

Abundance of Atlantic white-sided dolphin (*Lagenorhynchus acutus*) during summer off northwest Scotland

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ABSTRACT

A shipboard cetacean survey was conducted in July/August 1998 within an area to the west of Scotland, UK, commonly known as the Atlantic Frontier. The aim of the survey was to document the distribution and abundance of cetaceans to provide baseline population data for an area that is being increasingly explored and developed by oil companies. A double platform 'independent observer' (IO) method was used to estimate the abundance of the Atlantic white-sided dolphin (*Lagenorhynchus acutus*) using standard line-transect and distance sampling methodology. Previously, uncorrected Atlantic white-sided dolphin abundance was estimated as 27,194 (CV = 0.29) from this survey. This paper presents abundance estimates corrected for $g(0) < 1$ using a direct duplicate method. The value of $g(0)$ was estimated to be 0.61 (CV = 0.09). The abundance in two strata was estimated as 21,371 (CV = 0.54) to the west of the Outer Hebrides and 74,626 (CV = 0.72) in the Faroe Shetland Channel. The high CVs are the result of small sample sizes, particularly of the duplicate data set. However, the abundance estimates represent the first for this species to the northwest of Scotland and adds to existing baseline abundance estimates for small cetaceans in UK waters. The results could be useful for planning future surveys that aim to calculate more precise abundance estimates. These results, together with opportunistic sightings data collected during other surveys, suggest that the waters to the west of Scotland are an important habitat for the Atlantic white-sided dolphin. Presently, threats to this species in the area are relatively unknown but a baseline population estimate will be an integral part of any management regime should there become a need in future.

KEYWORDS: ATLANTIC OCEAN; ABUNDANCE ESTIMATE; G(0); SURVEY-VESSEL; WHITE-SIDED DOLPHIN

INTRODUCTION

The Atlantic white-sided dolphin (*Lagenorhynchus acutus*) is widely distributed in temperate and sub-polar waters of the North Atlantic. Its range extends from eastern Labrador (Rice, 1998), Greenland (Kapel, 1975) and Spitzbergen, ca 77°N (Øien, 1996) in the north, to North Carolina, 35°N (Palka *et al.*, 1997), the Azores (McBrearty *et al.*, 1986) and the Straits of Gibraltar (Hashmi and Adloff, 1995) in the south. The abundance of the Atlantic white-sided dolphin throughout its range is presently unknown. The estimates available within parts of its range are almost exclusively from the western North Atlantic (Table 1). Only some of these estimates take account of school size bias (Baylock *et al.*, 1995) and the probability of detecting a group on the trackline (Baylock *et al.*, 1995; Waring *et al.*, 1998) whilst estimates in the Gulf of St Lawrence (Kingsley and Reeves, 1998) were uncorrected for either. In the northern North Atlantic, an approximate abundance of 37,622 Atlantic white-sided dolphins (no variance calculated) was estimated from the North Atlantic Sightings Surveys (NASS) in Icelandic and adjacent waters in 1987 (Sigurjónsson and Víkingsson, 1997). A preliminary abundance of 20,444 (95% CI = 12,714–32,874) *Lagenorhynchus* sp. was estimated from aerial surveys conducted in Icelandic waters in 2001 (NAMMCO, 2002).

There is very little information about the abundance of the Atlantic white-sided dolphin in the northeast Atlantic, with only two unpublished estimates (Hughes *et al.*, 1998; O'Cadhla *et al.*, 2001). Around Britain, its distribution is centred in offshore waters beyond the continental shelf-edge off the western coast, although it does occur in the Celtic Sea and central North Sea in small numbers (Hammond *et al.*, 2002). It is probably one of the most abundant offshore odontocetes off northwest Scotland (Macleod *et al.*, 2003) but without baseline abundance estimates the status of this species cannot be assessed. Fisheries are a known source of mortality of Atlantic white-sided dolphins although direct and indirect takes are largely unquantified. Bycatch has been recorded in pelagic and mid-water trawls to the south and west of Ireland (Couperus, 1998; Morizur *et al.*, 1999) and is likely to occur in other areas of this species' range. Atlantic white-sided dolphins have been observed feeding around trawls during towing – a behaviour that may increase their susceptibility to being caught (Morizur *et al.*, 1999). There are occasional direct takes in drive fisheries on the Faroe Islands (e.g. Bloch and Hoydal, 1990; Gallien *et al.*, 2001). Additionally, waters to the west of Scotland and Ireland, commonly referred to as the Atlantic Frontier, are the frequent focus of oil and gas development and seismic surveys during the exploration phase. There is growing evidence that many marine mammals respond to acoustic

Table 1
Estimates of abundance of Atlantic white-sided dolphins in the western North Atlantic.

