Distance estimation experiment for aerial minke whale surveys

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ABSTRACT

A comparative study between aerial cue–counting and digital photography surveys for minke whales conducted in Faxaflói Bay in September 2003 is used to check the perpendicular distances estimated by the cue-counting observers. The study involved 2 aircraft with the photo plane at 1,700 feet flying above the cue–counting plane at 750 feet. The observer–based distance estimates were calculated from head angles estimated by angle-boards and declination angles estimated by declinometers. These distances were checked against image–based estimates of the perpendicular distance to the same whale. The 2 independent distance estimates were obtained for 21 sightings of minke whale, and there was a good agreement between the 2 types of estimates. The relative absolute deviations between the 2 estimates were on average 23% (se: 6%), with the errors in the observer–based distance estimates resembling that of a log-normal distribution. The linear regression of the observer–based estimates (*obs*) on the image–based estimates (*img*) was *Obs*=1.1*Img* (R^2=0.85) with an intercept fixed at zero. There was no evidence of a distance estimation bias that could generate a positive bias in the absolute abundance estimated by cue–counting.

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INTRODUCTION

An important part of the NASS has been the aerial surveys that have covered the coastal area of Iceland (Borchers *et al.* (MS) 1997, Borchers (MS) 2003, Borchers *et al.* 2009 NAMMCO 1998, 2003, Pike *et al.* 2009). These surveys have been directed towards minke whales using the cue–counting technique (Hiby and Hammond 1989), where whale behaviours, such as a surfacing or a blow, are counted, rather than the whales themselves as in line transect surveys.

The cue–counting method was adopted for the coastal Icelandic surveys mainly because it was recognized that estimates derived from aerial line transect surveys would have a severe negative bias because of the large proportion of the animals that would be submerged when the plane passed over. This problem is avoided by the cue–counting technique that was specifically designed to correct for submerged animals (Hiby and Hammond 1989). Nevertheless, the technique has not been widely adopted for cetacean surveys. It is demanding of observers, sensitive to observer error and differences in sighting patterns, and tends to give estimates with higher variance than the line transect method (Pike *et al.* 2009).

The sensitivity to observation errors have resulted in large differences between abundance estimates using the same data from 1987 (Borchers *et al.* 2009, Hiby *et al.* 1989). Another potential problem is biased distance estimates, although not specific to aerial cue–counting surveys. If observers are systematically underestimating the distance this could generate an abundance estimate that is positively biased to some unknown degree.

Normally it is not possible to check whether the observed distances have a bias. A unique opportunity to study this arose in September 2003 where a comparison between the aerial survey techniques of digital images and cue–counting was conducted for minke whales in Faxaflói Bay on Iceland. This paper uses the images that contain both the cue–counting plane and the minke whales seen by the cue count observers to obtain independent estimates of the perpendicular distances between the cue–counting plane and the observed minke whales.

METHODS

Survey

The study was performed in Faxaflói Bay using the tracklines of block 1 of the NASS 1995 and 2001 surveys. The flying involved 2 aircraft, a cue–counting plane (Partenavia Observer P-68, with 1 bubble window on each side of the plane) and a photo plane (Piper Seneca). The same Partenavia and pilot were also used in NASS 2001 and 1995, and the same type of aircraft in 1987.

Both planes were equipped with a GPS and the start and end coordinates of all tracklines were entered into the GPS navigation systems prior to the survey. On effort the cue–counting plane was flying 750 feet (239 m), while the photo plane was flying 1,700 feet (518 m) right above the cue–counting plane. The target ground speed was 95 nm/hr, but this varied somewhat with wind direction and speed.

