Wandering Whale Watches:

The Effectiveness of Whale Watches as a Platform of Opportunity for Data Collection

by
Stacie Koslovsky
Dr. Patrick Halpin, Advisor
Dr. Andrew Read, Advisor
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Abstract

Most data used to assess the distribution and abundance of whales are derived from scientific surveys that are designed carefully to minimize sources of variation and reduce the potential for bias. Gathering data in this fashion tends to be both time consuming and costly. Similar data, however, can be collected from platforms of opportunity, including commercial vessels, ecotourism operations and whale watch vessels. The goal of the current project was to make recommendations for data collection procedures aboard whale watch vessels so that such observations are as comparable as possible to data collected from scientific surveys. To accomplish this goal, a sightings data set was obtained from three whale watch companies on Stellwagen Bank, Massachusetts during summer 2007. Vessel and sightings data were obtained via GPS for the duration of whale watches out of Gloucester and Boston, Massachusetts. Whale sightings data were combined with vessel trackline data to calculate species-specific sightings-per-unit-effort (SPUE). These SPUE values were then compared to similar data derived from scientific surveys conducted in the same area. Additionally, sightings data from whale watches from 1994-2006 were analyzed for long-term trends in abundance and distribution. Whale watch vessels offer a large, valuable and largely untapped source of data on the distribution and abundance of whales. Whale watch data collected in a standardized fashion could contribute significantly to scientific and conservation efforts.

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Introduction

Scientific surveys are a common tool used to assess the distribution and abundance of marine mammals. This technique aims to minimize bias by creating strict protocols for data collection. While these biases are important to control for, surveys are a time-consuming and expensive method for gathering information.

Platforms of opportunity are an alternative resource for collecting similar data, including commercial shipping vessels (Williams et al., 2006; Williams, 2003), ferries (Kiszka et al., 2007), cruise ships (Compton et al., 2007) and whale watches (Hauser et al., 2006). Data from these opportunistic platforms are widely used for scientific studies looking at the abundance, encounter rate and/or distribution (Ingram et al., 2007; Macleod et al., 2004; Weinrich et al., 1997) of whales or other marine mammals. Such platforms are often available for research, although under certain constraints, and can provide continuous coverage of research areas.

While there is great value in this approach, there are limitations in the use of whale watch data due to fundamental differences in the data collection techniques when compared to structured scientific surveys. Rather than following tracklines, the vessels randomly search for whales, often returning to areas where whales are known to be or where whales are reported by other whale watching vessels. Whale watches adhere to a set schedule, limiting when research activities can take place. Research can be compromised at times when naturalists/observers are interacting with the public (Clapham, 1988; Douglas, 1988). Despite these drawbacks, whale watch vessels are a feasible alternative for gathering data on the abundance and distribution of marine mammals.

Whale watching provides benefits to marine mammal conservation for a number of reasons. The public learns about marine mammals in their natural environment. Additionally, such activities can raise the environmental consciousness of the public (Corkeron, 2006; Corkeron, 2004; Clapham, 1988; Douglas, 1988). Research groups gain from the data they are able to collect and from donations they receive from the public. Injured or entangled whales are also more likely to be sighted and responded to (Douglas, 1988).

Whale watching also has important economic benefits for the tourist industry and research groups who use these vessels as a platform of opportunity. World-wide, whale watching is a billion dollar industry, attracting more than 9 million participants in 87 countries and territories. In 2001, this industry drew 1.23 million people to New England, where they spent more than $30.6 million to go whale watching (Hoyt, 2001). This is a substantial tourist industry for the region and provides important support for research and conservation organizations. As long as people are traveling to New England, specifically to go whale watching, this platform will exist for researchers to collect data. The value of using a whale watch as a research platform was found to be $1,000 per day (Hoyt, 1994). Throughout the whale watching season, this is a value of nearly $125,000 for research institutions that rely heavily on whale watch vessels for collecting data. Without whale watching as a platform of opportunity, research efforts on Stellwagen Bank would be significantly curtailed. Data collected from whale watches are one of the largest sources of information regarding marine mammal behavior and distribution on Stellwagen Bank. These benefits are important to consider in places where whale watching is already established and those where whale watching efforts are being developed.

Unfortunately, some long-term behavioral changes in marine mammals have been documented in response to whale watch vessels. Over time, minke whales (*Balaenoptera acutorostrata*) have become less likely to approach a whale watch vessel, while humpback whales (*Megaptera novaeangliae*) have become more likely to interact with a whale watch vessel (Tyack, 1988). Other studies identify significant behavioral responses observed when whales are in the presence of whale watch vessels (Bejder et al., 2005; Corkeron, 1995). Researchers must be aware of how these changes can impact the sightings information collected on whale watch vessels.

The biases associated with collecting data on whale watch vessels limit their use in scientific analyses. While the movements of the whale watch vessel cannot be controlled, it is possible to prescribe how the data is collected and processed. Understanding the biases allows them to be addressed in analysis, as is done routinely for scientific surveys.

The goal of this project is to examine whale watch data collected in Stellwagen Bank National Marine Sanctuary and to evaluate the potential of these data for scientific analysis. Identifying the biases associated with these data sets will help to develop recommendations on how data is collected to minimize bias and make the data more useful for scientific and conservation efforts.

Study area

New England whale watching is characterized by two different forms of commercial whale watching. Smaller whale watching companies, including those that depart from Gloucester, MA, operate 65-100 foot long vessels traveling at 16-20 knots, carrying 100-150 people. Their trips typically last 4-5 hours (Beach & Weinrich, 1989); these companies strive to get the best trip for their passengers because repeat business and customer satisfaction are extremely important for the sustainability of their business. In contrast, Boston whale watch companies use fast-speed catamarans, up to 120 feet in length and capable of taking up to 399 passengers. Their trips are usually limited to 3-3.5 hours, often traveling only to the closest whales to Boston harbor because of the strict schedule they maintain.

Most whale watch companies employ an on-board naturalist to educate passengers about whales and marine ecology. Many of these naturalists are additionally responsible for data collection throughout the trip. The typical data collected on a whale watch are the time and location of whale sightings, individual identification and behavior sequence. Whale watches operate from April through October due to the seasonality of whales in New England. Up to two whale watches per boat are conducted per day (Beach & Weinrich, 1989).

Whale watches departing from Boston and Gloucester typically travel to and watch whales in the Stellwagen Bank National Marine Sanctuary (SBNMS) (Figure 1). This area was officially designated as a National Marine Sanctuary in June 1993 (Eldridge, 1993). The SBNMS today reflects what the citizens of Massachusetts wanted to protect: a unique marine habitat with a variety of plentiful marine life. Under National Marine Sanctuary status, Stellwagen Bank is protected from sand and gravel mining, ocean discharge, alteration of the seabed, take of marine mammals, sea turtles and seabirds, installation of pipelines or cables and transfer of fuel at sea (Eldridge, 1993).

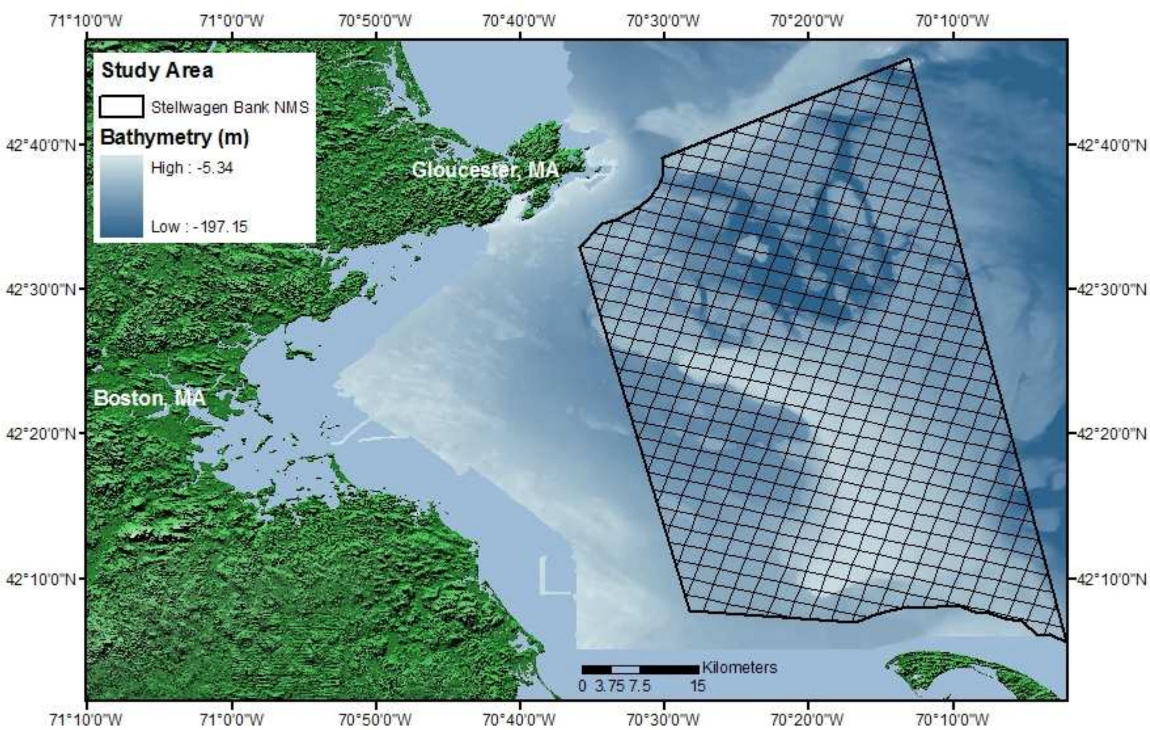


Figure 1. Stellwagen Bank National Marine Sanctuary study area showing the 2 x 2 km grid cells used for long-term trend study.

Stellwagen Bank is an underwater plateau located between Cape Ann and Cape Cod, MA (Figure 1). It stretches 21 miles long and between 2 and 7 miles wide. The average water depth on Stellwagen Bank is 100 feet, with some areas as shallow as 60 feet. Average water depth on either side of the Bank can reach 300 feet or more (Ward, 1995). Upwelling occurs regularly around Stellwagen Bank due to the sharp rise in depth along the edges of the plateau. As oceanic currents encounter the base of the plateau, nutrient-rich waters are forced to the surface. The mixing of these nutrients with sunlight and dissolved oxygen at the surface creates an extremely productive environment.

