T-NASS Icelandic aerial survey: Survey report and a preliminary abundance estimate for minke whales.

Daniel G. Pike[1], Thorvaldur Gunnlaugsson[2] and Gísli Víkingsson[2]

[1]*Esox Associates, 1210 Ski Club Road, North Bay, Ontario, Canada, P1B 8E5.* kinguq@gmail.com
[2]*Marine Research Institute, P.O. Box 1390, IS-121 Reykjavík, Iceland*

ABSTRACT

The Icelandic aerial survey component of the T-NASS project is a continuation of a series of surveys covering Icelandic shelf waters, using nearly identical design and methodology, conducted in 1987, 1995 and 2001. The primary target species is the common minke whale (*Balaenoptera acutorostrata*) with humpback whales (*Megaptera novaeangliae*) and harbour porpoises (*Phocoena phocoena*) as secondary targets. Cue counting methods are used for baleen whales while standard line transect procedures are used for other species. The latest survey was conducted in June – July 2007 and achieved 79% of planned coverage under acceptable conditions. A total of 431 unique sightings were made, including 70 groups of minke whales, 119 of harbour porpoises, 58 of humpback whales and 109 of white-beaked dolphins (*Lagenorhynchus acutus*). The general distribution pattern of most species was similar to that seen in previous surveys, with some exceptions. Minke whales occurred in lower numbers and were absent from some nearshore areas where they were abundant in previous surveys. The abundance estimate for minke whales using unique sightings from all observers and standard cue counting methods is 10,680 (95% CI 5,873, 17,121), only 24% of the estimate from 2001, a significant decrease. This decrease is almost certainly not an artefact of changes in survey methods. Several factors that may have contributed to the apparent decrease are presented but the proximate cause remains uncertain. Harbour porpoises sightings were made in all nearshore blocks in much higher numbers than previously seen: this is probably primarily because an experienced harbour porpoise observer was employed on the survey. Humpback whales were absent from eastern Iceland where they have been abundant previously, but this may have been the result of gaps in coverage. Recommendations to improve future surveys in the area are presented.

INTRODUCTION

The Icelandic aerial survey component of the T-NASS project is a continuation of a series of surveys, using nearly identical design and methodology, conducted in 1987, 1995 and 2001 (Pike *et al.* in press). Additional partial surveys have been conducted under the Icelandic Research Program between 2003-2005. Surveys using similar methodology have been conducted off West Greenland in 1987, 1989 and 1993 (Donovan 1990, Larsen *et al.* 1989, Larsen 1995) and most recently in September 2005 and 2007 (Heide-Jørgensen *et al.* 2006). The main target species of these surveys have been minke whales (*Balaenoptera acutorostrata*) (Iceland and Greenland) and fin whales (*Balaenoptera physalus*) (Greenland), however sightings of all species are registered. The cue counting procedure (Hiby and Hammond 1989) has generally been used only for minke and fin whales: for other species standard line transect methods are used. The cue-counting data collection procedure produces data suitable for either analytical method.

The survey was conducted successfully in June-July 2007.

MATERIALS AND METHODS

The T-NASS was planned under the auspices of the Scientific Committee of NAMMCO in a series of meetings between 2005 and 2007. To maintain consistency with earlier surveys, it was decided that the survey area, stratification and methodology of the survey would be remain as similar as possible to that used previously. However some relatively minor changes in methodology, as well as some additional coverage, were implemented in 2007.

Target species

Target species, in order of priority, were minke whales, harbour porpoise (*Phocoena phocoena*) and humpback whales (*Megaptera novaeangliae*) However all species encountered were recorded using the standard methodology.

Survey design

The survey design was identical to that used in 2001 (Fig. 1). It was decided by the Planning Committee that additional effort would be designed for some fiords and flown on an opportunistic basis, to assess whether harbour porpoises were concentrated in fiords. Therefore special designs, using diagonally oriented equally spaced parallel lines, were developed for 3 fiord systems: Ísafjörður, Eyjafjörður and Reyðarfjörður using DISTANCE survey design software (Fig. 1 and 2). In addition, extra effort, using N-S oriented equally spaced parallel lines, was developed for Breiðafjörður as initial coverage suggested that minke whale density was higher there than expected (Fig. 2).

Aircraft and equipment

The airplane used in the survey was a Partenavia Observer P-68, with one bubble window on each side of the plane. The same aircraft and pilot were used in 1995 and 2001, and the same type of aircraft was used in 1987. The plane was equipped with a GPS and the start and end coordinates of all tracklines were entered into the GPS prior to the survey. The survey was flown at an altitude of 600 ft (183 m) except when conditions necessitated minor deviations from this altitude. In previous years the survey was flown at 750 ft (229 m); the lower altitude was chosen to improve the survey for harbour porpoises, as this is the same altitude used in SCANS and other dedicated harbour porpoise surveys. The target ground speed was 90 kts (167 kmph), however this varied somewhat with wind direction and speed. The aircraft had an endurance of about 10 hours.

The data collection system was similar to that used on previous surveys. Data was entered by voice and recorded on separate laptop computers using the HVAL software for each of the 3 observers. When the microphone was opened, a time and position signal from the GPS was also recorded so that the time and position of every observation was known. Time and position data were also transferred via modem to a laptop computer every minute while on effort.

Sea surface temperature data was collected using an infrared temperature probe (Linear MX-6B15-RS2) mounted through a port in the belly of the plane and recording temperature readings at approximately 1 second intervals. However we experienced problems with the equipment and recording software and the system was not operational until July 7, about half way through the survey.

Declination angles were measured with a hand-held declinometer (Suunto PM5), and lateral angle from the nose of the airplane was estimated using an angle board mounted on the window frame.

Data collection

The survey crew 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 primaries maintained full observational effort throughout the survey. The cruise leader was visually isolated from the primary behind him by a curtain. Aural isolation was maintained while on effort by moving the intercom microphones away from the mouth. The primaries changed sides at least every day.

As agreed by the Planning Committee, one of the primary observers was highly experienced in aerial surveys for harbour porpoises and had participated in SCANS-II as well as other surveys in the North Sea. The other observer was experienced in aerial surveys for minke and fin whales in Iceland and Greenland.

For the purpose of this survey a "cue" was considered to be a dive by a minke whale or harbour porpoise, or a blow by a large whale. The following data were recorded for every cue sighted: time at which cue sighted, angles of declination and from the head of the aircraft, time at which the angles were measured, position when the angles were measured, cue type, school size and direction of travel. For this survey a greater emphasis was placed on collecting the declination as the sighting came abeam, as this generally produces more accurate distances. Whales that did not display the cue were also counted. For species other than the targets, the same data were collected, but animals rather than specific behavioral cues were counted.

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, sightability (scale 1 – 3) and glare (intensity and angle). This information was recorded by voice so that the cruise leader could maintain searching effort. In addition the specialized harbour porpoise observer recorded sightability in the same manner as was done in SCANS-II, as this was somewhat different than the scale used here. Off-effort sightings were also recorded when possible.

The survey was conducted mainly in passing mode, as closing on uncertain minke whale and harbour porpoise sightings was not generally productive. Sightings of other species were sometimes investigated for species identification. Survey effort was abandoned if Beaufort sea state increased above 3, or if fog, mist or heavy rain obscured visibility.

Training

Ground training was conducted on 19-20 June and 2 short training flights were done on 21-22 June. As usual ground training was found to be the most useful exercise. Observers were trained in the plane on the ground, using objects dragged under the wing as viewing targets. In this way the observers could record multiple sighting sequences in a short period, with immediate evaluation and correction. Training flights functioned primarily to ensure that the equipment was working properly

Data analysis

Data preparation

All data collected at Beaufort sea state >4 was dropped prior to analysis. For minke whales and harbour porpoises, all data collected at Beaufort sea state >3 was dropped.

Radial, perpendicular and forward distances to the whale at the time the animal was sighted was calculated as follows:

Where:

$$R_1 = ALT \bullet \tan(90 - \alpha)$$

and

$X = R\ x \sin(\beta)$

and

$$Y_1 = \sqrt{R_1^2 - X^2}$$

then

$$Y_2 = Y_1 + (V \bullet ET)$$

and

where:

R_1 = radial distance to sighting at time measurements were recorded;

α = declination angle to sighting;

ALT = altitude;

X = perpendicular distance to sighting;

β = angle from the head of the airplane to the sighting, corrected for aircraft drift angle;

Y_1 = distance ahead of the plane at the time measurements were recorded;

Y = distance ahead of the plane of the sighting at the time the sighting was made;

V = ground speed:

ET = time elapsed between making the sighting and recording the angle measurements;

R = radial distance to sighting at the time the sighting was made.

In cases where the declination measurement was taken abeam of the aircraft, the putative head angle of 90° was corrected for aircraft drift angle and sighting distances were calculated as above.

Duplicate identification

Candidate duplicate sightings between primary (rear) and the secondary (front) observer were initially identified through coincidence in the time and location of the sighting. Prospective duplicates were grouped into 2 certainty classifications: Class 1: Difference in sighting time 3 seconds or less, difference in radial distance to sighting 30% or less; Class 2: One or both of these criteria exceeded but still suspected to be a duplicate. For analytical purposes the angle measurements made by the primary observers were considered more reliable than those made by the secondary observer unless the observer indicated otherwise.

Abundance estimation

Data analyses were carried out using the DISTANCE 5.0 (Thomas *et al.* 2006) software packages and stratified cue counting methods (Hiby and Hammond 1989, Hiby *et al.* 1989, Buckland *et al.* 2001). The cue rate was assumed to be 53 cues per whale per hour, the same rate used in previous analyses (Hiby *et al.* 1989, Borchers *et al.* in press). No variance was available for this cue rate so the variance of the abundance estimates does not include this source of variation.

POST STRATIFICATION

Some areas received no coverage, so post stratification was required in blocks 5, 7 and 9 (Fig. 3). Abundance was estimated using both the original and post stratified blocks.

OBSERVERS

In addition to the analysis using unique sightings from all 3 observer positions, additional estimates were done using sightings from the primary (rear) observers and from one of the primary observers. In the latter case the sampling fraction was reduced by half.

MODEL SELECTION

A suitable truncation distance was chosen by visual inspection of the radial distance histograms.

Calculation of effective detection radius (*edr*) was pooled over geographical strata while encounter rate (*n/T*) was calculated separately for each stratum. There was no variation in cue-pod size (*s*) as no multiple simultaneous cues were seen.

A variety of models for the detection function *f(x)* were initially considered, and the final model was chosen by minimisation of Akaike's information criterion (AIC) (Buckland *et al.* 2005), goodness of fit statistics and visual inspection of model fits. Covariates were then considered for inclusion in the model to improve precision and accuracy. Covariates were assumed to affect the scale rather than the shape of the detection function, and were incorporated into the detection function through the scale parameter in the key function (Thomas *et al.* 2006). Covariates were retained only if the resultant AIC value was lower than that for the model without the covariate.

CALCULATION OF ABUNDANCE

The number of whales in each block was calculated as follows:

where

N_i = number of whales in block i;

n_i = number of cues detected in block i;

$h(0)$ = slope of the probability density function of detection distances, evaluated at distance 0;

A_i = area of block i;

$g(0)$ = probability of detecting cue at radial distance 0, assumed to be 1;

ϕ = sector angle scanned (180°);

T_i = effort (hrs) for block i;

ρ = cue rate, 53 cues per hour.

Bootstrap variances for N were calculated in DISTANCE, and the 2.5% and 97.5% percentiles of the bootstrap distribution of N were used to derive 95% confidence intervals (Buckland *et al.* 2001).

RESULTS

Coverage

An activity log of the survey is presented in Table 1. Of the 30 days the plane was available, at least some effort was flown on 20. Up to July 15 flying was mostly done off western and southern Iceland, as persistent northerly winds brought fog and/or high sea states to the north and east coasts. After July 15 we were finally able to cover the north and east parts of the survey area in acceptable conditions.

Unlike in previous years pack ice covered much of the northwestern part of the survey area, including the northern part of Block 3 and the western parts of Blocks 4 and 5. Pack ice coverage ranged from 0 to 90% in these areas. No whales were seen in the pack ice, although humpback and killer whales and dolphins were common along the ice margin.