Region	Relevant period	Estimate (CV)	Reference
Cape Hatteras to Nova Scotia: shelf and shelf-edge	1978-1982	28,600 (0.21)	CeTAP (1982)
Northern Gulf of Maine and lower Bay of Fundy	July-Sept 1991 and 1992	20,400 (0.63)	Baylock <i>et al.</i> (1995)
Southern Georges Bank to southeast Scotian Shelf	June-July 1993	730 (0.47)	Baylock <i>et al.</i> (1995)
Virginia to the Gulf of St Lawrence	July-Sept 1995	27,200 (0.43)	Waring <i>et al.</i> (1998)
Gulf of St Lawrence	August-Sept 1995	11,740 (0.47)	Kingsley and Reeves (1998)
Georges Bank to the Gulf of St Lawrence	July-August 1999	51,640 (0.38)	D. Palka, pers. comm. in Waring <i>et al.</i> (1998)

and physical disturbance associated with industrial development (Harwood and Wilson, 2001). Sighting rates of Atlantic white-sided dolphins were significantly reduced when airguns were firing compared to when they were not during seismic surveys in UK waters between 1998 and 2000 (Stone, 2003).

This paper presents an abundance estimate for Atlantic white-sided dolphins in waters off northwest Scotland. Data were collected during an Independent Observer (IO) line-transect survey, conducted in an area of the Atlantic Frontier to the west of the Outer Hebrides and in the Faroe-Shetland Channel during July-August 1998. The aim was to record the distribution of cetaceans in the region (Macleod *et al.*, 2003) and to estimate the abundance of cetacean species where possible. The precision of the abundance estimate is low and the problems with it are discussed. However, the estimate is considered an important baseline since it represents the first published for this species in these waters and the wider northeast Atlantic.

METHODS

Data collection

The survey was conducted from 13 July –14 August 1998 on board MV *Neptun* searching at an average speed of 10 knots. The area surveyed included the outer continental shelf to offshore waters, extending from the Outer Hebrides in the south to the Shetland and Faroe Islands in the north (Fig. 1). Indices of abundance estimated from the Sea Birds at Sea Team off the west of Scotland (Weir *et al.*, 2001) suggested that the relative density of cetaceans throughout the region differed and so two strata were defined (Fig. 1), one to the west of the Outer Hebrides (A) and one in the Faroe-Shetland Channel (B). The survey design was based on predetermined saw-tooth tracklines with a random start point.

The ship provided two separate observation platforms, for which mean eye height above sea level was measured as 7.3m (lower team) and 9.6m (upper team). An IO method, involving two independent teams of observers, was used to record distance sampling data. The two teams of four observers remained the same throughout the survey and were isolated from one another, both visually and acoustically, during surveying periods. The teams were chosen so that the experience of the observers on each was comparable. The lower team of observers communicated between themselves using two-way radios since the bridge house separated the port and starboard bridge wings. On both platforms, the observers were rotated through the observation positions and a 'rest position' on their platform every 30 minutes. Searching was primarily carried out using the naked eye but binoculars were used by both platforms intermittently to scan greater distances and aid species identification and group size estimation. The survey was carried out in 'passing mode' in which the vessel did not approach sighted cetaceans. A sighting was defined as a single individual or a group of individuals, which appeared in close proximity spatially and were engaged in the same general behaviour. Sub-groups were defined as sightings using this definition in the event of encounters with large aggregations of animals. Radial distances and sighting angles were measured using Fujinon 7 × 50 reticle binoculars and angleboards, respectively, mounted on the railings of each observation platform. Visual estimates of distance were only recorded when the sighting was close to the ship, rendering both the horizon and animals outside the field-of-view of the binoculars. A two-day training period for observers took

place before the survey to practise angle and distance estimation using the equipment and by eye, each taken in turn to check estimates to surrounding vessels or headlands against the radar.

Survey effort continued throughout daylight hours (generally 06:00-21:00) but was suspended when sighting conditions were unsuitable (Beaufort sea state >4 or poor visibility). All sightings, effort and environmental data were recorded onto data sheets. Sightings data included time of initial cue, position (latitude and longitude), species identification and certainty, group size (min, max and best) and other associated notes. Effort and environmental data, including sea state and swell height, were logged at the beginning, end and at 30-minute intervals or whenever conditions changed throughout the day. The data collected by the lower team were also entered directly into a laptop running the LOGGER (IFAW, 1992-1994) program and linked via an NMEA interface to a Garmin II Plus Global Positioning System (GPS).

