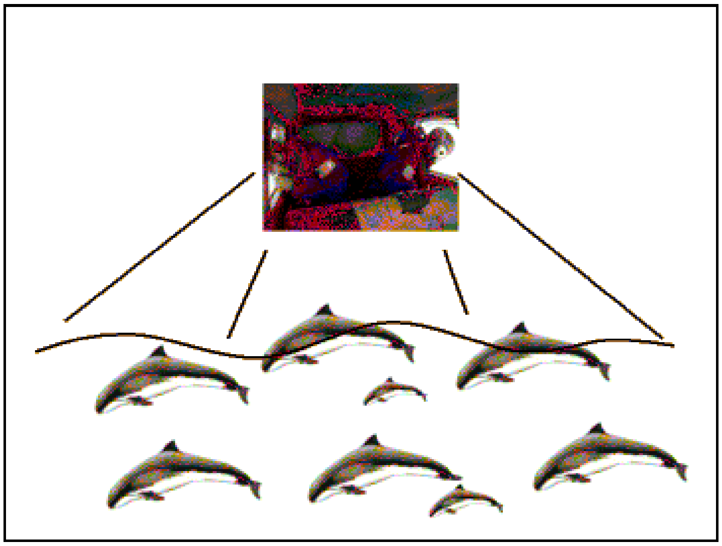
PROCEEDINGS OF THE WORKSHOP ON

ESTIMATION OF G(0) IN LINE-TRANSECT SURVEYS OF CETACEANS

Held at the
European Cetacean Society's 18th Annual Conference,
Vildmarkshotellet at Kolmarden Djur Park, Kolmården, Sweden,
28th March 2004



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Proceedings of the workshop on

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INTRODUCTION TO WORKSHOP

Frank Thomsen[1,2] and Fernando Ugarte[3, 4]

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Estimating g(0) – the probability that an object that is on the line is detected, is crucial for any study on abundance and distribution using standard line-transect methods. In cetaceans, g(0) is usually <1, since whales and dolphins are submerged most of the time and are therefore unavailable for detection. Furthermore, species such as minke whales or harbour porpoises are inconspicuous and can easily be missed by observers. It is difficult and challenging to estimate g(0) precisely. Most approaches involve the analysis of data obtained from independent platforms. There are also new approaches, for example combinations of acoustic and visual surveys, which might provide exciting prospects for future studies.

The aim of the workshop was to exchange ideas and share experiences about how to estimate g(0) in line-transect surveys of cetaceans. Our intention was that those who have worked with the issue could see what other teams are doing, while those who are planning new surveys would be able to receive inspiration and ideas.

The workshop took place on Sunday, 28 March 2004, at the Vildmarkshotellet of the Kolmårdens Djurpark, Kolmården, Sweden prior to the start of the 18th Annual Conference of the European Cetacean Society. Around 80 persons from 14 countries attended the workshop (see list of participants at the end of this volume).

The event started with an introduction to statistical methods, including a review of how g(0) was estimated for the SCANS 1994 survey. Next, methods to estimate g(0) for aerial surveys were presented, including the 'circle-back' method and a mark-recapture approach. This was followed by a session on diving behaviour. Methodology for shipboard surveys was covered thereafter. Acoustics and new techniques were topics of the subsequent session, including the use of a new towed-array system for combined visual- and acoustic surveys on harbour porpoises. Finally, experts summarised the results of the workshop and gave an overview of future research directions.

We are very grateful to all contributors for their efforts. Thanks a lot to the assigned helpers – A. Englund, R. de Stephanis, T. Genov, P. Kotjnek, P. Lastra, R. Riesch and M. Simon - who did such a great job throughout the meeting. We would also like to thank the organisers of the ECS conference for their help prior to and during the workshop. Many thanks go to Phil Hammond for helping us to set up the scheme, and, finally, a special thanks goes to 'Biola' (Hamburg, Germany) for sponsoring the venue.

ESTIMATING DETECTION PROBABILITY FROM LINE-TRANSECT CETACEAN SURVEYS WHEN DETECTION ON THE LINE IS NOT CERTAIN: AN OVERVIEW

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INTRODUCTION

Conventional line-transect theory rests on the assumption that objects on the transect-line (at perpendicular distance $x=0$) are detected with certainty. In symbols, this is usually written as "$g(0)$" = 1, where $g(x)$ is the probability of detecting an animal at perpendicular distance x. The function $g(x)$ is called the detection function. Here I use $p(x)$ for detection functions which can be less than 1 on the transect line, i.e. those for which $p(0)\leq 1$. On many cetacean surveys, the assumption that $p(0)=1$ is questionable or known to be false.

Animals on the track line are missed for two reasons:

1. they may be unavailable for detection because they are underwater (bias from this source is called "availability bias"), or
2. observers may fail to detect them even though they are available (bias from this source is often called "perception bias").

How available animals are depends not only on their behaviour, but also on the detection process. For example, large cetaceans with shallow diving behaviour might be available to observers from a high shipboard observation platform often enough that availability bias is zero. But some of the same animals could be unavailable to an observer on a fixed-wing aircraft because they are underwater in the much shorter time that they are visible to this observer, so that availability bias from the aircraft is not zero.

The most successful approaches to date for estimating abundance from line-transect surveys with uncertain detection on the transect-line use independent observers and mark-recapture ideas to get at $p(0)$. The basic idea is very simple. Here it is: suppose you and I search independently, you see 10 animals on the track line and of these, I see 5. I've seen half of the 10 you knew were there, so we estimate that for me, $p(0)=5/10=0.5$. Simple. There are two ways things get more complicated. The first is that we need to estimate detection probability at all distances, not just on the transect line ($x=0$). I return to this later. The second is that not all animals are equally detectable. Suppose both you and I could only detect frequently-surfacing animals and that only half the animals are frequent-surfacers. Then although I may have detected half the frequent-surfacers on the track line, these are only half the animals on the track line, so I've really detected only a quarter of the animals on the track line. My estimate of $p(0)$ is biased because some animals are more detectable than others. This problem is called "unmodelled heterogeneity". It turns out to be a difficult problem to deal with.

I focus on estimation of detection probability. Laake and Borchers (2004) summarise associated abundance estimation methods.

MARK-RECAPTURE LINE-TRANSECT ESTIMATION METHODS

Estimating detection probability at all distances

One way to extend the simple mark-recapture idea outlined above, to estimate detection probability at all distances, is just to apply it within each of a number of distance intervals. For example, consider Fig. 1, taken from Cañadas *et al*. (2004), which shows this estimated detection probability, $p(x)$, in each of six perpendicular distance "bins" from a survey of common dolphins. In the first bin (0 to 0.05 km), $p(\mathrm{x})$ is estimated to be just over 0.7, in the second bin (between 0.05 and 0.1 km, it is estimated to be just over 0.8), and so on.

While this method of estimating $p(x)$ is easy to follow, it is not optimal because (a) we know that detection functions should not normally have "steps" in them – they should be smooth, and (b) we're not making most efficient use of the data because we're only using the data in one interval to estimate $p(x)$ in that interval. A better way of estimating p(x) is to specify some smooth form for it and to use unbinned data. Unbinned data for the simple example above, from which we estimate a detection function for me, consist of a distance at which you saw the animal (x) and a binary response (seen/missed by me) for each of your detections. Formulated in this way, the problem of estimating my $p(x)$ is a binary regression problem, and one of the nice things about this is that there is an existing body of statistical theory and software for binary regression problems. A logistic functional form, $p(x)=\exp(\Omega \mathrm{x})/[1+\exp(\Omega \mathrm{x})]$, is commonly used because it has the right general shape for a detection function, and is readily available in binary regression estimation software (Ω is a parameter to be estimated). So this gives us a sound method for estimating $p(x)$ at all distances - but what about the problem of unmodelled heterogeneity?

Estimating detection probability at all distances and covariate values

Suppose we could observe the things which make some animals more detectable than others. I used the example of frequently-surfacing behaviour above as a thing making some animals more detectable than others. I'll call these things covariates. The problem with surfacing behaviour is that it is a covariate which is very difficult and sometimes impossible to observe. I'll return to this below, but for the moment, say that the only thing other than distance which makes some groups of animals more detectable than others is the group size: small groups are less detectable to observers on both platforms and large groups are more detectable to both. Bias arises in the same way as with surfacing behaviour.

To see this, suppose that there are only "small" and "large" groups and that half the groups are large. Suppose also that small groups are nearly undetectable. Finally, suppose that at some distance x, I detected half the groups you detected and so we estimated my $p(x)$ to be 0.5. If all the groups you detected were large, this is a positively biased estimate of $p(x)$ on the survey as a whole (because $p(x)$ is much lower for small groups). Even if some of the animals you detected were small groups, you will have detected more large groups, so the estimate of $p(x)$ will tend towards that for large groups. To get around this problem, we put group size into our detection function model. Using a logistic form, it could become $p(x,z)=\exp(\Omega_1 x+\Omega_2 z)/[1+\exp(\Omega_1 x+\Omega_2 z)]$, where z is group size. Fig 2 illustrates this kind of detection function.

We can easily extend this estimation method to include any number of variables which might affect detection probability, in addition to distance. In this way, we can model heterogeneity in detection probability. "Heterogeneity" in this context means differences in detection probability of different animals or groups. Heterogeneity is modelled if we can include the variables causing it (like group size) in our detection function model. The trouble is that it can be very difficult to include all variables causing heterogeneity. We may (a) know something is causing heterogeneity but we cannot observe it, or we may (b) think we have recorded all things causing heterogeneity but it turns out we have not. Surfacing behaviour can be a variable of the first kind – we cannot observe animals that do not surface in our field of view. I deal briefly with (b) and then with (a) below.

Unmodelled Heterogeneity I: Point independence

The mark-recapture-based methods of estimating $p(x)$ and $p(x,z)$ described above, assume that there is no unmodelled heterogeneity at any value of x or z. (In general, z can be a vector, containing many variables but I'll stick with a single variable z here for simplicity.) Laake (1999) developed a method which relaxes this assumption somewhat. The method was picked up and developed further by Borchers *et al*. (submitted), who called it "point independence". The motivation for the method came from observing that the shape of $p(x)$ estimated as above was sometimes much flatter than the shape estimated from the perpendicular distance distribution of detected animals by the platform in question. This sort of difference is seen between Fig 1 and Fig. 3 below. In the context of the survey from which these figures come, responsive animal movement is the most likely explanation for the difference, but Borchers *et al*. (submitted) document similar differences in aerial pack-ice seal surveys in which responsive movement is not a possible explanation.

In the absence of responsive movement (and correlation between distance and variables causing heterogeneity), the perpendicular distance distribution of detections should be an unbiased representation of the shape of the detection function in the x dimension. The estimate of $p(x)$ using the mark-recapture methods described above, on the other hand, is only an unbiased representation of the shape of the detection function if there is either no unmodelled heterogeneity, or equal unmodelled heterogeneity at all x. If unmodelled heterogeneity increases with distance (because at larger distances both observers tend to see an increasing proportion of the more detectable animals) we expect the estimate of $p(x)$ using mark-recapture methods to decrease more slowly with distance. The methods of Laake (1999) and Borchers *et al*. (submitted) assume no unmodelled heterogeneity on the trackline (x=0) and estimate $p(0)$ (or $p(0,z)$) from the mark-recapture data, but then use the perpendicular distance distribution together with this estimate to estimate $p(x)$ (or $p(x,z)$) at $x>0$.

The advantage of the method over the binary regression approach described above, is that it makes weaker assumptions about unmodelled heterogeneity. Model selection methods allow the user to choose between the two approaches.

Unmodelled Heterogeneity II: The Availability Process

Surfacing behaviour is, for many species, a source of heterogeneity in detection probability: those animals which surface near the observer, and/or frequently, are more detectable than those which do not. Surfacing behaviour, by its nature, can be very difficult to observe adequately to include in a detection function model.

If separate data are available on surfacing patterns (from radio-tagging studies, for example), one can use this to deal with heterogeneity from surfacing pattern. The double-platform cue-counting approach developed by Hiby *et al*. (1989) is one such approach. Here, cues (some instantaneous observable thing the target animals generate – like blows) are the sighting unit and no attempt need be made on the survey to decide which cues came from which animals. The probability of detecting a cue is estimated from the survey. Information on cue rate is then used to convert an estimate of cue density into an estimate of animal density. These methods use radial distances, not perpendicular distances and really have more in common with point-transect surveys (see Buckland *et al*. 2001) than with line-transect surveys.

Schweder (1974) and Skaug and Schweder (1999) developed methods specifically for animals which are discretely available. Most line-transect methods model detection probability as a function of perpendicular distance but not along-track line distance. The methods of Schweder (1974) and Skaug and Schweder (1999) involve modelling detection probability as a function of both perpendicular distance (x) and along-track line distance (y). They model heterogeneity due to surfacing behaviour by integrating this detection function over the surfacing process, whose parameters are estimated outside of the survey.

Cooke (1997) and Schweder *et al*. (1997, 1999) developed methods for surveys in which animals are tracked after initial detection and all detected cues from these animals are recorded. Cooke (unpublished) noted that in this case, the fraction of duplicate detections of whales (by different platforms) that involve detections of the same cue by the two platforms, contains information on the surfacing process. If most duplicates involve detection of the same cue, this suggests that there were not many undetected cues within detectable range, whereas if very few duplicates involve detections of the same cue, this suggests that each platform missed many cues. Cooke (unpublished) and Okamura *et al*. (2003) developed methods which implement this idea. Okamura *et al*. (2003) found, perhaps not surprisingly, that using additional information on the cue process led to improved estimation.

