AN ANALYSIS OF OPPORTUNISTIC DATA TO INVESTIGATE HUMPBACK WHALE (*MEGAPTERA NOVAEANGLIAE*) SIGHTING PATTERNS AND VESSEL RISK IN THE NORTHWESTERN NEW YORK BIGHT

by

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DEDICATION

This thesis is primarily dedicated to my husband Bill, whose patience, support, and sense of humor helped to keep me motivated throughout my graduate school career. Bill is not only my partner in life, but also my conference travel buddy and my practice audience. I am truly grateful for his encouragement, and I hope that he finds the completion of this thesis as validating as I do. I would also like to dedicate this thesis to my parents who are always there to support me and celebrate my accomplishments.

In addition to my family, I would like to dedicate this thesis to every person who has ever helped me on my academic career path. I was fortunate to be offered many opportunities, and without the help of my professors, mentors, supervisors, directors, co-workers, and colleagues, I would never have made it this far.

Lastly, my work is dedicated to all of the students, volunteers, and interns that I have worked with over the years. I hope that my work inspires them to aim high in their life goals and serves as proof that anything can be achieved with hard work, determination, and persistence.

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LIST OF ABBREVIATIONS

Name	Abbreviation
Distinct Population Segment	DPS
Gulf of Maine	GOM
National Marine Fisheries Service	NMFS
New York Bight	NYB
New York City Humpback Whale Catalog	NYCHWC
New York State Department of Environmental Conservation	NYS DEC
North Atlantic Humpback Whale Catalog	NAHWC
Northwestern New York Bight	NWNYB
Port of New York and New Jersey	PNYNJ
Unusual Mortality Event	UME

ABSTRACT

AN ANALYSIS OF OPPORTUNISTIC DATA TO INVESTIGATE HUMPBACK WHALE (*MEGAPTERA NOVAEANGLIAE*) SIGHTING PATTERNS AND VESSEL RISK IN THE NORTHWESTERN NEW YORK BIGHT

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This study formalizes data collected opportunistically on humpback whales in the northwestern New York Bight from 2011-2016. This area is of significance due to its proximity to New York City and the presence of high levels of anthropogenic activity. Previous data suggest that humpback whales were not historically common in this area. Therefore, documenting their presence is crucial for both short- and long-term management. The most current and consistent data collected during the study period come from *Gotham Whale*, an organization that collects sightings through whale watching and anecdotal reports. These opportunistic data were analyzed to better understand humpback whale sighting patterns and the risks posed to them from vessel traffic.

Linear regression showed that both sightings and the number of identified individuals increased significantly from 2011-2016. An analysis of individual sighting

histories resulted in a mean occupancy length of 35.1 days, a mean occurrence rate of 3.93 days, and mean annual return of 40%. Geospatial analyses were used to examine the overlap between humpback whale sightings and vessel density maps created using AIS data. From this analysis, high-risk areas were identified in Ambrose Channel, upper New York Bay, the lower Hudson River, and the East River. High densities of sightings were also found along the south shore of western Long Island, NY, coinciding with high recreational vessel activity. To investigate population identity, photographs collected by *Gotham Whale* were compared to other catalogs in the North Atlantic. It was determined that 28% of humpback whales belong to the Gulf of Maine feeding population. Individuals were also matched regionally to Montauk, NY and Cape May, NJ.

This study supports the theory that the United States mid-Atlantic region is becoming increasingly important for humpback whales. Due to the likelihood of negative interactions between vessels and whales, it is essential that mitigation measures in the northwestern New York Bight be initiated as quickly as possible. A combination of vessel speed restrictions, passive acoustic monitoring, real-time sighting alerts, and educational programs for recreational boaters should all be considered in future management.

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) can be found in all the world's oceans. They have been described as "enigmatic" (Smith and Pike 2009) and "cosmopolitan" (Reeves et al. 2004, p. 775, Straley et al. 2009, p. 428). Smith and Pike (2009) suggested that we know more about the humpback whale than "virtually any other cetacean," but acknowledged that there is still much to learn.

The humpback whale is one of the most identifiable whales in the family Balaenopteridae. They are well-known for their acrobatics and can reach lengths of 13.0-15.6 meters (Johnson and Wolman 1984, Clapham and Mead 1999), with pectoral flippers that extend to nearly one-third of their body length (Johnson and Wolman 1984). They are black in color dorsally with white ventral coloration, but the amount of white can vary by region (Baker et al. 1986, Allen et al. 1994). Humpback whales are also known for unique patterns on the ventral sides of their flukes that can be used to photographically identify individuals (Katona et al. 1979, Katona and Whitehead 1981). This has greatly facilitated research into the population biology and movements of the species. Patterns and scarring on the dorsal fin, pectoral flippers, and body have also been used to identify individuals (Katona and Whitehead 1981, Clapham and Mayo 1988, Glockner-Ferrari and Ferrari 1988). Fluke patterns can range from mostly black to mostly white, can be symmetrical or asymmetrical, and vary across feeding grounds, breeding grounds, and ocean basins (Allen et al. 1994, Rosenbaum et al. 1995).

Most humpback whale populations migrate between summer feeding grounds and winter breeding grounds (Martin et al. 1984, Baker et al. 1985, Clapham et al. 1993, Stevick et al. 1998), with the exception of the Arabian Sea population (Mikhalev 1997, Rosenbaum et al. 2009). Their distribution in relatively shallow coastal waters makes them highly susceptible to anthropogenic interactions, most notably, vessel strikes and entanglements (Wiley et al. 1995, Laist et al. 2001, Van Waerebeek and Leaper 2008). Humpback whales are also at risk of harassment from vessel presence, and there is evidence of whales moving away from areas where large ships (>100 tons) are present, while also decreasing their dive times and increasing aerial behaviors (Baker and Herman 1989). Humpback whales have also been found to alter their behavior in response to the approach of smaller vessels, including changing from feeding to travelling, increasing swim speed, dive times, and blow rate (Bauer 1986, Baker and Herman 1989, Corkeron 1995).

North Atlantic Humpback Whales

In the North Atlantic, humpback whales are particularly well-studied and have been since the 1970s. The YoNAH (Years of the North Atlantic Humpback) project, conducted in 1992-1993, was an international effort that included intensive sampling on both the feeding and breeding grounds in the North Atlantic (Smith et al. 1999). MoNAH (More North Atlantic Humpback Whales) was conducted in 2004-2005, and included additional breeding ground sampling as a follow-up to YoNAH (Fulling and Clapham 2004). Analyses of data collected from both YoNAH and MoNAH have provided significant information on the movements and population structure of North Atlantic humpback whales (Smith et al. 1999, Stevick et al. 2003, Fulling and Clapham 2004, Stevick et al. 2006).

In the North Atlantic, there are five primary feeding aggregations; the Gulf of Maine, eastern Canada, and western Greenland in the western North Atlantic, and Iceland and Norway in the eastern North Atlantic (Katona and Beard 1990). Distribution on feeding grounds is maternally directed, based on where calves were taken by their mothers in their first year (Baker et al. 1985, Clapham and Mayo 1987, Clapham et al. 1993, Weinrich 1998). This maternal direction has led to variation in mitochondrial DNA haplotypes among subpopulations (Baker et al. 1990, Baker et al. 1994, Larsen et al. 1996). Feeding grounds can be further broken down into discrete feeding sites where humpback whales often congregate to feed. Their distribution among these feeding sites can vary across years, and temporary fluctuations have been connected to prey distribution (Payne et al. 1986, Weinrich 1997).

North Atlantic humpback whales migrate between 2,300 and 10,000 km to wintering grounds in two locations, the West Indies in the western Atlantic and the Cape Verde Islands in the eastern Atlantic (Katona and Beard 1990, Palsboll et al. 1997). Although whales from both the eastern and western North Atlantic feeding grounds have been documented in the West Indies (Katona and Beard 1990, Clapham et al. 1993, Stevick et al. 2003, Kennedy et al. 2013), the majority that migrate to this wintering location are from western North Atlantic aggregations (Katona and Beard 1990). Only whales from the eastern North Atlantic have been documented in the Cape Verde Islands (Jann et al. 2003, Wenzel et al. 2009). In the West Indies, the predominant wintering grounds are in the Greater Antilles, most notably Silver Bank, Navidad Bank, and Samana Bay in the Dominican Republic (Winn et al. 1975, Whitehead and Moore 1982, Katona and Beard 1990, Smith et al. 1999) and in Puerto Rico (Smith et al. 1999), although whales do move between other areas in the West Indies (Kennedy et al. 2013).

What little is known of humpback whale migratory routes suggests that migration takes place offshore, closer to the mid-Atlantic ridge (Clapham and Mattila 1990, Reeves et al. 2004, Kennedy et al. 2013). Sightings collected from historic whaling data suggest that migration may not be as structured as previously thought (Reeves et al. 2004), although satellite tagged whales with similar feeding ground destinations travelled along a similar track after leaving the wintering grounds (Kennedy et al. 2013).

Though humpback whales are known for extensive movements during migration (Stevick et al. 2011), long-distance movements during the feeding season, such as those between feeding grounds, are rare (Stevick et al. 2006, Robbins 2007). In the North Atlantic, movements such as these were found to occur at a rate of only 0.98%, and most often between feeding grounds with the shortest distance between them, such as the Gulf of Maine and eastern Canada (Stevick et al. 2006). Movements between feeding grounds are likely in response to changes in prey availability (Weinrich 1997, Stevick et al. 2006).

Humpback whales have been documented feeding in locations outside of known North Atlantic feeding grounds such as in the Irish Sea (Smith and Pike 2009) and in the mid-Atlantic United States (New York to North Carolina) (Swingle et al. 1993, Brown et al. 2018). Both Swingle et al. (1993) and Brown et al. (2018) reported that feeding humpback whales were likely juveniles, based on length estimates in the field. Historic sighting data from whaling vessels describe humpback whale sightings far south of known feeding grounds near the mid-Atlantic Ridge during the summer, and it is possible that feeding also took place in this area (Reeves et al. 2004).

Not all individuals complete the seasonal migration, and both juveniles and adults have been documented in areas far north of known breeding grounds during the winter (Straley 1990, Clapham et al. 1993, Swingle et al. 1993, Barco et al, 2002, Murray et al. 2014). Strandings have also occurred in the mid-Atlantic during the winter when the majority of the population has migrated to the breeding grounds (Wiley et al. 1995), and both juveniles and females have been documented in the Gulf of Maine during the winter (Robbins 2007).

The coastal distribution and abundance of humpback whales made them a primary target for commercial whaling (Mitchell and Reeves 1983, Smith et al. 2012). At least 21,000 individuals were landed in the North Atlantic, with an estimated removal of 30,852 when including whales that may have been injured or killed but were not collected (Smith and Reeves 2010). A dramatic decrease in numbers led to their protection under the Endangered Species and Conservation Act in 1970 (the precursor to the Endangered Species Act) and the Marine Mammal Protection Act in 1972 (Braham 1984). Although small numbers of humpback whales are still hunted in St. Vincent, the Grenadines, and west Greenland, there is evidence that the population has grown considerably. However, complexities in their population structure have made it difficult to measure their recovery. Pre-whaling abundance estimates vary widely. Estimates based on catch-data only suggested a pre-whaling abundance of 20,000-46,000 (Punt et al. 2006), while genetic-based estimates suggest a much higher number of 150,000 to 240,000 whales (Roman and Palumbi 2003, Alter and Palumbi 2009). A more recent estimate that takes into account both population structure and genetic diversity suggests that there were approximately 112,000 humpback whales in the North Atlantic (Ruegg et al. 2013).

In 2009, the National Marine Fisheries Service (NMFS) initiated a status review of the humpback whale under the Endangered Species Act (NMFS 2016). By using humpback whale breeding grounds to define population, the NMFS identified 14 Distinct Population Segments (DPS) (Bettridge et al. 2015). Based on the best available scientific data, the DPS that breeds in the West Indies was determined to be stable and not in danger of extinction (Bettridge et al. 2015). Thus, this DPS was delisted from the Endangered Species Act.

Despite their delisting, there are still many risks posed to humpback whales in the North Atlantic. Vessel strikes (Laist et al. 2001, Jensen and Silber 2003) and entanglements (NMFS 1991, Wiley et al. 1995, Robbins and Mattila 2004) are common causes of injury and mortality. In 2017, the NMFS declared an Unusual Mortality Event (UME), or significant die-off, for humpback whales on the East Coast of the United States in response to the deaths of more than 50 whales between 2016 and 2017. Not all whales could be examined, but according to the NMFS, many whales exhibited signs of vessel strike.

The Northwestern New York Bight

Humpback whale research in the northwestern New York Bight (NWNYB) is relatively new, and consistent documentation only began in 2011. The limited data that exist come from *Gotham Whale*, a research organization based in Staten Island, New York. Since the inception of their whale research program, more than 500 humpback whale sightings have been recorded and a catalog of photographically identified whales contains approximately 80 unique individuals. Using these data, one study found that there has been a significant increase in humpback whale sightings inside the New York-New Jersey harbor estuary, where the Port of New York and New Jersey (PNYNJ) is located (Brown et al. 2018). The New York Department of Environmental Conservation (NYDEC) also acknowledged that humpback whales appeared to be increasing in the area (Schlesinger and Bonacci 2014).

Summary

Although the NMFS determined that the West Indies breeding population is no longer in danger of extinction, North Atlantic humpback whales are still subjected to considerable anthropogenic threats. The recent declaration of a UME for humpback whales in the northeast and mid-Atlantic United States exemplifies the importance of continuing research on the population, especially with regards to areas with high vessel activity such as the NWNYB.

This study uses opportunistic sighting data collected by *Gotham Whale* in the NWNYB from 2011-2016 to investigate whether humpback whale sightings have increased significantly during the study period. Spatial analysis is used to quantify the risks from vessel traffic and identify high-risk areas. Occupancy, occurrence, and annual return are calculated using the sighting histories of catalogued individuals, and fluke matching to other humpback whale catalogs provides insight into their population identity, age-class, and movement patterns.

METHODS

Photographic Identification

During whale-watching trips, repeated attempts were made to photograph the flukes, left and right sides of the dorsal fin, and any identifying markings (Katona et al. 1979) of all whales encountered. On-board photographs were taken by multiple photographers, including members of *Gotham Whale* and volunteers. When evaluating photographs, *Gotham Whale* staff considered both clarity and angle. Only the best quality photographs were compared to the New York City Humpback Whale Catalog (NYCHWC). When a previously unknown individual was identified, the clearest photo of the ventral flukes was subsequently added to the NYCHWC with a unique identification number. Occasionally, when the flukes were not photographed, the dorsal fin was entered into the NYCHWC. Linear regression was used to determine the linear relationship between the number of new identifications and year.

