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Population Size and Site Fidelity of North Atlantic Minke Whales (*Balaenoptera acutorostrata acutorostrata*) off the Atlantic Coast of Nova Scotia, Canada

Gemma B. Bartha,[1] Shannon Gowans,[2] Peter Simard,[3]
Michael Tetley,[4] and Edward O. Keith[5]

[1]*Springfield College, Biology/Chemistry Department, 263 Alden Street, Springfield, MA 01109, USA*
E-mail: GemmaBartha@gmail.com
[2]*Eckerd College, 4200 54th Avenue South, St. Petersburg, FL 33711, USA*
[3]*University of South Florida, College of Marine Science, 140 7th Avenue South, St. Petersburg, FL 33701, USA*
[4]*School of Ocean Sciences, Bangor University, Menai Bridge, Ynys Môn, LL59 5AB, UK*
[5]*Nova Southeastern University, Oceanographic Center, 8000 N. Ocean Drive, Dania Beach, FL 33004, USA*

Abstract

The site fidelity of North Atlantic minke whales (*Balaenoptera acutorostrata acutorostrata*) off the coast of Halifax, Nova Scotia, Canada (approximately 1,800 km^2) was examined and their population size estimated. During 258 d of boat-based surveys, 1,158 photographs (black and white film plus digital) of minke whales were collected during the summer months (primarily June through August) between 1997 and 2008. While 100 individuals were identified over the 10-y study, only 40 individuals possessed reliable marks (notches on the dorsal fin). Of the unique (i.e., reliably marked) individuals, 35% were observed on more than 1 d (14/40), and 12.5% were photographed in more than 1 y (5/40). The population size was estimated to be 43 unique individuals (28 SE) with an estimate loss rate (that includes mortality, permanent emigration, and mark change) of 35.2%/y (28.1 SE). As 51% of the population was estimated to possess reliable marks, the total population size for this area was estimated at 84 individuals.

Key Words: photo-identification, mark-recapture, minke whale, *Balaenoptera acutorostrata*, site fidelity

Introduction

Minke whales (*Balaenoptera acutorostrata,* Lacepède 1804) are found in all oceans of the world, including polar and tropical waters. Despite their widespread distribution, few populations have been well-studied because minke whales tend to be relatively difficult to approach and do not frequently make conspicuous surface displays. Currently, two species of minke whale are recognized: (1) the northern minke whales (*B. acutorostrata*) and (2) the southern or Antarctic minke whale (*B. bonaerensis*). There is evidence to support two separate subspecies of northern minke whale: (1) the North Atlantic minke whale (*B. a. acutorostrata*) and (2) the North Pacific minke whale (*B. a. scammon*) (Perrin & Brownell, 2002).

Northern minke whales are the smallest and most abundant species of baleen whale in North Atlantic waters (Skaug et al., 2004). Minke whales are mainly distributed over the continental shelf (Skaug et al., 2004) and are often observed alone or in relatively small groups; however, they may congregate in larger groups at feeding grounds (Reeves & Stewart, 2003). Minke whale distribution and group size while feeding are dependent upon the distribution of their prey (Macleod et al., 2004).

Minke whales are believed to migrate to temperate and tropical waters during the winter and travel to cooler waters in the summer (Reeves & Stewart, 2003). In the North Atlantic, minke whales are thought to travel as far south as the West Indies during the winter months for mating and calving. Migration patterns could be segregated by both size and gender (Christensen et al., 1990). However, minke whale distribution and migration patterns are not entirely understood, particularly their winter distribution, because of poor sighting records during that time of year (Skaug et al., 2004).

North Atlantic minke whales have been sighted year-round in the coastal waters near Halifax, Nova Scotia, although it has not been confirmed that the same individuals reside year-round. Minke whales are the most prevalent mysticete species found within the eastern coastal waters off Nova Scotia, including off the coast of Halifax. This area is used heavily by the commercial fishing industry, commercial shipping, recreational boaters, and whale watching vessels, increasing the probability of anthropogenic influences on minke whales and other local cetaceans (Simard et al., 2006).

No previous studies have focused directly on estimation of minke whale population size in eastern Canadian waters, although they have been included in several cetacean stock assessments conducted by the U.S. National Marine Fisheries Service (NMFS) and portions of the 2007 Trans North Atlantic Sighting Survey (TNASS) in Canada. These surveys have focused on sighting data and have used distance-based analytical techniques to estimate population size (Lawson & Gosselin, 2009; Waring et al., 2009).