Realized effort is shown in Fig. 3 and Table 2. Near complete coverage was achieved in Blocks 1, 2, 3, 6 and 8. Block 8 was covered twice. Blocks 4 and 9 received moderate coverage, while the offshore blocks 5 and 7 were covered less than adequately and required post-stratification. The northeast and southeast extremes of the survey area were not covered.

Total realized effort was 79% of planned effort. This does not include the double-coverage of Block 8, double coverage of some other transects and the extra effort in Reyðarfjörður and Eyjafjörður. This compares favourably to the 2001 (78%) and 1987 surveys, but is not as high as that achieved in 1995 (Pike *et al.* in press). Realized effort was higher than any other year when all effort is included. 95% of realized effort was flown at Beaufort sea state (BSS) 3 or less.

Attempts were made to fly the special fiord strata on several occasions, but these areas seem often to have high winds, even when it is not windy offshore. The Breiðafjörður lines were partially completed on 8 July and Reyðarfjörður was flown on 18 July. Three attempts were made to fly Eyjafjörður, without success, while the Ísafjörður transects were not attempted. We encountered no problems in flying the fjord areas and the designs seemed to be adequate.

Sea surface temperature

Sea surface temperature as recorded is mapped in Fig. 4. The recording unit functioned from 7 July on, so data from the early part of the survey are missing. Readings ranged between 4 and 14 C. Temperatures were coldest off eastern and northern Iceland, and warmest of southwestern Iceland. We found no way to validate these readings during the survey, but it may be possible to do so using measurements from other projects.

Sightings

Sightings are listed in Table 3 and their distributions are shown in Fig. 5. A total of 431 non-duplicate sightings were made by all observers.

Minke whales

A total of 70 non-duplicate sightings of minke whales were made by the primary and secondary observers. Of these 97% were of single animals, with single sightings of 2 and 3 animals. Minke whales were most common in blocks 1 and 2, with lesser numbers sighted in blocks 4 and 6. Minke whales were infrequently sighted in the offshore blocks.

A total of 71 cues were sighted by the primary and secondary observers at BSS 3 or less (Table 4). Of these 9 were cues sighted by both the secondary observer and the primary observer on the same side of the plane (*i.e.* duplicate cues) (Table 5). Four cues were sighted at higher BSS by the primary observers but none of these were duplicates. Observer P2 saw the most cues, observer P1 the fewest. Fig. 6 shows the spatial distribution of cue sightings by observer. Observer P1 appears to have a deficit of sightings within 200 m of the plane and in the area ahead of the plane. However this observer made 3 additional sightings of minke whales close to the plane that did not display a cue (not shown). Observer P2 has sightings distributed throughout the viewing field and some very close to the plane. Observer S1 lacks sightings within 200 m of the plane and in the area ahead of the plane.

Sightings made by the secondary observer and duplicated by the primary observers are shown in Table 5 and their spatial distribution is shown in Fig. 7. Unfortunately observer P1 sighted only 2 cues while on the right side of the plane, and neither of these were duplicates of sightings by the secondary observer. Observer P2 had all 9 duplicate sightings. The nearest secondary sighting that was not duplicated by the primary observers was at a radial distance of 369 m: 4 sightings within this distance were duplicated.

The error in the measurement of radial distance was assessed by comparing the distances measured by primary and secondary observers to duplicate sightings (Fig. 8). Including all duplicates, the error CV was 18%; including only class 1 duplicates, it was 9%. It appears that measurements made by P2 tended to be greater than those made by the secondary observer.

Humpback whales
Of the 58 non-duplicate sightings of humpback whales made, most were of single animals and the maximum group size was 4. Humpbacks were most frequently sighted to the NW of Iceland in blocks 2, 3, 4 and 5, and appeared to be strongly associated with the ice edge in some areas. Humpbacks were never sighted within the ice, however. A total of 60 non-duplicate humpback whale cues were sighted, which may make a cue counting analysis feasible.

Dolphins
By far the largest proportion of dolphin sightings was of white-beaked dolphins, although 3 sightings of white-sided dolphins and 1 of bottlenose dolphins were also reported. In addition, 16 sightings of unidentified dolphins were made. White-beaked dolphins were seen in groups ranging from 1 to 170 animals, but most commonly in group sizes of less than 10. White-beaked dolphins were seen in all blocks but were most common to the N and NE of Iceland.

Harbour porpoises
The harbour porpoise was the most frequently sighted cetacean in this survey. Most sightings were of single animals but sightings of pairs were also common. Harbour porpoises were seen in all strata but were most common in inshore areas and particularly off western Iceland. They were particularly common in Breiðafjörður (block 2A) but only one sighting was recorded in Reyðarfjörður, the other fiord stratum flown.

Other species
Large whales were not sighted frequently in the survey area. Only 7 groups of fin whales and 4 of sperm whales were sighted, in addition to 12 groups of unidentified large whales, which were mostly of distant blows. One very large mixed group of pilot whales and white-beaked dolphins (180 and 170 respectively) was sighted off SW Iceland. Killer whales were sighted infrequently in groups of 1 to 7 animals. Of interest was a sighting in block 8 of a group of 9 killer whales in 2 subgroups that were associated with a single minke whale. There was no visible evidence that the minke whale was being attacked by the killer whales, however.

Abundance estimation

Minke whales
A truncation distance of 1,200 meters was chosen, which resulted in a loss of about 10% of the sightings. Preliminary runs indicated that the half normal function performed best with these data. The following covariates were tested in the model: observer identity, glare intensity, cloud percent cover, side of plane and sightability. However the simple half normal model with a single cosine adjustment parameter resulted in the lowest AIC (Fig. 9).

Table 6 provides details of the abundance estimates for the original and post-stratified blocks. These estimates use data from both the primary and secondary observers, using the distance estimate of the primary observer if the sightings were duplicates. The total estimate for the original blocks is 10,680 (95% CI 5,873, 17,121). Post-stratification decreases this estimate by 12%. Using only data from the primary observers and the same model (which again had the lowest AIC) results in an estimate of 10,609 (95% CI 5,693, 17,658) (not shown). Using only data from observer P2 and the same model (lowest AIC) produces a somewhat higher estimate of 15,055 (95% CI 6,357, 27,278) (Table 7).

DISCUSSION AND CONCLUSIONS

Minke whales

Potential biases
Point transect models such as cue counting assume that all animals on the point, in this case directly under the plane, that are potentially visible are seen. Past experience shown that this is not always the case for minke whale surveys (Hiby *et al.* 1989, Borchers *et al.* in press) and that some observers do miss cues close to the plane. This can be

assessed and corrected using sight-resight methods as were employed in this survey. Unfortunately the low number of sightings, particularly by the secondary platform, precludes any meaningful statistical analysis of the data.

Observer P1 sighted fewer minke whale cues than P2 and unfortunately sighted only 2 of 17 cues while on the right side of the plane in double platform mode (Table 5). The observers switched sides every day and this fortuitously resulted in P1 being on the left side on days when high density areas were flown. In addition almost all cues seen by S1 in this configuration were rather far from the plane (Fig. 7). As P1 was a specialist harbour porpoise observer, this observer concentrated observing effort close to the plane and tended to miss distant sightings. Perhaps as a result of this P1 duplicated none of the 9 cue sightings made by S1 while in this configuration. Nevertheless the lack of duplicates is troubling and suggests that this observer's sighting pattern was not optimal for minke whales.

In contrast observer P2 duplicated 9 of 13 cues sighted by S1 while on the right side of the plane, and duplicated all cues (4) at a radial distance of less than 300 m from the plane (Table 5, Fig. 7). This observer sighted nearly twice as many cues as P1, including many sightings close to the plane (Fig. 6), suggesting that this observer was more effective for minke whales than P1.

Taken together, all cue sightings made by S1 at a radial distance of less than 300 m were duplicated by the primary observers. While this is evidence that *g(0)* may have approached 1, at least for observer P2, we actually have no evidence for observer P1 as no duplicate sightings were made by that observer. The fact that the abundance estimate using only data from observer P2 is 40% higher than the estimate using data from all observers (Table 7) suggests that *g(0)* may have been higher for this observer, but this must be interpreted with caution because the difference is not significant and the sample size is about half that recommended for a point count analysis (Buckland *et al.* 2001). Nevertheless further statistical analyses of the double platform data along the lines of Borchers *et al.* (in press) is unlikely to be productive because of the low sample size.

The second source of bias to be addressed results from the geometry of the area searched during cue counting. Because the area is semi-circular, the surface area of the search area increases as a squared function of the radial distance from the search platform. Because of this, random error in the measurement of radial distance results in a net transfer of sightings towards distance 0. Borchers *et al.* (in press.) developed maximum-likelihood estimators for distance sampling surveys in the presence of measurement. Conventional distance sampling estimators were found to be substantially biased by measurement errors when the coefficient of variation (CV) of measurement error is not small (greater than about 10%). The CV for the class 1 duplicate measurements of radial distance is 11% and for all duplicates 26%, which suggests that error in distance measurement may not be a serious problem for these data. However this is based on a very low sample size (5 class 1, 4 class 2 duplicates) and only for observers P2 and S1.

The cue rate of 53 cues per hour used here is based on work reported by Gunnlaugsson (1989) from the coastal areas of Iceland. However this estimate was based on limited data and may be biased to an unknown degree. No variance for cue rate was included in the abundance estimate, nor was this source of variance included in previous estimates (Hiby *et al*. 1989, Borchers *et al.* in press).

Distribution and abundance

It was obvious from the first flight of the survey that the distribution and abundance of minke whales had changed since the last full survey in 2001. This became even more apparent as the survey continued, as few whales were sighted in areas where they had previously been abundant, such as Faxafloi and block 8 in southeast Iceland. This perception is bourn out by the abundance estimates detailed in Table 6. The 2007 point estimate is 24% that from the 2001 survey. Abundance increased only in block 7, where it was 0 in 2001. In blocks 1, 4 and 8, which accounted for 52% of the estimate in 2001, abundance decreased by 77%, 66% and 98% respectively. Block 8 had the highest density of minke whales in the survey area in 2001; in 2007 only 1 minke whale was sighted in 2 nearly complete coverages of the block.

While abundance was much lower, the relative distribution of minke whales among strata was similar to that seen in previous surveys (Pike *et al.* in press), with highest density in inshore areas, particularly block 1. Of note however was the near total absence of minke whales from block 8 where they had been abundant in all previous surveys.

There are a number of possible reasons for the apparent changes in distribution and abundance since 2001, which may have acted separately or in concert.

CHANGES IN OBSERVER BIAS

The primary observers used in 2007 were not the same ones as were used in 2001 or any previous surveys. Nevertheless it seems very unlikely that observer bias was the sole or primary cause of the observed decrease in minke whale abundance. At least for observer P2, there is no evidence that cues close to the plane were missed. Observer S1 participated in both the 2001 and 2007 surveys. In 2001, S1 saw 71 cues in 49 hrs of effort, while in 2007 the same observer sighted 22 cues in 52 hrs of effort, a decrease in sighting rate of 71%. This decrease closely matches the decrease in estimated abundance over the period (76%). Therefore it seems unlikely that changes in observer bias were the primary cause of the decrease in estimated abundance.

CHANGE IN SURVEY ALTITUDE

The change in survey altitude to 600 ft from 750 ft in previous surveys would have resulted in a 44% reduction in the area searched if observers searched within the same declination angle. A concomitant decrease in the number of sightings (but not estimated density or abundance) might therefore be expected. As it happens this does not seem to be the case: *edr* was 9% lower in 2007 which means that the area searched was only 15% lower. The reduction in sighting rate from 2001 to 2007 (76%) far exceeds this.

