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Abundance of the Gulf of Maine/ Bay of Fundy Harbor Porpoise Based on Shipboard and Aerial Surveys during 1999

by

Debra Palka

May 2000

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Debra Palka

Woods Hole Lab., National Marine Fisheries Serv., 166 Water St. Woods Hole, MA 02543-1026

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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ABSTRACT

The Northeast Fisheries Science Center (NEFSC) conducted a line transect sighting survey that covered waters from Cape Cod to the Gulf of St. Lawrence during 28 July to 31 August 1999. An airplane and ship surveyed 8,212 km of track lines within a region of 225,400 km^2. Over 91% of the survey time was conducted in sighting conditions less than or equal to Beaufort sea state two. In total, 12 cetacean species, 2 seal species, and 2 turtle species were detected. The abundance estimate (and CV) of harbor porpoise was 89,700 (CV=22%). This estimate is greater than previous estimates made in 1991, 1992, and 1995. The 1999 estimate is significantly different from only the smallest estimate, which was made in1991. The main difference between the 1999 and previous surveys was in 1999 an additional region of 12,500 km^2 had harbor porpoise present. Within the sub-region surveyed during all years, the 1999 encounter rate was less than that from 1995 and greater than that from 1991 and 1992, the estimates of *g(0)* and average group size were similar for all years, and the 1999 effective strip half-width, and density estimates were slightly larger than that from previous years. The inter-annual changes in abundance could be due to experimental variability, population growth, small-scale changes in distribution of harbor porpoise and/or their prey, heterogeneities due to, for example, inter-annual differences in the observer skills or sighting conditions, or, most likely, some combination of these. Because the region where harbor porpoise were detected in 1999 was slightly larger than that from previous surveys, the time interval between surveys is fairly long (4 to 9 years), and the possibility of a positive growth rate, the best current abundance estimate for the Gulf of Maine/Bay of Fundy harbor porpoise stock is 89,700 (CV=22%), the 1999 estimate not averaged with other years. The 1999 and previous abundance estimates are minimum estimates because the shipboard surveys were not corrected for effects from responsive movement or dive time.

INTRODUCTION

The 1994 Amendments to the Marine Mammal Protection Act (MMPA) mandates periodic assessments of all cetacean stocks in US waters. To fulfill this mandate for the Gulf of Maine/Bay of Fundy harbor porpoise stock, the National Marine Fisheries Service (NMFS) has conducted line transect abundance surveys during the summers of 1991, 1992, 1995, and 1999 and provided annual estimates of harbor porpoise by-catch from US sink gillnet fisheries. As well, incidental takes of by-catch in the Canadian sink gillnet and herring weir fisheries have also been documented. Abundance estimates increased from 37,000 in 1991 to 74,000 in 1995 (Table 1A; Smith *et al.* 1993, Palka 1995a, Palka 1996a). By-catch in the US Northeast sink gillnet fishery decreased from 2,900 animals in 1990 to 332 in 1998 (Table 1B; Bravington and Bisack 1996; Bisack 1997; Rossman and Merrick 1999). Harbor porpoise by-catch in the US mid-Atlantic coastal gillnet fisheries varied from a low of 103 in 1995 to a high of 572 in 1997 (Rossman and Merrick 1999). By-catch in the Canadian sink gillnet fishery decreased from 424 in 1993 to 10 in 1998 (Trippel *et al.* 1996, 1999). By-catch in the Canadian herring weir fishery decreased from 33 observed takes in 1993 to 2 in 1998 (Waring *et al.* 1999). Study area, field procedures and analysis methods used in the 1999 abundance survey were similar to those used during previous surveys (Smith *et al.* 1993, Palka 1995a, Palka 1996a). This paper presents a description of the field procedures, analysis methods and results from the 1999 survey and compares the abundance estimates from 1991 to 1999.

METHODS

Study Area

The study area (225,400 km^2) extending from the eastern Scotian shelf to the southern Gulf of Maine (Figure 1) was surveyed by ship and airplane. A research ship, *R/V Abel-J*, surveyed the shallow waters (to approximately 100m) of the northern Gulf of Maine, western Scotian Shelf, and lower Bay of Fundy (30,300 km^2; Figure 1). An airplane, a NOAA Twin Otter, surveyed the deeper waters of the region surveyed by the ship and the waters from the coast to the 2750 m depth contour on the eastern Scotian Shelf (195,100 km^2; Figure 1).

The study area was composed of eight strata defined by harbor porpoise density, location, and survey platform (Figure 1). Strata surveyed by the airplane that had a very low expected harbor porpoise density were the Georges Bank/southern Gulf of Maine (SGOM) and eastern Scotian shelf (ENS) strata. Strata surveyed by the airplane that had an expected low density were the central Gulf of Maine (CGOM), upper Bay of Fundy (UBOF), and southern Scotian shelf (SNS) strata. Strata surveyed by the ship that had an expected intermediate density were the Maine bays (BAYS), and coastal waters of Maine and Nova Scotia (COAST). The stratum with the highest expected density, surveyed by ship, was the lower Bay of Fundy (LBOF) stratum.

The shipboard survey was conducted between 28 July and 31 August 1999 and the aerial survey was conducted between 10 and 29 August 1999. Within a stratum, track lines were approximately uniformly distributed with lines generally running perpendicular to the coastline; thus running through the expected density gradient, as recommended by Buckland *et al.* (1993) (Figure 1).

Field Methods - Ship

The survey was conducted while the ship traveled at 9-10 knots in Beaufort sea states of three and less. Data were collected by two "independent" teams to estimate *g(0)*, the probability of detecting a group on the track line. Each team consisted of four people, where three were on-duty and the fourth on break. On-duty observers used naked eye to scan for marine mammals and each observer recorded their own sightings. Observers within a team rotated positions every 30 minutes and remained with that team and location for the entire survey. The "upper" team was located in a crow's nest 14m above the sea surface at the bow of the ship; the "lower" team was in a lower crow's nest that was 9m above the sea surface. The area in front of the ship from 90° port abeam to 90° starboard abeam was searched, where 0° was defined as straight ahead on the track line.

Sightings data were recorded by each team on a hand-held computerized data entry system, similar to that described in Garrett-Logan and Smith (1997). Sightings data included time, bearing and distance to the initial position of the group, species composition of the group, best, high and low estimate of group size, behavior, sighting cue, and swim direction of the group when initially detected. Species were identified to the lowest taxonomic level feasible. Higher taxonomic groups include unidentified large whale and unidentified porpoise/dolphin. To facilitate determining which groups of animals were detected by both teams, information on the position and swim direction were recorded multiple times for a group when possible; especially at times when the swim direction changed as the group approached the ship.

Effort and environmental data were recorded on two other computers. A computer on the bridge that was connected to a differential GPS and bridge instruments collected information on the ship's location (position, speed and course) and on environmental conditions (wind speed and direction, depth, surface temperature, and drift set and direction). This information was collected once a minute. In addition, the Chief Scientist recorded, on another computer, effort data (observer's position) and other environmental conditions (swell height and direction, Beaufort sea state, direction of sun, magnitude of glare, and visibility). This information was recorded when any of the factors changed.