The sighting histories of whales seen more than once in a year were analyzed for occupancy length (number of days between the first and last sighting within a season), occurrence rate (number of days sighted within a season), and annual return (percentage that returned in the next consecutive year (Clapham et al. 1993).

The Study Area

The NWNYB, inclusive of the city of Manhattan, contains one of the most highly urbanized ecosystems in the United States. The marine habitat in this area has a history of dredging and filling, toxic waste spills, and sewage discharge (Mahoney and McLaughlin 1977, Waldhauer *et al.* 1978, Lodge *et al.* 2015). There is also significant recreational vessel activity and the “apex” of the NWNYB is home to the PNYNJ, the largest port on the east coast of the United States (Gibb 1997). Three major shipping lanes direct vessels into one of two channels; Ambrose Channel leads vessels north into New York Harbor, while the Sandy Hook channel leads ships west, serving New Jersey and western Staten Island, New York.

The data used in this study were collected within an approximately 900 km^2 area extending from the entrance to New York Harbor (41° 40 37N, 73° 58 23'W) east to Fire Island, NY (40° 36 51N, 73° 18 33W) and south to Manasquan Inlet, NJ (40° 06 03N, 74° 01 50W), and included Lower New York Bay and Raritan Bay (Figure 1).

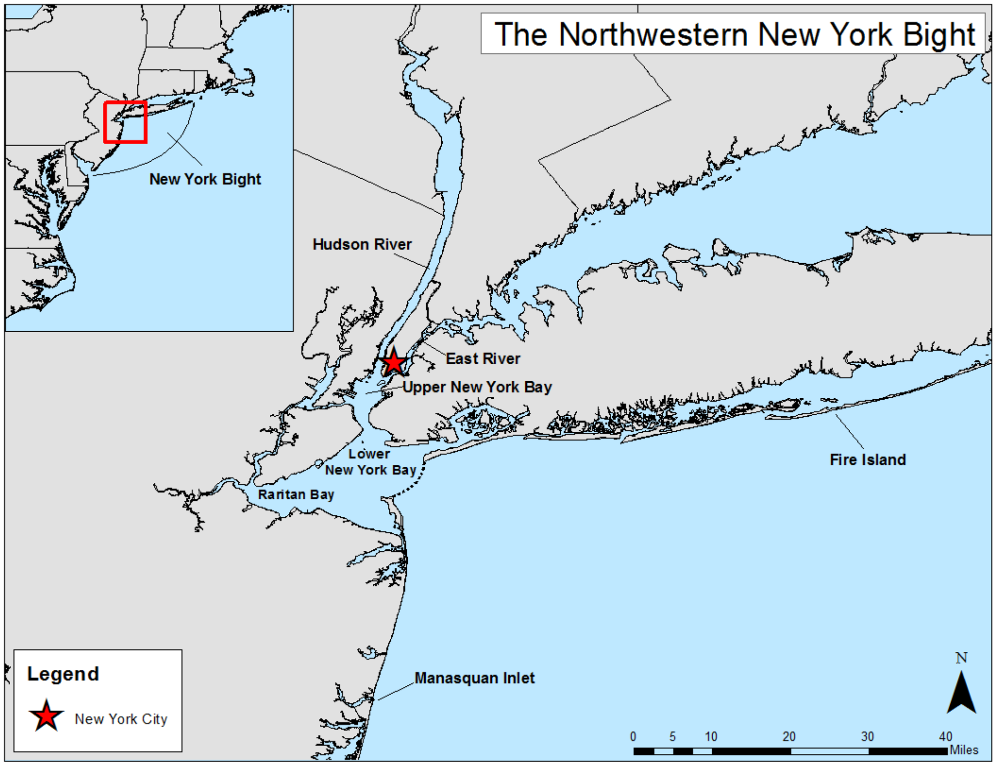

Figure 1: Map of the northwestern New York Bight. The study area extended from the entrance to the Port of NY and NJ (indicated by the dotted line) east to Fire Island, NY and south to the Manasquan Inlet, NJ, and included Lower NY Bay and Raritan Bay.

Data Collection

Humpback whale sighting data and fluke photographs were obtained from *Gotham Whale*, a non-profit research organization, based in Staten Island, New York. Sightings data were primarily collected during whale-watching trips on-board the *American Princess*, a 29-m whale-watching vessel. From 2011-2016, 280 trips were made, with a yearly increase in both frequency and seasonality from June-September in 2011 to April-December in 2016 (Table 1). Trips were approximately 3.5-4.5 hours in length and took place 1-3 days per week. These trips were opportunistic in nature and based on where whales were last reported.

Table 1: The annual and seasonal frequency of whale-watching trips, 2011-2016.

Year	Month	# of Trips
2011	June	3
2011	July	10
2011	August	8
2011	September	1
2012	June	6
2012	July	10
2012	August	13
2012	September	2
2013	June	6
2013	July	11
2013	August	12
2013	September	8
2013	October	3
2014	June	13
2014	July	12
2014	August	12
2014	September	11
2014	October	6
2015	May	5
2015	June	13
2015	July	15
2015	August	12
2015	September	9
2015	October	5
2015	November	1
2016	April	1
2016	May	8
2016	June	13
2016	July	11
2016	August	13
2016	September	11
2016	October	8
2016	November	6
2016	December	2

During whale-watching trips, multiple observers scanned the horizon using either binoculars or the unaided eye. Once a whale was sighted, standardized data sheets were used to record the following variables: date, time, weather condition, GPS location, number of whales, general behavior, and the New York City Humpback Whale Catalog (NYCHWC) identification number if applicable (Figure 2). GPS coordinates were recorded at the beginning of each sighting using the whale-watching vessel's GPS. The coordinates were given to all whales sighted within approximately 0.5 km of the first documented whale at each sighting location.

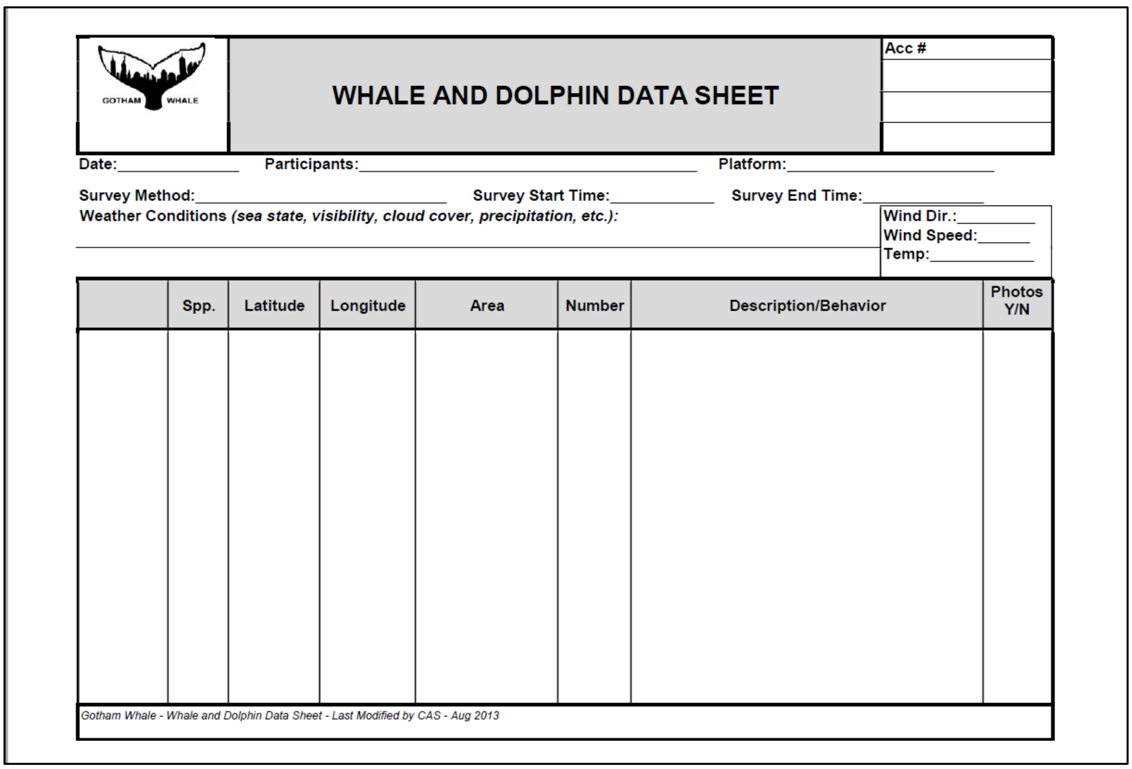

Figure 2: The datasheet used by Gotham Whale to record humpback whale sightings during whale-watching trips.

Additionally, anecdotal sources were used to collect data. These included citizen science, news, and social media reports. In these reports, the date, time, and GPS coordinates were recorded. Species was only recorded if there was photographic identification. If coordinates were not available, the GPS location was estimated based on photographs or a description of the area. Due to observer inexperience, anecdotal sightings were counted as one whale, even when multiple were reported.

Linear regression was used to determine the linear relationship between both whale-watching sightings and anecdotal sightings and year. To compensate for the variation in effort across years, a sighting ratio was calculated as the number of sightings divided by the number of trips. Linear regression was used to determine the linear relationship between the sighting ratio and year. All statistical analyses were performed using the JMP statistical software package.

Vessel Risk Analysis

Automatic Identification Systems (AIS) transmit data from ocean-going vessels to shore-based receiving stations. There are two different classes of AIS; Type A and Type B. Each type uses similar protocols and requirements, although Type A transmissions occur in 2-10 second intervals, and Type B transmissions occur in 30 second intervals. Type A systems transmit at 12.5 watts, while Type B systems transmit at 2 watts. Both Type A and Type B broadcast the Maritime Mobile Service Identity (MMSI) number (this defines the vessel type), along with GPS position, course, and speed. AIS systems were originally developed to prevent collisions between vessels, but they have shown to be useful in assessing the risks to cetaceans. The following vessels are required by International Maritime Law to carry either a Type A or Type B AIS (Automatic Identification System 2015):

I. A self-propelled commercial vessel of 65 feet or more in length.
II. A commercial towing vessel of 26 feet or more in length and more than 600 horsepower.
III. A self-propelled vessel that is certified to carry more than 150 passengers.
IV. A self-propelled vessel engaged in dredging operations in or near a commercial channel or shipping fairway in a manner likely to restrict or affect navigation of other vessels.
V. A self-propelled vessel engaged in the movement of certain dangerous cargo.
VI. Commercial fishing vessels;

Density layers were generated using AIS data from 2012 for vessels transiting the PNYNJ during that year (Mid-Atlantic Ocean Data Portal 2014); Track lines were created by connecting the GPS positions for the following vessel types defined by AIS: Cargo, Passenger, Tanker, and Tug/tow (Table 2). The track lines were converted into raster density grids using the ArcGIS Kernel Density option (Mid-Atlantic Ocean Data Portal 2014). The resulting grid consisted of 100m grid cells, each showing the total vessel tracks (in km) for that year (Mid-Atlantic Ocean Data Portal 2014). An additional density layer for All vessels included the four categories listed above, as well as ships identified by AIS as Pleasure, High-speed ferry, Military, Fishing, and Other (Mid-Atlantic Ocean Data Portal 2014). The All vessels category also included vessels that do not report a specific type.

Humpback whale sightings were imported into ArcMap (version 10.4) and an “Extract Values to Points” command was used to associate the total km travelled per cell with the closest point. The number of encounters, as well as the mean, standard deviation, and range of vessel density was then calculated for each vessel type.

To identify high-density sighting areas, a "Point Density" map was generated using all collected humpback whale sightings. To determine vessel-strike risk, the resulting point density map was layered over the All vessel density map. Humpback whale sighting densities at each grid point were then multiplied by the nearest vessel density value (Williams and O'Hara 2010).

Table 2: A detailed list of the Automated Identification System (AIS) vessel types used in this study.

AIS Vessel Type	Detailed Type
Tug/Tow	Towing Vessel
	Tug/Tender
	Tug/Supply Vessel
	Tug/Fire Fighting Vessel
	Tug
	Tug/Pilot Ship
	Anchor Handling Salvage Tug
	Towing/Pushing
	Tug/Ice Breaker
	Tractor Tug
	Tug/Support
	Articulated Pusher Tug
	Icebreaker
	Inland Tug
	Pusher Tug
Passenger	Passengers Ship
	Inland Passengers Ship
	Inland Ferry
	Floating Hotel
	Ferry
	Ro-Ro/Passenger Ship

	Accommodation Ship
	Accommodation Barge
	Accommodation Jack Up
	Accommodation Vessel
	Passengers Landing Craft
	Houseboat
	Accommodation Platform
	Air Cushion Passenger Ship
	Air Cushion Ro-Ro/Passenger Ship
Cargo	Passenger/Cargo Ship
	Livestock Carrier
	Bulk Carrier
	Ore Carrier
	General Cargo
	Wood Chips Carrier
	Container Ship
	Ro-Ro Cargo
	Reefer
	Heavy Load Carrier
	Barge
	Ro-Ro/Container Carrier
	Inland Cargo
	Cement Carrier
	Reefer/Containership
	Vegetable/Animal Oil Tanker
	Obo Carrier
	Vehicles Carrier
	Inland Ro-Ro Cargo Ship
	Rail/Vehicles Carrier
	Pallet Carrier
	Cargo Barge
	Hopper Barge
	Deck Cargo Ship
	Cargo/Containership
	Aggregates Carrier
	Limestone Carrier
	Ore/Oil Carrier
	Self Discharging Bulk Carrier

	Deck Cargo Pontoon
	Bulk Carrier With Vehicle Deck
	Pipe Carrier
	Cement Barge
	Stone Carrier
	Bulk Storage Barge
	Aggregates Barge
	Timber Carrier
	Bulker
	Trans Shipment Barge
	Powder Carrier
	Cabu Carrier
	Vehicle Carrier
	Cargo
Tanker	Tanker
	Asphalt/Bitumen Tanker
	Chemical Tanker
	Crude Oil Tanker
	Inland Tanker
	Fruit Juice Tanker
	Bunkering Tanker
	Wine Tanker
	Oil Products Tanker
	Oil/Chemical Tanker
	Water Tanker
	Tank Barge
	Edible Oil Tanker
	Lpg/Chemical Tanker
	Shuttle Tanker
	Co2 Tanker
	Lng Tanker
	Lpg Tanker
	Gas Tanker

Recreational vessel density data were collected through the 2012 Northeast Recreational Boater Survey (Northeast Ocean Data Portal 2013). A random selection of 4,297 vessel owners from May 1, 2012 through October 31, 2012 were asked to identify the areas where they recreated on the ocean, along with the routes they used. The routes identified were converted into Shapefiles using ArcMap, and a line density analysis was performed using a 250m grid cell size. The resulting raster grids were each re-projected and joined together, leaving a boundary of cells between the two raster grids with no data value. The focal statistics expression took the mean of all cells in a 4x4 neighborhood around each blank cell. The values were then converted to Z-scores using the raster calculator by taking the log of the density values, subtracting the mean value, and dividing the resulting value by the standard deviation. This layer was clipped again using the NOAA medium resolution shoreline dataset (Northeast Ocean Data Portal 2013). A full description of the recreational vessel density methods can be found in Appendix 1. Once the humpback whale sightings layer was mapped over the recreational density layer, an "Extract to Raster" command was used to associate the z-score in each cell with the closest point. The number of encounters, as well as the mean, standard deviation, and range could then be calculated.

