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Editors:

Frank Thomsen[1,2], Fernando Ugarte[3,4] and Peter G.H. Evans[4,5]

[1] Biologisch-landschaftsökologische Arbeitsgemeinschaft (biola), Gotenstraße 4, D-20097 Hamburg, Germany
[2] Biozentrum Grindel, Universität Hamburg, Martin-Luther-King-Platz 3, D-20146 Hamburg, Germany
[3] Cardigan Bay Marine Wildlife Centre, New Quay, Ceredigion SA45 9PS Wales, UK
[4] Sea Watch Foundation, 11 Jersey Road, Oxford 0X4 4RT, UK
[5] Dept. of Zoology, University of Oxford, South Parks Road, Oxford 0X1 3PS, UK

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AERIAL SURVEYS IN THE NORTHWEST ATLANTIC: ESTIMATION OF *g(0)*

Debi Palka

National Marine Fisheries Service, 166 Water St., Woods Hole, MA USA 02543 (debra.palka@noaa.gov)

INTRODUCTION

Applying *g(0)*, the probability of detecting a group on the track line, to cetacean abundance estimates derived from aerial line-transect surveys results in less biased estimates of population size. In 1995, the Northeast Fisheries Science Center (NEFSC) of the U.S. National Marine Fisheries Service estimated *g(0)* for harbour porpoises (*Phocoena phocoena*) using a combined aerial/shipboard survey approach (Palka, 1996). In 2002, NEFSC staff estimated *g(0)* for three groups of cetaceans using the Hiby circle-back survey method (Hiby, 1999). The purpose of this paper is to describe these two methods.

MATERIALS AND METHODS

General aerial survey methods During 1995 and 2002, aerial line-transect sighting surveys were conducted to estimate *g(0)* to generate unbiased abundance estimates of cetaceans. A NOAA DeHavilland Twin Otter plane was used in both surveys, which were conducted in the Gulf of Maine, Georges Bank and Scotian Shelf regions in the northwest Atlantic. These surveys were conducted during good sighting conditions: Beaufort sea state # 3, visibility >3.7 km (2 nm), and no rain or fog. The plane flew 183 m (600 ft) above the sea surface at 200km/hr (110 knots). Five scientists comprised the sighting team: one searched through each side bubble window, one searched through a downward looking belly window, one recorded data, and one was at rest. Observers rotated among the sighting positions. Observers scanned by naked eye and used binoculars to confirm a species identification or group size, when needed.

Data recorded for each sighting included: time, latitude and longitude, species composition, group size, number of calves, and angle of declination between the vertical line straight down, and the line of sight to the group when the group passed abeam of the plane. Effort and environmental data recorded included: time and corresponding latitude and longitude when search effort started and ended, observer sighting position, Beaufort sea state, and percent cloud cover. As well, for each sighting position, data were recorded on magnitude of glare (none, slight, moderate or excessive) and overall viewing quality (excellent, moderate, fair or poor). Data were updated every minute and when conditions changed.

Ship-plane experiment to estimate g(0) In 1995, *g(0)* for harbour porpoises detected from the Twin Otter plane was estimated during a three-day experiment in which both a research vessel (*R/V Abel-J*) and the DeHavilland plane surveyed the same track lines on the same day (Palka, 1996). This experiment was part of a large-scale line-transect abundance survey conducted by the *R/V Abel-J* (2,396 km of track line) and the Twin Otter plane (5,643 km of track line). During each day of the experiment, the *R/V Abel-J* surveyed the pre-selected track lines once, while the plane surveyed the same track lines 3 or 4 times (each time is referred to as a run). The value of *g(0)* for the plane during run *i*, $g_{i.plane}(0)$, was estimated by scaling the *g(0)*-uncorrected density as estimated from the plane for run *i*, $D_{i.unc.plane}$ to the *g(0)*-corrected density as estimated by the ship for the same track line, $D_{i.cor.ship.}$ That is, $g_{i.plane}(0) = \frac{D_{i.unc.plane}}{D_{i.cor.ship}}$. $D_{i.unc.plane}$ was estimated using standard line-transect analysis methods, where the effective strip half width (ESHW) was estimated using data pooled over all days and other parameters were run-specific. $D_{i.cor.ship}$ was estimated using the direct duplicate analysis method, described in Palka (this volume). The best estimate and variance of $g_{plane}(0)$ were the mean and variance of the $g_{i.plane}(0)$ estimates.