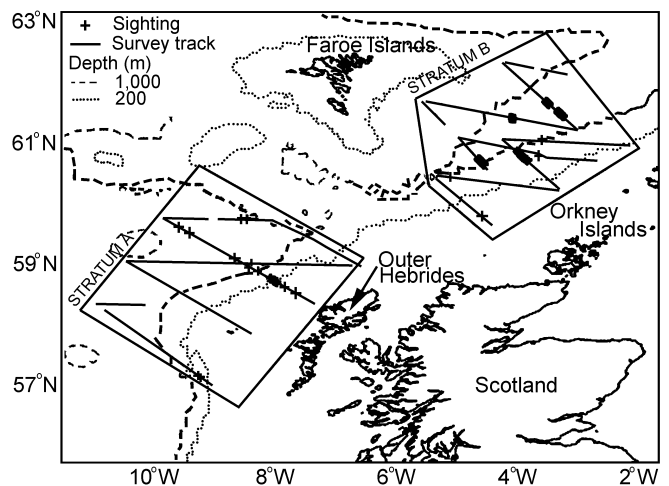


Fig. 1. Survey area showing transects surveyed on effort and distribution of sightings of the Atlantic white-sided dolphin.

Data analysis

The abundance estimate was corrected for sightings missed on the trackline to compensate for violation of one of the fundamental assumptions of distance sampling theory—that all objects are detected on the trackline with certainty (Buckland *et al.*, 2001). The value of the detection function at zero distance, $g(0)$, and absolute abundance were calculated using the direct duplicate method (Palka, 1995).

Duplicate identification

Duplicate sightings were identified from the Atlantic white-sided dolphin sightings recorded by the upper and lower platforms. They were identified by comparing the times of sightings, estimates of distance and sightings angle, best estimates of group size and group headings. A duplicate required there to be an exact match in time, or within a minute, of sighting times of the initial cue; sighting angles to be within 5° of each other; and sighting distances to be within one reticle eye division. Best estimates of group size could vary but the range had to be within two animals. This is particularly important when there were a large number of groups aggregated in a relatively small area and short space

of time. The species identification had to correspond for both teams of observers. Definite duplicates were determined after the survey was completed.

Abundance estimation

Applying the direct duplicate method, corrected animal abundance from a stratified survey is estimated by:

$$N = \sum_{i=1}^2 D_i \cdot A_i = \sum_{i=1}^2 \frac{D_{iup} \cdot D_{ilo}}{D_{idup}} \cdot A_i \quad (1)$$

where

- N = estimated abundance of animals, corrected for $g(0)$, across strata;
- D_i = estimated density of animals, corrected for $g(0)$, within stratum i (n/km^2);
- A_i = area of stratum i (km^2);
- D_{iup} = density of animals as seen by the upper team, not corrected for $g(0)$, within stratum i ;
- D_{ilo} = density of animals as seen by the lower team, not corrected for $g(0)$, within stratum i ;
- D_{idup} = density of animals as seen by both teams (duplicates), not corrected for $g(0)$, within stratum i .

where

$$D_{iup} = \frac{n_{iup} \cdot f_{iup}(0) \cdot E(s_{iup})}{2L_{iup}} \quad (2)$$

and

- n_{iup} = number of sightings detected by the upper team, within stratum i ;
- $f_{iup}(0)$ = estimated probability density function of perpendicular distances for the upper team, within stratum i , evaluated at zero ($f(0) = 1/\mu$ where μ is the effective strip half-width);
- $E(s_{iup})$ = estimated group size, within stratum i ; for the upper team; and
- L_{iup} = total survey effort for the upper team, within stratum i .

Similarly, equation 2 was used to estimate D_{ilo} and D_{idup} .

Only sightings and effort collected in Beaufort sea state 2 or below were used in the analysis. For each dataset, $f(y)$ was modelled from perpendicular distance data pooled over strata because of the limitations imposed by small sample sizes in stratum A and of the duplicate dataset. The reticle distances and angles were converted to radial distances (km) using the equation of Lerczak and Hobbs (1998). The radial distances were converted to perpendicular distances ($d = r \cdot \sin\theta$); histograms of their distributions for both platforms and the duplicate data are shown in Fig. 2. Each dataset was modelled in Distance 3.5 (Thomas *et al.*, 1998) using the combinations of key functions and series expansions identified as model robust (Buckland *et al.*, 2001). The data were grouped into distance intervals for analysis (Buckland *et al.*, 2001). The need for, and number of, adjustment terms in the series expansion were assessed by the Likelihood Ratio test (Buckland, 1987; Buckland *et al.*, 2001) and Akaike's Information Criteria (AIC). The best model was judged from visual inspection of the model fit and on the basis of the lowest value of AIC. Expected group size was estimated using size-bias regression of the log of cluster size

against $g(y)$ for data pooled across strata. Encounter rates and density were estimated for each stratum and observation platform. Additionally, estimates of density were combined over strata, weighted by stratum areas.