The primary aim of the synchronised flying, with the photo plane flying right above the cue–counting plane, was to have the cue–counting plane positioned at the centre of the lower edge of the images (seen in the flight direction), so that the images would cover the search area of the observers in the cue–counting plane. In order to obtain this, the synchronisation was performed by letting the cue–counting plane fly on the trackline with as steady a speed as possible, while the camera operator on the photo plane would instruct the pilot of the photo plane to make minor corrections to the speed in order to have the cue–counting plane in the right position. If the cue–counting plane started to drift off the trackline of the photo plane the pilot of the photo plane would use the radio to call the cue–counting plane back on trackline.

The crew for the cue–counting plane consisted of the pilot and cruise leader in the left and right front seats, and 2 primary observers in the right and left rear seats, using the bubble windows. The cruise leader and primary observers maintained full observational effort throughout the survey. The pilot also recorded sightings, however his flying duties detracted from his efficiency as an observer. The cruise leader and pilot were visually isolated from the primary observers by a curtain. To the extent possible, aural isolation was maintained while on effort by moving the intercom microphones away from the mouth, however it was still sometimes possible to hear another observer making an observation. The primary observers changed sides at least every other day.

The data collection system for the cue count resembled that used on the previous NASS. Data was entered by voice and recorded on separate laptops for each of the 4 observers. When the microphone was opened, the GPS time and position was saved on a laptop computer, so that the time and position of every observation was known. Declination angles were measured with a hand held declinometer, and lateral angle from the nose of the plane was estimated using a manual angle board that was placed in the window frame.

As in NASS, a cue was considered to be a dive of a minke whale, *i.e.*, when the back is out of the water and the whale is diving. The following data were recorded for every cue sighted: time, angles of declination and from the head of the aircraft, time at which the angles were measured, position when the angles were measured, and school size if more than 1 animal was diving at the same time. If possible the declination angle and time when the cue position was abeam was also recorded. In addition to recording cetacean sightings, the cruise leader also monitored all changes in survey effort and environmental conditions, such as the beginning and end of each transect, interruptions in effort, weather conditions, Beaufort sea state, visibility and glare.

The crew for the photo plane consisted of the pilot and a camera operator. The photo system was 2 Hasselblad cameras with Phase One 10.6 mega-pixel H10 digital backs, mounted in a sideward horizontal angel of 16 degrees to ensure only marginal sideward overlap. The digital backs were oriented with 3,992 pixels in the forward direction, and 2,656 pixels in the sideward direction. The light sensitivity of the H10 backs was set to 400 ASA, the shutter speed to 1/500 sec., and the lenses were 40 mm. Combined with a flying altitude of 1,700 feet it provides forward coverage of approximately 480 m, and approximately 320 m to each side. On average images were taken 2.6 sec. apart, and any point on the ground would generally be on 4 subsequent images. For each image the GPS time and position of the exposure were saved so that it was possible to use the GPS time to match the images with the observations made by the observers on the cue–counting plane.

Distance estimation

As the distance estimates obtained from the photo survey are calculated from accurate readings of the digital images, they can be expected to be more accurate than the observer–based estimates that are calculated from the head and declination angles obtained during the flight. The image–based distance estimates are therefore used as a background against which the observer–based estimates are checked. The relative drift angles between the 2 planes were ignored in this analysis because the drift angle of the cue–counting and the photo plane were almost identical.

The observer–based estimates of the perpendicular distance of a minke whale to the cue–counting plane were obtained by combining head angles read from angle boards with the declination angles read from declinometers and the altitude of the plane. The radial distance is given by the altitude times *tan* of 90 degrees minus the declination angle, and the perpendicular distance is given by the radial distance times *sin* of the head angle.

