Combined line-transect and cue-count estimate of sperm whale abundance in the North Atlantic, from Icelandic NASS-2001 shipboard survey

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ABSTRACT

Sperm whales (*Physeter macrocephalus*) pose a particular problem to shipboard surveys as they dive for extended periods and are therefore likely to be missed (not available) even if they are right under the track line. To address these problems the NAMMCO planning committee for the NASS 2001 survey drew up guidelines to be followed when sperm whales were sighted. This required every deep dive to be recorded and considered to be a cue, from which a cue-count estimate is calculated if the cue rate is known. For those whales that did not dive before coming abeam, a conventional line-transect estimate is calculated, which gives an instantaneous surface estimate from which a total estimate can be obtained if the proportion of the time spent at the surface is known. These estimates are compared and combined. Precise dive cycle information is missing for the mostly single all male sperm whales in this area but a preliminary estimate of 11,185 (cv 0.34) is obtained for the surveyed area with an assumed surface time of 20% and two deep dives per hour.

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INTRODUCTION

The 2001 North Atlantic Cetacean Sighting Survey (NASS-2001) was a continuation of periodic synoptic sightings surveys conducted in the Eastern and Central North Atlantic in 1995, 1989 and 1987. Presented here is an analysis of the Icelandic vessel data with respect to sperm whales. The planning and conduct of the surveys is detailed in cruise-reports (Desportes *et al.* MS 2002, Víkingsson *et al.* MS 2002).

Sperm whales pose a particular problem to shipboard surveys as they dive for extended periods and are therefore likely to be missed even if they are right on the track line. The area covered, called the effective search width, depends on the distribution of perpendicular sighting distances, whereas the proportion missed depends on the forward sighting distances and the dive cycle of the animal. Sigurjónsson and Víkingsson (1997) presented an estimate of sperm whale abundance based on NASS-87 Icelandic shipboard data, but as it was not clear where in the dive cycle the animal was when it was sighted, certain simplifying assumptions had to be made (Gunnlaugsson and Sigurjónsson 1990).

To address these problems the NAMMCO planning committee for the NASS 2001 survey drew up guidelines to be followed when sperm whales were sighted. This protocol called for the sperm whales to be tracked to determine the spot where the animal deep dived. This methodology is made possible because the deep dive of the sperm whale is a distinctive event as they "fluke up" before a deep dive. As it was feared that the animals might dive to avoid the approaching vessel, the procedure called for the vessel to slow down or stop if it was heading to within 0.5 nm of a sperm whale. The distance (radial) to the spot where the animal deep dived relative to the vessel, was however to be determined as if the vessel had continued at normal speed. The vessels sail 0.5 nm in just 3 minutes, so stopping for a maximum of 3 minutes is sufficient to exclude the possibility that the whale would have reacted to avoid the vessel and dived before coming abeam. The animals that did not dive before coming abeam, if the vessel had continued at normal speed, were to be remarked as such.

Only male sperm whales have been caught (Martin 1981) or stranded in Icelandic and adjacent waters. Females are believed to have been observed only in the NASS-89 survey south of 55°N. The present survey did not extend this far south.

A synoptic aerial survey was conducted in the coastal waters off Iceland simultaneously with the ship survey, and reported 4 sightings comprising 5 sperm whales (Pike *et al.* 2009a). No estimate will be derived from these sightings. The Icelandic vessels had little effort within the aerial survey block and made no sperm whale sightings there so no estimate is made for this overlapping area here.

The block surveyed by the NASS-2001 Faroese vessel overlaps partly with the Icelandic aerial block. Eleven of the 61 sperm whale sightings reported by this vessel were from inside the overlap with the aerial survey, which, however, reported no sightings in this area. Data collected onboard the Faroese vessel were not fit for the application of the method used here.

MATERIALS AND METHODS

A general overview of the surveys is given in Pike *et al.* (2009b). Binoculars with reticules for distance estimation and/or distance estimation sticks were available on all platforms. All the vessels operated most of the time with independent primary platforms except when the special sperm whale protocol was followed. This protocol called for slowing down or stopping the vessel if it was heading within 0.5 nm of a sperm whale. This made the other platform aware of the sighting so, in case of sperm whales, there was no point in keeping the platforms independent and no material for estimating the probability that an animal is overlooked by the primary platform has been compiled. The primary observers searched with primarily naked eye the area in front of the vessel (180°).