Variance of $f(y)$, $E(s)$ and uncorrected density for each platform was estimated empirically in Distance 3.5. Confidence intervals (CI) and coefficients of variation (CV) of the corrected abundance estimates were calculated using a nonparametric bootstrap. Within each bootstrap replicate, transects were resampled with replacement independently within each stratum, and estimates of D_{iup} , D_{ilo} and D_{idup} and therefore D were calculated. 999 replicates were performed and confidence limits were calculated as the 2.5 and 97.5th percentile of the bootstrap distribution. The bootstrap procedure was complicated using stratum A transects by the small sample sizes. When there were no duplicate sightings on a transect, D_{idup} was zero and, following from equation 1, D and consequently N were infinity. These resamples were excluded for the calculation of the CV and CI for density in stratum A. The delta method (Buckland *et al.*, 2001) was also used to estimate the CV of density estimates as a comparison to the bootstrap estimates, particularly given the problems associated with the small sample sizes for stratum A.

Estimating $g(0)$

The value of $g(0)$ can be estimated by:

$$g_i(0) = g_{iup}(0) + g_{ilo}(0) - (g_{iup}(0) \cdot g_{ilo}(0)) \quad (3)$$

where

$$g_{iup}(0) = \frac{n_{idup} \cdot f_{idup}(0)}{n_{ilo} \cdot f_{ilo}(0)} \quad (4)$$

and $g_{ilo}(0)$ can be calculated similarly. Given that

$$f(0) = 1 / \int_{y=0}^w g(y) dy$$

$$g_{iup}(0) = \frac{n_{idup}}{n_{ilo}} \cdot \frac{\int_{y=0}^w g_{ilo}(y) dy}{\int_{y=0}^w g_{idup}(y) dy} \quad (5)$$

and

$$g_{ilo}(0) = \frac{n_{idup}}{n_{iup}} \cdot \frac{\int_{y=0}^w g_{iup}(y) dy}{\int_{y=0}^w g_{idup}(y) dy} \quad (6)$$

The shape of the detection curve $\int_{y=0}^w g(y) dy$ was modelled

by estimating the probability density function, $f(y)$, using perpendicular distances y in Distance 3.5. The CV of each $g(0)$ estimate was obtained from 100 bootstrap resamples of

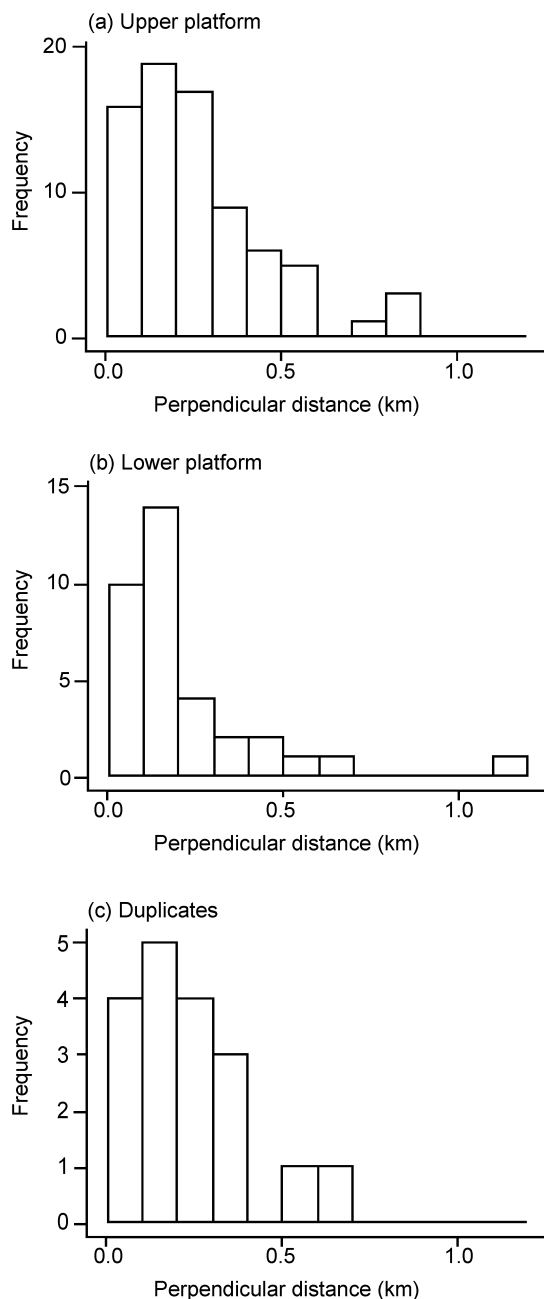


Fig. 2. Frequency histograms of the perpendicular distances (km) for the (a) upper, (b) lower and (c) duplicate sightings.