Fluke Matching

To analyze for population identity and age-class of humpback whales sighted in the NWNYB, the NYCHWC was compared to the basin-wide North Atlantic Humpback Whale Catalog (NAHWC) managed by Allied Whale. This catalog contains fluke photographs collected from all North Atlantic feeding grounds and breeding grounds. Flukes were arranged into five categories based on the percentage of black pigmentation (Mizroch et al., 1990). T1 refers to flukes with 0-20% black, T2 from 20-40%, T3 from 40-60%, T4 from 60-80%, and T5 from 80-100%. Flukes are then further categorized into 12 potential pigmentation patterns (Figure 3).

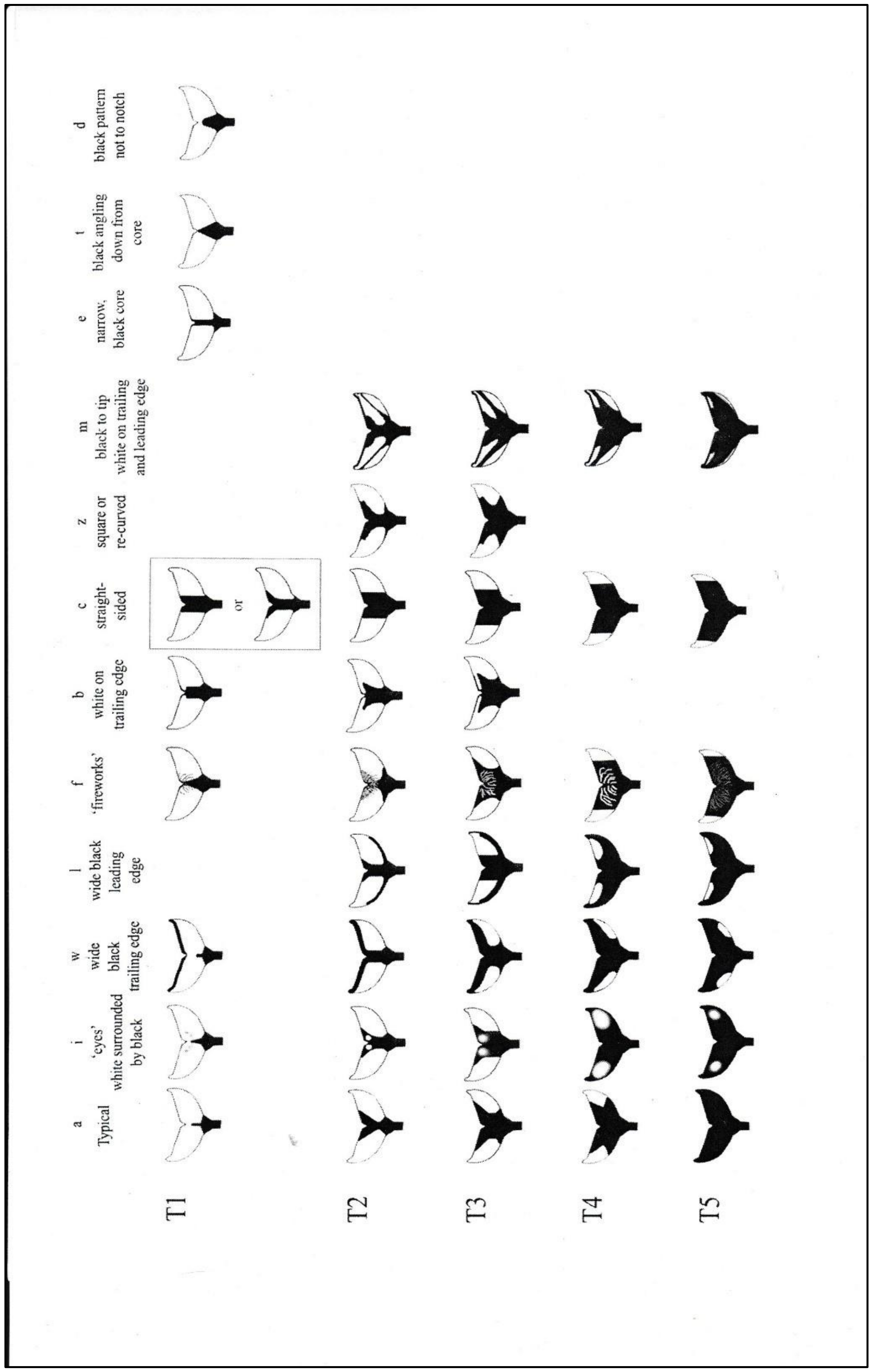

Figure 3: Pigmentation categories used for identification of humpback whales in the North Atlantic (Courtesy of Allied Whale).

During analysis, the NAHWC had been compiled up to December 2015, and partial data were available for 2016. To compensate for whales that may have been sighted but not yet entered or submitted, the NYCHWC was matched to the following regions directly; The Gulf of Maine, eastern Canada, and west Greenland. To investigate the seasonal movements of whales between the NWNYB and other areas, the NYCHWC was also compared to two other locations in the New York Bight; Montauk, New York and Cape May, New Jersey.

RESULTS

Sightings

Between 2011-2016, there were 424 humpback whale sightings in the NWNYB, with 324 recorded during fieldwork (mean per year = 54.00, SD = 37.56) and 100 from anecdotal sources (mean per year = 16.67, SD = 18.03). There was a positive relationship between the number of sightings from each source and year, and the correlations in both cases were significant (Figures 4 and 5). There was a positive relationship between the sighting ratio and year, but the correlation was not significant (Figure 6). The highest frequency of whale-watching sightings occurred during the summer, while the highest frequency of anecdotal sightings occurred during the fall. When all sightings were combined, summer was the season with the highest frequency (Figure 7).

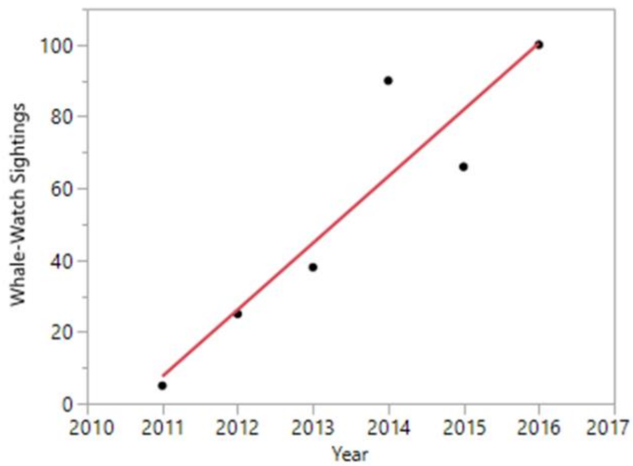

Figure 4: Linear regression showed that there was a positive relationship between the frequency of whale-watching sightings collected from 2011-2016 and year, and the correlation was significant (b_1=18.57, R^2=0.86, p=0.0082).

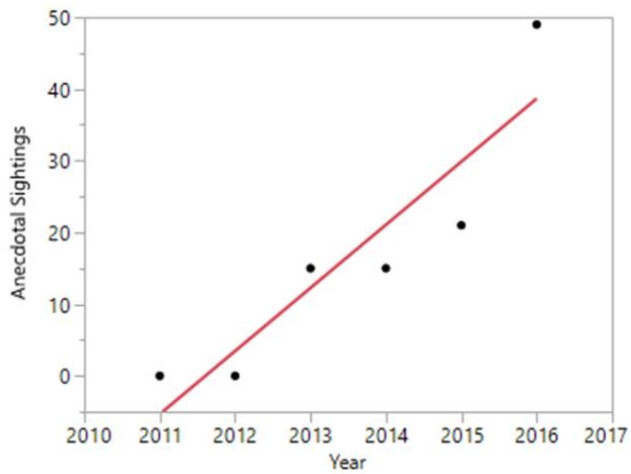

Figure 5: Linear regression showed that there was a positive relationship between the frequency of anecdotal sightings collected from 2011-2016 and year, and the correlation was significant (b_1=8.8, R^2=0.83, p=0.01).

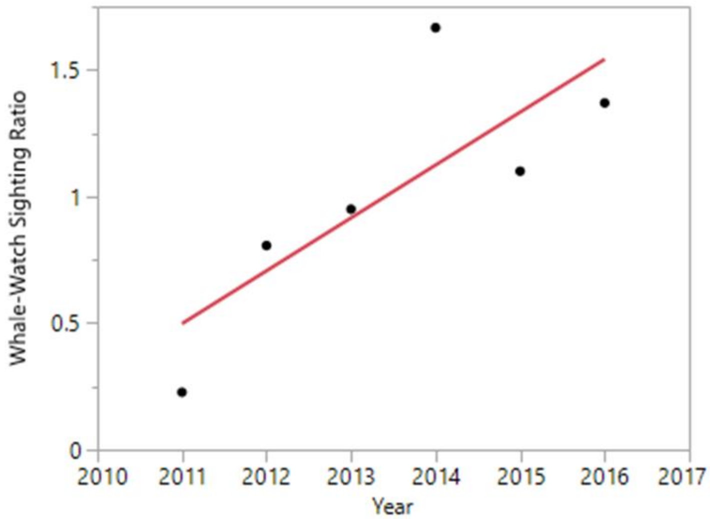

Figure 6: Linear regression showed that there was a positive relationship between the sighting ratio (sightings per trip) and year, but the correlation was not significant (b_1=0.21, R^2=0.62, p=0.06).

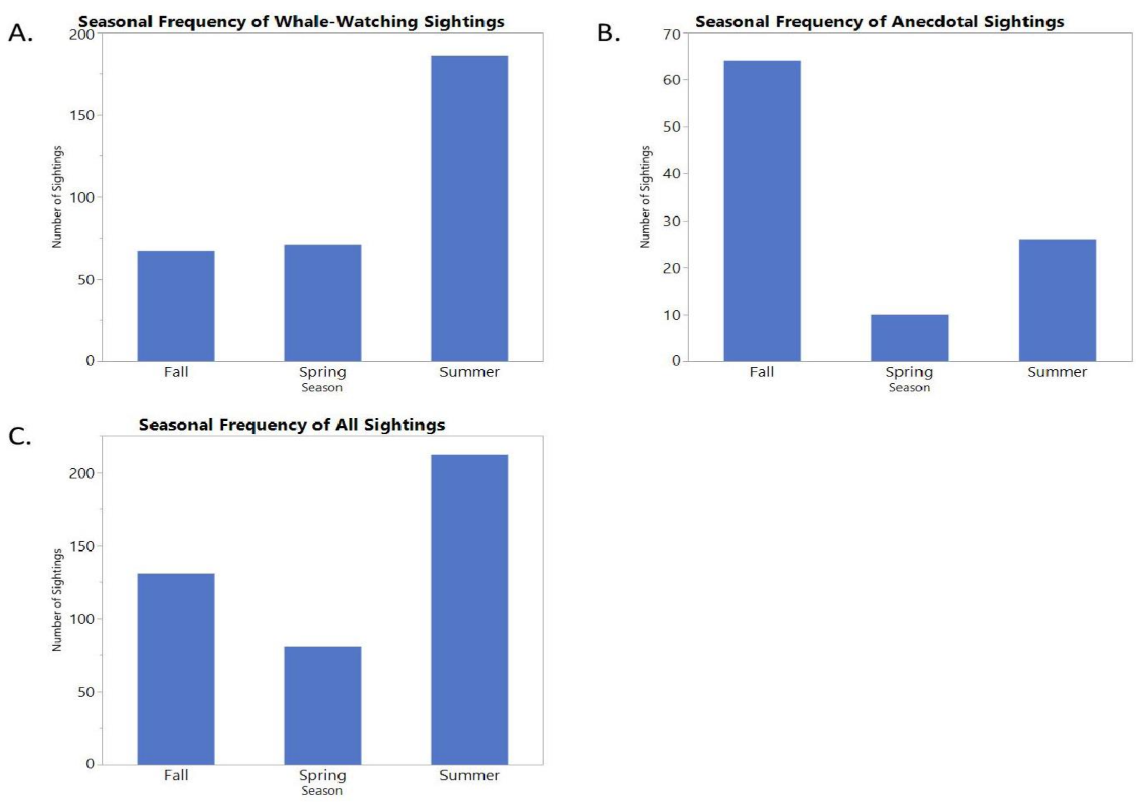

Figure 7: The seasonal frequencies of A) anecdotal sightings, B) whale-watching sightings, and C) all sightings from 2011-2016.

Vessel Risk

GPS data were available for 409 humpback whale sightings (Figure 8). Point density analysis showed that there were four high-density sighting areas (Figure 9). These high-density areas overlapped with AIS vessel categories with 401 (98.0%) sightings in the track of at least one vessel. There were 110 (26.9%) sightings located in the track of at least one Cargo vessel, 162 (39.6%) in track of at least one Passenger vessel, 163 (39.9%) in the track of at least one Tanker vessel, and 318 (77.8%) fell into the track of at least one Tug/tow vessel (Figure 10).