In conjunction to the usual line transect data mentioned above, two types of ancillary data were collected that could be used to reduce bias and increase the precision of the abundance estimate. One type of ancillary data were harbor porpoise vocalizations recorded by a hydrophone trailing behind the ship. Because the hydrophone's ability to accurately record vocalizations does not change with weather conditions to the extent that the ability of visual observers to detect harbor porpoise deteriorates with increasing Beaufort sea state, it is possible that the joint analysis of the visual and passive acoustic data could lead to a less biased abundance estimate. This study is currently underway.

The second type of ancillary data were harbor porpoise sightings detected using 25x150 power binoculars in waters ahead of the region the visual observers were surveying. It is likely that harbor porpoise detected far from the ship will not be actively avoiding the ship. It is known that if animals avoid the sighting platform before they are detected by visual observers than the estimated abundance will be negatively biased. If the binocular observer detected harbor porpoise before they reacted to the ship, then a more reliable abundance estimate could be produced by analyzing the data collected by the visual and binocular observers in combination. These data will be analyzed in the future.

Field Methods - Airplane

Surveying was conducted when Beaufort sea state conditions were less than or equal to three and visibility was greater than 3.7 km (2 nautical miles). The airplane flew 182m (600 ft) above sea surface at 200 km/hr (110 knots). The airplane stayed on the track line (i.e., was in 'passing mode') except when an unidentified group or individual was within 3.7 km of the track line. On these occasions the plane broke effort and circled the group to correctly identify the species and obtain accurate group size estimates. If another marine mammal group was detected during the time away from the track line, the new group was recorded as 'off effort' and was not used in the abundance estimate.

The observation team consisted of four on-duty people and one person at rest. The on-duty compliment consisted of one observer on each side of the airplane, each viewing through a bubble window, one observer viewing through a window in the belly of the plane, and one person recording data on a lap-top computer. The recorder was dedicated to this job for the entire survey. The remaining four scientists rotated approximately every 30 minutes between the observation windows. All observers scanned using the naked eye and used binoculars, if needed, to confirm a species identification or group size.

Data recorded for each sighting included: time to the nearest second, latitude and longitude (automatically recorded by the plane's GPS which was connected to the data recording computer), species composition, best estimate of group size, best estimate of number of calves, and angle of inclination to the animal group. The angle of inclination, measured when the group passed abeam of the plane, is defined as the angle between the line of sight to the animal group and a vertical line straight down, and measured by either an electronic protractor (inclinometer) or calibrated markings on the window which delineated angles into 10° bins. The inclinometer was always used for harbor porpoise sightings.

Data collected on effort and environmental conditions included: time (to the nearest second) of data being entered and its corresponding position, the location of each scientist, Beaufort sea state, percent of cloud cover, and for each observation position, magnitude of glare (none, slight, moderate or excessive) and overall viewing quality (excellent, good, moderate, fair or poor). As weather conditions changed, or at the beginning of each transect, environmental data were updated with the time and position of the update. Time and position information were automatically recorded every four seconds. Surface water temperature was measured using an infra-red temperature sensor mounted in the belly of the aircraft. The temperature was measured every second and a one-minute average was recording on another computer dedicated to logging this data.

To estimate the probability of detecting a harbor porpoise group on the track line, *g(0)*, two approaches were attempted. First, the Hiby circling procedure (Hiby 1999) was followed when any harbor porpoise sighting was detected. This protocol requires that 20 seconds after a harbor porpoise group was detected the plane leaves the track line (recording the time) and circles back to a spot on the track line prior to the harbor porpoise sighting. During the circling period the observers were off-effort. When the plane returned to the track line (and the time was recorded) observers went back on-effort to re-search the same section of track line where the harbor porpoise was detected. Given the time and position of the original and any re-sightings, the Hiby algorithm determines the probability the sightings are the same group. These probabilities are then used to estimate *g(0)*.

The second approach was similar to that conducted during the 1995 survey (Palka 1996a). That is, both the ship and airplane surveyed the same track lines on the same day (Overlap stratum in Figure 1). The estimate of *g(0)* from the plane is:

$$g(0)_{plane} = \frac{\textit{corrected density from ship}}{\textit{uncorrected density from plane}} \tag{1}$$

where the calculation for the density estimates are given in the next section.

Analytical Methods

The standard formula (Buckland *et al.* 1993) was used to estimate the uncorrected density, D_{ij}, within stratum i for team j:

$$D_{ij} = \frac{n_{ij} \cdot s_{ij}}{2\, L_i \cdot ESW_j} \tag{2}$$

where n_{ij} = number of groups detected in stratum i by team j,
s_{ij} = expected group size in stratum i estimated by team j,
ESW_j = effective strip half-width for team j
= 1/sighting probability density at zero perpendicular distance for team j,
L_i = length of transect line in stratum i.
j = team: *plane*=single team on the plane, *upper*=upper team on ship, and *lower*=lower team on ship.

To account for group-size bias, the regression method (from Buckland *et al.* 1993) as implemented in the computer program DISTANCE version 2.03 (Laake *et al.* 1993) was used. Group-size bias results when the probability of detecting a group at a particular distance is dependent on the size of the group. For example, in the case where at far distances, the probability of detecting a large group is significantly higher than the probability of detecting a small group at the same distance, the arithmetic mean of the group size is biased towards larger groups and so the abundance estimate is biased high. In this study, both the arithmetic mean group size and group size as estimated by the regression method were computed. If the regression-corrected mean was significantly different than the arithmetic mean, the corrected mean was used as the expected group size, s_{ij}. However, if the difference between the two means was insignificant, then the arithmetic mean was used as the expected group size.

The *ESW* was estimated from the best fitting detection function of the perpendicular distances; that is, the model with the lowest Aikake Information Criteria (AIC). The choices of models included the uniform model with cosine adjustments, half-normal with hermite adjustments, and the hazard model with cosine adjustments. The computer program DISTANCE was used to fit these detection functions.

The probability of a shipboard team detecting a group on the track line, *g(0)*, was estimated from the shipboard data using the modified direct duplicate (DD) method (Palka 1995a), as was done for previous abundance estimates. The DD method was programmed in Splus. The parameter *g(0)* for the airplane was estimated using the Hiby procedure (Hiby 1999).

The shipboard density estimate, corrected for *g(0)*, within stratum *i*, $D_{c.i.ship}$, was estimated by:

$$D_{c \cdot i \cdot ship} = \frac{D_{i \cdot upper} \bullet D_{i \cdot lower}}{D_{i \cdot duplicate}} \qquad (3)$$

where D_{upper} = density using only the upper team's data in Eq. 2
D_{lower} = density using only the lower team's data in Eq. 2
$D_{duplicate}$ = density using only first sighting of harbor porpoise groups that were seen by both the upper and lower team in Eq 2.