The high primary and secondary productivity witnessed in these waters supports a wide variety of marine life, including sand lance (*Ammodytes americanus*). These fish are the primary prey item of large whales found on Stellwagen Bank (Payne et al., 1986). In years when sand lance are abundant on the Bank, many whales will be found in the area; the opposite is true when sand lance levels are low (Weinrich et al., 1997; Payne et al., 1990).

The cetacean species most commonly sighted within SBNMS are humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), minke whales (*Balaenoptera acutorostrata)* and Atlantic white-sided dolphins (*Lagenorhynchus acutus*) (NOAA NCCOS, 2006). These species occur here due the reliability of prey resources, and most of their behavior on Stellwagen Bank is geared towards feeding. These species are found on Stellwagen Bank seasonally. The fin, humpback and minke whales are most commonly sighted during the summer when prey resources are at their peak. Atlantic white-sided dolphins are a cold water species most commonly sighted in the spring and fall (Selzer & Payne, 1988).

Regulation of interactions with marine mammals in SBNMS is managed in part by the guidelines developed by NOAA’s National Marine Fisheries Service. These guidelines apply to commercial whale watch vessels, recreational boaters and the commercial shipping industry. A "whale awareness zone" is established a quarter-mile around any individual whale. Within this range, boats are to avoid excessive speed or drastic course changes. The "standby zone" begins 600 feet away from the whale. Only three vessels are allowed within this area. Idle speeds or "no wake" speeds should be used, and the vessel must move in parallel speed and direction of the whale. The "close approach zone" is established within 300 feet of a whale. Only one boat is allowed in this zone at a time; other vessels should standby, maintaining a distance of at least 300 feet from whale as long as the other vessel is within the close approach zone. The boat that is closely approaching the whale should limit its time in this area to 15 minutes. There is no intentional approaching of whales within 100 feet. If a whale approaches within this distance, the engine should be placed in neutral until the whale has been observed at the surface, far enough away that the engine can be re-engaged safely (NOAA Fisheries, 2008). These guidelines are only capable of protecting whales from short-term harassment and behavioral modifications (Beach & Weinrich, 1989). As whale watch vessels are required to follow these guidelines, there are potential impacts on the sightings data collected from this platform.

Methods

Whale watch sightings data were collected during summer 2007 from three whale watch companies based out of Boston and Gloucester, Massachusetts. Data were collected on every whale watch I was employed on as a naturalist from 10 July – 20 August 2007. This totaled to 32 whale watches, 15 of which departed from Boston, 17 from Gloucester. Search effort began as soon as the whale watch vessel left their respective harbor.

During the whale watch, a GPS unit recorded the location of the vessel every 15 seconds from the time it left the harbor until the last whale was left to head back to the dock. Sighting locations and times were recorded for humpback whales, fin whales, minke whales and Atlantic white-sided dolphins, in addition to changes in effort. Two different types of effort were differentiated during the whale watch: search effort and whale effort. Search effort occurred when the vessel was underway, actively searching for whales. This value includes the traverse from the harbor to the first whale. It also includes the time spent traveling between groups of whales if the first group was left and searching began again. Whale effort occurred when the whale watch vessel was watching a whale or a group of whales. This effort ended either when the trip was over or searching began for another whale.

Sightings-Per-Unit-Effort (SPUE)

To understand the biases associated with data collected from whale watch vessels, sightings-per-unit-effort (SPUE) values were calculated. SPUE values normalize sightings data by calculating a ratio of the number of whales seen to the distance or time spent searching. Applying SPUE to whale watch data and developing a strict protocol for the usage of data allowed SPUE values from summer 2007 to be compared with SPUE values from a recent ecological characterization of SBNMS (NOAA NCCOS, 2006). This comparison will identify any differences that may exist between the two survey techniques and help identify ways to reduce bias from the data collected on whale watch vessels.

Data were included in the SPUE analysis if they met the following conditions:

(1) Visibility greater than 1 nm,
(2) Beaufort sea state less than 5,
(3) Data collected from the first whale watch of the day (if there were multiple whale watches on the same whale watch vessel on the same day).

The first two criteria were selected to be consistent with the SBNMS study (NOAA NCCOS, 2006). The third criterion used was the same as one from another WCNE study to be consistent in the methodology (Sardi et al., 2005). After these conditions were applied, data from 17 whale watches were used for analysis.

The effort data were analyzed to obtain the distance traveled in kilometers for each whale watch. Each whale watch was divided into two different categories (search effort and whale effort) and the distances were calculated for each segment within the whale watch. Trip effort reflects search effort for the entire trip.

SPUE was calculated using two simple formulas:

For distance as the unit effort
Original SPUE = [(# of Groups of Whales) / (Distance Traveled in km)] * 1000
For SPUE of individual whales
Effort SPUE = (Original SPUE) * (Average Group Size)

The unit for effort in this study was 1000 km, chosen to produce SPUE values directly comparable to those produces in the SBNMS study (NOAA NCCOS, 2006).

SPUE values were calculated for each species and used for three different questions. The first question aimed to understand how duplicate sightings of whales impact SPUE. Scientific studies are structured to minimize the potential of re-sighting individual whales during a survey. Duplicate sightings are common on a whale watch, as the same individual whales may be sighted multiple times during the same trip. For the purpose of this study, duplicate sightings were defined as a group of whales that was returned to later in the trip (with other whales or searching in between) or an association change when a previously unsighted individual joined an already recorded group. Duplicate sightings were verified through photo-identification of individual humpback and fin whales; it was assumed that there were no duplicate sightings of minke whales or Atlantic white-sided dolphins, unless the group was knowingly returned to later in the trip. Comparing the SPUE values derived with and without duplicates allowed me to assess whether duplicate sightings have an impact on the estimation of whales in a particular area. In this case, I expected that the SPUE values would be significantly higher when duplicate sightings were included.

Second, I compared the SPUE values for whale watches departing out of Boston and Gloucester harbors to determine how the location of departure influences the number of whales sighted. It was expected that Gloucester SPUE values for search effort would be significantly higher than Boston because the whale watch vessels travel at a slower speed and the whale watch captains strive to sight as many whales as possible during the trip, whereas the Boston whale watches are often confined by strict time constraints.

The final analysis tested one of the criterion used for the selection of whale watch to be included in the SPUE analysis. Sardi et al. (2005) assumed there was within-day dependence when there were multiple trips on the same whale watch vessel on the same day. Because whale watch data were collected from both the morning and the afternoon on whale watches out of Gloucester, I was able to test this assumption. If within-day dependence exists, search time would be expected to be greater in the morning and whale time and whale sightings to be greater in the afternoon.

Once SPUE values were calculated, Wilcoxon nonparametric tests were used to test for significant differences in the comparisons described above. Search effort values were expected to differ more than values for whale effort because once a vessel has stopped to watch a group of whales, there should be an equal chance of sighting another whale or group of whales. Nonparametric tests were employed because the data were not normally distributed. Although SPUE values were calculated for Atlantic white-sided dolphins, they were excluded from statistical analysis because of a small sample size.

Additionally, all search effort SPUE values were compared to values derived by SBNMS scientists (NOAA NCCOS, 2006). This study was used to develop an ecological characterization of the Stellwagen Bank National Marine Sanctuary region. Data from the North Atlantic Right Whale Consortium, Manomet Bird Observatory and NOAA's Northeast Fisheries Science Center were used to generate SPUE values for winter, spring, summer and fall. The whale watch SPUE values were compared to the summer values generated for Stellwagen Bank (Table 1). The search effort SPUE values were expected to be similar to those in the SBNMS study.

Table 1. SPUE values for humpback whales, fin whales, minke whales and Atlantic white-sided dolphins during the summer within Stellwagen Bank National Marine Sanctuary (NOAA NCCOS, 2006).

SBNMS Ecological Assessment	SPUE Value
Humpback whale	189
Fin whale	136.6
Minke whale	43.5
Atl. white-sided dolphin	1246.9

Long-term Trends

Whale sightings data from 1994 to 2006 were provided by the Whale Center of New England (WCNE) for analysis of long term trends in distribution and abundance. WCNE is a non-profit organization that specializes in the research and conservation of marine mammals. Since 1979, WCNE has used whale watch vessels as a platform of opportunity to collect data on the whales in the coastal waters of Massachusetts throughout the spring, summer and fall. The whales considered in this part of the present study are humpback whales, fin whales, minke whales and Atlantic white-sided dolphins because of their consistent sightings in WCNE data.

Data extracted from the WCNE database were gathered between July 10 and August 20 between 1994 and 2006. This six-week period is the same as that for which data for the SPUE analysis were collected. Sighting conditions were not considered, however, because over a six-week time period with up to 14 whale watches per day, weather was expected to have little impact on overall trends in abundance.

Random trips were selected for each day between July 10 and August 20. The raw data were sorted by date, and a random number generator was employed to a random trip from each day. Some days, there was only one whale watch, while others there could be as many as 14 trips. The potential problem with using all of the data collected every day is that many of the sightings were likely of the same animal(s). As whale watch vessels communicate with one another and often travel to the same locations to watch whales, the likelihood of many of the whale sightings being duplicative of one another was high. Selecting random trips from each day over the six-week period provided a representative sample of the location of whales.

The data from randomly selected whale watches were then aggregated into 2x2 kilometer grids within SBNMS (shown in Figure 1) by species: humpback whale, fin whale, minke whale and Atlantic white-sided dolphin. The lowest estimate of group size, as opposed to the highest estimate of group size, was used and the number of whales sighted within each cell was summed. (NOTE: a detailed description of all GIS analysis for SPUE and long-term trends can be found in the Appendix)

Results

Sightings-Per-Unit-Effort (SPUE)

The analysis revealed important differences between search effort and whale effort. Of 534 whale sightings, 212 (40%) were seen after another whale had been sighted (Table 2b). This trend was primarily the result of observations of humpback whales. Twice as many humpback whales were sighted once a whale watch vessel was watching whales than when searching. In contrast, more fin whales were sighted when whale watch vessels were searching for whales than when watching whales, as was also the case for Atlantic white-sided dolphins. Minke whales sightings were approximately the same when searching for and watching whales. Humpback whales were the most commonly sighted whale. Atlantic white-sided dolphins were the most numerous species, but their numbers reflect a small number of relatively large groups, rather than the much smaller groups of humpback whales, fin whales and minke whales. Table 2a and 2b highlight how the larger group size for Atlantic white-sided dolphins skews interpretation of how frequently they are sighted compared to the other species. Figure 2 displays the distribution of the 2007 sightings on Stellwagen Bank. Sightings were concentrated along the northern and western edges of Stellwagen Bank. Most

Table 2a. The number of marine mammal groups sighted from 17 whale watches conducted on Stellwagen Bank from July 10, 2007 – August 20, 2007.