Photo-identification has been demonstrated to be a non-invasive and inexpensive tool for studying minke whales (Dorsey, 1983; Dorsey et al., 1990; Stern et al., 1990; Murphy, 1995; Macleod et al., 2004; Ingram et al., 2007; Tetley et al., 2008). Particular markings found on minke whales include scars and lateral coloration as well as dorsal fin nicks and notches (Dorsey, 1983; Dorsey et al., 1990) that aid in photo-identification. Photo-identification techniques can be used to estimate population size and can also give information about residency rates and movements (Dorsey, 1983; Dorsey et al., 1990; Gowans et al., 2000; Baumgartner, 2008)

The objectives of the present study were to examine whether North Atlantic minke whales found off the southern coast of Nova Scotia exhibited site fidelity within the study area and to estimate population size within the study area using mark-recapture based on photo-identification techniques. This information complements existing population estimates and will be essential in understanding how minke whales use the coastal waters off Halifax, Nova Scotia.

Materials and Methods

Field Data Collection

Data were collected in the southeastern coastal waters of Nova Scotia, Canada, within 18 km off shore; a study area bounded by approximately 44° 10' to 44° 38' N and 63° 15' to 64° 20' W (Figure 1). A variety of vessels, ports of operation, and cameras were used in this study (Table 1); however,

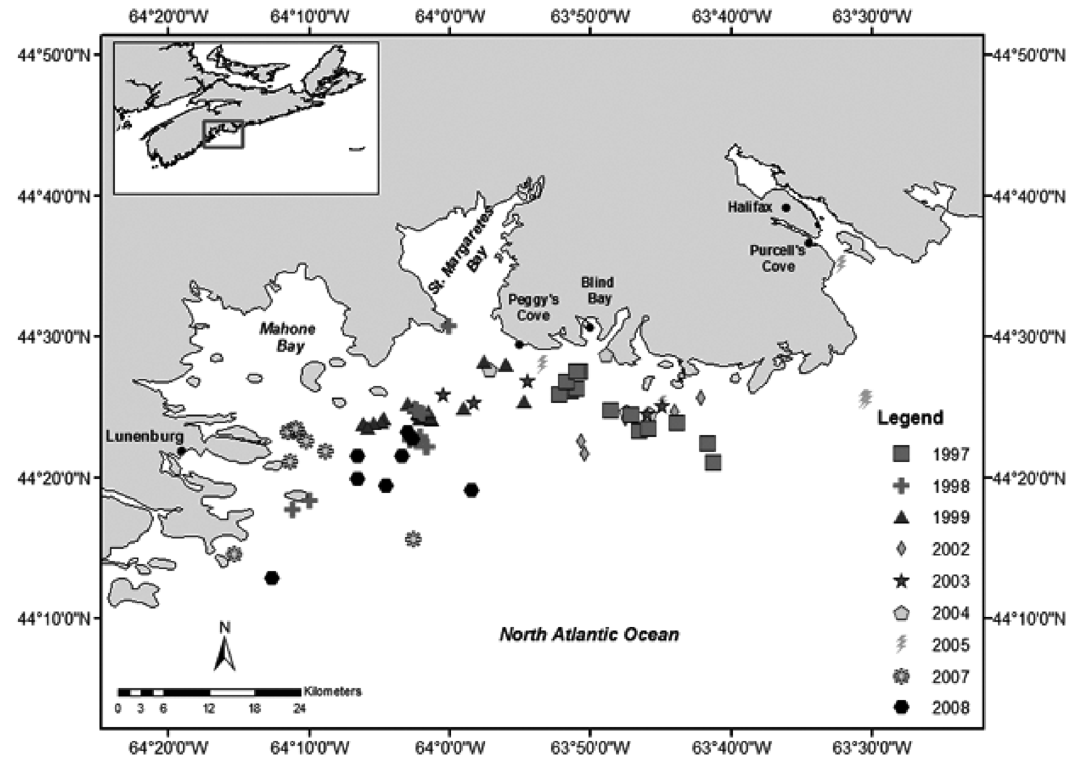

Figure 1. Study area was bound by approximately 44° 10' to 44° 38' N latitude and 63° 15' to 64° 20' W longitude. Survey sites: Peggy's Cove (1997 to 1999), Purcell's Cove (2000), Blind Bay (2002 to 2005), and Lunenburg (2007 to 2008). Symbols indicate sighting position of 89 identified minke whales (*Balaenoptera acutorostrata acutorostrata*) off the southwestern coast of Nova Scotia. Each symbol signifies a different field season.