The image–based distance estimates of the perpendicular distance between the cue–counting plane and an observed minke whale were obtained by subtracting the perpendicular distance between the photo plane and the

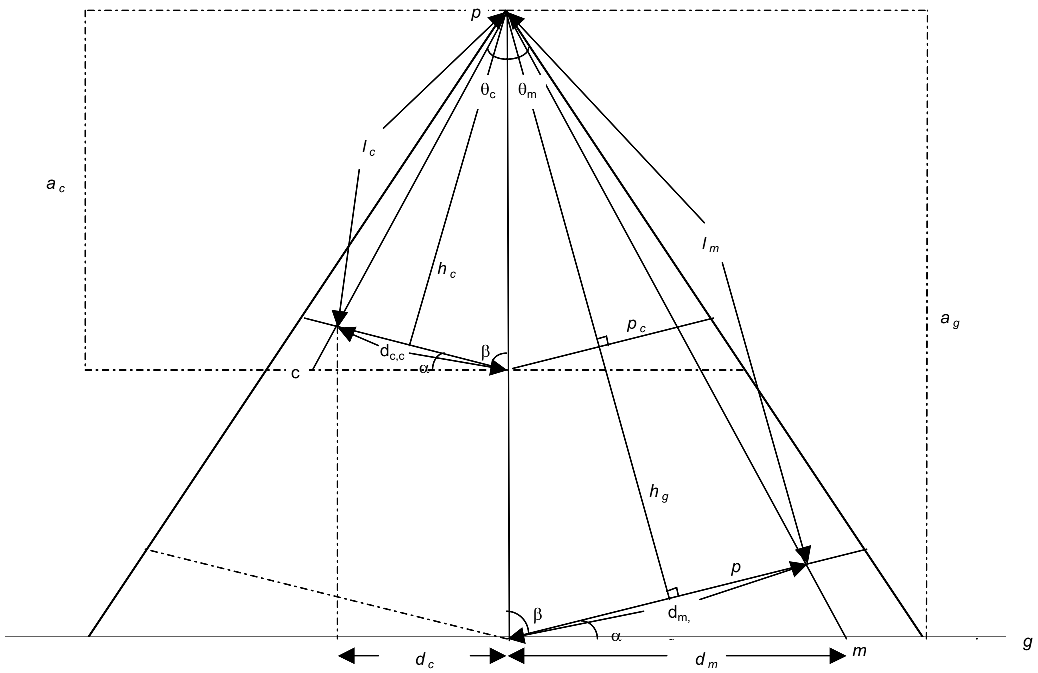

Fig. 1. *A vertical representation of the photo fields of the 2 cameras, including the photo plane (p), the cue–counting plane (c), and an observed minke whale (m). The sideward horizontal angle of the cameras is α=16.6 degrees, and* p_c *and* p_g *represents photo lines with a constant distance* k_c *and* k_g *covered by each pixel. This distance is equal to the distance covered by the innermost pixel at the level of respectively the cue–counting plane (c) and the ground (g).*

cue–counting plane from the perpendicular distance between the photo plane and the minke whale, with the former distance being positive if the cue–counting plane was on the same side of the photo plane as the whale, and negative if it was on the opposite side.

This calculation is illustrated by Fig. 1 which shows a vertical representation of the photo fields of the 2 cameras, including the photo plane (*p*), the cue–counting plane (*c*), and an observed minke whale (*m*). The photo lines p_c and p_g represent the lines where each pixel on an image cover a constant distance k_c and k_g that is also the distance covered by the innermost pixel at the level of respectively the cue–counting plane (*c*) and the ground (*g*). With altitudes of 1,700 feet for the photo plane and 750 feet for the cue–counting plane, the distances covered by a pixel on the photo lines p_c and p_g were k_c=0.062 m and k_g=0.11 m.

The projected distances $d_{c,c}$ and $d_{m,g}$ of the perpendicular distance to the cue–counting plane (*c*) onto the photo line p_c and the perpendicular distance to a minke whale (*m*) onto the photo line p_g are then given as $d_{c,c}=k_c nr_c$ and $d_{m,g}=k_g \mathrm{nr}_m$ where $1 \le nr_c \le 2{,}656$ and $1 \le nr_m \le 2{,}656$ are the pixel number of the cue–counting plane and the minke whale on the image where 1 is the innermost pixel and 2,656 is the outermost pixel.

