Distribution and abundance of humpback whales in Icelandic coastal waters in summer 2007.

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ABSTRACT

The Icelandic coastal aerial survey was a component of the Trans North Atlantic Sightings Survey (T-NASS) conducted in summer 2007. Here we provide estimates of humpback whale abundance from the survey. Humpback whale sightings were concentrated off northwest Iceland, and most whales were seen close to the pack ice edge there. Unlike in 1995 and 2001, no humpbacks were seen off eastern Iceland. Double platform (DP) effort was maintained on one side of the plane, data from this side were used to provide correction factors for perception bias for the primary and combined platforms. Four estimates were provided: 2 using conventional distance sampling techniques for the combined platforms and the primary platform, one using the right side DP data and MRDS methods to provide an estimate corrected for perception bias for the primary platform, and one using the same data to provide a similarly corrected estimate for the combined platforms. The conventional estimate using data from both platforms was 1,138 (95% CI 565, 2,039), while that for the primary platform only was 810 (95% CI 370, 1,770). Incorporation of a mean *p(0)* of 0.70 (cv 0.17) for the primary platform raised that estimate to 1,162 (95% CI 497, 2,717), and *p(0)* 0.91 (cv 0.06) for the combined platforms increased that estimate to 1,242 (95% CI 632, 2,445). Post stratification of the survey area to that which was well covered lowered all these estimates by 19-23%. These estimates are not corrected for whales that were diving and hence not visible as the plane passed over, and are therefore negatively biased. Total abundance estimated for 2007 using comparable methodology was 52% and 72% lower than 1995 and 2001 respectively, however neither decrease is significant ($P>0.05$).

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.* 2009a). The main target species of these surveys has been minke whales (*Balaenoptera acutorostrata*), however sightings of all species are registered. The cue counting procedure (Hiby and Hammond 1989) has generally been used only for minke and other baleen whales: for other species standard line transect methods are used. The cue-counting data collection procedure produces data suitable for either analytical method.

Previous estimates of humpback whale (*Megaptera novaengliae*) abundance from the survey series between 1986 and 2001 have been compiled by Pike *et al.* (2009a). Despite excellent coverage in 1986, there were insufficient sightings of humpbacks to derive an estimate. In 1995, however, 89 sightings were made resulting in a total estimate (uncorrected for whales missed by observers and for whales diving and not available to be seen) of 1,674 (95% CI 656 – 4,269). In 2001, despite low coverage in areas where humpback whales were expected, 158 sightings were made resulting in an estimate of 2,937 (95% CI 1,655 – 2,182). Correcting this estimate for whales missed by observers (perception bias) increased this estimate to 4,928 (95% CI 1,926 – 12,611). The estimated rate of population growth over the period 1986 to 2001 was 0.12 (95% CI 0.05 – 0.19). Similar increases have been detected by the NASS ship surveys in the broader area around Iceland (Paxton *et al.* 2009, Pike *et al.* 2005). Smith and Pike (2009) put these results in context with what is known about humpback whale populations in the North Atlantic, and noted that the rapid increase in humpback whale numbers around Iceland cannot be readily incorporated into current population models.

The T-NASS Icelandic aerial survey was conducted successfully in June-July 2007. Pike *et al.* (2008) provide details of the conduct and results of the survey, as well as an abundance estimate for minke whales. Here we provide an abundance estimate for humpback whales from the survey, and discuss its implications both in relation to previous surveys and the wider T-NASS effort.

MATERIALS AND METHODS

Survey design

The survey design was identical to that used in 2001 (Fig. 1), and nearly the same as those flown in 1987 and 1995 (Pike *et al.* 2009a). Some additional effort was conducted in fiord systems, and additional effort was applied to Breiðafjörður in block 2; these changes are detailed by Pike *et al.* (2008). In any event the changes are not relevant to the determination of humpback whale abundance as humpbacks were not sighted in these areas.

Data collection

Survey methods are given in detail by Pike *et al.* (2008). 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.

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. 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).

The survey was conducted mainly in passing mode, but sightings were sometimes investigated for species identification and group size estimation. Survey effort was abandoned if Beaufort sea state increased above 3, or if fog, mist or heavy rain obscured visibility.

Data analysis

Data preparation

All data collected at Beaufort sea state >3 was dropped prior to analysis. This resulted in no loss of humpback whale sightings.

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 the right 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

Abundance was estimated in 4 ways.

COMBINED PLATFORM ESTIMATE (CP)

For the combined platform analysis (CP) all unique sightings from both platforms were used. Density and abundance were estimated using stratified line transect methods (Buckland *et al.* 2001) using the DISTANCE 6.0 (Thomas *et al.* 2009) software package. The perpendicular distance data were truncated such that about 10% of the greatest distances were discarded. The data were left-truncated if there was a substantial decrease in sighting frequency close to the trackline.

The Hazard Rate and Half Normal 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.* 2001). Covariates were considered for inclusion in the model to improve precision and reduce bias. 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.* 2009). Covariates were retained only if the resultant AIC value was lower than that for the model without the covariate. The following covariates were considered: BSS; observer identity, platform, glare (3 level intensity), sightability (subjective, 3 levels), visibility and cue type (blow, blow and body, body, underwater). Bootstrap variance estimates were used with the detection function estimated at the global level.