Totals for the Season (17 trips)	Trip Effort	Search Effort	Whale Effort
# of Whales	229	95	134
# of Humpback Whales	150	53	97
# of Fin Whales	20	14	6
# of Minke Whales	56	27	29
# of Atl. White-sided Dolphins	3	1	2

Table 2b. The number of marine mammals sighted from 17 whale watches conducted on Stellwagen Bank from July 10, 2007 – August 20, 2007.

Totals for the Season (17 trips)	Trip Effort	Search Effort	Whale Effort
# of Whales	534	322	212
# of Humpback Whales	230	80	150
# of Fin Whales	21	14	7
# of Minke Whales	60	28	32
# of Atl. White-sided Dolphins	223	200	23

sightings occurred within the boundaries of SBNMS with only a minke whale, a fin whale and several humpback whales sighted outside the sanctuary.

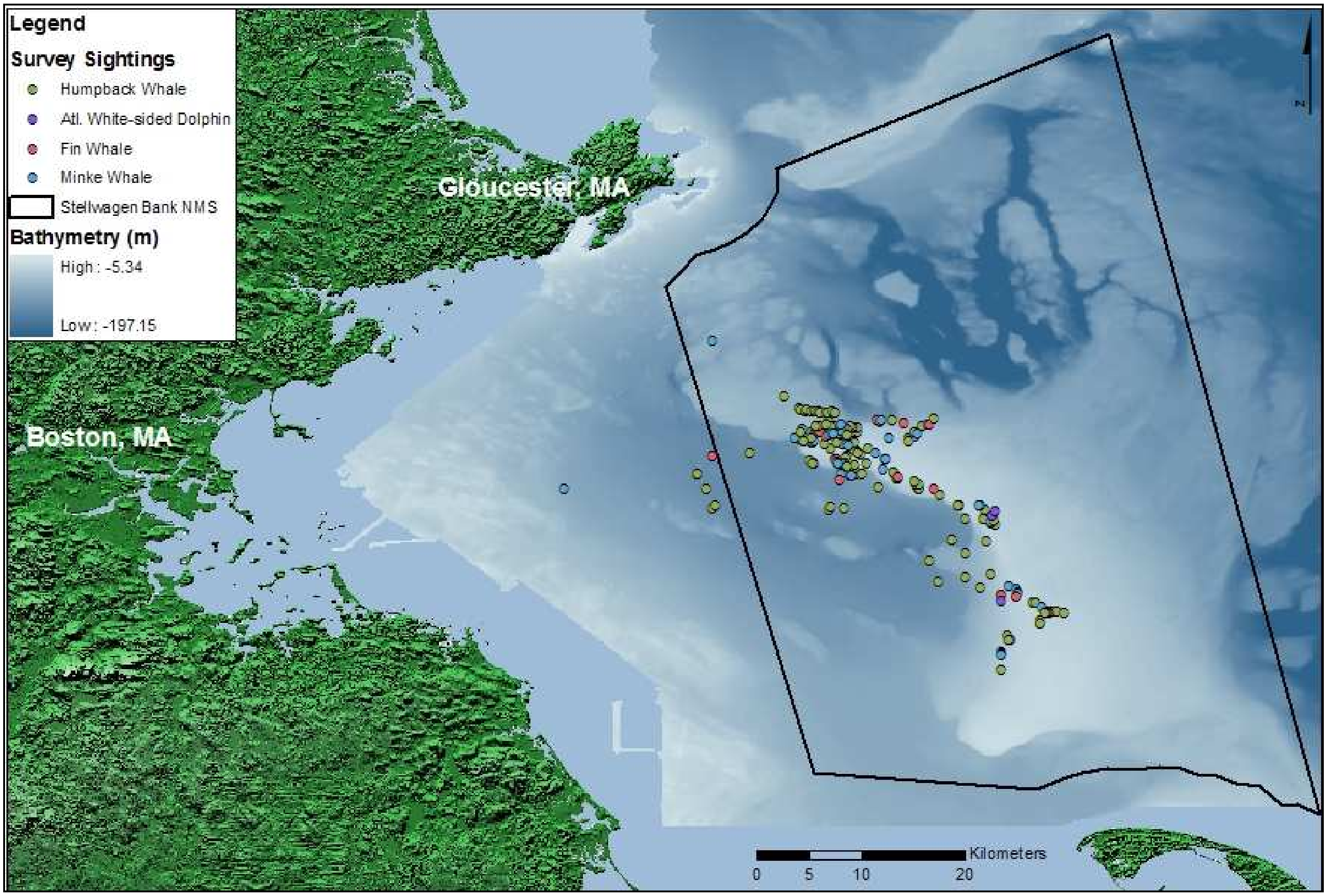


Figure 2. Whale sightings from 17 whale watches conducted on Stellwagen Bank from July 10, 2007 – August 20, 2007. These represent sightings from whale watches leaving from both Boston and Gloucester, MA.

The average time spent looking for whales and the average time spent watching whales were remarkably similar, at about an hour each. The distance traveled in these two scenarios, however, was drastically different. On average, a whale watch traveled 41 km looking for whales and only 8.5 km traveling after a whale was sighted (Table 3). The average speed while watching whales was 4.87 knots, while the average speed while searching was 20.63 knots. The trackline data from these whale watches illustrate the differences in distance covered when on search effort and whale effort (Figure 3). The black lines represent whale watch vessels in transit and searching for whales. This portion of the whale watch covered the greatest distance and a majority of the habitat surveyed. The areas covered by whale watch vessels when watching whales, represented by the orange lines, were much more concentrated. These records also highlight the areas where there was no search effort. Whale watches predominantly covered the western edge of Stellwagen Bank. No whale watches from Gloucester or Boston went to the southern or eastern portions of Stellwagen Bank during 2007.

Table 3. The average time spent and distance traveled when looking for whales or watching whales on Stellwagen Bank from July 10, 2007 – August 20, 2007.

Average Search Effort	Average Time (hr)	Average Distance (km)
Search Effort	1:04:03	40.7911
Whale Effort	1:04:40	8.4413
Trip Effort	2:08:43	49.2325

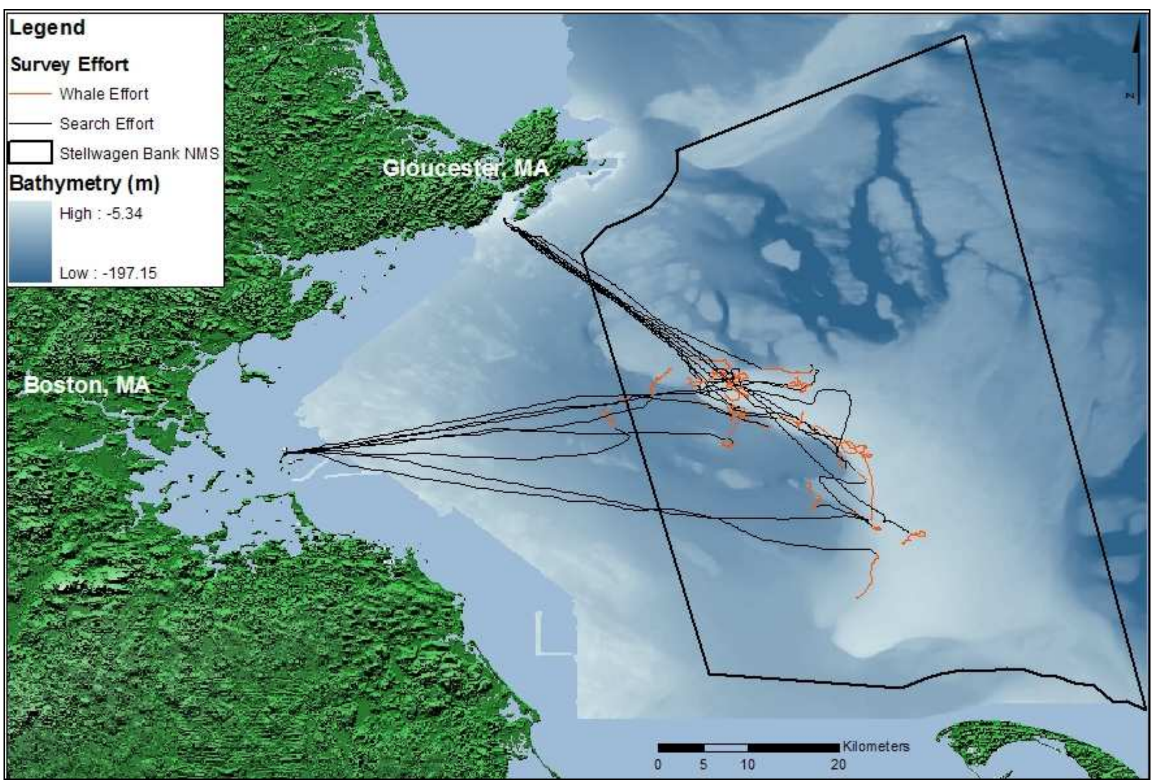


Figure 3. The paths of whale watch vessels after they have left Gloucester or Boston harbor in pursuit of whales on Stellwagen Bank from July 10, 2007 – August 20, 2007.

Once the sightings were combined with the trackline data, SPUE values were calculated for each species (Table 4). There was no significant difference in humpback whale SPUE when duplicates were included ($p<0.9243$). There were no duplicate sightings of fin whales, minke whales or Atlantic white-sided dolphins. As no significant difference was found for humpback whales, further analysis of the SPUE values included duplicate sightings. Search effort SPUE most closely reflected the SPUE values calculated in the SBNMS study. Whale effort SPUE and trip effort SPUE overestimated encounter rates of whales. Compared to the SBNMS study, during search effort, humpback whale and fin whale encounter rates were underestimated. Minke whale encounter rates were similar to the values estimated in the SBNMS study.

Table 4. The SPUE (for number of whales). The SPUE calculations are the average values for search effort, whale effort and effort for the whale watches conducted from July 10, 2007 – August 20, 2007 on Stellwagen Bank. The unit effort is per 1000 km.

