoustic recorders detected NARWs during these months in multiple years (Estabrook et al., 2019, 2020). Collectively, these results indicate NARWs were present off the coast of NY year-round. A majority of vocal activity detected in our study occurred from November to April while the Port of NY-NJ SMA was active, and peak vocal states only occurred within this period from November to February. Over a similar period, aerial surveys conducted once a month sighted NARWs from November to February. Over a similar period, aerial surveys conducted once a month sighted NARWs from November to February.

Given the Port of NY-NJ SMA boundary was 28.9 km outside the spatial bounds of the Port of NY-NJ SMA, SMA boundaries should be adjusted to better protect NARWs. This issue is not unique to the NYB; previous authors have found that SMA spatial boundaries are inadequate and have advocated for their expansion (Hodge et al., 2015; Schik et al., 2009; van der Hoop et al., 2015). NARWs were acoustically detected outside the temporal bounds (November 1 to April 30) of the Port of NY-NJ SMA during our study. We detected NARWs in May, June, July, and/or October depending on the year. Moreover, our study, in combination with Estabrook et al. (2019, 2020), showed that NARWs occur off the coast of NY year-round. In addition, NARWs were acoustically detected year-round off the coast of NJ (Whitt et al., 2013). Therefore, some portion of the NARW population does occur in the NYB when speed restrictions are absent. Hence, the temporal bounds of the Port of NY-NJ SMA should be revised. Similarly, in southern regions of the US mid-Atlantic NARW are present year-round (Hodge et al., 2015; Salisbury et al., 2015). Our work, in conjunction with these other studies, indicates NARWs occur across the US mid-Atlantic throughout the year, and SMA boundaries should be adjusted to better protect NARWs from vessel strikes.

4.1 Seasonal management areas

NOAA implements mandatory SMAs and voluntary DMAs/SZs to mitigate vessel strikes. Before SZs, DMAs were the only mitigation measures activated outside SMAs. Between 2010 and 2019, five DMAs occurred in the NYB, which is equivalent to <1 DMA per year (NOAA, 2020). DMAs were activated by sightings from aerial surveys (e.g., Pettis et al., 2021); therefore, the low number of DMAs was presumably due to limited survey effort rather than a lack of NARW presence outside the SMA (e.g., Schlesinger & Bonacci, 2014; Whitt et al., 2013). Mariner cooperation with DMAs was low, reducing the effectiveness of these mitigation measures when they were activated (NOAA, 2020). The Port of NY-NJ SMA, therefore, is the principal management action for mitigating vessel strikes in the NYB. The protection provided by SMAs is nullified when NARWs occur outside SMA boundaries (e.g., van der Hoop et al., 2015). Our results illustrate that NARWs occurred outside the Port of NY-NJ SMA, indicating whales were not adequately protected from vessel strikes in this region.

NARWs detected in our study most likely occurred outside the spatial bounds of the Port of NY-NJ SMA given the buoy location and reported detection ranges of NARW calls. The buoy in our study was located 28.9 km from the Port of NY-NJ SMA border, and detection ranges for NARW calls reported in the literature are 3–15 km with a maximum of 30 km (Figure 1; Clark et al., 2010; Estabrook et al., 2020, 2021; Laurinolli et al., 2003; Johnson et al., 2022). At a recorder, 6 km from our buoy site, detection ranges for NARW calls were 5 km at 95th percentile ambient noise levels, 11 km at 50th percentile ambient noise levels, and 28 km at 5th percentile ambient noise levels (Estabrook et al., 2021). This suggests a detection range ≥ 28 km would require low ambient noise conditions that were rare in this area. Given the Port of NY-NJ SMA boundary was 28.9 km from our buoy site, vocal activity detected in our study most likely stemmed from whales located outside of this SMA. Likewise, NARWs were never sighted within the Port of NY-NJ SMA during concurrent aerial surveys (Zoidis et al., 2021). The spatial boundary of this SMA did not encompass NARWs detected in our study nor ones sighted by Zoidis et al. (2021); therefore, this boundary should be revised to better protect NARWs. This issue is not unique to the NYB; previous authors have found that SMA spatial boundaries are inadequate and have advocated for their expansion (Hodge et al., 2015; Schik et al., 2009; van der Hoop et al., 2015).