To determine if there was size bias in pod detectability, ln(s) (pod size) was regressed against the estimated detection probability. If this regression was significant at the P<0.15 level, the detection of groups was considered to be size biased and the estimate of mean group size was adjusted using this regression.

PRIMARY PLATFORM ESTIMATE (PP)

For the primary platform analysis (PP) only sightings from the primary (rear) platform were used. Methods were otherwise identical to those detailed above.

PRIMARY PLATFORM CORRECTED ESTIMATE (PP-C)

Double platform data were produced on the right side of the plane only. Data from the right side of the plane were therefore analyzed separately using mark-recapture distance sampling (MRDS) techniques (Laake and Borchers 2004) using DISTANCE 6.0. For this analysis the independent observer (IO) configuration was used (Laake and Borchers 2004), which assumes the platforms are symmetrical. We assumed “point independence” (PI), wherein sightings from the platforms are considered independent only on the trackline (Laake and Borchers 2004), as responsive movement was not observed or expected. (Trial runs conducted under the assumption of “full independence”, wherein sightings from the platforms are considered independent at all perpendicular distances, produced quantitatively similar results.) The resulting *p(0)* for the primary platform was then applied to the PP estimate, under the assumption that *p(0)* was the same for the right and left sides.

COMBINED PLATFORM CORRECTED ESTIMATE (CP-C)

As there was no observer on the left side of the secondary (front) platform, this position was in effect "blind". We analyzed the full dataset, including data for the "blind" observer, who (obviously) never resighted a whale seen on the same side by the primary platform. Consequently we expected *p(0)* values for the secondary and combined platforms to be lower than those estimated for the right side only An additional covariate identifying the blind position was included. Otherwise the MRDS analysis was the same as that described for the PP-C.

RESULTS

Coverage

Realized effort is shown in Fig. 2 and Table 1. 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.

Sightings

Sightings of humpback whales are listed in Table 2 and their distribution is shown in Fig. 3. A total of 44 non-duplicate sightings were made by all observers. Observer P2 sighted more humpbacks than P1, and S1 had more sightings than either primary observer. Observer P2 duplicated a higher proportion of sightings by the secondary observer than did P1. No observer had any humpback sightings within 200 m perpendicular distance from the trackline.

Most sightings were of single animals, and the maximum group size sighted was 4.

Humpback whale sightings were concentrated to the north and northwest of Iceland and were strongly associated with the edge of pack ice off northwest Iceland (Fig. 3). Humpbacks were never sighted within the ice, however. Unlike in previous surveys, no humpbacks were sighted off eastern Iceland.

Abundance estimation

Combined platform analysis

Inspection of the distribution of perpendicular distances revealed that sighting probability was depressed within about 200 m of the trackline; therefore, the data were left truncated at 200 m. A right truncation distance of 1,500 m was chosen, resulting in <10% loss of sightings. The half-normal function with no adjustments provided the best fit to the data, and no covariates tested improved the fit of the model (Fig. 4a).

Table 3 provides details of the abundance estimates for the original and post-stratified blocks. Total abundance for the original strata was 1,138 (95% CI 565, 2,039). Post- stratification reduced this estimate by 20%.

Primary platform estimate

The same left and right truncations were warranted for the primary platform dataset as for the combined platform. Again the half-normal function with no adjustments provided the best fit, and no covariates improved the fit (Fig. 4b). Total abundance for the original strata was 810 (95% CI 370, 1,770) and post-stratification reduced this by 23%. (Table 4).

Primary platform corrected estimate

Data were restricted to the right side only for the MRDS analysis, and left and right truncation distances were the same as those used above. Inclusion of covariates for perpendicular distance and observer identity improved the fit of the conditional detection function (Fig. 5). The final model predicted an average probability of detection at perpendicular distance 0 (*p(0)*) of 0.70 (cv 0.17) for the primary platform, 0.87 (cv 0.11) for the secondary platform, and 0.96 (cv 0.04) for the combined platforms.

Applying the *p(0)* value of 0.70 to the PP estimate detailed above resulted in a total abundance estimate of 1,162 (95% CI 497, 2,717) and post-stratification reduced the estimate by 23% (Table 5).

Combined platform corrected estimate
Left and right truncation distances were the same as those used above. Inclusion of covariates for perpendicular distance and observer identity improved the fit of the conditional detection function. The estimated *p(0)* for the combined platforms was 0.91 (cv 0.06) Total abundance was 1,242 (95% CI 632, 2,445) and post stratification reduced the estimate by 19% (Table 6).

DISCUSSION AND CONCLUSIONS

Potential biases
We produced 4 estimates abundance in order to 1) provide comparability to earlier estimates, particularly those by Pike *et al*. (2009a), and 2) produce the best estimate possible with the data at hand. Each of the estimates is, however, biased to a greater or lesser degree.

Line transect methods assume that all animals on the trackline are available to be seen, but this is clearly not the case for whales. Some unknown proportion of the humpback whales were under water and therefore invisible to observers as the plane passed over. A cue-counting analysis could overcome this “availability bias”, and sufficient cues (60) were recorded to support such an analysis. However the cueing rate for humpback whales has not been estimated for this area, to our knowledge. The cueing rate could be estimated by satellite or radio tracking, or by observational experiments.