Table 1. Summary of fieldwork by year. Although a number of different ports, vessels, and cameras were used, field methods were relatively standard. The number of days in the field varied, and the percent of days in the field in which minke whales were sighted also varied, although on average, minke whales were photographed on over half of the days spent in the field.

Year	Field dates	Port	Vessel type	Camera (lens)	Number of days in field	Days photographed (% of total days)
1997	6 June–4 Oct	Peggy's Cove	Whale watching	Pentax Super Program (70-210 mm)	59	22 (37)
1998	21 June–21 Aug	Peggy's Cove	Whale watching	Pentax Super Program (70-210 mm)	7	5 (71)
1999	3 April–31 Aug	Peggy's Cove	Whale watching	Pentax Super Program (70-210 mm)	56	12 (21)
2000	22-30 Aug	Purcell's Cove	Chartered whale watching	Canon Elan IIe (100-300 mm)	4	4 (100)
2002	13 May–2 Aug	Blind Bay	Dedicated research	Canon Elan IIe (100-300 mm)	14	4 (29)
2003	21 April–19 Sept	Blind Bay	Dedicated research	Canon Elan IIe (100-300 mm)	46	11 (24)
2004	20 May–5 Aug	Blind Bay	Dedicated research	Nikon D1 (100-400 mm)	15	3 (20)
2005	1 June–9 Aug	Blind Bay	Dedicated research	Canon EOS 20D (100-400 mm)	17	13 (76)
2007	14-29 July	Lunenburg	Whale watching	Canon 30D (100-300 mm)	14	13 (93)
2008	6 July–2 Aug	Lunenburg	Whale watching	Canon 30D (100-300 mm)	26	24 (92)
Average (SE)					25.8 (6.4)	56% (6.6)

similar research methodologies were used in all years with at least two observers present during each survey. Fieldwork was conducted from 1997 to 2008 (although no data were collected in 2001 or 2006). Each year, fieldwork was predominantly conducted from June through August with additional work in some years as early as April and as late as October (Table 1). Three different types of vessels were used: (1) commercial whale watching boats on regularly scheduled tours, (2) whale watching vessels chartered specifically to collect cetacean photo-identification data, and (3) a dedicated research vessel. Whale watching vessels were between 12 to 13 m in length, while the dedicated research vessel was a 4.2-m rigid hulled inflatable. Height above water for all observers while aboard the vessels ranged between 2 to 6 m. Four separate ports were used by these different vessels; however, all boats surveyed the same general waters (Figure 1). All field effort was weather dependent (whale watching vessels: < 15 kts wind and > 500 m visibility; research vessel: < 10 kts wind and > 500 m visibility). For all vessels, systematic surveys were not conducted. Instead, the vessels would target areas where minke whales were previously sighted. The position of the vessel was automatically recorded every 1 to 5 min with a GPS. Sightings began when a whale was first observed; the time was noted when the vessel arrived within ~50 m of the whale, and sightings ended when either the boat left the animal or there was an elapse in time of 10 min without sighting another minke whale.

From 1997 to 2003, photographs were taken with black and white ISO 400 film. From 2004 forward, digital images were obtained (Table 1). Ideally, whales were approached within 10 m, with the path of the whale parallel to the vessel path (the whale being directly at the side of the vessel). A suite of photographs were taken of surfacing whales in order to record all markings from blowhole to peduncle. In order to obtain high-quality photographs for both sides of the animal, the suite of photographs were first obtained from one side of the whale. When this was accomplished, the vessel would then drop behind the whale's path, maneuvering to the opposite side for a second photographic suite. However, it was often not possible to obtain high-quality photographs of both sides of the same individual, and a particular side (i.e., the left side over the right side) of the individual was not consistently targeted. The time of each photographic suite was recorded.