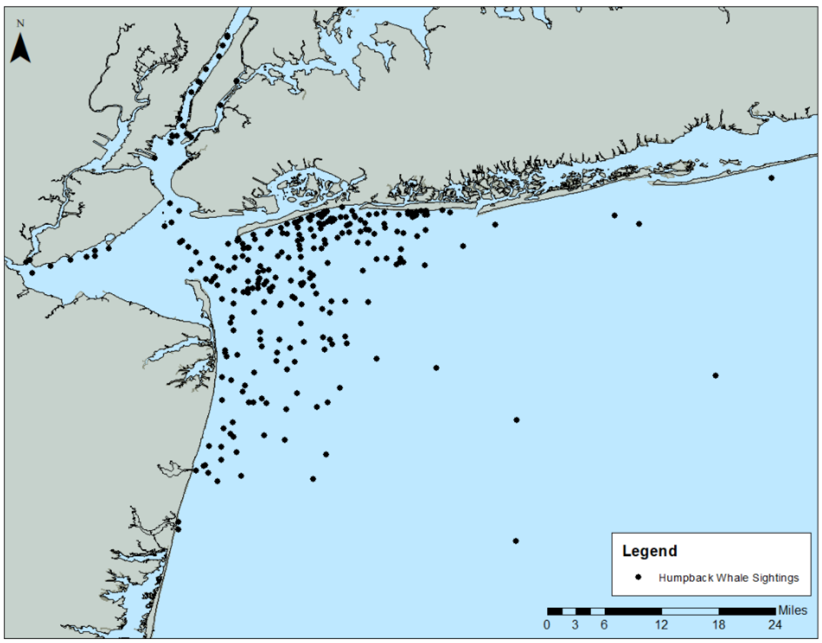

Figure 8: The spatial distribution of humpback whale sightings collected in the northwestern New York Bight, 2011-2016.

Over all, the mean vessel density at humpback whale sighting locations was 45.02 km per year, with a range of <1 to 4992.69 km per year. For Cargo vessels, the average density was 3.75 km/year, with a range of <1 to 38.0 km/year. The average density for Passenger vessels was 61.35 km/year, with a range of <1 to 4321.70. The average density for Tanker vessels was 2.25 km/year, with a range of <1 to 69.11 km/year. Lastly, the average density for Tug/tow vessels was 5.36 km/year, with a range of <1 to 171.23 km/year. Areas with high overlap between vessels and whales were found in the vicinity of Ambrose Channel, in upper New York Bay, the lower Hudson River, and the East River (Figure 11). When sightings were plotted against recreational vessel traffic, 250 (61.1%) sightings fell into the track of at least one recreational vessel (Figure 10). The average z-score was 0.02, with a range of -3.07 to 1.97. The distribution of humpback whale sightings in relation to vessel density maps of each type can be found in Appendix II.

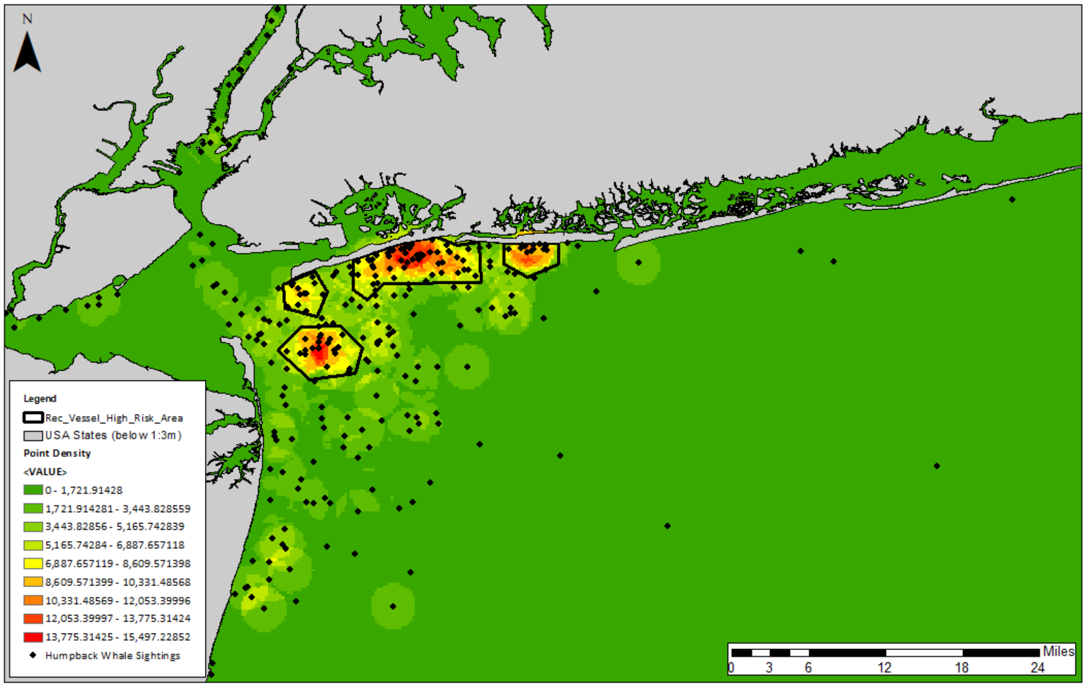

Figure 9: Point density analysis of humpback whale sightings in the northwestern New York Bight, 2011-2016. Polygons have been drawn around high-density sighting areas. Values represent the sighting density in each cell divided by the area.

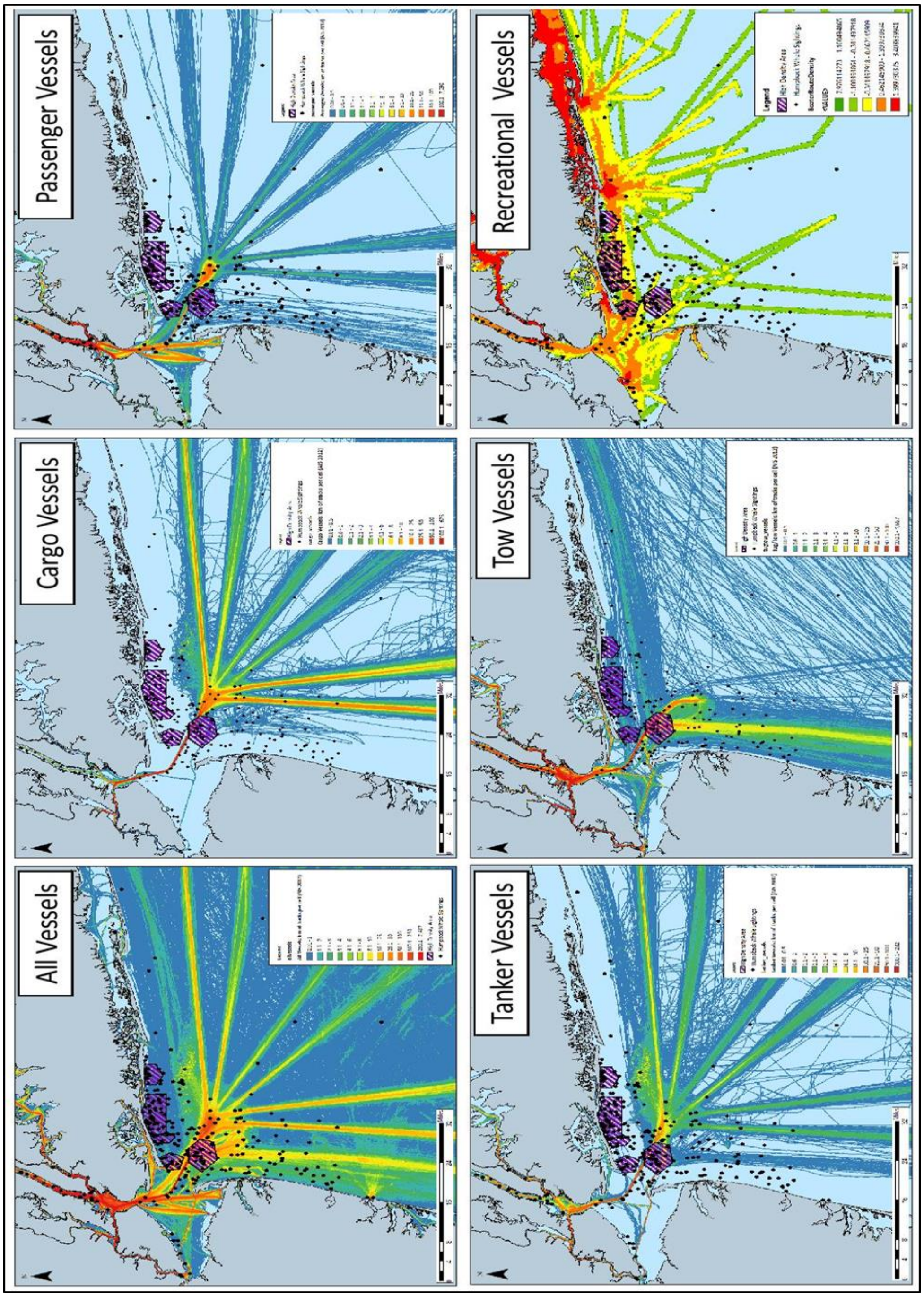

Figure 10: High-density polygons compared to commercial and recreational density maps. Commercial vessel layers obtained from http://midatlanticocean.org. Recreational vessel layer obtained from http://www.northeastoceandata.org.

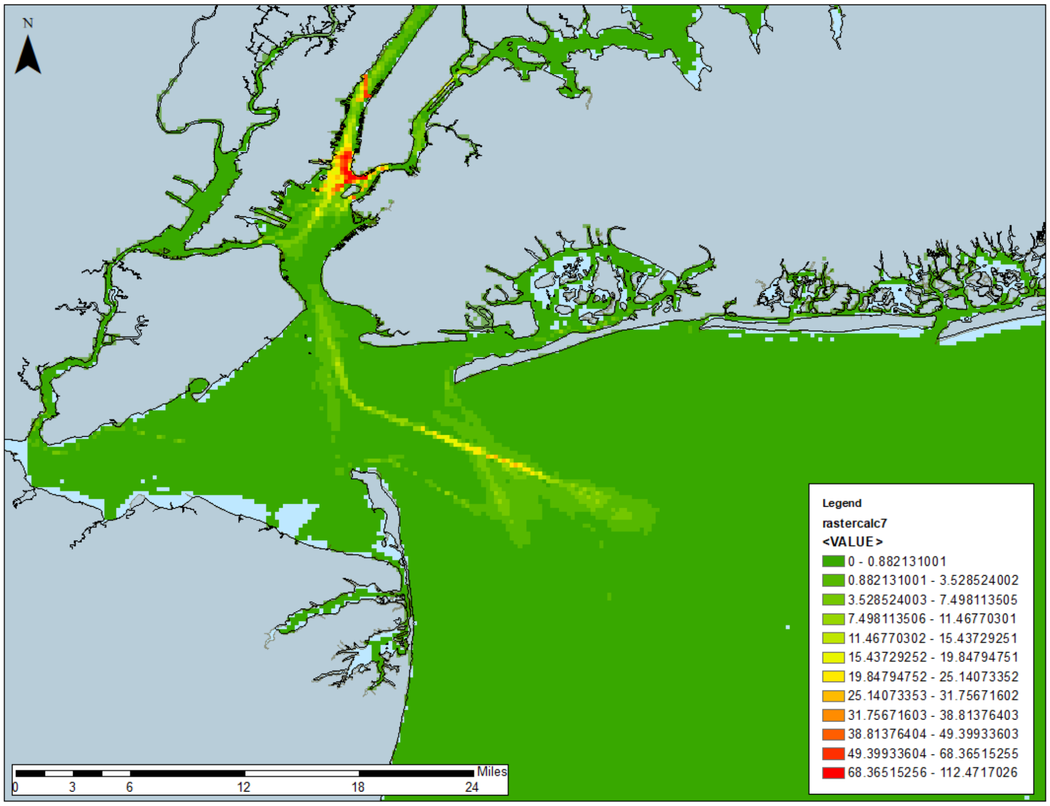

Figure 11: Areas with the highest overlap between large vessels and whales. Risk was calculated as the sighting density in each cell multiplied by the corresponding vessel density value. Vessel density layer obtained from http://midatlanticocean.org.

Occurrence, Occupancy, and Annual Return

A total of 55 whales were identified between 2011 and 2016. Three individuals were removed from the analysis due to lack of photographic or sighting data: NYC0006, NYC0053, and NYC0054. There were no whales identified in 2011, 4 identified in 2012, 8 in 2013, 8 in 2014, 13 in 2015, and 19 in 2016. There was a positive relationship between the number of new identifications and year, and the correlation was significant (Figure 12).

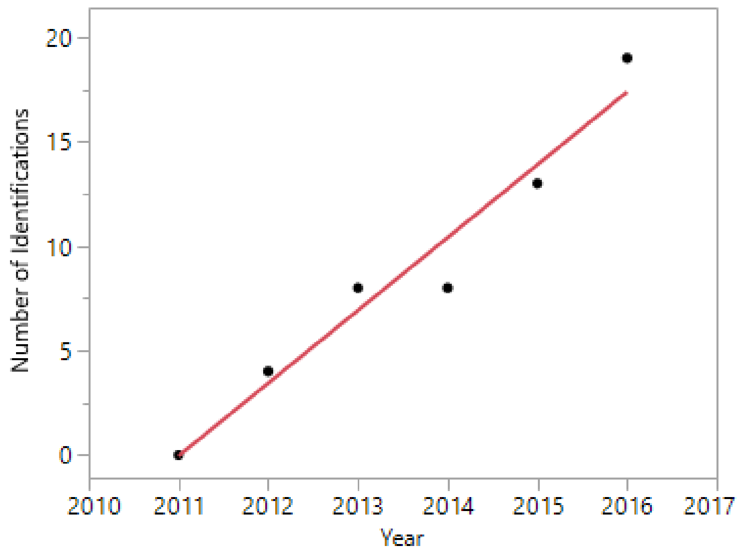

Figure 12: Linear regression showed that there was a positive relationship between the frequency of new identifications and year, and the correlation was significant (b1=3.49, R2=0.95, p=0.0009).

Table 3: Sighting frequencies of individual humpback whales identified in the northwestern New York Bight, 2011-2016. There were no whales identified in 2011.