Two of the estimates (CP and PP) are biased by the proportion of whales that were visible but not seen by observers (perception bias). This bias was directly estimated for the primary, secondary and combined platforms in the MRDS analysis, and the CP-C and PP-C estimates are corrected for this.

The Independent Observer approach used assumes that the platforms are symmetrical. This is not the case for the configuration used on the survey plane as the front (secondary) platform does not use a bubble window. However the left truncation of 200 m does appear to make the platforms roughly equivalent; indeed, the *p(0)* estimated for the secondary platform was somewhat higher than that for the primary platform. Analyses using the “Trial” configuration, in which the secondary platform serves only to generate sight-resight experiments for the primary platform, were also carried out and produced similar estimates of *p(0)* for the primary platform.

Distribution and abundance
Humpback whale sightings were heavily concentrated off NW Iceland and were strongly associated with the edge of pack ice there (Fig. 3). This area was also a major area of concentration for humpbacks in 1995, which was the only other survey that managed to cover this frequently foggy area (Pike *et al.* 2009a). It was very obvious to the observers that humpbacks were congregating along the edge of the pack ice, and most were seen within sight of this ice edge. The pack ice edge was unusually close to Iceland for that time of year, and previous surveys have not been flown in pack ice. It appears that humpback whales do not penetrate the pack ice in this area as none were seen there despite considerable effort.

Unlike in 1995 and particularly 2001, no humpback whales were seen off eastern Iceland. In 2001 this was the major area of concentration for the species, with 90 of 158 primary sightings made there (Pike *et al.* 2009a). Unfortunately coverage was poor off NE Iceland due to weather conditions for both the aerial and ship components of T-NASS, so it is possible that a concentration area here was missed. It does appear that the summer distribution of this species is highly variable around Iceland, perhaps in response to variations in the distribution of its pelagic piscine prey.

Our best estimate of humpback whale abundance, uncorrected for perception or availability bias, is the CP estimate of 1,138 (95% CI 565, 2,039). Our best estimate corrected for perception bias is the CP-C estimate of 1,242 (95% CI 632, 2,445). In both cases the lower estimates for the post-stratified survey area are more conservative in that they do not extrapolate into areas that were not covered by the survey.

As a direct consequence of the apparent absence of humpbacks off eastern Iceland in 2007, estimated abundance was lower than that observed in 2001 and even 1995. The PP estimate is directly comparable to estimates from the 1995 and 2001 surveys produced by Pike *et al.* (2009a). Total abundance in 2007 was 52% and 72% lower than 1995 and

2001 respectively, however neither decrease is significant (P>0.05). Our PP-C estimate is also comparable to a similarly corrected estimate for 2001 of 4,928 (95% CI 1,926, 12,611). The estimate for 2007 is 76% lower than this.

The T-NASS ship survey overlapped with the aerial survey off northern and western Iceland (Fig. 6) (Pike *et al.* 2009b). The area off NW Iceland was poorly covered by ship; nevertheless most sightings of humpback whales were made in this area and particularly in the overlap area. The pack ice had apparently receded to the west between late June (when the area was covered by air) and mid-July (when it was covered by ship). This makes combining the estimates from the aerial and ship surveys difficult if not impossible, as the whales may have followed the receding ice edge into areas that were later covered by ship.

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BLOCK	AREA (nm^2) Design	Post	DURATION (hrs)	DISTANCE (nm)	P1	P2	S1	TOTAL
1	4,418		7.71	774				**0**
2A	1,780		3.21	317				**0**
2B	2,208		2.18	218		6	1	**7**
3	14,066		7.02	698	5	4	4	**13**
4	12,392		8.47	852	3	1	5	**9**
5	10,782	6,008	3.81	384	4	9	1	**14**
6	3,602		3.87	385				**0**
7	14,384	10,064	3.27	334				**0**
8	3,728		4.33	443			1	**1**
9	18,186	14,204	7.13	716				**0**
EYA	133		0.35	34				**0**
REY	38		0.19	19				**0**
TOTAL	**85,717**	**72,641**	**51.53**	**5,174**	**12**	**20**	**12**	**44**
				MIN	1	1	1	1
				MAX	4	2	3	4
				MEAN	1.667	1.2	1.615	1.444
				SD	0.888	0.41	0.87	0.725

Table 1. Survey effort and non-duplicate sightings of humpback whales by the primary (P) and secondary (S) observers. Mean, minimum, and maximum group sizes are also shown.

	S1
with P1	13
dup P1	2
with P2	11
dup P2	9
with P1 & P2	11

Table 2. Sightings of humpback whales by the secondary observer with each of the primary observers, and numbers of sightings that were duplicated by that observer.

BLOCK	n	n/L		E(s)		esw		D	N			
											L	U
1	1	0.00129	(0.92)					0.00183	8	(0.96)	0	26
2A	0											
2B	6	0.02752	(0.67)					0.03843	85	(0.64)	0	204
3	13	0.01862	(0.35)					0.02643	372	(0.35)	140	644
4	7	0.00822	(0.61)					0.01254	155	(0.62)	0	375
5	12	0.03125	(0.48)					0.04691	506	(0.58)	110	1,209
5P	12	0.03125	(0.48)	1.44	(0.11)	1,132	(0.18)	0.04705	283	(0.6)	59	741
6	0											
7	0											
7P	0											
8	1	0.00226	(0.9)					0.00320	12	(0.92)	0	37
9	0											
9P	0											
TOTALP	**40**							**0.12900**	**916**	**(0.3)**	**475**	**1,535**
TOTAL	**40**							**0.12490**	**1,138**	**(0.33)**	**565**	**2,039**

Table 3. Abundance of humpback whales from the NASS-2007 Icelandic aerial survey, CP estimate. *esw* – effective strip width (m), *n/T* - encounter rate, sightings per nm; *D* - density, whales/nm^2, *N* - abundance estimate, CI - bootstrap 95% confidence interval. Coefficients of variation are in parentheses.