The duplicate identifier had the responsibility to monitor sperm whales up to abeam, or to record the point where they deep dived. All observers were instructed to report if they happened to see a sperm whale fluke up. The purpose of the procedure was to determine the radial distance to the dive location relative to where the vessel would have been when the sperm whale dived. Every deep dive was considered to be a cue from which a cue count estimate was calculated.

For those whales that did not dive before coming abeam, perpendicular sightings distances were calculated from the last re-sighting before coming abeam where both an angle and distance estimate had been recorded and particularly where a binocular reticule or distance estimation stick had been used from the higher platform, as this resulted in more accurate measurements. From this data subset a conventional line transect estimate was calculated.

Not all sightings of sperm whales were described clearly enough to determine if the animal dived before coming abeam or the exact location where it dived. In some cases the deep dive probably was not noticed and so nothing was recorded after the initial record. In other cases the vessel may have slowed down but this was not accurately recorded and the positions were not logged sufficiently frequently to detect a short slowdown. In cases of doubt, we have assigned sightings close to the vessel to the line transect data set, as errors in assignment would have a smaller impact on the transect estimate than on a cue count estimate. A conventional line transect estimate using all sightings, that does not lend it self to be corrected for availability, has also been calculated for comparison.

Data analysis

All data collected at Beaufort Sea State >5 was dropped prior to analysis. This did not result in loss of sightings, but 5.0% of total effort from the Icelandic data was excluded from the analysis. Sperm whales are quite visible when at the surface and sighting distances are not likely to be greatly affected unless the sea state is at the higher limit, where sample size is in fact low. Therefore stratification by sea state was not attempted. Median sighting distances did not show a clear relation to the platform heights of the Icelandic vessels so all the Icelandic vessels were combined.

Data analyses were carried out using the DISTANCE 4.0ß4 (Thomas *et al.* 2001) software package and stratified line transect and cue–counting methods (Hiby and Hammond 1989, Buckland *et al*. 2001). The cue rate was assumed to be 2 cues per whale per hour (see below).

The survey area had been stratified geographically (Víkingsson *et al.* 2002), primarily according to prior knowledge of the abundance of the target species (fin whales). Calculation of model parameters: effective detection radius (*edr*) for cue counts, effective search width (*esw*) for line transects, and pod size (*s*), was pooled over geographical strata while encounter rate (*n/T* for cue counts, *n/L* for line transects) was calculated separately for each stratum.

Truncation distances were chosen by visual inspection of the detection probability histograms. There was some evidence of rounding to favoured radial and perpendicular distances, so the effectiveness of grouping (binning) the radial and perpendicular distance data before analysis was investigated. Binning was employed if it resulted in a better model fit as determined by a chi-square test and a more precise estimate of *edr* or *esw*. A variety of models for the detection function *f(x)* was initially considered, and the final model was chosen by minimisation of Akaike's information criterion (AIC) (Buckland *et al.* 2001), goodness of fit statistics and visual inspection of model fits.

Cue count and line transect estimates of abundance were calculated by standard methods (Buckland *et al.* 2001). For the line transect estimates, we assume that no animal would escape being noticed, if it was at the surface close to the vessel. Variances for *N* were calculated in DISTANCE, and log-normal confidence intervals were used.

As the line-transect estimates only incorporate animals that were at the surface when the vessel would have come abeam, it refers only to the proportion of whales that are at the surface at any given moment. The cue count estimate is of course heavily dependent on the cue rate used. To derive estimates of abundance corrected for these factors, data on cue rate (frequency of deep dives) and the proportion of time spent at the surface during search hours is needed, preferably from the survey areas and the survey season. As these figures are straightforward to apply to the estimates as they may become available at a later time, we proceed here with an assumption of a cue rate of 2 (deep dives per hour) and 20% of the time spent at the surface (6 min. per surfacing). These figures were considered likely based on the findings of Lockyer (1997). Thus the line transect on surface abeam estimate multiplied by 5 should be roughly equal to the cue count estimate if this cueing rate and the surface time figures are correct.

To derive a weighted average of these two estimates with minimum variance each should be weighted in proportion to the inverse of its variance, if the estimates were independent. This however is not the case as encounter rate is the dominating factor of the variance and where many deep diving sperm whales are spotted there are also likely to be many whales at the surface when abeam of the vessel on the same leg. Instead we have calculated one estimate from all the sightings combined and used the variance due to encounter rate from this estimate. As the variance due to other factors is small and of the same order for both estimates it is reasonable to weight them in proportion to the number of sightings. The variance of the weighted average will then be the variance due to encounter rate from all sightings plus for each estimate the weighted variances due to other factors.