Photographic Analysis
Photo quality rating systems are often used to reduce heterogeneity in recaptures, which can negatively bias mark-recapture estimates (Gowans et al., 2000; Friday et al., 2008). From 1997 to 2005, each image was assigned a photo quality value between one and four (Q1 to Q4), with Q1 representing high-quality images. Only images with an assigned value of $Q \leq 3$ were used for statistical analysis. A photographic quality value was calculated consistently by the same researcher by averaging the following five different characteristics subjectively on a point scale from one to four (with one having best quality and four having poor quality): (1) focus, (2) exposure, (3) percent coverage, (4) angle, and (5) proportion of the whale visible. All photographic quality assessments were assigned without consideration of the markings present on the individual. Thus, an animal with obvious markings could be assigned a quality value of Q4, while an animal with no distinguishable markings, making that animal unidentifiable, could be assigned a quality value of Q1 based solely on the quality of the image. In 2007 and 2008, none of the photographs were assigned a photographic quality; however, only photographs comparable in quality to $Q \leq 3$ were selected and included in the analysis. While all markings on the dorsal fin and body were used in the matching process, only notches on the dorsal fin were considered reliable and used for mark-recapture analysis. While some scars on the flank persisted over time, they were not considered reliable markings for this study as photographs were not consistently obtained from either the left or right side. Inclusion of these individuals in the mark-recapture analysis would have increased the heterogeneity of capture probabilities. Photographs of the left and right sides of an individual with notches on the dorsal fin could be linked to that individual based on the location of the notches. Any photograph that did not show the dorsal fin of the whale was not included in the analysis. Reliably marked individuals (those with notches on the dorsal fin) were considered unique individuals, unlikely to be represented twice in the dataset.

Identification photographs were taken of all minke whales encountered. Thus, the proportion of unique (i.e., reliably marked) individuals in the population should be similar to the proportion of photographs containing unique individuals. This proportion was used to scale the estimated population size of unique individuals to the total population.

Spatial Distribution
The highest quality photograph of each identified individual in each sighting was selected to represent spatial distribution of that individual. The time of the photograph was matched with the closest corresponding GPS position of the vessel. The corresponding GPS position for each identifiable individual in each sighting was plotted using *ArcMap*® (ESRI, Redlands, CA, USA).

Mark-Recapture Population Estimate
The fundamental concept of mark-recapture is that animals are generally "marked" (i.e., via photography or tagging), placed back into the population, and then recaptured at a later date. Population size can then be estimated using the proportion of marked to unmarked animals in random samples from the entire population. Population size for this study was estimated using the *POPAN* module within the program *Socprog*, Version 2.4 (Whitehead, 2009). Only photographs of $Q \leq 3$ of unique individuals (those with notches in their dorsal fin) were included in this analysis. As unique individuals could be identified from photographs taken from both sides of the whale, photographs from both the left and right sides were included in the analysis.

A discovery curve plot was examined to investigate patterns of identification rates. Population parameters were obtained for two open population models, and the lowest Akaike Information Criterion (AIC) value was used to select the best fit model (Demidenko, 2004):

1. *Mortality:* A population of constant size where mortality (possible permanent emigration) is balanced by birth (possible immigration)
2. *Mortality + Trend:* A population growing or declining at a constant rate

Jackknife estimates of SE were applied to population parameters of the models.

Results

Field Data
Over the ten individual field seasons, 258 d were spent in the field. Minke whales were sighted on 158 d. The number of field days per year varied greatly from as few as 4 d to as many as 59 d (Table 1). Minke whale sighting rates varied, although minke whales were photographed on 111 out of the 258 d in the field.

Photo Analysis
Over the combined 10-y study period, 1,158 photos were taken, 612 photographs of the left side, 538 photographs of the right side, and eight other photographs of a minke whale either moving

towards or away from the boat. There were 368 good quality photographs (Q ≤ 3) taken overall. Unique individuals represented 170 of those good quality photographs. The proportion of good quality photographs containing unique individuals was 0.514; this can be considered the proportion of marked individuals in the population (Table 2).

Identification and Resightings

Over the 10 y, 100 individuals were identified—40 of which were unique. Location of the sighting for 89 of the 100 identified individuals was plotted using corresponding vessel GPS coordinates (Figure 1) with nine identifications from field season 2000 and two from field season 2003 not mapped because of equipment malfunctions.