BLOCK	***n***	***n/L***		***E(s)***		***esw***		***D***	***N***		**CI**	
											L	**U**
1	0											
2A	0											
2B	5	0.02294	(0.68)					0.03166	70	(0.70)	17	290
3	9	0.01289	(0.46)					0.01780	250	(0.50)	91	692
4	3	0.00352	(0.75)					0.00508	63	(0.78)	15	262
5	11	0.02865	(0.57)					0.03957	427	(0.60)	126	1,446
5P	11	0.02865	(0.57)	1.36	(0.09)	1,110	(0.17)	0.03957	238	(0.60)	70	806
6	0											
7	0											
7P	0											
8	0											
9	0											
9P	0											
TOTALP	**28**							**0.00855**	**621**	**(0.36)**	**305**	**1,262**
TOTAL	**28**							**0.00945**	**810**	**(0.39)**	**370**	**1,770**

Table 4. Abundance of humpback whales from the NASS-2007 Icelandic aerial survey, PP estimate. See Table 3 for variable definitions.

BLOCK	*n*	*n/L*		*E(s)*		*esw*		$g(0)_P$		*D*	*N*		95% CI L	95% CI U
1	0	0.00000												
2A	0	0.00000												
2B	5	0.02294	(0.68)							0.04544	100	(0.72)	24	424
3	9	0.01289	(0.46)							0.02555	359	(0.53)	124	1,042
4	3	0.00352	(0.75)							0.00729	90	(0.79)	21	386
5	11	0.02865	(0.57)							0.05681	612	(0.63)	175	2,139
5P	11	0.02865	(0.57)	1.36	(0.09)	1,110	(0.17)	0.70	(0.17)	0.05681	341	(0.63)	98	1,192
6	0	0.00000												
7	0	0.00000												
7P	0	0.00000												
8	0	0.00000												
9	0	0.00000												
9P	0	0.00000												
TOTALP	**28**									**0.01227**	**891**	**(0.40)**	**408**	**1,946**
TOTAL	**28**									**0.01356**	**1,162**	**(0.43)**	**497**	**2,717**

Table 5. Abundance of humpback whales from the NASS-2007 Icelandic aerial survey, PP-C estimate. $g(0)_p$ – estimated proportion of visible whales seen by the primary observers. See Table 3 for other variable definitions.

BLOCK	*n*	*n/L*		*E(s)*		*g(0)*$_C$		*D*	*N*		95% CI L	95% CI U
1	1	0.00129	(0.92)					0.00129	6	(0.99)	1	34
2A	0											
2B	6	0.02752	(0.67)					0.02745	61	(0.72)	14	263
3	13	0.01862	(0.35)					0.03108	437	(0.50)	158	1,211
4	7	0.00822	(0.61)					0.01516	188	(0.69)	51	687
5	12	0.03125	(0.48)					0.04871	525	(0.56)	166	1,659
5P	12	0.03125	(0.48)	1.44	(0.11)	0.91	(0.06)	0.04705	293	(0.56)	93	925
6	0											
7	0											
7P	0											
8	1	0.00226	(0.90)					0.00705	26	(0.96)	4	174
9	0											
9P	0											
TOTALP	**40**							**0.01391**	**1,010**	**(0.33)**	**526**	**1,938**
TOTAL	**40**							**0.01450**	**1,242**	**(0.34)**	**632**	**2,445**

Table 6. Abundance of humpback whales from the NASS-2007 Icelandic aerial survey, CP-C estimate. $g(0)_C$ – estimated proportion of visible whales seen by observers on both platforms. See Table 3 for other variable definitions.