NARWs were acoustically detected outside of the temporal bounds (November 1 to April 30) of the Port of NY-NJ SMA during our study. We detected NARWs in May, June, July, and/or October depending on the year. Moreover, our study, in combination with Estabrook et al. (2019, 2020), showed that NARWs occur off the coast of NY year-round. In addition, NARWs were acoustically detected year-round off the coast of NJ (Whitt et al., 2013). Therefore, some portion of the NARW population does occur in the NYB when speed restrictions are absent. Hence, the temporal bounds of the Port of NY-NJ SMA should be revised. Similarly, in southern regions of the US mid-Atlantic NARW are present year-round (Hodge et al., 2015; Salisbury et al., 2015). Our work, in conjunction with these other studies, indicates NARWs occur across the US mid-Atlantic throughout the year, and SMA boundaries should be adjusted to better protect NARWs from vessel strikes.
NARW vocal activity detected while the Port of NY-NJ SMA was inactive was elevated enough to be categorized as medium or high vocal states, suggesting on a daily basis numerous whales may utilize the NYB when the SMA is inactive. A majority of peak, high, or medium vocal states detected in our study corresponded to higher NARW abundance estimates (Zoidis et al., 2021), suggesting elevated vocal activity stemmed from greater numbers of NARWs. Similarly, Matthews et al. (2001) found that vocalization rates increased with larger NARW aggregation sizes. While the Port of NY-NJ SMA was inactive, daily vocal activity in our study was often categorized as high or medium vocal states implying multiple whales produced this vocal activity. However, other NARW studies have not found a directly proportional relationship between number of calls and number of whales (Clark et al., 2010; Parks et al., 2011). Given the relationship between number of whales and level of vocal activity remains inconclusive, it is possible lone whales were responsible for these high or medium vocal states. Whether it was lone whales or multiple whales producing the vocal activity, either scenario is concerning since a PBR of <1 whale per year indicates one human-induced mortality per year impedes this species’ ability to survive, especially any mortality involving reproductive females.

We, therefore, recommend the Port of NY-NJ SMA boundaries be revised to fully capture NARW presence in this region. To identify the spatiotemporal boundaries needed to encapsulate NARW presence, data from our survey, Estabrook et al. (2019, 2020, 2021) and Zoidis et al. (2021) should be combined to produce a comprehensive understanding of NARW spatiotemporal distribution in the NYB. During a data synthesis workshop, participants recommended an integration of these surveys, but also recognized that insufficient resources (time and funding) posed a barrier to this work (Wildlife Conservation Society, 2021). Before our study, a sparsity of historical data and a lack of survey data off the coast of NY during summer months (i.e., Knowlton et al., 2002; Muirhead et al., 2018) made it difficult to conclude with certainty that NARWs were present while the SMA was inactive. We, therefore, have accomplished a vital first step in the revision process; illustrating that the Port of NY-NJ SMA boundaries are inadequate given NARWs regularly occur outside these boundaries. An integration of these various surveys is an important next step in modifying this SMA.

### 4.2 Dynamic management areas

Dynamic management actions incorporate whale distributions in near real-time (Hausner et al., 2021; Maxwell et al., 2015), complementing mitigation measures with fixed spatiotemporal boundaries. With shifts in mysticete distributions due to climate change, implementing speed restrictions in a dynamic fashion is increasingly important (Hausner et al., 2021; Kerosky et al., 2012; Santora et al., 2020; Silber et al., 2017). Dynamic management areas are triggered by visual or acoustic detection of mysticetes (e.g., Hazen et al., 2017; Wood et al., 2020). Our work reinforces the value of utilizing NARW acoustic detections to trigger dynamic management areas.