SPUE and Group Size Summary Data	SBNMS SPUE	Search Effort SPUE	# of trips	Whale Effort SPUE	# of trips	Trip Effort SPUE	# of trips
INCLUDING DUPLICATES							
Humpback Whales	189	119.33	16	1194.77	15	309.95	17
Fin Whales	136.6	18.75	8	51.51	4	24.61	9
Minke Whales	43.5	39.57	9	278.64	11	73.63	13
Atl. White-sided Dolphins	1246.9	181.69	1	88.05	1	177.04	2
EXCLUDING DUPLICATES							
Humpback Whales	189	117.98	16	982.73	15	264.84	17
Fin Whales	136.6	18.75	8	51.51	4	24.61	9
Minke Whales	43.5	39.57	9	278.64	11	73.63	13
Atl. White-sided Dolphins	1246.9	181.69	1	88.05	1	177.04	2

The next stage of analysis grouped the 17 whale watches by their departure harbor to identify biases associated with vessels leaving from Boston or Gloucester. The areas covered by the whale watch vessels out of Gloucester and Boston were notably different (Figure 4). During this study, whale watches departing from Gloucester nearly always followed the same path when heading towards Stellwagen Bank when searching for whales. As the whale watches approached Stellwagen Bank, their paths spread out a bit more. Whale watches departing from Boston, however, had more flexibility in their approach to Stellwagen Bank. Different courses were taken on most of the trips. Once the whale watches made it to Stellwagen Bank, though, their movements were quite different. Whale watches leaving from Gloucester covered a greater portion of Stellwagen Bank as they moved around looking for whales, alternating between search and whale effort. Whale watches out of Gloucester saturated the northwestern portion of Stellwagen Bank with both true and whale effort. Boston whale watches, on the other hand, typically stayed on whale effort once the first group was sighted and little searching took place during the remainder of the trip. The whale watches out of Boston covered less of Stellwagen Bank. All of their movements were concentrated along the western edge of the bank.

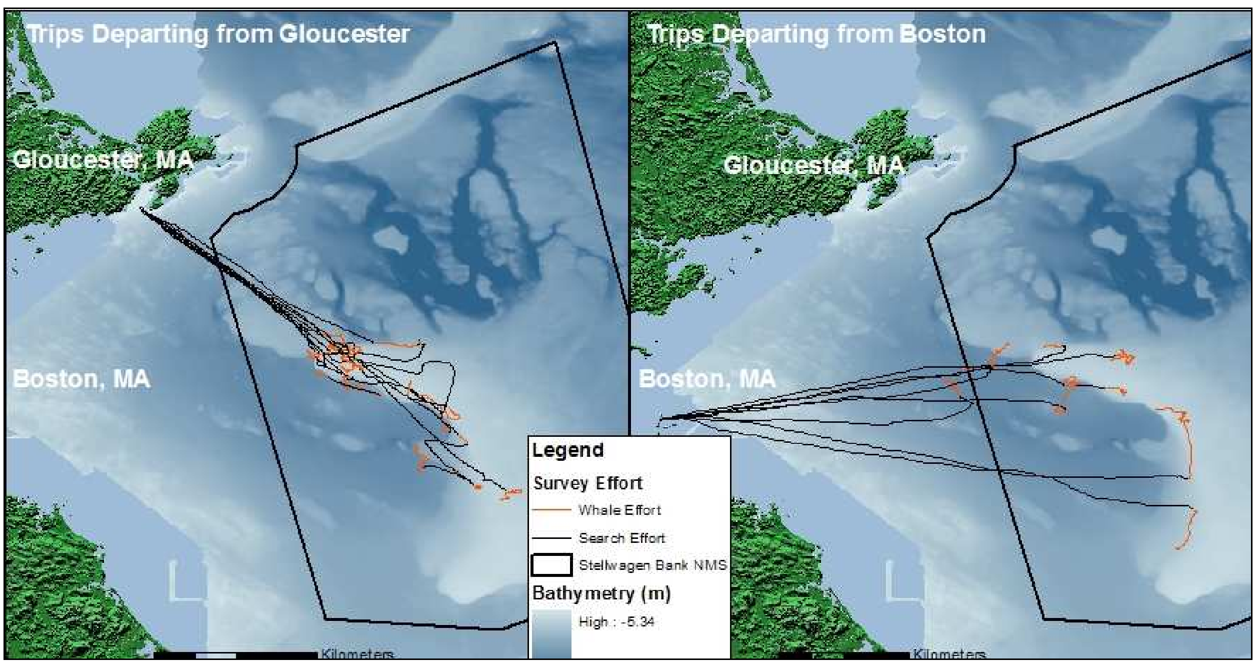


Figure 4. A comparison of the path of whale watches departing from Boston and Gloucester, MA between July 10, 2007 and August 20, 2007.

Whale watches departing from Boston spent 46% of the trip searching for whales and 54% of the trip watching whales (Table 5). Their average speed while searching was 27.42 knots and while watching whales was 4.43 knots. Whale watches leaving from Gloucester spent 52% of their whale watch searching for whales and the remaining 48% watching whales. Although whale watches leaving from Gloucester spent smaller portion of their trip watching whales, the actual time spent watching whales was higher on Gloucester whale watches. The average searching speed for Gloucester was 16.91 knots and the average speed while watching whales was 4.09 knots. Boston and Gloucester covered approximately the same distance throughout the trip, both for search effort and whale effort.

Table 5. Average sightings for the season from Boston and Gloucester trips.

Averages for the Season	**Trip Effort**		**Search Effort**		**Whale Effort**	
	Boston	Gloucester	Boston	Gloucester	Boston	Gloucester
Time (hr)	1:44:42	2:30:04	0:48:19	1:18:02	0:56:23	1:12:02
Distance (km)	48.5913	49.8024	40.8805	40.7117	7.7109	9.0907
# of Whales	15.8750	45.2222	4.3750	32.1111	11.7500	13.1111
# of Humpbacks	9.3750	17.2222	2.6250	6.5556	6.7500	10.6667
# of Fin Whales	0.7500	1.6667	0.7500	0.8889	0.0000	0.7778
# of Minke Whales	2.8750	4.1111	0.7500	2.4444	2.1250	1.6667
# of Atl. White-sided Dolphins	2.8750	22.2222	0.0000	22.2222	2.8750	0.0000

Gloucester whale watches sighted approximately 45 whales per trip compared to 16 for Boston whale watches (Table 5). The average for Gloucester was skewed due to one sighting of 200 Atlantic white-sided dolphins. If that sighting was removed, the average for Gloucester whale watches was reduced to 23 whales. There was no significant difference between Gloucester and Boston

Table 6. The search effort SPUE calculations for whale watches out of Gloucester and Boston, MA for the whale watches conducted from July 10, 2007 – August 20, 2007 on Stellwagen Bank. The unit effort is per 1000 km.

SPUE and Group Size Summary Data	**SBNMS SPUE**	**Search Effort SPUE**	**# of trips**
BOSTON			
Humpback Whales	189	42.67	7
Fin Whales	136.6	17.33	3
Minke Whales	43.5	19.16	3
Atl. White-sided Dolphins	1246.9	0.00	0
GLOUCESTER			
Humpback Whales	189	111.89	9
Fin Whales	136.6	20.01	5
Minke Whales	43.5	55.14	6
Atl. White-sided Dolphins	1246.9	1.72	1

sightings during search effort for humpback whales ($p<0.0987$), fin whales ($p<0.1640$) or minke whales ($p<0.4652$). The whale effort average sightings were similar, as was expected (Table 5).

The SPUE values for Boston and Gloucester emphasize the differences in sightings between the whale watches that depart from each harbor (Table 6). Whale watches departing from Gloucester had a significantly higher SPUE value for humpback whales ($p<0.0433$). There was no significant difference between the SPUE values calculated for fin whales ($p<0.7546$) and minke whales ($p<0.1407$). SPUE values from Gloucester whale watches were more similar to the SBNMS data for humpback whale and minke whale abundance, while fin whales were under-represented. The data collected from Boston whale watches significantly underestimated the encounter rates of humpback whales, fin whales and minke whales.

Finally, the sightings data were compared for 7 days when data were gathered on morning and afternoon whale watches out of Gloucester (Figure 5). Morning trips moved around on the northwestern portion of Stellwagen Bank while looking for whales. The whale watches in the afternoon spent less time looking for and watching whales. In the afternoon, whale watches traveled directly to where whales were seen in the morning and covered significantly less area.

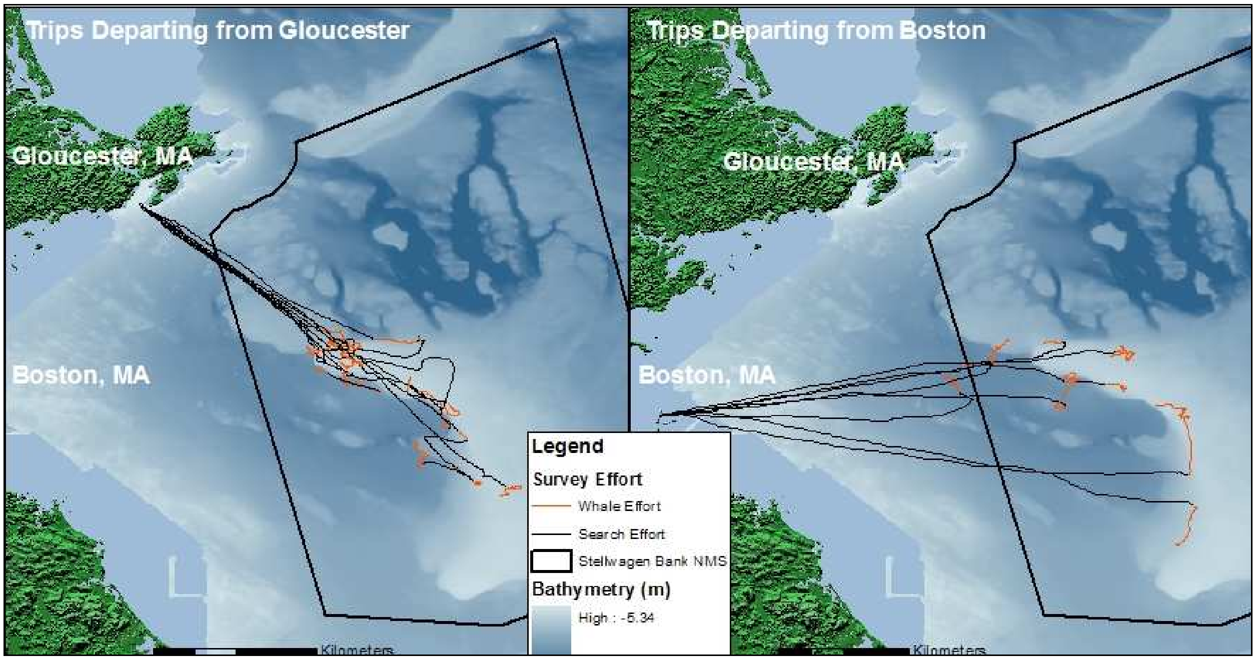


Figure 5. A comparison of the morning and afternoon whale watches out of Gloucester, MA between July 10, 2007 and August 20, 2007.