In some cases it is possible to design out heterogeneity due to the surfacing process. Heterogeneity is only a problem if it affects both observers. To illustrate with a simple contrived example, suppose animals go around in single-sex groups and the fraction of these groups of each size is the same for both species (i.e. group size is independent of sex). Suppose also that you preferentially detect female groups (of any size) and I preferentially detect large groups (of any sex). Your detections are a random sample of group sizes, so if I detect half the animals you see, then 0.5 is an unbiased estimate of the probability that I detect any animal in the population. This idea can be used to remove heterogeneity due to surfacing pattern.

With two visual observers (you and I, say), the key is to separate the times you and I search any particular area of sea by some time. If the separation is sufficient that an animal surfacing when you search the area is independent of whether it will surface when I search the area, your detections contain a random sample of animals available to be detected by me and surfacing pattern will not cause heterogeneity. Having one observer search farther ahead than the other can achieve this. The degree of separation depends on the species' surfacing pattern and for some long-diving species the idea is not workable.

Another variant on this design is to use a visual observation platform(s) and an acoustic detection platform. If animals' surfacings are independent of their vocalisations, visual detections are a random sample of animals available to the acoustic detector, and vice-versa. While the idea seems good, methods to implement it have not yet been developed to a usable state.

Responsive Animal Movement

Responsive movement before detection can lead to very biased estimation. For some species (dolphins which bow-ride, for example) this is a serious problem. If animals are attracted to the surveyors, this gives negatively biased estimates of detection probability and positively biased estimates of abundance. For example, Cañadas *et al*. (2004) estimated that conventional line-transect estimates of dolphin abundance were positively biased by a factor of nearly 4 due to attractive movement. If animals avoid the surveyors, this leads to positively biased estimates of detection probability and negatively biased estimates of abundance.

Unbiased estimation is possible using independent observer methods if one of the two independent observer platforms search sufficiently far ahead that animals will not have responded prior to detection by this platform. This platform need not survey all the time – it just needs to generate sufficient detections to allow estimation of the other platform's detection function. Details of the method can be found in Buckland and Turnock (1992) and Borchers *et al*. (1998). It is often difficult to know how far ahead animals begin responding. Palka and Hammond (2001) developed a method of estimating the distance at which animals respond, using data on animal headings.

SOME DOUBLE-PLATFORM DESIGN CONSIDERATIONS

The methods above have been described in the context of estimating the detection function for only one of the two independent observer platforms. Unless you are in a situation where one observer searchers farther ahead to catch a subset of animals before they respond, the roles of the two platforms can be reversed. In this case, it is possible to estimate both detection functions simultaneously (see Buckland and Breiwick, 1992, Borchers *et al*., 1998) and to estimate a combined detection function for both platforms. Laake and Borchers (2004) call this an "independent observer" configuration. They call the design in which only one detection function is estimated a "trial-observer" configuration.

The trial-observer configuration can make duplicate identification easier if the trials platform follows every animal it detects. In this case, the only decision to be made on duplicate status is "was this detection seen by the other platform?" With the independent observer configuration, one needs to decide whether any of the detections by one platform could be duplicates with any of the detections by the other platform. The trial-observer configuration can also be easier to implement because it requires only one-way independence: the trial platform need not be kept unaware of the other platform's detections.

Duplicate identification can be difficult and this should be given careful consideration in designing a survey. Options include use of a third observer with responsibility for identifying duplicates and use of methods and equipment which gives accurate recording of distances, angles and detection times (which can greatly aid objective duplicate identification after the survey). Methods that involve separation of search areas and/or using a combination of visual and acoustic detection platforms usually makes duplicate identification more difficult.

Entirely cue-based methods have the advantage that no tracking of animals is required (this can be difficult) but they do require information on the cue generation process. They also tend not to work well on species that are found in groups, because it is very difficult to estimate the cue generation process of a group reliably.

Hiby (1998) developed an innovative cue-based method for aerial surveys in which duplicates are not explicitly identified. The method was initially developed for double-aircraft survey but has since been developed for single aircraft surveys in which the aircraft periodically circles back on itself, and thus acts as both platform 1 (on the first pass) and platform 2 (when it circles back). The method was developed specifically for aerial surveys of harbour porpoise, and extension to other species requires some customisation and is unlikely to be feasible for some species occurring in groups.

SOFTWARE

Distance 5 (2004) now incorporates the animal-based trial-observer and independent observer methods described above. Software implementing the other methods may be available from the authors of those methods.

CONCLUSION

The most successful methods for estimating detection probability and abundance from line transect surveys when detection of animals on the line is not certain involve use of independent observers and mark-recapture ideas in some form. There is a growing variety of estimation methods based on these ideas, some customized for specific species or scenarios, others more general. All are subject to bias from unmodelled heterogeneity; the more one is able to model heterogeneity, the less the bias. This makes it important to gather data on all variables which might affect detection probability. In the case of species for which surfacing pattern might be a source of substantial heterogeneity, consideration should be given to observer configurations which can minimise or remove the heterogeneity, and to analysis methods which are able to deal with this kind of heterogeneity.

If there is uncertainty about whether or not all animals on the line are detected, it is advisable to do some independent observer survey in order to estimate detection probability on the line. It may be that this results in estimated detection probability on the line, of 1 or very nearly 1 – in which case you might decide that regular use of independent-observer survey in future is not worthwhile. But until you do some independent-observer survey effort and analysis, you may not know what detection probability on the line is.

Finally, I would caution against using estimates of detection probability on the line from other surveys, even if they are in the same place from the same survey platform. Detection probability has been found to vary very substantially between observers, platforms, with weather conditions and other variables so that the probability that applies on one occasion may be quite different from that which applies on another.

REFERENCES

Borchers, D.L., Laake, J.L., Southwell, C. and Paxton, C.L.M. (submitted.) Accommodating unmodelled heterogeneity in double-observer distance sampling surveys. (*submitted to Biometrics, November 2004*).

Buckland, S.T. and Turnock, B.J. 1992. A robust line transect method. *Biometrics*, **48**: 901-909.

Borchers, D.L., Buckland, S.T., Goedhart, P.W., Clarke, E.D. and Hedley, S.L. 1998. Horvitz-Thompson estimators for line transect surveys. *Biometrics* **54**: 1221-1237.

Buckland, S.T. and Breiwick, J.M. 1992. Estimated trends in abundance of eastern Pacific gray whales from shore counts, 1967/68 to 1995/96. *Journal of Cetacean Research and Management*, **4**: 41-48.

Buckland, S.T., Anderson D.R., Burnham, K.P, Laake, J.L., Borchers, D.L. and Thomas, L. 2001. *Introduction to distance sampling*. Oxford University Press, Oxford: 432pp.

Cañadas, A., Desportes, G. and Borchers, D.L. 2004. The estimation of the detection function and g(0) for short-beaked common dolphins (*Delphinis delphis*), using double-platform data collected during the NASS-95 Faroese survey. *Journal of Cetacean Research and Management* **6**: 191-198.

Cooke. J.G. (unpublished) A modification of the radial distance method for dual-platform line transect analysis, to improve robustness. Paper SC/53/IA31.

Cooke, J.G. 1997. An implementation of a surfacing-based approach to abundance estimation of minke whales from shipborne surveys. *Report of the International Whaling Commission*, **47**: 513-528.

Hiby, L., Ward, A. and Lovell, P. 1989. Analysis of the North Atlantic sightings survey 1987: aerial survey results. *Report of the International Whaling Commission*, **39**: 447-455.

Hiby, L. and Lovell, P. 1998. Using aircraft in tandem formation to estimate abundance of harbour porpoise. *Biometrics* **54**: 1280-1289.

Laake, J.L. 1999. Distance sampling with independent observers: reducing bias from heterogeneity by weakening the conditional independence assumption. 137-148 *in* G. W. Garner, S. C. Amstrup, J. L. Laake, B. F. J. Manly, L. L. McDonald, and D. G. Robertson, G. W. Garner, S. C. Amstrup, J. L. Laake, B. F. J. Manly, L. L. McDonald, and D. G. Robertson. *Marine Mammal Survey and Assessment Methods*. Balkema, Rotterdam.

Laake, J.L. and Borchers, D.L. 2004. Methods for incompolete detection at distance zero. 108-189 *in* Buckland, S.T., Anderson D.R., Burnham, K.P, Laake, J.L., Borchers, D.L. and Thomas, L. *Advanced Distance Sampling*. Oxford University Press, Oxford.

Okamura, H. Kitakado, T., Hiramatsu, K. and Mori, M. 2003. Abundance estimation of diving animals by the double-platform line transect method. *Biometrics* **59**: 512-20.

Palka, D.L. and Hammond, P.S. 2001. Accounting for responsive movement in line transect estimates of abundance. *Canadian Journal of Fisheries and Aquatic Sciences* **58**: 777-787.

Schweder, T. 1974. *Transformations of point processes: Applications to animal sighting and catch problems, with special emphasis on whales*. PhD. thesis, University of Califrnia, Berkeley.

Schweder T., Skaug, H.J., Dimakos, X,K., Langaas, M. and Øien, N. 1997. Abundance of northeast Atlantic minke whales, estimates for 1989 and 1995. *Report of the International Whaling Commission*, **47**: 453-483.

Schweder T., Skaug, H.J., Langlaas, M. and Dimakos, X,K. 1999. Simulated likelihood methods for complex double-platform line transect surveys. *Biometrics*, **55**: 678-687.

Skaug, H.J. and Schweder, T. 1999. Hazard rate models with independent observer. *Biometrics* **55**: 29-36.

Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H. and Bishop, J.R.B. 2004. Distance 5.0. Release 1. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

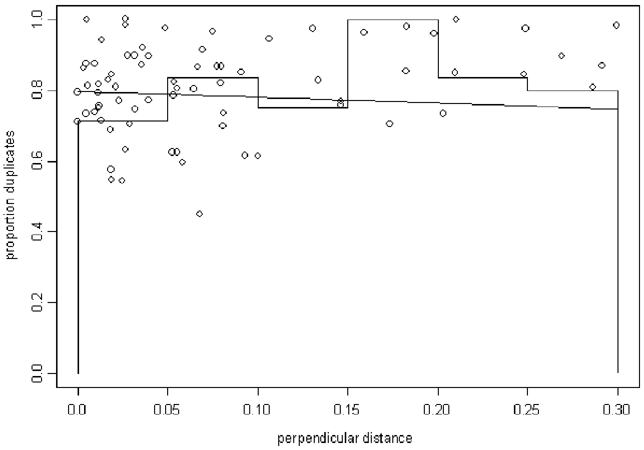

Fig. 1..The histogram shows the distribution of the proportion of detections made by platform 2, which were also detected by platform 1 in each of six perpendicular distance intervals. The smooth line is the estimated detection function when perpendicular distance, group size and Beaufort sea state are in the detection function model. The dots represent the predicted detection probability for individual detections. Taken from Cañadas *et al*. (2004).

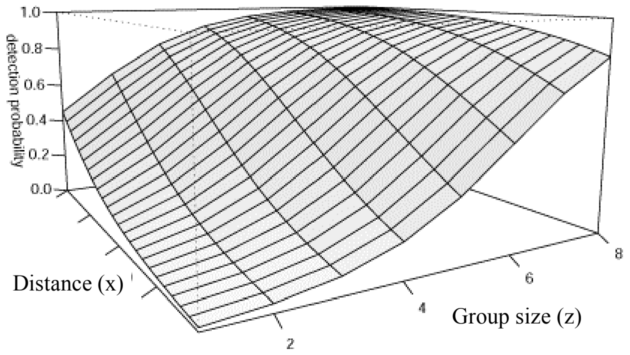

Fig. 2. Example of a logistic detection probability as a function of distance (x) and group size (z): $p(x,z)=\exp(\Omega_1 x+\Omega_2 z)/[1+\exp(\Omega_1 x+\Omega_2 z)]$

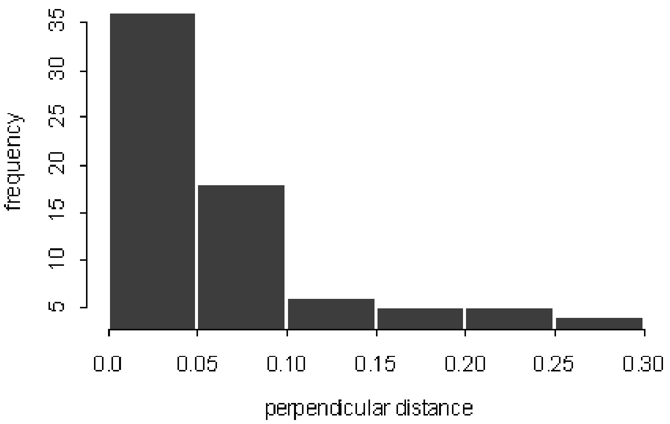

Fig. 3. Perpendicular distance distribution

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

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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:

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

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).

REFERENCES

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001. *Introduction to Distance Sampling*. Oxford University Press, Oxford.

Forney, K.A., Barlow, J. and Carretta, J.V. 1995. The abundance of cetaceans in California waters. Part 2: Aerial surveys in winter and spring of 1991 and 1992. *Fishery Bulletin* 93(1): 15-26.