The distance l_m, between the photo plane and the projection of a minke whale on the photo line p_g, is:
(1)

$$l_m = \sqrt{a_g^2 + d_{m,g}^2 - 2a_g d_{m,g} \cos\beta}$$

the top angle θ_m is:
(2)

$$\theta_m = \arccos \frac{a_g^2 + l_m^2 - d_{m,g}^2}{2a_g l_m}$$

and the perpendicular distance to the photo plane:
(3)

$$d_m = a_g \tan\theta_m$$

The perpendicular distance between the cue–counting and the photo plane is calculated in a similar way.

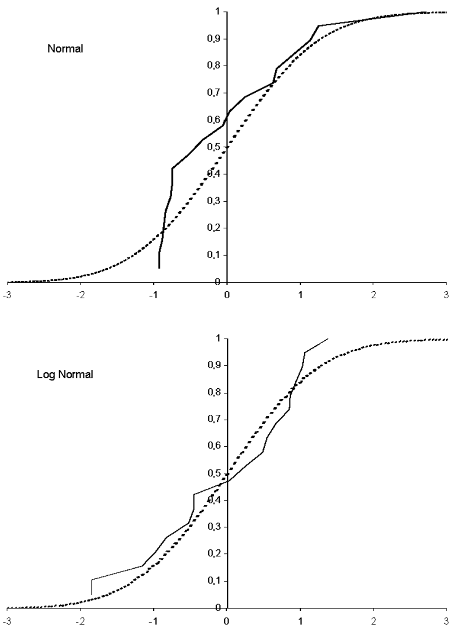

Fig. 2. *The cumulated probability distribution of the distance estimation errors (solid curves) under the assumption that the errors are normally distributed (top figure) and the assumption that they are log-normally distributed (bottom figure). The dotted curves show the theoretically expected curves of the normal and the log-normal distribution (the log-normal distribution is transformed into normal distribution for comparison).*

RESULTS AND DISCUSSION

Although minke whales were easily seen on images if they were surfacing within the photo frame when an image was taken, there were several other factors that determined that not all the whales that were seen by the cue-count observers would allow for image–based distance estimates. There were some problems in holding the optimal position of the cue–counting plane on the images, so even if a minke whale was seen relatively close to the cue–counting plane, the cue–counting plane might not be within the photo frame of the images and nor might the minke whale. The strip width of the images was also relatively narrow. On average the images covered approximately 320 m on each side of the cue–counting plane, but approximately half of the observed minke whales were observed at greater perpendicular distances. The total number of minke whales and likely minke whales that were seen by the observers on the cue–counting plane was 76. Of these there were 21 sightings that were matched by images to the degree that image–based distances could be estimated.

Table 1 lists the image–based estimates of the perpendicular distances between the photo plane and a whale (*Whale*), the photo plane and the cue–counting plane (*Cue*), the cue–counting plane and a whale (*Img*), together with the observer–based estimates of the perpendicular distance between the cue–counting plane and a whale (*Obs*) and the relative absolute deviation *Dev=[Obs–Img]/Img* between the perpendicular distance estimates of a whale to the cue–counting plane. Generally there was good agreement between the image and observer–based estimates. However, there were 2 outliers that indicate that they most probably represent image and observer–based distance estimates to different whales. Excluding the 2 outliers, the average relative absolute deviation is *dev*=0.23 (SE: 0.06).

Excluding the 2 outliers, we examined whether the observation errors in distance estimates were normally or log normally distributed. The top image in Fig. 2 shows the cumulated probability distribution of the normalised errors together with the normal distribution, under the assumption that the errors are normally distributed, and the bottom figure shows the corresponding

TABLE 1. The image based perpendicular distances (in meters) between the photo plane and a whale (*Whale*), the photo plane and the cue–counting plane (*Cue*), the cue–counting plane and a whale (*Img*), the observer based estimate of the perpendicular distance between the cue–counting plane and a whale (*Obs*), and the relative absolute deviation *Dev=[Obs– Img]/Img*. Day is the flying day in September, and Time the mark time of the observation.