Duplicate sightings were determined by using the location, time and swim direction of each team's sightings in a Visual Basic program that mapped out the position of each sighting relative to the ship at the time of each sighting. For each time of a sighting, the predicted position of previously detected groups were also plotted. The predicted position was estimated by the swim direction, time and location of previous sightings, along with the ship's speed and estimated swim speed of the group. The swim speed could be adjusted for each sighting. To facilitate determining duplicate sightings, information on the position and swim direction were recorded multiple times for some groups, particularly for those groups where the swim direction changed as the group approached the ship. Only the initial sightings were used in the density estimates, the follow-up sightings were used only to determine duplicate sightings.

The plane density estimate, corrected for $g(0)$, within stratum *i*, $D_{c.i.plane}$, was estimated by:

$$D_{c \cdot i \cdot plane} = \frac{D_{i \cdot plane}}{g_{plane}(0)} \tag{4}$$

The total abundance of harbor porpoise in stratum *i* for *j* (the airplane or ship), N_{ij}, was estimated as:

$$N_{ij} = D_{c \cdot ij} \bullet A_i \tag{5}$$

where A_i = area of stratum i.

The total abundance from all strata was the sum of the abundance from each stratum.

The coefficient of variation (CV) of density within a stratum was estimated using bootstrap re-sampling techniques (Efron and Tibshirani 1993). The aerial estimates were obtained by using the bootstrap option in DISTANCE and the shipboard estimates were obtained by using the bootstrap function in Splus. For shipboard estimates, the re-sampling unit was a day of surveying within a stratum, with the constraint that the sum of track length within a stratum in a bootstrap replicate was approximately the same length of the tracks within the original stratum. For the plane estimate, the empirical formula for the CV of density within stratum *i* for team *j*, CV(D_{ij}), was used where the CV(*ESW*) was estimated by bootstrapping the observations within a stratum:

$$CV(D_{ij}) = CV\left(\frac{n_{ij}}{L_i}\right) + CV(s_{ij}) + CV(ESW_j) \tag{6}$$

The CV of the total abundance, CV(N_T), for either platform (ship or airplane) and both platforms was calculated using:

$$CV(N_T) = \sqrt{\frac{var(D_T)}{D_T^2}} \tag{7}$$

where

$$var(D_T) = \sum_{i=1}^{m} \left(\frac{A_i}{A_T} \bullet SE(D_i)\right)^2 \tag{8}$$

$$D_T = \sum_{i=1}^{m} \frac{A_i}{A_T} \bullet D_i \tag{9}$$

and D_T = weighted total density from a platform
$SE(D_i)$ = standard error of D_i
A_T = total area of all strata surveyed by that platform
m = maximum number of strata surveyed by that platform.

RESULTS

The plane and ship surveyed 8,212 km of track lines (Figure 1) within 225,400 km^2. The *R/V Abel-J* surveyed 2,563 km of track lines in an area of 30,298 km^2 (Table 2) and the NOAA Twin Otter airplane surveyed 5,649 km of track lines in an area of 195,103 km^2.

The survey was conducted during good viewing conditions. Nearly all (91%) the track lines were surveyed in sea conditions of Beaufort 2 and less (Table 3). The airplane surveyed 58% of their track lines in Beaufort 1 and less, while the ship surveyed 67% of their track lines in Beaufort 2.

During the shipboard survey there were 10 positively identified species of cetaceans, 2 seal species and 2 turtle species (Table 4). During the aerial survey there were 8 positively identified species of cetaceans, 1 seal species, and 2 turtle species (Table 4). The upper team on the ship detected 599 harbor porpoise groups, the lower team detected 563 groups, and the aerial team detected 31 harbor porpoise groups. Harbor porpoise were detected in the strata where they were seen previously (LBOF, COAST, BAYS, CGOM). In addition, they were found in higher densities then expected in two strata outside the typical harbor porpoise habitat: the upper Bay of Fundy (UBOF) and the southern Nova Scotian shelf (SNS) (Figure 2). Only abundance estimates from harbor porpoise are presented in this document.

The *ESW* for shipboard harbor porpoise sightings from the upper and lower teams were 375 m (%CV=5.0) and 237 m (%CV=5.6), respectively. The *ESW* from duplicate sightings was 270 m (%CV=7.1). The best fitting detection function used to estimate the *ESW* for the upper team was the uniform model with one cosine adjustment (χ^2= 2.47 p=0.78); the hazard model with one cosine adjustment best fit the lower team data (χ^2= 0.82 p=0.85); and the half-normal model with no adjustments best fit the duplicate sightings data (χ^2=10.32 P=0.07) (Figure 3a, 3b, and 3c). The truncation perpendicular distance for the shipboard detection curves was 700m. The *ESW* for the aerial harbor porpoise sightings was 165 m (%CV=8.9). The uniform model with one cosine adjustment best fit the aerial data (χ^2=5.14 p=0.40), where the truncation perpendicular distance was 274 m, which was the farthest distance of a harbor porpoise sighting (Figure 3d).

The average group sizes, as recorded by the upper and lower teams from the ship, varied more between strata than between teams (Table 5). The average group size was highest in the Coastal stratum (3.16 and 3.18 from the upper and lower teams, respectively) and lowest inside the Bays (1.74 and 1.54 from the upper and lower teams, respectively). The average group size from the aerial survey was 2.69 (%CV=11). Because there were so few sightings within the aerial strata, it was not possible to accurately determine if there were stratum differences in the average group size of aerial sightings. Within all strata, except one, there was no indication of group-size bias in the shipboard or aerial data. Thus, the expected group size in the equation 2 was defined as the arithmetic mean group size. The group size data collected by the lower team while surveying in the lower Bay of Fundy had an indication of group-size bias, where the uncorrected group size was 3.15 (%CV=5.6) and the bias-corrected average group size was 2.73 (%CV=2.5). The bias-corrected average was used in the abundance estimate in this case.

The estimates of *g(0)* for the upper team on the ship varied from 0.248 (%CV=17) in the Bays stratum to 0.387 (%CV=16) in the Coastal stratum. For the lower team, the estimate of *g(0)* varied from 0.493 (%CV=28) in the Bays stratum to 0.569 (%CV=13) in the Coastal stratum (Table 5). When both teams were surveying together, it was estimated they missed from 26% (1-0.736) to 38% (1-0.619) of the harbor porpoise groups on the track line, depending on the stratum (Table 5)

The estimate of *g(0)* for the aerial team using the Hiby circling methodology was not stable because there was an insufficient number of re-sightings. There were 27 harbor porpoise sightings that triggered the circling procedure and 5 groups of harbor porpoise were detected on the second time the track line was searched. Of the five possible re-sightings, two had a high probability of being a re-sighting of the same group seen initially. More surveys using this methodology in the same airplane are needed to accurately estimate *g(0)*.