Hammond, P.S., Berggren, P., Benke, H., Borchers, D.L., Collet, A., Heide-Jorgensen, M.P., Heimlich, S., Hiby, A.R., Leopold, M.F. and Øien, N. 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *J. of Applied Ecology* 39(2): 361- 376.

Hiby, L. 1999. The objective identification of duplicate sightings in aerial survey for porpoise. Pp. 179. In *Marine Mammal Survey and Assessment Methods*. (Eds. Garner, G.W., S.C. Amstrup, J.L. Laake, B.F.J. Manly, L.L. McDonald and D.G. Robertson). A.A. Balkema, Netherlands. 287pp.

Laake, J.L., Calambokidis, J., Osmek, S.D. and Rugh, D.J. 1997. Probability of detecting harbour porpoise from aerial surveys: estimating g(0). *J. Wildl. Manage.* 61(1): 63-75.

Palka, D. 1996. Update on abundance of Gulf of Maine/Bay of Fundy harbour porpoises. *NMFS Northeast Fisheries Science Center Reference Document* 96-04. 37pp.

Palka, D. (this volume). Shipboard surveys in the northwest Atlantic: Estimation of g(0).

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	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

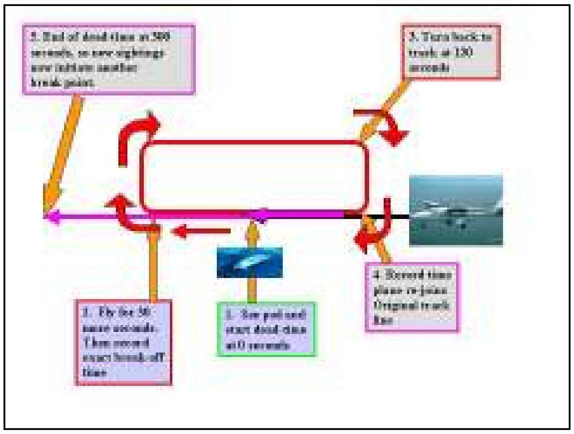

Fig. 1. Procedure used to collect data to estimate *g(0)* using the Hiby circle-back method

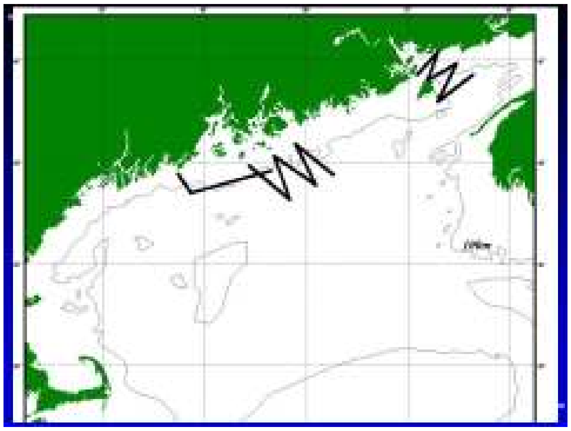

Fig. 2. Track lines flown during the 1995 ship-plane experiment to estimate *g(0)*

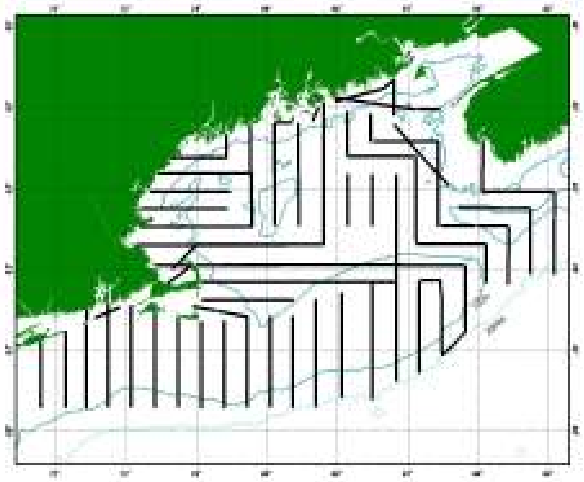

Fig. 3. Track lines flown during the 2002 survey using the Hiby circle-back method

APPLYING THE CIRCLE-BACK METHOD TO ESTIMATE G(0) – EXPERIENCES AND RESULTS FROM AERIAL SURVEYS IN GERMAN WATERS

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INTRODUCTION

During line-transect distance sampling it is important to obtain estimates of g(0) for the species investigated. One method used in cetacean surveys, the tandem flight, has been applied during the 1994 SCANS survey (Hammond et al. 1995). This document discusses the experiences and results from applying the new development of the circle-back (or raceback) method (developed by Hiby and Lovell) during aerial surveys in German waters. The theory behind the circle-back method has been described in Hiby 1998 and Hiby and Lovell 1998. This document focuses on the advantages and disadvantages of applying this method in the field.

MATERIALS AND METHODS

The airplane surveyed at an altitude of 600 feet (183m) and a speed of around 100 knots (185km/h). Bubble windows allowed each of the two observers on the aircraft to search the area on their side of the aircraft, from the abeam line to the track line. Another observer in the co-pilot seat recorded all changes in sighting conditions during on-effort periods as well as all sightings. For cetacean sightings, estimated pod size was recorded and also the declination angle to the pod as it came abeam. This was estimated using a hand-held inclinometer and, in conjunction with aircraft altitude, provided an estimate of the perpendicular distance to the sighting. Additionally, behaviour, swimming direction and pod composition (presence of calves) was noted. The environmental conditions recorded included sea state, cloud cover, angle obscured by glare, severity of glare, turbidity and a subjective assessment of overall sighting conditions as “good”, “moderate” or “poor”. The sightings and conditions data were entered into a laptop computer during the flight via the VOR program designed by Lex Hiby and Phil Lovell. The laptop continuously accepted output from a GPS receiver. The times at which porpoise pod sightings came abeam of the aircraft were recorded by pressing, at that exact moment, one of two laptop keys assigned for sightings by the left and right hand observer.

Circle-back flights were conducted whenever the environmental subjective conditions were good or moderate An example is shown in Figure 1. After a sighting of a porpoise pod, a 30-second countdown started. At the end of these 30 seconds, the navigator started the circle by pressing the “circle” button and the observers went off effort. The pilot started to fly a holding and, after 150 seconds, returned to a point about 30 seconds before the original sighting was made. As soon as the track line was joined again, the navigator went back on effort (“rejoined”). A normal survey flight continued, and sightings were recorded by the navigator. The aircraft takes about 30 seconds to complete each turn, so this procedure provided the potential for duplicate sighting of a sample of pods following a time interval of about three minutes. As this is well in excess of the average duration of a dive cycle (Westgate *et al.*, 1995), we assumed that the probability a pod would be near the surface at the time of the second overflight would not be affected by the fact it had been seen on the first overflight (and was therefore near the surface at that time).

Estimation from these data of the shape of the sighting function, g(y), its value on the track line, g(0), and hence the effective strip width, is described in Hiby (1998) and Hiby & Lovell (1996). Briefly, the synchronous recording of GPS data, abeam times, and declination angles allows the positions of pods sighted on the first and second overflights to be calculated relative to the aircraft locations at those times. Given a decision as to which of the pods seen on the first and second overflights were duplicates, the likelihood of those positions can be maximised with respect to g(0), the parameters of the g(y) function, and a number of other "nuisance" parameters: the mean density of porpoise pods in those regions of the survey area inhabited by porpoises, the proportion of the area covered by those regions, and the parameters of the function describing the shift in location of pods between the first and second overflights. Synchronous recording of GPS data and sighting conditions allows the sighting locations to be assigned to sections of effort completed under specific conditions and estimates of g(0), the scale parameter of the sighting function and hence the effective strip width, to depend on those conditions.

To apply this method, it was necessary to identify the duplicate and non-duplicate pairs of sightings from the first and second overflights. Some of the sighting times from the two overflights are too far apart to be duplicates. The remaining sightings form groups within which pairs of sightings from the first and second overflights may or may not be of the same pod - there are no distinguishing features that can be used to identify individuals. The approach from Hiby and Lovell was to use a recursive code to generate all possible pairings of sightings within each group (including the special case of no duplicates at all). Those arrangements form an exhaustive set of mutually exclusive events so that the probability for the observed sighting positions equals the sum of the probabilities for each possible arrangement. In this way, Hiby and Lovell calculated the likelihood for the data on each section of the survey conducted under consistent conditions; the log likelihood for the entire survey was obtained as the sum of the log likelihood for each section.

RESULTS

A hazard rate curve was fitted to the resulting frequency distribution of perpendicular distances to porpoise pod sightings under good and moderate conditions. The resulting half-strip width was 226 metres under good conditions, and 217 metres under moderate conditions. Data collected under "poor" conditions were excluded from the analysis.

The likelihood is maximised at a value of 0.568 for g(0) under good conditions, with an estimated 71% reduction (i.e. to 0.164) under moderate conditions (the reduction in the width of the sighting function is only 4%). The corresponding effective half-strip widths are 128 and 36 metres. The likelihood curve does not have a sharp maximum so that 95% confidence limits on g(0) are very wide, from 0.1 to 1 under good conditions. The limits are estimated as the values of g(0) at which the log likelihood is 1.92 less than the maximum likelihood, as indicated by the dotted line. The upper curve in Figure 2 shows the log likelihood for all sighting positions as a function of g(0), the value at zero of the estimated sighting function under good conditions.

DISCUSSION

Problems in the field

Several of the practical problems concerning the circles are general problems that occur during aerial surveys, such as failure of the power supply for the computer or the navigation system. Other logistical reasons for not conducting circles was the limited endurance of the plane forcing a return to the airport, as well as weather and daylight limitations, especially during winter months.

When initially applying the circling method, some problems occurred during the circling. Sometimes the holding pattern was flown in a way that the rejoining was done at the position of the last sighting (more like a "man-over-board" manoeuvre). This was improved soon with experience of pilot and navigator. Another problem was that the turning point was sometimes chosen too early so that the repeated track line did not pass over the location with the initial sighting. This happened, for example, when the plane was facing strong head winds after the turn. Then the standard setting of 120 seconds for the return time had to be increased. All these errors were solved throughout the survey due to the improved communication between navigator (who could follow the flight path on the computer in real time) and pilot.

Due of the limited time available to conduct aerial surveys, and the number of circles needed for calculation of g(0), some of the circle-back flights were specifically done in high density areas. This led to problems in the analyses (see below) because the circle was not abandoned if an additional sighting was made (in the 30 seconds) after the first sighting.

Problems during the analyses

During our surveys, the results for g(0) values resulted in a large confidence interval. If we accept that the mean rate of displacement of a pod is probably no more than 2 m/s and it takes about 200 seconds for the aircraft to circle round to the place from which the pod was seen on the first overflight, then a pod should not have moved more than about 400 metres (see Fig. 3). That would result in a deviation of observed from expected sighting time of, at most, 8 seconds if movement was along the track line.

Figure 4 shows a frequency distribution for the difference between expected and observed sighting times for sightings from the second overflights considered as re-sightings of the pod seen on the first overflight. We would expect a cluster of time differences to occur between -5 and +5 seconds, with a scatter of times beyond those limits due to "new" pods seen on the second overflight. However, the differences are spread almost evenly over the –30 to +30 seconds range, so that a set of parameters corresponding to high pod movement, many re-sightings, and a high g(0) generate almost the same likelihood as a set corresponding to low pod movement, few re-sightings, and a low g(0). Thus a more reliable estimate of g(0) depends on obtaining more data from circling manoeuvres conducted under lower pod densities.

Initially, two potential reasons for the observed problem were identified:

(1) Either the accuracy in recording the leading and trailing sighting times was not sufficient to identify the cluster; or

(2) the pod density in the areas used for circling was so high that the number of "new" trailing pods largely obscured the cluster of re-sightings. Either or both factors may have affected the data.

The use of a keyboard press rather than individual tape recorders (as used during SCANS) to record each sighting, increases the risk that the recording will be delayed because the observer needs to inform the recorder over the "intercom" that the sighting is "abeam". A delay of even a few seconds will greatly reduce the potential for inference, particularly if pod density and hence the frequency of "new" trailing pods is high. To determine if the time delay between sighting and recording could be responsible for the problems, we simulated sightings and checked the time from the call to the recording, and could not find any time lapse that would be more than a second. The observers and the navigator are constantly noting trash/boats/fishing gear and thus the navigator is always expecting a sighting. We therefore do not think that this factor by itself can explain the problem found.

The other potential reason – the high density, now seems to be the most likely cause of the analytical problems. Due to the time limitation and the necessity to include two international observers that were only available for a limited time (August 2002), we did most of the circling (66%) in an area of high density. Also, several times we had more than one sighting before starting the circling, thus making it impossible to match re-sightings during the second, circled leg. We continued to fly until August 2003, and increased the circling numbers. We obtained enough circles to calculate a g(0); however, the C.I. is extremely wide (see below).

Judging from our experience of the 2002 and 2003 aerial surveys in German waters, the circle-back method was easy to use after an initial training. The additional navigator was a comfortable luxury allowing the observers to fully concentrate on their task, and it provided the chance to rotate observers during the flights thus avoiding fatigue. It also gave more flexibility in adapting the flight plan due to unexpected changes (e.g. military activities, sea fog), and allowed immediate control of the data after the flight to check for errors.