CHANGE IN SPATIAL DISTRIBUTION

The areas that were not covered in this survey, the offshore NE and SE, had very low densities of minke whales in previous surveys (Pike *et al.* in press). Therefore it seems unlikely that a change in distribution within the survey area could have resulted in the observed decrease in abundance. However it is quite possible that minke whales that used to come to Icelandic waters in June and July were somewhere outside the survey area during the survey period. If so we might expect higher than usual densities of minke whales to be observed somewhere outside of Icelandic waters during the TNASS. Unfortunately the TNASS did not cover all possible habitats for minke whales in the North Atlantic. In addition, some parts of the North Atlantic, such as Canada, have not been surveyed previously, so it would be impossible to determine if density there has increased since 2001. Also, the Icelandic TNASS vessels have fin whales as a primary target species and often survey in weather conditions that are not conducive to sighting minke whales (Pike *et al.* in press). In recent years pronounced changes have occurred in oceanographic conditions and relative distribution and abundance of several species of fish (including sandeel (*Ammodytes* sp.) and capelin (*Mallotus villosus*)) and seabirds in Icelandic waters. Such changes would be expected to affect the distribution of minke whales for example through shifts in distribution of important prey species.

CHANGE IN TEMPORAL DISTRIBUTION

The 2007 survey was conducted in the same late June/July period as all previous Icelandic aerial surveys. If minke whales have changed their migration pattern such that they arrive later in or depart earlier from the survey area, a reduction in abundance in the survey area might be observed when there has been no reduction in population abundance. There is some limited evidence that minke whale density was increasing over the course of the survey, suggesting that the peak in seasonal abundance might have been missed. Block 1, which has 2 sets of transects covering the entire stratum (Fig. 1), was surveyed on 5 and 12 July, resulting in 6 and 15 cues sightings respectively. This equates to an increase in sighting rate of 139% in about 1 week. Furthermore, the western part of Block 4 was surveyed on 23/24 June and only 2 minke whales were sighted. The central and eastern parts of the block were surveyed later in July and more minke whales were sighted in this part of the block (Fig. 4). While this could have been due to spatial variation within the block, it does suggest that density may have increased over the period. Therefore there is some evidence that minke whale density may have been increasing over the course of the survey. However the survey was not designed to detect temporal trends within the period, so this remains somewhat speculative.

POPULATION DECREASE

There remains the possibility that the minke whale population utilizing the area may have undergone a rather drastic reduction since 2001. While there has been some hunting of minke whales in the area since 2003, this has been at a very low level (a total of 207 in 5 years) and certainly could not account for the observed decrease. Given the magnitude of the observed decrease and the increased mortality that would have been required to affect it, some indication of increased mortality might have been expected, for example a dramatic increase in dead strandings. This has not been observed. Nevertheless it remains possible that an actual decrease has occurred in the area, accounting for some portion of the observed decrease.

In conclusion the cause of the apparent decline in common minke whale numbers cannot be determined without additional research. It does however seem certain that the decrease in abundance in the survey area is real and not an artefact caused by changes in observers and/or survey methodology. It is likely that changes in the seasonal abundance of minke whales in the area may have contributed to the apparent decline. Shifts in distribution and abundance of important prey species in the area might be a contributing factor. Future research should be conducted to determine when the peak of minke whale abundance is occurring in the area, perhaps by surveying a small, high density area such as Faxaflói at intervals throughout the spring, summer and fall. In addition the results of the

TNASS survey as a whole should be examined closely to determine if there are any indications of increased densities in nearby areas surveyed by vessels or that minke whales were moving in to the area over the course of the survey. Fortuitously, scientific whaling has been conducted in the area since 2003. Information from this program should be examined to determine if there are any indications of a population in decline, such as poor body condition, low pregnancy rate or perhaps a sudden shift in diet.

Survey evaluation

While this survey is the fifth of a series that began in 1986, it incorporated some objectives and methods that were not used in previous surveys (NAMMCO 2007). To facilitate planning of future surveys it is of interest to determine if these measures were successful.

1. Measures to increase survey effectiveness for harbour porpoises.
   - i. Decrease in survey altitude to 600 ft. This appeared to be successful, in that no problems were encountered in surveying at this altitude, and a large number of harbour porpoise sightings were recorded. The altitude decrease did not seem to detract from the efficiency of the survey for minke whales, in that the effective search area decreased by only 15% compared with 2001.
   - ii. Secondary fiord strata. These strata (Fig. 2) were added because it was suspected that harbour porpoises might be especially abundant within fiords. They were to be flown on an opportunistic basis, when weather conditions were unsuitable for surveying in other areas. Of the 4 secondary strata designed, only Breiðafjörður (block 2A) and Reyðarfjörður were flown successfully. Winds within the fiords were often stronger than outside, which prevented our completion of the Eyjafjörður stratum. In the limited effort that was completed, it did not appear that harbour porpoises were especially abundant in the fiords. Only one sighting was made in Reyðarfjörður and none in Eyjafjörður. In contrast 11 sightings were made on the additional Breiðafjörður transects so this is likely a high density area for the species. The extra Breiðafjörður effort was incorporated into the survey through post stratification of block 2. No operational difficulties were encountered in flying the sometimes very short fiord transects. Generally this was considered to be a worthwhile addition to the survey.
   - iii. Specialized harbour porpoise observer. Observer P1 had participated in the SCANS II and German North Sea porpoise surveys and was very experienced with this species. Observer P1 recorded 78 sightings of harbour porpoise compared to 38 for observer P2. The total number of harbour porpoise sightings was far greater than in any previous survey. It also seemed that observer P2 increased in effectiveness for this species in response to the large number of sightings made by P1. Therefore this measure should be considered a resounding success.
   - iiii. Use of cue counting for harbour porpoises. The intention here was to try cue counting with the dive as a cue, as for minke whales. This was less successful than anticipated. Of the 78 porpoise sightings made by P1, only 17 displayed a definite cue. Many of the animals were recorded as resting on the surface, milling or underwater. It therefore seems that cue counting may not be viable method for this species.
2. Data entry and observer monitoring during the survey. It has proven difficult in previous surveys to monitor the observers by displaying and graphing their sighting data during the survey. This is important in order to correct problems with observers as they occur. For this survey an assistant was available to enter data. This was successful and was invaluable for providing feedback to the observers. However, the number of minke whale sightings was too few to provide any meaningful feedback during the survey, as a preponderance of sightings were made late in the survey. Also, most of the humpback whale sightings made by P2 were made in a single flight. Some problems were evident in the resulting data and the observer was alerted to this, but made few humpback whale sightings afterwards.
3. Protocol modifications. The previous protocol emphasized taking declination and head angles while the cue was in front of the airplane. The modified protocol placed a greater emphasis on collecting the declination when the sighting cam abeam. This appeared to function very well and should be continued. For harbour porpoises, this is the only feasible method, as sighting distances are typically so short that the sighting comes abeam very quickly
4. Confirming dolphin school size estimates. The intention was to close on a subsample of dolphin schools to get a confirmed school size and potentially to provide a correction for the school size estimated in passing mode. This proved to be too time consuming and was not carried out. It should be done if dolphins become a higher priority for future surveys.
5. Large school protocol. Given that large schools of large and small cetaceans are sometimes encountered, it was considered advisable to develop a protocol to collect the most accurate counts possible for such

occurrences. This was done and put into practice on one occasion when a very large mixed group of pilot whales and white-beaked dolphins was sighted. The protocol involved closing on the school and overflying it along its longest axis twice, with observers counting all animals in sight on both overflights. The protocol functioned adequately and was valuable because it enabled the cruise leader to provide clear and unambiguous instructions to the pilot and observers. Even though such situations are rare in the survey area, such a protocol should be maintained in future surveys.

6. Use of Sea Surface Temperature sensor. This device was not functional until 7 July, about half way through the survey, due to a software issue. Eventually a new software program had to be written by an Icelandic technician. After that the sensor worked flawlessly and required little attention from the operator. The data certainly shows contrast in SST throughout the survey area, but we were unable to 'ground-truth' the instrument by overflying areas of known surface temperature. It may be possible to do this *post facto* if there were recording instruments in the survey area. These data are potentially valuable for spatial modelling of abundance, but the incompleteness of the dataset may preclude its use for this.

Other problems encountered

SECONDARY PLATFORM

The secondary platform is inadequate in that it does not have a bubble window and does not allow a good view of the trackline. Consideration should be given to alternate methods of determining *g(0)* (see below).

ACCOMMODATIONS

We encountered great difficulty in finding accommodations, particularly in Akureyri and Egilsstathir. The survey is conducted during the high tourist season, and it is usually not possible to know where the plane will be landing more than one day in advance due to constantly changing weather conditions. This created difficulties for the crew on a few occasions and is an irritant that is not needed.

Recommendations

1. The seasonal distribution of common minke whales in Icelandic waters should be further investigated, perhaps by a series of small scale surveys in a high density area.
2. Survey altitude should be chosen with regard to the target species. If harbour porpoises are a target, survey altitude should be maintained at 600 ft.
3. The secondary fiord strata should be further developed and flown on an opportunistic basis.
4. The protocol modifications emphasizing the collection of abeam declinations should be maintained.
5. The Large School Protocol should be further developed and maintained.
6. The SST sensor is inexpensive, compact, trouble free in operation and potentially provides valuable data for spatial modelling. It should be used in future surveys. However, a way of ground truthing the temperature measurements should be found.
7. A reliable way of finding accommodations in the towns used as bases in Iceland (Isifjorthur, Akureyri, Egilsstaðir, Hofn) at short notice should be found.
8. The use of high definition video as a secondary platform should be investigated. I had the opportunity to use such a system in Antarctica in 2008, and was very impressed by the image quality and our ability to sight Antarctic minke whales on the video. This seems to be far easier than with still photos. Available systems are compact and relatively inexpensive. A single camera could be pointed straight down, or 2 cameras pointed slightly to the side could be used to widen the area covered. Used as a secondary platform, a video system would be independent, provide a clear and unobstructed view of the transect and point, and provide a permanent record that could be reviewed at any time. It would also provide additional information on sea state and ice conditions. If such a system were in use, the flight leader could enter data in flight, as is done in SCANS, American and Canadian aerial surveys.

REFERENCES

Borchers, D.L., Pike, D.G., Gunnlaugsson, Th. and Vikingsson, G.A. In press. Minke whale abundance estimation from the NASS 1987 and 2001 aerial surveys using cue counting with distance estimation errors. *NAMMCO Sci. Publ.* 7:xxx-xxx.

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, New York, 432 pp.

Donovan, G.P and Gunnlaugsson, Th. 1989. North Atlantic Sightings Survey 1987: Report of the aerial survey off Iceland. *Rep. int. Whal. Commn* 39:437-41.

Franke, R., and Nielson, G. 1980. Smooth Interpolation of Large Sets of Scattered Data, *International Journal for Numerical Methods in Engineering*, v. 15, p. 1691-1704.

Gunnlaugsson, Th. 1989. Report on Icelandic minke whale surfacing rate experiments in 1987. *Rep. int. Whal. Commn* 39:435-436.

Heide-Jørgensen, M.P., Borchers, D.L., Witting, L., Simon, M.J., Laidre, K.L., Rosing-Asvid, A. and Pike, D.G. 2006. Summary of an aerial survey of large whales in West Greenland in 2005. SC/58/AWMP7 for the IWC Scientific Committee.

Hiby, A.R. and Hammond, P.S. 1989. Survey techniques for estimating current abundance and monitoring trends in abundance of cetaceans. *Rep. Int. Whal. Commn* (Special issue 11):47-80.

Hiby, L., Ward, A. and Lovell, P. 1989. Analysis of the North Atlantic Sightings Survey 1987: Aerial survey results. *Rep. int. Whal. Commn* 39:447-455.

Larsen, F., Martin, A.R.and Nielsen, P.B. 1989. North Atlantic sightings survey 1987: Report of the West Greenland aerial survey. *Rep. int. Whal. Commn* 40: 443-446.

Larsen, F.1995. Abundance of minke and fin whales off West Greenland, 1993. *Rep. int. Whal. Commn* 45: 365-370.

[NAMMCO] North Atlantic Marine Mammal Commission. 2007 Report of the NAMMCO Scientific Working Group on Planning the Trans North Atlantic Sightings Survey, St Andrews, March 30 – April 1, 2007.

Pike, D.G., Gunnlaugsson, Th., Víkingsson, G.A., Desportes, G. and Bloch, D. In press. Estimates of the abundance of minke whales (Balaenoptera acutorostrata) from Faroese and Icelandic NASS shipboard surveys. *NAMMCO Sci. Publ.* 7:xxx-xxx.