While many individuals were re-identified on the same day, 15 individuals were resighted on separate days (Table 3), and 14 were unique (35% of all unique individuals). Nine individuals were resighted during the same field season with a maximum duration of 90 d between sightings. Of the 40 unique individuals, five were resighted in different years (12.5%), with a maximum span of 4 y between sightings. One individual with large scars on the flank (BSM01) was also identified in two

Table 2. Summary of photo-identification data; unique individuals are those individuals with notches in the dorsal fin. Only images with an assigned value of Q ≤ 3 (with Q1 representing high-quality images; see "Materials and Methods" section) were used for mark-recapture analysis.

Year	Number of individuals identified	Number of unique individuals	Number of photographs Q ≤ 3	Number of photographs of unique individuals	Proportion of photographs with unique individuals
1997	14	3	36	10	0.278
1998	12	4	51	11	0.226
1999	23	5	102	39	0.382
2000	9	3	41	24	0.585
2002	8	3	26	14	0.538
2003	7	4	24	18	0.750
2004	4	3	23	14	0.609
2005	6	2	18	7	0.389
2007	11	8	23	14	0.609
2008	12	10	24	19	0.792
Average (SE)	10.6 (1.7)	4.5 (0.8)	36.8 (7.92)	17.0 (2.87)	0.514 (0.061)

Table 3. Temporal pattern of multiple sightings of individual minke whales over the ten field seasons, arranged by increasing time span between the first and last sighting; the spatial pattern of these resightings can be found in Figure 3. All individuals except BSM01 were considered unique and included in mark-recapture analysis.

Whale ID	Number of days sighted	Dates	Time span (Days)
DEM13	2	16 July 2008, 17 July 2008	1
DEM04	3	16 July 2007, 17 July 2007, 18 July 2007	2
DEM01	2	14 July 2007, 17 July 2007	3
DEM18	2	6 August 2008, 11 August 2008	5
DEM12	2	16 July 2008, 23 July 2008	7
DEM10	4	18 July 2007, 21 July 2007, 22 July 2007, 25 July 2007	7
DEM15	2	23 July 2008, 5 August 2008	13
15	3	12 August 1997, 18 August 1997, 25 August 1997	13
201	3	19 May 1999, 12 August 1999, 17 August 1999	90
111	2	21 August 1998, 3 August 1999	347
BSM01	8	14 July 2007, 16 July 2007, 18 July 2007, 19 July 2007, 15 July 2008, 20 July 2008, 21 July 2008, 25 July 2008	377
DEM05	4	17 July 2007, 18 July 2007, 5 August 2008, 7 August 2008	387
225	2	27 August 1999, 15 July 2002	1,053
302	2	22 August 2000, 3 September 2003	1,107
610	3	13 June 2003, 19 July 2007, 23 July 2007	1,501

different years, but this individual was not used for mark-recapture analysis of population abundance estimation. Three of these 15 individuals were resighted both during the same field season and between separate field seasons. While field effort ranged from late April to early October, most of the resightings of individuals occurred between June and August, suggesting greater site fidelity in these months.

Overall, the average number of whale identifications per year was 10 (± 5.19 SD) with a mean number of 1.7 (± 2.40 SD) resightings per year. Most resightings of the same individual were within 30 km of the original sighting; however, the entire study area was not sampled each year and thus it is difficult to determine if there was fine-scale site fidelity (Figure 2).

Mark-Recapture Population Estimate

The non-asymptotic nature of the discovery curve indicated that newly identified individuals continued to be photographed in the study area over the entire 10-y sampling period; this was true even if only unique individuals were included (Figure 3). Using only unique individuals, two open population models were assessed using *Socprog*, Version 2.4. The best fit model (lowest AIC; Table 4) estimated a population size of 43 unique individuals (28 SE) with an estimated mortality (plus mark change and permanent emigration) rate of 35.2%/y (28.1 SE). A more complex model, including a change in population size over time, had a somewhat higher AIC indicating some support for this model; however, the addition of this extra parameter did not better explain the observed data. Based on the estimated proportion of unique individuals (0.514; Table 2), the total population of minke whales in the study area over the 10-y study was estimated to be 84 individuals. Closed models were not considered as individuals likely entered the population over the 10-y study.