There is a possibility that observers are more alert during the re-circling part of the track. They know they had a sighting and might tend to scan more intensively. However, we tried to ensure constant alertness by including frequent pauses (during the transits between parallel transects), rotating the observers (using the navigator as a “fresh” observer), and by including miscellaneous data as sightings. These sightings included debris, boats and fishing gear, and were taken without angle to avoid taking the eyes from the observation area. This constant noting of sightings kept both the observers and the navigator alert.

In terms of g(0) and the sighting probability, the advantage of getting continuous data throughout a larger survey time seems to outweigh the potential bias in alertness. If the observers are alert and this would lead to a bias, at least it would lead to an under-estimate of abundance which is always preferable to an overestimate.

The circle-back flights have continued this year and the analyses will show if the improvement of the field protocol (no circles in high density areas, awareness for accurate entrance of sighting times) will lead to an improved estimate of g(0).

ACKNOWLEDGEMENTS

We thank Lex Hiby and Phil Lovell who have developed the software used during all flights to enter sightings and to conduct the circles. They have also calculated the g(0) and the *esw* for the German aerial surveys. This work was financed through two projects that are investigating the distribution and abundance of marine mammals in German waters. They are funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) within the Investment-in-future program (ZIP) as part of the project MINOS and by the Federal Agency for Nature Conservation (BfN). Our special thanks go to the pilots of the survey planes, especially Peter Siemiatkowski from Aeroline, and Leif Petersen from the Danish Air Survey. The completion of the surveys was only possible through the dedication of the observers Jörg Adams, Patrik Börjesson, Helena Herr, Iwona Kuklik, and Kristina Lehnert, Maik Marahrens and Carsten Rocholl.

REFERENCES

Hammond, P.S., Benke, H., Berggren, P., Borchers, D.L., Buckland, S.T., Collet, A., Heide-Jørgensen, M.P., Heimlich-Boran, S., Hiby, A.R., Leopold, M.F., and Øien, N. 1995. *Distribution and abundance of the harbour porpoise and other small cetaceans in the North Seaand adjacent waters*. Final Report to the European Commission DG XI/B/2, under contract LIFE 92-2/UK/027.

Hiby, A.R. 1998. The objective identification of duplicate sightings in aerial survey for porpoise. In: *Marine Mammal Survey and Assessment Methods* Rotterdam. Balkema.

Hiby A.R. and Lovell, P. 1996. Using aircraft in tandem formation to estimate abundance of harbour porpoise. *Biometrics* **54**:1280-1289.

Westgate, A.J., Read, A.J., Berggren, P., Koopman, H.N. and Gaskin, D.E.. 1995. Diving behaviour of harbour porpoises, *Phocoena phocoena*. *Canadian Journal of Fisheries & Aquatic Sciences* **52**: 1064-1073.

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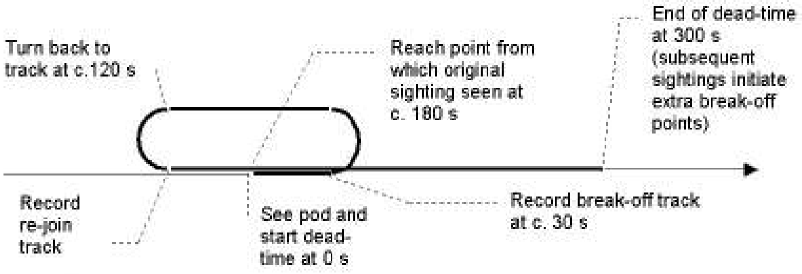
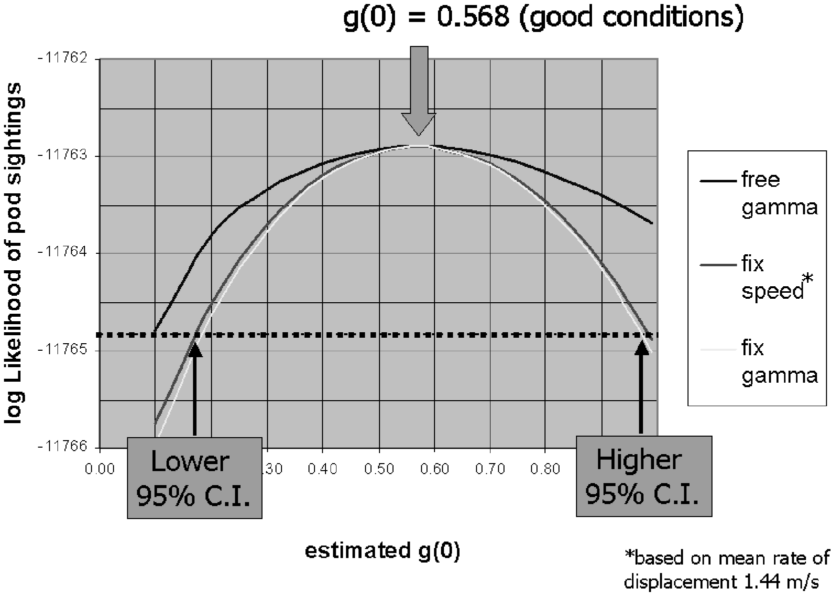


Fig. 1. Flight path used to provide duplicate sighting effort over selected track line sections. The section from the recorded re-join point to the recorded break-off point is assigned to duplicate effort by the database management system



*based on mean rate of displacement 1.44 m/s

Fig. 2. The upper curve shows the log likelihood for all sighting positions as a function of g(0), the value at zero of the estimated sighting function under good conditions.

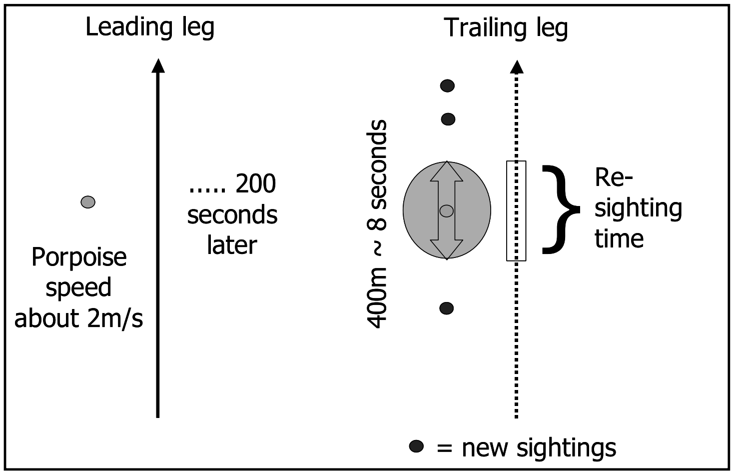


Fig. 3. Expected position of porpoise sighting after a flown circle

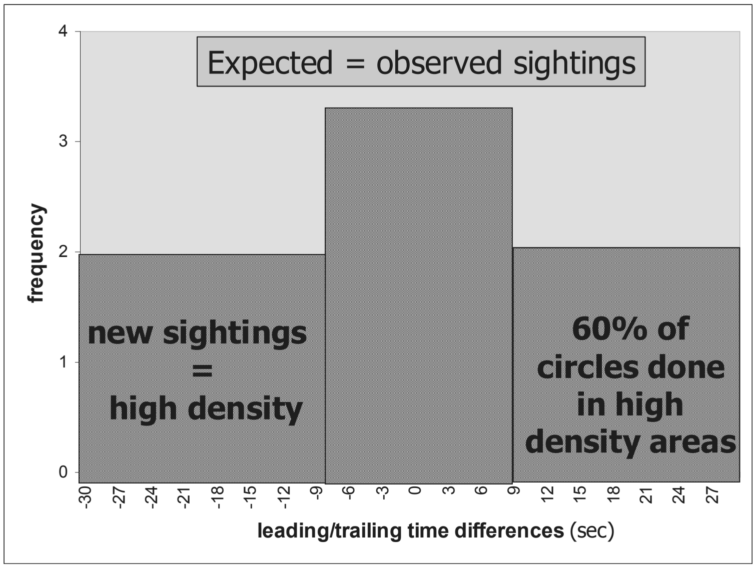


Fig. 4. Frequency distribution for the difference between expected and observed sighting times for sightings from the second overflights considered as re-sightings of the pod seen on the first overflight. The sightings in the shaded areas could be explained by circlings conducted in high density areas.

AERIAL SURVEYS IN THE GERMAN BIGHT – ESTIMATING G(0) FOR HARBOUR PORPOISES (*PHOCOENA PHOCOENA*) BY EMPLOYING INDEPENDENT DOUBLE COUNTS

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BACKGROUND

In the framework of environmental impact assessment studies, we conducted combined aerial surveys for harbour porpoises and seabirds in the German Bight. In the years 2001 to 2003, we carried out 44 flights in three different areas.

DATA RECORDING

We used twin engine high-winged "Partenavia (P 68)" planes to fly transects, which were separated by 3 km. The aircrafts were equipped with "bubble-windows", which enabled us to look straight down below the aircraft. The flight altitude was 76 m (250 feet). In summer, harbour porpoises are sufficiently abundant to ensure enough (at least 60 to 80) sightings to run statistical analysis for a single survey with the software package DISTANCE 4.0 (Thomas *et al.*, 1998). In winter, pooling of data was necessary.

Three observers formed a counting team. On one side of the plane there were always two observers seated, sitting behind each other without having contact due to headsets and screen from view. This enabled us to quantify the number of missed animals. Every observer independently noted the following parameters on handheld tape recorders: school size, age category (new born and adult animal), time (minutes and seconds), sighting angle and observation cue. The ground speed of the plane was approximately 185 km/h (100 knots). A GPS-logger registered the position of the plane every five seconds.

Various studies stressed the influence of different sighting conditions (i.e. sea state, wind speed, sun glare, cloud coverage, altitude and observer skill) on detection rates of harbour porpoises (Barlow *et al.*, 1988; Forney *et al.*, 1991; Heide-Jørgensen 1992, 1993; Hammond *et al.*, 1995, 2002). Considering these findings, we excluded transect sections with sea state higher than 2, and unfavourable sighting conditions like glare, from the survey effort. When the conditions became unfavourable for a longer period of time, we stopped the survey. The accuracy of the distance measurement is crucial for computing densities with DISTANCE 4.0 (Thomas *et al.*, 1998). In order to achieve an ungrouped data set, we measured the angle to each sighting without rounding.

Estimating g(0)

We have to consider an incomplete detection of animals at distance zero: $g(0) < 1$. In order to calculate densities, it is crucial to estimate the value of g(0). We estimated g(0) by combining two different sources of bias:

- proportion of missed animals near the sea surface (perception bias),
- proportion of diving animals (availability bias).

g(0) = perception bias x availability bias

Perception bias

We estimated the number of missed animals near the sea surface with our own data of independent double counts of two observers on one side of the plane. For this reason we calculated a sighting and re-sighting ratio. Flying at an altitude of 76 m, we were able not only to detect emerged harbour porpoises, but also animals in the upper first metre below the sea surface.

Data from two observers, recorded at the same time and side of the plane, were compared and the following ranking for the double sighting identification (animal or group of animals) was applied:

1. number of animals and presence of calves,
2. temporal proximity,
3. spatial proximity,
4. cue.

If both sightings from the observers sitting behind each other consisted of more than one animal, this school characteristic was reliable to identify a double sighting. This was also the case for other parameters such as temporal proximity of less than 10 seconds. Most sightings were single animals, so the time measurement primarily contributed to the double sighting identification. 79% of the identified double sightings differed from one another by only up to three seconds (Fig. 1). Additionally, we considered the angle and cue of the sighting (emerged/submerged animal, splash, bird etc.). The generally low sighting rates are favourable for the double count identification.

Pollock *et al.* (1987) described line-transect surveys with two observers on one side of the plane, and stressed both the necessity as well as the difficulty in achieving independent counts. We ensured independent counts by visual (curtains between the two rows of seats of the plane) and acoustic (headsets) isolation of the observers. Furthermore, the frequent sightings of birds mask the more rare sightings of harbour porpoises.

Availability bias

The portion of time spent in different depths of the water column has been measured with time-at-depth-loggers (TAD) by different researchers. Teilmann *et al.* (1998) tracked a juvenile harbour porpoise (30 kg), which dived 351 times within 10 hours of registration with a mean dive duration of 1.1 min. The animal swam 34% of the time in water depths between 0 and 2 metres. More detailed studies relating to diving patterns of harbour porpoises come from the US and Canadian east coast (Westgate 1995), from Japan (Otani *et al*., 1998, 2000) and from the inner Danish Waters (Teilmann, 2000). Despite study areas on different continents, the common outcome was a diving rate of 30 dives per hour in spring and summer. We feel confident to refer to the large TAD data set of Teilmann (2000) for our density estimations due to approximately equal water depths and approximately the same prey species and sizes involved. We did not take into account the diurnal variation of TAD data (Teilmann, 2000) because our effort covered a large part of the daytime (Figure 2).

RESULTS

In total, the first observer detected (marked) 772 schools, and the second observer at the same side of the plane detected (recaptured) 446 schools: the general ratio was 0.58. This ratio decreased with increasing distance to the transect line (Fig. 3). Due to the fact that we did not see enough schools on the proper transect line with g = 0, we had to include more distant sightings, and created a g(0)-zone rather than referring to a proper g(0)-line. We suggest to pool the sighting/re-sighting rates up to 120 m (33° at a flight altitude of 250 ft), and to generate a general rate of 0.66 for the overall perception bias (Fig. 3). In 9 out of 44 surveys, more than 25 schools were marked. The flight specific ratio differed from 0.41 to 0.71 (Table 1).

