Assessing Cetacean Presence in the New York Harbor Using Passive Acoustic Monitoring

Bottlenose dolphins in the New York Harbor. Photo © WCS / Image taken under MNFS MMPA/ESA Permit no. 18786-14

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Executive Summary

As whales and dolphins (cetaceans) increasingly visit New York's heavily urbanized waterways, there is growing interest in, as well as concerns about, potential impacts from anthropogenic activities that overlap with their habitat use. This area has seen an increasing number of sightings, many of which have received national and international attention.[1] However, as whale sightings appear to be increasing, so too are reports of strandings (DiGiovanni, personal communication), and risk of collisions with boaters.[2] Despite increasing efforts to better understand cetacean distribution and habitat use in the broader New York Bight (NYB), considerable knowledge gaps still exist. The outcome of a workshop convened by WCS and the Hudson River Foundation in 2016 identified the area in and around the Lower and Upper Bay of the New York Harbor (hereafter, when appropriate to generalize, referred to as the NY Harbor) as a significant knowledge gap. In response to the pressing need for baseline information on cetaceans in this data poor area, a Passive Acoustic Monitoring (PAM) project was implemented in 2018 with the aim to fill some of these important knowledge gaps.

With support from the Hudson River Foundation, WCS pursued two key project objectives, as follows:

- Investigate the temporal and spatial distribution of vocalizing cetaceans (focal species: bottlenose dolphins, harbor porpoise, humpback whales, North Atlantic right whales (NARW), minke whales, and fin whales) over a two-year period in the Lower Bay and into the Upper Bay.
- Characterize temporal and spatial variability in noise levels in the Lower and Upper Bay areas at frequency bandwidths relevant to commonly detected cetacean species.

Here, we present the Final Report from these efforts describing the temporal and spatial distribution of cetacean species and ambient noise environment in and around the NY Harbor.

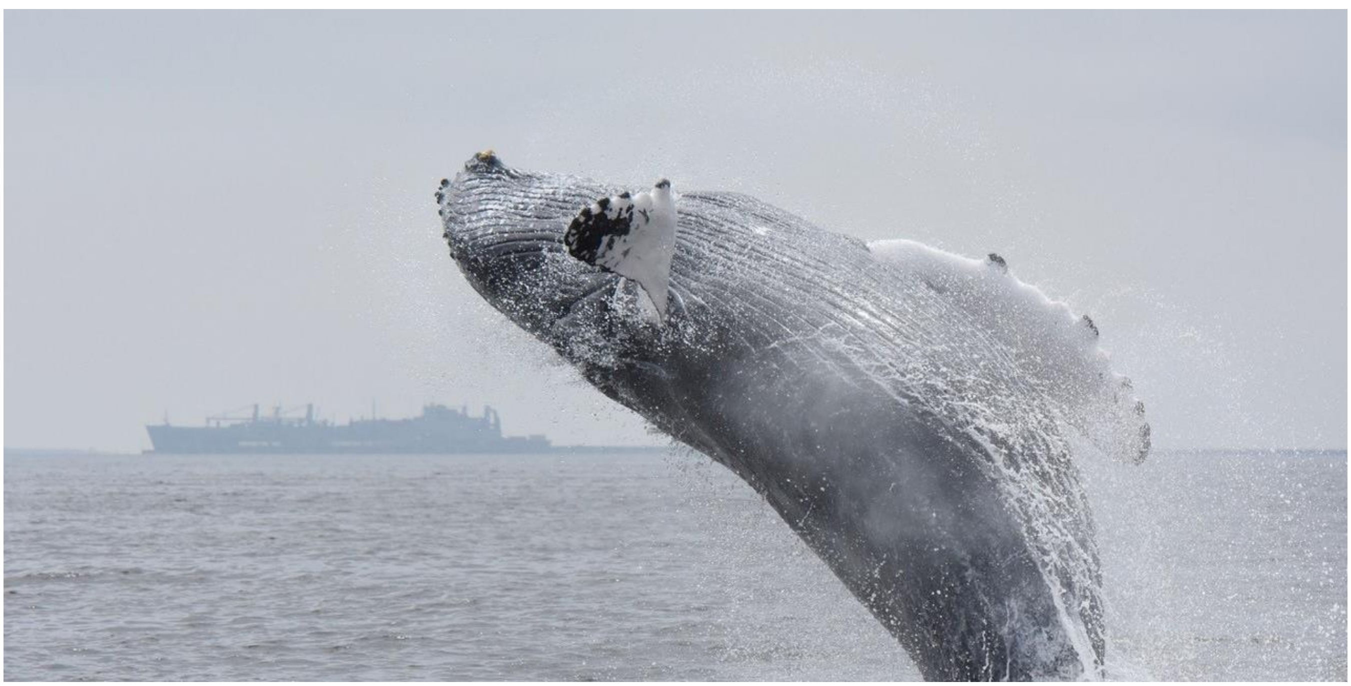
Acoustic recorders were deployed from October 2018 to October 2020 in, or in close proximity to, the Lower and Upper NY Bay. The recorders were set to record across a wide frequency bandwidth to target both the low frequency vocalizing large whale species and the higher frequency vocalizing delphinid species. There were a number of surprising and noteworthy results, including:

- Five species (humpback whale, bottlenose dolphin, minke whale, possible pilot whale, and harbor porpoise) were detected in the NY Harbor either year-round or seasonally.
    - Humpback whales were detected over winter, spring, and fall and across all locations, even into the Upper NY Bay and, when paired with the high prevalence of sightings occurring in summer, suggest the NY Harbor is utilized by humpback whales year-round.
    - Bottlenose dolphins were detected seasonally, with some spatial and temporal variation, from April to November across all locations in the Lower NY Bay.
    - Harbor porpoise, a highly cryptic and acoustically sensitive species, were detected in the NY Harbor area year-round, with peaks in distribution from January to June.

[1] See https://www.dailymail.co.uk/news/article-9032403/Humpback-whale-New-York-Harbor-ready-closeup-Statue-Liberty.html
[2] See https://www.thrillist.com/news/nation/humpback-whale-nearly-capsizes-boat-new-york

  - There were few minke whale detections, with the only detections occurring during late summer and fall on the two recorders located either just inside the mouth of the Lower NY Bay or outside, at the Rockaway reef location.
- Ambient noise levels were generally very high across all locations and seasons, with median decibel (dB) levels corresponding to frequency bandwidths that overlap with—and undoubtedly mask—vocalizations of larger whales.
  - Median noise levels were higher than those reported previously in the NYB and other areas in the mid-Atlantic (Rice et al., 2014).
  - Despite relatively quieter median noise levels in the higher frequency bandwidths, corresponding to delphinid vocalizations, bottlenose dolphin whistling behavior, which is associated with social activity, was altered in the presence of elevated vessel noise.

The results from this PAM project provide an important start to generating a series of baseline information on species seasonal presence and the ambient noise environment to which they are subjected. Despite the human dominated NY Harbor seascape, it is apparent that cetacean species are present year-round (harbor porpoise and humpback whales) or seasonally (bottlenose dolphins, minke whales, possible pilot whale) in the area. However, the coincident increase in strandings and close encounters with vessels are cause for concern, and particularly as the NY Harbor area faces the potential for additional development in coming years. [3,4] Moving forward, continued monitoring is recommended to ensure that any development activities are informed by the best available science and mitigation measures implemented to ensure adequate protection of vulnerable species.



Humpback whale in the New York Harbor. Photo © WCS / Image taken under MNFS MMPA/ESA Permit no. 18786-04

[3] See https://www.nan.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/2275281/fact-sheet-new-york-and-new-jersey-harbor-deepening-and-channel-improvements-st/
[4] See http://ny.anbaric.com/wp-content/uploads/2020/08/2020-08-05-New-York-Offshore-Transmission-Final-2.pdf

Background

The NYB, an area encompassing 16,000 square miles between Cape May, New Jersey and Montauk, NY, is home to approximately 27 species of marine mammals,[5] yet the majority of these species inhabit offshore waters. In recent years however, sightings of a number of cetacean species in near-shore waters has captivated the general public and helped raise awareness, at local and international levels, to the fact that NY City has a rich and biodiverse ocean at its doorstep. However, along with the increase in cetacean sightings has been a rising number of reports of injured or dead animals, and a number of species occurring in the NY Harbor (humpback, NARW and minke whales) are currently undergoing an Unusual Mortality Event (UME) along the Atlantic Coast.[6]

Of the five large whale species that may be acoustically detected in the NY Harbor (minke whales, *Balaenoptera acutorostrata*; North Atlantic right whales, *Eubalaena glacialis*; fin whales, *Balaenoptera physalus*; sei whales, *Balaenoptera borealis*; and humpback whales, *Megaptera novaeangliae*), humpback whales are the species seen with more frequency in recent years (Brown et al., 2018, 2019). Of the smaller toothed whale species, inshore bottlenose dolphins (*Tursiops truncatus*) are commonly sighted seasonally in and around the NY Harbor. One species less commonly sighted, though known to be present in coastal waters of the NYB, are harbor porpoise (*Phocoena phocoena*). They are a cryptic species and like humpback whales and bottlenose dolphins, are highly vocal, and therefore easily monitored using PAM methods. All of these species are known to be highly susceptible to impacts from shipping, fisheries and ocean noise (e.g., Nashteim et al., 2020; see Appendix A for further background information).