Discussion

Data Collection and Photographic Analysis

Over the course of this study, minke whales were sighted, photographed, and identified based on natural markings. Previous research on North Pacific minke whales indicated that dorsal fin markings, scarring, and lateral body pigmentation remained either consistent over time or are altered at a slow enough rate that researchers were able

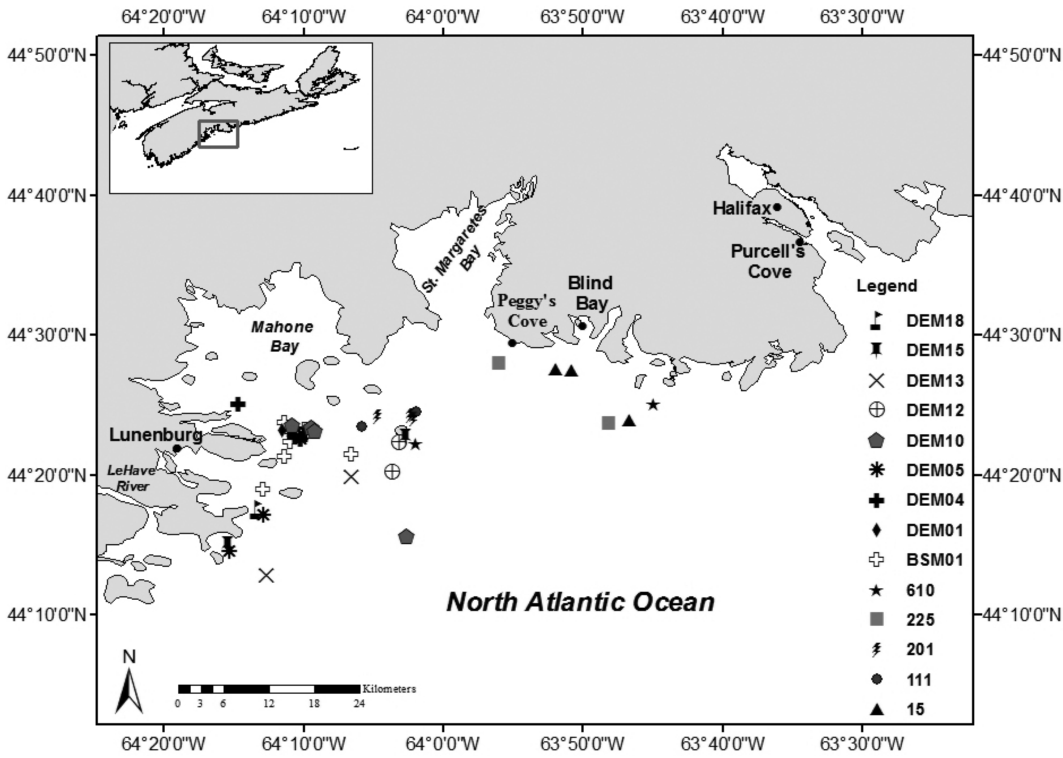

Figure 2. Multiple sightings of individual minke whales between 1997 and 2008; each symbol represents a different individual. The temporal pattern of resights can be found in Table 3.