The other approach to estimate *g(0)* for the airplane was to compare the *g(0)*-uncorrected estimated density from the airplane to the *g(0)*-corrected estimated density from the ship in a region where both platforms surveyed the same track lines on the same day. Only three harbor porpoise groups were seen by the ship's teams during the day surveying the Overlap stratum. Thus, there were insufficient data to calculate *g(0)* for the aerial team using this approach. Because both approaches attempted during 1999 to estimate *g(0)* were unsuccessful, the value of *g(0)* for the aerial team that was estimated during 1995 was used. It is assumed this value is still valid because it was estimated using the same airplane, some of the same observers, was in the same region and time of year, and for the same target species, harbor porpoise. In conclusion, the estimate of *g(0)* for aerial harbor porpoise sightings was assumed to be 0.24 (%CV=86), the value estimated from the 1995 survey (Palka 1995a).

The lower Bay of Fundy (LBOF) stratum had the highest estimated density, 4.18 harbor porpoise/km^2 (Table 6). The upper Bay of Fundy (UBOF) stratum had the lowest positive density, 0.25 porpoise/km^2; this was the first time the UBOF stratum was surveyed. In total, the abundance estimate was 89,739 (%CV=22) harbor porpoise (Table 6).

DISCUSSION

Comparison between 1999 and previous estimates

The 1999 abundance estimate is higher than previous estimates (Table 1), however it is significantly different from only the lowest abundance estimate (z=2.32 p=0.0102), that estimated in 1991. There is an increasing trend in the point estimates over the years (Figure 4); thus warranting a more detailed investigation to determine possible reasons for the inter-annual differences.

The Coastal, Bays, Central Gulf of Maine, and Lower Bay of Fundy strata constitute the region where it was expected all, or nearly all, of the Gulf of Maine/Bay of Fundy harbor porpoise stock would reside during the survey time period. This "main" region was surveyed in all years: 1991, 1992, 1995 and 1999. One possible reason the1992 point estimate was nearly twice the 1991 point estimate, was the harbor porpoise habitat was actually larger than the "main" region. To address this in 1995 and 1999, aerial surveys were conducted in waters surrounding the "main" region (Figures 2 and 5). During 1995, two harbor porpoise groups were detected just outside the "main" region on Browns Bank (Figure 5) and during 1999, eleven harbor porpoise groups were seen outside the "main" region (Figure 2). Most of the 1999 sightings were in habitats not previously surveyed: the Northern Bay of Fundy and Southern Nova Scotia strata. In 1999, 14% of the estimated total abundance was in these previously un-surveyed strata. If animals always existed in these previously un-surveyed strata, then abundance estimates from the 1991 to 1995 surveys may have missed a portion of the stock; consequently, it would not be possible to determine trends by directly comparing the actual abundance estimates. However, if the "outside" regions are inhabited only periodically, for example, because of changing environmental factors, or just recently, for example, because of an increasing population, then it would be possible to directly compare the actual abundance estimates. To address both of these possibilities, two approaches were explored: (1) only the "main" region surveyed during all years were compared, and (2) trends of estimated abundances were examined.

Components of the abundance estimate from the "main" region were examined to identify patterns (Table 7). The average expected group size and *g(0)* varied little from year to year. The total area of the region defined as the "main" region varied by less than 6% between years. The areal difference was due to several reasons. First, methods of estimating area have improved over the years as mapping computer programs have become available. Second, due to weather and logistical reasons, regions could not always be surveyed in their entirety every year. Lastly, small-scale harbor porpoise distribution changes between years required changing the geographic area within the high, intermediate, and low density strata. In particular, the density of harbor porpoise in the region south of Grand Manan and east of Maine (Overlap stratum in Figure 1) was assigned to the CGOM stratum (low density stratum) in some years (1991 and 1999) and to the Coastal stratum (intermediate density stratum) in other years (1992 and 1995). Thus, the sum of the Coastal and CGOM areas for the different years are more similar than the areas of each stratum separately.

The difference between the 1995 and 1999 estimated *ESW* for the airplane team was not statistically different. *ESW* estimates for a shipboard team varied between years and from the other team on the ship. Differences between teams were expected because teams are at different heights above the water and so sightability also differ. However, within a team between years, the difference between the largest *ESW* and the smallest *ESW* for that same team were statistically different. These differences could be due to model mis-specification, observer skill heterogeneities, or sighting condition heterogeneities. The data were tested for model mis-specification, so this is unlikely to be a major cause for the differences. The teams were on the same ship and on the same platforms, so these potentially influential factors have not changed over the years. However, the observers were not the same every year and sighting conditions also varied from year to year (Table 8). Future work should incorporate co-variates into the *ESW* estimation to reduce potential biases and thus, possibly reduce inter-annual variability.

The component with the largest inter-annual variability was the encounter rate (Table 7). In all the years, the overall large-scale pattern was the same. That is, the encounter rate and corrected density was the highest in the LBOF stratum and the lowest in the CGOM stratum. However, the magnitude of the changes differed between years. The encounter rate of groups in the Bays stratum had the largest variability, from 0.009 to 0.062 groups/km^2. This stratum is small (approximately 5% of the main stock region), so it can not contribute a large amount to the inter-annual difference in the total abundance estimate. Palka (1995b) demonstrated that small-scale harbor porpoise distribution and density differences between 1991 and 1992 were correlated with small-scale changes in the surface water temperature and an index of density of herring and silver hake (common harbor porpoise prey). Thus, the inter-annual variability within a stratum could be caused by small-scale inter-annual spatial re-distributions. In the future, water temperature and other environmental factors will be investigated to determine if environmental variation can explain re-distribution and can be used to improve the abundance estimates.

Another possible reason the density estimates increased between surveys is a net population growth. Theoretical potential growth rates for this stock have been estimated at 4% (Woodley and Read 1991), 9.4% (Barlow and Boveng 1991), and 10% (Caswell *et al.* 1998). Using the four abundance estimates as reported in Table 1 and assuming a constant exponential growth rate for each year and abundance estimates with no error, the average net annual growth rate between 1991 and 1999 was 8.6% (CV=49%; Multiple R^2 of regression=0.68, p-value of H_0:rate=0 was 0.18) and 4.1% between 1992 and 1999 (CV=12%; Multiple R^2 of regression=0.99, p-value of H_0:rate=0 was 0.08). In both time periods, the estimated net growth rate (slope of the curve) was not statistically different from zero. These cases, which assume no error in the abundance estimate, are not realistic. Error in the abundance estimates can be incorporated in several ways. One approach is by weighted regression, where each abundance estimate is weighted by its inverse CV^2. By doing so, the net growth rate is 7.6% between 1991 to 1999 (CV=51%; Multiple R^2 of regression=0.66, p-value of H_0:rate=0 was 0.19) and 4.1% between 1992 to1999 (CV=13%; Multiple R^2 of regression=0.98, p-value of H_0:rate=0 was 0.08). Another approach is to use the 1000 bootstrap estimates from each year to estimate 1000 net growth rates. Using this approach, the annual net growth rate is estimated to be 3.8% between 1991 to 1999 (CV=67%, H_0:rate=0 vs H_A:rate>0 p=0.16) and 4.7% between 1992 to 1999 (CV=78%, H_0:rate=0 vs H_A:rate>0 p=0.29). Incorporating error about the abundance estimates increases the CV of the growth rate and down weights the low 1991 abundance estimate that has the largest CV. The net effect of accounting for measurement error is that it is even less likely that the stock's net growth rate is different than zero.

