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Update on Abundance of Gulf of Maine/Bay of Fundy Harbor Porpoises

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ABSTRACT

Abundance of harbor porpoises in the Gulf of Maine/Bay of Fundy during summer 1995 was estimated using techniques developed for the 1991 and 1992 abundance estimates. Line transect sighting survey methods were used so that the probability of detecting an animal on the track line, $\hat{g}(0)$, was included in the abundance estimate. The 1995 estimated total abundance was 74,000 (95% CI= 40,900 to 109,100; %CV= 20%). This estimate is 51% more than the 1991 estimate, and 9% more than the 1992 estimate. For reference, abundance estimates from 1991 and 1992 were 37,500 (CV= 28.8%; 95% CI= 26,700 to 86,000) and 67,500 (CV= 23.1%; 95% CI= 32,900 to 104,600), respectively. All of these annual abundance estimates may be negatively biased due to several factors including ship avoidance and environmental conditions. The magnitude of these biases are not known.

INTRODUCTION

Gulf of Maine/Bay of Fundy harbor porpoises (*Phocoena phocoena*) migrate into the northern Gulf of Maine and lower Bay of Fundy region during July and most remain in this area until September, at which time they move to unknown wintering grounds (Palka *et al.* 1996). During September to December and April to June, harbor porpoises generally inhabitat the lower Gulf of Maine, coastal waters off Nova Scotia to Halifax, and waters off the northern US mid-Atlantic states, in particular off New York and New Jersey, though not in the densities observed in the Bay of Fundy during summer. Through out December to March, harbor porpoises occur in offshore of the US mid-Atlantic, from North Carolina to Massachusetts, as indicated by beach strandings (Haley and Read 1993) and sighting surveys (Winn 1982; Northridge 1996; Palka 1995d). Two beach strandings of harbor porpoises have been documented in Florida during March 1984 and 1985 (Smithsonian Marine Mammal Database 1994), thus, delimit the extreme southerly extent. However, typically most of the population remains north of Cape Hatteras, North Carolina.

There are five previous estimates of abundance for portions of the Gulf of Maine/Bay of Fundy made by various investigators (Gaskin 1977; Prescott *et al.* 1981; Winn 1982; Kraus *et al.* 1983; Gaskin *et al.* 1985). Two previous estimates for the entire region were made by the National Marine Fisheries Service (NMFS) (Smith *et al.* 1993; Palka 1995a).

Surveys conducted before 1991 covered only part of the summer habitat of harbor porpoises. With the exception of Kraus *et al.* (1983), these surveys led to downwardly biased estimates of abundance because they did not specifically account for difficulties in detecting harbor porpoises.

The 1991, 1992 and 1995 surveys were conducted in a study area that encompassed nearly all of the harbor porpoise summer range and explicitly accounted for difficulties in detecting harbor porpoises. The 1991 survey was described in detail in Palka (1995a) and was critically reviewed and accepted (NEFSC 1992). The 1991 and 1992 surveys have been reviewed further and accepted (Smith *et al.* 1993; Palka 1994). The abundance estimates from the 1991 and 1992 surveys were 37,500 (CV= 28.8%; 95% CI= 26,700 to 86,000) and 67,500 (CV= 23.1%; 95% CI= 32,900 to 104,600), respectively. Pooling these two estimates resulted in an average estimate of 47,200 (CV= 19.0%; 95% CI= 39,500 to 70,600; Smith *et al.*1993).

Study area, field procedures and analysis methods used in the 1995 survey were similar to that used during the 1991 and 1992 surveys. This paper presents a complete description of the field procedures, analysis methods and results from the 1995 survey. Comparisons are made to the previous NMFS 1991 and 1992 surveys.

METHODS

Overview

During July to September 1995, two ships (*R/V Abel-J* and *R/V Pelican*) and one airplane (NOAA Twin Otter) conducted a sighting survey for all cetacean species in the waters from the beaches of Norfolk, Virginia, USA, offshore to the northern wall of the Gulf Stream, then north to the entrance of the Gulf of St. Lawrence, Canada (Fig. 1). Harbor porpoises were seen only in the northern Gulf of Maine, lower Bay of Fundy and southern Scotian shelf by one of the ships (*R/V Abel-J*) and the airplane (Fig. 2). Harbor porpoises seen from both of these platforms were used in the abundance estimate for 1995.

The study region for the 1995 survey was approximately the same as that used in 1991 and 1992. Both the ship and airplane were needed to cover the entire study region. Data collected on the shipboard survey were used to 1) estimate the abundance of most of the study region (the Gulf of Maine, Bay of Fundy and part of the Scotian shelf area) using methods consistent with that for 1991 and 1992, 2) re-survey the Maine coast at the end of the survey to determine if general spatial density patterns changed during the survey, and 3) survey Jeffreys Bank at the end of the survey to determine if whether harbor porpoises occur outside of the survey region. Data collected on the plane survey was used to 1) estimate the abundance of the rest of the Scotian shelf area, 2) confirm the boundaries of the study region, and 3) investigate the efficiency of aircraft surveys relative to shipboard surveys.

From 06 August to 05 September 1995, a shipboard survey was performed on the *R/V Abel-J* in waters of the northern Gulf of Maine-lower Bay of Fundy-southern Scotian shelf area (Fig. 3). During 14 to 31 August 1995, the NOAA DeHavilland Twin Otter airplane surveyed the entire Gulf of Maine and southern Scotian shelf to Halifax, Nova Scotia, Canada (Fig. 4). To compare sighting efficiencies of the two platforms and estimate $\hat{g}(0)$ for the plane, the *R/V Abel-J* and Twin Otter surveyed the same track lines on the same day during 19 August, 23 August, and 02 September 1995 (Fig. 5).

The survey area extended from just north of Portland, ME, to north of Grand Manan Island, New Brunswick, Canada, and east to Liverpool, Nova Scotia (dotted lines in Figs. 3 to 5). The survey area was stratified first by depth into a shallow inshore and deeper offshore stratum. The offshore stratum was further stratified by harbor porpoise density into a 'high density', 'intermediate density' and 'low density' stratum. The inshore stratum covered waters within the bays off the Maine coast. The high density stratum covered the lower

Bay of Fundy around Grand Manan Island. The low density stratum covered the middle of the Gulf of Maine, around Jordan Basin. The intermediate density stratum covered the rest of the northern Gulf of Maine to Liverpool, Nova Scotia. Part of this last stratum was surveyed only by plane. So, that part surveyed by ship will, hereafter be referred to as the 'intermediate density' stratum, while that part surveyed by plane will be referred to as the 'plane stratum'. In total, there were five strata (the inshore, high density, intermediate density, low density and plane stratum) of which data collected by plane were used to estimate abundance in the plane stratum and data collected by ship were used to estimate abundance from the remaining strata.

Field procedures

***R/V Abel-J* shipboard survey**

The *R/V Abel-J* is 32m (106ft) long and has a 4m (13ft) draft. The configuration of the ship permits two teams of people to independently search the waters in front of the ship. There are no obstructions in front of the observers, thus allowing excellent viewing conditions from starboard abeam to port abeam. The platforms used by the teams are located on a mast approximately 6m (20ft) from the bow. One platform, the 'upper' crow's nest, is 14m above the sea surface; the other platform, the 'lower' crow's nest, is located vertically below the upper team and is 9m above the sea surface. In addition, the ship is quiet because an extensive dampening system has been installed. Engine generators are separated from the ship's hull by sound isolation mounts, exhaust stacks and the entire engine room is isolated with sound absorbing material, and the propeller shaft has sound and vibration isolation couplings. As a result, reduced vibration and noise is transmitted to the surrounding air and water. Because of all these features the vessel is ideally suited for marine mammal surveys.