NYCHWC ID #	2012	2013	2014	2015	2016
NYC0001	1	0	0	0	0
NYC0002	1	0	0	0	0
NYC0003	1	0	0	0	0
NYC0004	1	3	4	0	0
NYC0005	-	1	0	0	0
NYC0007	-	1	1	0	0
NYC0008	-	1	4	0	0
NYC0009	-	4	1	0	0
NYC0010	-	1	5	0	0
NYC0011	-	7	8	12	0
NYC0012	-	3	3	0	0
NYC0013	-	-	2	0	0
NYC0014	-	-	2	2	0
NYC0015	-	1	8	1	0
NYC0016	-	-	5	3	0
NYC0017	-	-	2	1	0
NYC0018	-	-	1	0	1

NYC0019	-	-	1	0	0
NYC0020	-	-	-	3	0
NYC0021	-	-	-	3	0
NYC0022	-	-	-	1	0
NYC0023	-	-	-	1	0
NYC0024	-	-	-	3	0
NYC0025	-	-	-	1	0
NYC0026	-	-	-	1	0
NYC0027	-	-	-	2	1
NYC0028	-	-	-	1	0
NYC0029	-	-	-	1	1
NYC0030	-	-	-	1	0
NYC0031	-	-	-	1	0
NYC0032	-	-	1	0	0
NYC0033	-	-	-	-	1
NYC0034	-	-	-	-	1
NYC0035	-	-	2	0	1
NYC0036	-	-	-	-	1
NYC0037	-	-	-	-	10
NYC0038	-	-	-	-	2
NYC0039	-	-	-	-	2
NYC0040	-	-	-	-	1
NYC0041	-	-	-	-	2
NYC0042	-	-	-	-	3
NYC0043	-	-	-	-	2
NYC0044	-	-	-	-	2
NYC0045	-	-	-	-	1
NYC0046	-	-	-	1	0
NYC0047	-	-	-	-	1
NYC0048	-	-	-	-	1
NYC0049	-	-	-	-	1
NYC0050	-	-	-	-	1
NYC0051	-	-	-	-	1
NYC0052	-	-	-	-	1
NYC0055	-	-	-	-	5

Half of the identified whales were seen only once, while the other half exhibited some type of either seasonal fidelity or annual return (Table 3). The mean occupancy duration was 35.1 days (Figure 13), and the mean occurrence rate was 3.93 days (Figure 14). The mean annual return rate was 40% (Figure 15).

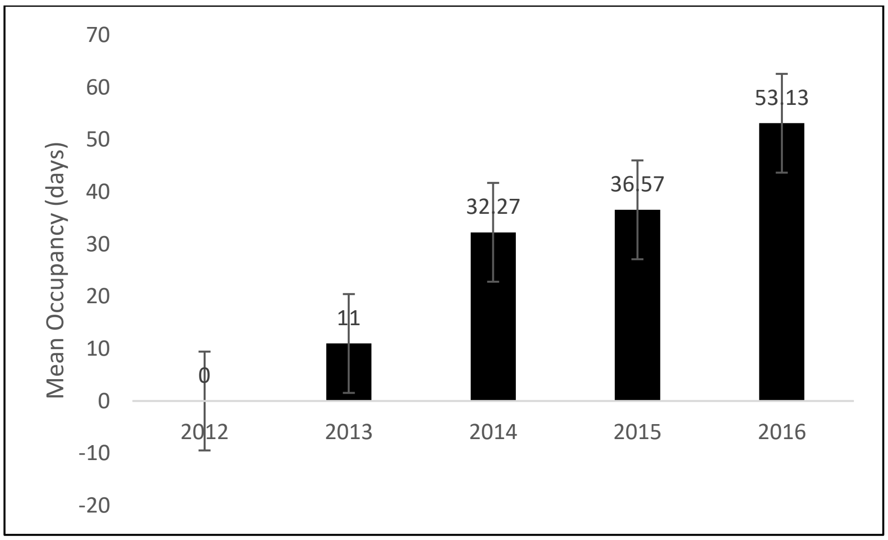

Figure 13: Mean annual occupancy for humpback whales in the northwestern New York Bight, 2011-2016. Duration rate was calculated as the number of days between the first and last sighting in a season. No whales were identified in 2011.

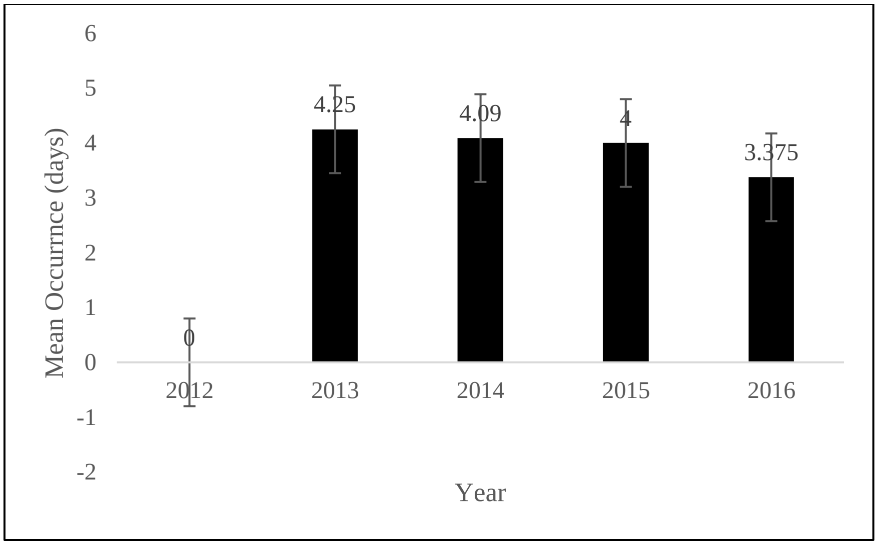

Figure 14: Mean annual occurrence for humpback whales in the northwestern New York Bight, 2011-2016. Occurrence was calculated as the number of days sighted within a season. No whales were identified in 2011.

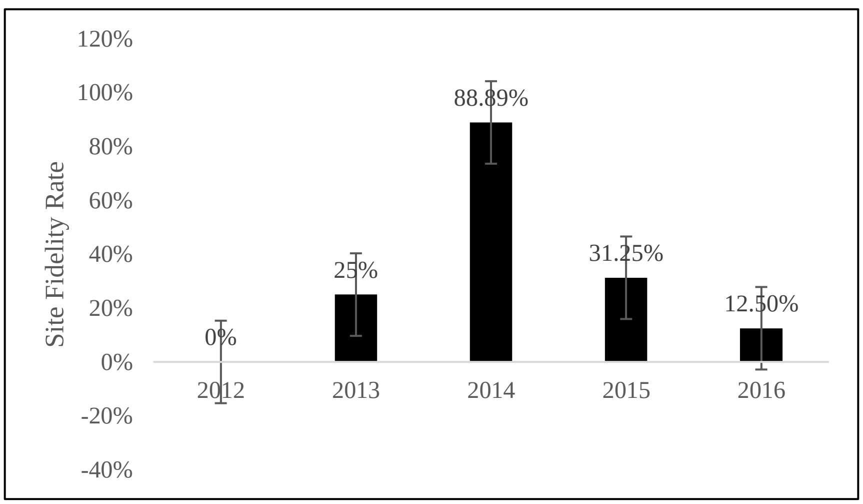

Figure 15: Mean annual return for humpback whales in the northwestern New York Bight, 2011-2016. Annual return was calculated as the percentage of identified whales that were resighted in the next consecutive year. No whales were identified in 2011.

Fluke Matching

In addition to the three whales that were removed from the above analyses, NYC0040 and NYC0041 (animals identified only by their dorsal fins) were excluded due to the absence of fluke photographs. Of the remaining 50 whales, 23 (46.0%) were matched to at least one other region of New York or New Jersey (Table 4) (Figure 16). The only feeding ground with confirmed matches was the GOM.

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Table 4: Individual whales from the New York City Humpback Whale Catalog that were matched to other catalogs in the North Atlantic.

NYCHWC ID #	Gulf of Maine	Cape May, NJ	Montauk, NY
NYC0001			
NYC0002			
NYC0003	√		
NYC0004	√	√	
NYC0005			
NYC0007			
NYC0008	√		
NYC0009			
NYC0010			
NYC0011	√	√	
NYC0012	√		√
NYC0013			
NYC0014			
NYC0015			
NYC0016		√	
NYC0017	√	√	
NYC0018	√		
NYC0019			
NYC0020			
NYC0021			
NYC0022			√

NYC0023			
NYC0024		√	
NYC0025		√	
NYC0026			
NYC0027			
NYC0028	√	√	
NYC0029			
NYC0030	√		
NYC0031		√	√
NYC0032		√	
NYC0033	√		
NYC0034			
NYC0035		√	
NYC0036			
NYC0037		√	
NYC0038			
NYC0039			
NYC0042	√		√
NYC0043		√	
NYC0044	√	√	
NYC0045			
NYC0046			
NYC0047			
NYC0048			
NYC0049	√	√	
NYC0050	√		
NYC0051			
NYC0052			
NYC0055			

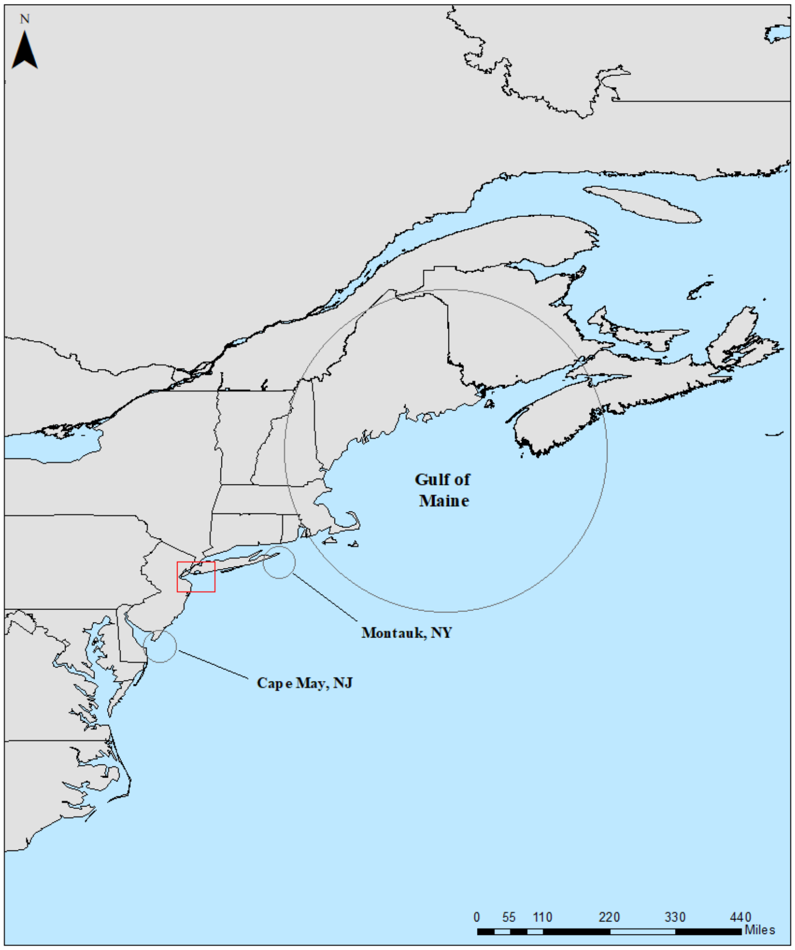

Figure 16: Individual humpback whales from the New York City Humpback Whale Catalog were matched to the Gulf of Maine, Montauk, NY, and Cape May, NJ. The study area is identified by the rectangular box.

There were 14 whales matched to the Gulf of Maine feeding population (Table 4), and no matches to any other feeding ground. GOM sighting histories provided information on the birth year and approximate age-class of 6 whales. When first sighted in the NWNYB, three were juveniles less than 3 years old, one was a lone adult, and the other was an adult female accompanied by a calf. Although the age class of the other 8 whales was not known, none of them were seen in the GOM for the first time prior to 2012.

All matches to the GOM were present there at some point during the study period except for NYC0017. When comparing the sighting histories between the NWNYB and the GOM, only the two adults were seen in both locations in the same year. The lone adult was seen in the NWNYB in the early spring (April) and the mother-calf pair were seen in the fall (November).

There were 14 (28.0%) matches to whales sighted off Cape May, NJ, 11 (78.6%) of which were seen in both the NWNYB and Cape May in the same year. The shortest amount of time between both locations was 8 days (mean = 29.1 days), and in 81.1% of these cases the individual was seen in Cape May first. There were 4 (8.0%) matches to whales sighted in Montauk, NY, 3 (75.0%) of which were seen in both locations in the same year. The shortest time between sightings was 12 days (mean = 29.25 days), and in 2 (67.0%) of these cases, the individuals were seen in the NWNYB first.

DISCUSSION

Sightings

The present study is the first detailed description of humpback whales in the NWNYB. There was a significant increase in both sightings and the number of newly identified individuals between 2011-2016. Prior to this time period, cetacean abundance surveys detected humpback whales infrequently in the NWNYB (Winn 1982; Palka 2006, 2012). However, Sadove and Cardinale (1993) described sightings in western Long Island and New York Harbor. Whale-watching did occur in the NWNYB during the 1990s (NMFS 1994, as cited in NEPA Draft EIS for the U.S. Coast Guard, APLMP Initiative, 31 July 1996). Anecdotal evidence suggests that these trips took place primarily during winter and humpback whales were one of the species sighted (Kamin 1993, Demasters 1997). Unfortunately, whale-watching data from this time-frame is unpublished and the organizations are no longer in business, and so the data are unavailable.

In the present study, whale-watching effort increased and varied both seasonally, weekly, and annually. The calculation of a sighting ratio and the collection of year-round anecdotal reports helped to eliminate some of the potential bias. Both the sighting ratio and the number of anecdotal reports also increased throughout the study period, suggesting that the increase in sightings may be independent of whale-watching effort.

The absence of winter sightings may be due to the lack of effort during this season, however there were also no anecdotal reports during winter. The seasonality described in this study is comparable to what has been found on the nearest primary feeding ground in the Gulf of Maine (e.g., Clapham et al. 1993, Robbins 2007).

The cause of increased sightings in unknown, but prey availability can affect humpback whale distribution (Payne et al. 1986, Piatt et al. 1989, Payne et al. 1990, Stevick et al. 2006), and an increase in prey may be driving the increase in humpback whales in the NWNYB. The prey species most recently documented in the NWNYB was Atlantic menhaden (*Brevoortia tyrannus*) (Brown et al. 2018). Menhaden have declined since the 1960s (Ahrenholz et al. 1987), but there is evidence of an increase in juveniles along the Atlantic coast from 2000 to 2013 (Simpson et al. 2016).

Vessel Risk

Nearly all sightings (98%) fell into the track of at least one large vessel. Sightings were most often (79.3%) located in the track of a Tug/tow vessel. The smaller size of tug/tow vessels enables them to travel outside of dredged shipping channels and closer to shore, where the majority of humpback whale sightings were located. Close encounters with this vessel type were observed in this study (Appendix III). Fortunately, vessels in this category typically travel slower on average than other vessels. Wiley et al. (2011) found that the average speed for Tug/tow vessels in Stellwagen Bank National Marine Sanctuary was 8.6 knots, which is lower than the 11.8 knot threshold where the likelihood of mortality in a vessel collision is at least 50% (Vanderlaan and Taggart

2007). The vessel type that overlapped any one humpback whale sighting with the greatest density were passenger vessels. This category includes any vessels whose primary function is the transportation of passengers, and includes cruise ships. Cruise ships are known sources of whale mortality, and they have been known to return to port with deceased whales on their bulbous bows (Laist et al. 2001, Jensen and Silber 2003). There are three major cruise terminals in the PNYNJ, with some of the largest ships in the world transiting the area weekly during high-season (https://www.panynj.gov/port/cruise-terminals.html).