Hiby circle-back method to estimate g(0) During the 2002 survey, the Hiby circle-back method (Hiby, 1999) was used to estimate *g(0)*. In this method, standard single plane line-transect methods are modified by having the plane circle back and re-survey a portion of the track line (Figure 1). The criterion that initiates a circle-back is a sighting of one small group (#5 animals) of animals within a 30-second time-period. The part of a circle that re-surveys the track line is referred to as a "trailing" leg; the part of the circle that initiates a circle is referred to as a "leading" leg; and the track line between the circles is referred to as "single-plane" leg. Density, corrected by *g(0)*, is estimated by multiplying the value of *g(0)* (using data from the leading and trailing legs) by the uncorrected density estimate (using data from the equivalent of a single-plane survey: *i.e.,* from the single-plane and leading legs).

The circle-back procedure, in detail, is as follows (Fig. 1):

1. Mark time and location of initial sighting when passing abeam to start a 30-second timer.
2. During the 30-seconds, additional sightings are recorded. If an additional sighting of the same species that triggered the circle is recorded, then the circle is aborted (because animal density is too high to accurately determine if a group is detected on both the leading and trailing legs).
3. At the end of the 30-seconds, if the above criterion is passed, the plane starts to circle back and the observers go off-effort. The exact time leaving the track line is recorded, which starts another timer for 120 seconds.
4. During the 120 seconds, the plane circles back 180E and travels parallel to the original track line, in the opposite direction, on either side of the original track line.
5. At the end of the 120 seconds, the plane starts to fly back to the track line.
6. When the plane intercepts the original track line, time is marked, observers go back on-effort and a 5-minute timer is started.
7. All sightings are then recorded as usual.
8. The circle-back procedure is not initiated again until a sighting is made after the 5-minute timer has elapsed. This is to ensure forward progress on the track line

Due to small sample sizes in the 2002 survey, species were pooled to obtain *g(0)* estimates for three species groups: harbour porpoises, small cetaceans, and large cetaceans. Small cetaceans included Atlantic white-sided dolphins (*Lagenorhynchus acutus)*, offshore bottlenose dolphins (*Tursiops truncatus*), common dolphins (*Delphinus delphis*), Risso's dolphins (*Grampus griseus*), and unidentified dolphins. Large cetaceans included minke whales (*Balaenoptera acutorostrata*), humpback whales (*Megaptera novaeangliae*), beaked whales (*Mesoplodon* spp. and *Ziphius cavirostris*), pilot whales (*Globicephala* spp.), sperm whales (*Physeter macrocephalus*), fin whales (*B. physalus*), sei whales (*B. borealis*), either fin or sei whales, right whales (*Eubalaena glacialis*) and unidentified whales.

For comparison, estimates of *g(0)* were derived using both the direct duplicate and Hiby probability estimators. The direct duplicate estimator (Palka, this volume), as applied to aerial surveys, estimates *g(0)* for small leading leg sightings of species group *j* (#5 animals) by:

$$g(0)_{j\cdot small\cdot leading} = \frac{n_{j\cdot small\cdot dup} \cdot ESHW_{j\cdot trailing}}{n_{j\cdot small\cdot trailing} \cdot ESHW_{j\cdot dup}} \quad (1)$$

where

$n_{j,small.trailing}$	= number of small groups of species group *j* seen on trailing legs
$n_{j,small.dup}$	= number of duplicate small groups of species group *j* (from leading and trailing legs)
$ESHW_{j.trailing}$	= effective strip half width of sightings of species group *j* from trailing legs
$ESHW_{j.dup}$	= effective strip half width of duplicate sightings of species group *j*.

Duplicates were determined by comparing the location of groups seen on leading and trailing legs.

The Hiby circle-back estimator (Hiby, 1999) derives *g(0)* and the effective strip half width (ESHW) by maximising a joint probability density for the location (relative to the plane) of the leading and trailing sightings using a likelihood that is a function of five models (which describe the detection function, diving, movement, spatial heterogeneity, and encounter rate). This likelihood determines the probability that a pair of sightings in the leading and trailing legs is a duplicate. This contrasts with the direct duplicate method, which requires duplicates to be defined *a priori*. The Hiby estimate of *g(0)* is then the sum over all possible pairings. In the analysis of the 2002 data, cetacean dispersion rates (animal swim speeds) were set at 1 m/s for porpoises and whales, and at 1.5 m/s for dolphins.

RESULTS

Ship-plane experiment to estimate g(0) The 1995 ship-plane experiment was conducted on 19 and 23 August and on 2 September and covered 443 km of track lines (Fig. 2). During the experiment, 273 groups (747 individuals) of harbour porpoise were recorded by the aerial survey team. The numbers of groups detected in a single run ranged from 8 (24 individuals) to 49 (132 individuals). Group size bias was evident during two of the runs (runs 3 and 10) so the expected group size was calculated using the regression method (Buckland *et al.*, 2001). The ESHW of all harbour porpoise aerial sightings (n=417) was 184 m (SE=6.3). Estimates of $g_{plane}(0)$ for each run ranged from 0.02 to 0.68 (Table 1). The average of these estimates, the best estimate of $g_{plane}(0)$, was 0.235 (SE=0.207; CV=88%).