The Port of New York and New Jersey is the largest and busiest port on the eastern seaboard, and surrounding waters are used intensely by both commercial and recreational vessels, fishing, tourism and, more recently, the offshore wind industry (Federal Register 2018; see Blake et al., 2013; BOEM, 2016a; BOEM, 2016b). Forthcoming development activities such as the NY-NJ Harbor Estuary deepening and channel improvement project[7] and the cable route for offshore wind energy through the Lower NY Bay[8] has the potential to continue to alter the NY Harbor and disrupt an already fragile ecosystem if not properly managed. The threat of the Williams Pipeline running straight through the Lower NY Bay was blocked by the NY State government in 2019,[9] thanks in part to the efforts of research organizations and eNGOs providing valuable information on the importance of this habitat for marine wildlife.

These anthropogenic pressures can have negative and often cumulative impacts for whales (Jensen & Silber, 2003; Southall et al., 2007; Clark et al., 2009; Henry et al., 2013). Ocean noise impacts are now recognized as one of the most pressing concerns for marine conservation at national and international levels (Chou et al., 2021). Whales rely on sound for critical life functions (Tyack, 2008), and there is growing evidence that there are a multitude of potential impacts from noise exposure, from acute injury

[5] See https://www.dec.ny.gov/ lands/108559.html
[6] See https://www.fisheries.noaa.gov/national/marine-life-distress/2016-2021-humpback-whale-unusual-mortality-event-along-atlantic-coast; https://www.fisheries.noaa.gov/national/marine-life-distress/2017-2021-minke-whale-unusual-mortality-event-along-atlantic-coast; https://www.fisheries.noaa.gov/national/marine-life-distress/2017-2021-north-atlantic-right-whale-unusual-mortality-event
[7] See https://www.nan.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/2275281/fact-sheet-new-york-and-new-jersey-harbor-deepening-and-channel-improvements-st/
[8] See http://ny.anbaric.com/wp-content/uploads/2020/08/2020-08-05-New-York-Offshore-Transmission-Final-2.pdf
[9] See https://www.nytimes.com/2019/05/15/nyregion/williams-pipeline-gas-energy.html

to sub-lethal effects such as habitat displacement, acoustic masking, disruptions to social and foraging behavior, and chronic stress (Nowacek et al., 2007; Clark et al., 2009; Williams et al., 2013). As one of the busiest waterways in the world, the NYB and the NY Harbor are of particular concern. Previous work characterizing broadscale ambient noise levels in the NYB found that these waters experienced the highest equivalent sound levels compared to other locations along the eastern seaboard in 2008-2009 (Rice et al., 2014). Ambient noise levels in and around the NY Harbor were not investigated, presenting a significant gap in understanding the potential impacts to whales utilizing these waters. The current study, and subsequent publications, will further characterize ambient noise levels in and around the NY Harbor and investigate the potential impact to species – information that will be critical for informing future conservation and management efforts.

Methods

<u>Study Area</u>

The NY Harbor, encompassing the Upper and Lower NY Bay, flows out into the greater NYB which extends from Cape May, New Jersey to Montauk, NY. The NY Harbor contains one of the largest ports on the eastern seaboard and major shipping lanes run through the NYB and into the Port of NY-NJ. To ensure adequate coverage across the NY Harbor area, four acoustic recorders were deployed at strategic locations throughout the Lower Bay (NJ1, NJ2, NY1, NY3 in Figure 1) and one recorder was placed at the entrance to the Upper Bay (NY2). One recorder was also placed at Rockaway Reef, located in close proximity to the Harbor entrance and where there have been numerous sightings of both humpback whales and bottlenose dolphins (WCS, unpublished data).

Figure 1. Recorder deployment locations from October 2018 to October 2020.

<u>Acoustic Deployment Information</u>

SoundTrap ST300 HF recorders with inbuilt harbor porpoise click detectors were deployed over six consecutive deployments from October 4, 2018 to October 6, 2020. Four recorders were deployed for the first and second deployments (total deployment duration = 174 days) and six recorders were deployed for the third, fourth, fifth and sixth deployments (total deployment duration = 522 days). It is worth noting that the last set of over-winter recovery of units (June 2020) and subsequent last deployment and recovery (July to October 2020) occurred during the COVID-19 pandemic, which required additional coordination, logistics, and safety measures. Due to some equipment malfunction while deployed, not all units recorded for the entire duration of the project (see Table A1 in Appendix A for further details). However, the failures only related to reduced recording capacity and partial datasets rather than lost equipment. All units were successfully retrieved and are in working order after minimal maintenance.

The units were set to record at 96 kHz, effectively monitoring across a 48 kHz frequency bandwidth to detect both large baleen whales and delphinids. The ultrasonic harbor porpoise clicks were isolated with the automated harbor porpoise click detector and data snippets stored for post processing to determine harbor porpoise presence. Due to limitations with data storage capacity and battery life when recording at high frequencies, the units were set to record on a duty cycle of 20 mins/60 mins to ensure recording coverage throughout winter when retrieval and re-deployment are challenging. The recorders were all deployed in the relatively shallow waters of the NY Harbor at a range of depths from 28 to 45 feet depending on deployment location (Appendix A, Table A1).

<u>Acoustic Analysis</u>

- **Manual review for species temporal and spatial distribution**
  The recordings were sub-sampled (4th hour/4th day) due to the size of the data set (approximately 2 years of recordings from 6 recorders) and the labor-intensive process of manually browsing a 48 kHz bandwidth for cetacean vocalizations. Several automatic detection methods were used for detecting delphinids in the higher frequency bandwidths (PAMGuard click detector and whistle and moan detector). However, automated detectors were less effective for detecting lower frequency vocalizing species due to the high levels of background noise in the lower frequency bands. Therefore it was decided that manual browsing would be the most effective method for processing the data. The 20-minute files were viewed as spectrograms (4,096 pt FFT, 75% overlap) and browsed in the 10-1,000 Hz bandwidth for low frequency vocalizing species (analyzed files were decimated) and 1,000-48,000 Hz bandwidth for higher frequency vocalizing species.

- **Automated detection of harbor porpoise**
  Click detection data were imported into PAMGuard using the SoundTrap Click Detector module (v. 2.01.03, Gillespie et al. 2009) and custom click classifiers were built in PAMGuard (v. 2.01.03) to classify harbor porpoise clicks. A test frequency band of 110-150 kHz and control band of 40-90 kHz (Cosentino et al., 2019), minimum energy difference of 12 dB (Clausen et al., 2019), peak frequency range of 125-145 kHz (Alonso et al., 2014), click length measured over 80% of total energy (Cosentino et al., 2019), click length range of 0.05-0.175 ms (Cosentino et al., 2019), max amount of time between detections of 125 ms (Clausen et al., 2019), keeping all other parameters at their default values. The proportion of days with harbor porpoise detections were calculated per month for each recorder.

- **Investigating environmental drivers of habitat use and the potential impacts of vessel noise on bottlenose dolphin acoustic behavior**
  Automated detection methods were used to identify bottlenose dolphin whistles and foraging buzzes from a subset of the data to explore the potential environmental drivers of habitat use and the impact of elevated ambient noise levels on whistle structure and foraging activity in the NY Harbor. As

these projects are outside the deliverables for the project report, we have provided further details in Appendix C.

- **Ambient noise analysis**
  Sound levels were measured using RavenX software (Dugan et al., 2011). To visualize measured sound levels at each location, broadband and third-octave band spectrograms were generated. Sound levels were averaged over 1-hour time intervals and shown in dB re: 1 µPa. The time-integrated data were then aggregated across frequency bins in third octaves to reflect the typical processing of noise by the mammalian ear (Richardson et al., 1995; U.S. National Research Council, 2003), and allowing for more accurate characterization of potential masking of communication signals (Ketton, 2000).

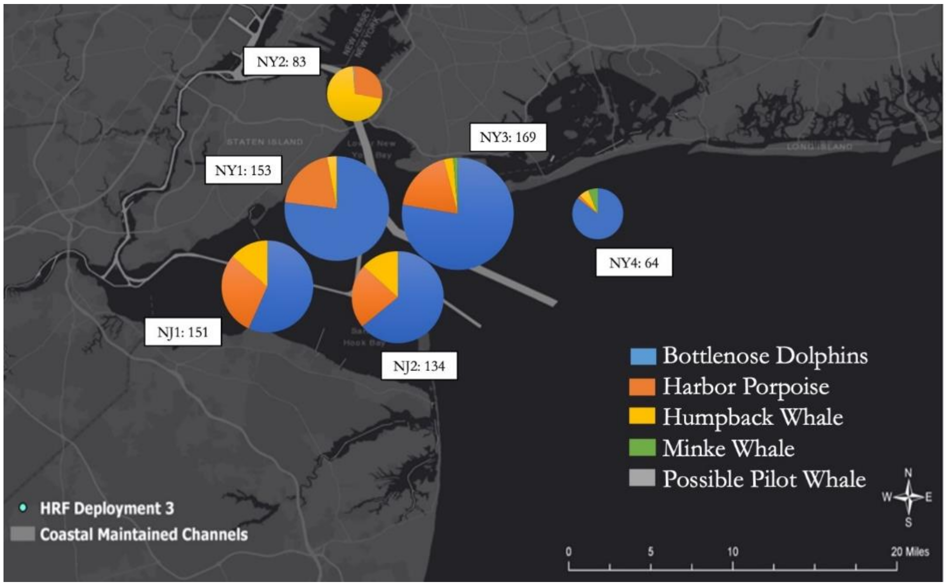
  Equivalent Sound Levels (L_{eq}) were calculated for each 1 Hz bin averaged across the seasons (Rice et al., 2014). L_{eq} percentile values (95^{th}, 75^{th}, 50^{th}, 25^{th} and 5^{th}) were calculated for each of the 1 Hz frequency bins, averaged per season for all deployments, and representing the RMS level at which the given percentage of time slices were below the indicated received level (e.g., the 95^{th} percentile is the RMS value in dB re: 1 µPa for which only 5% of time slices during the month were at a higher level). The median (50^{th} percentile) values are presented to explore variability over time and between locations. The median values were converted to acoustic intensity, then averaged across 100 Hz bands and converted back to dB, allowing for direct comparisons between recorder locations (see Rice et al., 2014).