Pike, D.G., Paxton, C.G.M., Gunnlaugsson, Th. and Víkingsson, G.A. In press. . Distribution and abundance of cetaceans from Icelandic aerial surveys, 1986-2001. *NAMMCO Sci. Publ.* 7:xxx-xxx.

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., Bishop, J.R.B. and Marques, T.A. 2006. Distance 5.0. Release 21. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

DATE	ACTIVITY	Start	End
18 Jun	Arrived in Iceland		
19-20 Jun	Ground training, set up plane		
21 Jun	First training flight.	Reykjavik	Reykjavik
22 Jun	Second training flight.	Reykjavik	Reykjavik
23 Jun	Northern Blk 3, Western Blk 4	Reykjavik	Ísafjörður
24 Jun	Parts of Blks 4 and 5.	Ísafjörður	Akureyri
25 Jun	Blk 8	Akureyri	Egilsstadir
26-27 Jun	Weathered out.	Egilsstadir	Hornafjorthur
28 Jun	Parts of Blks 8 and 9.	Hornafjorthur	Reykjavik
29 Jun	Parts of Blks 2 and 3.	Reykjavik	Reykjavik
30 Jun	Blk 2	Reykjavik	Reykjavik
1 July	Parts of Blks 2, 4 and 5.	Reykjavik	Akureyri
2 July	Weathered out, ferried to Reykjavik.	Reykjavik	Akureyri
3-4 July	Weathered out, plane maintenance.		
5 July	Blk 1, first transect series.	Reykjavik	Reykjavik
6 July	Weathered out.		
7 July	Parts of Blks 9 and 3.	Reykjavik	Reykjavik
8 July	Breiðafjörður, extra transects.	Reykjavik	Reykjavik
9 July	Blk 9	Reykjavik	Hornafjorthur
10 July	Blk 8, second coverage	Hornafjorthur	Hornafjorthur
11 July	Parts of Blk 9	Hornafjorthur	Reykjavik
12 July	Blk 1, second transect series.	Reykjavik	Reykjavik
13-14 July	Weathered out.		
15 July	Parts of Blk 4	Reykjavik	Egilsstadir
16 July	Blk 6	Egilsstadir	Egilsstadir
17 July	Blks 6 and 7	Egilsstadir	Egilsstadir
18 July	Blks 6 and 7	Egilsstadir	Egilsstadir
19 July	Blks 7, 4 and 5	Egilsstadir	Akureyri
20 July	Blks 4 and 5	Akureyri	Reykjavik

Table 1. Activity log of 2007 Icelandic aerial survey.

		PLANNED		NON-DUPLICATE		ALL	
BLOCK	**AREA**	***K***	***L***	***L***	***D***	***L***	***D***
1	4,418	16	776	787	7.83	828	8.23
2A	1,780	9		308	3.07	344	3.48
2B	2,208	9		231	2.30	231	2.30
2	3,988	18	417	538	5.37	575	5.77
3	14,066	11	778	714	7.11	714	7.11
4	12,392	22	1257	897	8.82	924	9.11
5	10,782	11	652	395	3.87	395	3.87
5P	6,008	11		395	3.87	395	3.87
6	3,602	15	383	361	3.56	413	4.09
7	14,384	7	740	356	3.48	356	3.48
7P	10,064	7		356	3.48	356	3.48
8	3,728	15	338	285	2.74	459	4.46
9	18,186	16	1106	773	7.61	766	7.61
9P	14,204	9		773	7.61	766	7.61
EYA	133	15	69	34	0.35	34	0.35
ISI	999	16	244	0	0.00	0	0.00
REY	38	4	19	20	0.19	20	0.19
TOTAL	**85,546**	**131**	**6447**	**5,107**	**50.39**	**5,430**	**53.72**
TOTAL-P	**72,470**			**5,107**	**50.39**	**5,430**	**53.72**
TOTAL-F	**1,170**	**35**	**332**	**54**	**0.53**	**54**	**0.53**

Table 2. Planned and realized effort for the 2007 Icelandic aerial survey. Non-duplicate effort excludes repeat effort on some transects. P refers to post-stratified blocks, and F to extra effort in fiords (see Fig. 2). *L*- effort (nm); *D* – effort (hrs); AREA (nm^2).

BLOCK	BA	BP	D?	GM	LA	LL	MN	OO	PM	PP	TT	HA?	ULW	USW	UBW	UW
1	26	1	0	0	5	0	1	1	0	9	0		1	1		1
2A	7	0	1	0	2	0	1	1	0	23	0		2	0		
2B	5	0	4	0	5	0	7	0	0	7	0		1	0		
3	1	0	1	0	11	0	15	3	0	14	0		1	2		2
4	12	1	2	0	27	1	11	1	3	14	1		2	0		
5	2	0	6	0	24	2	21	3	0	6	0		2	1		
6	10	0	0	0	12	0	0	0	0	11	0		0	2		
7	3	0	0	0	1	0	0	0	0	1	0		1	1		
8	1	0	0	0	8	0	2	0	0	9	0		0	0		
9	3	5	2	9	7	0	0	2	1	24	0	1	2	1	3	1
EYA	0	0	0	0	3	0	0	0	0	0	0		0			
REY	0	0	0	0	0	0	0	0	0	1	0		0			
TOTAL	**70**	**7**	**16**	**9**	**105**	**3**	**58**	**11**	**4**	**119**	**1**	**1**	**12**	**8**	**3**	**4**
MIN	1	1	1	1	1	3	1	1	1	1	2	1	1	1	1	1
MAX	3	6	10	180	170	17	4	7	1	5	2	1	1	2	4	1
MEAN	1.04	2.33	5.00	31.67	7.33	9.00	1.44	3.36	1.00	1.45	2.00	1.00	1.00	1.33	2.67	1.00
S.D.	0.27	1.97	3.21	72.68	17.41	7.21	0.71	2.42	0.00	0.76	.	.	0.00	0.52	1.53	0.00

Table 3. Non-duplicate sightings of cetacean groups by all observers. Designations include both certain and uncertain species identifications. Minimum, maximum, mean and standard deviation of the mean group sizes are also shown. BA – minke whale; BP – fin whale; D? – dolphin, unkown; GM – short finned pilot whale; LA – whitebeaked dolphin; LL – whitesided dolphin; MN – humpback whale; OO – killer whale; PM – sperm whale; TT – bottlenose dolphin; HA – northern bottlenose whale; UL – large whale unknown; US – small whale unknown; UB – beaked whale unknown; UW – whale unknown.

BLOCK	DURATION (hrs)	DISTANCE (nm)	P1	P2	S1	TOTAL
1	7.71	772	10	11	8	29
2A	3.32	329	0	2	2	4
2B	2.18	219	0	2	5	7
3	6.98	701	0	1	0	1
4	8.53	863	7	3	4	14
5	3.76	384	0	1	1	2
6	3.87	391	0	7	1	8
7	3.27	335	0	3	0	3
8	4.33	445	0	1	0	1
9	7.20	734	0	1	1	2
EYA	0.35	34	0	0	0	0
REY	0.19	20	0	0	0	0
TOTAL	**51.68**	**5,227**	**17**	**32**	**22**	**71**

Table 4. Survey effort and sightings of minke whale cues by primary (P) and secondary (S) observers at BSS 3 or less.

	S1
with P1	9
dup P1	0
with P2	13
dup P2	9
with P1 & P2	9

Table 5. Sightings of minke whale cues by the secondary observer with each of the primary observers, and numbers of sightings that were duplicated by that observer.

BLOCK	*edr* (m)		*h(0)*		*n*	*n/T*		*D*	*N*		CI L	CI U	N_{2001}	CI L	CI U
1					23	2.0913	(0.26)	0.4023	1,778	(0.38)	717	3,352	7,678	4,984	11,830
2A					3	0.8767	(0.52)	0.1669	297	(0.59)	0	690			
2B					4	1.7435	(0.66)	0.3206	707	(0.69)	0	1,869			
2					7			0.2582	1,030	(0.55)	342	3,097	1,728	631	4,730
3					0								4,887	2,343	10,195
4					10	1.0968	(0.42)	0.2034	2,520	(0.42)	802	4,910	7,500	4,641	12,120
5	464.15	(0.10)	9.27E-05	(0.26)	2	0.5209	(0.96)	0.0985	1,062	(1.02)	0	3,433	3,623	1,436	9,157
5P					2	0.5498	(0.92)	0.0923	554	(1.03)	0	1,913			
6					8	2.0073	(0.39)	0.3785	1,363	(0.44)	330	2,748	5,562	2,955	10,467
7					3	0.8443	(0.39)	0.1620	2330	(0.46)	594	4744	0	0	0
7P					3	0.8447	(0.39)	0.1672	1682	(0.47)	385	3330			
8					1	0.2311	(0.98)	0.0466	174	(1.13)	0	672	7,292	3,202	16,607
9					1	0.1342	(0.95)	0.0246	447	(0.97)	0	1,556	5,360	1,907	15,065
9P					1	0.1273	(0.95)	0.0235	334	(1)	0	1,111			
TOTALP					**55**			**0.1290**	**9,349**	**(0.28)**	**5,202**	**15,280**			
TOTAL					**55**			**0.1249**	**10,680**	**(0.27)**	**5,873**	**17,121**	**43,633**	**30,148**	**63,149**

Table 6. Abundance of minke whales from the NASS-2007 Icelandic aerial survey. *edr* - effective detection radius (m), *h(0)* – slope of the detection function at radial distance 0; *n/T* - encounter rate, cues per hr; *D* - density, whales/nm^2, *N* - abundance estimate, CI - bootstrap 95% confidence interval. Coefficients of variation are in parentheses. The estimate from 2001 (N_{2001}) (Borchers *et al.* in press) is shown for comparison.

BLOCK	***edr*** (m)		***h(0)***		***n***	***n/T***		***D***	***N***		**CI** L	**CI** U	***N2001***	**CI** L	**CI** U
1					11	1.0120	(0.31)	0.4903	2,166	(0.46)	659	4,529	7,678	4,984	11,830
2A					1	0.2960	(1.02)	0.1499	267	(1.22)	0	1,004			
2B					2	0.8832	(0.64)	0.4134	913	(0.69)	0	2,314			
2					7		(0)	0.2902	1,157	(0.61)	0	2,838	1,728	631	4,730
3					0								4,887	2,343	10,195
4					2	0.2154	(0.67)	0.1058	1,311	(0.78)	0	3,917	7,500	4,641	12,120
5	416.58	0.12	1.17E-05	0.31	1	0.2579	(0.98)	0.1186	1,278	(0.99)	0	4,182	3,623	1,436	9,157
5P					1	0.2692	(0.98)	0.1243	747	(1.05)	0	2,488			
6					7	1.6500	(0.46)	0.7754	2,793	(0.51)	456	5,884	5,562	2,955	10,467
7					3	0.8447	(0.37)	0.4088	5880	(0.49)	1449	12119	0	0	0
7P					3	0.8661	(0.35)	0.4189	4215	(0.47)	1096	8487			
8					1	0.2345	(0.99)	0.1197	446	(1.12)	0	1,831	7,292	3,202	16,607
9					0								5,360	1,907	15,065
9P					0										
TOTALP					**28**			**0.1807**	**13,091**	(0.33)	**5,792**	**23,035**			
TOTAL					**28**			**0.1760**	**15,055**	(0.36)	**6,357**	**27,278**	43,633	30,148	63,149

Table 7. Abundance of minke whales from the NASS-2007 Icelandic aerial survey, using sightings by observer P2 only. See Table 6 for variable definitions.