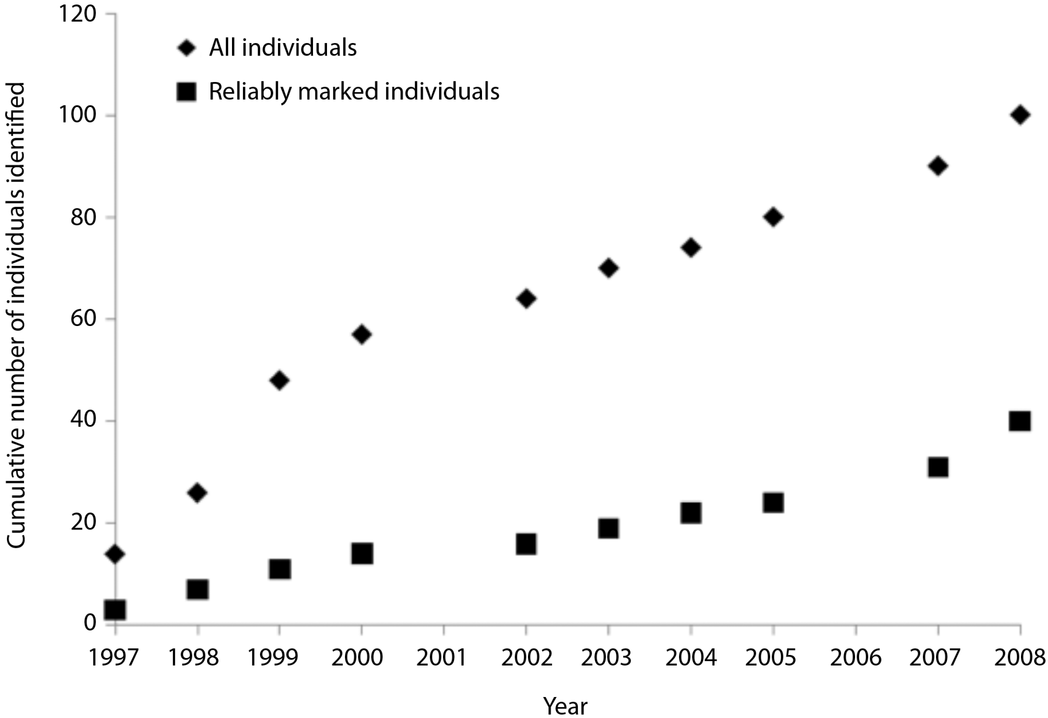

Figure 3. Discovery curve showing the number of newly identified individuals each year for all identified individuals and for unique individuals only; failure to reach an asymptote indicated that the population was not closed and that new individuals entered the population throughout the study.

Table 4. Population estimates of unique individuals using two models from *Socprog*, Version 2.4 from photographic identifications of Q ≤ 3 (with Q1 representing high-quality images; see "Materials and Methods" section) over a 10-y period (jackknife SE in parentheses)

Model	Population size	Mortality/mark change % per year	Trend % per year	AIC
Mortality	43 (28)	35.2% (28.1)	--	43.17
Mortality + Trend	42 (38)	32.2% (27.6)	7.7% (18.7)	44.80

to make re-identifications up to 11 y later (Dorsey et al., 1990). Out of the 15 resightings in the present study, only one was not based on notches on the dorsal fin (BSM01); it was based instead on a large scar along the flank.

Our study showed that the longest period between sightings of an individual minke whale was 1,501 d (June 2003 to July 2007) with little observed change in identification markings. The second longest interval was 1,107 d (August 2000 to September 2003) with little change of the fin between sightings. The alterations in the fin outlines were not sufficient to create doubt that they were the same individuals.

Site Fidelity

Fifteen minke whales were resighted over the combined 10 y of field effort. Short-term site fidelity was observed for 12 of the 15 resightings (sighted between two and three times in one field season). This could imply that individuals are not just passing through the study area but may possibly remain for days or even months at a time.

Within the study area, individuals did not display site fidelity as sightings within the same year were often widespread. The spatial and temporal patterns of individuals observed in this study were similar to those found in minke whales in the Moray Firth of Scotland where 41% of individuals were resighted within the same season and 23%

were resighted in two of more years (Baumgartner, 2008; N. Baumgartner, pers. comm., 20 November 2010). Similarly, in Scotland, most of the resightings were less than 30 km from the original sighting. Most sightings of minke whales occurred within this same 30 km section of coastline; however, some resightings were clustered, suggesting some site fidelity (Baumgartner, 2008). Minke whales within the North Pacific, however, displayed small-scale site fidelity. Early research within the San Juan Islands in Washington State suggested the presence of three non-overlapping subregions (Dorsey, 1983). An expanded study along the west coast of North America (San Juan Islands, Washington; Monterey Bay, California; northern Vancouver Island) found two of the three study sites (San Juan Islands and Monterey Bay) displayed strong site fidelity of individuals to particular subregions (Dorsey et al., 1990). Within Monterey Bay, minke whales were observed to turn around as they approached the border of a particular subregion. A total of 31 minke whales (56.4%) were resighted over 2 y, while 12 minke whales (21.8%) were resighted over 5 y (Dorsey et al., 1990). With all of these studies, including this one, it is likely that expansion of the study area may indicate larger area use by minke whales over long-time scales.