  Lastly, third octave noise level values were aggregated across multiple third octave frequency bands to assess total noise in bandwidths commonly used by cetaceans in the NYB area (see Table A2 in Appendix A for species-specific third octave frequency bands used to generate the figures).

Results

<u>Species Temporal and Spatial Distribution</u>

Four cetacean species (bottlenose dolphin, humpback whale, minke whale, and possible pilot whale) were detected during the manual review. Of those species, bottlenose dolphin and humpback whale vocalizations were the most prevalent across the majority of recorders (Figure 2; Appendix B, Figure B1). Although harbor porpoise were not detected through manual review, the automated detection data are included to show seasonal presence relative to the other species (Figure 2). Fish (spp.) vocalizations were also abundant throughout the recordings and although they were not a focus of the analysis, fish vocalizations were noted and were the species with the highest proportion of days across all locations (Figure B1).



Bottlenose dolphin detections showed clear seasonality with presence generally occurring from spring through to fall at most locations (Appendix B, Figure B2a). There were no bottlenose dolphin detections at NY2, located at the entrance to the Upper Bay. The highest proportion of days with confirmed bottlenose dolphin calls occurred in the summer and early fall of 2019 at the NJ2 site (93% of days in the summer with confirmed bottlenose dolphin calls, 41% in fall, with detections every day in the months of July, September, and October). However, overall there was a higher proportion of days with detections in NY waters than in NJ waters (30.15% of total days with confirmed dolphin calls in NJ waters versus 37.35% in NY waters, excluding the site with no detections). There was a high proportion of foraging buzzes detected at each location (with the exception of NY2; Appendix C).

Figure 2. Pie charts showing the proportion of detections of each whale species across all deployments for all recorders with pie chart size relative to the number of days of recording (listed next to the deployment location in the white label) at each location.

The majority of humpback whale detections occurred between fall and winter across all recorders (Appendix B, Figure B2b). The highest proportion of days with confirmed humpback calls occurred across fall and winter 2019-2020 at the NY2 site (fall, 30% of days with detections; winter, 28% of days with detections). The month with the highest proportion of detections at NY2 occurred in January 2020 (50% of days with detections). In general however, humpback whale detections were higher on the recorders in NJ waters (6.5%) than those in NY waters (4.8%). There were no other detections of large whales on any of the recorders.

Porpoises were detected in and around the NY Harbor year-round; however, there was some seasonal variation with a general peak in detections on most recorders from January-June, although this trend was most apparent in 2019 when there were a higher number of detections (Appendix B, Figure B2c). Porpoise presence was overall higher on the recorders located in NJ waters than those located in NY waters. NY1 had the highest total detections out of the recorders located off of NY, and the highest percentage of days with porpoise click detections. There were few detections on NY4 (Appendix B, Figure B2c).

Ambient Noise

All recording locations experienced periods of time with high levels of ambient noise that covered a wide frequency bandwidth (see example from NJ2, Figure 3). Ambient noise was pervasive in the lower frequency bands and more intermittent into the higher frequency bands (more apparent when viewing the 3rd octave band frequency spectrograms, Figure 3)**.** The noise events in the higher frequency bandwidths may relate to fish choruses, delphinid vocalizations, wind and rain events, development noise and/or self-noise of the recorder (i.e., banging chain, etc.). Sources of particular noise events will be further explored for publication.

At all locations, when looking across the species specific aggregated 3rd octave bands (corresponding to fin, NARW, humpback and delphinid; Appendix A, Table A2) the fin, NARW, and humpback bands, respectively, tended to have the highest ambient noise levels (see Figure 3, panel 3 for NJ2 example). These are the frequency bands used for communication signals by the humpback and minke whales detected at these locations. Noise levels in these frequency bands were consistently above 110 dB (dB re: 1 µPa) for all locations, and there were substantial periods with noise above 120dB (dB re: 1 µPa) in the lower frequency bands, which may contribute to masking of whale species vocalizations.

Examination of the variation in equivalent sound levels across recorder locations showed little variability between locations or across seasons, with median levels highest at between 110-120 dB (dB re: 1 µPa) at all locations in the 0-100 Hz frequency bands and over 100 dB (dB re: 1 µPa) in the 0-200

Hz bands (Figure 4). Although noise levels tended to decrease above 200 Hz, noise levels still remained above 80 dB until at least 2,000 Hz for most locations (Appendix B, Figure B2). There was only marginal “quieting” observed during the COVID-19 shutdown in the NY Harbor in summer in the 0-100 Hz frequency bins (see example from NJ2, Appendix B, Figure B3).

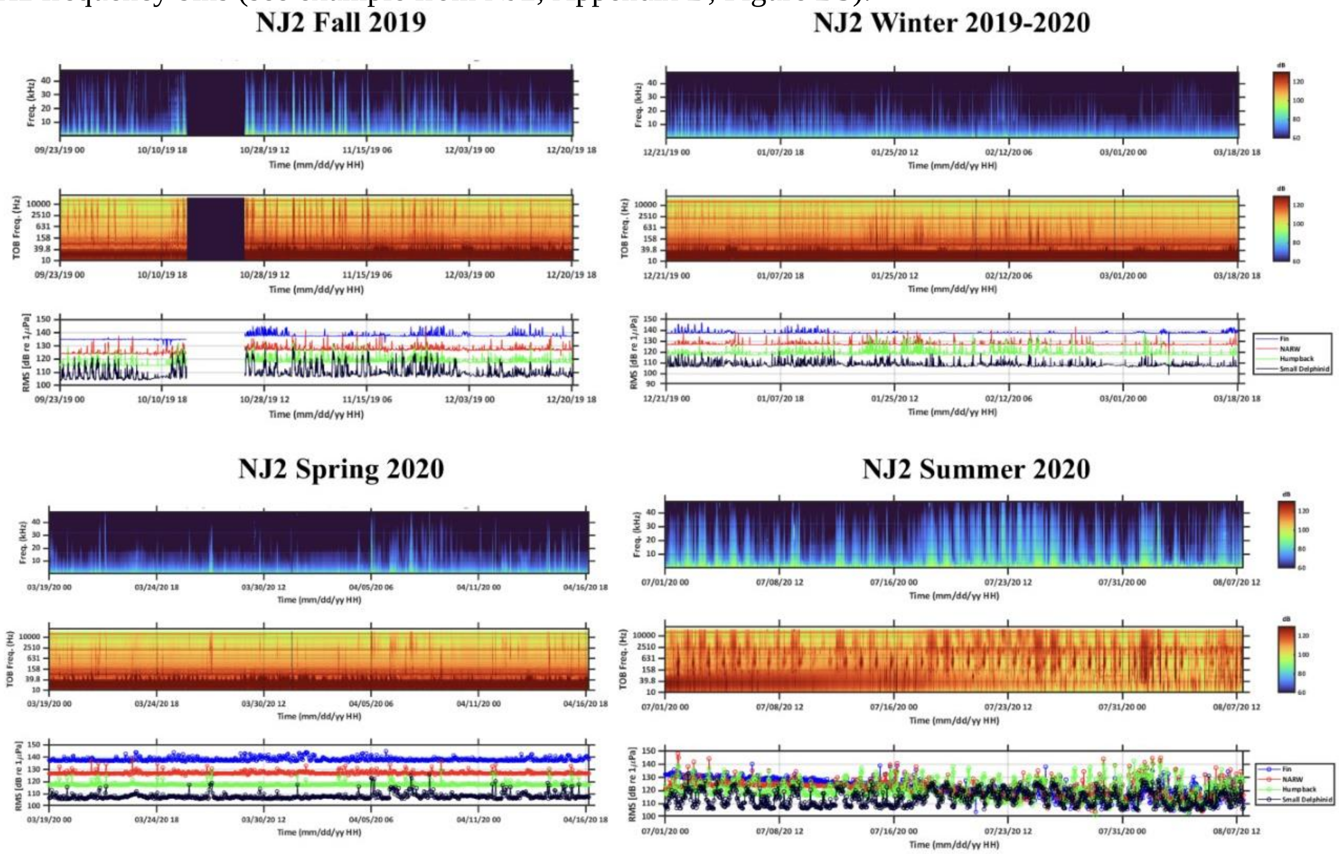


Figure 3. Spectrograms (top panel is acoustic data represented as a linear frequency scale and middle panel is the 3rd octave band frequency scale) and aggregated 3rd Octave bands for fin (blue), NARW (red), humpback (green) and small delphinid (black) for NJ2 over fall, winter, spring and summer 2019-2020.