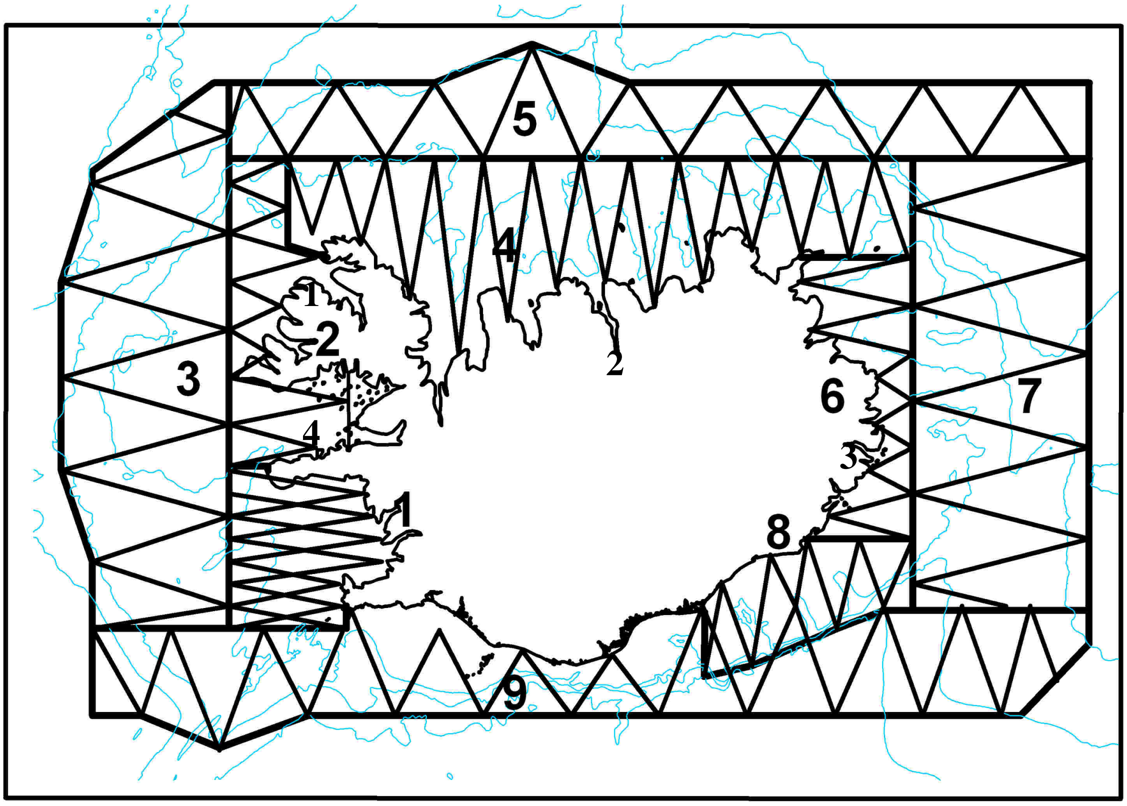

Fig. 1. Icelandic aerial survey, planned effort. Large numbers are block numbers, and smaller numbers show locations of fiords where extra effort was planned (See Fig. 2). 1. Ísafjörður; 2. Eyjafjörður; 3. Reyðarfjörður; 4. Breiðafjörður.

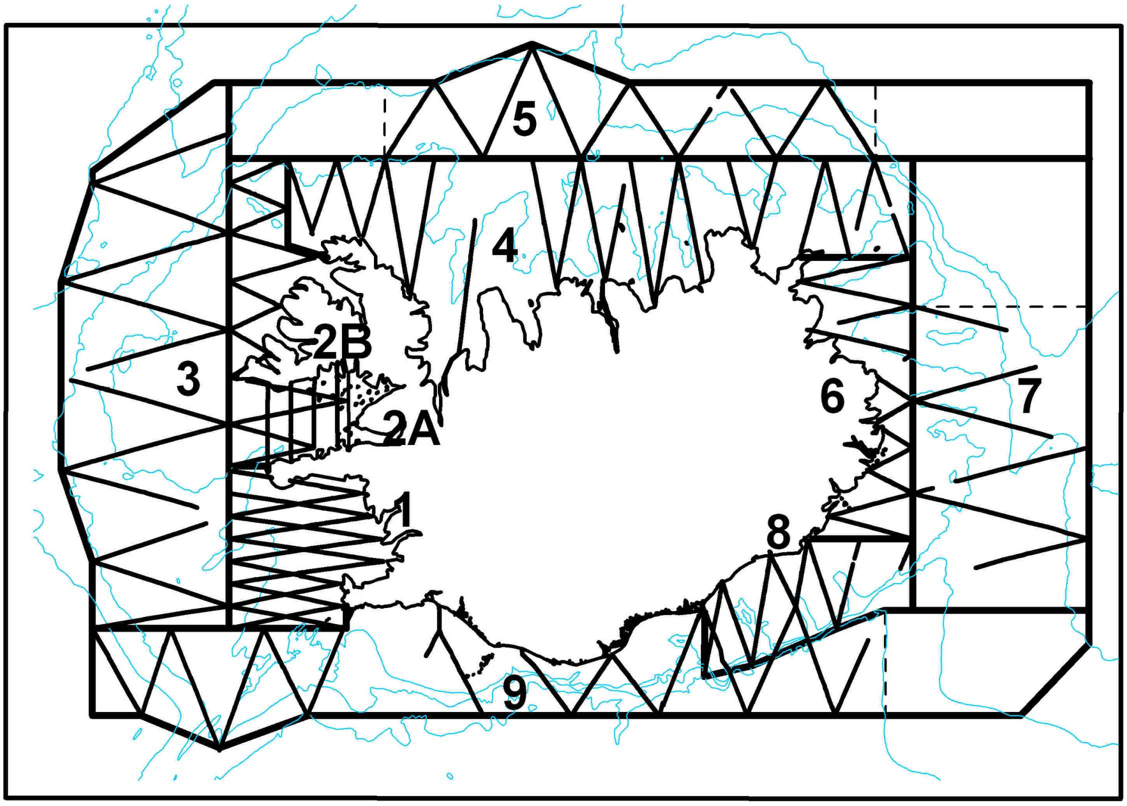

Fig. 2. Realized effort , 2007 Icelandic aerial survey. Dashed lines show boundaries of post-stratified blocks 2, 5, 7 and 9. Isobaths shown are 1000 m, 500 m and 200 m.