the lower, upper and duplicate datasets. A sample within each stratum was defined as all effort completed on a single day (one transect), so as to increase independence between samples. Resampling was conducted across strata.

RESULTS

Survey effort in strata A and B amounted to 1,082km and 1,074.6km, respectively. The total survey effort in Beaufort sea state 2 or less was 627.5km in stratum A and 800km in stratum B. The upper team recorded more sightings than the lower platform and the sample sizes for each were $n_{lo} = 35$ and $n_{up} = 79$. From these datasets, only 18 definite duplicates were identified. Examination of the histograms of sighting perpendicular distances (Fig. 2) led to the right truncation of both the upper and lower teams data at 0.8km and 0.64km, respectively, to remove outliers. The resulting sample sizes were $n_{up} = 73$ and $n_{lo} = 34$. The histogram of duplicate data showed no obvious outliers and was not truncated ($n_{dup} = 18$).

The data were analysed as grouped. Histograms of perpendicular distances to sightings (Fig. 2) suggested some responsive movement of white-sided dolphins to the approach of the research vessel, with fewer detections in the first 100m than the second. Consequently, when modelling $f(y)$, the first interval was chosen to be wide enough that animals moving away from the trackline would still be in the first interval. The half-normal key function, without a series expansion, was the best model of $f(y)$ for each of the three datasets. The point estimates of $f(0)$ for the upper, lower and duplicate data were 2.77 (CV = 0.09), 3.16 (CV = 0.14) and 2.95 (CV = 0.20), respectively (Table 2). The plots of the probability density function for the lower, upper and duplicate data are shown in Fig. 3. The effective strip half-width (μ) for the upper and lower platforms was 360m (SE = 30) and 320m (SE = 40), respectively.

Encounter rates were higher in stratum B compared to stratum A and on the upper platform compared to the lower platform (Table 2). Cluster size bias was significant for the upper and lower platforms, which meant that larger schools were more likely to be detected at distance than smaller schools. The regression estimates of group size of Atlantic white-sided dolphins for the upper platform was 5.26 (SE = 0.53) and 6.78 (SE = 0.68) for the lower platform (Table 2). The mean group sizes, pooled over strata, for the lower and upper platforms were 6.06 (SE = 0.57) and 4.97 (SE = 0.49), respectively. Observed group sizes estimated by the upper platform ranged from 1-22 individuals compared with 2-16 individuals for the lower platform.

Estimates of density and abundance, not corrected for $g(0)$, are shown for each stratum and observation platform in Table 3. The uncorrected abundance estimate for the whole survey area using the upper platform data was 32,947 (CV = 0.30). Uncorrected abundance estimates using the lower and duplicate data were 22,213 (CV = 0.35) and 7,609 (CV = 0.37), respectively. The values of $g(0)$ were estimated from the pooled data across strata, and were $g_{up}(0) = 0.48$ (CV = 0.10), $g_{lo}(0) = 0.26$ (CV = 0.17) and $g(0) = 0.61$ (CV = 0.09). During the bootstrap resampling of stratum A

Table 2

Summary of parameter estimates for the upper, lower and duplicate data. The encounter rate (n/L) was estimated by stratum; remaining parameters estimated from data pooled over strata.

Stratum	Platform	n	L (km)	No. transects	A (km ²)	n/L (SE)	f(0) (SE)	E(s) (SE)	μ (SE)
A	Upper	13				0.02 (0.01)	2.77 (0.25)	5.26 (0.53)	0.36 (0.03)
	Lower	5	627.5	7	54,720	0.008 (0.003)	3.16 (0.44)	6.78 (0.68)	0.32 (0.04)
	Duplicate	3				0.005 (0.003)	1.95 (0.39)	4.65 (0.60)	0.34 (0.07)
B	Upper	60				0.07 (0.02)	2.77 (0.25)	5.26 (0.53)	0.36 (0.03)
	Lower	29	800.2	9	45,213	0.04 (0.01)	3.16 (0.44)	6.78 (0.68)	0.32 (0.04)
	Duplicate	15				0.02 (0.006)	1.95 (0.39)	4.65 (0.60)	0.34 (0.07)