The above estimated net growth rates include natural and human-induced mortalities. To estimate natural growth rates, the human-induced mortalities must be added back into the above net growth rates. The annual percent of the stock removed due to human interactions is the ratio of by-catch to abundance: 0.053, 0.018, 0.022, and 0.009[1] for 1991, 1992, 1995 and 1999, respectively. The average percent removed due to human interactions was 2.5% (CV=77%) during 1991 to 1999 and 1.6% (CV=41%) during 1992 to 1999. Natural growth rates can then be estimated by adding the average percent removed due to human interactions to the net natural and human-induced growth rates. By doing this, the estimated natural growth rate was 6.3% (=3.8+2.5) (CV=51%) between 1991 to 1999 and 6.3% (=4.7+1.6) (CV=59%) between 1992 to 1999. However, due to the high CV's, the estimated natural growth rates do not differ significantly from zero (for two-sided z-test p=0.05 and p=0.09 for 1991-1999 and 1992-1999, respectively).

With four surveys conducted within nine years, it is difficult to statistically detect a small trend. That is, assuming exponential growth, a one-tailed test for positive growth, CV= 0.20, and α=0.2, the power (1-β) of detecting a 4% growth rate is 0.51. In other words, under these conditions, the minimum rate of change that is detectable with 90% power is a 9.6% growth rate. Thus, to detect a population trend with statistical confidence, future work could include reducing the CV's of the abundance and by-catch estimates, investigating if the 1991 abundance estimate was more negatively biased than the recent years, conduct more surveys in the future, or incorporate the by-catch estimates and their CV's into a more detailed population model.

Previous best abundance estimates for this stock were averaged over several years. Because the 1999 survey region covered more harbor porpoise habitat, the time interval between surveys is long (4 to 9 years), and the possibility of a positive growth rate, the best current abundance estimate for the Gulf of Maine/Bay of Fundy harbor porpoise stock is 89,700 (CV=22%), the 1999 estimate, not averaged with other years.

Potential biases in the abundance estimates

The abundance estimates from 1999 and previous years have moderate levels of uncertainty associated with them, as reflected in CVs of 20-29% (Table 1). The largest component of this variability is from the encounter rate (*n/L*) (Table 9; Palka 1995a). By definition, the CV(*n/L*) should only include sampling variation. However, practically, the CV(*n/L*) includes both sampling variation and variation in the spatial distribution of the animals. The encounter rate does have spatial structure; i.e., there is evidence of a density gradient related to depth (Figure 2). Other analytical methods are needed to account for this spatial variability (i.e., the methods developed to estimate the abundance of Norwegian minke whales by Schweder *et al.* (1999) and Cooke and Leaper (1998)).

Several other possible sources of uncertainty are unaccounted for. These include porpoise avoidance of the ship, observer and/or platform heterogeneities, and effects of environmental conditions on

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[1] Because 1999 by-catch estimates are presently not available, this ratio is the 1998 by-catch estimate over the 1999 abundance estimate.

sighting rates and *g(0)*. It has been suggested that harbor porpoise avoid ships (Polacheck and Thorpe 1990). If harbor porpoise avoid the ship before they are detected by the observers on the ship, the abundance estimates will be negatively biased (Buckland *et al.* 1993). The extent of this bias depends on how many harbor porpoise groups react before being detected. To investigate this, during 1999 harbor porpoise far from the ship were detected by another team of observers who surveyed using 25x150 power binoculars. These data will be used to estimate abundance using the Buckland-Turnock method (Buckland *et al.* 1993) and the modified Buckland-Turnock method (Palka and Hammond, in review).

Other potential sources of bias are heterogeneities due to differences between observers, platforms and weather conditions. These types of heterogeneities can cause negative or positive biases, depending on the type of heterogeneity. The extent of bias depends on the extent of the differences. Palka (1996b) reported that estimates of *g(0)*, encounter rate and density were influenced by sighting conditions as defined by Beaufort sea state. As Beaufort sea state increased (weather worsened), estimated density decreased. To account for heterogeneities, these factors need to be explicitly modeled using methods similar to Cooke and Leaper (1998) or Hammond *et al.* (1995).

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Table 1A. The estimated abundance, % coefficient of variation (%CV), and 95% confidence interval of the Gulf of Maine/Bay of Fundy harbor porpoise stock and area surveyed during 1991 to 1999.

Year	Abundance (number of animals)	% CV	95% Confidence Interval	Area (km^2)
1991	37,500	29	26,700 - 86,000	47,700
1992	67,500	23	32,900 -104,600	45,900
1995	74,000	20	40,900 -109,100	357,200
1999	89,700	22	53,400 - 150,900	225,400

Table 1B. By-catch estimates (Byc) and percent coefficient of variation (%CV) from the US Northeast sink gillnet and mid-Atlantic coastal gillnet fisheries and the Canadian sink gillnet and herring weir fisheries from years when estimates are available.

Year	US Northeast sink gillnet		US mid-Atlantic coastal gillnet		Canadian sink gillnet[1]	Canadian herring weir[1]	TOTAL
	Byc	%CV	Byc	%CV	Byc	Byc	Byc
1990	2,900	32	–	–	–	–	2,900
1991	2,000	35	–	–	–	–	2,000
1992	1,200	21	–	–	–	–	1,200
1993	1,400	18	–	–	424	33	1,857
1994	2,100	19	–	–	101	13	2,214
1995	1,400	27	103	57	87	5	1,595
1996	1,200	23	310	31	20	2	1,532
1997	782	22	572	35	43	2	1,399
1998	332	46	446	36	10	2	790

[1] Coefficients of variation are not available from the estimates from the Canadian fisheries.

– Estimates not available because an observer program was not in place.

Table 2. The length of track line (in km) and area (in km^2) of each stratum covered by the 1999 aerial and shipboard survey.

Stratum	Track length (km)	Area (km^2)	Stratum	Track length (km)	Area (km^2)
Aerial survey			**Shipboard survey**		
Central GOM	1,108	18,510	Lower BOF	565	6,162
Upper BOF	399	4,563	Coastal	1,770	21,860
S. Nova Scotia	702	29,680	Bays	228	2,276
E. Nova Scotia	1,211	61,350			
Southern GOM	2,229	81,000			
SUB-TOTAL	5,649	195,103	SUB-TOTAL	2,563	30,298
SHIP AND AERIAL TOTAL	8,212	225,401			

Table 3. Length (and percentage) of track line surveyed in Beaufort sea state conditions 0-3 during the 1999 survey.