Day	Time	*Whale*	*Cue*	*Img*	*Obs*	Dev
15	10:44:04	294	14	279	375	0.34
15	12:44:38	233	14	219	192	0.12
15	12:44:54	157	75	82	82	0.01
15	13:01:44	228	14	213	208	0.03
15	14:08:33	184	48	136	132	0.03
15	14:16:38	148	14	134	443	2.31
15	14:17:26	28	14	14	507	36.4
15	14:45:08	220	14	206	198	0.04
22	16:51:49	228	82	146	189	0.30
25	11:57:39	163	9	172	181	0.05
25	12:56:02	237	0	237	168	0.29
25	12:56:41	250	8	259	278	0.07
25	15:18:28	81	31	50	89	0.80
25	11:51:15	178	47	131	60	0.54
25	11:51:49	7	32	39	40	0.04
25	12:49:58	103	31	72	20	0.72
25	12:54:28	230	51	281	272	0.03
25	15:26:49	327	3	324	405	0.25
28	12:56:33	320	47	367	527	0.44
28	13:42:03	281	2	282	373	0.32
28	13:43:11	110	47	63	66	0.05

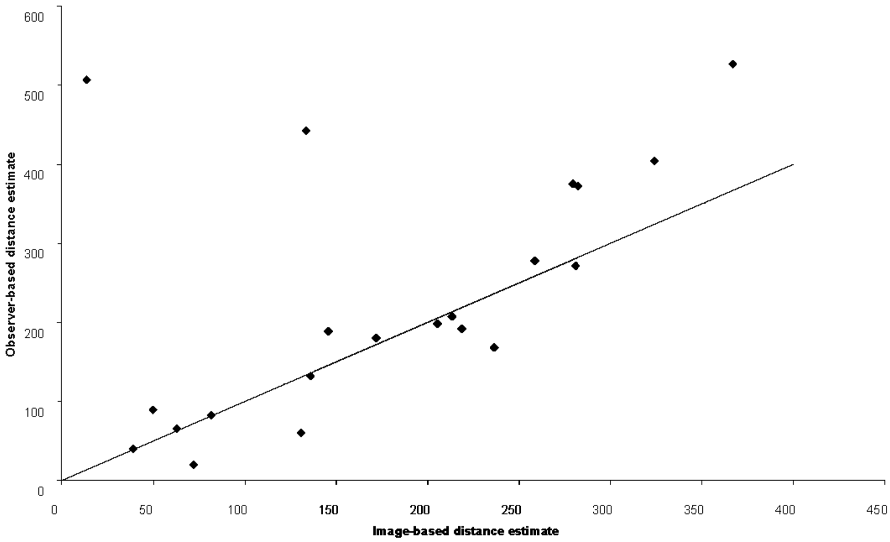

Fig. 3. *The observer based estimates of the perpendicular distance given as a function of the image based estimates. The solid line represents the case where the 2 distances are identical.*

distributions under the assumption that the estimation errors are log normally distributed. The error distribution is clearly skewed under the assumption of normally distributed errors, while it is relatively even for the case of log-normally distributed errors indicating that the estimation errors are likely log-normally distributed.

Fig. 3 examines the relationship between the ”true” perpendicular distance estimated from the digital images and the perpendicular distance estimated from the cue–counting observations. A linear regression of the observer–based estimates on the image–based estimates is *Obs*=1.3*Img*+43 (R^2=0.87), or *Obs*=1.1*Img* (R_2=0.85) if the intercept is constrained to zero. As neither of these slopes are significantly different from 1 there is no significant evidence of a bias in the estimated perpendicular distances. If anything, Fig. 3 indicates that a potential bias would be slightly positive at larger distances. This would result in a slightly negatively biased density estimate and a slightly overestimated effective search area. A final absolute abundance estimate would thus be slightly negatively biased.

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