The sightings data reflected a similar trend in the amount of time and distance covered when searching for and watching whales. The morning trips spent about 20 minutes more looking for whales and 20 minutes less watching whales than the afternoon trips. Overall, the same number of humpback whales were sighted in the morning and the afternoon, but more humpbacks were sighted while searching in the morning ($p<0.0469$). There was no significant difference in the number of fin whales and minke whales sighted in the morning compared to the afternoon ($p<0.3125$; $p<0.4063$). These results confirm the assumption of within-day dependence of the whale watch data.

Table 7. Average sightings for morning and afternoon whale watches out of Gloucester, MA from July 10, 2007 – August 20, 2007.

Averages for the Season	**Trip Effort**		**Search Effort**		**Whale Effort**	
	AM	PM	AM	PM	AM	PM
Time (hr)	2:31:43	2:30:59	1:20:45	1:03:54	1:10:58	1:27:05
Distance (km)	51.0596	44.4942	41.8774	31.7380	9.1822	12.7562
# of Whales	53.8571	79.2857	40.0000	4.8571	13.8571	74.4286
# of Humpbacks	19.0000	19.0000	7.7143	3.4286	11.2857	15.5714
# of Fin Whales	1.5714	0.4286	0.8571	0.1429	0.5714	0.2857
# of Minke Whales	4.7143	2.4286	2.8571	1.2857	1.8571	1.1429
# of Atl. White-sided Dolphins	28.5714	57.1429	28.5714	0.0000	0.0000	57.1429

The SPUE values for the morning and the afternoon whale watches out of Gloucester depicted a significant difference in humpback whale abundance (Table 8). More humpback whales were sighted on morning whale watches during search effort than in the afternoon (p<0.0391). There was no significant difference in fin whale sightings (p<0.1563) or minke whales (p<0.1875). There was no difference in the SPUE value for whale effort between the morning and afternoon trip for any of the species.

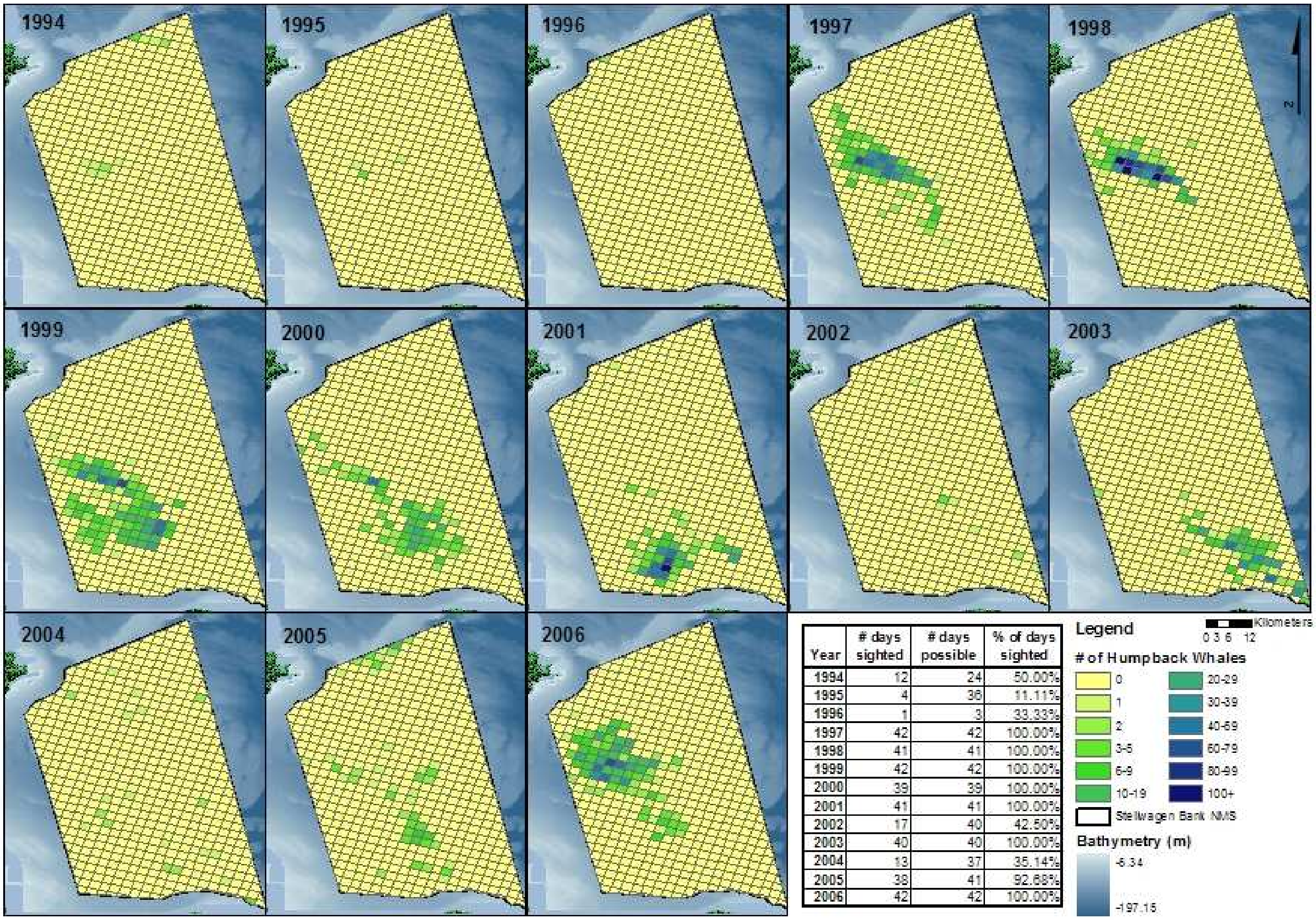
Table 8. Morning and afternoon SPUE for whale watches departing out of Gloucester, MA from July 10, 2007 – August 20, 2007.

SPUE and Group Size Summary Data	**SBNMS SPUE**	**Search Effort SPUE**	**# of trips**
AM TRIP			
Humpback Whales	189	198.41	7
Fin Whales	136.6	19.13	4
Minke Whales	43.5	67.59	5
Atl. White-sided Dolphins	1246.9	441.25	1
PM TRIP			
Humpback Whales	189	104.30	7
Fin Whales	136.6	4.97	1
Minke Whales	43.5	41.52	5
Atl. White-sided Dolphins	1246.9	0.00	0

When the morning and afternoon SPUE values were compared to the values generated from the SBNMS study, humpback whale SPUE values in the morning were similar to the SBNMS study, while those from the afternoon underestimated humpback whale abundance. Fin whales, both sightings in the morning and afternoon, were under-represented. Both the morning and the afternoon whale watches represented minke whales comparably to the SBNMS study.

Long-term Trends

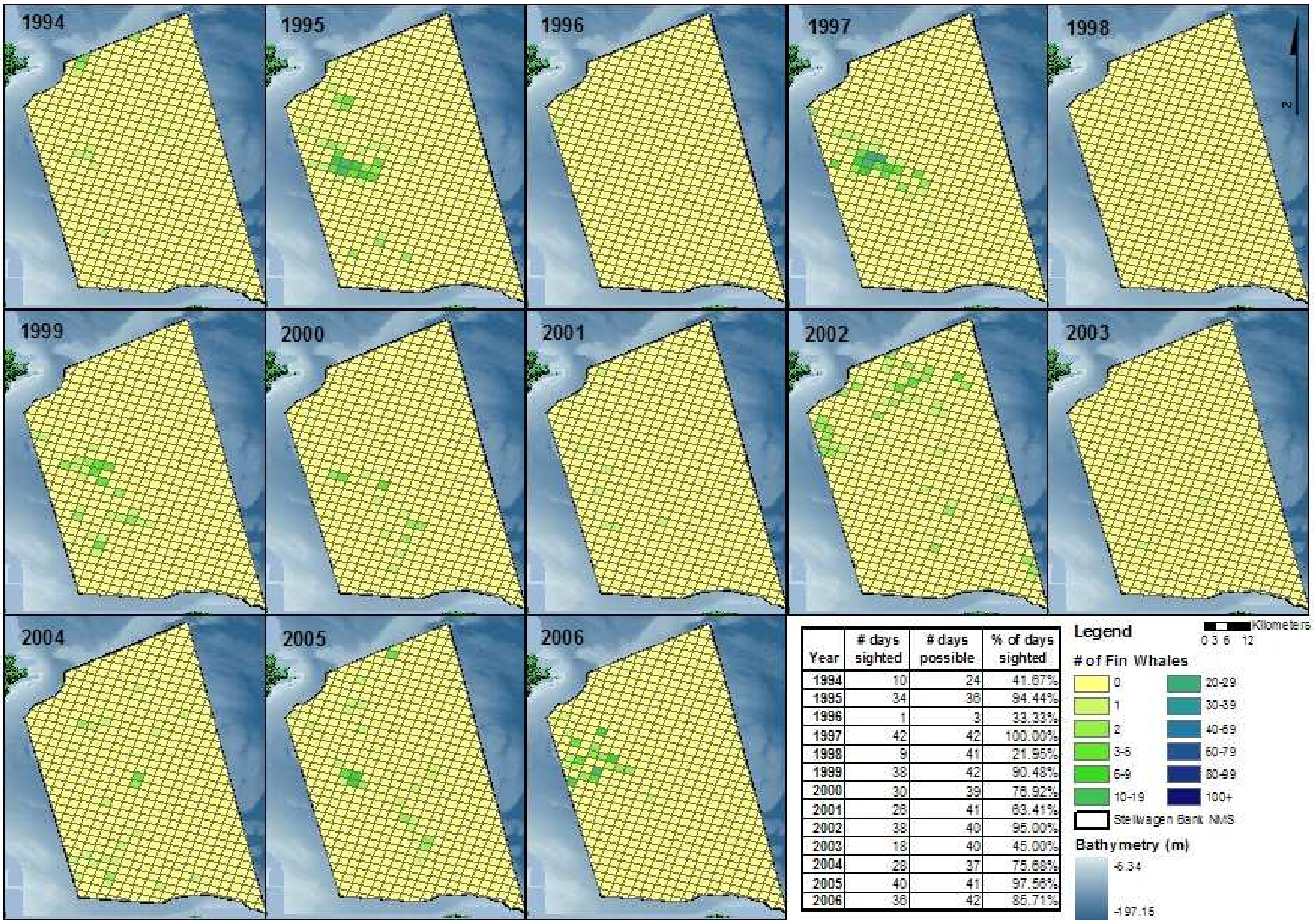
The analysis of data collected between 1994 and 2006 showed considerable long-term variation in the distribution of in whale sightings on Stellwagen Bank. In particular, humpback whale relative abundance and distribution fluctuated consistently from year to year (Figure 6). From 1994-1996, few humpback whale sightings were recorded on Stellwagen Bank. In fact, humpback whales were sighted on less than half of the whale watches traveled to Stellwagen Bank in those years. An increase in humpback whale sightings followed from 1997 to 2001. Humpback whales were sighted every day on Stellwagen Bank between July 10 and August 20 in each of those years. In 1997 and 1998, the sightings were concentrated in the northwest corner of Stellwagen Bank. From 1998 to 2001, there was a shift in humpback whale sightings to the southern portion of Stellwagen Bank. The year 2002 was similar to 1994-1996 with few sightings of humpback whales. In 2003, humpback whale sightings were concentrated in the southeastern portion of SBNMS. 2004 and 2005 were relatively low-sighting years, with an increase of sightings seen in 2006. When humpback whales were abundant within SBNMS, their sightings were clumped in particular areas. In years with fewer humpback whale sightings, their distribution was more uniformly spread within SBNMS.