By definition a stratum should encompass areas with similar harbor porpoise densities. In two small regions on the edge between two strata, the observed density differed between 1991 and 1992, so it was uncertain which stratum these small regions belong in. One region in question was between the high density and intermediate density stratum, covering waters south of Grand Manan Island, stretching from Machias, Maine to Digby, Nova Scotia. The other region was between the intermediate density and low density stratum, covering waters off northern Maine between the 50 and 100 fathom contours. During 1995, in these questionable regions, track lines surveyed in the past were used again and the areas were assigned to appropriate strata depending on observed densities. Resulting strata boundaries were most similar to those used in 1991. The area south of Grand Manan Island was assigned to the high density stratum and the offshore Maine area was assigned to the intermediate density stratum.

Track line mileage in the high density and intermediate density strata was slightly higher than proportional to the stratum area, while the track line length in the low density stratum was less than proportional to its area. Track line allocation was accomplished by dividing each stratum into 'boxes', each approximately 600nmi^2. Within each box 90-100 nmi were surveyed, roughly one day's effort. The order the boxes were surveyed in did not follow any potential north-south or inshore-offshore pattern. Track lines within a box followed a zig-zag pattern running along hypothesized harbor porpoise density gradients (i.e., perpendicular to density contour lines), where density was hypothesized to be greatest inshore and less offshore (Gaskin 1977). Starting points within boxes were chosen to be either offshore or onshore, constrained so that the starting point could be reached by traveling during the night.

Track lines were divided into 'transects' and 'legs' to facilitate estimating a bootstrap confidence interval of the abundance estimate, as has been done in other marine mammal sighting surveys (Øien 1990; Gerrodette and Wade 1991; Hammond *et al.* 1995). There were 4 to 10 'transects' per day, where a transect was defined as the time during which the ship's heading and speed was constant. A transect was made up of a consecutive series of 'legs', where a leg was defined as the time during which all environmental factors, positions of observers, and ship's speed and heading were constant.

Standard 'passing mode' line transect methods (Buckland *et al.* 1993; Butterworth and Borchers, 1988) were used, where the independent two-team sighting procedure allowed estimation of $\hat{g}(0)$, the probability of detecting a group of animals on the track line. Two teams of observers searched simultaneously for marine mammals using unaided eyes. Binoculars were available to confirm species identification and sizes of groups. One team was located on the 'upper' crow's nest, while the other team was located vertically below the upper team on the 'lower' crow's nest. The two teams could not see or hear each other.

There were four observers per team. Observers did not rotate between teams. Each team surveyed from only one sighting platform. On each platform there were three observation positions: port, center and starboard. Observers rotated between positions every 30 minutes, moving from the port to center to starboard observation position and then to a rest position which was not located on the observation platform. Every morning starting positions of team members were chosen randomly. Surveys were conducted from 0600 to 1800, with one hour break for lunch, when the Beaufort sea state was less than or equal to three and the visibility was greater than 500m.

To facilitate determining which groups of animals were detected by both teams, observers tracked harbor porpoise groups, when possible, recording positions of two or three surfacings. Data collected for each marine mammal sighting included: time of sighting (recorded to the nearest second), species, radial distance between the ship and animal group (estimated visually), bearing angle between the ship's line of travel and line of sight to the animal (measured with a polarus mounted in front of each observation position), group size (best, high and low estimates), direction the group was travelling (measured using the polarus), number of mother-calf pairs, and sighting cue (body, splash, bird, etc.). High (low) estimates of group size were defined as the largest (smallest) number of animals that were thought to be in the group. Best group size was defined as the observer's judgement of the most likely group size. Data were recorded by each observer onto a computerized 'data sheet' activated by a stylus. This data sheet consisted of boxes with pull-down menus displaying a list of choices, and boxes where observers wrote numbers that the computer interpreted digitally. This computerized data collection method is referred to as 'Pingle' (Garrett-Logan and Smith 1995).

Effort and environmental data were collected by the chief scientist at beginning of legs and at the end of the day. These data include: time, location of each observer and environmental conditions - swell direction and height, Beaufort sea state, presence of rain or fog, percentage of cloud cover, vertical and horizontal position of the sun and the direction of and magnitude of the glare. A computerized logging program, connected with the ship's differential GPS (Global Positioning System), recorded at the beginning of every minute: the ship's position, speed and bearing, water surface temperature, wind speed and direction. Latitude and longitude locations of marine mammal sightings were estimated, after the survey, by interpolating between positions recorded by the GPS logger program.

To obtain accurate visual estimates of radial distances between the ship and harbor porpoise, observers were trained and tested. This was accomplished by observers estimating the distance to a floating wooden replica of a harbor porpoise that was placed at various distances and bearings around the ship. Actual distances were measured using ship's radar and a laser rangefinding binocular. During training, after all observers made their estimates, actual distances were immediately reported. During testing, actual distances were withheld until the end of the test. Training and testing occurred for full day before the survey started and for a few hours about once a week during the survey.

Twin Otter airplane survey

The NOAA DeHavilland Twin Otter is a twin-engine, high-wing airplane, 15.8m (52 ft) long. To conduct marine mammal sighting surveys, the plane was modified by constructing two 'bubble windows', a 'belly window', and an extra fuel tank. The fuel tank system provides enough fuel for 6-7 hours of continuous flying. Bubble windows are approximately 2 ft (0.6m) high and bulge 8 inches (0.2m) outside the lines of the fuselage. They provide good visibility ahead of, to the side of, below and behind the observer. Visibility ahead and behind ranges from the horizon straight ahead to approximately 35° aft. Visibility to the sides range from the horizon abeam to directly below the plane and beyond to about 10° on the other side of the track line. The port bubble window, located behind the pilot, is approximately 15 ft (4.5m) behind the nose of the plane. The starboard bubble window is located directly across the port window and is behind the co-pilot. The belly window is located on the floor near the middle of the plane, approximately 35 ft (10.5m) from the nose. This window affords a good view of the region directly under the plane ranging from approximately 30° to either side of the track line.

The entire Gulf of Maine, lower Bay of Fundy, Scotian shelf region was surveyed by the airplane to 1) validate strata borders, 2) provide an abundance estimate for part of the study region that was not surveyed by the ship, and 3) investigate the efficiency of aircraft surveys relative to shipboard surveys.

Sighting procedures followed standard aerial line transect methods (Buckland *et al.* 1993), where two potential methods were used to estimate $\hat{g}(0)$. Surveying was conducted when Beaufort sea state conditions were less than or equal to three and visibility was greater than 2 nmi, i.e., it was not raining, foggy, or smoky. The plane flew 600 ft (182m) above sea surface at 110 knots (200 km/hr). Most of the survey was conducted in 'passing mode', except when a few hard to identify groups were encountered. At these times, the plane stopped primary search effort, went 'off effort', and circled a group to correctly identify species and obtain accurate group size estimates. If another marine mammal group was detected while off effort, than the new group was recorded as 'off effort' and was not used in the abundance estimate. Because harbor porpoises were the target species and so most are seen close to the track line, there were relatively few instances of off effort sightings.

Data were collected to estimate $\hat{g}(0)$ for the airplane in two different ways. One method involved both the plane and ship surveying the same track lines on the same day. Then $\hat{g}(0)$ is a parameter scaling the density estimate resulting from the plane's data to the $\hat{g}(0)$ corrected density estimate resulting from the ship's data. To obtain estimates of variability the airplane surveyed the track lines 3 or 4 times within the same day. The other method is similar to that used on the ship. Sightings seen by an "independent" observer using the belly window were used to determine sightings near the track line missed by the primary team, which are two observers using bubble windows. Only the first method was investigated in this paper.