To investigate the effect of environmental conditions, estimates of $g_{i.plane}(0)$ were recalculated including only times when the viewing quality was rated as either 'excellent' or 'good' (*i.e.,* approximately 60% of the time). The resulting $g_{plane}(0)$ estimate was 0.236 (SE=0.206; CV=87%). This estimate (Table 1) is not significantly different from the *g(0)* estimate obtained using all of the data.

Hiby circle-back method to estimate g(0) During summer 2002, 7,772 km of track lines were surveyed (Fig. 3). During the equivalent of a conventional single plane sighting survey (7,465 km), 331 whales, dolphins and porpoise groups were detected (Table 2). Estimates of *g(0)* for the three species groups derived from the direct duplicate estimator were slightly lower than those from the Hiby estimator (Tables 2 and 3), although these differences are not significant.

DISCUSSION AND CONCLUSIONS

The estimate of *g(0)* for harbour porpoises derived in 2002 using the circle-back method (0.40 CV=0.62) is not significantly different than that obtained in 1995 using the two-platform method (0.24 CV=0.88) according to the z-test (z=0.51, p=0.61). However, due to the large CV's, it is not possible to confidently determine if the two methods actually do result in similar estimates or if the circle-back method results in higher estimates, perhaps because when on trailing legs observers know there was a group so they search harder, thus resulting in a higher *g(0)*.

There are advantages and disadvantages in using either estimation method. The two-platform method was used to estimate *g(0)* for only one species using both an plane and ship for three days (a total of 886 km of track line) that generated a large CV (0.88). In contrast, the circle-back method was used to estimate *g(0)* for three species groups using a single aerial survey team for 30 days (7,772 km of track line length) that generated a moderate average CV (0.60) for the three species groups.

An advantage of the Hiby probability estimator over the direct duplicate estimator is that all candidates among the leading/trailing sighting pairs are considered, instead of selecting pairs based on a subjective assessment of which groups are duplicates. A disadvantage of the Hiby method is the need to define the distributions of five models and to set parameter values for these models.

Estimates of $g_{plane}(0)$ from the present study are in the range of estimates of *g(0)* derived from other aerial survey studies. For harbour porpoise, other estimates of *g(0)* are: 0.25 using data from two planes and the Hiby probability analysis method (Hammond *et al.,* 2002) and 0.29 using data from a plane and shore observers (Laake, 1997). For small cetaceans, Forney *et al.* (1995) estimated *g(0)* to be 0.67 for groups of size 1-10 when using an independent observer in the same plane. In the same study, Forney *et al.* (1995) estimated *g(0)* to be 0.95 for large whales in groups of sizes 1-22. Because of the different large whale group sizes, the *g(0)* estimates from the present study (groups # 5) should not be compared to the Forney *et al.* estimate (groups #22).

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Table 1. For each day and run during the ship-plane experiment the following statistics are reported: track line length, sighting rate, expected group size, density of individuals, and *g(0)* using all data and only times when the viewing conditions were 'excellent' or 'good'. The runs where the expected group size was corrected for size-bias are identified by *.

Date (track length)	Platform	Run	Sighting Rate	Expected Group Size	Estimated Density of individuals	$g_{plane}(0)$ All data	$g_{plane}(0)$ High quality
19Aug95	Plane	1	0.18	282	2.57	0.23	0.48
		2	0.11	2.20	1.18	0.11	0.22
(176 km)		3	0.43	2.15*	4.71	0.42	0.40
		4	0.46	2.16	5.03	0.45	0.30
	Ship	-	0.53	2.28*	11.09	-	-
23Aug95	Plane	5	0.16	1.64	1.32	0.09	0.14
		6	0.47	4.39	10.56	0.68	0.67
(130 km)		7	0.35	2.08	3.68	0.24	0.18
		8	0.14	1.60	1.17	0.08	0.08
	Ship	-	0.97	2.26*	15.44	-	-
02Sep95	Plane	9	0.62	2.48	7.82	0.22	0.02
		10	0.12	1.39*	0.87	0.02	0.03
(137 km)		11	0.11	3.28	1.66	0.05	0.08
	Ship	-	1.54	2.80*	35.59	-	-
Average	Plane	All	-	-	-	0.235	0.236