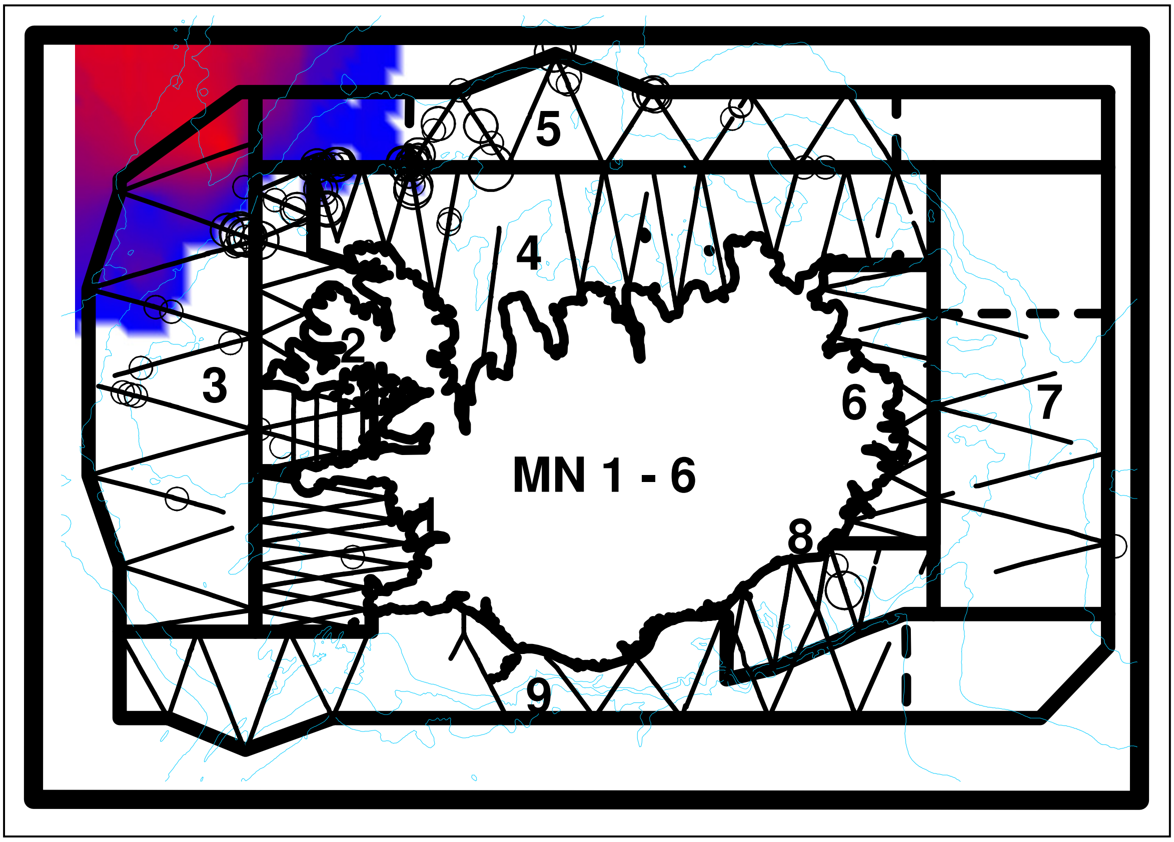

Fig. 3. On and off effort sightings of humpback whale groups. Symbol size is proportional to the range of group sizes from 1 to 6. Coloured area is pack ice concentration as encountered on effort, interpolated by kriging. Ice concentration ranges from 5% (blue) to 80% (red).