As for the shipboard survey, the plane's track lines were divided into 'transects' and 'legs'. Definitions are the same. Plane track lines also followed a zig-zag pattern running along the hypothesized density gradient: high density inshore and less offshore. Order that the transects were surveyed were mostly south to north because of logistic constraints due to starting and ending at an airport.

Five scientists were divided into the 'primary' team and 'independent observer'. The primary team consisted of four people: two observers, one viewing through each bubble window, one person recording their data onto a lap-top computer and one person resting. The 'independent observer' is a person who viewed through the belly window and recorded their data onto a tape recorder. The independent observer was not in auditory contact with the primary team, who communicated through the plane's intercom system. The person recording data for the primary team was dedicated to this job for the entire survey. Remaining four scientists rotated every 30 minutes from the port bubble window observation position, to the starboard bubble window position, to the rest position, to the belly window position, then back to the starboard bubble window position.

All observers scanned using the naked eye and used binoculars only if needed to confirm a species identification or group size. Because harbor porpoises were the target species, search effort was concentrated close to the track line, to within 45° of the track line, approximately 200m from the track line.

Data recorded for each sighting included: time (to the nearest second), latitude and longitude (measured by the plane's GPS which was connected to the primary team's computer), species composition, best estimate of group size, best estimate of number of calves, and angle of declination between the line of sighting to the animal group when the group passed abeam of the plane and the vertical line straight down. Angle of declination was measured in two ways. One was with an inclinometer, which measures the angle of tilt that the instrument was held at. This method is preferred because it provides more accurate estimates. When the inclinometer was unavailable, angles were estimated by using calibrated markings on the window which delineated angles into 10° bins.

Effort and environmental data that were entered into the computer by the primary team's recorder included: time (to the nearest second) that each leg of effort started and ended, corresponding latitudes and longitudes, 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, moderate, fair or poor). As weather conditions changed, environmental data were updated with the time and position of the update. In addition, time and position were automatically recorded every minute.

Sighting data recorded by independent belly window observers included: time (to the nearest second) of the sighting, species identification, best group size, best estimate of number of calves, and angle of declination (using either an inclinometer or markings on the window labeled every 10° on either side of the track line). Effort data included: time started and stopped surveying, observer's name, and glare and viewing quality conditions.

Analytical procedures

R/V Abel-J shipboard estimate

As for the 1991 and 1992 abundance estimates, abundance of animals, $\hat{N}$, was estimated using the direct-duplicate method (Palka 1993; Palka 1995a):

$$\hat{N} = \sum_{i=1}^{3} \hat{N}_i = \sum_{i=1}^{3} \hat{D}_i \cdot A_i = \sum_{i=1}^{3} \frac{\hat{D}_{iup} \cdot \hat{D}_{ilo}}{\hat{D}_{idup}} \cdot A_i \qquad (1)$$

where

$\hat{N}_i$ = estimated abundance of animals, corrected for $\hat{g}(0)$, within stratum i
$\hat{D}_i$ = estimated density of animals, corrected for $\hat{g}(0)$, within stratum i
A_i = area of stratum i
i = stratum index, i= 1 to 3 (high, intermediate and inshore strata)
$\hat{D}_{iup}$ = density of animals as seen by the upper team, not corrected for $\hat{g}(0)$
$\hat{D}_{ilo}$ = density of animals as seen by the lower team, not corrected for $\hat{g}(0)$
$\hat{D}_{idup}$ = density of animals detected by both teams, not corrected for $\hat{g}(0)$.

$\hat{D}_{iup}$, was estimated by

$$\hat{D}_{iup} = \frac{n_{iup} \cdot \hat{f}_{iup}(0) \cdot \hat{E}(s_{iup})}{2L_i} \qquad (2)$$

where

n_{iup} = number of sightings detected by the upper team within stratum i
$f_{iup}(0)$ = probability density of observed perpendicular distances from stratum i, where the distance equals zero
$\hat{E}(s_{iup})$ = best estimate of average size of groups detected by the upper team within stratum i

L_i = length of track line surveyed within stratum i.

$\hat{D}_{ilo}$ and $\hat{D}_{idup}$ were estimated similarly.

To compare results using above methods to results for other surveys conducted by other investigators, the value of $\hat{g}_i(0)$, probability of detecting a group on the track line within stratum i, was estimated using

$$\hat{g}_{i(up+lo)}(0) = \hat{g}_{iup}(0) + \hat{g}_{ilo}(0) - [\hat{g}_{iup}(0) \cdot \hat{g}_{ilo}(0)] \tag{3}$$

where

$$\hat{g}_{iup}(0) = \frac{n_{idup}}{n_{ilo}} \cdot \frac{\int_{y=0}^{w} \hat{g}_{ilo}(y)\ dy}{\int_{y=0}^{w} \hat{g}_{idup}(y)\ dy} \quad and \quad \hat{g}_{ilo}(0) = \frac{n_{idup}}{n_{iup}} \cdot \frac{\int_{y=0}^{w} \hat{g}_{iup}(y)\ dy}{\int_{y=0}^{w} \hat{g}_{idup}(y)\ dy}$$

and $\hat{g}_{iup}(y)$ = probability of upper team detecting a group at perpendicular distance y within stratum i

$\hat{g}_{ilo}(y)$ = probability of lower team detecting a group at perpendicular distance y within stratum i

$\hat{g}_{idup}(y)$ = probability of both teams detecting a group at perpendicular distance y within stratum i

w = maximum perpendicular distance.

A discussion on how each parameter in Equation (2) was calculated follows below, where the method used with the 1995 data is followed by a comparison to that used in 1991 and 1992.

For 1995, the best estimate of average size of groups, $\hat{E}(s)$, was an average corrected for size-bias. Size-bias refers to the situation when the probability of detecting a group of animals changes as a function of the size of that group (Quinn 1985; Drummer and McDonald 1987; Buckland *et al.* 1993). For example, because it is easier to see a large group of animals far away than to see a small group of animals at the same distance, the size of the group biases the probability of detecting it. As was done in 1991 and 1992, data collected during 1995 were investigated for size-bias, using the computer package DISTANCE (Laake *et al.* 1991), by regressing the ln(group size) onto the probability of detecting that group, g(y). A significant relationship indicates size-bias. For 1991 and 1992, there was no evidence of size-bias, and so the best estimate of average group size was the arithmetic mean of the best estimates of group size.

The parameter $\hat{f}(0)$ was estimated using DISTANCE where the hazard rate model was fitted to unsmeared perpendicular distances and the maximum perpendicular distance (w) was

400m. Goodness-of-fit was investigated using the AIC score (Akaike Information Criteria; Akaike 1974), Chi-squared test, and visual inspection of the fit near the origin, the most critical region (Burnham *et al.* 1980). This procedure was the same as that used with the 1991 and 1992 data.

Equation (2) may represent an over-parameterised model. That is, some parameters within the equation may not differ between strata and, therefore, do not have to be estimated separately (Burnham *et al.* 1987). In 1991, to create a reduced, more parsimonious model, each parameter was investigated to determine if parameter values differed between the high density, intermediate density and inshore strata. The low density stratum had too few sightings and was, therefore, excluded from the test. It was determined that, within a team, shapes of the $\hat{f}(y)$ curves were similar between strata, and group sizes differed. For consistency this procedure was also applied to the 1992 and 1995 data.