Referring to Teilmann (2000), harbour porpoises spend on average half of the time (0.56) in the upper two metres of the water column. This rate decreases from 0.64 in April to 0.51 in August.

The estimation of g(0) for density calculation with DISTANCE 4.0 is now feasible:

	g(0) = perception bias	x	availability bias	
in general:	g(0) = 0.66	x	0.56	= 0.37
flight specific:	g(0) = 0.41 to 0.71	x	0.51 - 0.64	= 0.21 - 0.45

Method evaluation of g(0) estimation

Advantages

- Both platforms are in one plane: no assumptions for swimming speed or directionality of animal movements are necessary.
- The independent observers have identical sighting conditions: position of the platforms, glare and sea state.
- No additional plane is necessary (availability of planes and high charter costs).
- Flight specific g(0) estimation is possible (integrating conditions, observer skills, seasonal differences in diurnal dive patterns) or pooling of subsequent surveys in low density areas or seasons.

Disadvantages

- The values for 0 - 1 and 0 - 2 m (TAD) differ up to 15% (Teilmann, 2000) and the water depth in which the animal was detected cannot be measured by the observer from the plane.
- Only few data on the time that porpoises spent in different water depths are available. No data exist from the German Bight.

ACKNOWLEDGEMENTS

We wish to thank the Offshore-Bürger-Windpark-Butendiek GmbH & Co KG, and two other enterprises who made this study possible. Ib Kragh Petersen introduced us to transect surveys and helped to analyse the data. Meike Scheidat and Frank Thomsen were helpful in discussing survey design. Special thanks go to Ralf Aumüller, Monika Dorsch, Martin Gottschling, Bodo Grajetzky, Steffen Gruber, Heike Mumm, Jan v. Rönn and Jorg Welcker for help in the surveys, as well as to our pilots Peter Siemiatkowski and Michael Lange (Aero-line Sylt), Leif Petersen and Mats Heisung (Danish Air Survey), and Stefan Hecke and Christoph Wehr (FLM Kiel).

REFERENCES

Barlow, J., Oliver, C.W, Jackson, T.D. and Taylor, B.L. 1988. Harbour porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon and Washington: II Aerial surveys. *Fish. Bull*. **86**: 433-444.

Heide-Jørgensen, M.-P., Mosbach, A., Teilmann, J., Benke, H. and Schultz, W. 1992. Harbour porpoise (*Phocoena phocoena*) densities obtained from aerial surveys north of Fyn and in the Bay of Kiel. *Ophelia* **35**: 133-146.

Forney, K., Hanan, D.A. and Barlow, J. 1991. Detecting trends in harbour porpoise abundance from aerial surveys using analysis of covariance. *Fish. Bull*. **89**: 367-378.

Hammond, P.S., Benke, H., Berggren, H., Borchers, D.L., Buckland, S.T., Collet, A., Heide-Jørgensen, M.-P., Heimlich-Boran, S., Hiby, A.R., Leopold, M.F. and Øien, N. 1995. *Abundance and distribution of harbour porpoises and other small cetaceans in the North Sea and adjacent waters*. Life 92-2/UK/027. Final report to the European Commission, October 1995, 242 pp.

Hammond, P.S., Berggren, P. , Benke, H., Borchers, D.L. , Collet, A. , Heide-Jørgensen, M.-P. , Heimlich, S. , Hiby, A.R., Leopold, M. F. and Øien, N. 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters*.* *J. Appl. Ecol*. **39**: 361–376.

Heide-Jørgensen, M.-P., Teilmann, J., Benke, H. and Wulf, J. 1993. Abundance and distribution of harbour porpoises *Phocoena phocoena* in selected areas of the western Baltic and the North Sea. *Helgoländer Meeresunters*. **47**: 335-346.

Otani, S. , Naito, Y. , Kawamura, A. , Kawasaki, M., Nishiwaki, S and A. Kato, A. 1998. Diving behaviour and performance of harbour porpoises, *Phocoena phocoena*, in Funka Bay, Hokkaido, Japan. *Mar. Mamm. Sci*. **14**: 209-220.

Otani, S. , Naito, Y., Kato, A. and Kawamura, A. 2000. Diving behaviour and swimming speed of a free-ranging harbour porpoise, *Phocoena phocoena*. *Mar. Mamm. Sci*. **16**: 811-814.

Pollock, K.H. and Kendall, W.L. 1987. Visibility bias in aerial surveys: A review of estimation procedures. *J. Wildl. Manage*. **51**: 502-510.

Teilmann, J., Heide-Jørgensen, M.-P., Dietz, R., Sonntag, R., Benke, H., Siebert, U. and Desportes, G. 1998. Diving behaviour of a harbour porpoise (*Phocoena phocoena*) in Danish waters. P. 201. In: *European Research on Cetaceans – 11*. (Editors P.G.H. Evans, E.C.M. Parsons and S.L. Clark). Proceedings of the Eleventh Annual Conference of the European Cetacean Society, Stralsund, Germany, 10-12 March 1997. European Cetacean Society, Kiel, Germany. 314pp.

Teilmann, J., 2000. *The behaviour and sensory abilities of harbour porpoises (Phocoena phocoena) in relation to bycatch in Danish gillnet fishery*. Ph. D. thesis, University of southern Denmark, Odense.

Thomas, S.C., Laake, J.L., Derry, J.F., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Strindberg, S. Hedley, S.L., Marques, F.F.C., Pollard, J.H. and Fewster, R.M. 1998. *Distance 3.5*. Research Unit for Wildlife Population Assessment, University of St Andrews, St Andrews, UK.

Westgate, A.J. , Read, A. , Berggren, P., Koopman, N.H. and Gaskin, D.E. 1995. Diving behaviour of harbour porpoises, *Phocoena phocoena*. *Can. J. Aquat. Sci*. **52**: 1064-1073.

Table 1: Flight specific re-capture ratio of schools (9 out of 44 flights with > 25 marked schools)

date	mean sea state	marked schools	re-captured schools	ratio
27.05.2003	1,0	76	54	0,71
17.06.2003	0,3	70	53	**0,76**
02.06.2002	1,5	66	37	0,56
16.08.2002	0,6	66	46	0,70
30.04.2001	0,5	44	30	0,68
13.04.2003	1,0	41	17	**0,41**
21.08.2001	1,0	33	22	0,67
14.07.2003	1,6	30	14	0,47
03.08.2003	0,3	27	17	0,63

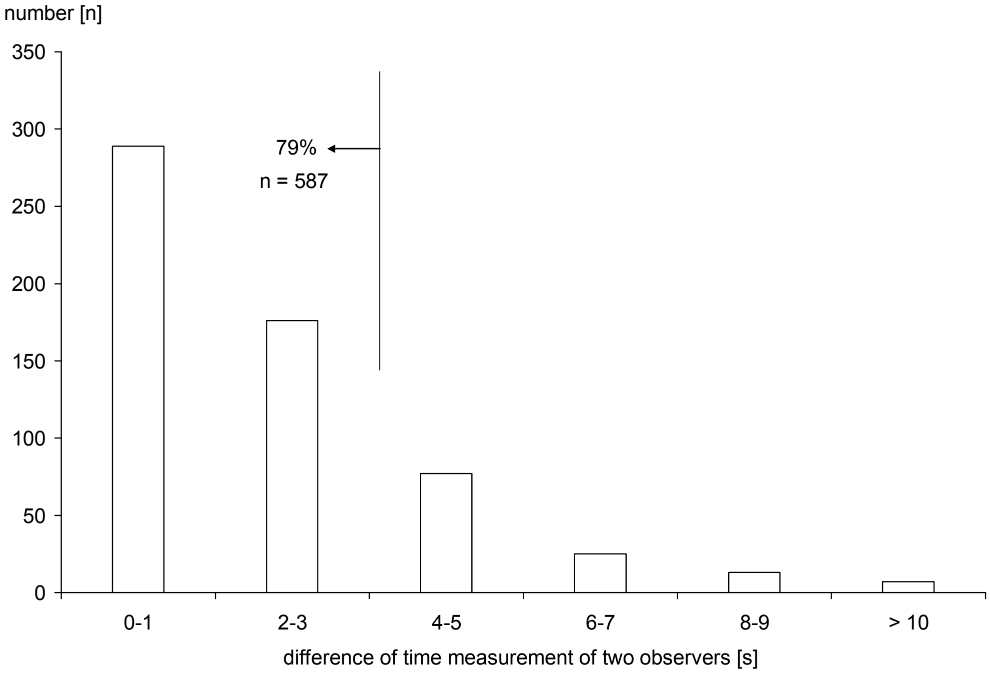

Fig 1. Error of time measurement for identified double sightings

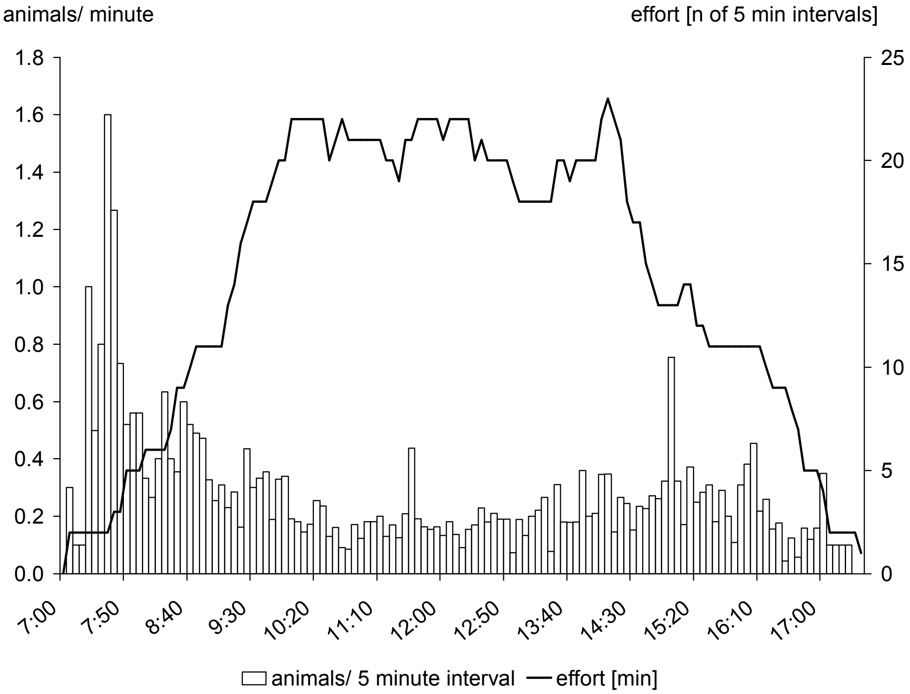

Fig. 2. Effort of the survey and number of harbour porpoises (29 flights in one study area)

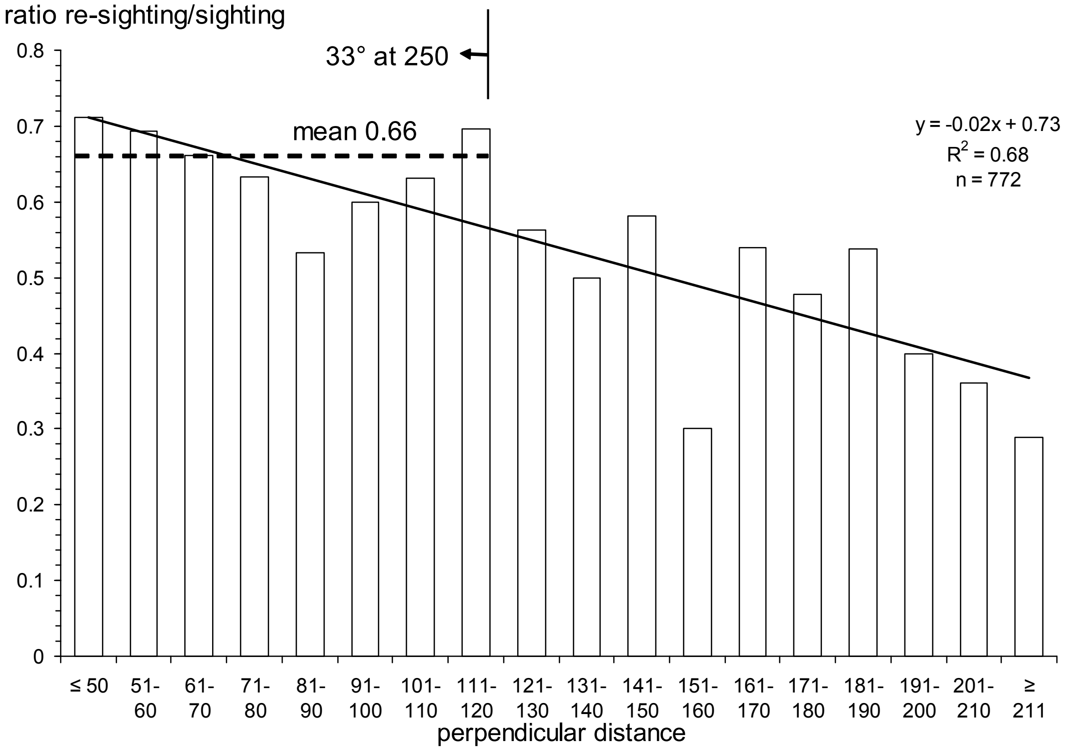

Fig. 3. Influence of distance of the animals to the transect line on the sighting / re-sighting ratio

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

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INTRODUCTION

Since 1991, staff from the Northeast Fisheries Science Center of the U.S. National Marine Fisheries Service have been conducting shipboard cetacean abundance surveys that provide an estimate *g(0)*, the probability of detecting a group on the track line. To estimate *g(0)*, two teams on the same ship simultaneously collect standard line-transect data. These data are then analysed using the direct duplicate method (Palka, 1995), a type of sight-resight (mark-recapture) analysis.