Beaufort sea state	Ship survey		Aerial survey	
	Track line length	%	Track line length	%
0	239	9.3	1,636	29.0
1	352	13.7	1,641	29.0
2	1,706	66.6	1,926	34.1
3	266	10.4	446	7.9
total	2,563	100.0	5,649	100.0

Table 4. Number of groups of each species detected by the shipboard and aerial teams while on effort during 1999.

Species		Number of groups		
Common name	scientific name	upper ship team	lower ship team	aerial team
harbor porpoise	*Phocoena phocoena*	599	563	31
white-sided dolphin	*Lagenorhynchus acutus*	44	42	31
common dolphin	*Delphis delphus*	0	0	4
Risso's dolphin	*Grampus griseus*	0	0	5
pilot whale, unidentified	*Globicephala spp.*	10	9	13
minke whale	*Balaenoptera acutorostrata*	105	80	11
fin whale	*B. physalus*	55	41	13
sei whale	*B. borealis*	2	3	0
fin or sei whale	*B. physlus or B. borealis*	8	38	5
humpback whale	*Megaptera novaeangliae*	40	49	7
right whale	*Eubalaena glacialis*	10	38	0
killer whale	*Orcinus orca*	2	1	0
sperm whale	*Physeter macrocephalus*	0	1	0
unid large whale	--	36	64	10
unid porpoise/dolphin	--	11	9	12
harbor seal	*Phoca vitulina*	98	99	4
grey seal	*Halichoerus grypus*	22	10	0
unid seal	--	1	11	0
leatherback turtle	*Dermochelys coriacea*	5	5	18
loggerhead turtle	*Caretta caretta*	0	0	28
hawksbill turtle	*Eretmochelys imbricata*	0	1	0
unid turtle	--	0	2	1

Table 5. For each stratum observed during the 1999 abundance survey, the number of harbor porpoise groups detected within the truncation distance, encounter rate (and %CV), average size of harbor porpoise groups (and %CV) and estimated *g(0)* (and %CV) for the upper and lower teams on the ship, the duplicate sightings detected from the ship (dups) and the aerial team.

Stratum	team	number of groups	n/L (groups/ km)	%CV of n/L	Ave group size	%CV of size	*g(0)*[1]	%CV of *g(0)*
Lower BOF	upper	217	.384	40	2.86	5.5	.313	17
	lower	227	.402	40	2.73*	2.5	.519	15
	dups	81	.143	49	3.05	2.9	.670	12
Coastal	upper	315	.178	29	3.16	3.8	.387	16
	lower	293	.166	27	3.18	4.7	.569	13
	dups	129	.073	35	3.46	3.5	.736	9
Bays	upper	31	.136	37	1.74	7.0	.248	17
	lower	39	.171	29	1.54	4.3	.493	28
	dups	11	.048	35	1.64	18.5	.619	20
Central GOM	aerial	17	.015	37	2.69	11	.240	86
Upper BOF		3	.008	58				
S. Nova Scotia		8	.011	67				
E. Nova Scotia Southern GOM	aerial	0	0	–	0	–	0	–

[1] The estimate *g(0)* for the "dups" team is the estimate of *g(0)* for both teams together.

* School size bias was present according to the regression method (Buckland *et al.* 1993).

– Not applicable.

Table 6. The 1999 density, abundance, %CV, and 95% confidence interval (CI) of the abundance of harbor porpoise within each stratum.

Stratum	Density (animals/km^2)	Abundance (number of animals)	%CV	95% CI of Abundance
Lower BOF	4.18	25,751	27	12,292 - 34,983
Coastal	1.78	39,008	18	21,085 - 43,991
Bays	1.20	2,725	39	853 - 4,864
TOTAL SHIP	2.23	67,484	15	41,089 - 75,562
Central GOM	0.52	9,629	95	7,550 - 20,288
Upper BOF	0.25	1,163	87	996 - 1,792
S. Nova Scotia	0.39	11,463	1.23	7,154 - 36,562
E. Nova Scotia	0	0	0	0
Southern GOM	0	0	0	0
TOTAL AIRPLANE	0.11	22,255	76	16,400 - 53,400
GRAND TOTAL	0.40	89,739	22	53,366 - 150,903

Table 7. Comparison of components of the abundance estimate from the 1991, 1992, 1995 and 1999 harbor porpoise surveys for the four main stock strata (LBOF, Coastal, Bays, and CGOM). The average is between the upper and lower shipboard teams. The ESW is by team (upper, lower, duplicates, and airplane).

Stratum[1]	Area (km^2)				average encounter rate (/km)			
	91	92	95	99	91	92	95	99
LBOF	5,323	7,374	5,128	6,162	.349	.309	.481	.393
Coastal	30,999	24,695	29,998	21,860	.138	.140	.262	.172
Bays	2,185	2,185	2,185	2,276	.054	.283	.543	.157
CGOM	9,172	11,662	11,662	18,510	.009	.032	.033	.062[2]
TOTAL	47,679	45,919	48,973	48,808	.047	.075	.243	.157

Stratum	average expected group size				g(0) for both teams together			
	91	92	95	99	91	92	95	99
LBOF	3.0	3.0	2.2	2.8	.73	.70	.83	.67
Coastal	2.6	2.7	2.2	3.2	.71	.73	.71	.74
Bays	3.8	2.0	1.8	1.6	.82	.73	.71	.62
CGOM	2.0	2.6	1.3	2.7[2]	.71	.73	.79	.24[2]
TOTAL	2.8	2.8	2.2	2.6	.72	.73	.74	.71[2]

Stratum	density (animals/km^2)				ESW (m)				
	91	92	95	99		91	92	95	99
LBOF	4.55	3.32	3.53	4.18	up	258	292	268	375
Coastal	0.85	1.29	1.54	1.78	low	296	257	185	236
Bays	1.66	4.02	3.48	1.20	dup	183	235	167	270
CGOM	0.07	0.20	0.18	0.52[2]	plane	--	–	184	165
TOTAL	0.79	1.47	1.51	1.58					

[1]

Stratum	Full name used this year	Name used in past
LBOF	Lower Bay of Fundy	High density
Coastal	Coastal waters of Maine and Nova Scotia	Intermediate density
Bays	Bays of Maine	Inshore
CGOM	Central Gulf of Maine	Offshore

[2] During 1999 in the CGOM stratum, the airplane was used to survey. Thus, the encounter rate and *g(0)* estimates from this year/stratum are not directly comparable to the other years within this stratum. To make 1999 more comparable to previous years, the 1999 CGOM encounter rate was corrected by it's g(0), and the 1999 total estimate for g(0) excludes the CGOM stratum.

Table 8. Length of track line (km) and cumulative percentages (Cum %) of the length surveyed by the ship in various Beaufort sea states during 1991, 1992, 1995 and 1999.