To estimate $\hat{g}(0)$ and abundance, it was necessary to determine which sightings were seen by both teams, i.e., identify duplicate sightings. During 1991 and 1992, two people independently categorized each sighting as a duplicate or non-duplicate sighting by examining lists and plots of times of sightings, locations of sightings in relationship to the ship and nearby sightings, direction of travel, and the best, high and low estimate of group size. Duplicate sightings were categorized as 'definite' or 'possible', depending on the confidence of the judgement. During 1995, this subjective method was replaced by an objective computer program which identified duplicate sightings by determining how close a sighting seen first would be at the time of a second sighting. When the first sighting's location was predicted to be very close to the second sighting's location (within measurement error), then this pair of sightings were categorized as a 'definite' duplicate. If the predicted position is farther from the second sighting, though still within measurement error, then the pair was defined as a 'possible' duplicate. Information used included ship's speed at the time of the first sighting, and for each sighting: time, location relative to the ship, and swim direction. If there was no swim direction, but timing indicated that it was feasible for a harbor porpoise to swim to the second position, then that pair was defined as a 'maybe' duplicate. From a sub-sample of the 1995 data, the previous subjective results were similar to that obtained from the computer program.

Equations (1)-(3), the direct-duplicate method, were used to estimate abundance and $\hat{g}(0)$ of harbor porpoises within the high density, intermediate density and inshore strata. For the low density stratum, the above equations were modified because only four harbor porpoise groups were detected by each team, of which there were no duplicate sightings. Thus, abundance for the low density stratum was estimated assuming that detection functions, $\hat{g}_{up}(0)$ and $\hat{g}_{lo}(0)$ were the same in the low density and intermediate density stratum, and values of $\hat{E}(s)$, n_i, L_i and A_i were those associated with the low density stratum. Because no duplicates were identified within the low density stratum, a simplification of Equation (1) had to be used: the Butterworth & Borchers product-integral method (Butterworth and Borchers 1988). The product-integral method has more stringent assumptions of independence between the two teams. Distributions of duplicate sightings in the product-integral method are assumed to be the product of $\hat{g}_{up}(0)$ and $\hat{g}_{lo}(0)$, while in the direct-duplicate method, the distribution of duplicates is estimated directly from those sightings which were duplicates. For a detailed comparison between these two methods see Palka (1993). Abundance for the low density stratum corrected for $\hat{g}(0)$, $\hat{N}_{lodensity}$, is then estimated by

$$\hat{N}_{lodensity} = \hat{D}_{lodensity} \cdot A_{lodensity} = \frac{n_{uniq} \cdot \hat{f}_{uniq}(0) \cdot \hat{E}(s_{uniq})}{2 \cdot L_{lodensity} \cdot \hat{g}_{uniq}(0)} \cdot A_{lodensity} \tag{4}$$

where

$\hat{D}_{lodensity}$ = density estimated for the low density stratum, corrected for $\hat{g}(0)$
$A_{lodensity}$ = area of low density stratum
n_{uniq} = number of unique sightings seen by both teams in the low density stratum
= $n_{up} + n_{lo} - n_{dup}$
$\hat{f}_{uniq}(0)$ = probability density of observed perpendicular distances of unique sightings from the intermediate density stratum
$\hat{E}(s_{uniq})$ = best estimate of group size of unique sightings from the low density stratum
$L_{lodensity}$ = track line length surveyed in the low density stratum
$\hat{g}_{uniq}(0)$ = probability of detecting a unique sighting on the track line in the intermediate density stratum:

$$\hat{g}_{uniq}(0) = \hat{g}_{up}(0) + \hat{g}_{lo}(0) - [\hat{g}_{up}(0) \cdot \hat{g}_{lo}(0)] \tag{5}$$

where

$$\hat{g}_{up}(0) = \frac{n_{dup}}{n_{lo}} \cdot \frac{\int_{y=0}^{w} \hat{g}_{lo}(y)\, dy}{\int_{y=0}^{w} \hat{g}_{up}(y) \cdot \hat{g}_{lo}(y)\, dy} \quad and \quad \hat{g}_{lo}(0) = \frac{n_{dup}}{n_{up}} \cdot \frac{\int_{y=0}^{w} \hat{g}_{up}(y)\, dy}{\int_{y=0}^{w} \hat{g}_{up}(y) \cdot \hat{g}_{lo}(y)\, dy}$$

Note, the difference in the estimates of $\hat{g}_{up}(0)$ and $\hat{g}_{lo}(0)$ between the direct-duplicate and product-integral method is in the denominator (Equation (3) versus (5)).

Variability of a parameter for a stratum or for the whole study area was described by the coefficient of variation (CV), 95% confidence interval (CI), and standard error (SE). Measures of variability for parameters within a stratum were estimated by using bootstrap re-sampling techniques (Efron 1982), where parameters for a single stratum were density, corrected and uncorrected for $\hat{g}(0)$, effective strip width (ESW), $\hat{g}_{up+lo}(0)$, $\hat{g}_{up}(0)$, $\hat{g}_{lo}(0)$, $\hat{g}_{uniq}(0)$, and abundance estimates. A bootstrap sample was generated by randomly selecting data, with replacement, from the original data. Re-sampling units were a 'transect' of survey effort within a stratum (4-10 transects per day; 4-57 per stratum). Within a bootstrap sample, numbers of transects in a stratum were constrained so that total length of track line within a stratum equals the length in the actual survey. If, after choosing a random transect, the track line length exceeded the actual track length, then only the first portion of the transect needed to reach the desired track length was used in that bootstrap sample. The re-sampling procedure was repeated 1000 times.

Point estimates of a parameter for a stratum were defined as that estimated from the actual data collected. Endpoints of the 95% confidence interval of a parameter were estimated by the 2.5 and 97.5 percentile of the bootstrap distribution of that parameter. SE of a parameter was taken as the standard deviation of the 1000 bootstrap estimates of the parameter. CV of a parameter is the SE of that parameter divided by its point estimate.

Point estimates of the total abundance, $\hat{N}$, was defined as the summation of point estimates from each stratum, $\hat{N}_i$. CV of the total abundance [CV($\hat{N}$)] was estimated using

$$CV^2(\hat{N}) = \frac{\hat{var}(\hat{D}_T)}{\hat{D}_T^2} \tag{6}$$

where

$$\hat{var}(\hat{D}_T) = \sum_{i=1}^{4}\left(\frac{A_i}{A} \cdot se(\hat{D}_i)\right)^2$$

$$\hat{D}_T = \sum_{i=1}^{4}\left(\frac{A_i}{A} \cdot \hat{D}_i\right)$$

and

$\hat{D}_T$ = weighted total density of individuals corrected for $\hat{g}(0)$
A = total area within all strata involved.

SE($\hat{D}_i$) was estimated by the standard deviation of the 1000 bootstrap estimates from stratum i. Percent coefficient of variation of $\hat{N}_i$ (%CV($\hat{N}_i$)) was estimated by:

$$\%CV\left[\hat{N}_i\right] = \frac{SE(\hat{N}_i)}{\hat{N}_i} \cdot 100 \tag{7}$$

where $SE(\hat{N}_i)$ equals the standard deviation (SD) of the 1000 bootstrap $\hat{N}_i$ estimates.

Estimates of variability for the entire survey area for the follow parameters: density of individuals, corrected and not corrected for $\hat{g}(0)$, $\hat{g}_{up+lo}(0)$, $\hat{g}_{up}(0)$ and $\hat{g}_{lo}(0)$ were made using area weighted estimates of the corresponding parameter values from each stratum, as shown in Equation (6) for $\hat{D}_T$.

Twin Otter airplane estimate

Data collected on the plane were used to estimate the abundance of harbor porpoises that were located from the southern tip of Nova Scotia to Liverpool, Nova Scotia, i.e., the plane stratum. This stratum is part of the area with an intermediate density, as defined in 1991, that was not surveyed by the ship during 1995. This area is 2474 nmi^2.