During observer sight-resight surveys, animals can be missed at any distance from an observer. If heterogeneity exists in the probability of detecting animals, the resulting abundance estimates will be biased. To account for such heterogeneity, the direct duplicate method presented in this paper assumes that detections are independently conditional on perpendicular distance (x) and other covariates. Typically, only perpendicular distance is used to explain heterogeneity in the detection probability. However, when important covariates are excluded, the remaining heterogeneity generates biased abundance estimates. The direct duplicate estimator, based on the standard Lincoln-Petersen sight-resight estimator, assumes that detections on the track line (x=0) made by multiple observers are independent; this is referred to as "track line conditional independence" (Laake, 1999). As such, covariates, other than perpendicular distance, are only needed to account for heterogeneity in the detection of groups on the track line. The track line conditional independence assumption is less restrictive than full conditional independence, which presumes no heterogeneity at any distance from the track line. This latter assumption is implicit in some other abundance estimation methods, such as those by Manly *et al.* (1996) and Borchers *et al.* (1998).

In this paper, I describe the direct duplicate method and show how covariates can be incorporated into the analysis. I then provide estimates of *g(0)* for cetaceans in pelagic waters off the east coast of the U.S., based on data collected during a 1998 cetacean abundance line-transect sighting survey.

MATERIALS AND METHODS

Field Data Collection Methods Data were collected by two "independent" sighting teams aboard the ship *R/V Abel-J*, which travelled at 17-19 km/hr (9-10 knots) during survey operations. Surveying was conducted when Beaufort sea states were four and less and was continuously performed, whenever weather conditions allowed, between 6 am and 6 pm, with one hour off for lunch. Observers searched the waters from directly in front of the vessel to 90 degrees left and right of the track line, and from the ship out to the horizon. Each team consisted of four people: three on-duty and one at rest. The upper team was located in a crow's nest 14 m above the sea surface and the lower team was located on top of the bridge, 8.5 m above the sea surface. To ensure animals were seen before they reacted to the ship, two of the three on-duty observers used binoculars to search far from the ship while the third observer recorded data and scanned with naked eye closer to the ship. Because of the physical size of the sighting platforms, the upper team searched with 20x60 binoculars and the lower team searched with 25x150 binoculars.

Sightings data were recorded on hand-held data entry computers (e.g., Garrett-Logan and Smith, 1997). For each sighting, the following data were recorded: time of initial detection, bearing and distance to the group, species composition of the group, best, high and low estimate of group size, group behaviour, sighting cue, and swim direction. To determine which groups were detected by both the upper and lower teams (duplicate sightings), data on time, position, and swim direction were recorded for subsequent surfacings of as many groups as possible.

A computer on the bridge connected to a differential GPS and bridge instruments recorded the following once per minute: time, wind speed and direction, depth, surface temperature, surface drift speed and direction, and the ship's position, speed and course. In addition, the following were recorded every half hour or whenever conditions changed: time, observer's position, swell height and direction, Beaufort sea state, direction of sun, magnitude of glare, and visibility.

Direct Duplicate Analysis Method

Using the direct duplicate estimator, density, corrected for *g(0),* for species *i*, D_{ci}, is calculated as:

$$D_{ci} = \frac{D_{i.upper} \cdot D_{i.lower}}{D_{i.duplicate}} \tag{1}$$

where $D_{i.upper}$ is the density of species *i* using only the upper team's data, $D_{i.lower}$ is the density using only the lower team's data, and $D_{i.duplicate}$ is the density using only data from sightings seen by both teams (duplicate sightings). Each of these three densities are estimated in the usual way:

$$D = \frac{n \cdot E(s)}{2L \cdot ESHW} \tag{2}$$

For example, density of duplicate sightings, $D_{i.duplicate}$ is where n is the number of detected duplicate groups, $E(s)$ is the expected group size of duplicate sightings, L is the length of the track line and *ESHW* is the estimated strip half width for duplicate sightings. Thus, *g(0)* for species *i* as seen from the upper team, $g(0)_{i.upper}$, and lower team, $g(0)_{i.lower}$, are derived as follows:

$$g(0)_{i.upper} = \frac{n_{i.duplicate} \cdot ESHW_{i.lower}}{n_{i.lower} \cdot ESHW_{i.duplicate}} \quad and \quad g(0)_{i.lower} = \frac{n_{i.duplicate} \cdot ESHW_{i.upper}}{n_{i.upper} \cdot ESHW_{i.duplicate}} \tag{3}$$

After the sightings data were collected, duplicate sightings were determined using a Visual Basic program that, for the time of each sighting, mapped the position of the sighting relative to the ship and predicted positions of previous sightings from both teams. Predicted positions were calculated using swim direction, time, previous sighting locations, ship's speed, and estimated animal swim speed. Swim speeds were adjusted for different species. Coefficients of variation (CV) of density and *g(0)* estimates were derived using bootstrap re-sampling techniques (Efron and Tibshirani, 1993).

Incorporating Covariates into the Direct Duplicate Estimator

Covariates can easily be incorporated into the above formulas by inclusion within any of the density estimates in Equation 1. A different set of covariates can be used for each team and for duplicate sightings. The covariate models in DISTANCE 4 (Buckland *et al.,* 2001) were used in the present study to estimate the three densities (*i.e.,* the appropriate *ESHW*'s in Equation 2). The minimum AIC criterion was used to select the best set of covariates.

Choices of covariates included the following animal-related metrics (group size, group behavior and initial cue) and survey-related metrics (observer, Beaufort sea state, wind speed and water depth). Group size was defined as the best estimate of group size. Group behaviour was defined as the behaviour when the group was initially detected and was originally recorded in one of 12 categories. For this analysis, behaviour categories were lumped into three different levels of activity: swimming (low profile types of activities including swimming, feeding, logging and milling), porpoising (medium profile activities including porpoising, bow riding, courting, diving and fluking), and charging (high profile activities including charging, aerobatics and breaching). Initial cue was defined as the behavioural phenomenon that caught the attention of the observer when the group was initially detected (body, splash or blow). Observer was defined as the specific individual who initially detected the group. Because wind speed and Beaufort sea state are highly correlated, the detection function model was not allowed to include both. Depth was water depth (in metres), as measured at the ship's location when the group was initially detected.

RESULTS

During July 6 to August 4, and August 8 to September 6, 1998, the *R/V Abel-J* surveyed: (a) continental shelf edge waters between the 100 m and 2000 m isobaths, and (b) the Gulf Stream and off-shelf waters greater than the 2000 m depth contour (Fig. 1). The ship surveyed 2,985 km in the shelf edge stratum (area = 55,798 km^2) and 1,429 km in the off-shelf stratum (area = 113,201 km^2). Sixteen species of whales, dolphins, and porpoises were detected. Species included in this analysis were those where more than ten groups were detected by a team: common dolphins (*Delphinus delphis*), Risso's dolphins (*Grampus griseus*), offshore bottlenose dolphins (*Tursiops truncatus*), striped dolphins (*S. coeruleoalba*), fin whales (*Balaenoptera physalus*), sperm whales (*Physeter macrocephalus*), pilot whale spp. (*Globicephala* spp.), and beaked whales (*Mesoplodon* spp. and *Ziphius cavirostris*).

For all species except Risso's dolphins, estimates of *g(0)* were generally higher for the upper team than for the lower team (Table 1). Without covariates, *g(0)* estimates ranged from 0.28 for sperm whales to 0.99 for offshore bottlenose dolphins. At least one covariate was found significant for each species, except for Risso's dolphins. Beaufort sea state (or wind speed) was the most common significant covariate, followed by group size and initial cue. When covariates were included, all estimates of *g(0)* decreased or remained the same (to within two decimal places), except for the pilot whale estimates which increased. A decrease in *g(0)* implies an increase in the abundance estimate. Excluding pilot whales, on average there was a 12% reduction in the *g(0)* estimate with covariates, versus without them.

It is presumed that the estimate of *g(0)* for pilot whales increased when covariates were included because this species was attracted to the ship. Attraction is a common pilot whale behaviour; and, when accounted for, will reduce the abundance estimate. And indeed, this is what happened when covariates were incorporated into the *g(0)* estimate.

DISCUSSION AND CONCLUSIONS

In this study, the effect of excluding covariates resulted in a negative bias of about 12% in the estimate of species abundance. This pattern has been shown in other studies. For example, Schweder (1999) demonstrated that without accounting for heterogeneities in weather, sea state, and observer skill, the estimated abundance of Northeast Atlantic minke whales was negatively biased by 27%.

Other potential covariates that might be considered are habitat metrics, such as plankton types and densities, salinity, bottom slope, and distance from a front. The covariate 'observer' was not found to be significant in the present study presumably because there were too many observers and thus too many degrees of freedom to detect differences large enough to be significant. Perhaps a more efficient way to incorporate observer effects (if they exist) is to create, say, three categories of observers: highly experienced, intermediate level of experience, and little experience. Experience could be measured as the amount of previous time spent conducting abundance surveys, or as a function of the observer's sighting rate.

Responsive movements and dive patterns should also be accounted for to derive the least biased estimates of *g(0)* and density (or abundance). Given the responsive attraction of pilot whales towards the survey ship, a more appropriate method to estimate *g(0)* and density for this species is the Buckland-Turnock analysis method (Buckland and Turnock, 1992). There are two types of bias that could occur when an animal is missed. Perception bias occurs when an animal is missed because the observer simply did not recognise it, even though it was at the surface. Availability bias occurs when an animal is missed because it was submerged during the entire time that the ship was passing by. The direct duplicate method described in this paper can account for perception bias, but not availability bias. For example, long diving animals, such as sperm whales and beaked whales, can be submerged for up to an hour, and when this happens there is generally no opportunity for either team to make a sighting. To derive a less biased abundance estimate for these species, it is necessary to include dive time patterns into the estimation of *g(0)*, as was done, for example, by Schweder *et al.* (1999).

REFERENCES

Borchers, D.L., Buckland, S.T., Goedhart, P.W., Clarke, E.D. and Hedley, S.L. 1998. Horvitz-Thompson estimators for double-platform line transect surveys. *Biometrics* **54(4)**: 1221-1237.

Buckland, S.T. and Turnock, B.J. 1992. A robust line transect method. *Biometrics* **48**: 901-909.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001. *Introduction to Distance Sampling*. Oxford University Press, Oxford. 432pp.

Efron, B. and Tibshirani, R.J. 1993. *An Introduction to the Bootstrap*. Chapman and Hall. New York. 436pp.

Garrett-Logan, N. and Smith, T. 1997. A hand-held, pen-based computer system for marine mammal sighting surveys. *Marine Mammal Science* **13(4)**: 694-700.

Laake, J. 1999. Distance sampling with independent observers: Reducing bias from heterogeneity by weakening the conditional independence assumption. Pp. 137-148. In: *Marine Mammal Survey and Assessment Methods* (Eds. Garner, G.W., S.C. Amstrup, J.L. Laake, B.F.J. Manly, L.L. McDonald and D.G. Robertson) A.A. Balkema. 287pp.

Manly, B.F.J., McDonald, L.L. and Garner, G.W. 1996. Maximum likelihood estimation for the double-count method with independent observers. *J. of Agri, Biol and Envir Stat* **1**: 170-189.

Palka, D. 1995. Abundance estimate of the Gulf of Maine harbour porpoise. Pp. 27-50. In: *Biology of the Phocoenids, Special issue 16* (Eds. Bjørge, A. and Donovan, G.P.).

Schweder, T., Skaug, H.T., Langaas, M. and Dimakos, X. 1999. Simulated likelihood methods for complex double-platform line transect surveys. *Biometrics* **55(3)**: 120-128.