RESULTS

As in earlier surveys sperm whales were frequently encountered in the deep waters west and south west of Iceland but highest densities were observed midway between Iceland and North Norway (Fig. 1). On 2 intersecting legs there were 51 (18 and 33) animals sighted, with the intersection being the apparent approximate centre of this concentration. As this is out of a total of just 146 animals sighted from Icelandic vessels, it causes a high variance in the estimate due to encounter rate.

Table 1 provides details of the line transect and cue count analyses, and Fig. 2 shows the detection functions for each analysis.

The corrected line transect estimate based on sightings on surface abeam only is 13,900 (2,780*5) (n=49).The cue count estimate based only on whales that dived before abeam is 6,625 (n=76). The weighted average is 9,477 ((13900*49 + 6625*76)/(49+76)). The cv due to encounter rate is 0.388 and due to the fitted distributions and pod size, 0.12 for both estimates. The resulting cv for the average is 0.406.

The uncorrected line transect estimate based on all Icelandic sightings is 6,726 (cv 0.395). The corrected estimate is 1.41 times higher (se 0.15), implying a $g(0)$ value of 0.71 (cv 0.1). If this correction is also applied to the Faroese survey blocks an estimate of 11,185 (cv 0.34) is obtained. The reported precision does not include dive cycle uncertainties.

DISCUSSION

These estimates do not include any correction for missed animals at the surface on the track line or close to the vessel (perception bias) as duplicate platform data was not collected for this species as explained above. Animals that deep dive close to the vessel before coming abeam have in most cases spent several minutes at the surface blowing close to the track line where also the effort is concentrated and are therefore not likely to have been missed. Animals at the surface when abeam that contribute to the on surface abeam transect estimate, may have surfaced shortly before close to the abeam line and thus are more likely to have been missed, although this is probably not a significant downward bias in moderate sea state. An animal about to surface close

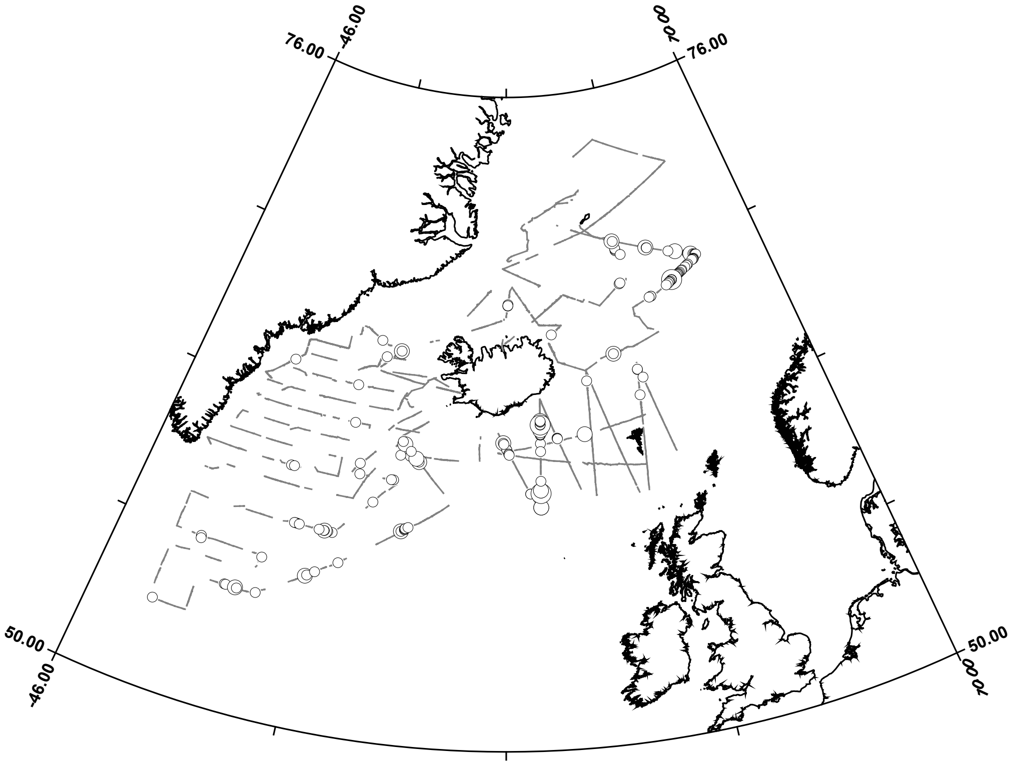

Fig. 1. *Sightings of sperm whales during the 2001 NASS. Symbol size is proportional to group sizes ranging from 1 to 3. The tracks around the Faroe Islands up to South-East Iceland were covered by Faroese vessels and could not be included in the present analysis.*