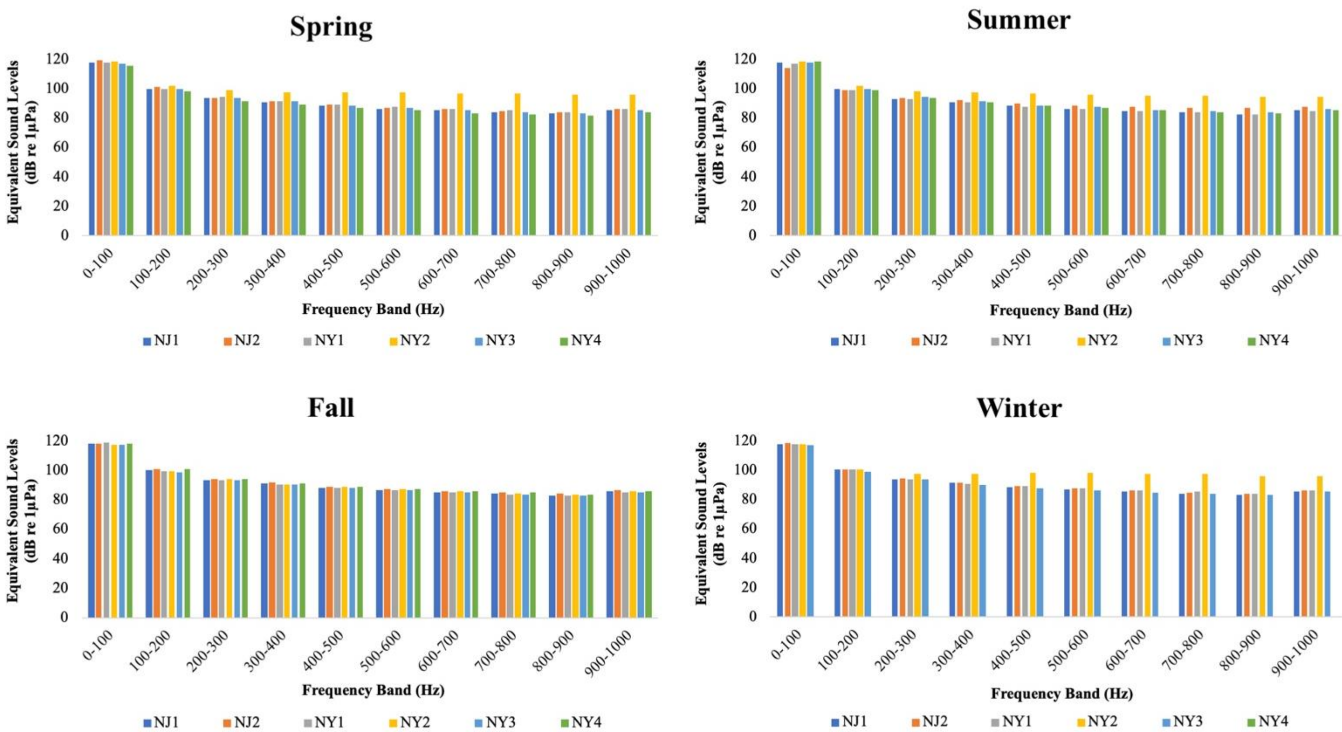


Figure 4. Median equivalent sound level L_{eq} (dB re: 1 µPa) averaged across 100Hz frequency bins (up to 1000 Hz) for all recorders aggregated by season (summer, fall, winter and spring) for the entire deployment.

Discussion

Bottlenose dolphins, harbor porpoise and humpback whales were the most frequently detected species in the NY Harbor over the two-year period. Other species detected included probable pilot whales, minke whales, and a variety of fish species. Seasonal trends were apparent for bottlenose dolphins and, to a lesser extent, harbor porpoise; however, there was some variation in these trends between years. This was particularly apparent for harbor porpoise with fewer detections in 2020 than 2019. In other species, inter-annual variability in migration timing to and from foraging areas has been linked to environmental variables and prey availability (Szesciorka et al., 2020). In the NY Harbor, bottlenose dolphins are commonly observed foraging in the Lower NY Bay and surrounding coastal waters (WCS, unpublished data). Additionally, the high prevalence of foraging buzz detections for bottlenose dolphins (see Appendix C) suggest that the NY Harbor may be an important foraging area for these species. Ongoing analysis efforts for publication will continue to explore the relationship between environmental variables and foraging activity for these species, as this will facilitate better interpretation of behavioral and ecological responses to a changing environment – both through coastal development and climate change.

Humpback whales were detected in all seasons, with the exception of summer, and were more commonly recorded over winter at a time when humpback whales are thought to be migrating south to the breeding grounds (Katona and Beard, 1990; Palsbøll et al., 1997; Smith et al., 1999). Humpback whales are commonly sighted feeding in and around the NY Harbor area over spring and summer (WCS, unpublished data; King et al., in review) and the lack of vocal detections during this time is exceptionally noteworthy and an important finding of our work. However, the visual observations (WCS, unpublished data; King et al., in review) were primarily of single individuals and therefore it is plausible to expect less production of the calls usually associated with foraging in groups (Cerchio and Dalheim, 2001), or social interactions (Dunlop et al., 2008), and there is generally little singing activity occurring on the summer feeding grounds (Vu et al., 2012). High ambient noise levels, due largely to an increase in vessel traffic, are also a likely factor in masking the lower amplitude humpback whale calls and reducing the detection range to which calls would be recorded.

One surprising finding was that one of the highest percentage of days with humpback whale detections occurred on NY2 over winter in 2019-2020, the recorder located near the entrance to the Upper NY Bay. All vocalizations detected were social calls rather than the male song breeding displays usually produced during the typical winter "breeding" season in the Caribbean, or over winter in NY waters (Zeh et al., 2020). There have been a number of sightings of humpback whales in the NY Upper Bay into December, although there were no known reports corresponding to the timing of the acoustic detections.[10] Given the high level of shipping activity in the area, the year-round presence of humpback whales in the NY Harbor warrants further monitoring efforts to better understand seasonal presence and habitat use, which is particularly important, especially in light of the ongoing Unusual Mortality Event for this species along the Atlantic coast.

Conclusions

Overall, the results of this project demonstrate that the NY Harbor has a diversity of vocal marine species that, despite high levels of anthropogenic activity, utilize this area either seasonally or year-round for foraging and potentially other key behaviors. There were considerably high ambient noise levels relative to previous studies (Rice et al., 2014), and there may be potential consequences for both individuals and population (Gomez et al., 2016). Such sustained high noise levels have shown to cause varied behavioral responses by the cetacean species found in this study in other locations (e.g., Fouda et al., 2018). Previous research for example, has demonstrated that bottlenose dolphins alter whistle parameters in response to environmental noise (May-Collado & Wartzok, 2008; Marley et al., 2017; Fouda et al., 2018). Similarly, humpback whale singing behavior has shown to cease during high noise events (Cerchio et al., 2014). In this study, we found that as ambient noise levels increased in the NY Harbor there were significant changes to certain whistle parameters (see Appendix C). Given the high levels of ambient noise found in this study, it is imperative that further research focuses on gaining a better understanding of how noise levels are potentially impacting these species. This information is vital for developing mitigation measures to protect these vulnerable species from the additive noise producing activities slated to occur in the coming years (i.e., NY-NJ Harbor Estuary deepening and channel improvement project and the cable route for offshore wind energy), and to begin to address cumulative impacts from multiple stressors in the human dominated NY Harbor.

Project Dissemination, Communication and Outreach

The project findings have already generated wide-appeal and some key aspects disseminated through a number of different channels including social media and through online forums such as the Edward A. Ames seminar presented by Dr. Howard Rosenbaum and Dr. Melinda Rekdahl in December 2020.

Results on ocean noise and bottlenose dolphins were presented at the World Marine Mammal Conference in December 2019 (abstracts in Appendix D). Some aspects of the results have been highlighted in presentations including 2020 webinars for the Mid-Atlantic Regional Council on the Oceans and NYSERDA's State of the Science Workshop. Scientific manuscripts for publication are

[10] See https://www.theguardian.com/environment/2016/dec/31/humpback-whale-new-york-city-east-river; https://www.travelandleisure.com/animals/humpback-whale-spotted-hudson-river-new-york-city

currently being prepared with the goal of submitting all listed publications by the end of 2021. Additionally, an important graduate student training component formed the basis of a Master's Thesis for Sarah Trabue, whose overall project was also supported by the Tibor T. Polgar Fellowship.

Planned publications:

Rekdahl, M. L., Trabue, S. G., King, C., & Rosenbaum, H. C. *Acoustic detections of harbor porpoise in the New York-New Jersey Harbor and surrounding waters*. Manuscript in preparation.

Rekdahl, M. L., King, C., & Rosenbaum, H. C. *Ambient noise levels and relevance for cetaceans in the New York - New Jersey Harbor and surrounding waters*. Manuscript in preparation.

Trabue, S. G., Rekdahl, M. L., & Rosenbaum, H. C. *Effects of Vessel Noise on Whistling Behavior of Bottlenose Dolphins (Tursiops truncatus) in the NY-New Jersey Harbor*. Manuscript in preparation.

Trabue, S. G., Rekdahl, M. L., King, C. D., & Rosenbaum, H. C. *Environmental drivers of bottlenose dolphin (Tursiops truncatus) foraging behavior in the NY-New Jersey Harbor*. Manuscript in preparation.

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Appendix A: Methods

Background Species Information

Humpback whales migrate seasonally in the North Atlantic from feeding grounds along the US and Canadian Atlantic coast to breeding areas in the Carribean (Katona and Beard, 1990; Palsbøll et al., 1997; Smith et al., 1999). A relatively small proportion of North Atlantic humpback whales occur in US waters (Bettridge et al., 2015) and it is uncertain what proportion of the population (estimated at 10,752 individuals; Stevick et al., 2003) are utilizing NY waters. Fin whales are considered to be present year-round in the NYB, and minke whales and critically endangered North Atlantic Right Whale (NARW) present seasonally, although sightings in nearshore waters are rare (Morano et al., 2012, Whitt et al., 2013, Risch et al., 2014). All species are vocal and produce species specific vocalizations. Humpback whales are one of the more vocal species that are easily detectable via PAM methods as they produce both complex song breeding displays and a variety of non-song calls (Payne and McVay, 1971; Thompson et al., 1977; Tyack, 1983; Silber, 1986).