Table 1. For each species or species group, estimates of *g(0)*, with and without covariates (covs), and covariates that were significant for the upper and lower teams, and for duplicate sightings. Covariate abbreviations are: Beaufort = Beaufort sea state, Wind = wind speed, Size = group size, Behaviour = behaviour category, Cue = cue category, Temp = water temperature, and None = no significant covariate

Species	Team	Number of groups	*g(0)*		Significant covariates
			Without covs	With covs	
Beaked whales	Upper	53	0.50 (0.41)	0.50 (0.66)	Beaufort
	Lower	58	0.51 (0.40)	0.46 (0.63)	None
	Duplicates	17	-	-	None
Bottlenose dolphin	Upper	61	0.99 (0.84)	0.93 (0.61)	None
	Lower	79	0.69 (0.80)	0.69 (0.58)	Temp, Wind
	Duplicates	36	-	-	None
Common dolphin	Upper	30	0.95 (0.30)	0.52 (0.89)	Cue
	Lower	42	0.87 (0.39)	0.76 (0.87)	Cue, Wind
	Duplicates	20	-	-	None
Fin whales*	Upper	27	0.80 (0.59)	0.68 (0.80)	Beaufort, Cue
	Lower	10	0.44 (0.47)	0.32 (0.87)	Size, Wind
	Duplicates	7	-	-	None
Risso's dolphin	Upper	122	0.51 (0.36)	0.51 (0.36)	None
	Lower	144	0.61 (0.31)	0.61 (0.31)	None
	Duplicates	58	-	-	None
Sperm whale	Upper	63	0.42 (0.34)	0.36 (0.66)	None
	Lower	49	0.28 (0.34)	0.28 (0.67)	Cue
	Duplicates	21	-	-	None
Striped dolphin	Upper	45	0.77 (0.29)	0.76 (0.77)	Wind
	Lower	53	0.68 (0.32)	0.61 (0.77)	Size
	Duplicates	32	-	-	Size
Pilot whales	Upper	36	0.52 (0.86)	0.59 (0.68)	Behaviour
	Lower	40	0.48 (0.55)	0.50 (0.65)	None
	Duplicates	20	-	-	Cue

* *ESHW* was estimated from data pooled over groups identified as fin whale, fin or sei whale (*Balaenoptera borealis*) (7 groups detected by the upper and 7 groups detected by the lower team) and sei whale (2 groups detected by upper team).

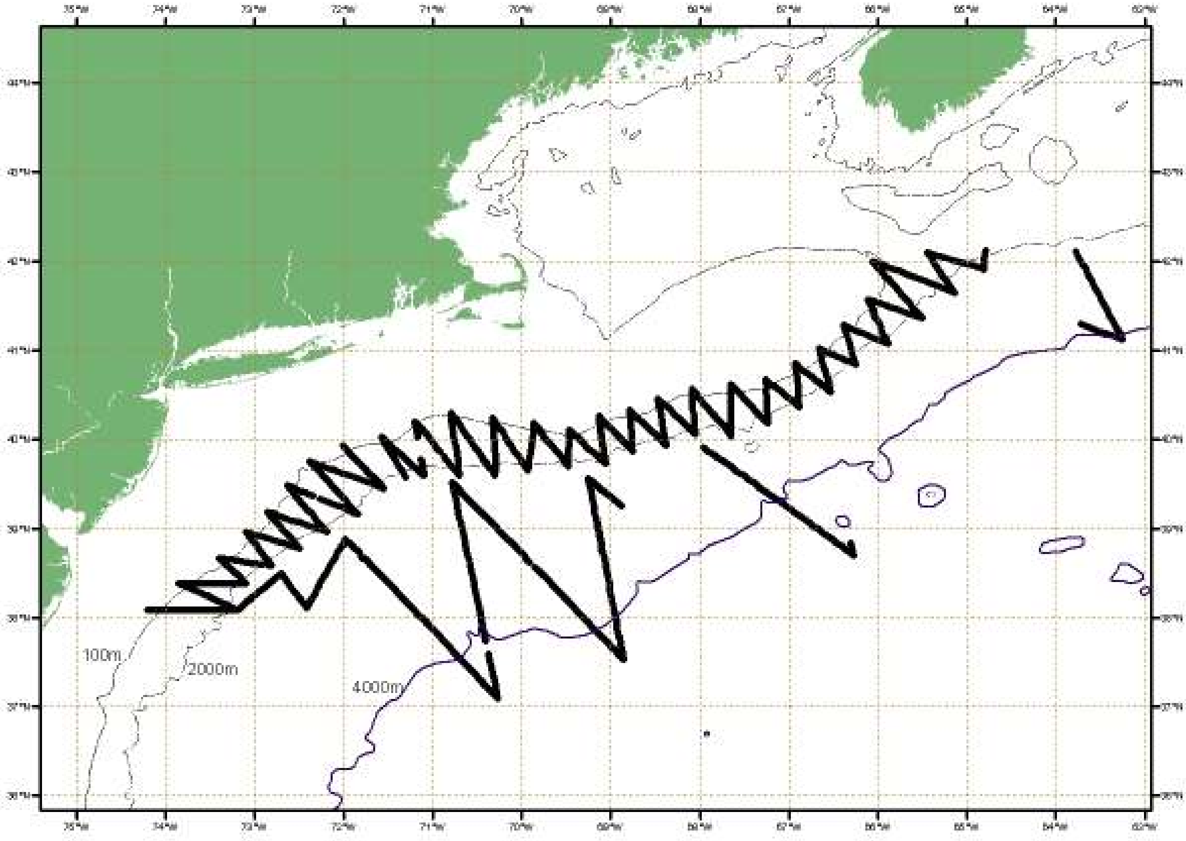

Fig. 1. Track lines surveyed by the *R/V Abel-J* during the 1998 cetacean abundance survey

ESTIMATION OF g(0) IN LINE-TRANSECT SURVEYS OF CETACEANS - ACOUSTICS: IFAW'S TOWED ARRAY SYSTEM

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INTRODUCTION This presentation discusses some aspects of the acoustic detection system developed and used by IFAW in the context of determining detection functions and estimating g(0). Acoustic surveying has some important benefits over visual surveying in certain circumstances; it also shares some of the problems – lack of availability of animals to be detected on the track line and animals' responsive behaviour - and it also has some problems of its own. These benefits and problems are discussed in the context of determining g(0).

USEFUL CHARACTERISTICS OF PASSIVE ACOUSTICS (see section on problems and solutions for some of acoustics' shortfalls).

For species with suitable vocalisation characteristics, the value of the acoustic g(0) may approximate to 1. Such characteristics occur when an animal's vocalisation 'duty-cycle' and source level are such that animals on or below the track line are unlikely to be missed by an acoustic detection system. Examples of animals with suitable vocalisation rates include sperm whales (*Physeter macrocephalus*) and singing humpback whales (*Megaptera novaeangliae*).

An acoustic detection system can also be used as the second platform in a 'double platform' survey in order to improve abundance estimates and estimates of g(0), for example see Fristrup and Clark (1997) and Borchers (1999). Such a combination of platforms has the advantage that acoustic and visual cues may be independent, whereas double-platform surveys with the same mode (visual-visual or acoustic-acoustic) will certainly not be. Further research is needed to assess vocalisations in relation to dive-cycles. Furthermore, the relatively high accuracy of acoustic localisation can facilitate the identification of duplicates in double platform surveys.

Acoustic detection systems allow survey parameters such as background noise, angles and ranges to animals, and system characteristics to be measured objectively, and errors quantified. Raw data can be stored allowing detections to be reviewed, and allowing the re-use or re-analysis of the whole survey. Acoustic data lend themselves to automatic or semi-automatic analysis by software, making such analysis less subjective.

Surveys where g(0)<1 are not 'pooling robust' i.e. the dependence of the detection function on covariates must be modelled. Here, acoustic surveying could be advantageous because physical models for the effect of acoustic covariates (e.g. background noise, propagation characteristics) can be used. In contrast, the factors affecting the visual sighting process (e.g. cloud cover, glare, swell height) rely on empirical models that may be less robust.

Acoustic surveys are very efficient in terms of effort; surveys can be run at night, in poor visibility, and in high sea-states. They can potentially cover 360° by 180° horizontally and vertically respectively (it is possible that sound from a small part of this hemisphere may be masked by the survey vessel – see later for discussion). Maximising the number of detections improves the precision of g(0) and therefore the abundance estimate.

For some species (most likely large whales) the acoustic detection range may be large compared to the distance from the vessel at which animals may react to the vessel. This may allow animals to be detected acoustically before such a response, and for any such responses to be investigated by tracking acoustically.

As acoustic data can be collected automatically without the need for a team of observers, then there is potential to use smaller vessels. Smaller vessels will generally produce less noise and therefore less disturbance, and so minimise responsive behaviour of animals.

Basic system and procedure for acoustic line-transect surveying

Figure 1 shows the design and design considerations of a typical 2-element hydrophone array used to carry out line-transect surveys. The procedure for collecting data with such an array involves:

1. Use standard line-transect survey design to lay out tracks - as for sightings surveys.
2. Survey at optimum speed for target species.
3. Data analysis, involving the following steps, can either be real time or conducted post-acquisition if the relevant data are stored.
4. Detect potential target sounds from background noise – e.g. candidate clicks and whistles.
5. Classify sounds – determine sounds belonging to target species and classify other species if possible and required.
6. Determine angle to sound – use the time difference in the arrival time of the click or whistle at the two elements to calculate angle to sound from the array.
7. Track sound source to obtain further angles to sound.
8. Determine perpendicular distance from hydrophone – Figure 2 shows triangulation of angles to a click to determine *d* (distance) of animal from array and track.
9. Plot histogram of detection distances and determine acoustic detection function.
10. Estimation of g(0), determination of effective strip width and abundance estimate.

IFAW'S TOWED SYSTEM ARRAY This presently comprises a two-element hydrophone and analysis components:

<u>High-frequency 'Porpoise' system 50–125 kHz</u>. The system, described in Gillespie and Chappell (2002), consists of a high-frequency 2-element hydrophone array, signal processing equipment, and 'Porpoise' analysis software. Porpoises produce high-frequency narrow band clicks at about 125 kHz. The system detects clicks and uses their characteristics at 50, 70 & 125 kHz to discriminate between clicks from porpoises, dolphins, shrimps, echo-sounders, etc and noise. The system has been used with harbour porpoise (*Phocoena phocoena*), vaquita (*Phocoena sinus*), (e.g. Jaramillo-Legorreta *et al.*, 2002), and the finless porpoise (*Neophocaena phocaenoides*), and has potential to be used with other porpoises and *Cephalorhynchus* dolphins. This system is currently being developed so that signal processing, originally carried out by external equipment, will be conducted within Rainbow Click analysis software; this should make the system simpler, cheaper, and more versatile.

<u>Medium-frequency system 20 Hz–48 kHz.</u> Consists of a 2-element hydrophone array, amplifier, and acquisition and analysis software suite comprising 'Rainbow Click', 'Whistle' and 'Call Seeker'. The system is designed for detecting and localising clicks, whistles and other tonal calls. Leaper *et al.,* (2000) describe the configuration of a system for surveying sperm whales (using Rainbow click). This is used with dolphins, sperm whales, fin, right and blue whales.

SAMPLE RESULTS In certain circumstances, acoustic g(0)≈1; this is probably the case with sperm whales. Sperm whales have characteristics which make them highly suitable to acoustic surveying. Sperm whales dive for long periods, typically 45-70 minutes; for much of this period they produce regular loud clicks with source levels up to 236 dB re 1 μPa (rms) (Møhl *et al.,* 2003). After a dive, they usually remain at the surface for 10 to 20 minutes when they are quiet or producing quieter clicks. For a vessel surveying at 7 knots with a conservative detection range of 8 km, animals would be in range for approximately 75 minutes – i.e. animals on or below the track line would only be missed if they were quiet for longer periods than this. It is known that, very occasionally, sperm whales at the surface may stay silent for prolonged periods (e.g. Barlow and Taylor, 1998), It may therefore be necessary to apply a correction, based on behavioural information. A review of acoustic surveying techniques and values of g(0) for sperm whales is contained in Leaper *et al.*, (2003).

Surveys of sperm whales using the IFAW system have been conducted in Antarctica (Leaper and Scheidat, 1998; Leaper *et al*., 2000) and the Mediterranean (Lewis *et al*., 2003). Surveys, using systems based on that described above, have been used to carry out point sample (as opposed to continuous) line-transect surveys in the Antarctic (Leaper *et al*., 1992), the northeast Atlantic (Lewis *et al*., 1999), and the Mediterranean (Gannier *et al.,* 2002). Figure 6 shows the localisation of individual whales using triangulation of detection angles as the boat proceeds along the track line for the 1998-99 survey of Antarctic waters (Leaper *et al*., 2000). Figure 7 shows a plot of the detection function for this survey.

In other circumstances, where g(0)<1, acoustics may provide a second platform to allow estimation of g(0). In 1999, the porpoise system was used in a dual-mode harbour porpoise survey of the Gulf of Maine, USA. Figure 3 shows a plot of the angle from the hydrophone of clicks against time for a typical click train from the survey. The analyst has selected clicks within the train by enclosing them in a polygon. The program has then fitted a curve to the selected clicks; this curve marks the expected trajectory of clicks if the hydrophone were passing a stationary object at perpendicular distance 'Dist Off' from the hydrophone. This allows an acoustic detection function to be calculated. An exploratory dual-mode analysis of the acoustic and visual data from this survey, has been carried out to obtain a value of g(0).

The histogram also highlights an area where improvements in the localisation of animals could be made. The theoretical maximum range at which porpoises might be detected can be calculated using measurements of click source levels and system response; for this system, this value lies between 270-800 m - see Gillespie and Chappell (2002) for details. It can be seen that there are detections beyond this maximum range. These, and potentially distances to other detections, are probably an artefact of the simple target-motion model used that assumes targets are stationary. A consequence of this assumption is that any porpoises travelling in the same direction as the vessel will have an artificially increased range; the converse is also true. Such an error can be addressed by using more sophisticated target-motion analyses. Models allowing variation in other parameters are currently being investigated; these include allowing targets to have a constant velocity and varying their depth.

The data from this survey also show indications of responsive movement by animals. Figure 4 is a histogram of perpendicular detection distances. A dip in the distribution close to the track line, 0-50 m, with a peak at 100-150 m may represent an avoidance reaction of porpoises to the vessel; whereby porpoises vacate the track line with a concomitant increase in numbers in the adjacent area.