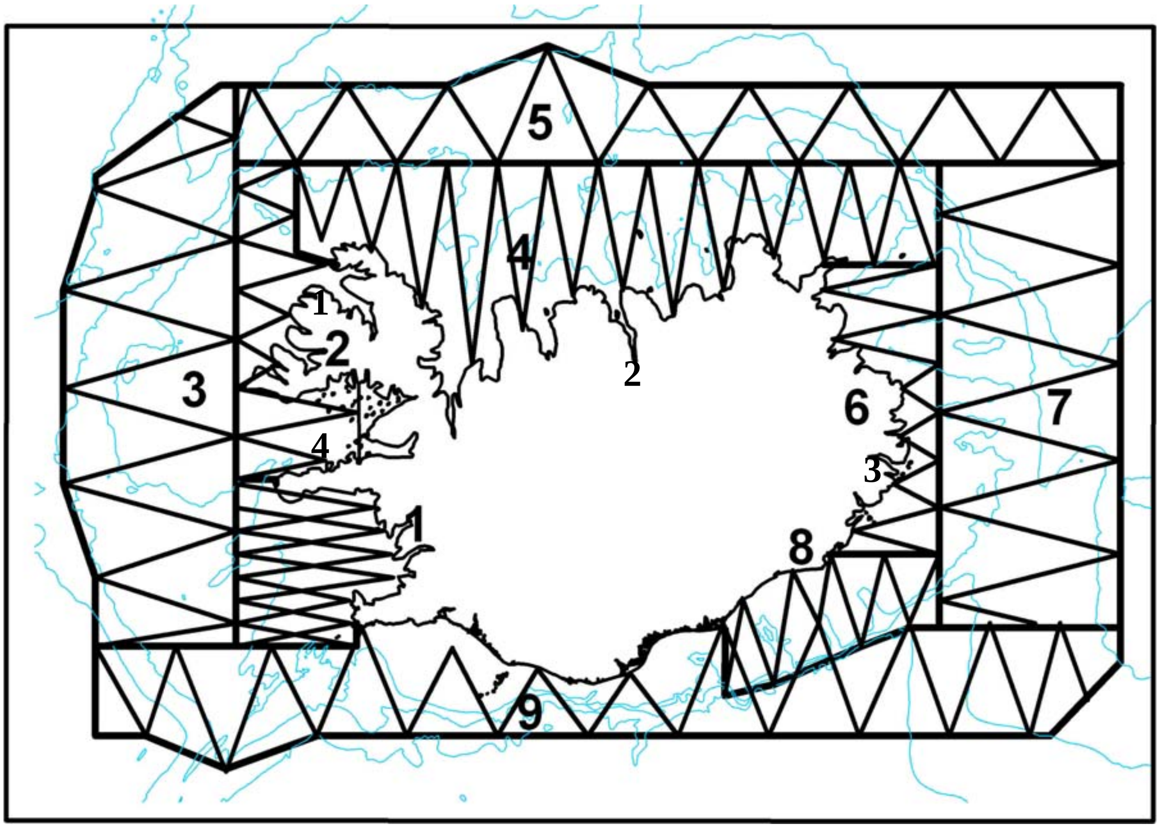


Fig. 1. Icelandic aerial survey, planned effort. Large numbers are block numbers, and smaller numbers show locations of fiords where extra effort was planned (See Fig. 2). 1. Ísafjörður; 2. Eyjafjörður; 3. Reyðarfjörður; 4. Breiðafjörður.

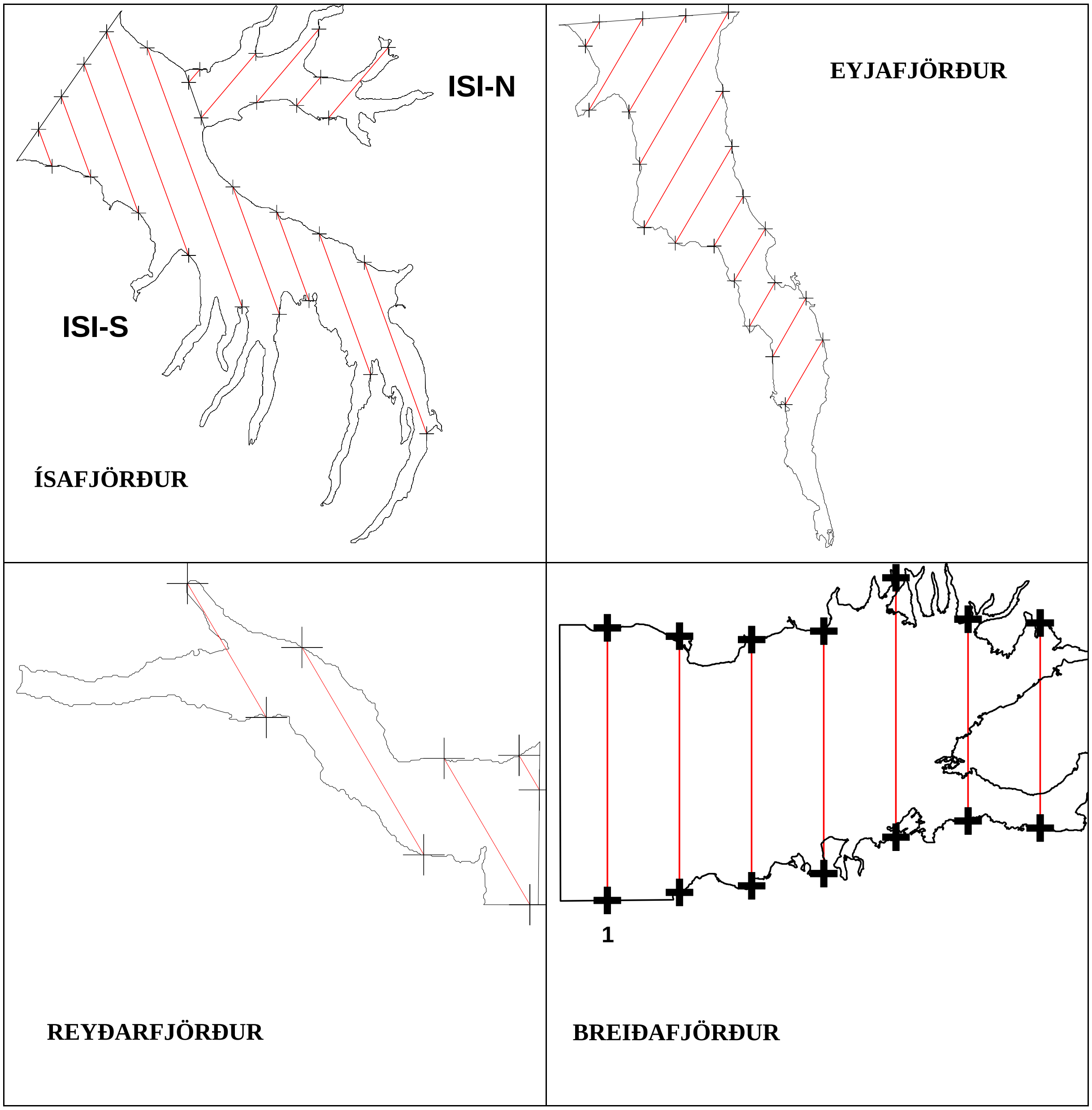


Fig. 2. Transect designs for 4 Icelandic fiords.

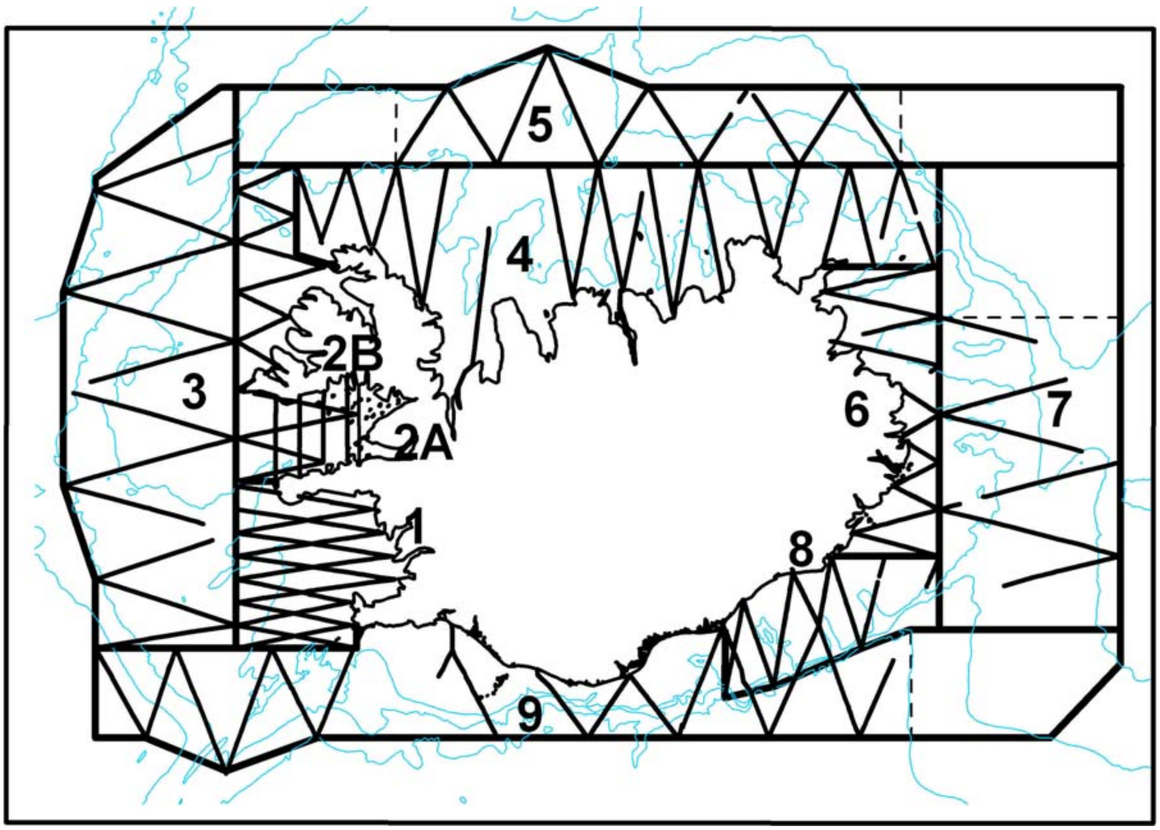


Fig. 3. Realized effort , 2007 Icelandic aerial survey. Dashed lines show boundaries of post-stratified blocks 2, 5, 7 and 9. Isobaths shown are 1000 m, 500 m and 200 m.