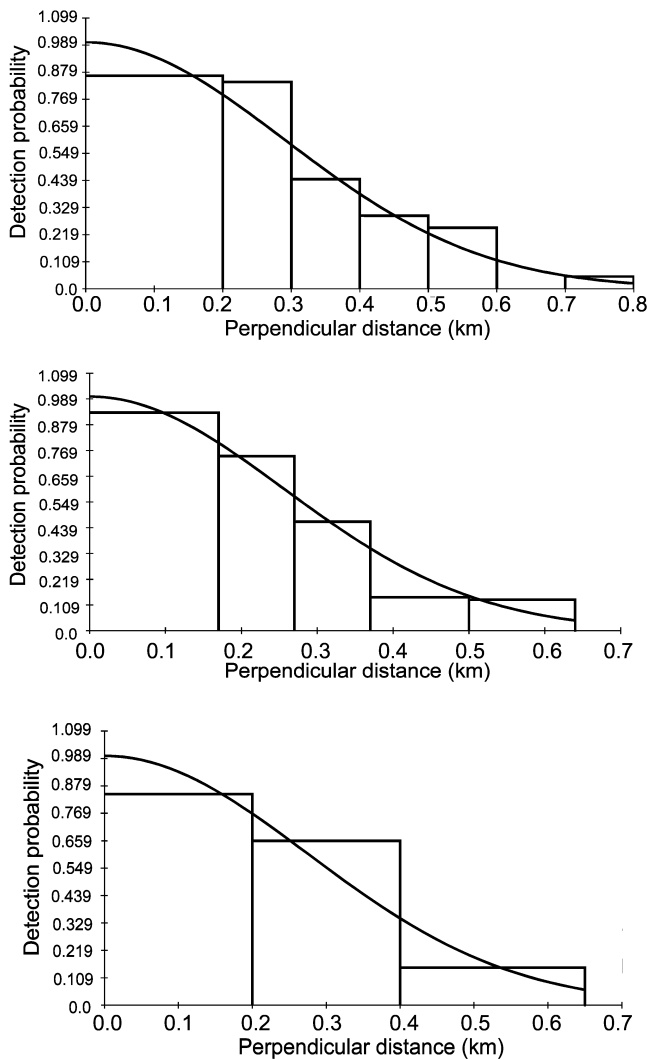


Fig. 3. Sightings distribution of the Atlantic white-sided dolphin against perpendicular distances for the upper (top), lower (middle) and duplicate (lower) data. The data are fitted with a half-normal key function and the fitted curve indicates the estimated probability density function.

transects, 20.3% of the resamples were infinity due to zero duplicate sightings on some transects. These resamples were removed and the calculation of CV and 95% CI of density were based on 796 resamples. The bootstrap estimate of CV will be an underestimate and the delta estimate is considered a more realistic value for stratum A. In stratum A, the corrected animal density and abundance was estimated to be 0.39 (Bootstrap CV=0.54 and 95% CI=0-0.74; Delta CV=0.96) and 21,371 (Bootstrap CV=0.54, 95% CI=0-40,659), respectively. In stratum B, density was estimated as 1.65 (CV=0.72, 95% CI=0.19-5.42; Delta CV=0.66) white-sided dolphins and an animal abundance of 74,626 (CV=0.72) corrected for $g(0) < 1$ (Table 3).

DISCUSSION

The corrected abundance estimate presented here represents one of two for this species in the eastern North Atlantic. O’Cadhla *et al.* (2001) estimated the abundance of Atlantic white-sided dolphins to be 5,490 (CV=0.43) in an area of approximately 100,000km² to the west of Ireland and over the Rockall Trough during August 2000. The value of $g(0)$ used to correct this estimate was obtained from a pooled dataset of Atlantic white-sided and common dolphin

Table 3

Summary of uncorrected and corrected density and abundance estimates. CVs were estimated using bootstrap resampling.