Year	# days sighted	# days possible	% of days sighted
1994	12	24	50.00%
1995	4	36	11.11%
1996	1	3	33.33%
1997	42	42	100.00%
1998	41	41	100.00%
1999	42	42	100.00%
2000	39	39	100.00%
2001	41	41	100.00%
2002	17	40	42.50%
2003	40	40	100.00%
2004	13	37	35.14%
2005	38	41	92.68%
2006	42	42	100.00%

Figure 6. Humpback whale abundance within Stellwagen Bank National Marine Sanctuary from 1994 – 2006 between July 10 and August 20.

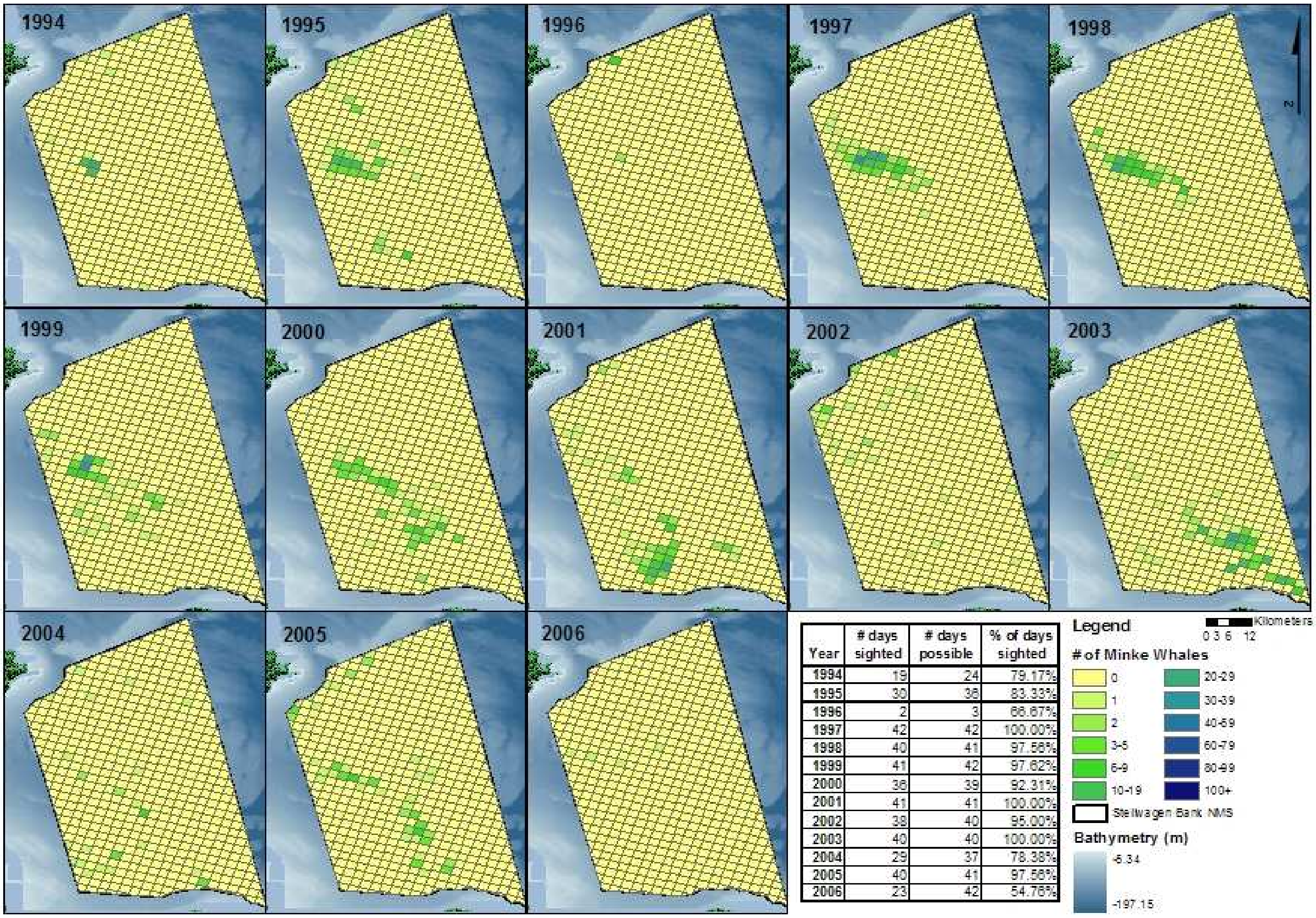
Fin whale sightings occurred less frequently than humpback whale sightings within SBNMS (Figure 7). In 1997, humpback whales and fin whales were sighted on every trip that searched for whales on Stellwagen Bank, but more humpback whales were sighted than fin whales. In 1995, more fin whales were sighted on Stellwagen Bank than humpback whales. In years where there were many sightings of humpback whales (1998, 1999, 2000, 2001), there were fewer sightings of fin whales (1995, 2002). No grid cell within SBNMS ever had more than 20 fin whales sighted in it. The distribution of fin whales was more uniform than that of humpback whales.



Year	# days sighted	# days possible	% of days sighted
1994	10	24	41.67%
1995	34	36	94.44%
1996	1	3	33.33%
1997	42	42	100.00%
1998	9	41	21.95%
1999	38	42	90.48%
2000	30	39	76.92%
2001	26	41	63.41%
2002	38	40	95.00%
2003	18	40	45.00%
2004	28	37	75.68%
2005	40	41	97.56%
2006	36	42	85.71%

Figure 7. Fin whale abundance within Stellwagen Bank National Marine Sanctuary from 1994 – 2006 between July 10 and August 20.

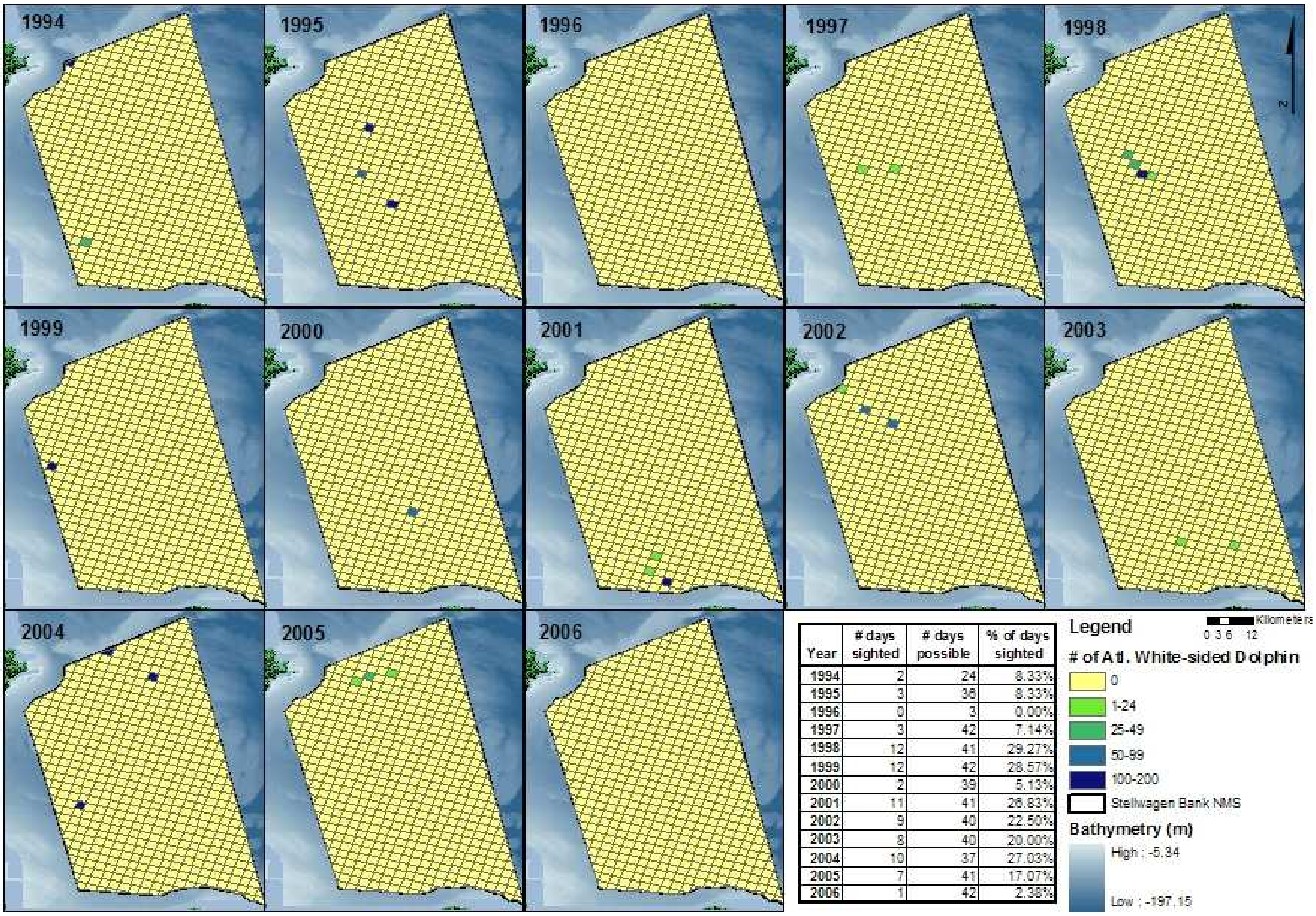
Minke whale distribution was similar to that of fin whales. On the whole, relatively few minke whales were sighted within SBNMS compared to humpback whales (Figure 8). Minke whales, however, were the most consistently sighted whale within SBNMS. More than 50% of whale watches sighted minke whales; in most years, minke whales were sighted on 80% or more of trips. There were many years when humpback whales were seen on 100% of trips traveling to SBNMS; in years with few humpback whales, though, minke whale sightings were more consistent. Minke whale sightings appeared to be closely linked to those of humpback whales. The yearly fluctuations in distribution for both species followed the same patterns; where humpback whales were abundant, so were minke whales. Minke whales, however, were sighted more consistently over time. Their abundance on Stellwagen does not seem to boom and bust in the same way as humpback whales.