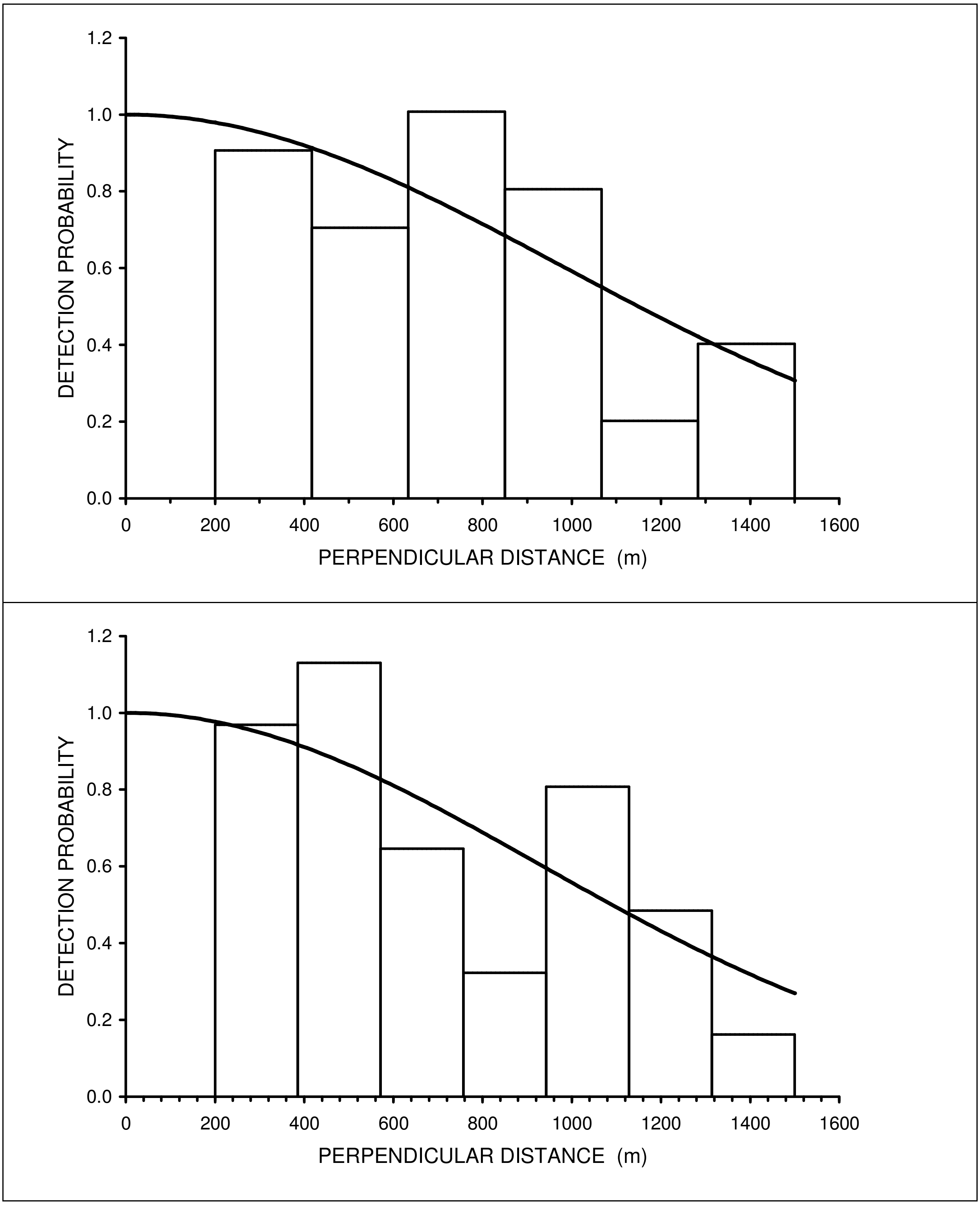

Fig. 4. Detection functions for humpback whales. Top: combined platforms. Bottom: primary platform.