Abundance for this region was estimated using an equation that is basically a combination of Equations (1) and (2):

$$\hat{N} = \hat{D}_{cor.plane} \cdot A_{plane} = \frac{n_{plane} \cdot \hat{f}_{plane}(0)}{2L_{plane} \cdot \hat{g}_{plane.ship}(0)} \cdot \hat{E}(s_{plane}) \cdot A_{plane} \tag{8}$$

where

$\hat{D}_{cor.plane}$	= density of animals, corrected for $\hat{g}(0)$, as seen from the plane
A_{plane}	= area of the plane stratum
n_{plane}	= number of groups detected by the primary team from the plane in the plane stratum
$\hat{f}_{plane}(0)$	= probability density of observed perpendicular distances from all harbor porpoise groups made from the plane, where the distance equals zero
L_{plane}	= track length surveyed by the plane in the plane stratum
$\hat{g}_{plane.ship}(0)$	= probability of a group being detected on the track line by the plane, using a comparison of the density as estimated by the ship and plane
$\hat{E}(s_{plane})$	= best estimate of average group size seen within the plane stratum.

The value of $\hat{f}_{plane}(0)$ was estimated using the hazard rate model in DISTANCE, where all harbor porpoise sightings were used. Nearly all (94%) sightings were made using the inclinometer, so the distribution of perpendicular distances was treated as continuous data. This distribution was right truncated 375m from the track line, and left truncated 25m from the track line. Left truncation was necessary because very few sightings were recorded as being close to or directly on the track line. This is a typical situation encountered with aerial survey data. Left truncation is the preferred method of handling the lack of data in this region of the curve (Buckland *et al.* 1993).

The value of $\hat{g}_{plane.ship}(0)$ was estimated using data collected during the three days in which the ship and plane surveyed the same track lines. Within each day the plane surveyed the track lines 3-4 times, where each time is referred to as a 'run'. The value of $\hat{g}_{iplane.ship}(0)$ for run i within a day was estimated by scaling the density uncorrected for $\hat{g}(0)$ as estimated

$$\hat{g}_{iplane.ship}(0) = \frac{\hat{D}_{iunc.plane}}{\hat{D}_{icor.ship}} \tag{9}$$

from the plane on run i, $\hat{D}_{iunc.plane}$, to the $\hat{g}(0)$ corrected density of harbor porpoises as estimated by the ship for the same track lines, $\hat{D}_{icor.ship}$,:

The point estimate of $\hat{g}_{plane.ship}(0)$ is the mean of the $\hat{g}_{iplane.ship}(0)$ estimates.

To determine the best value for $\hat{E}(s_{plane})$, data were investigated for size-bias using the same technique as described for the shipboard survey.

The 95% confidence interval of the abundance from the plane stratum were estimated assuming that abundance is lognormally distributed, as suggested in Buckland *et al.* (1993). Log-based lower and upper confidence intervals ($\hat{N}_L$ and $\hat{N}_U$, respectively) were calculated by:

$$\hat{N}_L = \frac{\hat{N}}{C} \tag{10}$$

$$\hat{N}_U = \hat{N} \cdot C$$

where

$$C = \exp\left\{1.96 \cdot \sqrt{(\log_e(1 + [CV(\hat{N})]^2)}\right\}$$

Total abundance estimate

Total estimate of harbor porpoises in the study region is simply the sum of harbor porpoises as estimated from the shipboard survey and that from the plane survey. The %CV of the total abundance estimate, %CV($\hat{N}_{total}$), was estimated using Equation (6), where there were five strata: four from the shipboard survey and one from the plane survey.

RESULTS

R/V Abel-J shipboard survey

During 06 August to 05 September 1995, *R/V Abel-J* surveyed in the study region approximately 1293 nmi under acceptable weather conditions. Amount of track line surveyed within each stratum is found in Table 1. In addition to these strata, 72 nmi were re-surveyed during a day at the end of the time period. The purpose was to re-survey the entire Maine coast along the 50 fathom line to confirm that the general spatial distribution of harbor porpoises did not change during the survey. A plot of the location of sightings revealed that the spatial distribution was similar at the beginning and end of the survey. Thus, data collected on this day were not used any further. On September 4, 1995 Jeffreys Bank was surveyed for 102 nmi. This region is outside the traditional summer habitat, but was visited during August and September by a satellite-tagged harbor porpoise (A. Read, pers. comm.). No harbor porpoises were seen on Jeffreys Bank on September 4, 1995. Thus, these track lines were not used in the abundance estimate and strata borders appear to encompass nearly all harbor porpoises in the Gulf of Maine/Bay of Fundy region.

For each component in Equations (1) - (5), results from 1995 will be reported and than compared to that from 1991 and 1992. During 1995, the upper team saw 804 harbor porpoise groups, and the lower team saw 761 groups (Table 1). Within 400m of the track line, the upper team saw 671 harbor porpoise groups and the lower team saw 657 groups (Table 1). These numbers were higher than observed during 1991 (433 and 345 for the upper and lower teams in 1991, respectively (Palka 1995a) and only slightly higher than that during 1992 (631 and 558 for the upper and lower teams in 1992, respectively (Smith *et al.* 1993)).

During 1995, average sizes of groups observed in the four shipboard strata were 2.32 (%CV= 3.5) and 2.22 (%CV= 3.7) for the upper and lower teams, respectively. This is slightly lower than that for 1991 (2.93 and 2.75 for upper and lower teams, respectively) and 1992 (2.91 and 2.68 for upper and lower teams, respectively). These inter-annual differences were insignificant ($p > 0.05$). Sizes of groups varied between strata. During 1995, group sizes in the high density stratum were slightly larger than that in the intermediate density stratum, and group sizes in the inshore stratum were lower than that seen offshore. There was evidence of weak size-bias in 1995, particular for the lower team. This was illustrated by (1) decreases of 4% and 9% for the upper and lower teams, respectively, in the average size of groups within 200m of the track line in contrast to that within 400m (Table 1); (2) a significant relationship between ln(group size) and $\hat{g}(y)$ when using sightings within 400m and by a non-significant relationship for sightings within 200m. Because of this size-bias, best estimates of group size, $\hat{E}(s)$, were calculated using sightings detected within 200m of the track line. Calculations for other parameters incorporated sightings data within 400m. During 1991 and 1992, size-bias was not evident and so $\hat{E}(s)$ was estimated by the arithmetic mean of the observed group sizes.

Numbers of 'definite' and 'possible' duplicates as defined by the computerized routine were 80 (= 45 definite and 35 possible) , 120(= 62 definite and 58 possible), 0, and 40 (= 19 definite and 21 possible) for the high density, intermediate density, low density and inshore strata, respectively. To fairly compare these numbers to those seen in previous years, the ratio of the number of duplicates in a stratum to the number of sightings seen by the upper team for that stratum were compared. In 1995 this ratio varied from 0.32 to 0.42 (Table 2), with an average for all strata of 0.36. This average was similar to that reported in 1991 (0.35 and 0.31 for judge A and B, respectively).

As was done in previous years, the detection function was estimated for each team pooled over strata. The hazard rate model fit the perpendicular distance data well (χ^2 p-value for upper team= 0.29 and for the lower team= 0.74). Estimates of effective strip width (ESW= $1/\hat{f}(0)$) for the upper and lower teams were 268m (SE= 25) and 185m (SE= 19), respectively, and 167m (SE= 44) for duplicate sightings (Table 3). ESW for the upper team is similar to that from previous years (1991: 258, 1992:292). ESW estimate for the lower team is lower than previous values (1991: 296, 1992: 257). Consequentially, ESW for duplicate sightings is also slightly lower than previous years (Judge A:1991= 160, 1992:226; Judge B:1991= 205, 1992= 243).