Table 1. Estimates of sperm whale abundance from NASS-2001 Icelandic shipboard surveys. First estimate is a line transect estimate based on animals at surface abeam only and needs to be corrected for availability by dividing by the proportion of the time spent at the surface. Second estimate is line transect based on all sightings and can not be corrected for availability. Third estimate is cue count estimate (fluke ups) with an assumed cue rate of 2 per hour. Coefficients of variation (%) are in parentheses. *W* - truncation distance; *edr* - effective detection radius, for cue count; *esw* - effective search width, for line transects; *n/L* - encounter rate, whales per nm, for line transects; *n/T* - encounter rate, whales per hour, for cue count; *s* - mean pod size; *N* - abundance estimate for the survey area.

ESTIMATE	MODEL	*W* (m)	*edr/esw* (m)	*n/L* or *n/T*	*s*	*N*
Iceland surface, line transect (uncorrected)	half-normal	4,000	2,142 (11.7)	0.0094 (33.0)	1.143 (4.4)	2,780 (32.8)
Iceland all, line transect uncorrected	half-normal	4,000	2,156 (7.0)	0.0162 (34.6)	1.112 (2.7)	6,726 (39.5)
Iceland, cue count	hazard rate	6,000	3,927 (6.0)	0.0938 (34.6)	1.053 (2.5)	6,625 (47.6)

to the vessel might be scared away, which could cause a downward bias in the on surface abeam estimate. So in general, the cue count estimate would be less likely to be downward biased.

The cue estimate includes the length of the dive cycle (*i.e.* the inverse of cue rate) and the corrected transect estimate includes the length of the dive cycle over length of time on surface per dive cycle. The ratio of the cue count over the line transect estimate is therefore directly proportional only to the assumed absolute time spent on the surface per dive cycle. The high variance due to encounter rate does not apply when comparing these estimates since both estimates are affected in the same way by patches of high or low densities on different legs. When comparing, it is more appropriate to consider just the number of sightings behind the estimates and the variance due to the fit of the detection function. When considered this way the corrected cue count and line transect estimates are significantly different, which implies that either the absolute time spent at the surface per dive cycle here, assumed to be 6 minutes, is too short, or the treatment of the data is to blame.

Papastavrou (1989) reports cycle times of around 50 minutes with 10 minutes at the surface for sperm whales at the Galapágos Islands. Whitehead *et al.* (1992) report a dive cycle range of 30 to 80 min. with on average 8 min. at the surface for male sperm whales on the Scotian Shelf. Jaquet *et al.* (2000) found that male sperm whales foraging of Kaikoura, New Zealand had a mean surface interval and dive duration of 9.1 minutes (cv 0.24) and 41.3 minutes (cv 0.22) respectively (cycle time 50.4 min), again suggesting a lower cueing rate than that used here. If the average time at surface per dive cycle were taken to be 9 min instead of 6 which has been assumed here, it would bring the ratio of the cue count estimate over line transect up by a factor of 1.5 and alleviate the incompatibility. Sperm whales have occasionally been observed to lie like floating logs in the surface for extended periods. If some dive cycles and times at surface during daylight are extra long, that would also make the cue count estimate higher and the surface derived estimate lower. However, Jaquet *et al.* (2000) conclude that both extended surface intervals and non-foraging intervals are rare during daylight hours.

In the treatment of the data, for some sightings there was uncertainty as to whether the animal had deep dived just before coming abeam, but they were assumed to have been at surface when abeam. If some of these animals actually dived shortly before coming abeam, this would result in a higher cue count estimate and somewhat lower line transect estimate. This was done so that the weighted average presented here would be more likely downward biased. Also an animal may have dived later (closer to the vessel) than the last record indicates. The last record may for instance mention several blows and then a fluke-up dive. If the spot where the animal actually deep dived was in some cases closer to the vessel than is apparent from the records, then the cue count estimate is biased downwards.

Although sperm whales are generally solitary, they appear to feed in close proximity to one another in the same area. Cases in which one whale dives as another surfaces close by may only be resolved as a sighting of two whales by continuous tracking. Future surveys should consider more intense tracking and detailed recording of sperm whale sightings, to enable more accurate estimates to be derived.