Sea state	1991		1992		1995		1999	
	km	Cum %	km	Cum %	km	Cum %	km	Cum %
0	265	7.3	356	9.6	104	1.7	239	9.3
1	1243	41.5	1558	51.6	482	9.6	352	23.1
2	1573	84.8	1276	86.0	4175	78.0	1706	89.6
3	421	96.4	467	98.6	1343	100.0	266	100.0
4	131	100.0	52	100.0	0	100.0	0	100.0
TOTAL	3634	100.0	3710	100.0	6104	100.0	2563	100.0

Table 9. Coefficient of variation (CV) and percentage of the total CV of parameters in the density equation when g(0) is assumed to equal one, using data from 1999 for the Lower Bay of Fundy (LBOF), Coastal, and Bays of Maine (BAYS) strata, using data from the upper and lower teams on the ship.

Parameter	LBOF		COASTAL		BAYS	
	CV	%	CV	%	CV	%
UPPER TEAM						
n/L	0.404	82.7	0.292	74.7	0.366	78.1
ESW	0.050	1.3	0.050	2.2	0.050	1.5
group size	0.055	1.5	0.038	1.3	0.070	2.9
g(0)	0.169	14.5	0.158	21.9	0.174	17.6
Density	0.444	100.0	0.338	100.0	0.415	100.0
LOWER TEAM						
n/L	0.400	85.5	0.268	75.7	0.289	49.4
ESW	0.056	1.7	0.056	3.3	0.056	13.7
group size	0.025	0.3	0.047	2.3	0.043	10.6
g(0)	0.153	12.5	0.133	18.6	0.284	69.0
Density	0.432	100.0	0.307	100.0	0.411	100.0

Figure 1. Track lines surveyed by ship (solid light zig-zag lines) and plane (dashed light lines) during the 28 July to 31 August 1999 harbor porpoise abundance survey.

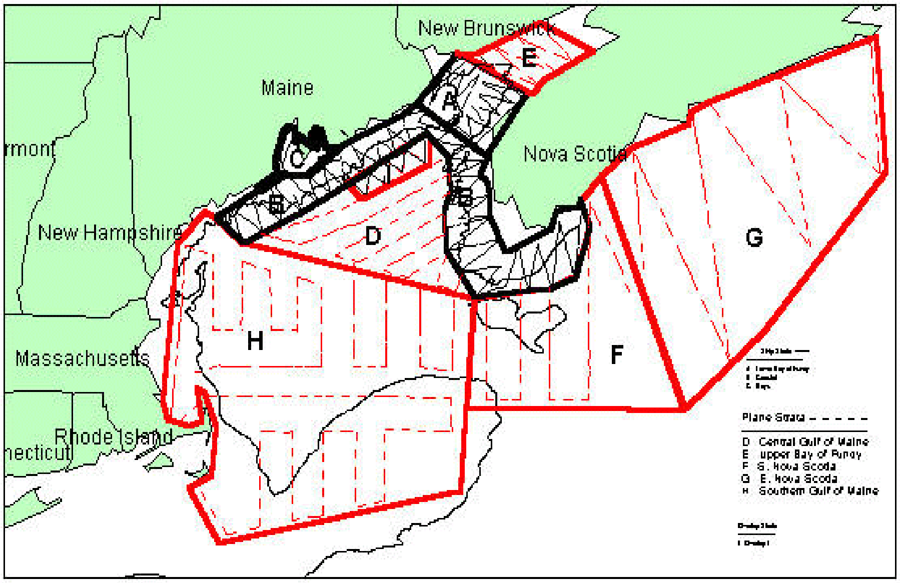

Figure 2. Location of harbor porpoise groups detected by the upper and lower teams on the ship and the aerial team during the 1999 survey.

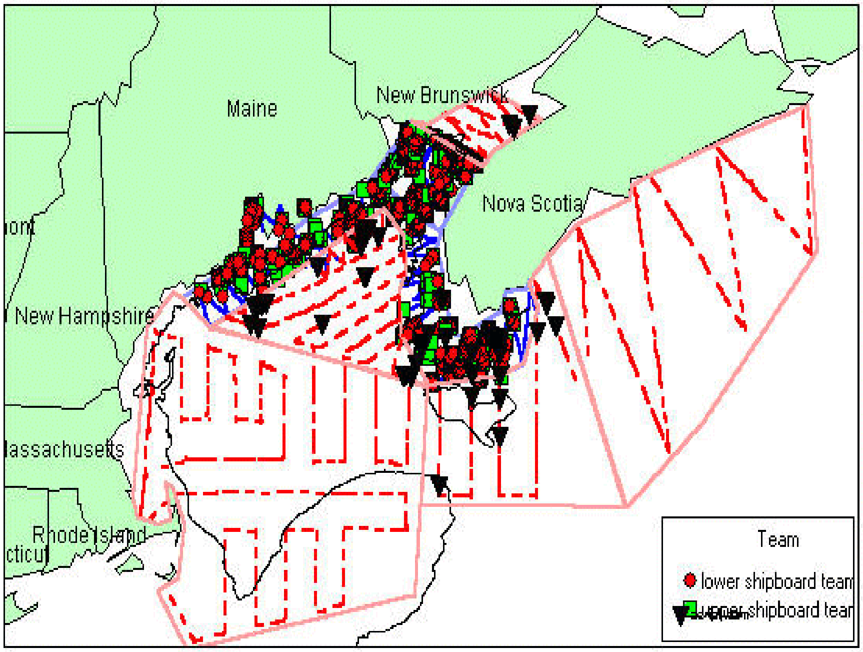

Figure 3. A histogram of the observed number of sightings dectected by perpendicular distance and the predicted detection function line. A. Upper team. B. Lower team.