Figure 5 shows a histogram of detection distances from a preliminary analysis of an acoustic survey of porpoises in the Baltic (2001-02) made from “Song of the Whale” (an auxiliary powered sailing vessel). These data shows a similar dip in detections close to the track line. By dividing detections between those made when the engine was on and when it was off (under sail), it can be seen that the peak in detections is further from the track when the engine is on than when it is off. This may be due to animals moving further from the vessel when it was producing more noise. Further analysis of this, and other such similar situations, may allow corrections for responsive movements to be made.

PROBLEMS AND SOLUTIONS A number of problems associated with acoustic surveying are outlined, and potential solutions suggested.

Animal movement – As the speed of animals increases relative to the survey vessel, then the localisation becomes less accurate. To some extent, this can be overcome by increasing the speed of the vessel, by using more sophisticated localisation analyses, or by using a multi-element hydrophone array that may allow for the instantaneous localisation of animals.

Vocalisation behaviour and rates - Whereas marine mammals must surface to breath, so making them available to be sighted, vocal rates can be unpredictable or poorly understood i.e. vocalisation patterns are generally more unpredictable than dive patterns. Furthermore, vocalisations are usually directional; therefore, detectability may vary with the animal’s orientation. Localisation usually depends on triangulating on individuals or groups, requiring that an individual or group can be tracked over a suitable period - this may not be possible if animals stop vocalising. Where gaps in knowledge exist, there is a need for further research into vocalisation behaviour and rates, source levels, and directionality. Ultimately, for some species which do not make enough noise, or because they cannot be detected or identified, then acoustic surveying may not be appropriate.

Rotational ambiguity of angles to clicks (sometimes referred to as left-right ambiguity) - If animals are not at the surface, the perpendicular distance obtained from a 2-D localisation will be an over-estimate, and will result in a dip in the distribution near the track line. This may not be a significant problem, but could be overcome by using a large first bin in the detection histogram, by correcting distances using knowledge of the animal’s diving behaviour, or by using an array with an extra hydrophone element offset from the line of the others in order to resolve the positional ambiguity.

Forward masking of a narrow semi-cone of sea ahead by noise from the towing vessel - This can be mitigated by increasing the distance that the hydrophone is towed behind the vessel, and/or reducing the vessel’s noise, e.g. by varying the survey speed and/or modifying the propulsion system.

Finally, compared to visual surveys, acoustic surveys are not really very well developed, either in their methodology or analysis.

SUMMARY In certain favourable circumstances, it may be safe to assume acoustic g(0)=1 for abundance estimation; in other circumstances, dual mode analysis can be carried out using acoustic detections and visual sightings, to determine g(0). Efficiencies in acoustic tracking may allow a greater number of detections per unit effort to provide a better estimate of the detection function. Acoustic tracking may allow responsive movements of animals to be determined, and an appropriate correction applied to abundance estimates. Examples show how acoustic systems have been used to survey for sperm whales and porpoises. Although some problems do exist for particular species, these problems may be small or surmountable; for others, acoustic surveying may simply not be appropriate.

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REFERENCES

Barlow, J. and Taylor, B. L. 1998. Preliminary abundance of sperm whales in the Northeastern Temperate pacific estimated from a combined visual and acoustic survey. *Paper presented to IWC scientific committee 1998. SC/50/CAWS20.*

Borchers, D.L. 1999. Composite mark-recapture line transect surveys. In: *Marine Mammal Survey and Assessment Methods*. Garner et al eds. Balkema, Rotterdam.

Fristrup, K.M. and Clark, C.W. 1997. Combining visual and acoustic survey data to enhance density estimation. *Rep. Int. Whal. Commn* **47**: 933-936.

Gannier, A., Drouot, V. and Goold, J.C. 2002. Distribution and relative abundance of sperm whales in the Mediterranean Sea. *Mar Ecol Prog Ser*. **243**: 281–293.

Gillespie, D. and Chappell, O. 2002. An automatic system for detecting and classifying the vocalisations of harbour porpoises. *Bioacoustics* **13**:37-61.

Jaramillo-Legorreta, A., Rojas-Bracho, L., Gordon, G. & Gillespie, D. 2002. Progress report of vaquita acoustic surveys. 2002. *Paper presented to IWC scientific committee 2002. SC/54/SM17*.

Leaper, R. Gordon, J. and Chappell, O. 1992. The development of practical techniques for surveying sperm whale populations acoustically. *Rep. int. Whal. Commn.* **42**: 549–560.

Leaper, R. and Scheidat, M. 1998. An acoustic survey for cetaceans in the Southern Ocean Sanctuary conducted from the German Government research vessel *Polarster*n. *Rep. int. Whal. Commn.* **48**:431-437.

Leaper, R., Gillespie, D. and Papastavrou, V. 2000. Results of passive acoustic surveys for odontocetes in the Southern Ocean. *J. Cetacean Res. Manage.* **2**(3): 187-196.

Leaper, R., Gillespie, D., Gordon, G. & Matthews, J. 2003. Abundance assessment of sperm whales. Paper presented to IWC Scientific Committee 2003. SC/55/O13.

Lewis, T., Swift, R., Gozalbes, P., Butler, J. and Gordon, J. 1999. Passive acoustic survey of cetacean distributions northwest of the Hebrides, winter 1997-1998. P. 34. In: *European Research on Cetaceans – 13.* (editors P.G.H. Evans, J. Cruz and J.A. Raga). Proceedings of the thirteenth annual conference of the European Cetacean Society, Valencia, Spain, 5-8 April 1999. 484pp.

Lewis T., Gillespie D., Lacey C., Leaper R., Matthews J., Moscrop A. and McLanaghan R.2003. Report of the summer 2003 sperm whale survey by the International Fund for Animal Welfare; preliminary findings and some considerations for a Mediterranean-wide survey. Report presented to the 2nd meeting of the scientific committee of ACCOBAMS, Istanbul, 2003.

Møhl, B., Whalberg, M., Madsen, P.T., Heerfordt, A. and Lund, A. 2003. The monopulsed nature of sperm whale clicks. J. Acoust. Soc. Am. **114** (2): 1143-1154.

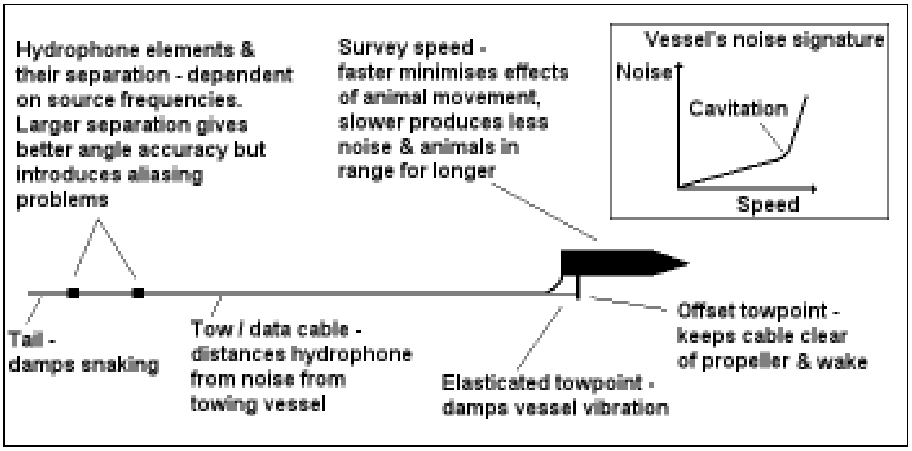


Fig. 1. Design of a typical 2-element hydrophone array used to carry out line-transect surveys

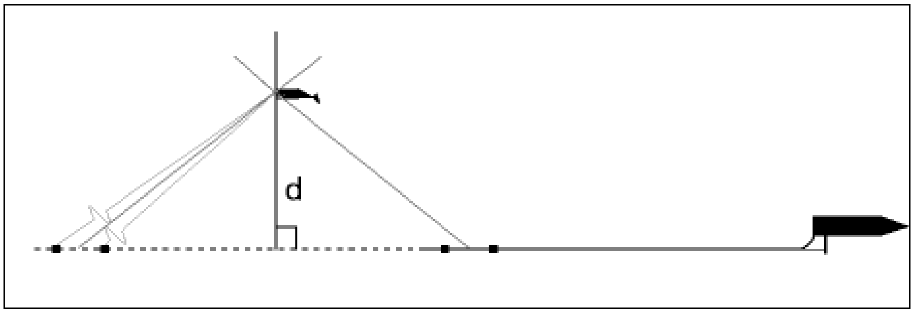
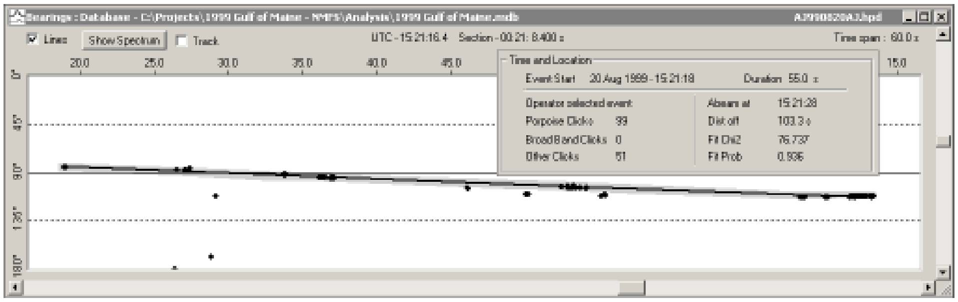


Fig. 2. Calculation of perpendicular distance of clicking animal from the array and track



UTC - 15:21:16.4 Section - 00:21: 8.400 s

Time span : 60.0 s

Time and Location

Event Start 20 Aug 1999 - 15:21:18 Duration 55.0 s

Operator selected event

Porpoise Clicks 99

Broad Band Clicks 0

Other Clicks 51

Abeam at 15:21:28

Dist off 103.3 s

Fit Chi2 76.737

Fit Prob 0.936

Fig. 3. Porpoise click train from 1999 survey of the Gulf of Maine.porpoise clicks are marked by black dots (narrow band clicks at 125 kHz). Axes are time versus angle to hydrophone. Click train selected by analyst is marked with grey polygon. Curve fitted automatically to click train by 'Porpoise'. This fit assumes the porpoise is stationary, the perpendicular distance (Dist off) is output as a time (s) which is converted to a distance by multiplying by the speed of the survey vessel.

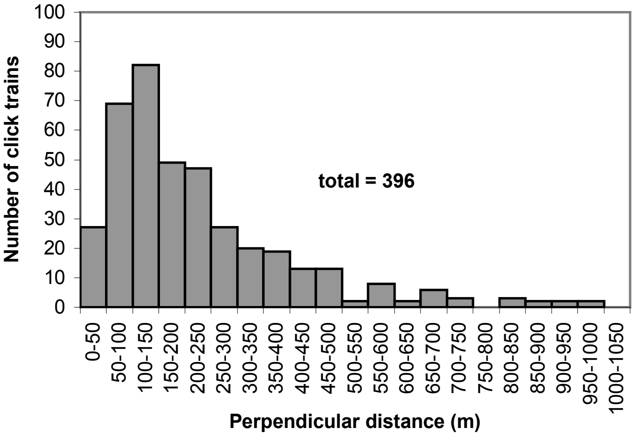


Fig. 4. Histogram of click train detections for acoustic porpoise survey of the Gulf of Maine 1999.

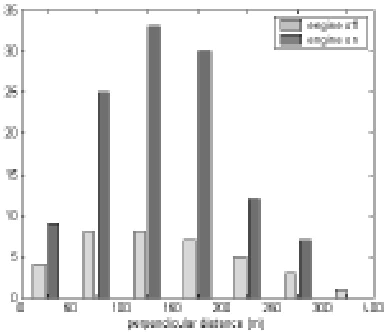


Fig. 5. Histogram of click train detection perpendicular distances, by engine on and off.

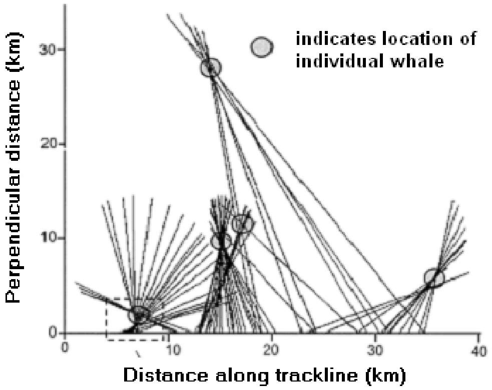


Fig. 6. Localisation of individual sperm whales relative to track line during survey in Antarctic Ocean, from Leaper *et al.,* 2000.

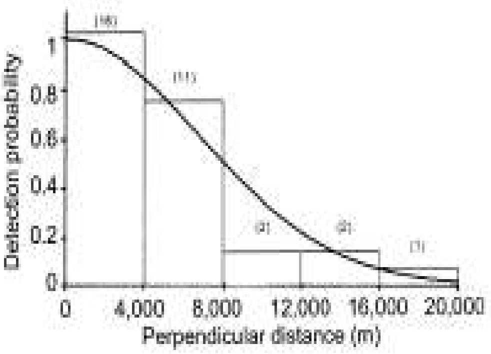


Fig. 7. Acoustic detection function for sperm whales for survey in Antarctic Ocean, from Leaper *et al.,* 2000.

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