Stratum	Platform	Uncorrected density (CV)	Uncorrected abundance (CV)	Corrected density (CV)	Corrected abundance (CV)
A	Upper	0.15 (0.55)	8,217 (0.55)	0.39 (0.54)	21,371 (0.54)
	Lower	0.08 (0.47)	4,668 (0.47)		
	Duplicate	0.03 (0.64)	1,795 (0.64)		
B	Upper	0.55 (0.34)	24,730 (0.34)	1.65 (0.72)	74,626 (0.72)
	Lower	0.39 (0.40)	17,545 (0.40)		
	Duplicate	0.13 (0.39)	5,814 (0.39)		

(*Delphinus delphis*) sightings. The corrected estimates presented here are 21,371 (CV = 0.54) Atlantic white-sided dolphins to the west of the Outer Hebrides and 74,626 (CV = 0.72) in the Faroe-Shetland Channel. A combined abundance of 11,760 (CV = 0.26) Atlantic white-sided and white-beaked dolphins (*L. albirostris*) for the North Sea and adjacent waters was estimated from shipboard double platform surveys in July 1994 (Hammond *et al.*, 2002). This estimate is, however, mainly representative of the North Sea, which is an area of relatively low density of Atlantic white-sided dolphins compared to white-beaked dolphins.

The abundance estimates available suggest that northwest Scotland has the greatest summer abundance of Atlantic white-sided dolphins in surveyed British waters. Estimates of density support this and suggest that, at least during summer, animal density appears to increase towards the northern end of the range of this species. Existing density estimates indicate a gradient from western Ireland of 0.046 animals/km² (O’Cadhla *et al.*, 2001), to the Outer Hebrides of 0.39 animals/km², peaking in the Faroe-Shetland Channel at 1.65 animals/km². The importance of the west coast is further reflected by the difference in encounter rates (density estimates for the North Sea are not available) of Atlantic white-sided dolphins between the North Sea and western Britain. Group encounter rates recorded by the upper team were 0.07/km (SE = 0.01) in the Faroe-Shetland Channel and 0.02/km (SE = 0.02) to the west of the Outer Hebrides. Within the North Sea, an encounter rate of only 0.005/km was estimated for the Atlantic white-sided dolphin from data collected during July 1994 (Borchers *et al.*, 1995). Atlantic white-sided dolphins occur year-round in these waters but spatial trends in densities may vary seasonally. Observations recorded during seabird surveys off northwest Scotland, show a large increase in numbers of white-sided dolphins during August, with twice as many dolphins recorded as in any other month (Weir *et al.*, 2001).

The assumption that all animals are detected on the trackline with certainty is usually violated during cetacean surveys and the value of $g(0)$ has been found to be less than one for a range of species (Hammond *et al.*, 2002). These data were originally analysed assuming that $g(0) = 1$ (Hughes *et al.*, 1998) and by using a single dataset of unique sightings formed by combining both the upper and lower platforms and eliminating duplicates ($n = 102$, and assuming $f(y)$ was the same for both platforms) across all sea states (0-4). The combined estimate of abundance for the Faroe-Shetland Channel and the west of the Outer Hebrides was 27,194 (CV = 0.29), which is considerably lower, but more precise, than the corrected estimates. In addition to missing animals on the trackline, the histograms of perpendicular distances to white-sided dolphin sightings (Fig. 2) suggested some responsive movement of the dolphins away from the research vessel, which further

violates the basic distance sampling assumptions. Evasive behaviour by Atlantic white-sided dolphins has been documented in the North Atlantic (Palka and Hammond, 2001) and it leads to underestimation of density. Future surveys for Atlantic white-sided dolphins should use a survey methodology that enables an estimate of $g(0)$ robust to responsive movement. Such a method was used during the Small Cetacean Abundance in the North Sea and adjacent waters (SCANS) (Hammond *et al.*, 2002) survey and involved two teams of observers on independent platforms, but one team (the 'tracker') searched farther ahead of the vessel than the other. The assumption was that sightings recorded by the 'tracker' platform had not yet reacted to the approach of the survey vessel (Buckland and Turnock, 1992). However, the method cannot fully account for responsive movement if the assumption routinely fails. Palka and Hammond (2001) have recently developed a different approach to account more fully for responsive movements based on animal orientation data and this approach should be considered for future surveys for Atlantic white-sided dolphins.

Another source of bias in the corrected abundance estimate is the identification of duplicate sightings. Delays in recording the first time of sightings (since this was not automated) and potential changes in the swimming direction of groups between the initial sighting by one team and detection by the other makes identification of definite duplicates difficult. The reticle binocular readings were also more prone to error than the angle board measurements since swell sometimes made it difficult to hold them steady. These problems were kept in mind when trying to identify duplicates. The duplicate dataset was also small, with just 18 sightings used for modelling the detection function. Buckland *et al.* (2001) suggested sample size minima of forty sightings, but the half-normal model of the duplicate data appeared to fit the data well and the data showed no spurious outliers or 'spikes'. However, bias in the estimation of $g_{dup}(y)$ from such a small sample size can arise when using the direct duplicate method (Palka, 1995). A third observer on the IO survey, who could have determined duplicates at sea, as used on SCANS (Hammond *et al.*, 2002) may have been more successful at duplicate identification than post-survey.