While 35% of reliably identified individuals were resighted, 65% were not. A lack of overall site fidelity to the study area is somewhat speculative because of the varied field time during the overall study. Low site fidelity could signify an unreliable or low prey density distribution. However, linking prey abundance to site fidelity in this study is hypothetical because no data were gathered concerning prey while on-effort. In the northern North Atlantic, minke whales consume the most abundant prey species during the season and have been observed to adaptively switch to plankton, or other prey species, if herring (*Clupea harangus*), capelin (*Mallotus villosus*), and cod (*Gadus morhua*) abundances are low (Schweder et al., 1998). However, minke whales display reluctance to feed on plankton when other prey choices are available, thus indicating a slight prey preference (Skaug et al., 1997).

Other possible reasons for low site fidelity could be a limited sample size (temporal under-sampling) or a much larger home range than the current study area (spatial under-sampling). Minke whales were most intensively sampled during the summer months, although they were also seen at other times of the year (Simard et al., 2006). Future research should include more on-effort field days per year and the expansion of the area studied.

Mark-Recapture Population Estimate

Based on a population model that only includes mortality, the estimated number of unique individuals was 43 (28 SE), with an estimated mortality rate of 35.2%/y (28.1 SE). Estimated mortality includes all losses of individuals to the population and thus also includes permanent emigration and mark loss. The restriction to only high-quality photographs of unique individuals attempted to reduce the mark loss, although it is still likely that some individuals suffered mark change which prohibited them from being re-identified. Given the low resighting rate for minke whales, it is likely that many of these individuals permanently left the study area. It is also likely that some of the mortality rate could be attributed to the low field effort during the overall study.

Approximately 51% of the minke whales in the study area were unique and thus the total population of minke whales was estimated to be 84 individuals. This mark-recapture estimate was based on relatively few individuals (only 40 unique individuals), 14 of which (35%) were resighted during this study. Additional data would certainly improve this population estimate; however, this is the first attempt to estimate population size within the study area using mark-recapture based on photo-identification techniques.

While no population estimates using similar methods are available to compare with this study, several line transect studies have been conducted in the Western North Atlantic. In 2006, the NMFS estimated abundance for the Canadian Eastern Coastal Stock of minke whales from aerial surveys with a study area that extended over 10,000 km (Waring et al., 2009); the current study area encompassed about 17% of the NMFS study area (approximately 1,800 km^2). After approximating the density of estimated minke whales (overall estimated population size over the overall study area size) within the two study areas, NMFS's estimate yielded a density of minke whales six times higher than this study (0.31 minke whales/km^2 vs 0.046 minke whales/km^2, respectively). A higher density in the NMFS study could be attributed to minke whales congregating more frequently in areas outside of the current study area. A more recent survey, for which only preliminary analysis is available, indicates a density of 0.047 minke whales/km^2 on the Scotian Shelf and Gulf of Saint Lawrence with an overall population size of 1,526 (95% CI 1,021 to 2,279) on the Scotian Shelf (Lawson & Gosselin, 2009). This Canadian survey density is very similar to our study results and lower than the NMFS survey, which may indicate a higher density of minke whales in U.S. waters. Alternately, differences in population studies could be due to differences in methodology.

One key assumption of most mark-recapture studies is that all animals have an equal probability of being captured (Calambokidis & Barlow, 2004). Mark-recapture through photographic identification might violate this assumption: individuals can differ in behavior (e.g., individual tendencies to avoid/approach boats), habitat use patterns, morphology, and mark distinctiveness (Whitehead, 2001; Calambokidis & Barlow, 2004). Mark-recapture is an important and accurate method of estimating cetacean abundance. However, limited and irregular geographic sampling can lead to bias causing severe underestimation (Calambokidis & Barlow, 2004). It is feasible that this population estimate is an underestimation, and the population size may be higher providing a population density more similar to that found by Waring and colleagues (2009).

While the sample size for this study was small, the results indicate that photo-identification can be used to estimate minke whale population sizes. In addition, minke whales in the Northeast and Northwest Atlantic appear to show similar residency patterns that are different from those found in the North Pacific. Continued long-term photo-identification in the study area is required to improve this population estimate and to properly assess the degree of site fidelity exhibited by minke whales found in the area. Future studies should compare identifications made by other researchers across the Atlantic, thereby increasing spatial scale and sample size, providing more accurate home range and abundance estimates for minke whales.

Acknowledgments

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