Year	# days sighted	# days possible	% of days sighted
1994	19	24	79.17%
1995	30	36	83.33%
1996	2	3	66.67%
1997	42	42	100.00%
1998	40	41	97.56%
1999	41	42	97.62%
2000	36	39	92.31%
2001	41	41	100.00%
2002	38	40	95.00%
2003	40	40	100.00%
2004	29	37	78.38%
2005	40	41	97.56%
2006	23	42	54.76%

Figure 8. Minke whale abundance within Stellwagen Bank National Marine Sanctuary from 1994 – 2006 between July 10 and August 20.

Atlantic white-sided dolphins were sighted infrequently on Stellwagen Bank. This species was sighted on less than 30% of the days that whale watches traveled to Stellwagen Bank. That was consistent with observations from 2007, where they were seen on only three whale watches out of 17.



Year	# days sighted	# days possible	% of days sighted
1994	2	24	8.33%
1995	3	36	8.33%
1996	0	3	0.00%
1997	3	42	7.14%
1998	12	41	29.27%
1999	12	42	28.57%
2000	2	39	5.13%
2001	11	41	26.83%
2002	9	40	22.50%
2003	8	40	20.00%
2004	10	37	27.03%
2005	7	41	17.07%
2006	1	42	2.38%

Figure 9. Atlantic white-sided dolphin abundance within Stellwagen Bank National Marine Sanctuary from 1994 – 2006 between July 10 and August 20.

Discussion

The analysis of SPUE highlighted some of the biases in data collected on whale watch vessels. Biases were caused by the non-random search patterns employed, the location of the home port and the sequence of trips in which data were collected. Each of these factors contributed to limiting the search efforts of whale watch vessels to a concentrated area during the 2007 season.

The finding that duplicate sightings did not impact the SPUE is important because scientific surveys are often designed to reduce the probability of duplicate sightings. This strategy is not possible for whale watches. Knowing that the duplicate sightings have little impact on the value generated means that in places where photo-identification is limited either by the species or the equipment, duplicate sightings will have a minimal impact on the estimates of abundance.

Bias was found to exist in data collected from whale watches departing from different harbors. Because the departure harbor impacts the sightings data, gathering sightings data on a number of whale watch vessels operating over a wide area will provide the most useful data from research or conservation purposes. In this study, data were only collected on whale watches out of Gloucester and Boston, MA. Several other harbors support whale watches that travel to Stellwagen Bank, including, Plymouth, Barnstable and Provincetown. Data should be gathered from all of these harbors to get the best representation of the abundance and distribution of whales within the Sanctuary.

The within-day dependence component of the study revealed interesting results. When actively searching, humpback whales were encountered more often in the morning that the afternoon. This is different from what was expected. The morning trips were expected to spend more time searching for whales with fewer seen than the afternoon; in theory, the afternoon whale watches would go directly to where whales were sighted from the morning, minimizing the distance covered when searching for whales. On average, the morning whale watch searched for 10 km more than the afternoon trip during search effort. When these values were generalized to the SPUE value, though, significantly more whales were sighted in the morning. There are several possible explanations for the opposite effect being observed. Whale behavior may change from the morning to the afternoon, causing whales to be more easily sighted in the morning. Alternatively, whales could be more active in the afternoon, prompting whale watch captains to stay with the first group they sight, rather than searching for more whales. There may also be changes in how the whale watches operate between the morning and afternoon.

Within-day dependence can be easily controlled for, allowing the data to be used with minimal bias. Using sightings from the first whale watch of the day produced the most unbiased data set. There are cases, though, where within-day dependence may not be as much of an issue. In particular, there may be times when the sightings from the morning lead to more searching in the afternoon or traveling to a different location to seek out “better” whales. In this situation, there may be little to no within-day dependence, and both sets of data could be used. During summer 2007, there were no days in which the morning and afternoon whale watches traveled to completely different locations. In the future, this would be important to test for in order to determine the best use the two different sets of data.

One source of bias that cannot be controlled is the communication that occurs between different whale watch companies and vessels. Many whale watch captains talk with one another, reporting locations and behaviors of whales. The captains will be in communication with one another throughout the trip, while searching for whales, watching whales and heading back into the dock. This information often influences the captain and naturalist’s decision about where to search for whales. Unfortunately, this is a form of bias that cannot be controlled, unless there is only one whale watch company in a particular area. Knowing that this bias exists is important and should be considered in the data collection process.

From data collected in 2007, it is clear that the distribution of past sightings affects the survey coverage of a particular habitat. Whales were concentrated along the western edge of Stellwagen Bank throughout the study period, so whale watch vessels did not travel beyond this area. There was no need to continue searching if whales could be found close to the departure harbor. Thus, our understanding of habitat use in 2007 is not representative of the entire Bank, just the areas where whale watch vessels worked most intensively.

The sightings data in 2007 are most similar to those of 1997 and 1998 and lessons from 2007 can be applied to the data from these years. Whale sightings were concentrated on the northwest corner of Stellwagen Bank, so it is a safe assumption to make that whale watch vessels searched in few other areas of the habitat in 1997 and 1998. Areas where whales were not sighted, represented by zeroes, may not represent true absences. Whales may have occurred in many of those areas during the study period; whale watch vessels from Gloucester and Boston did not search far enough to find them. This contrasts with years such as 2001 and 2003 in which whale sightings were concentrated in places much farther from Gloucester and Boston harbors. In these years, whale watch vessels covered a good portion of Stellwagen Bank when traveling to where whales were sighted. The absences in these years may be more representative of the broader habitat use than in years where whales were found closer to Gloucester and Boston. Understanding how this bias impacts our interpretation of the data is valuable when these data are used for long-term studies and conservation efforts.

Some of the trends in SPUE values may be due to differences in species or due to the focus of the whale watch. Fin whales appear to have a more uniform distribution on Stellwagen Bank than the clumped distribution of humpback whales and minke whales. Humpback whales are the target species of whale watches, so it makes sense that minke whales and humpback whales are potentially over-represented in the SPUE analysis, while fin whales would be under-represented.

This study was limited by a small sample size. Once the criteria were applied to the whale watch data to be included in the SPUE analysis, the sample size was restricted to 17 trips. High wind speed and poor visibility each removed three whale watches from our data set. Using only the morning whale watches excluded eight whale watches from the final analysis. Data collection was also limited to the days that I was working. Gathering more data for SPUE analysis would strengthen the results of this project. The SPUE data were also limited to only one whale watch season when whales were abundant. Data should be collected from additional seasons to ensure that inter-annual variation in abundance is accounted for in the SPUE analysis.

The current study would further be enhanced by the inclusion of several other components for analysis. There are limitations to the ability to sight whales in poor weather conditions. Fog, rain and rough seas may reduce an observer's ability to sight whales. It would be interesting to compare the SPUE values in various weather conditions. Variability may also exist between different whale watch platforms due to their height and the speed they travel at when searching for whales. Further comparison could analyze whale watch data to explore these possibilities and determine how these factors affect SPUE.

Boston and Gloucester whale watches have significant differences in SPUE because of the time constraints of whale watches out of Boston and the greater concern for customer satisfaction on whale watches out of Gloucester. It would be interesting to analyze the sightings for whale watches on the same day out of each harbor to further expose those differences.

Future analysis could also examine whether or not weather has an impact on long-term trends in abundance and distribution. Weather criteria were used to remove observations from the SPUE analysis because fog, rain and high wind speeds were assumed to impact the ability to sight a whale. In the long-term analysis, however, weather conditions were not considered because over an extended period of time, it was expected that weather would have minimal impact on our understanding of the distribution of marine mammals on Stellwagen Bank. This is an important assumption that would be interesting and useful to test.

Recommendations

Based on the analysis completed in this project, there are several ways in which bias can be minimized when using whale watch vessels as a platform of opportunity for data collection. The sequence of trips in which data is collected from has an obvious impact on the sightings. Using the first trip of the day will diminish the likelihood of within-day dependence. Caution should also be given to the harbor from which whale watches are departing from and the proximity of the harbor to where whales are most commonly sighted. Data may need to be collected from multiple whale watch companies and harbors in order to achieve complete coverage of an entire habitat. As was seen in the case of the SPUE data from summer 2007, only small portions of Stellwagen Bank were covered by the whale watches. A more thorough survey of the area may have been possible with the inclusion of whale watches departing from ports other than Gloucester or Boston.

Differences in species ecology and long-term variation in the distribution and abundance of marine mammals will have significant impacts on where whale watches will travel to watch whales and the areas that will be covered. These impacts need to be considered and factored into the design of the studies using whale watch data. If data are being used for long-term analysis, it is critical that the biases that are identified in the data collection process are applied when identifying long-term trends.

One of the most important conclusions of this project is that gathering data on effort (the tracks of whale watch vessels on Stellwagen Bank) is as equally important as the sightings data typically gathered from whale watches. From the trackline data, we were able to identify sources of bias and apply what we learned to our interpretations of the long-term data that had been previously collected. This insight was invaluable for looking at the perceived trends in the movements of whales and understanding how other factors may arbitrarily alter their distribution. Greater efforts should be made to gather effort data in addition to sightings data on whale watch vessels.