Of the smaller toothed whale species, inshore bottlenose dolphins (*Tursiops truncatus*) are the most common species sighted in and around the NY Harbor. These dolphins belong to the Western North Atlantic Northern Migratory Coastal Stock, which is estimated to have over 6,500 individuals (NOAA Stock Assessment Report, 2018). Bottlenose dolphins are present in the NY Harbor from spring to fall, and migrate south to North Carolina during the cold weather months where they overlap with other Atlantic stocks (NOAA Stock Assessment Report, 2018). Little is known about other species potentially in the area, aside from strandings reports or occasional sightings of pilot whales (*Globicephala melas)*, risso's dolphins (*Grampus griseus*), common dolphins (*Delphinus delphis*) and striped dolphins (*Stenella coeruleoalba).* Like the large whales, all dolphin species rely on sound for critical life functions, including foraging, navigating their environment, and socializing and are therefore highly susceptible to acoustic disturbance. Dolphins produce a variety of complex sounds including tonal whistles used primarily for social interactions, echolocation clicks used primarily for navigation and foraging, and buzzes primarily produced during foraging and social activity (Elliot et al. 2011; Fouda et al., 2018; Pirotta et al. 2015). When foraging, dolphins produce a typical buzz when honing in on prey that can be used as a proxy for foraging activity (Miller et al., 2004; Madsen et al., 2005; Pirotta et al., 2015).

One species less commonly sighted, though known to be present in coastal waters of the NYB, are harbor porpoise (*Phocoena phocoena*). They are a cryptic, yet highly vocal, species and are therefore more easily monitored using PAM methods. There is relatively little known about harbor porpoise in the NY Harbor or for the populations occurring in the wider western North Atlantic. Four populations are currently recognized: Gulf of Maine/Bay of Fundy, Gulf of St. Lawrence, Newfoundland and Greenland (Gaskin, 1984, 1992; Johnston 1995; Wang et al. 1996; Westgate and Tolley, 1999). Broad population estimates from North Carolina to the lower Bay of Fundy estimate 62,000 individuals (NMFS, 2013), the majority of these animals are from the Gulf of Maine stock (~60%) and they are also found in NY waters (Rosel et al., 1999; Hiltunen, 2006; NMFS, 2013). Distribution is known to shift seasonally and there can be considerable overlap in habitat use by different populations (Rosel et al., 1999; Hiltunen, 2006; NMFS, 2013). Although Harbor porpoise are not listed under the Endangered Species Act (ESA), they are designated a species of special concern by the state of NY due to a high number of yearly human-caused injuries and mortalities (NOAA stock assessment report, 2019). A number of harbor porpoise populations in other areas are classified as vulnerable or critically endangered as they are highly susceptible to impacts from fisheries and ocean noise (Nashteim et al., 2020).

Deployment Schedule Rationale

Only four recorders were initially deployed for the first and second deployments (Table A1) after discussion with the New York Aquarium dive team and serious consideration and concern about safe dive operations and retrieval of units in the highly turbid, high current, and near freezing (during winter) waters of the NY Harbor. The permits also restricted the use of a surface buoy that would have aided the divers to find and locate the recorders. All of these factors led to the decision to purchase acoustic releases to ensure quick and easy retrieval of units and reduce the time divers would be needed in the water. Due to the considerable added expense of these acoustic releases, funding was only able to be secured for four acoustic releases to be trialed during the first and second deployments. The additional two acoustic releases were purchased in early 2019 and all six units were used for the subsequent deployments. There were unfortunate delays in retrieving the fifth deployment due to the COVID-19 pandemic; and, due to the continued uncertainty of safe operation throughout the pandemic, it was decided to only deploy three recorders at "hotspot" areas to monitor throughout summer and into fall.

Table A1. Acoustic recorder deployment and retrieval information and the total number of files and recording hours analyzed per recorder over the duration of the project.

Recorder ID	No. Deployed	First Date Deployed	Last Date Retrieved	Average Depth (ft)	Total Hours Recorded	Total Recording Days	Total Files
NJ1	5	10/4/18	6/16/20	31.82	391.33	151	1,174
NJ2	6	10/4/18	10/6/20	36.08	352.33	134	1,057
NY1	6	10/4/18	10/6/20	32.85	387.67	153	1,163
NY2	3	4/4/19	6/16/20	32.3	165.67	83	497
NY3	6	10/4/18	10/6/20	43.02	409.67	169	1,229
NY4	3	4/4/19	6/16/20	42.67	127.33	64	382

Table A2. Aggregate third octave frequency bands used to assess noise in frequency bands relevant to fin whales, North Atlantic right whales, humpback whales and minke whales and small delphinids.

Species	Low Frequency (Hz)	High Frequency (Hz)
Fin Whale	14.1	35.5
North Atlantic Right Whale	70.8	224
Humpback Whale and Minke Whale	224	892
Small Delphinid	5620	14100

Appendix B: Results

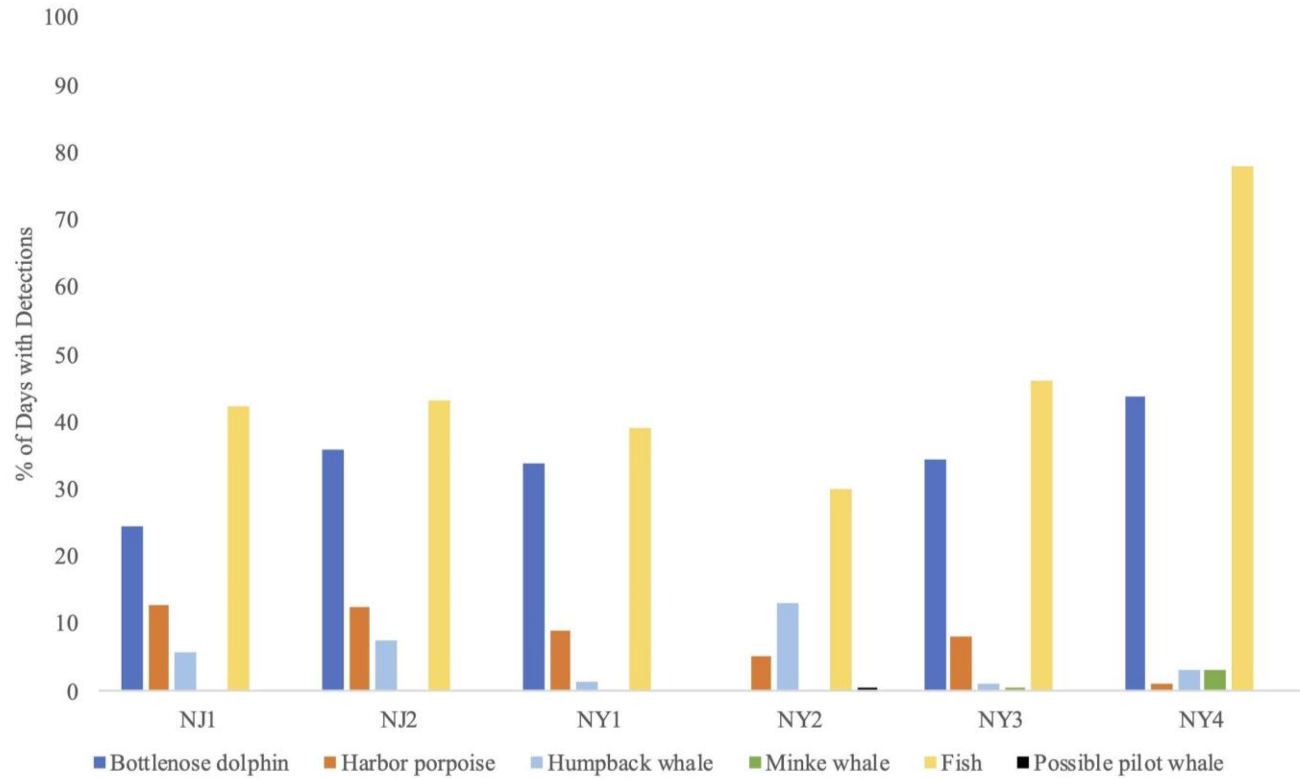

Figure B1. The percentage of days with detections for each species across the entire deployment from October 2018 - October 2020.