NARW vocal activity during our study was greatest at night when visual sightings of NARW are impractical. We acoustically detected NARW calls when concurrent aerial surveys did not visually detect NARWs (Zoidis et al., 2021), presumably due to low whale densities (e.g., Clark et al., 2010). Our results illustrate that acoustic detection of NARWs is a viable method of triggering dynamic management areas when NARWs are vocalizing, but are not visually detected due to low visibility or low whale densities. Since whales may be present but not vocalizing (e.g., Parks et al., 2011), visual sightings of NARWs should also be used to trigger dynamic management areas.

Understanding NARW vocal activity in the NYB can improve the activation of dynamic management areas. The opportunity to acoustically detect NARWs in near real-time decreases when their calling rate is reduced and/or vocal activity occurs intermittently (Baumgartner et al., 2019). Increasing the rate and/or the amount of data transmitted in near real-time could improve the near real-time detection of NARWs during these periods. In our study, days with medium or low vocal states had minimum number of calls and hours of vocal activity, therefore reduced calling rates (i.e., number of calls/hours of vocal activity). From March through October, including periods while the Port of NY-NJ SMA was inactive, days with NARW vocal activity were predominantly categorized as medium or low vocal states. This vocal activity was sporadic as the period of vocal activity was 1, 2, or 3 days. During these months, particularly while the SMA is inactive, increasing the amount of data and/or rate of data transmission may enhance our ability to detect NARWs in near real-time, improving the implementation of SZs at a time when speed restrictions are lacking.

NOAA implements SZs based on visual or acoustic detection of NARWs. Our work supports the use of SZs triggered by acoustic detections as a management tool that alerts stakeholders to NARW presence in areas with a significant risk of vessel strikes. Since adherence with speed restrictions in SZs, or the avoidance of SZs, is voluntary, their efficacy may be constrained by low mariner cooperation (e.g., NOAA, 2020). Mariner cooperation
increases when adherence is mandatory and enforced, when mariners are better informed, and when the International Maritime Organization (IMO) adopts a mitigation measure (Silber et al., 2014; Silber, Vanderlaan, et al., 2012; Vanderlaan & Taggart, 2009). The efficacy of SZs may be improved if mariner adherence was mandatory, compliance was enforced, and the IMO adopted SZs. However, we recognize that SZs present logistical challenges in terms of managing vessel traffic by reducing predictability and jeopardizing on-time port arrivals. Given these challenges, a spatiotemporal expansion of SMAs may offer a more precautionary solution for vessel strikes, until these logistical challenges can be resolved. SZs based on near real-time monitoring may still be necessary for areas and/or times when NARWs are unexpected yet there is a high risk of vessel strikes.

5 | CONCLUSION

Our results, in conjunction with other surveys, illustrate NARWs are present year-round and occur outside the Port of NY-NJ SMA, thus the boundaries should be revised. During our study, NARW vocal activity was greater at night and we acoustically detected NARWs at times when aerial surveys did not. Acoustic detection of NARWs, particularly in near real-time, is a useful means of alerting stakeholders to the imminent risks NARWs face from vessel strikes, even when whales cannot be visually sighted due to low visibility or low whale densities. Dynamic management actions triggered by near real-time visual and acoustic detections of NARWs may be more effective if compliance is mandatory and enforced, but this approach poses logistical challenges and may be difficult to implement. In areas where NARW presence is well understood, whales may benefit more from expanded mandatory SMAs that are predictable, therefore, easier to comply with and enforce.

AUTHOR CONTRIBUTIONS

All of the authors conceived of the research idea, and made significant intellectual contributions to the work. Anita Murray conducted the acoustic and statistical analyses, wrote the MATLAB and R scripts for analyses, created figures and tables, wrote the original manuscript, and edited subsequent versions of the manuscript. Melinda L. Rekdahl, Mark F. Baumgartner, and Howard C. Rosenbaum reviewed and edited the original manuscript and subsequent version of the manuscript, and secured the funding support. Mark F. Baumgartner oversaw all aspects of the fabrication, deployment, and recovery of the acoustic buoy as well as programming and preparation of the DMON instrument, and provided the LFDCS software.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data for this study are available at https://whalesofnewyork.wcs.org/Publications-and-Webinars/Publications-and-Reports

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SUPPORTING INFORMATION
Additional supporting information can be found online in the Supporting Information section at the end of this article.

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