The value of $g(0)$ varied between the upper (0.48) and lower platforms (0.26). The probability of detection would be expected to be greater for the upper platform because of the advantage which height above sea level confers on the ability of observers to sight cetaceans. Observers on the higher platform can probably see animals further away from the vessel than the lower platform and this is reflected in the slight differences in the estimates of effective strip-half width ($\mu_{up} = 360\text{m}$ (SE = 30) and $\mu_{lo} = 320\text{m}$ (SE = 40)). The probability of detection for observers on the higher platform may also be better than the lower platform when sea state increases. Although the observer teams were chosen so that the level of experience on each was similar, there will be individual observer variability that will influence overall team efficiency and the detection function for that team. Similarly, differences in environmental conditions, such as the amount of glare, may differ between platforms thus affecting the detection function. An assumption of using distance sampling data to model the detection function is that detection of an object depends solely on its distance from the trackline. In reality, many variables are likely to affect the detection probability (Marques and Buckland, 2003). The double platform survey method and modified mark-recapture model used for analysis in this study, also

assume that the detections by the platforms are independent but this is often not the case (for example, the behaviour of a group of dolphins may increase the probability of detection by one team but also the other). If heterogeneity in the detection probability is not modelled, then abundance estimates will be negatively biased (Borchers *et al.*, 2002). There are two methods which can be used to minimise heterogeneity and these are stratification of the data by covariates and incorporating covariates into $f(0)$ estimation (Marques and Buckland, 2003). Stratification of small datasets is not possible. Future surveys should ensure that covariates are recorded so that heterogeneity can be modelled and unbiased abundance estimated.

The combined estimate of $g(0)$ for the white-sided dolphin was 0.61 (CV = 0.09) which is similar to the value of $g(0)$ generated from SCANS for *Lagenorhynchus* sp. of 0.65 (Hammond *et al.*, 1995). The SCANS estimate of $g(0)$ for the white-beaked dolphin (*L. albirostris*) was 0.71 (Hammond *et al.*, 1995). It would not be appropriate to use a combined *Lagenorhynchus* sp. $g(0)$ as a general multiplier of abundance estimates for either the white-beaked or Atlantic white-sided dolphin. In the northeast Atlantic, the observed behaviour of these species in the field suggests that their detection probabilities would be different. Both *L. albirostris* and *L. acutus* are active swimmers but, from personal observations, the white-sided dolphin tends to be seen in large aggregations making them easier to detect. On the other hand, *L. albirostris* is slightly larger, has a more prominent dorsal fin, and the ability to detect this species is influenced less by Beaufort sea state (Macleod, 2001). The Atlantic white-sided dolphin appears to exhibit evasive behaviour in the presence of vessels whereas white-beaked dolphins commonly approach vessels (Palka and Hammond, 2001). An estimate of $g(0)$ for the Atlantic white-sided dolphin in the western Atlantic was 0.62 and was calculated from shipboard line transect surveys in the Gulf of Maine/lower Bay of Fundy (Palka *et al.*, 1997).

The abundance of the Atlantic white-sided dolphin was highest in the Faroe-Shetland Channel, although a number of biases in the estimates have been highlighted. The corrected estimates also have substantial uncertainty. The non-parametric bootstrap assumes that the sampling units from which resamples are drawn are independent. A sampling unit was defined as the length of transect surveyed in one day so that this assumption was not seriously violated. However, this resulted in a number of transects (Table 2) below the recommended minima of 15-20 (L. Thomas, pers. comm.) for the bootstrap procedure which may give rise to unreliable estimates of variance.

Data from dedicated cetacean surveys in these waters was previously limited to the NASS conducted in the late 1980s and 1990s (Gunnlaugsson and Sigurjónsson, 1990; Buckland *et al.*, 1992). However, the focal species of these surveys were whales and coverage in Scottish waters was extremely low. Therefore, the NASS data were of little value to the planning stages of this survey and estimating required coverage. The abundance estimates presented are the first for this region and can aid the planning of future surveys with aim of estimating more precise abundance (e.g. Hammond and Macleod, 2003). Offshore waters west of the Outer Hebrides and Northern Isles probably have the highest densities of this species in British waters, which suggest that the area provides an important habitat for them. Abundance estimates are important in areas undergoing rapid industrialisation that may have adverse effects on local populations. They are also vital to assessing the sustainability of removals caused by other sources,

particularly fisheries bycatch. Baseline abundance estimates should be considered against subsequent estimates as a way of long-term monitoring of cetacean populations and as an integral part of an assessment of the status of a species.

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