The area weighted average estimate of $\hat{g}(0)$ for all shipboard strata for the upper team, $\hat{g}_{up}(0)$, was 0.41 (SE= 0.072), which is lower than that for the lower team, where $\hat{g}_{lo}(0)$ is 0.54 (SE= 0.103). The area weighted average for both teams together, $\hat{g}_{up+lo}(0)$, was 0.73 (SE= 0.461). Estimates for each strata-team combination are reported in Table 4. Weighted averages for both teams are similar to that estimated for previous years (1991:

0.72; 1992: 0.71). In contrast to 1995, the 1991 and 1992 weighted average for the upper team was higher than that for the lower team. Though in all years differences between platforms were not significant.

Density estimates (corrected and uncorrected for $\hat{g}(0)$) and abundance estimates by strata and for the entire region surveyed by the ship are reported in Table 5. Abundance from the region surveyed by the ship was about 70,600 (95% CI:38,300 to 106,500; %CV= 20.3).

Twin Otter plane survey

Covering the entire Gulf of Maine north of Cape Cod, the lower Bay of Fundy, and Scotian shelf region to Halifax, Nova Scotia, the plane surveyed 3045 nmi of track line during 13, 14, 15, 18, 26, 28, 29 and 31 August 1995 (Fig.4). During this time, 31 on-effort harbor porpoises sightings (85 individuals) were detected; an additional three groups (13 individuals) were detected while off-effort. Average group size (and SE) of all the on-effort groups were 2.74 (SE= 0.33). Three groups were detected outside the survey strata (Fig. 4), one near the southwest border off Portland, ME and two near the southeastern border on Browns Bank.

The airplane-ship experiment to estimate $\hat{g}(0)$ was conducted on 19 and 23 August 1995 and 02 September 1995. Track lines surveyed on 23 August 1995 were in the high density stratum, while the other two days were in the intermediate density strata. During all three days, 273 groups (747 individuals) of harbor porpoises were reported by the primary team on the plane. Because the plane surveyed the same track lines several times in one day, above numbers are not of unique groups or individuals. On 19 and 23 August 1995, the plane conducted four runs of the track lines, and on 02 September 1995 three runs were conducted, where a run is defined as one pass over the track lines. Numbers of groups detected in a single run ranged from 8 groups (24 individuals) to 49 groups (132 individuals). During days when the plane and ship surveyed the same track lines, for each run the track length and sighting rates for each platform are reported in Table 6.

Size-bias was investigated separately for each run within a day. On two of the runs (third run 19 August 1995 and second run 02 September 1995) size-bias was evident. Consequentially, the best estimate of group size for these two runs is predicted by a regression of ln(group size) versus g(y), and so is less than the straight arithmetic mean. Best estimates of group size for other runs is the arithmetic mean (Table 6).

ESW of all harbor porpoise sightings (n= 417) was 184m (SE= 6.3) when data were right truncated at 375m and left truncated at 25m. Table 6 contains estimates of density of individuals uncorrected for $\hat{g}(0)$ for the plane, and density of individuals corrected for $\hat{g}(0)$

for the ship for each day involved in the ship-plane experiment. Variability within the plane density estimates is large. Estimates of $\hat{g}_{plane}(0)$ for each run ranged from 0.02 to 0.68 (Table 6). The average of these runs, the best estimate of $\hat{g}_{plane}(0)$, is 0.235 (SE= 0.207; CV= 88%).

On 28 August 1995, the plane surveyed the 'plane' stratum. Eight harbor porpoise groups (18 individuals) were detected during 253 nmi of track line. Previously defined ESW of all harbor porpoise sightings (n= 417) seen by the observers on the plane was 184m (SE= 6.3m). Arithmetic mean of sizes of groups seen in the plane stratum were 2.25 (SE= 0.49). Using the regression between ln(group size) and $\hat{g}(y)$, there was evidence of significant size-bias (t-test of the slope of the regression; p= 0.056). Thus, the best estimate of group size for this day is size-bias corrected (1.94; SE= 0.41). Density uncorrected for $\hat{g}(0)$ was 0.31 animals/nmi^2 (SE= 0.13); density corrected for $\hat{g}(0)$ was 1.38 animals/nmi^2 (SE= 1.34); and abundance was approximately 3400 animals (CV= 97%; 95% CI= 700 to 16,900); see Table 5.

Total 1995 abundance estimate

Adding the estimated number of animals seen by the plane and ship result in a grand total of 74,000 harbor porpoises (CV= 20%; 95% CI= 40,900 to 109,100) in the study region during 1995. This total was 51% higher than the 1991 estimate, which is marginally insignificant (z= 1.96; p= 0.05), and 9% higher than the 1992 estimate, which is not significant (z= .30; p= 0.76).

DISCUSSION

Shipboard survey

The cause of increase in abundance between 1991 and 1992 appears attributable primarily to an increase in sighting rates (Smith *et al.* 1993). This same reason appears to be why the 1995 estimate is much greater than the 1991 estimate and only slightly greater than the 1992 estimate. To compare the three annual abundances, each component involved in the abundance (Equations (1) - (5)) will be compared, possible reasons for inter-annual differences will be explored, and effects of these differences will be discussed. Components of the abundance estimate are average group size, effective strip width (ESW), $\hat{g}(0)$, and sighting rates (the number of groups seen per nmi searched).

In 1995 average group size decreased slightly over both the 1991 and 1992 average group sizes, although differences were not significant. If this was the only factor that changed, then the 1995 abundance estimate would be lower than the previous estimates. Size-bias was evident only in the 1995 data, probably because variability in group sizes from 1995 were higher than in previous years. Groups of greater than 15 animals were observed only in 1995.

ESW for the upper team was similar in all years. However, ESW for the lower team was lower in 1995 than previously, by about 60%. If this was the only factor that changed, the decrease in ESW would cause an increase in the abundance estimate. One might question representativeness of the 1995 ESW estimate for the lower team. The hazard rate had the best fit (best AIC) as compared to the half normal and uniform models, both with and without adjustments. Another way to change the ESW is to change the maximum perpendicular distance (w). However, when doing this, a percent decrease in ESW does not translate directly into a similar percent increase in abundance, because ESW and sighting rate are inter-related. So, when using the lower team data, if w was increased from 400m to 500m, then ESW increased to 212m, but sighting rates also increased. Net effect on the abundance estimate was a decrease of 81 animals, approximately 0.1% of the entire abundance estimate. In conclusion, estimated ESW for the lower team is accurate and insensitive to the maximum perpendicular distance when in a reasonable range.

The weighted average estimate of $\hat{g}(0)$ for both teams during 1995 (0.73) was the same as that estimated for 1991 and 1992 (0.72 and 0.71, respectively). For 1995 $\hat{g}_{lo}(0)$ was approximately 20% higher than that for previous years. This is to be expected because the unconditional probability of detecting a group is defined by the product of ESW and $\hat{g}(0)$. So, if the ESW goes down it is expected that $\hat{g}(0)$ goes up (if the density remains the same). This is what happened for the lower team in 1995. Thus, inter-annual changes in ESW and $\hat{g}(0)$ do not fully explain the inter-annual changes in abundance.

Sighting rates during 1995 for all shipboard strata were 0.56 and 0.52 animals per nmi^2 for the upper and lower team, respectively. This is approximately 30% higher than the 1992 sighting rate and 60% higher than that from 1991 (Table 7). The area with the largest difference was in the intermediate density stratum, both along Maine and the western Nova Scotian coast. Many harbor porpoises were observed off southern Maine in 1992 and 1995, but not in 1991. However, only during 1995 were many animals also observed off the northern Maine coast. Along western Nova Scotia harbor porpoises were observed south of Digby; however, only in 1995 did those observations extend south towards Yarmouth.