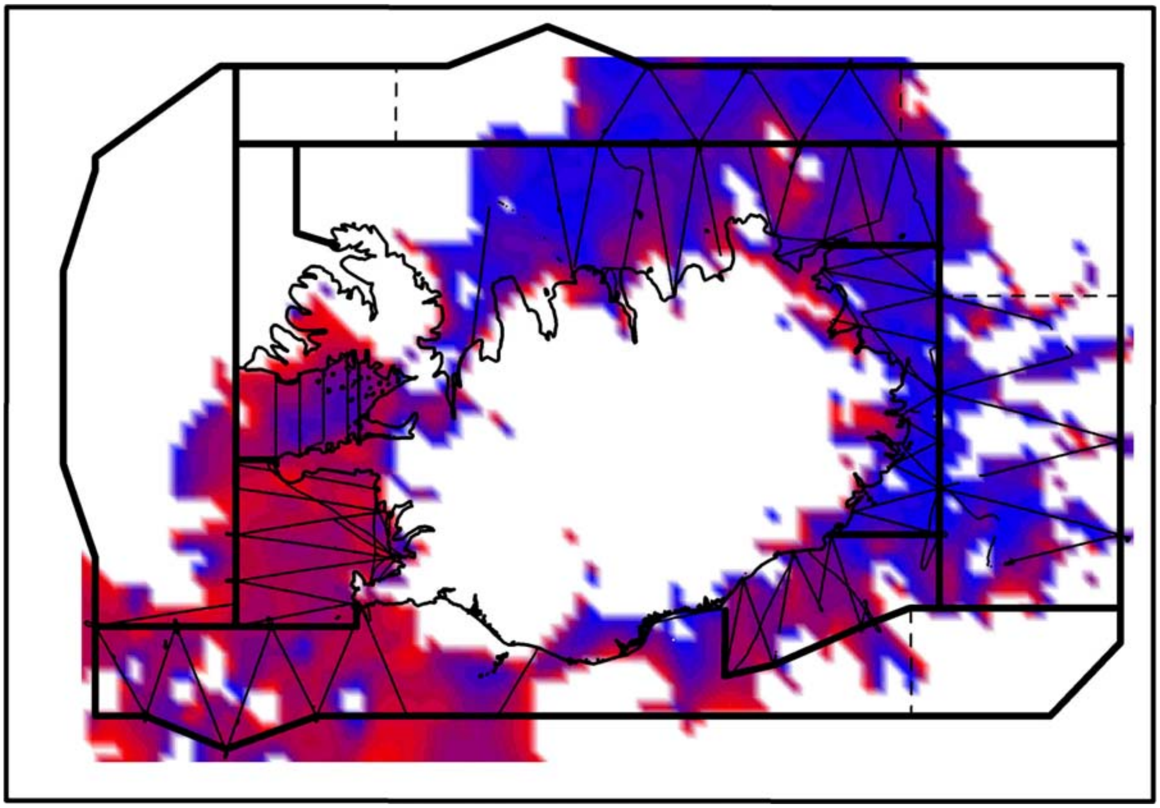
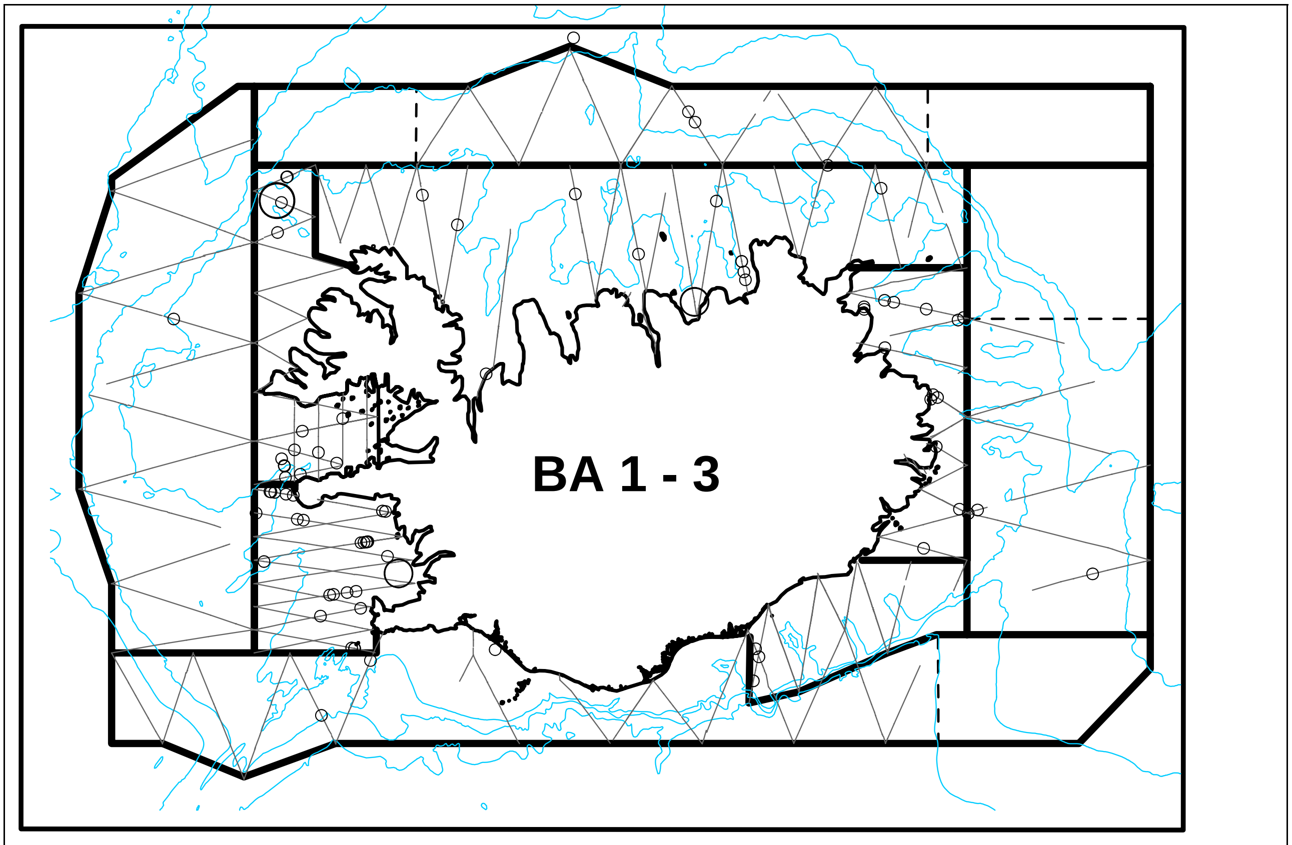
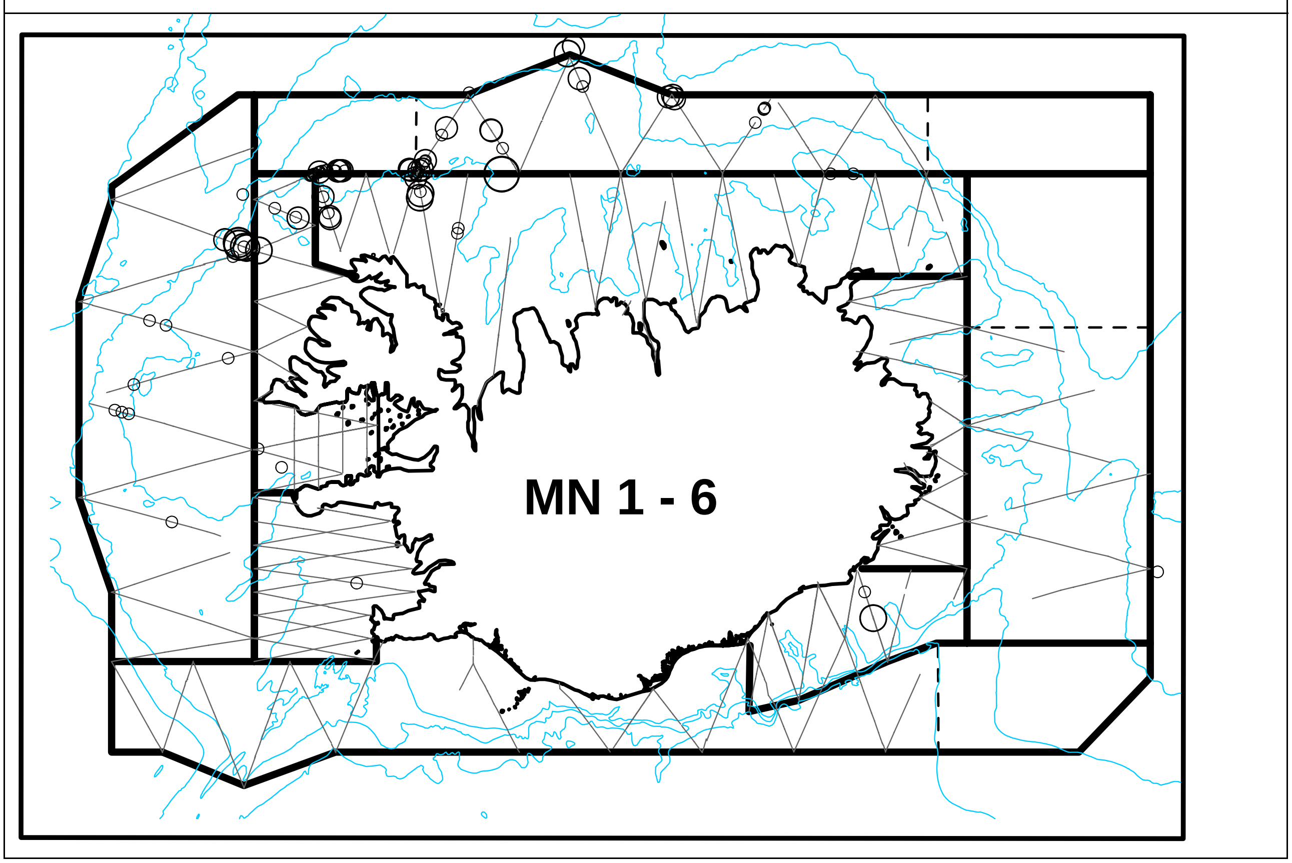
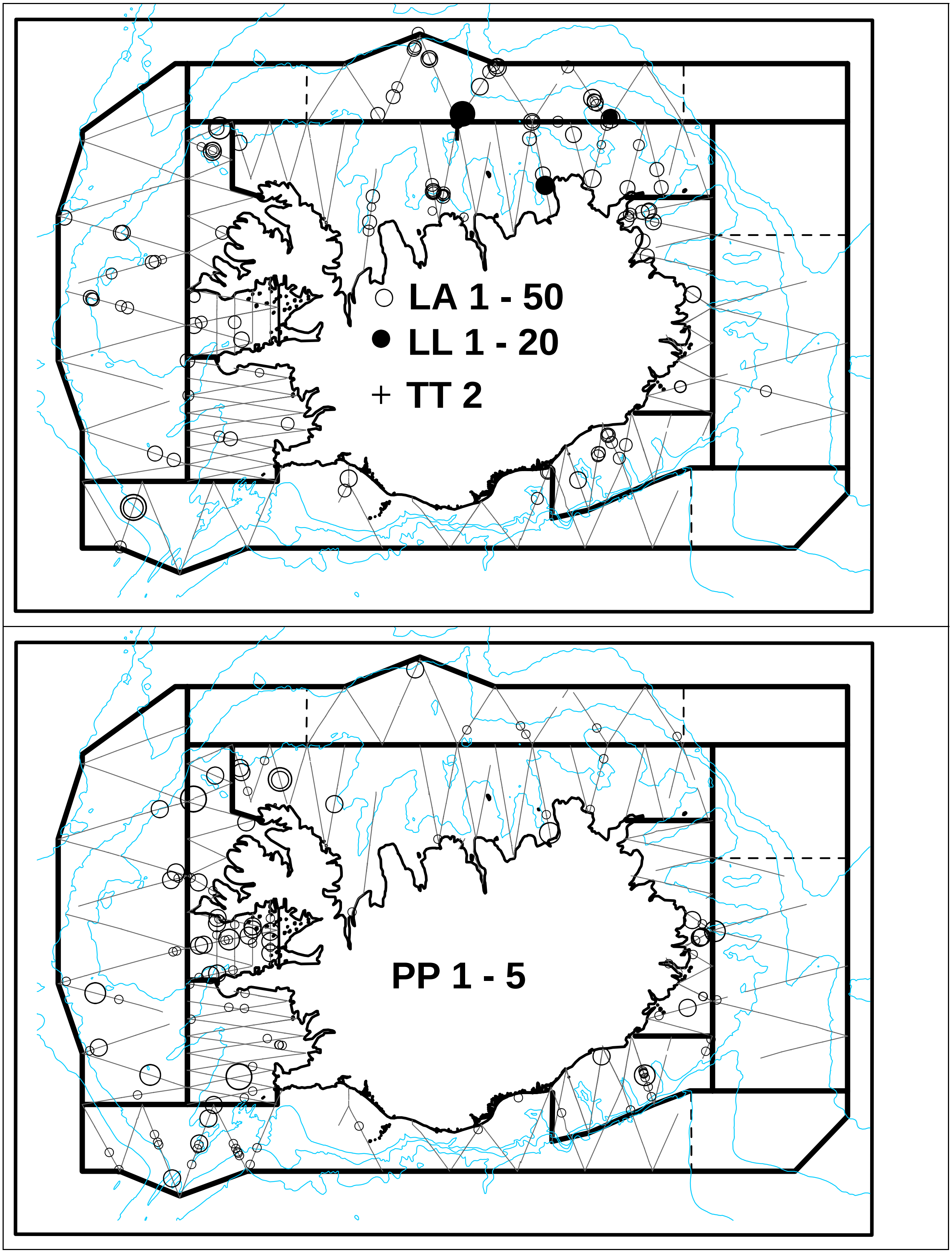
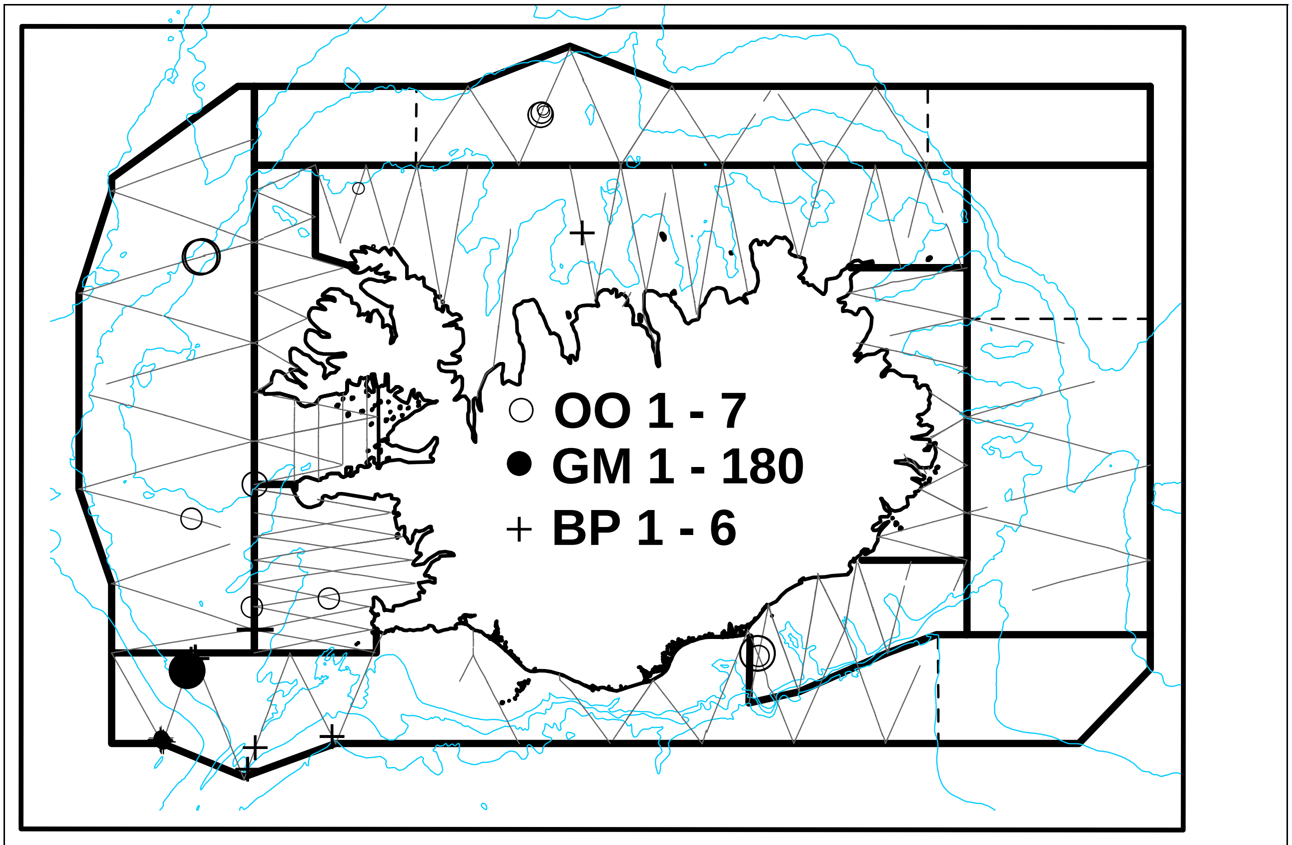