The high amount of overlap between vessels and whales found in the upper New York Bay, lower Hudson River, and the East River was irrespective of the low sighting densities in these locations. This provides insight into the dangers posed to large whales that enter these areas. One whale, NYC0041, was identified in the study area (Raritan Bay), and then 7 days later was identified outside of the study area in the Long Island Sound, near New Rochelle, New York. It is possible that this whale and other humpback whales are using the East River as a transit route between these locations.

The density data for recreational vessels were collected differently than that for commercial vessels, and therefore it was not possible to make a direct density comparison. However, more humpback whale sightings (61.1%) fell into the track of a recreational vessel than a cargo, tanker, or passenger vessel. The recreational vessel density maps used only include boaters from New York and do not account for New Jersey. Therefore, the risks posed to humpback whales in the NWNYB are likely higher than those found in this study.

Vessel-risk analyses were conducted using only the initial sighting of all humpback whales. The analyses do not take into account that whales are mobile, and are likely to move into the tracks of several different vessel types. Additionally, these results are based on the spatial effort and sighting success by the whale-watching vessel, which was not recorded. Therefore, there may be other high-density areas that are not represented here. Nevertheless, it is clear that humpback whales in the NWNYB are encountering multiple vessel types, thus it is important to manage this area in a way that limits the risks from all vessels.

Occurrence, Occupancy, and Annual Return

There were 55 individual whales catalogued during the study period. Two of these were added with photographs of their dorsal fins only. However, this was not the case for other individuals for which only the dorsal fin was photographed. The reason for this was that all dorsal fins are not equally reliable as flukes as a primary source of identification, although they are helpful as a secondary identifier. The NWNYB is relatively shallow with a mean depth of approximately 6m, which makes it less likely for humpback whales to make deep dives and display their flukes. If more deep dives were observed, there likely would have been more catalogued individuals.

There appeared to be two different occurrence patterns in the NWNYB; individuals that were transient and only identified once during a season, and whales that were identified more than once during a season. The mean occupancy length was 35.1 days, which is higher than what was found for juveniles in coastal Virginia (8.1 days for whales seen more than once) (Swingle et al. 1993) and lower than what was described for the Gulf of Maine (88.1 days) (Clapham et al. 1993). However, the occupancy calculated in this study refers only to a small area. The number is likely higher for the entire NYB.

The average occurrence rate in the NWNYB was 3.93 days, which is lower than the 8.98 days found for the GOM (Clapham et al. 1993). Clapham et al. (1993) included whales seen only once in the calculation of occurrence. Therefore, the number is likely much higher for whales seen multiple times. The mean occurrence rate described for coastal Virginia is more comparable to the NWNYB, at 2.42 days (Swingle et al. 1993). Based on these results, it does not appear that humpback whales exhibit the same occurrence patterns in the NWNYB as in the GOM. The NWNYB may be more comparable to the mid-Atlantic United States, which evidence suggests may be an important feeding ground for juveniles (Swingle et al. 1993, Barco et al. 2002).

Fluke Matching

There were 14 (28.0%) individuals matched to the GOM, and no matches to any other feeding ground. This may be a result of the size difference in western North Atlantic humpback whale catalogs. The GOM catalog is much larger with more than 2,900 individuals (J. Robbins, personal communication[1]), compared to the Greenland Institute of Natural Resources with 494 whales (T. Boye, personal communication[2]), and the Mingan Island Cetacean Study with 851 whales (C. Ramp, personal communication[3]). Barco et al. (2002) also found that the majority of humpback whales photographed in the

[1]Dr. Jooke Robbins, Director, Humpback Whale Studies Program, Center for Coastal Studies, Provincetown, MA
[2]Dr. Tenna Boye, Scientist, Greenland Institute of Natural Resources
[3]Dr. Christian Ramp, Research Coordinator, Mingan Island Cetacean Study

mid-Atlantic United States were matched to the GOM; however, a small number (14.6%) were matched to eastern Canada, and many were not matched to any other catalog. Due to the fact that several individuals from the NWNYB were also not yet matched to any other catalog, there may be matches to other feeding grounds in the future.

A plausible explanation for whales not seen anywhere else other than the NWNYB could be the age-class. When examining matches to the GOM where age-class was known, 50% were independent juveniles between 1 and 5 years old when first sighted in the NWNYB. An additional 8 matches were not seen for the first time in the GOM prior to 2012, suggesting that they might also be juveniles. Young whales have had less time to be photographed, hence they are more difficult to match. A high number of juveniles has been described for other parts of the mid-Atlantic United States (Swingle et al. 1993, Barco et al. 2002).

Both of the known adults (NYC0033 and NYC0049) were transient in the NWNYB. This suggests that adults may pass through and not remain in the area during the feeding season. These whales were seen in May (NYC0033) and November (NYC0049), which coincides with the timing of migration in the North Atlantic (e.g., Clapham et al. 1993, Robbins 2007). It is possible that these whales passed through the NWNYB during migration. All of the known and suspected juveniles were seen from July through October, with the exception of one (NYC0042 was seen in both July and November), suggesting that juveniles may be using the NWNYB differently than adults.

Humpback whales exhibit both short- and long-distance movements while on their feeding grounds (Stevick et al. 2006, Heide-Jørgensen et al. 2007, Dalla Rosa et al.

2008), and, although infrequent, have been documented traveling distances in excess of 1,000 km between feeding sites (Dalla Rosa et al. 2008, Kennedy et al. 2014). It is conceivable that humpback whales are moving between the NWNYB and the GOM within the feeding season, which is a distance of <500 km; however, only the adults were seen in both locations during the same year. In the case of all other GOM whales, in the year(s) that they were identified in the NWNYB, they were not seen in the GOM. At present, there is no evidence of routine, within season movement between areas, particular during summer.

There were differences in the number of matches to both Montauk, New York and Cape May, New Jersey, although their respective distances from the NWNYB are nearly the same. It is unclear whether this was a factor of effort or catalog size. During the study period, whale-watching trips in Montauk, New York occurred approximately 1 day per week during the summer months only, while Cape May whale-watching took place between 2 and 7 days per week in spring, summer, and fall. Additionally, according to Dr. Arthur Kopelman, president of the Coastal Research and Education Society of Long Island, humpback whales are not the dominant species seen off Montauk, New York, whereas fin whales (*Balaenoptera physalus*) are more likely to be seen. A large percentage (81.1%) of within-year matches between Cape May and the NWNYB were seen in Cape May first, but were not seen again in Cape May during that year. This may suggest that humpback whales are traveling north to the NWNYB from the southern mid-Atlantic. There was a high percentage (66.7%) of within-year matches between the

NWNYB and Montauk that were seen in the NWNYB first, but the small sample size (n=2) makes it difficult to draw conclusions on movements between the two areas.

It appears that two different seasonality patterns exist between the northern mid-Atlantic (Montauk, New York south to Cape May, New Jersey) and the southern mid-Atlantic (Maryland south to North Carolina). Both Swingle et al. (1993) (Virginia) and Barco et al. (2002) (New Jersey to North Carolina) found that humpback whales were most often sighted during the winter months. However, the New Jersey sightings documented by Barco et al. (2002) came from Cape May, New Jersey, and occurred mainly during the summer. Summer was also the season with the highest frequency of sightings in the NWNYB, which is at the northernmost portion of the mid-Atlantic United States. It is difficult to draw conclusions on this theory since there are exceptions; however, it appears that some type of geographic variation in seasonality does occur.

Management of Humpback Whales in the Northwestern New York Bight

The New York State Department of Environmental Conservation (NYS DEC) recently acknowledged the need for baseline monitoring of large whales in the greater NYB (Schlesinger and Bonacci 2014). In 2014, a workshop was convened where researchers, non-governmental organizations, and government agencies discussed potential monitoring options, including vessel-based, aerial, and opportunistic surveys (Schlesinger and Bonacci 2014). Although the NYS DEC's focus was primarily on monitoring rather than identifying specific threats, they did acknowledge that vessel strikes could potentially increase (Schlesinger and Bonacci 2014). Some of the main objectives described by the NYS DEC were to determine the distribution and seasonality of occurrence of large whales in the NYB, including along major shipping lanes (Schlesinger and Bonacci 2014). The results in the present study facilitate these monitoring objectives. To supplement the goals of the NYS DEC, comparable monitoring plans should be discussed for the state of New Jersey. The NYS DEC refers specifically to the New York state portion of the NYB and, to date, there have been no comparable monitoring plans for large whales on the New Jersey side of the NYB. Previous research on large whales in New Jersey is lacking, but the present study found many sightings along the New Jersey coastline. A monitoring plan must also exist in New Jersey in order for any large whale management in the NWNYB to be successful.

Due to the opportunistic nature of the data used in this study, it is difficult to make conclusions on abundance or distribution. Systematic surveys, including the collection of environmental data such as temperature, salinity, and chlorophyll-a, would be beneficial for use in habitat modelling to better predict seasonal humpback whale occurrence. Additional research into the forces driving the increase in sightings, including potential changes in the regional abundance of Atlantic menhaden, should also be considered.

Even low numbers of vessel-related mortalities can have great effects on humpback whale populations due to their low reproductive rates (Laist et al. 2001). For this reason, mitigation measures are critical for their conservation. In other high-risk areas for whales, amendments to the shipping Traffic Separation Schemes (TSS) have been adopted to reduce whale-vessel collisions (Silber et al. 2012). In the present study, one area of high overlap between vessels and whales occurred inside Ambrose Channel. This channel is the only maintained route leading large vessels into New York Harbor. Due to the narrow geography and shallow bathymetry of the area, it is unlikely that this channel can be redirected. Furthermore, although high-risk areas were identified in this study, these data are too limited to conclusively say that there are no other high-risk areas in the NWNYB. In light of this, limiting vessel speed, promoting caution, and managing recreational boaters is recommended to limit negative interactions.

The NWNYB is located within a North Atlantic right whale (*Eubalaena glacialis*) Seasonal Management Area, and speed restrictions of 10 knots or less are in place from November 1 through April 30 (Silber and Bettridge 2012). These speed restrictions have shown to be successful in reducing the number of right whale deaths (Laist et al. 2014). The present study found humpback whale sightings to occur from April through December; therefore, the extension of speed restrictions to include May through October is recommended. Previous studies have found that voluntary speed restrictions may not be enough to prevent vessel strikes (Wiley et al. 2008, Lagueux et al. 2011, Silber et al. 2012), thus, any limits on vessel speed should be mandatory.

Large whale mortality is less likely if vessels travel at 10 knots or less (Laist et al. 2001, Vanderlaan and Taggart 2007), but additional measures must be taken to limit non-lethal injuries as well. Fresh vessel-related injuries were documented during this study (Appendix IV). If an extension of the Seasonal Management Area speed restrictions is not possible, a warning system used to alert vessels in advance of their transit through the NWNYB is recommended to ensure they maintain caution in the area.

Passive Acoustic Monitoring (PAM) methods have been used to detect the presence of cetaceans in high risk areas through the recording of vocalizations (e.g., Verfuß et al. 2007, Morano et al. 2012, Mussoline et al. 2012, Vu et al. 2012, Baumgartner et al. 2013, Lammers et al. 2013). Although they are more common at lower latitudes and primarily during the breeding season, humpback whale songs have been recorded at higher latitudes, (Mattila et al. 1987, Clark and Clapham 2004, Vu et al. 2012). However, vocalizations other than song are more common on feeding grounds, such as those used during cooperative feeding (Jurasz and Jurasz 1979, D'Vincent et al. 1985, Thompson et al. 1986). PAM requires a vocalization detection algorithm unique to each species (Baumgartner et al. 2013), and humpback whale sounds associated with feeding are often unpredictable, making them somewhat more complicated to detect (Cerchio and Dahlheim 2001, Schlesinger and Bonacci 2014). PAM systems can also be sensitive to high levels of background noise such as vessel traffic (Bingham 2011), but more advanced detection models have been developed to minimize these effects (Helble et al. 2012).

According to Dr. Howard Rosenbaum, Director of the Ocean Giants Program at the Wildlife Conservation Society, a digital acoustic monitoring buoy located approximately 35 km from Fire Island, NY was deployed in June 2016 for the purpose of detecting whale vocalizations near major shipping lanes. Additional PAM buoys placed within the high-risk areas identified in this study, such as along Ambrose Channel, may also be beneficial for real-time reporting and alerting vessels in transit. However, due to the high levels of background noise, the infrequency of cooperative feeding (D. Brown, personal observation), and the age-class of whales in the NWNYB (juveniles are unlikely to be singing), it may be difficult to detect them acoustically. Therefore, PAM systems should be supplemented with additional reporting options.

Dedicated observers have been implemented in other areas where redirecting ships or PAM had a lower likelihood of success (Constantine et al. 2015). Observers allow not only for whale avoidance but also for sightings to be relayed via radio transmissions. The short-surfacing intervals (D. Brown personal observation) and distinct feeding behavior of humpback whales (Appendix V) in the NWNYB makes visual reporting a feasible option. Due to the number of vessel transits through the PNYNJ, it is not feasible to have observers on-board every large vessel. Therefore, at the very minimum, positioning observers on-board cruise ships during high-season is suggested.

An additional recommendation is to educate maritime and docking pilots on the presence of whales in the PNYNJ. Pilots board vessels in need of navigational assistance and guide them through the PNYNJ, and also serve as tug/tow captains. According to the New Jersey Maritime and Docking Pilot Commission, in 2016 there were 81 maritime and docking pilots and apprentices serving the PNYNJ. Per the Sandy Hook Pilots Association, a pilot boat is stationed near the entrance to Ambrose Channel 365 days per year. Due to their extensive time on the water, pilots are likely aware of humpback whale sightings in the NWNYB, but they may not be aware of the risks. Providing educational materials to pilots would help to promote awareness and caution in the shipping community. Furthermore, pilots may be able to assist research and management efforts by reporting their humpback whale sightings.

In addition to the above, incorporating both PAM detections and observer sightings into a real-time mobile application or social media platform accessible by the shipping industry may facilitate mitigation efforts. Real-time mobile applications have shown to be successful in other areas (NMFS 2012, Davidson et al. 2014). However, if humpback whale sightings continue to be consistent in the NWNYB, the best protection would be to maintain a standing seasonal warning, such as an extension of the Seasonal Management Area mentioned above.