In general, one possible reason for high sighting rates is good viewing conditions. An indicator of viewing conditions is the Beaufort sea state scale, which describes the calmness of the sea surface. The lower the Beaufort sea state, the easier to see a harbor porpoise. The 1991 and 1992 data indicated that low estimated densities were associated with high Beaufort sea states of 2 and 3 (Palka 1996). In 1995, however, viewing conditions were generally worse than that experienced during 1991 and 1992 (Table 8). In fact, twice as much time during 1995 was surveyed under Beaufort 2 conditions, as compared to 1991 and 1992. This is directly related to the fact that in 1995 there were nine hurricanes or tropical storms during the summer in the N. Atlantic, in contrast to one hurricane in 1991 and none in 1992. Thus, if the relationship between Beaufort sea state and density as observed in 1991 and 1992 holds for 1995, then the 1995 abundance estimate is downwardly biased. These observations warrant a more detailed investigation between Beaufort sea state and observed harbor porpoise density during the three years.

Another possible reason for higher sighting rates is that there were actually more animals in the region, perhaps because of more favorable environmental conditions. The fine scale distribution of harbor porpoise as seen in 1991 and 1992 was correlated with the fine scale distribution of sea surface temperature and prey species (Atlantic herring) density. Harbor porpoises were most often found in waters that were 10-13.5°C and contained fish densities of 1.5-11 fish caught per minute of trawling (Palka 1995b). Estimated abundance from 1992 was 1.8 times higher than that for 1991, which also coincided with a similar magnitude of increase in the planar area covered by the above "preferred" water temperatures (1.5x) and fish density indices (1.6x). These relationships have not been investigated for the 1995 data, but visual inspection of contour maps of surface temperature indicate that the relationship still holds. A detailed investigation into spatial distributions of physical and biological factors present during 1995 may give some indication as to why the observed distribution of sightings occurred, or at least what physical and/or biological factors were correlated with harbor porpoise density distribution.

All of the annual abundance estimates may be negatively biased due to several factors. One factor is Beaufort sea state. As stated above, for 1991 and 1992 data low estimated densities were associated with high Beaufort sea states (Palka 1996). Thus, an estimated abundance which used data collected in Beaufort 2 and 3 were probably negatively biased. This relationship needs to be investigated with the 1995 data. Another factor which could bias an abundance estimate is ship avoidance. That is, if harbor porpoises move away from the ship before they are detected, then abundance is negatively biased. There was evidence of ship avoidance in 1991 and 1992 (Palka 1995c). The magnitude of this bias is unknown and needs further investigation. Data collected on the shipboard sighting survey in 1995 may provide an indication of the bias and its magnitude.

Plane survey

The plane surveyed a much larger area than that covered by the five strata used in the abundance estimate. Only three harbor porpoise groups were detected outside the strata. This indicates that the borders as defined contain nearly all of the harbor porpoises present at the time in the Gulf of Maine/Bay of Fundy/Scotian shelf region.

The amount of variability in the estimate of $\hat{g}_{plane}(0)$ is very large, CV= 88%. To investigate if this variability was due to environmental conditions, estimates of $\hat{g}_{plane}(0)$ were recalculated to include only times when viewing quality was rated as 'excellent' or 'good', which was approximately 60% of the time. The resulting $\hat{g}_{plane}(0)$ estimate was 0.236 (SE= 0.206; CV= 87%). The net difference was negligible, however, there were differences within each run (Table 6). In conclusion, it was not possible to explain why density estimated by the plane was so variable.

The estimate of $\hat{g}_{plane}(0)$ from the plane-ship comparison experiment (0.24) is in the range of estimates of $\hat{g}(0)$ from other aerial surveys. During 1994, a two-plane sighting survey was conducted in the North Sea and surrounding waters, where one plane flew behind the other plane on the same track line at 600 ft (182m) and the target species was harbor porpoises (Hammond *et al.* 1995). Sighting conditions were measured as 'excellent', 'moderate' and 'poor'. The tandem plane scheme allowed 'duplicate' sightings to be identified and thus resulted in an estimate of $\hat{g}(0)$. The estimated value of $\hat{g}(0)$ under 'excellent' viewing conditions was 0.25. However, when viewing conditions deteriorated to 'moderate', $\hat{g}(0)$ decreased to 0.19. The $\hat{g}(0)$ estimate from the plane-ship comparison in the present paper was slightly higher than that estimated using the tandem plane procedure, however differences are not large. Another estimate of $\hat{g}(0)$ for aerial surveys of harbor porpoises was based on the measured fraction of track line harbor porpoises that were seen during experiments using land-based validation of aerial observations in northern Puget Sound, Washington (Calambokidis *et al.* 1993). This survey was conducted at similar altitudes (152-213m) and used a high-wing airplane with bubble windows. They concluded $\hat{g}(0)$ was 0.324 (CV= 17%). The $\hat{g}(0)$ estimate from the plane-ship comparison in this study was slightly lower than that estimated using the plane-land based observer comparison, however differences were not large. Overall, the estimate of $\hat{g}(0)$ for the plane as estimated in this paper is consistent with values estimated in other ways.

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Table 1. Summary of results from the 1995 harbor porpoise survey for the high density, intermediate density, low density, inshore, airplane strata and total area. The reported results for each strata are: 1) length of survey track lines (% of total line length in parentheses); 2) area (% of total area in parentheses); 3) number of groups detected by the upper and lower team. The top line in this column is all sighting in good weather conditions. (The bottom line, in parentheses, is the number of sightings made in good weather conditions within 400m of track line.) 4) average group size for the upper and lower team (%CV($\bar{s}$) is in parentheses). The top line is the average group size seen within the truncation distances for perpendicular distances (0-400m for the ship and 25-375m for the plane). The bottom line is the average group size within the truncation distance for group sizes (200m). For the airplane strata, results from sightings detected by the primary team are reported under the "Upper" team columns.

Stratum	Track Length (%)	Area (%)	Number of groups: total (w/in perp dist)		Avg group size (%CV): w/in perp dist w/in group size dist	
			Upper	Lower	Upper	Lower
High	247 (16)	1,495 (11)	224 (189)	216 (194)	2.67(7.6) 2.31(7.9)	2.43(7.4) 2.08(5.4)
Interm	844 (55)	6,272 (44)	435 (369)	383 (335)	2.29(4.4) 2.33(6.3)	2.20(5.0) 2.09(4.4)
Low	65 (4)	3,400 (24)	4 (2)	4 (4)	3.50(71.4) 1.0(0.0)	3.25(40.5) 1.5(33.3)
Inshore	137 (9)	637 (4)	131 (111)	145 (124)	1.85(5.0) 1.78(6.2)	1.90(6.2) 1.82(7.0)
Total Ship	1,293 (84)	11,804 (83)	794 (671)	748 (657)	2.32 (3.5) 2.23 (4.4)	2.22 (3.7) 2.03 (3.1)
Airplane	253 (16)	2,474 (17)	8 (8)	-	2.25 (22.2) 1.94 (21.3)	-
Grand Total	1,546 (100)	14,278 (100)	-	-	-	-

Table 2. The ratio of number of duplicate groups to number of groups seen by the upper team that were detected within the various strata, where the duplicate groups were classified by level of confidence: definite, possible, maybe and the total of definite and possible duplicates (def+poss).

Stratum	definite	possible	maybe	def+poss
High	.23	.19	.01	.42
Intermediate	.17	.16	.04	.32
Low	.00	.00	.00	.00
Inshore	.17	.19	.04	.36
Total	.19	.17	.03	.36

Table 3. Estimates of the effective strip width (ESW) and its SE. For Equations (1) - (2), to be used for the high density, intermediate density and inshore stratum, the ESW for each team on the ship (upper and lower) and for duplicates of the upper and lower teams (duplicates). For Equation (4) the ESW used for the low density stratum (low density stratum only). For Equation (8) the ESW from the primary team on the plane (plane stratum only).