Another important lesson gained from this study is the value of collecting data from a variety of whale watches and having the data available for use. The data in this project were solely from the Whale Center of New England, which tends to saturate mostly the northern portions of Stellwagen Bank with effort during the summer. Getting the "big picture" from solely the Whales Center's data and resources is impossible. Other institutions collect similar data on Stellwagen Bank, but because data are valuable to each institution, the ability for collaborative efforts is, at times, minimized. Collecting trackline and whale sightings data in a standardized form from all of these institutions would provide the unique ability to capture a representative sample of data that would more accurately portray the distribution of whales within the Sanctuary throughout the summer.

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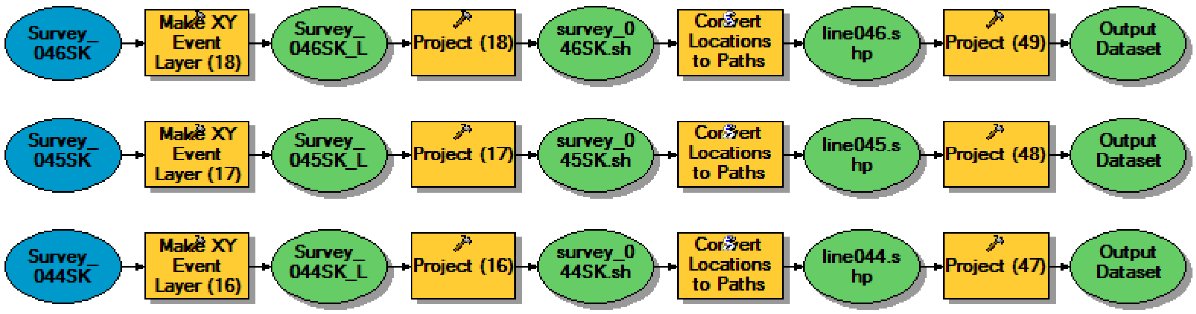
Appendix

Sightings-Per-Unit-Effort (SPUE)

Step 1: *Bring whale watch data in ArcGIS and convert points (as the data were collected in the GPS unit) into lines (for which a distance could be calculated).*

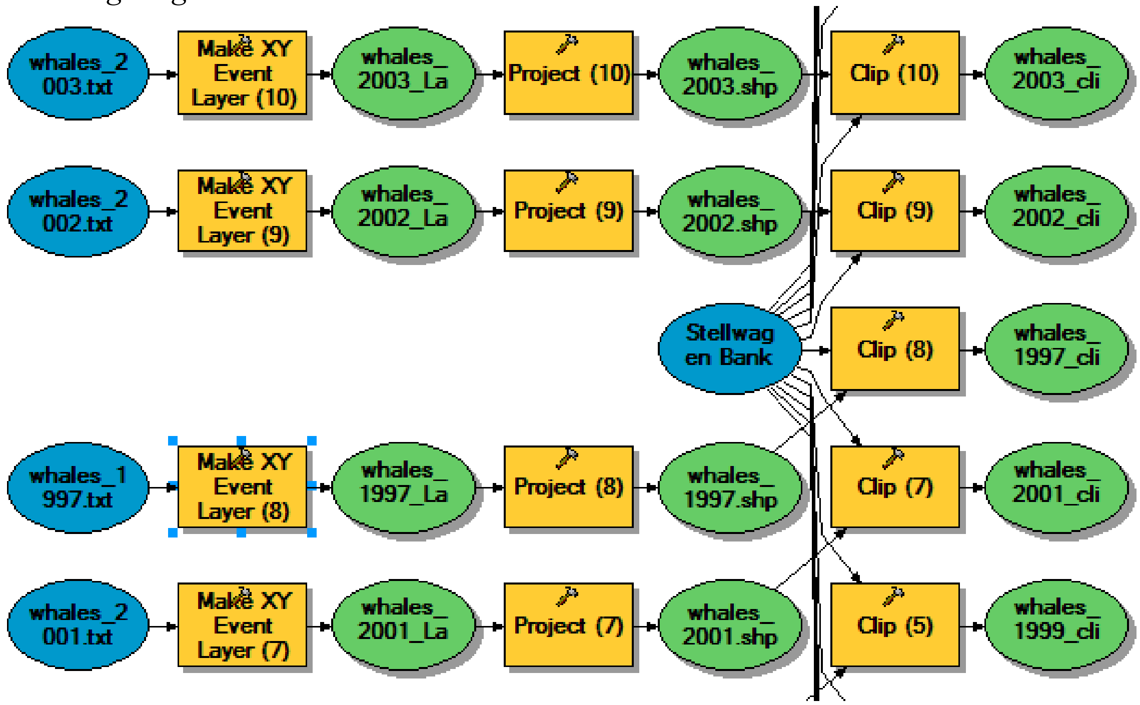


Data were imported into ArcGIS 9.2 and projected into GCS WGS 1984. In this form, the data collected were point data. In order to calculate the distances that the whale watch vessels traveled, the data needed to be converted to line data. This was done using the "convert locations to paths" tool developed by Hawthorne L. Beyer, part of the Hawth's Tool Analysis Extensions. The path ID was the search effort and on whale effort so that the line created could be differentiated by these categories. Once the lines were created for each whale watch, the data were re-projected into projected coordinate system (US Contiguous Conformal Conic) from a geographic coordinate system (GCS WGS 1984) so that the distances of each line could be calculated. (A graphic depiction of the model can be seen above. This model only represents the processing for 3 whale watches, though all used in analysis were processed with the exact same methodology)

Step 2: *Calculate the distance traveled when for search effort and whale effort.*
For each whale watch, a new field was created in the attribute table and the calculate geometry tool was used to calculate the distance traveled in kilometers along the line for each of the survey. On several trips, there were multiple search effort and whale effort periods. In these cases, the distances covered during each period of search effort and whale effort were summed to get a single value for the distance covered during true and whale effort for each whale watch. These values were then used with the sightings data in Excel to calculate the SPUE with distance as the effort.

Long-Term Trends

Step 1: *Bring long-term data into ArcGIS and select data within SBNMS.*

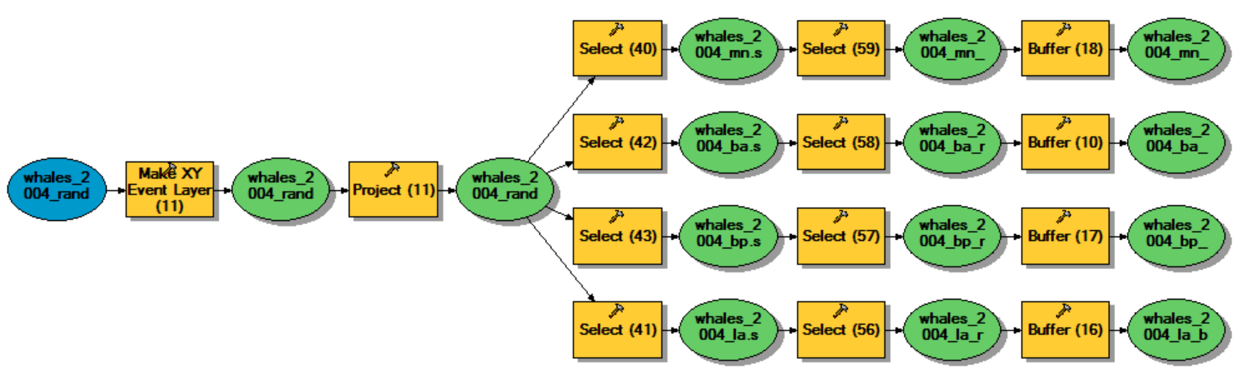


Data for each year between 1994 and 2006 were brought into ArcGIS and projected into GCS WGS 1984. The "clip" tool was used to select all whale sightings from each year that were within SBNMS. (A graphic model of the data processing can be seen again. This represents only 4 years of data, although all were processed the same way)

Step 2: *Code sightings data for random trip selection.*

Once all of the sightings within SBNMS were extracted from the entire data set, random trips for each day between July 10 and August 20 for each year needed to be selected. The number of trips each day ranged from 1 to 14. In order to reduce the risk of sightings of different whale watches being the same whales, only one whale watch from each day was selected. This was done by sorting the raw data by date and trip number. A random number generator was used to select one trip each day. The selected trip was coded with a 1, and the others were coded 0.

Step 3: *Preparing data for analysis.*



After the data were coded for random trips, each year's data was brought back into ArcGIS and projected into GCS WGS 1984. The "select" tool was used to create new shapefiles for each year by species: humpback whale, fin whale, minke whale and Atlantic white-sided dolphin. The randomly selected trips then needed to be extracted from the data, which was accomplished by, again, using the "select" tool. These points were then buffered by 0.1 meters, so that the resultant file would be a polygon shapefile, rather than a point shapefile, to aid with further analysis (step 5). (The above model shows the steps required for preparing the data for analysis)

Step 4: *Creating 2x2 kilometer grid cells within SBNMS.*
Before the long-term data could be analyzed, the 2x2 kilometer grid cells covering SBNMS needed to be created. This was done using the creating a vector grid with the same extent as SBNMS (from the USGS website). The spacing between lines was set to be 2 km in both the X and Y directions, creating uniform squares over the sanctuary. Originally created in UTM, the shapefile was reprojected into GCS WGC 1984 to be consistent with the other data. The "copy" tool was used to replicate this shapefile for each year and each species so that the long-term trends of abundance could be examined.

Step 5: *Calculating the number of sightings within each grid cell.*
The sightings in each grid cell were calculated by using the "polygon in polygon analysis" tool in Hawth's tools. The alternative tool that was considered for use was the "points in polygon analysis" tool, which would have eliminated the need to buffer each point in step 3. This tool, rather than the one ultimately used, simply counted the points. Each point within the data did not always represent one individual whale; often times, multiple whales were sighted at one location and were recorded in the data with a minimum and maximum estimate of group size. Counting the points would not have shown this component of the data. For each year and each species, the "polygon in polygon analysis" tool was used to create an attribute-based summary of the data. The attribute used for this analysis was the minimum estimate of group size and the sum of the sightings was calculated within each grid cell, producing a spatial representation of the changes in the abundance and distribution of whales from 1994-2006 within SBNMS.