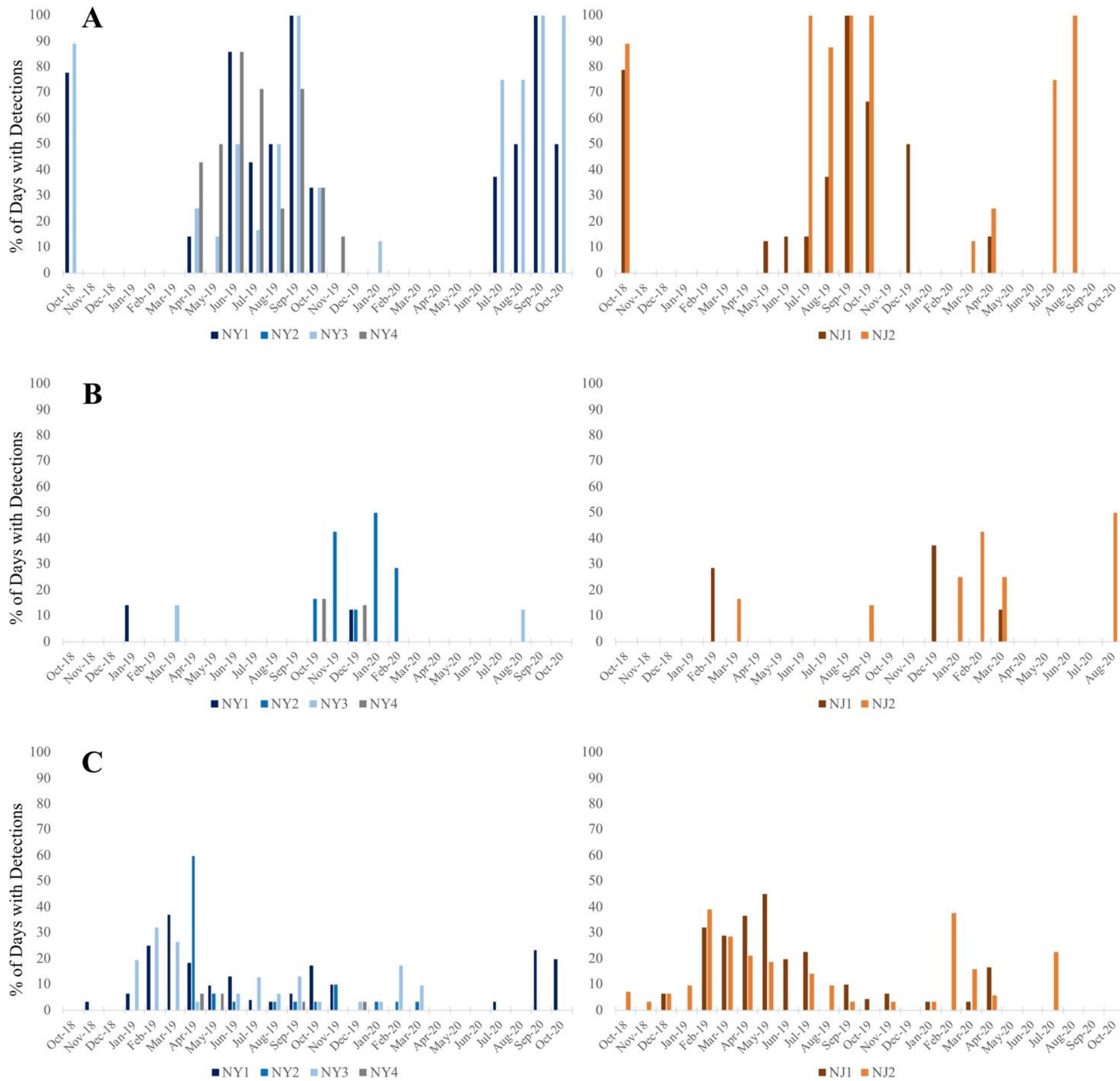

Figure B3a-c. The proportion of days with a) bottlenose dolphin, b) humpback whale and c) harbor porpoise detections per recorder for New York locations (left hand panel) and New Jersey locations (right hand panel) across the entire deployment.

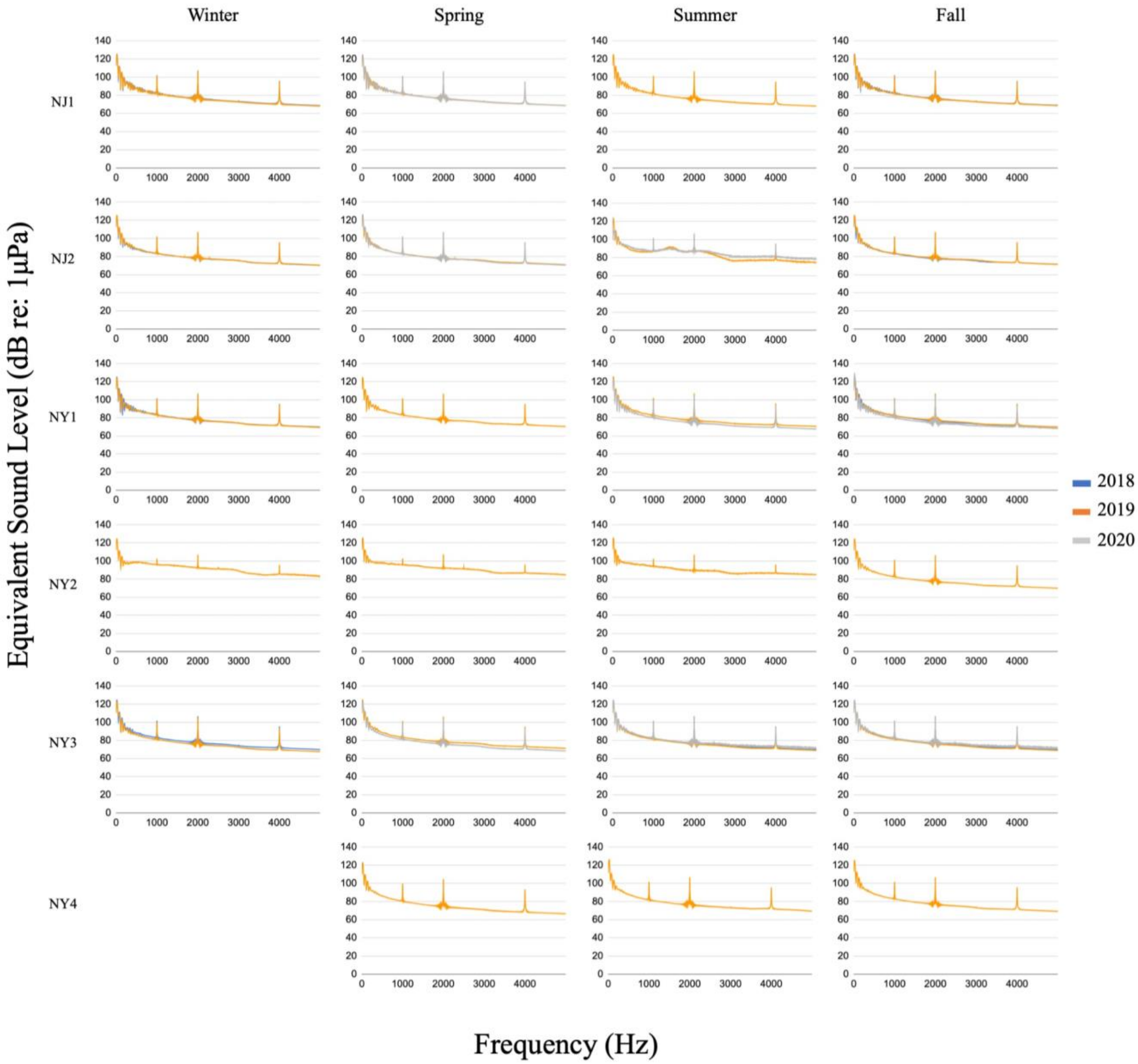

Figure B4. Median equivalent received level, L_{eq} (dB re: 1 µPa), by frequency (up to 5000 Hz) for all locations (NJ1, NJ2, NY1, NY2, NY3, NY4) by season (Summer, Fall, Winter and Spring) for 2018 (blue), 2019 (orange) and 2020 (grey). Plotted data are the L_{eq} values for 1 Hz bins integrated over the season; each line represents the levels at which the given percentage of time slices are below the indicated received level (dB).

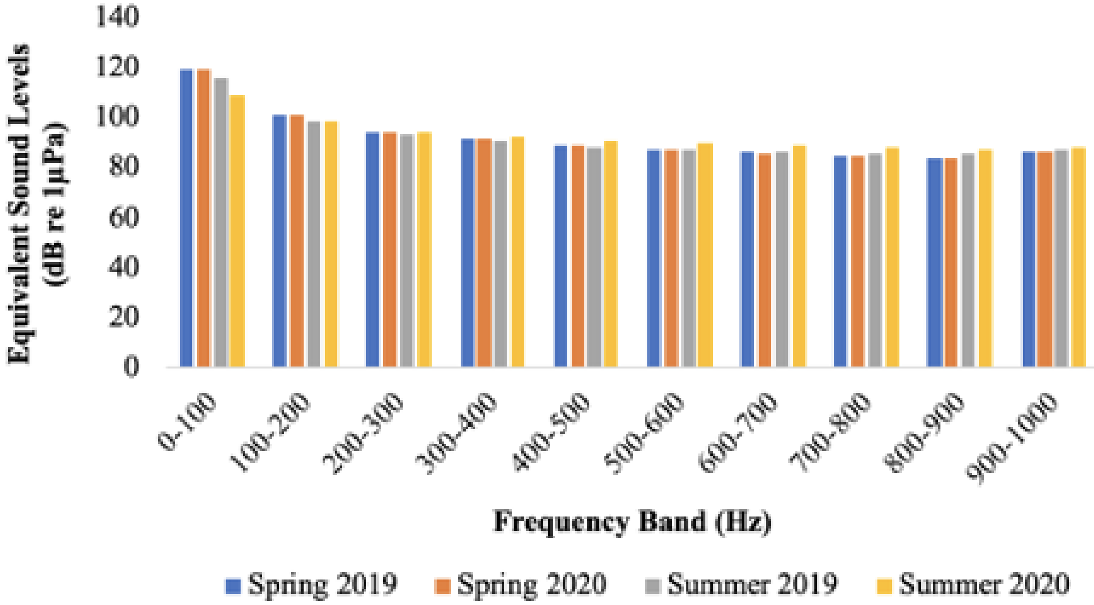

Figure B5. Median equivalent sound level L_{eq} (dB re: 1 µPa) averaged across 100Hz frequency bins (up to 1000 Hz) for NJ2 comparing spring and summer 2019 to spring and summer 2020 during the COVID-19 pandemic shutdown in NYC.

Appendix C: Additional Analyses on Bottlenose Dolphin

Bottlenose dolphin foraging buzz activity and relationship with environmental variables (forthcoming Master's thesis and publication by Trabue et al.)