There is not only a need for management of large vessels, but also for recreational vessels in the NWNYB. The most advantageous option for recreational whale-watchers is education. By informing local boaters on humpback whales' vulnerability from vessel strikes and harassment, as well as advising them of proper whale-watching guidelines, coexistence can be facilitated. Literature highlighting this information can be distributed at local marinas and fishing clubs, and incorporated into educational programs by local NGOs. It may also be beneficial for researchers, local vessel operators, and government agencies to collaborate on the implementation of whale-watching guidelines. Studies have found more success in compliance with guidelines when local vessel operators participate in their establishment (Parsons and Woods-Ballard 2003).

Previous research suggests that there are negative impacts of whale-watching on cetaceans (e.g., Parsons 2012, Avila et al. 2015, Argüelles et al. 2016). However, there are also many conservation benefits (Wilson and Tisdell 2003, Zeppel 2008). Wilson and Tisdell (2003) found that whale-watching patrons are often more likely to support whale conservation and Zeppel (2008) suggested that patrons are more likely to comply with regulations following their trip. Whale-watching operators are instrumental in influencing other boaters to comply with regulations, and may be able to assist in enforcement by reporting violators (Lien 2001). The *American Princess* is currently the only commercial whale-watching vessel operating in the NWNYB. However, if humpback whale sightings continue to increase and become more consistent, there is the possibility of additional whale-watching tours in the future. For this reason, it is important to manage whale-watching in the NWNYB proactively. Due to the existing level of vessel activity in the area, it would be prudent to limit the number of whale-watching vessels permitted to operate in the NWNYB.

CONCLUSION

It is especially important to obtain a better understanding of humpback whale occurrence in an area such as the NWNYB, where there are multiple sources of anthropogenic risk. Opportunistic data, such as that from whale-watching, can provide valuable information on cetaceans in areas where dedicated surveys are limited and data are required in a timely manner. The results presented here are not all encompassing, yet, these data are the only consistent data type collected on humpback whales from 2011-2016. Therefore, they must be considered in future management decisions. In addition to the large whale monitoring that has recently been initiated, management should include speed restrictions, real-time sighting notifications, and educating local recreational boaters on whale-watching regulations. Humpback whales in the waters surrounding New York City can no longer be considered as infrequent or rare. This study has shown that they are not only spending an extended period of time in the area, but are returning in consecutive years. If this continues, it may be necessary to re-evaluate the seasonal distribution of western North Atlantic humpback whales.

APPENDIX I

Northeast Recreational Boater Route Density

Northeast United States

March 20, 2013

Prepared for:

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INTRODUCTION

The Northeast Recreational Boating Density Layer was created based on results of the 2012 Northeast Recreational Boater Survey, which was conducted by SeaPlan, the Northeast Regional Ocean Council (NROC), states' coastal agencies, marine trade associations composed of many private industry representatives, and the First Coast Guard District. The methodology for the 2012 Northeast Recreational Boater Survey follows a protocol similar to the 2010 Massachusetts Survey with modifications based on the lessons learned and recommendations suggested in the Massachusetts Survey Final Report.

The methodology consists of surveying a random sample of selected boat owners throughout the Northeast through a series of monthly online surveys. The surveying period lasted throughout the 2012 boating season (May 1 through October 31, 2012), which was identified by the advisory committee (consisting of NROC and representatives from the recreational boating industry).

The project team decided to use a random sample survey approach because it successfully gathered statistically robust economic and spatial data on recreational boating activity by Massachusetts registered boaters during the 2010 boating season. This was also the only approach that would allow for the calculation of statistically robust economic impact estimates for both states and the region, which was identified as a priority (along with spatial data) by both NROC and the boating industry.

SURVEY SAMPLING METHODOLOGY

The sample for this survey came from seven databases, including the U.S. Coast Guard Documented Vessel Database and databases of state registered boaters from New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine. Recreational boaters who owned vessels that met the following criteria were eligible for the survey:

- Registration: Currently registered with a state in the Northeast and/or registered as a documented vessel with the U.S. Coast Guard, with a hailing port in the Northeast
- Primary Use: Recreational use designation
- Length: At least 10 feet in length
- Saltwater (if specified; only Maine and New Hampshire required this information)
- Location: Located in a “coastal county”. The survey team defined “coastal counties” as those that border saltwater, or those that were highlighted by state coastal planners as likely containing large amount of saltwater boating activity.

Based on the 2010 Massachusetts Survey and budgetary considerations, the project team determined an overall sample size that would provide sufficient spatial and economic data for both each state, as well as the whole Northeast. Because of the, at times, large discrepancies between the number of eligible boats in some states, the team decided that certain states with fewer eligible boats should also have a supplemental sample of boats in addition to the pure random sample. To ensure the sample represented the total population of registered boats in the Northeast, the sampling method included considerations of state, geography and size class. Of the 373,766 boats eligible for the survey, the base of randomly sampled boats included 50,000 boats from across all six states. In addition to this base, the survey team sampled 17,772 boats as a supplemental sample, including: 1,772 boats of 26 feet in length or more from across all six states to increase the number of large boats in the sample, and 16,000 additional boats to ensure each state had enough responses for the statistical analysis. These included 10,000 boats from Maine, 2,500 boats from Rhode Island, 2,000 boats from New Hampshire and 1,500 boats from Connecticut. This resulted in a total of 67,772 boaters invited to participate in the study.

Boater Recruitment and Response

In the survey invitation package, the survey team also sent invited boaters a questionnaire to verify eligibility to participate in the survey. Eligibility requirements consist of: boat is used in saltwater; boat is used for recreational purposes; and boaters have access to the internet with a working email address. 12,218 boaters responded to the invitation; however only 7,800 of these respondents were found to meet all of the above criteria. From this sample, 4,297 individual boaters completed at least one monthly survey.

Surveying Process

The study consisted of six monthly surveys and one end of season survey. The online monthly surveys gathered spatial and economic data on recreational boating activity that occurred during the previous month. The online survey had two parts: 1) a survey with questions about general boating activity during the previous month, and the boater's last trip of the month (specifically focusing on spending), and 2) a mapping application developed by Ecotrust where boaters plotted their boating route and identified any areas where they participated in activities, such as fishing, diving, wildlife viewing, swimming and relaxing at anchor. The end of season survey gathered a variety of information that could not be gathered in the monthly surveys. The end of season survey contained questions about yearly boating-related expenditures (e.g., dockage, storage, taxes, yearly maintenance), feedback on the survey itself, and general boating-related questions (e.g. whether boaters have taken a boating safety course).

Density Analysis:

The density analysis described in the following paragraphs was vetted by a technical advisory team consisting of representatives from the Massachusetts Office of Coastal Zone Management (MA CZM), NROC, Maine Coastal Program and Applied Science Associates (ASA) and was based on mapping and analysis protocols from the 2010 Massachusetts Survey.To develop the density layer, vessel routes were drawn in WGS 1984 in the Ecotrust mapping application and were imported into Excel, then ArcMap using a data frame in that coordinate system. Routes from the random sample were selected from that data layer, and the data layer was re-projected into two separate shapefiles, one in UTM 18 and one in UTM 19. A line density analysis using a 250 m square grid cell with a 675 m neighborhood was applied to each shapefile. The 675 m neighborhood was applied to account for inherent user error in the mapping tool. The line density analysis resulted in a raster grid for each UTM zone. Each raster was clipped by the boundaries of its UTM zone, re-projected into the North American Albers Equal Area Conic Projection, and the separate rasters were mosaicked together. At the boundary of the two raster grids there was a line of cells with no data value. This was a result of mosaicking rasters that originated in different coordinate systems. To approximate values in the blank cells, each blank cell was populated by a value from a focal statistics calculation. The focal statistics expression took the mean of all cells in a 4x4 neighborhood around each blank cell. The values were then converted to Z-scores using the raster calculator by taking the log of the density values, subtracting the mean value, and dividing the resulting value by the standard deviation of the value. This layer was clipped again using the NOAA medium resolution shoreline dataset.

PURPOSE

This dataset can be used by coastal planners in ocean planning activities to develop a better understanding of how and where humans use the ocean in the Northeast to inform regional ocean planning and minimize ocean use conflicts. This effort also fulfilled a recommendation from the 2010 Massachusetts Survey to expand the survey's geographic range to the Northeast Region, allowing for the capture of interstate traffic between states in the Northeast. Furthermore, this dataset can also be used by the boating industry to show the importance of recreational boating to the region and to inform business planning.

SOURCES AND AUTHORITIES

- 2012 Northeast Recreational Boater Survey, SeaPlan 2013
- NOAA Medium Resolution Shoreline Dataset

DATABASE DESIGN AND CONTENT

Native storage format: ArcGIS File Geodatabase Raster Columns and Rows: 3886, 4858

Number of Bands: 1 Cell Size: 250 meters Source
Type: continuous
Pixel Type: floating point Pixel
Depth: 32 Bit Statistics:
Minimum: -10.04834938049316
Maximum: 3.436755657196045
Mean: 0.09926157765271766?
Standard Deviation: 1.005643995322989
Dataset Name: RecreationalBoaterRouteDensity
Dataset Status: Complete

SPATIAL REPRESENTATION

Reference System: GCS North American 1983 Horizontal
Datum: North American Datum 1983
Ellipsoid: Geodetic Reference System 1980
Linear Unit: Meter (1.0)
Angular Unit: Degree (0.0174532925199433)
False Easting: 0.0
False Northing: 0.0
Central Meridian: -96
Geographic extent: -76.72 to -65.72, 35.00 to 45.18
IS0 19115 Topic
Category: environment, oceans, biota, economy, transportation Place
Names: Atlantic Ocean, Bay of Fundy, Cape Cod Bay, Chesapeake Bay, Delaware Bay, Gulf of Maine, Georges Bank, Long Island Sound, Massachusetts Bay, Nantucket Shoals, Northwest Atlantic, Rhode Island Sound
Recommended Cartographic Properties: (Using ArcGIS ArcMap nomenclature)
Unclassified Stretched, Histogram Equalize, Condition Number color ramp Scale range for optimal visualization: 6,771 to 6,933,504

DATA PROCESSING

Processing environment: ArcGIS 10.05, Windows 7 Ultimate SP5, Intel Xeon CPU

	Process Steps Description
1	Raw routes from mapping application imported into ArcMap
2	Routes from random sample selected using select by attributes query
3	Routes projected into two separate shapefiles (UTM Zones 18 & 19)
4	LINE DENSITY tool in spatial analyst applied to each shapefile using a 250 m square grid with a 675 m neighborhood
5	Resulting rasters clipped to their respective UTM Zones using the EXTRACT BY MASK tool
6	Rasters reprojected to North America Albers Equal Area Conic Projection, using PROJECT tool
7	MOSAIC tool used to merge rasters
8	Focal mean expression (4x4 neighborhood) used to approximate and fill cells with no data at the boundary between mosaicked rasters
9	Raster calculator used to calculated Z-scores ([(Ln(Value))-Mean]/Std. Deviation)
10	Raster clipped by NOAA Medium Resolution Shoreline data using EXTRACT BY POLYGON tool

QUALITY PROCESS

Attribute Accuracy: The lines used to generate the density grid were derived from a mapping tool used by boaters to reconstruct their boating routes. To ensure that boaters included their round-trip route the mapping applications would send the user an error message asking them to re-plot the route or the program would automatically return the route to the starting point. This application also restricted the scale at which users could draw their routes, reducing the amount of error that could occur from plotting routes at too small a scale. Clipping this layer with a regional ocean shapefile derived from the NOAA medium resolution shoreline dataset excluded route density resulting from routes drawn over land, in freshwater, or outside of northeastern waters.

Logical Consistency: None

Completeness: Only reported routes from the random sample were included. Routes from the supplemental sample were excluded from this analysis. Route density occurring over land, freshwater areas, or outside northeastern waters was excluded by the final geoprocessing step.

Positional Accuracy: The positional accuracy of the routes is dependent on the individual reporting routes through the mapping tool.

Timeliness: This dataset represents data collected from May through October of 2012.

Use restrictions: SeaPlan created this dataset with data provided by its own proprietary research. This data set must be cited on all electronic and hard copy products using the language of the Data Set Credit. SeaPlan shall not be held liable for improper or incorrect use of the data described and/or contained herein. Any sale, distribution, loan, or offering for use of these digital data, in whole or in part, is prohibited without the approval of SeaPlan. The use of these data to produce other GIS products and services with the intent to sell for a profit is prohibited without the written consent of SeaPlan. SeaPlan shall be acknowledged as data contributors to any reports or other products derived from this data set.

This data set is not intended for Navigation purposes.

Distribution Liability: All parties receiving these data must be informed of these restrictions.

APPENDIX II

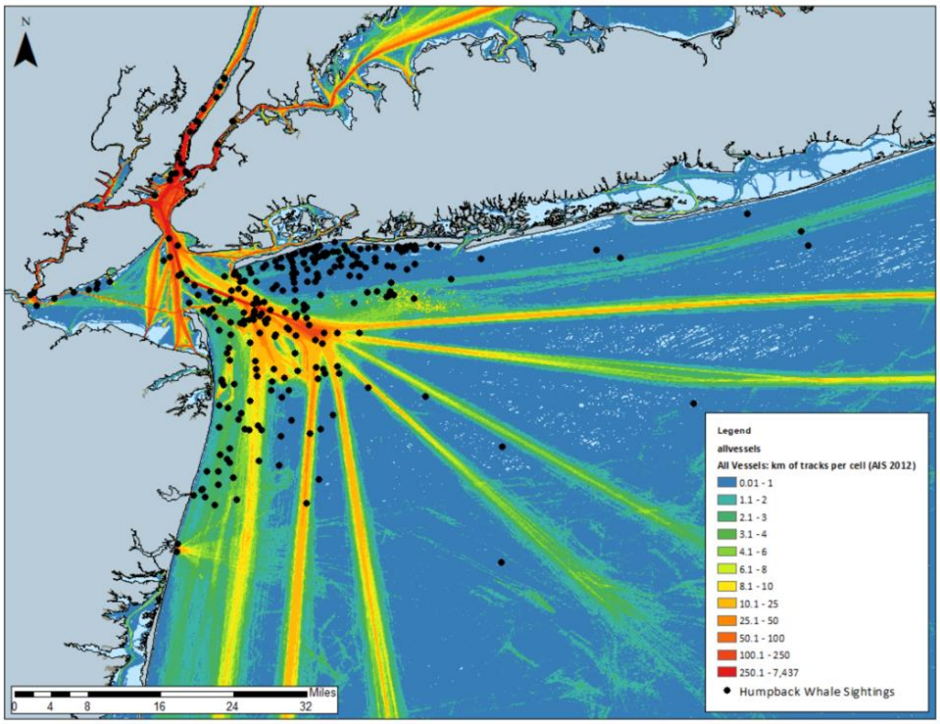


Figure 8: The distribution of humpback whale sightings compared to the density of All vessels.

