SC/66b/RMP/01

Estimates of the abundance of fin whales (Balaenoptera physalus) from the NASS Icelandic and Faroese ship surveys conducted in 2015.

Daniel G. Pike, Thorvaldur Gunnlaugsson, Bjarni Mikkelsen and Gisli A. Vikingsson

INTERNATIONAL WHALING COMMISSION

Estimates of the abundance of fin whales (*Balaenoptera physalus*) from the NASS Icelandic and Faroese ship surveys conducted in 2015.

Daniel G. Pike[1], Thorvaldur Gunnlaugsson[2], Bjarni Mikkelsen[3] and Gísli A. Víkingsson[2]

[1]*Esox Associates, 1210 Ski Club Road, North Bay, Ontario, Canada*
[2]*Marine Research Institute, P.O. Box 1390, IS-121 Reykjavík, Iceland*
[3] *Faroese Museum of Natural History, FO-100 Tórshavn, Faroe Islands*

ABSTRACT

The sixth North Atlantic Sightings Survey (NASS) was conducted in June/July 2015. Three vessels covered a large area of the northern North Atlantic, similar to the earlier NASS, but for the first time applying fully independent double platform observer mode. The fin whale (*Balaenoptera physalus*) was a target species in all areas. A contiguous area north and east of Iceland around Jan Mayen Island was covered simultaneously by a Norwegian vessel as a part of an annual cyclic mosaic survey and is not presented here. One of the Icelandic survey vessels was conducting coincident fisheries surveys and some observation effort was on transit transects aligned with expected high fin whale density. Rejecting this compromised effort, the total corrected estimate for the survey area using all fin whale sightings was 40,788 (cv 0.17, 95% CI 28,476 to 58,423). Restricting to high and medium confidence sightings using the same effort reduced the total estimate to 35,605 (cv 0.18, 95% CI 24,615 to 51,505). The estimated densities were higher than in earlier surveys in the area between West Iceland and East Greenland and in the Faroese survey area south of Iceland.

INTRODUCTION

The North Atlantic Sightings Survey (NASS) was conducted in June/July 2015 and covered a large area of the northern North Atlantic (Fig. 1). This was the sixth in a series of major North Atlantic cetacean surveys conducted previously in 1987, 1989, 1995, 2001 and 2007 (Pike *et al.* 2008, Víkingsson *et al.* 2009). The fin whale (*Balaenoptera physalus*) was a target species in all areas and a main target species of the Icelandic ship surveys. A contiguous area north and east of Iceland around Jan Mayen Island was covered simultaneously by a Norwegian vessel as a part of an annual cyclic mosaic survey and is not presented here, nor the aerial surveys conducted in coastal Icelandic waters and later in the season in coastal waters off Greenland.

Previous abundance estimates for fin whales from the Icelandic and Faroese NASS have been summarized by Víkingsson *et al.* (2009, 2015). Independent double platform methods were used beginning in the 2001 survey and estimates corrected for perception bias are available for the 2001 (Pike *et al.* 2006) and 2007 (Pike *et al.* 2008) surveys in addition to uncorrected estimates for the combined platforms. Earlier estimates were not corrected for visible whales that are missed by observers (perception bias) or whales that are missed because they are diving while the vessel passes (availability bias). Put another way, the probability of sighting a whale that was on the trackline (termed $g(0)$) was assumed to be 1. These biases were assumed to be relatively minor for fin whales, as they are large with a visible and easily spotted blow and can be seen from long distance, and do not frequently make long dives. However, estimates prior to 2001 are likely negatively biased to a similar or larger degree than later uncorrected estimates as observation effort during searching has increased and higher platforms were used in later surveys.

Here we present abundance estimates for fin whales from the Icelandic and Faroese survey areas. Combined platform estimates are provided using two levels of certainty in species identification. In addition we provide an estimate of perception bias for the combined platforms using mark-recapture methods (Laake and Borchers 2004).

MATERIALS AND METHODS

Vessels

Three vessels were used in the survey. Two of these (vessels B and H) where dedicated solely to the cetacean survey. One (vessel A) was a research vessel conducting redfish and mackerel surveys coincident with the cetacean survey. This research vessel steamed day and night, largely independent of weather conditions, with cetacean survey being conducted during daylight hours when conditions were acceptable (see below). This vessel covered strata IG and IW (see Fig. 1) coincident with the redfish survey from 10-29 June, then blocks IR, IE and additional parts of IG and IW from 7 July to 10 August coincident with the mackerel survey. The other two vessels (B and H) surveyed the areas south and north of the fisheries survey area with some overlap during transit, and due to last minute changes when the mackerel survey effort was extended to the South. Vessel B covered mainly strata IP and IQ, with some effort in the western and northern parts of stratum IG and IR. Vessel H covered the Faroese strata FC and FW.

Survey design

Transects for strata FC, FW, IP and the northern part of IR, which were covered by dedicated cetacean survey vessels, were designed using the program DISTANCE (Thomas *et al*. 2010) (Fig. 1). In these blocks a double set of equal-spaced zig-zag transects, starting from a random point along the design axis, was applied. In the triangular eastern part of the southern area (IQ), parallel lines (parallel to the eastern boundary) were used. These lines started in the south at the random points where the designed tracks in IP intersected the boundary between these blocks.