Data Source	ESW	SE
Upper team	268	24.8
Lower team	185	18.8
Duplicates	167	43.9
Low density stratum only	237	14.8
Plane stratum only	184	6.3

Table 4. Estimates of $\hat{g}(0)$ and its SE for the upper, lower and both teams (up+lo) on the ship and the primary team on the plane (plane only) within the high density, intermediate density and inshore strata. For the low density stratum, the unique sightings in the intermediate stratum were used. The area weighted average of all strata are reported under Total.

Stratum	team	$\hat{g}(0)$	SE
High Density	upper only	.46	.135
	lower only	.67	.212
	up+low	.83	.121
	plane only	.27	.164
Intermediate Density + Inshore	upper only	.40	.115
	lower only	.52	.165
	up + low	.71	.127
	plane only	.20	.231
Low Density	unique	.79	.040
Total	upper only	.41	.072
	lower only	.54	.103
	up + low	.73	.461
	plane only	.24	.207

Table 5. For each stratum and all strata surveyed by the ship [All ship], the plane stratum, and all strata surveyed by either the ship or plane, the following results are reported: estimates of density (animals per nmi^2) uncorrected for $\hat{g}(0)$ [Unc. Dens.] and corrected for $\hat{g}(0)$ [Cor. Dens.] and the resulting abundance estimate with its SE, CV and lower and upper 95% confidence limits [LCL and UCL].

Stratum	Unc. Dens. (se)	Cor. Dens. (se)	Abundance	SE(N)	CV(N)	LCL	UCL
High	4.10 (1.55)	12.09 (4.03)	18,080	6,023	.33	7,708	30,187
Interm.	2.13 (0.68)	6.82 (2.03)	42,816	12,726	.30	21,596	70,857
Low	0.48 (0.17)	0.61 (0.26)	2,086	768	.37	104	3,415
Inshore	3.42 (1.59)	11.92 (3.35)	7,601	2,134	.28	3,742	11,722
All ship	1.97 (0.42)	5.96 (1.21)	70,583	14,340	.20	38,316	106,487
Airplane	0.31 (0.13)	1.38 (1.34)	3,413	3,321	.97	689	16,901
Grand total	1.69 (0.35)	5.19 (1.03)	73,996	14,799	.20	40,919	109,090

Table 6. For each day and run that the plane-ship experiment was conducted the following statistics are reported: track line length, sighting rate, average group size, density of individuals estimate, and $\hat{g}(0)$ using all the data and only times when the viewing conditions were 'excellent' or 'good'. The runs refer to the times that the plane surveyed the same track lines. The columns where the run is referred to as 'ship' reports the results from the upper team on the shipboard survey of that day's track lines, except for the density estimate, which is the $\hat{g}(0)$ corrected density for both shipboard teams. The best estimate of the average group size for a few runs of the plane and all days on the ship is corrected for size-bias (delimited by *), while for the rest of the runs the average group size is the arithmetic mean.

Date (track length)	Run	Sighting rate	Average group size	Estimated density of individuals	$\hat{g}_{plane}(0)$	
					all data	high quality
19Aug95	1	.18	2.82	2.57	.23	.48
(95 nmi)	2	.11	2.20	1.18	.11	.22
	3	.43	2.15*	4.71	.42	.40
	4	.46	2.16	5.03	.45	.30
	ship	.53	2.28*	11.09	-	-
23Aug95	1	.16	1.64	1.32	.09	.14
(70 nmi)	2	.47	4.39	10.56	.68	.67
	3	.35	2.08	3.68	.24	.18
	4	.14	1.60	1.17	.08	.08
	ship	.97	2.26*	15.44	-	-
02Sep95	1	.62	2.48	7.82	.22	.02
(74 nmi)	2	.12	1.39*	0.87	.02	.03
	3	.11	3.28	1.66	.05	.08
	ship	1.54	2.80*	35.59	-	-

Table 7. Average sighting rate (number of animals per nmi^2), with its standard error (SE) and number of transects calculation was based on (k).

Year	Avg(n/L)	SE(n/L)	k
1991	.22	.45	220
1992	.38	.67	202
1995	.54	.80	110

Table 8. Number of miles surveyed in the various Beaufort sea states during 1991, 1992 and 1995. (Percent within the year are in parentheses).

Sea state	1991	1992	1995
0	144 (7.3)	193 (9.6)	22 (1.7)
1	670 (34.2)	842 (42.0)	102 (7.9)
2	850 (43.3)	688 (34.4)	885 (68.4)
3	228 (11.6)	252 (12.6)	284 (22.0)
4	70 (3.6)	28 (1.4)	0
total	1,962 (100.0)	2,003 (100.0)	1,293 (100.0)

Figure 1. All track lines covered by two ships and an airplane during the 1995 Northwest Atlantic Marine Mammal Sighting Survey. The ships surveyed from 08 July to 07 September 1995, and the airplane surveyed from 01 August to 18 September 1995. The dashed line is the north wall of the Gulf Stream at the time the track lines covering it were surveyed. The fine lines are the 50, 100 and 200 fathom depth contours.

Figure 2. All harbor porpoise sightings seen during the 1995 Northwest Atlantic Marine Mammal Sighting Survey were made on the *R/V Abel-J* during 06 August to 05 September 1995 (top) and on the NOAA Twin Otter airplane during 13 to 31 August 1995 (bottom). The shaded lines are the strata used during the abundance estimate: the high density, intermediate density, low density, inshore, and plane strata. The fine lines are the 50 and 100 fathom depths.

Figure 3. Track lines surveyed by the *R/V Abel-J* during 06 August to 05 September 1995. The shaded lines are the strata used during the abundance estimate: the high density, intermediate density, low density, inshore, and plane strata. The fine lines are the 50 and 100 fathom depth contours.

Figure 4. Track lines surveyed by the NOAA Twin Otter airplane in the Gulf of Maine, lower Bay of Fundy, and Scotian shelf region west of Halifax, Nova Scotia, Canada. This occurred during 13 to 31 August 1995. The shaded lines are the strata used during the abundance estimate: the high density, intermediate density, low density, inshore, and plane strata.

Figure 5. Track lines surveyed by both the NOAA Twin Otter and the *R/V Abel-J* on the same days. The northern lines were surveyed on 23 August 1995. The zig-zags off Bar Harbor, ME were surveyed on 19 August 1995. The southern most "L" shaped line was surveyed on 02 September 1995. The shaded lines are the strata used during the abundance estimate: the high density, intermediate density, low density, inshore, and plane strata. The fine line is the 50 fathom depth contours.

Figure 2A. All harbor porpoise sightings seen during the 1995 Northwest Atlantic Marine Mammal Sighting Survey were made on the *R/V Abel-J* during 06 August to 05 September 1995 (2A) and on the NOAA Twin Otter airplane during 13 to 31 August 1995 (2B). The shaded lines are the strata used during the abundance estimate: the high density, intermediate density, low density, inshore, and plane strata. The fine lines are the 50 and 100 fathom depths.

Figure 2B. All harbor porpoise sightings seen during the 1995 Northwest Atlantic Marine Mammal Sighting Survey were made on the *R/V Abel-J* during 06 August to 05 September 1995 (2A) and on the NOAA Twin Otter airplane during 13 to 31 August 1995 (2B). The shaded lines are the strata used during the abundance estimate: the high density, intermediate density, low density, inshore, and plane strata. The fine lines are the 50 and 100 fathom depths.