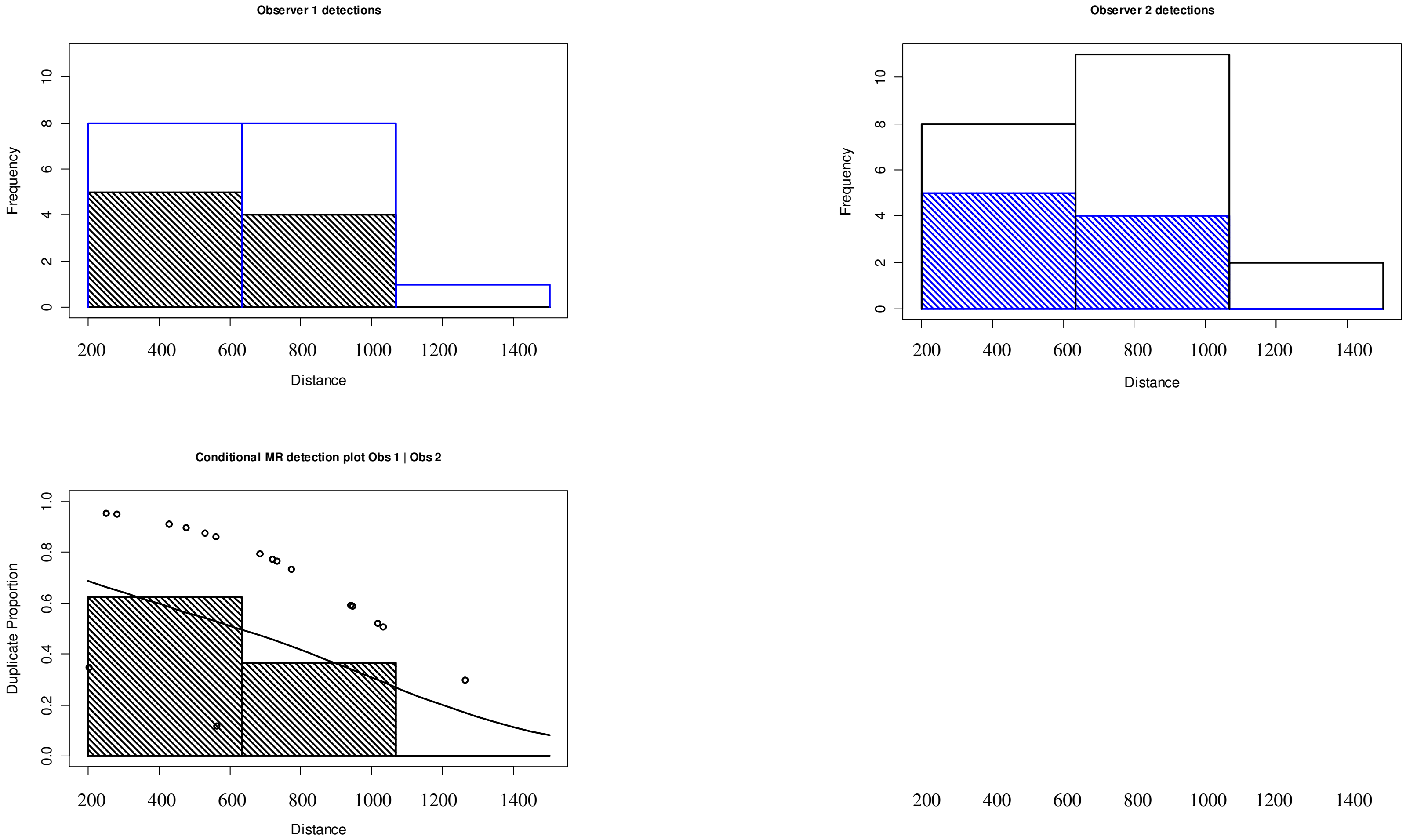

Fig. 5. Conditional detection functions, right side only, for the primary (Obs 1) and secondary (Obs 2) platforms. Top panels show the proportion of sightings by one platform duplicated by the other (filled area of bars). Bottom panels show the estimated conditional detection functions, with the plotted points showing the estimated probability of detection for each sighting.

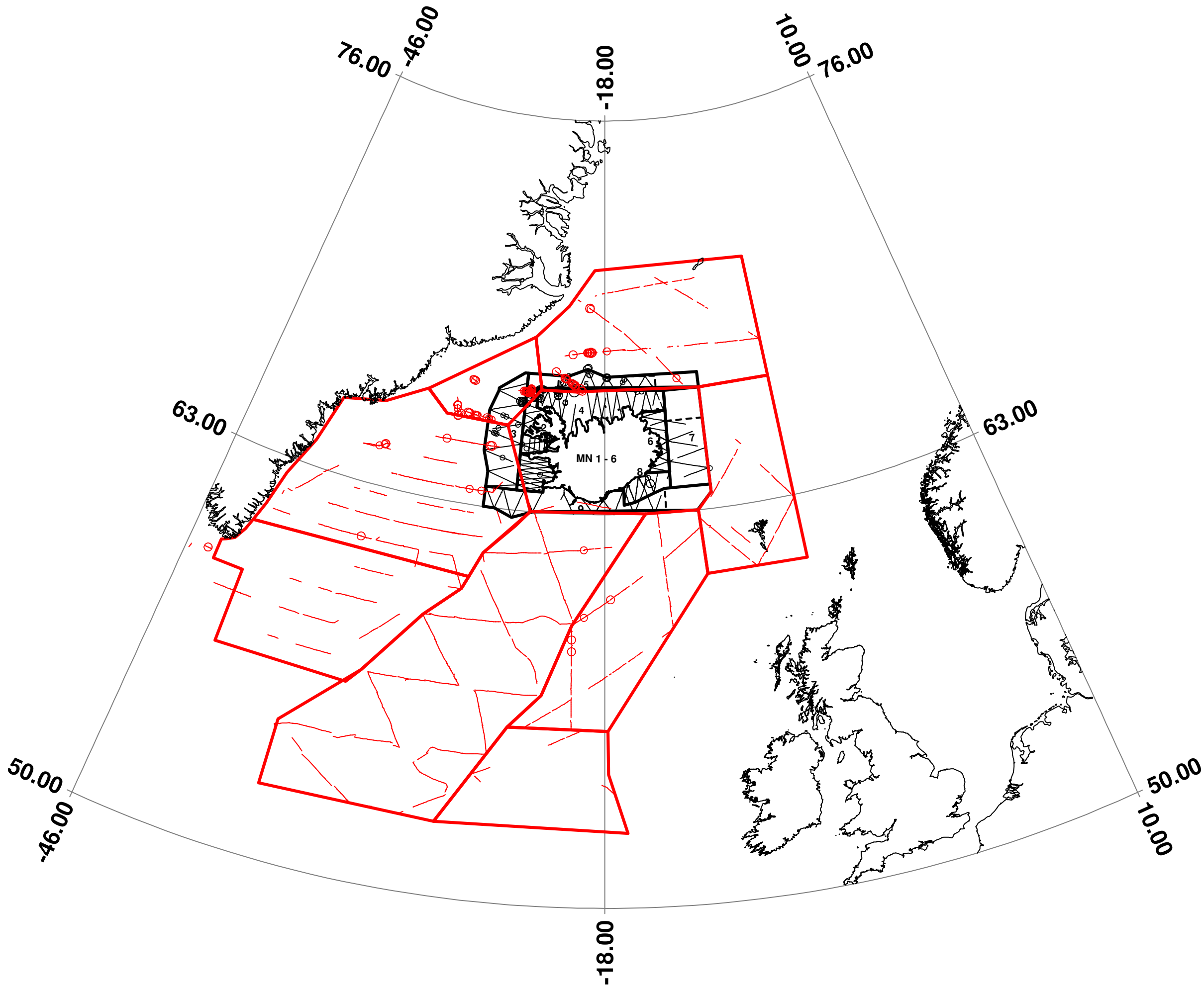

Fig. 6. Survey effort and sightings of humpback whales by the aerial (black) and shipboard (red) components of T-NASS around Iceland and the Faroes.