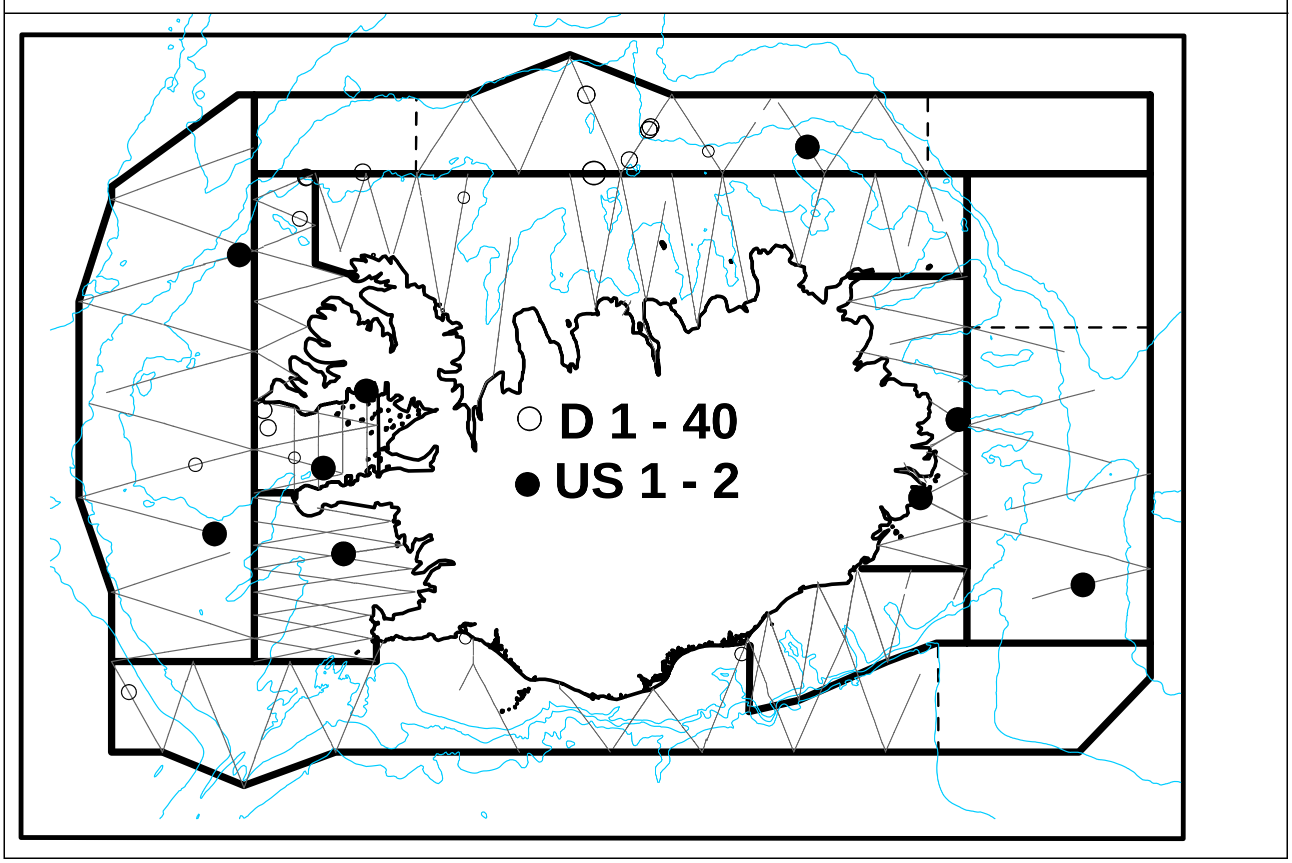
Fig. 4. Sea surface temperature recorded between 7-20 July 2007 along the flight paths shown in black. Temperature ranged from 4 to 14 degrees C and is interpolated using Modified Shepard's Method (Frank and Nielson 1980) using a colour gradient from blue (coldest) to red (warmest)


BA 1 - 3


MN 1 - 6


LA 1 - 50
LL 1 - 20
TT 2
PP 1 - 5


OO 1 - 7
GM 1 - 180
BP 1 - 6


D 1 - 40
US 1 - 2

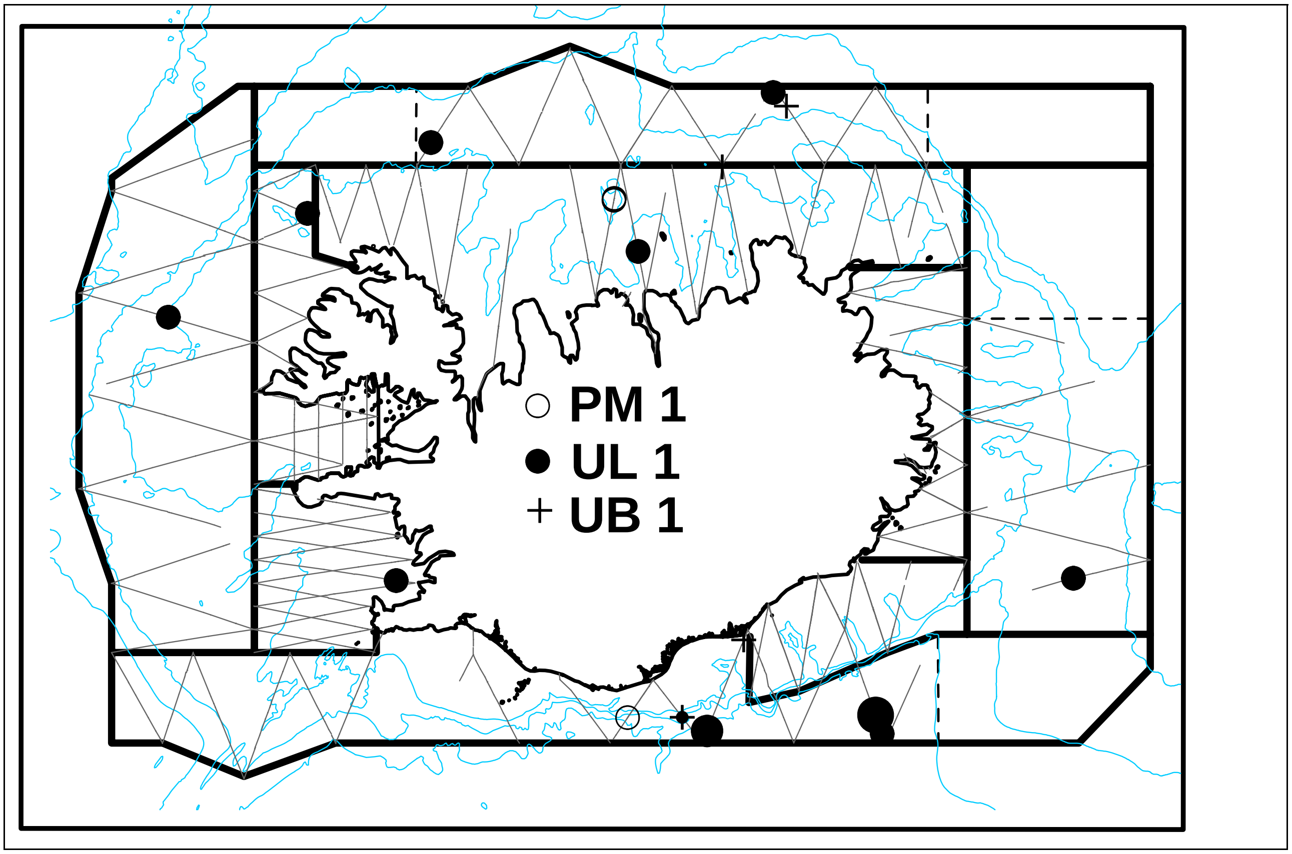


Fig. 5. On and off effort sightings of cetacean groups. Symbol size is proportional to the range of group sizes listed for each species. BA – minke whale; MN – humpback whale; LA – white-beaked dolphin; LL – white-sided dolphin; TT – bottlenosed dolphin; PP – harbour porpoise; OO – killer whale; GM – long-finned pilot whale; BP – fin whale; PM – sperm whale; D – dolphin, unknown species; US – unknown small whale; UL – unknown large whale; UB – unknown beaked whale.