Gunnlaugsson and Sigurjónsson (1990) reported an estimate of 1,256 (cv 0.17) sperm whales for a roughly comparable area from the 1987 NASS. Sighting rates were about 56% of those observed in 2001 however sighting distances were greater on average. Compared to the 2001 survey there were fewer sightings to the northeast of Iceland and more in western Denmark Strait. A total of 139 sperm whales were seen in the Icelandic blocks of the 1989 NASS, which extended far to the south of the other surveys (Sigurjónsson *et al.* 1991). No abundance estimate for sperm whales has been produced from this survey. The distribution of sperm whales observed in the 1995 NASS was similar to that observed in 1987 (Sigurjónsson *et al.* MS 1996, NAMMCO 1998), however encounter rate was more similar to that seen in 2001. Again no abundance estimate has been produced from these data.

In conclusion the averaged estimate is more likely downward biased, but the corrections for diving animals will have unknown biases until better estimates of cueing rate and a better description of the average dive cycle becomes available. These data could probably best be obtained through satellite or VHF telemetry of animals in the same survey area and in the same season as the survey was conducted if this is found to affect the average dive cycle length or time spent on surface.

Whitehead (2002) derived a worldwide estimate of sperm whale abundance by extrapolating survey estimates into unsurveyed areas using indirect indices of density. He used the estimate from the NASS-1987 reported by Gunnlaugsson and Sigurjónsson (1990) to extrapolate to a large area of the northwest Atlantic. Our estimated density from the combined analysis is about 6.5 times that used by Whitehead (2002), and even the uncorrected line transect density estimate is about 4.6 times the $g(0)$ corrected value used by Whitehead (2002). While accepting that our estimates are preliminary and dependent on the values for cueing rate and surface times used, it is likely that they are negatively biased for the reasons stated above. Therefore the global estimate of Whitehead (2002) must be negatively biased for this area.

The correction factor obtained here with respect to uncorrected conventional line transect estimates of 1.41 corresponds to a $g(0)$ bias due to availability of 0.71. A correction factor obtained this way may not however be applicable to other surveys with different effort characteristics. In particular, earlier NASS surveys had lower platforms, less effort in the higher platform and less binocular usage. Estimates from these surveys are thus likely to be more severely biased. This $g(0)$ estimate is not significantly different from the estimate of 0.87 obtained by Barlow and Taylor (MS 1998) for surveys in the northeast temperate Pacific.

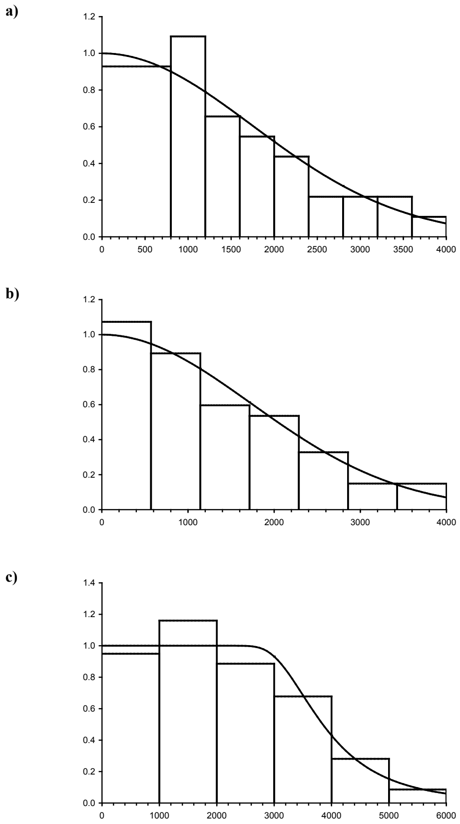

Fig. 2. *Detection functions for line transect and cue count analyses of sperm whale abundance from NASS-2001 Icelandic and Faroese ship surveys. a) Iceland, line transect, at surface abeam; b) Iceland, line transect, all sightings; c) Iceland, cue count.*

Here the sightings have been split up depending on whether the animal was at the surface when crossing the abeam line. This line could be chosen differently. For instance if observers concentrate within 45° from the trackline, the 45° line should be used, since some animals might surface in the sector between the 45° and abeam line and be missed. Also the line used could be some distance ahead of the vessel, so disturbance from the vessel would be of less concern. However, this distance must not be chosen too large as those animals surfacing closer to the vessel would not be used either for abundance estimate.

Although standard line transect information on sperm whale sightings has been recorded by dedicated cetacean observers, no method had been specified on how to obtain estimates unbiased by the long dives of these animals and therefore it has not been clear in what detail sighting information is needed. It is hoped that this attempt does clarify the importance of tracking sperm whale sightings up to some predefined point without disturbing them. In general sperm whale sightings are so few that this should not require a lot of extra time or work. The kind of extra information that needs to be collected should also be clear.

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