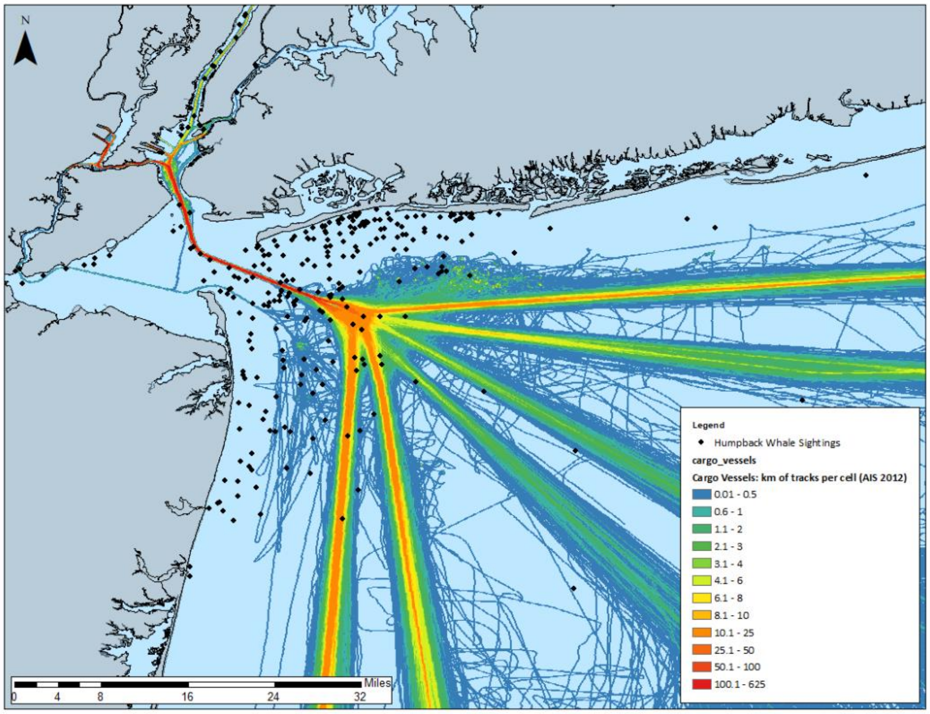


Figure 9: The distribution of humpback whale sightings compared to the density of Cargo vessels.

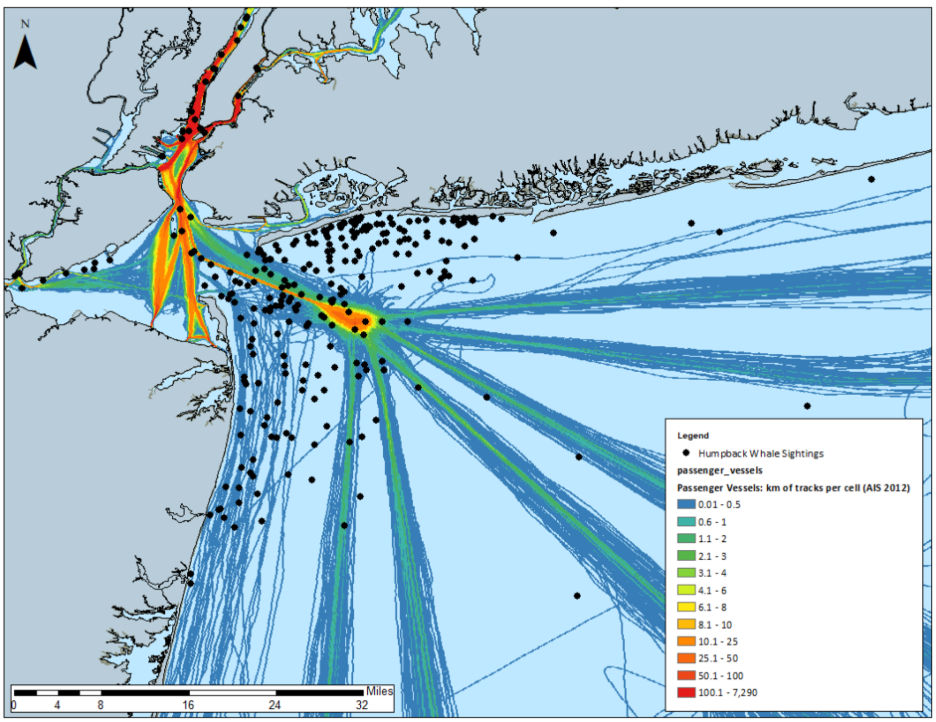


Figure 10: The distribution of humpback whale sightings compared to the density of Passenger vessels.

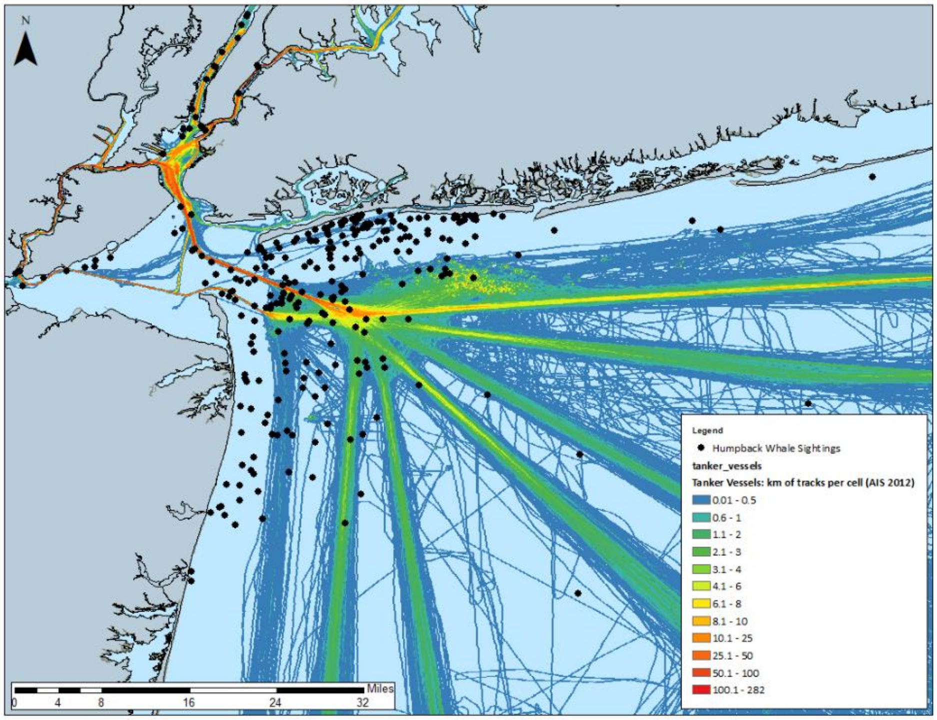


Figure 11: The distribution of humpback whale sightings compared to the density of Tanker vessels.

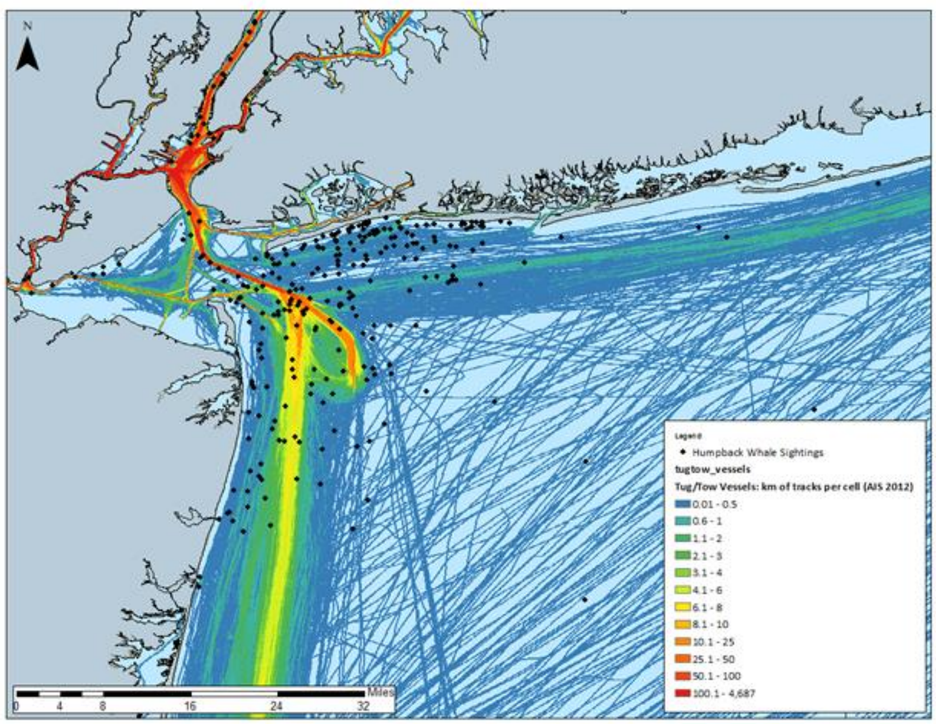


Figure 12: The distribution of humpback whale sightings compared to the density of Tug/tow vessels.

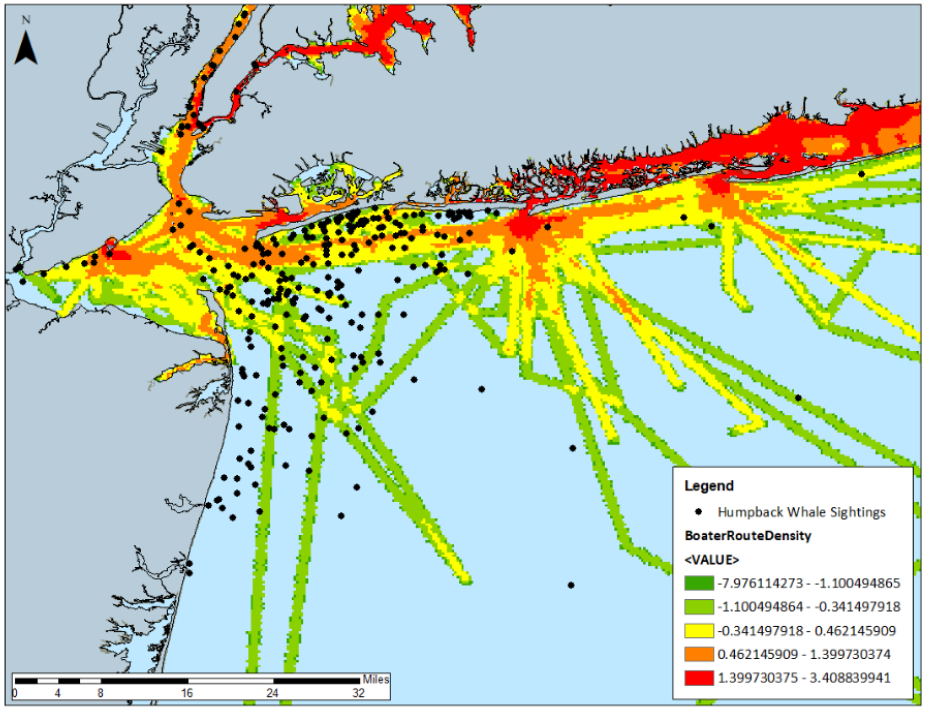
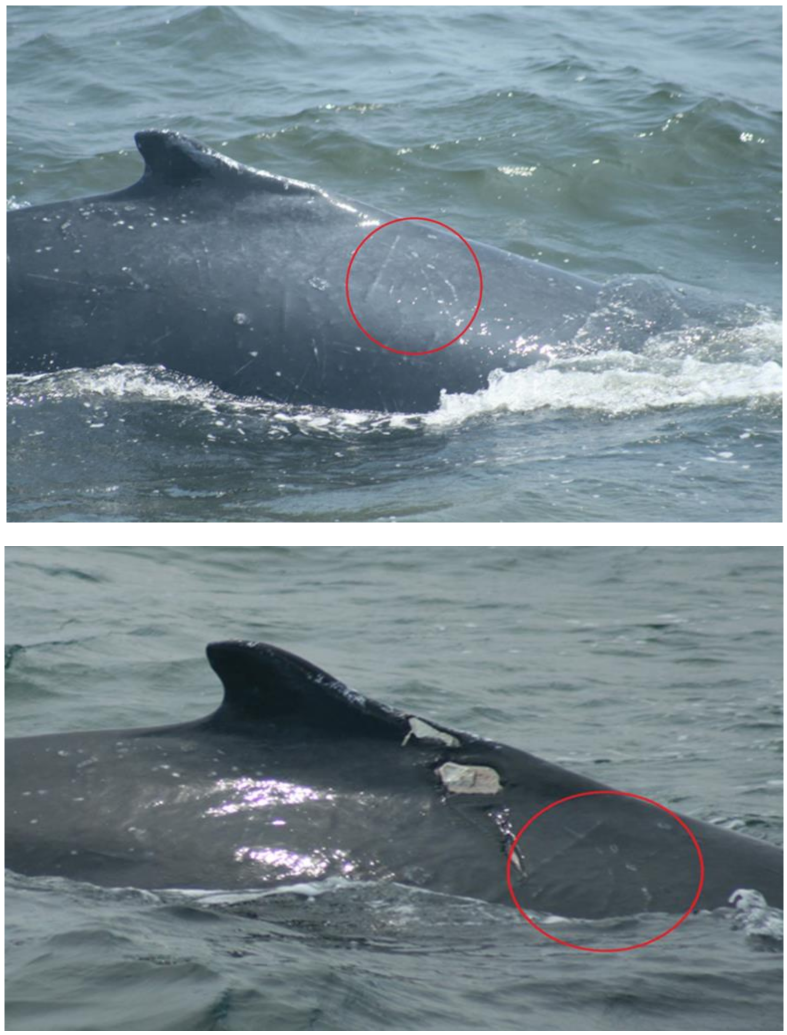


Figure 13: The distribution of humpback whale sightings compared to the density of recreational vessels.

APPENDIX III

A humpback whale surfaces in close proximity to a tug/tow vessel in the Northwestern New York Bight.

APPENDIX IV



Photos of NYC0037 before and after a suspected vessel injury. The top photo was taken in June 2016 and the bottom photo was taken in July 2016. The circled area highlights the scarring pattern used to identify the individual.

APPENDIX V

A humpback whale lunge feeding in close proximity to a recreational fisherman in the Northwestern New York Bight. This is the typical feeding behavior observed in this location.

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