Abstract

Bottlenose dolphin foraging behavior is influenced by a number of factors including environmental, biotic, and anthropogenic variables. Determining which environmental variables are related to foraging activity is important for understanding the conditions under which prey are available and feeding is most likely to occur. Once relevant environmental variables are identified, they can provide reliable predictors of habitat selection, particularly for foraging, and can be used to inform conservation and management efforts. In the New York Harbor, bottlenose dolphins are present seasonally from spring to fall. Their foraging behavior can be estimated using passive acoustic monitoring by measuring foraging-related vocalizations, termed *foraging buzzes*. In this study, we built a custom click detector module in PAMGuard to identify the presence foraging buzzes in the acoustic dataset. Environmental variables were collated and generalized additive models (GAMs) were built to look at the relationship between foraging buzz production and environmental variables. Foraging buzzes were detected commonly at all recorders with the exception of NY2 and were detected for the majority of the days that bottlenose dolphins were detected (Table C1). Foraging activity was particularly prevalent at NJ2, with foraging buzz detections occurring across the majority of days clicks were detected. The GAMs indicated that foraging buzz production related negatively to surface chlorophyll-a and positively to sea surface temperature and depth. These findings suggest that there is fine-scale geographic variation in foraging activity, and that foraging activity is more likely in deeper, warmer waters. This information could be used for consideration of further monitoring, potential mitigation, or best management practices.

Table C1. The percentage of days with dolphin presence and dolphin foraging activity during the months of April to October at each recorder.

Recorder	% Days Dolphin Presence	% Days Dolphin Foraging
NJ1	52	41
NJ2	59	55
NY1	62	53
NY2	2	1
NY3	71	62
NY4	51	42

Effects of Vessel Noise on Whistling Behavior of Bottlenose Dolphins (*Tursiops truncatus*) in the New York Harbor (forthcoming publication by Trabue et al.)

Abstract

The New York (NY) Harbor contains the largest maritime commercial port on the east coast of the United States, with high ambient underwater noise levels. Elevated underwater noise levels in this region likely reflect high vessel activity. Large ships and small vessels produce noise in different frequency bands, and both vessel types are frequently present in the NY Harbor. Despite intense vessel traffic, there has been an exciting recent recovery of marine mammals in the area, including bottlenose dolphins (*Tursiops truncatus)*. Bottlenose dolphins depend on sound for critical behaviors and are sensitive to acoustic disturbances. This study focused on dolphin whistles, which facilitate the transfer of information to conspecifics and promote group cohesion. Data were collected from two passive archival acoustic recorders deployed in the NY Harbor. We identified and measured 600 whistles and calculated ambient noise levels in frequency bands associated with vessels. Generalized additive models (GAMs) were used to evaluate if increased vessel noise is associated with changes in whistle structure across three frequency bands of interest. Whistle duration and complexity both related positively to vessel noise. Whistle frequency measures were also positively correlated to vessel noise, except for a negative correlation between end frequency and vessel noise in the 5000Hz frequency band. Our findings suggest that as underwater ambient noise levels increased in the NY Harbor, dolphins changed the structure of their whistles. Bottlenose dolphins are thought to imbed information in the structure of their whistles. Given that the NY Harbor consistently has elevated underwater ambient noise levels due to the intense vessel traffic of this area, it is important to explore any potential consequences of altered whistle behavior, both at the individual and population level. Understanding these sublethal effects of vessel noise on individual and population health will improve management of dolphin populations.

Appendix D: World Marine Mammal Conference Abstracts

The effect of anthropogenic noise on foraging buzz activity of bottlenose dolphins (*Tursiops truncatus*) in the New York Bight

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Abstract

Vessel noise has been shown to interfere with odontocete echolocation. When foraging, bottlenose dolphins produce shorter, faster clicks with shorter inter-click intervals (ICI<16ms), called *foraging buzzes.* Previous studies demonstrate that in heavily trafficked waterways, high vessel noise significantly reduced prey capture attempts in small cetaceans. Bottlenose dolphins are present in New York waters from spring to fall, migrating south during winter. Their more recent and extended presence suggests that the coast of New York provides important foraging habitat. Presently, little is known about the foraging behavior of these dolphins and the potential impact from feeding around the busy New York Harbor. We used passive acoustic monitoring to evaluate dolphin foraging behavior, indicated by foraging buzzes, in high-level and low-level (>96 & <96dB re 1μPa, respectively) anthropogenic noise conditions. Recordings were analyzed from six acoustic recorders deployed over one year in the New York Harbor. A click detector was used to identify all foraging buzzes, and only those with a signal-to-noise ratio of at least 10dB were included in the final analysis. Foraging buzzes were measured by the number of buzz sequences and total duration within each 1-minute segment where these buzzes were detected. A two-sample permutation test was used to test for a significant difference in foraging rates between noise conditions. Foraging activity tended to decrease under high-level noise conditions, even after taking into account masking effects. These results demonstrate a negative relationship likely attributed to anthropogenic noise on the foraging activity of dolphins. Interruption of foraging activity may impact the overall energetic budgets of these dolphins, possibly leading to decreased fitness or other consequences. Further research into the health, diet, and behavior of these dolphins is required to understand the extent to which anthropogenic noise is disrupting foraging and the long-term effects of such disruptions on population dynamics.

Assessing cetacean presence and ocean noise in and around one of the busiest waterways in the world: The New York Harbor

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Abstract

One of the most pressing concerns for marine conservation at national and international levels is increasing ocean noise from anthropogenic sources (i.e., shipping and energy exploration and development). Potential impacts from noise exposure range from acute injury to sub-lethal effects such as habitat displacement, acoustic masking, disruptions to social and foraging behavior, loss of anti-predator response and chronic stress (Tyack, 2008; Merchant, 2019), all of which may have long term impacts on population viability. Along the Atlantic coast, NOAA has declared an Unusual Mortality Event (UME) for humpback whales, minke whales and North Atlantic right whales (2017-2019), which may be directly or indirectly related to anthropogenic impacts. Within the New York Bight, cetaceans

have been documented with increasing frequency in recent years, including highly endangered North Atlantic right whales, humpback whales, minke whales, fin whales and bottlenose dolphins. However, there is currently only limited knowledge of the ambient noise environment and potential impacts from anthropogenic noise sources on marine life in the New York Bight and particularly within the New York Harbor; the largest and busiest port on the Eastern Seaboard.

SoundTrap ST300 recorders were deployed in the lower New York harbor area over a six-month period from October 2018-April 2019. Both automated and manual methods were used to document cetacean species presence, distribution, and soundscape characteristics. To visualize measured sound levels at each location, broadband and third-octave band spectrograms were generated using the RavenX toolbox for MATLAB (Dugan et al., 2016), and a quantitative assessment of median equivalent sound levels ($L_{eq\text{-}50}$) was conducted for each location. A preliminary analysis of the data over the Fall and Winter season found a variety of sound sources including anthropogenic activity, natural biological noise sources, cetacean vocalizations, and fish vocalizations. Overall, anthropogenic noise was pervasive throughout the New York harbor area, and measured sound levels were elevated compared to other locations within New York (3-12 dB re 1µPa higher in low frequency bands; Rice et al., 2014). Therefore, cetaceans within the New Harbor are exposed to noise levels that are often associated with long-term physiological and behavioral effects due to anthropogenic sound. With the growing conservation concerns for cetaceans within New York waters, the information collected throughout the project will help to inform the development of Best Management Practice mitigation measures and for marine spatial planning initiatives to ensure sustainable ocean use.

References

Dugan, P. J., Klinck, H., Roch, M. A., & Helble, T. A. (2016). Raven x high performance data mining toolbox for bioacoustic data analysis. arXiv preprint arXiv:1610.03772.

Merchant, N. D. (2019). Underwater noise abatement: Economic factors and policy options. *Environmental science & policy*, *92*, 116-123.

Rice, A. N., Tielens, J. T., Estabrook, B. J., Muirhead, C. A., Rahaman, A., Guerra, M., & Clark, C.W. (2014). Variation of ocean acoustic environments along the western North Atlantic coast: A case study in context of the right whale migration route. *Ecological Informatics*, 21, 89-99.

Tyack, P. L. (2008). Implications for marine mammals of large-scale changes in the marine acoustic environment. *Journal of Mammalogy*. 89(3), 549-558.

References

Bettridge, S., Baker, S. C., Barlow, J., Clapham, P. J., Ford, M., Gouveia, D., Mattila, D. K., Pace, III, R. M., Rosel, P. E., Silber, G. K., & Wade, P. R. (2015). Status review of the humpback whale (*Megaptera novaeangliae*) under the Endangered Species Act. *NOAA Technical Memorandum NMFS. US Department of Commerce.*

Brown, D. M., Robbins, J., Sieswerda, P. L., Schoelkopf, R., & Parsons, E. C. M. (2018). Humpback whale (*Megaptera novaeangliae*) sightings in the New York-New Jersey Harbor Estuary. *Marine Mammal Science*, 34(1), 250-257. doi.org/10.13140/RG.2.2.10113.66404

Brown, D. M., Sieswerda, P. L., & Parsons, E. C. M. (2019). Potential encounters between humpback whales (*Megaptera novaeangliae*) and vessels in the New York Bight apex, USA. *Marine Policy*, 106, 18. https://doi.org/10.1016/j.marpol.2019.103527

Cerchio, S., & Dahlheim, M. (2001). Variation in feeding vocalizations of humpback whales *Megaptera novaeangliae* from Southeast Alaska, *Bioacoustics*, 11, 277-295. https://doi.org/10.1080/09524622.2001.9753468

Chou, E., Southall, B. L., Robards, M., Rosenbaum, H. C. (2021). International policy, recommendations, actions and mitigation efforts of anthropogenic underwater noise. *Ocean & Coastal Management* (202): 105427.

Clark, C. W., Ellison, W. T., Southall, B. L., Hatch, L., Van Parijs, S. M., Frankel, A., & Ponirakis, D. (2009). Acoustic masking in marine ecosystems: intuitions, analysis, and implication. *Marine Ecology Progress Series*, *395*, 201-222.