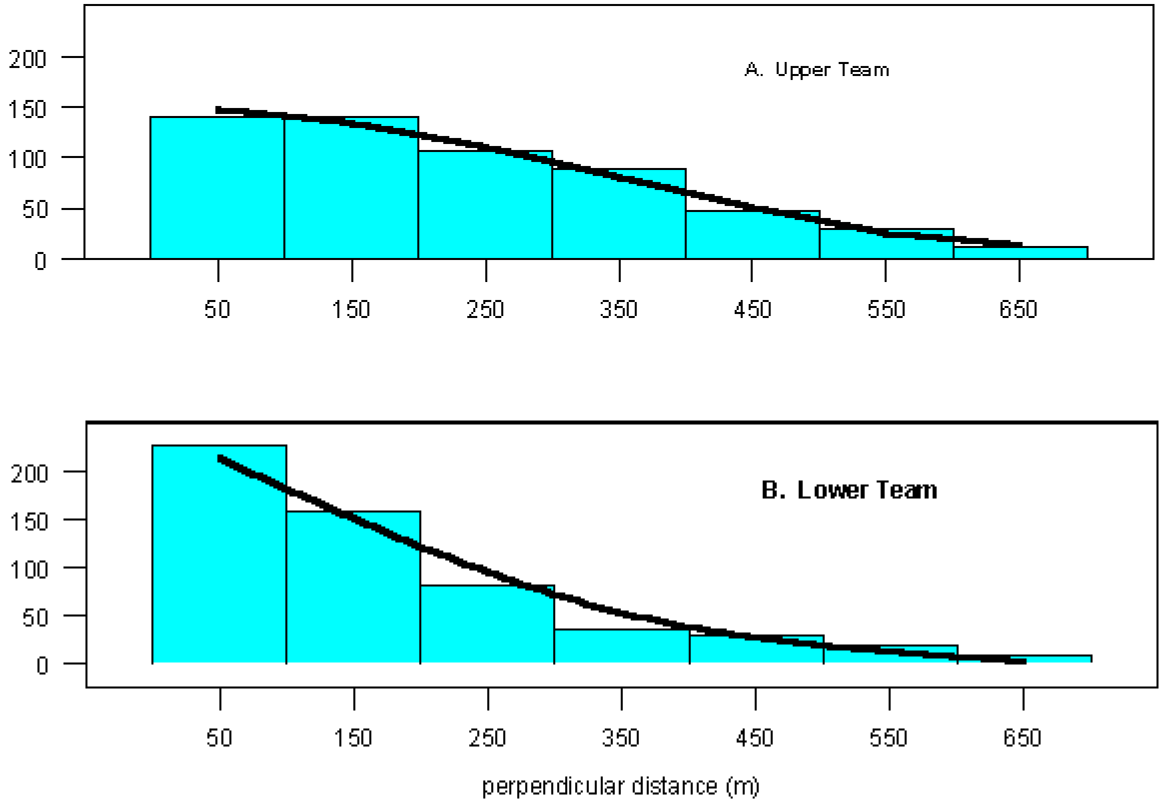

Figure 3. A histogram of the observed number of sightings detected by perpendicular distance and the perdicted detection function line. C. Duplicate sightings from the ship. D. sightings from the plane.

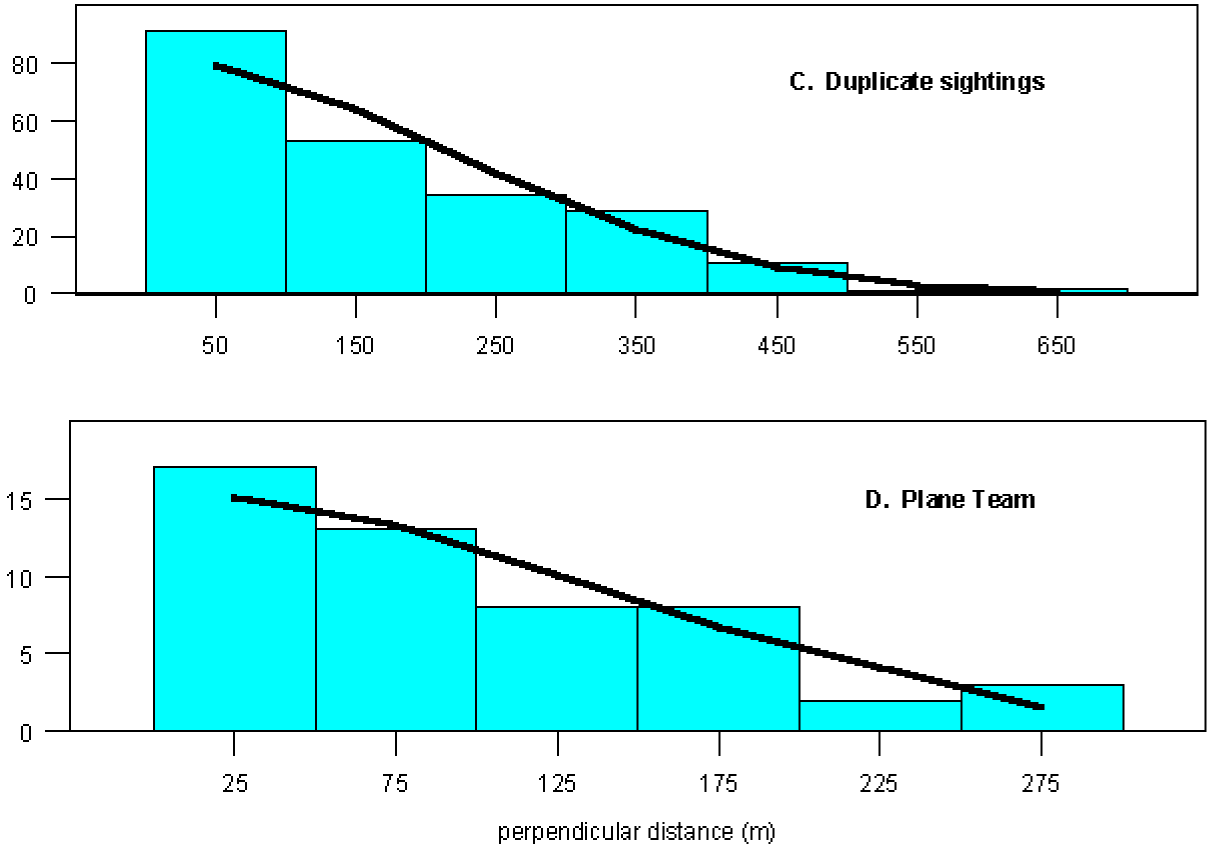

Figure 4. Abundance and 95% confidence limits estimates of Gulf of Maine/Bay of Fundy harbor porpoise stock in 1991, 1992, 1995, and1999.

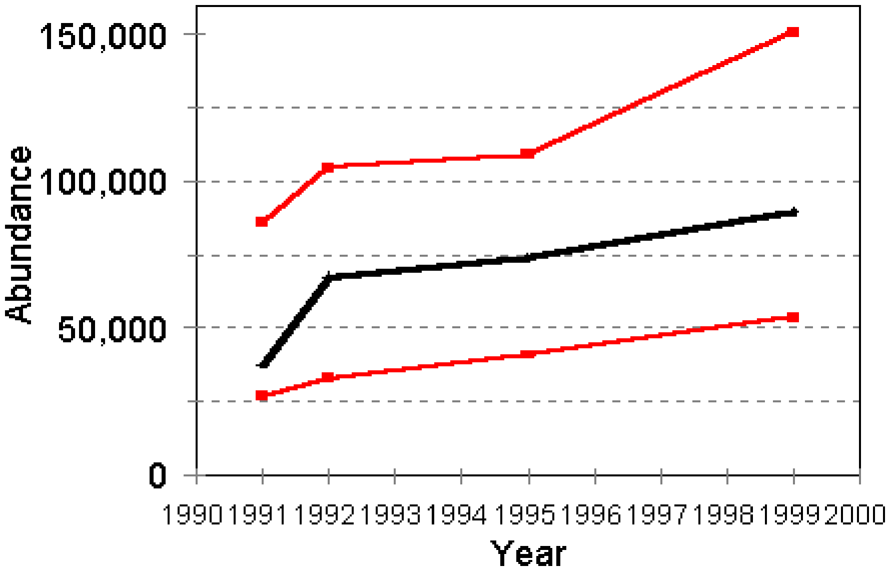

Figure 5. A. The track lines surveyed during 1995. B. A blow-up of region where harbor porpoise were present.