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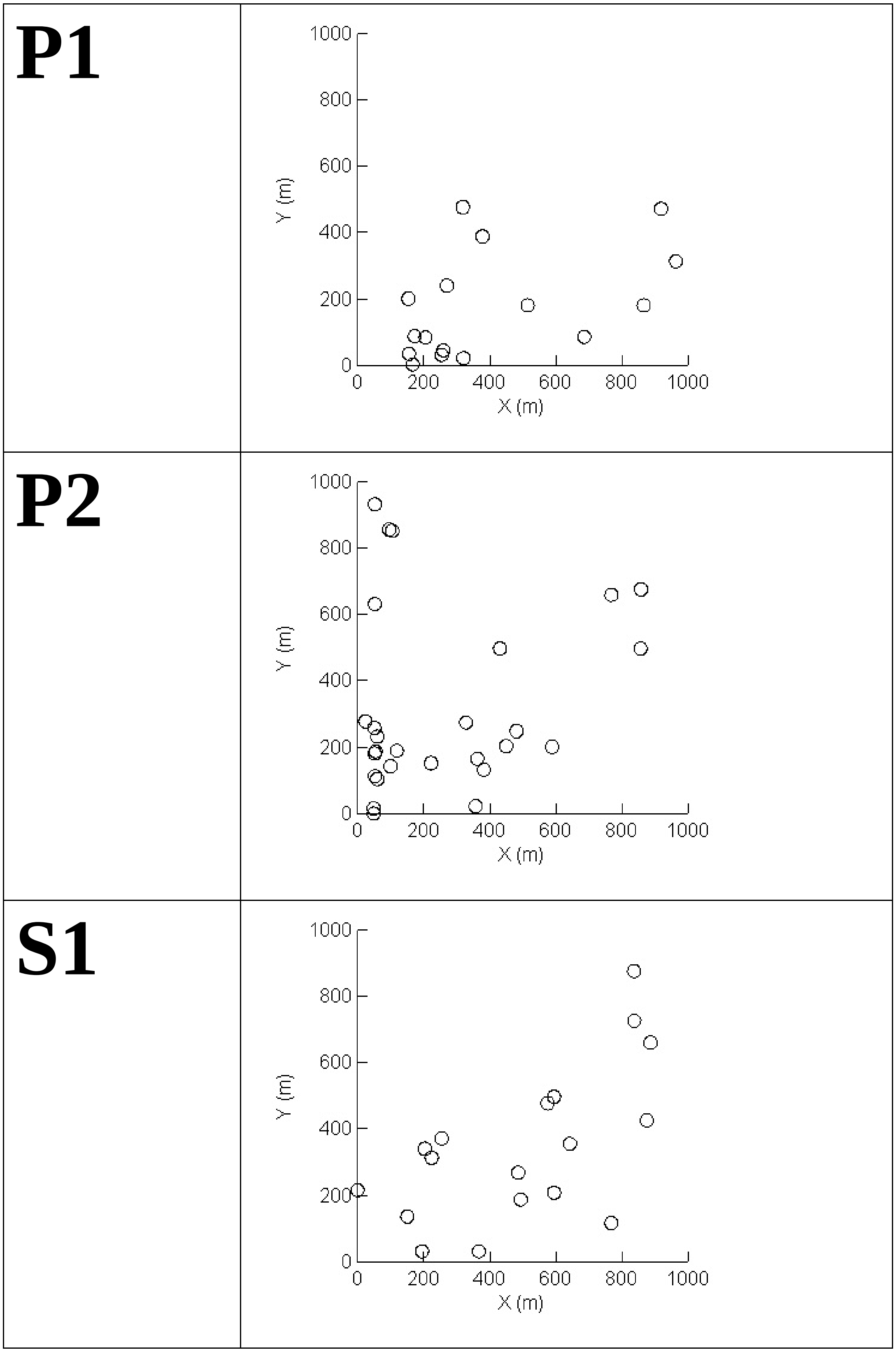
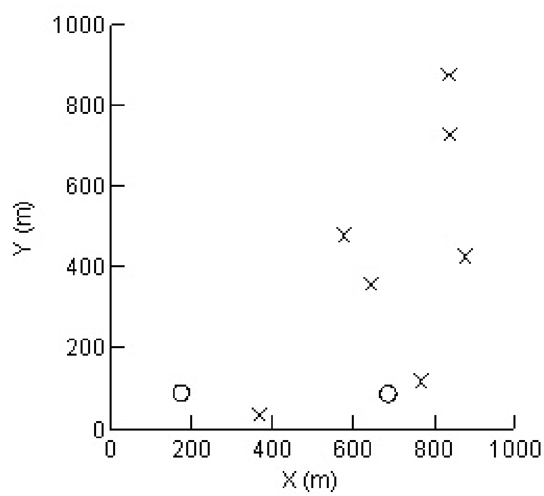
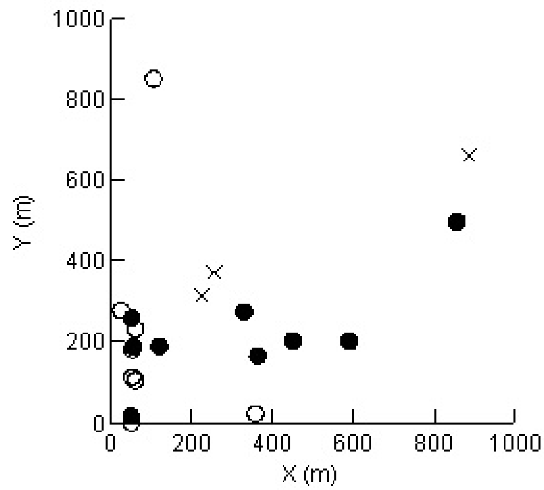


Fig. 6. Spatial distribution of sightings of minke whale cues made by the primary (P) and secondary (S) observers.

P1



P2



P1+P2

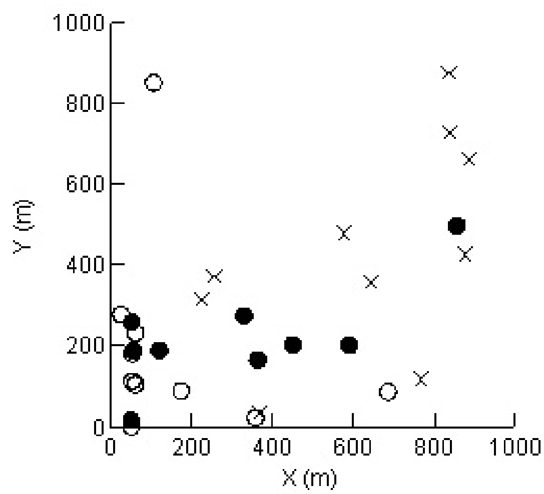


Fig. 7. Spatial distribution of sightings of minke whale cues by the primary (P) and secondary (S) observers while on the right side of the plane. Crosses – Secondary observer, not duplicated; Filled circles – Secondary and primary observer, duplicated; Open circles – Primary observer, not duplicated.

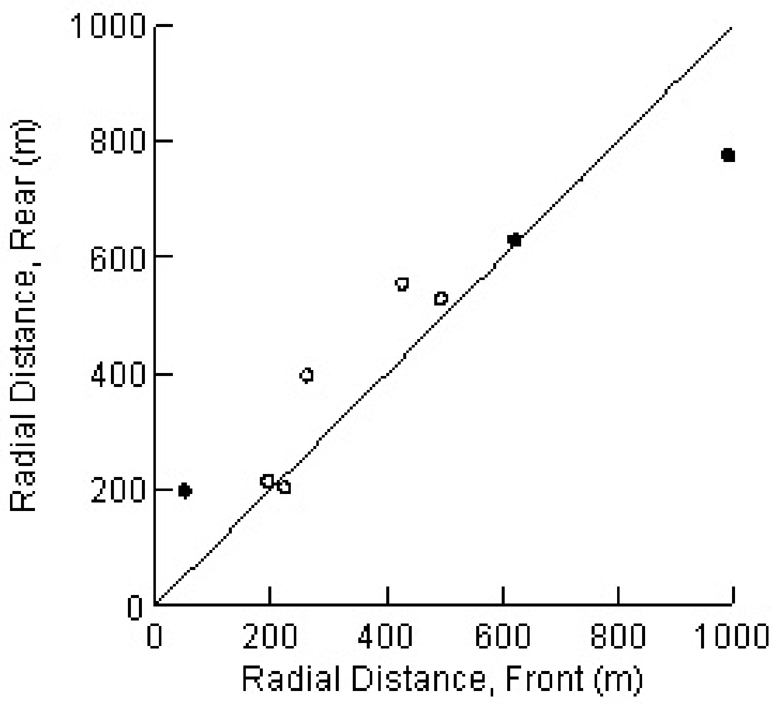


Fig. 8. Radial distance to duplicate sightings by the front (secondary) and rear (primary) observers. Open circles are duplicate certainty 1 (certain) and filled circles are duplicate certainty 2 (uncertain). The X=Y line is also shown.

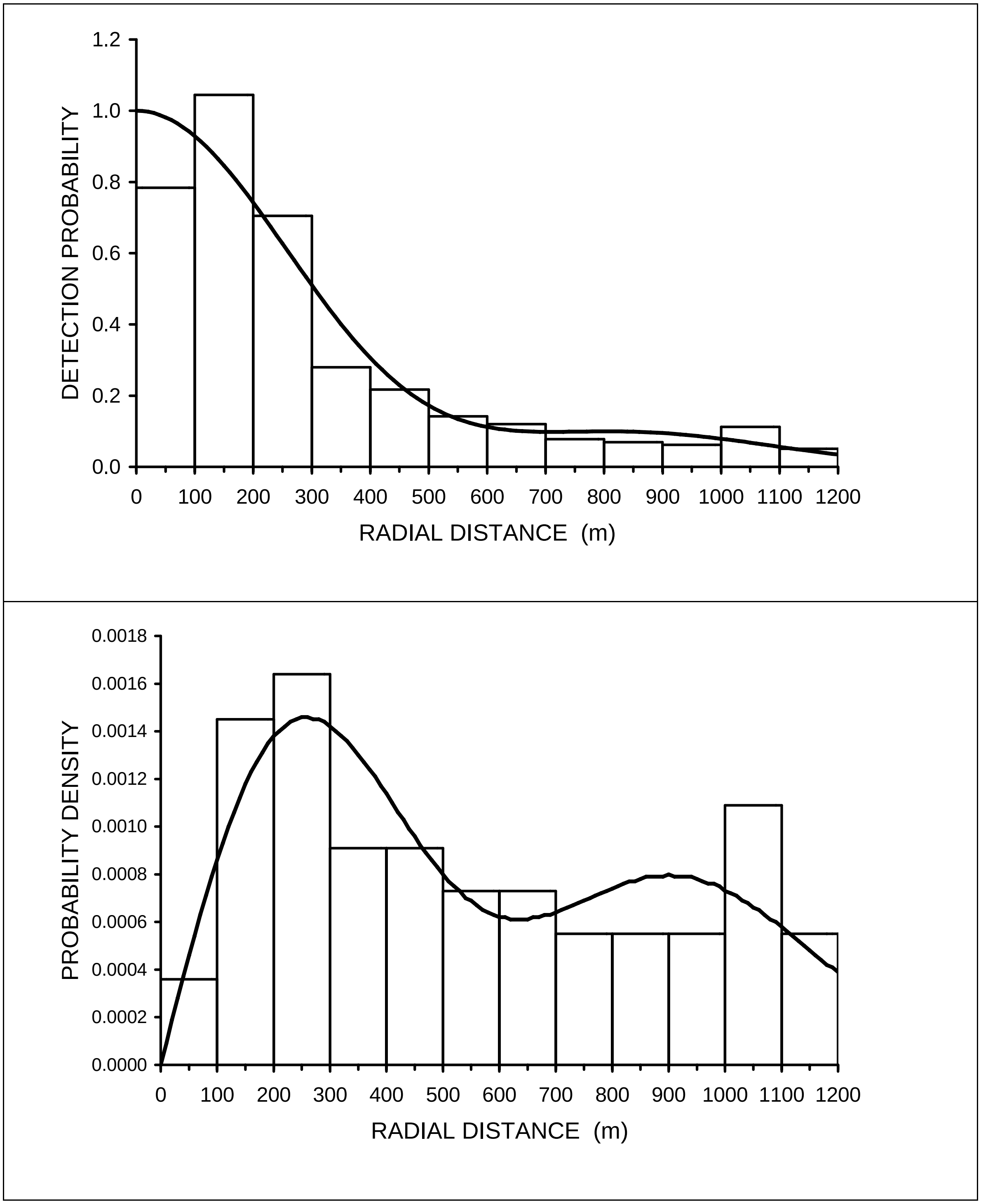


Fig. 9. Detection function for all observers for minke whales, showing detection probability scaled in inverse proportion to radial distance squared (top) and observed probability density (bottom).