Dunlop, R. A., Cato, D. H., & Noad, M. J. (2008). Non-song acoustic communication in migrating humpback whales (Megaptera novaeangliae). *Marine Mammal Science*, 24, 613-629. https://doi.org/10.1111/j.1748-7692.2008.00208.x

Elliott, R. G., Dawson, S. M., & Henderson, S. (2011). Acoustic monitoring of habitat use by bottlenose dolphins in Doubtful Sound, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 45(4), 637–649. https://doi.org/10.1080/00288330.2011.570351

Fouda, L., Wingfield, J. E., Fandel, A. D., Garrod, A., Hodge, K. B., Rice, A. N., & Bailey, H. (2018). Dolphins simplify their vocal calls in response to increased ambient noise. *Biology Letters*, 14(10), 20180484. https://doi.org/10.1098/rsbl.2018.0484

Gaskin, D. E. (1984). The harbour porpoise *Phocoena phocoena* (L.): Regional populations, status and information on direct and indirect catches. *Report of International Whaling Commission*, 34, 569-586.

Gillespie, D., Mellinger, D. K., Gordon, J., McLaren, D., Redmond, P., McHugh, R., Trinder, P., Deng, X.-Y., & Thode, A. (2009). PAMGUARD: Semiautomated, open source software for real-time acoustic detection and localisation of cetaceans. *Journal of the Acoustical Society of America*, 125, 2547–2547.

Henry, A., Cole, T. V. N., Hall, L., Ledwell, W., Morin, D. M., & Reid, A. (2013). Mortality determinations for baleen whale stocks along the Gulf of Mexico, United States east coast, and Atlantic Canadian provinces, 2007-2011. *Northeast Fisheries Science Center Reference Document*, 13-18.

Hiltunen, K. H. (2006). Mixed-stock analysis of harbor porpoises (*Phocoena phocoena*) along the U.S. mid-Atlantic coast using microsatellite DNA markers. Master’s thesis. The College of Charleston, Charleston, SC.

Jensen, A. S. & Silber, G. K. (2003). Large whale ship strike database. *U.S. Department of Commerce, NOAA Technical Memorandum*. NMFS-OPR.

Johnston, D. W. (1995). Spatial and temporal differences in heavy metal concentrations in the tissues of harbour porpoises (*Phocoena phocoena L.*) form the western North Atlantic. Master's thesis, University of Guelph, Guelph, Ontario, Canada. https://www.dec.ny.gov/docs/wildlife_pdf/sgcnharbporpoise.pdf

Katona, S. K., & Beard, J. A. (1990). Population size, migrations and feeding aggregations of the humpback whale (*Megaptera novaeangliae*) in the western North Atlantic Ocean. *International Whaling Commission- Special Issue*.

King, C.D., Rekdahl, M.L., Chou, E., Trabue, S.G., & Rosenbaum, H.C. (2021) Baleen whale distribution, behavior, and overlap with anthropogenic activity in coastal regions of the New York Bight. *Manuscript in preparation.*

Madsen, P. T., Johnson, M., Aguilar de Soto, N., Tyack, P., & Zimmer, W. M. X. (2005). Biosonar performance of foraging beaked whales (*Mesoplodon densirostris*). *Journal of Experimental Biology*, 208(2), 181-194. https://doi.org/10.1242/jeb.01327

Miller, P. J. O., Johnson, M. P., & Tyack, P. L. (2004). Sperm whale behaviour indicates the use of echolocation click buzzes 'creaks' in prey capture. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 271(1554), 2239–2247. https://doi.org/10.1098/rspb.2004.2863

Morano, J. L., Rice, A. N., Tielens, J. T., Estabrook, B. J., Murray, A., Roberts, B. L., & Clark, C. W. (2012). Acoustically detected year-round presence of right whales in an urbanized migration corridor. *Conservation Biology*, 26(4), 698-707. https://doi.org/10.1111/j.1523-1739.2012.01866.

Nowacek, D. P., Thorne, L. H., Johnston, D. W., & Tyack, P. L. (2007). Responses of cetaceans to anthropogenic noise: An update and review of behavioural and some physiological effects. *Mammal Review*, 37, 81-115. http://dx.doi.org/10.1111/j.1365-2907.2007.00104.x

Palsbøll, P. J., Allen, J. M., Berube, M., Clapham, P. J. (1997). Genetic tagging of humpback whales. *Nature*, 388(6644), 767-769. https://doi.org/10.1038/42005

Payne, R. S., & McVay, S. (1971). Songs of Humpback Whales. *Science*, 173(3997), 585-597. https://doi.org/10.1126/science.173.3997.585

Pirotta, E., Merchant, N. D., Thompson, P. M., Barton, T. R., & Lusseau, D. (2015). Quantifying the effect of boat disturbance on bottlenose dolphin foraging activity. *Biological Conservation*, 181, 82-89. https://doi.org/10.1016/j.biocon.2014.11.003

Rice, A. N., Tielens, J. T., Estabrook, B. J., Muirhead, C. A., Rahaman, A., Guerra, M., & Clark, C. W. (2014). Variation of ocean acoustic environments along the western North Atlantic coast: A case study in context of the right whale migration route. *Ecological Informatics*, 21, 89-99. https://doi.org/10.1016/j.ecoinf.2014.01.005

Risch, D., Castellote, M., Clark, C. W., Davis, G. E., Dugan, P. J., Hodge, L. E. W., Kumar, A., Lucke, K., Mellinger, D. K., Nieukirk, S. L., Popescu, C. M., Ramp, C., Read, A. J., Rice, A. N., Silva, M. A., Siebert, U., Stafford, K. M., Verdaat, H., & Van Parijs, S. M. (2014). Seasonal migrations of North Atlantic minke whales: novel insights from large-scale passive acoustic monitoring networks. *Movement Ecology*, 2(1), 1-17. https://doi.org/10.1186/s40462-014-0024-3

Rosel, P. E., Tiedemann, R., & Walton, M. (1999). Genetic evidence for limited trans-Atlantic movements of the harbor porpoise *Phocoena phocoena*. *Marine Biology*, 133(4), 583-591. https://doi.org/10.1007/s002270050498

Smith, T. D., Allen, J., Clapham, P. J., Hammond, P. S., Katona, S., Larsen, F., Lien, J., Mattila, D., Palsbøll, P. J., Sigurjónsson, J., Stevick, P. T., & Ølen, N. (1999). An ocean-basin-wide mark-recapture study of the North Atlantic humpback whale (*Megaptera novaeangliae*). *Marine Mammal Science*, 15(1), 1-32. https://doi.org/10.1111/j.1748-7692.1999.tb00779.x

Silber, G. K. (1986). The relationship of social vocalizations to surface behavior and aggression in the Hawaiian humpback whale (Megaptera novaeangliae). *Canadian Journal of Zoology*, 64(10), 2075-2080. https://doi.org/10.1139/z86-316

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene,Charles R., & Tyack, P. L. (2007). Research recommendations. *Aquatic Mammals*, 33(4), 474-521. Retrieved from http://pegasus.law.columbia.edu/scholarly-journals/research-recommendations/docview/197745866/se-2?accountid=147016

Stevick, P. T., Allen, J., Clapham, P. J., Friday, N., Katona, S. K., Larsen, F., Lien, J., Mattila, D. K., Palsbøll, P. J., Sigurjónsson, J., Smith, T. D., Øien, N., & Hammond, P. S. (2003). North Atlantic humpback whale abundance and rate of increase four decades after protection from whaling. *Marine Ecology Progress Series*, 258, 263-273. https://doi.org/10.3354/meps258263

Szesciorka, A. R., Ballance, L. T., Širović, A., Rice, A., Ohman, M. D., Hildebrand, J. A., & Franks, P. J. (2020). Timing is everything: Drivers of interannual variability in blue whale migration. *Scientific reports*, *10*(1), 1-9.

Thompson, P. O., Cummings, W. C., & Kennison, S. J. (1977). Sound production of humpback whales, Megaptera novaeangliae, in Alaskan waters. *The Journal of the Acoustical Society of America*, *62*(S1), S89. https://doi.org/10.1121/1.2016437

Tyack, P. (1983). Differential response of humpback whales, Megaptera novaeangliae, to playback of song or social sounds. *Behavioral Ecology and Sociobiology, 13*(1), 49–55. https://doi.org/10.1007/bf00295075

Tyack, P. L. (2008). Implications for marine mammals of large-scale changes in the marine acoustic environment, *Journal of Mammalogy, 89*(3), 549-558.

Wang, J. Y., Gaskin, D. E., & White, B. N. (1996). Mitochondrial DNA analysis of the harbour porpoise, (*Phocoena phocoena*), subpopulations in North American waters. *Canadian Journal of Fisheries and Aquatic Sciences, 53*(7), 1632-1645. https://doi.org/10.1139/f96-095

Westgate, A. J., & Tolley, K. A. (1999). Geographical differences in organochlorine contaminants in harbour porpoises *Phocoena phocoena* from the western North Atlantic. *Marine Ecology Progress Series*, 177, 255-268. https://doi.org/10.3354/meps177255

Whitt, A. D., Dudzinski, K., & Laliberté, J. R. (2013). North Atlantic right whale distribution and seasonal occurrence in nearshore waters off New Jersey, USA, and implications for management. *Endangered Species Research, 20*(1), 59-69. https://doi.org/10.3354/esr00486

Williams, R., Clark, C. W., Ponirakis, D., & Ashe, E. (2014). Acoustic quality of critical habitats for three threatened whale populations. *Animal conservation, 17*(2), 174-185. http://dx.doi.org/10.1111/acv.12076