Table 2. Using data from the 2002 Hiby circle-back survey, the number of sightings seen during the single, leading and trailing legs, number of duplicates sightings and estimates of $g(0)_{leading}$ and its coefficient of variance (CV) calculated using the direct duplicate and Hiby probability methods

	Number of sightings				$g(0)_{leading}$ (CV)	
Species	Single	Leading	Trailing	Dups	Direct-dup	Hiby prob
Harbour porpoise	56	36	20	12	0.40 (0.62)	0.49 (0.46)
Small cetaceans	121	22	12	7	0.58 (0.47)	0.77 (0.57)
Large cetaceans	75	21	15	5	0.19 (0.64)	0.21 (0.80)

Table 3. The ESHW (in meters) and expected group sizes (E(s)) of species groups used to estimate *g(0)* using the direct duplicate method

Type of data	Harbour Porpoise		Small Cetaceans		Large Cetaceans	
	ESHW	E(s)	ESHW	E(s)	ESHW	E(s)
Duplicates	260	3.00	500	17.71	1603	1.20
Trailing	181	3.43	500	26.25	890	1.21
Lead&single	182	3.37	258	22.67	858	1.43

Table 4. Parameter estimates of model values used in the calculation of *g(0)* when using the Hiby probability method

Parameter	Harbour Porpoise	Small Cetaceans	Large Cetaceans
Proportion zero	0.74	0.57	0.5
Mean displacement rate (m/s)	1.0	1.5	1.0
ESHW (m)	207	400	941

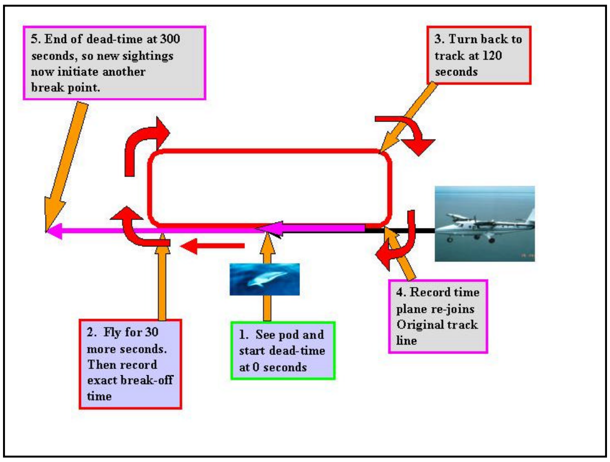

Fig. 1. Procedure used to collect data to estimate *g(0)* using the Hiby circle-back method

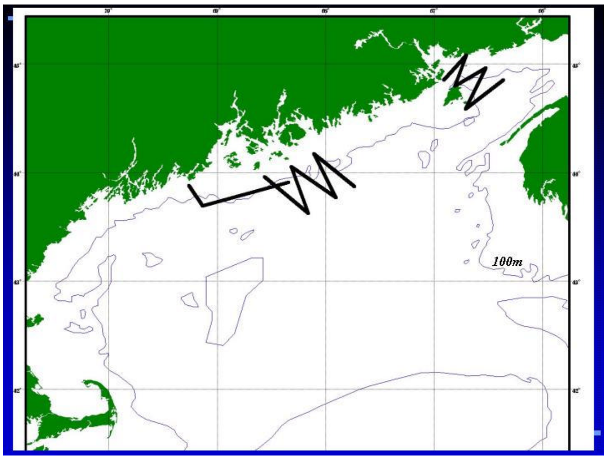

Fig. 2. Track lines flown during the 1995 ship-plane experiment to estimate *g(0)*

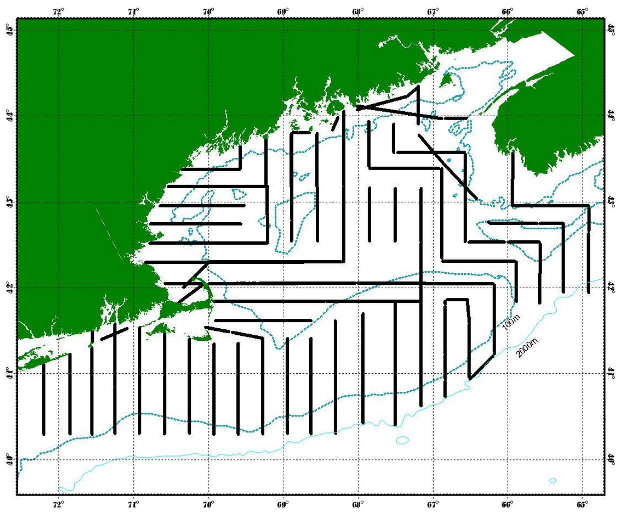

Fig. 3. Track lines flown during the 2002 survey using the Hiby circle-back method