In the remaining areas the redfish survey tracks were designed by the ICES Redfish group and the mackerel survey tracks by the ICES WGIPS. The mackerel survey tracks were changed to go farther south after the other surveys started, so this could not be taken account of when the decision was made on the boundaries of the originally designed survey blocks, which have been adjusted afterwards to give again more equal coverage within each block.

Field methodology

Survey procedures on the Icelandic and Faroese vessels are described in detail by Gunnlaugsson *et al.* (2016). Independent double platforms were used on all vessels. On the two Icelandic vessels, there were upper and lower platforms with eye height in meters 18.6/15.3 on vessel A and 16.3/10.3 on vessel B. On the Faroese vessel the two platforms were placed side by side with eye height 12.3. The platforms did not communicate while on effort. A minimum of two observers staffed each platform at all times. Observers were in teams and paired so that one would always be on the opposite platform to the other.

Binoculars were generally in use by at least one observer on a platform when conditions were good enough. Binoculars were frequently used for species ID and to estimate distance using reticule readings of declination angle from horizon. Sticks (rulers) were also available and used for distance estimation at closer range. Lateral angle was estimated using angle boards.

Searching was usually abandoned in poor visibility in Beaufort Sea State (BSS) 6 or more or when visibility from the vessel was one nautical mile (NM) or less. However, due to time constraints, searching was often continued when wind or fog may have influenced the probability of detecting even the large whale species.

If identification and/or group size was uncertain, the platforms on the dedicated vessels could, when abeam, communicate and slow/stop or turn on a sighting, afterwards returning at 45° degrees into the track off effort. Otherwise the survey was done in passing mode.

Data was recorded on time stamped digital dictaphones (or paper) and transferred to a spreadsheet during the rest hours. Validation and duplicate identification was mostly performed post cruise.

Data treatment

Post-stratification

In addition to stratum and total abundance estimates, regional estimates, each of which includes a combination of the original strata, were required for population modelling purposes (Fig. 2). These included estimates east and west of 18° W, which required the division of stratum FW into W (FW_W) and E (FW_E) sections (Fig. 1). Transects which crossed the dividing line were split and renamed. Separate estimates were performed using the original and post-stratified blocks.

Transect revision
In strata covered by the combined cetacean/fisheries research vessel, some cetacean survey effort was maintained while ferrying between transects, resulting in some transects that paralleled the Iceland or Greenland coast (Fig. 1). As these transects are aligned with expected high fin whale density gradients observed in previous surveys, their inclusion could result in positively biased estimates. Therefore abundance estimates were calculated both including and excluding these "compromised" transects.

Species identity
For many sightings there was uncertainty in species identification. Sightings were categorized according to the degree of identification certainty as High (BP: fin whale), Medium (coded with one question mark BP?, BP?BM: most likely fin whale possibly blue whale, *etc.*) and Low (coded with two question marks BP??, BP?BM? *etc.*). Sighting categories that were more likely fin whales than any other species, *i.e.* all species codes beginning with "BP", were included in the analyses (Table 1). While this does not include all categories that could have been fin whales, for example sightings of B? (unknown large whale), or BM?BP, which is a probable blue whale (*Balaenoptera musculus*), it does include sightings which may not be fin whales (*e.g.* BP?BM). We assessed the sensitivity of the estimates to uncertainty in species identity by carrying out two analyses: 1) including high (BP) and medium (BP?, BP?BB, BP?BM, BP?MN) certainty, and 2) including high, medium and low (BP??, BP?BA?, BP?BM?, BP?MN?, BP?PM?) certainty. The former category is likely conservative in that it underestimates the actual number of fin whales sighted, while the latter may still lack some sightings that were in fact of fin whales, but likely also contains "false positive" fin whale sightings

Data selection
The analytical procedure used required that all information about a sighting seen by both platforms (*i.e.* angle, radial distance, group size, species identification and covariates such as BSS) be the same. In some cases measurements of angle and distance, estimates of group size and even species identification differed between platforms for what appeared to be the same sighting. In these cases what were considered to be the most reliable measurements were used.

Radial distance estimation
For some sightings several estimates of radial distance and angle are available from one or both platforms. As only one estimate can be used in the analysis, the "best" estimate was chosen generally as the last estimate before the sighting came abeam where both angle and distance were given and estimates from the higher platform when other things were equal.

Beaufort Sea State (BBS)
Wind speed meters (m/s) were used on the Icelandic vessels (broken for the first half on vessel B), while BSS was estimated by the shift leader on the Faroese vessel. Wind speed was transformed into BSS for analysis. Only data recorded in a BSS of 5 or less were used in the analyses, resulting in a 5% reduction in effort and a loss of 15 fin whale sightings (Table 1).

Duplicate identification
On the dedicated vessels (B and H) the platforms sometimes made contact after a sighting was abeam to decide on closing, for example if the species identification was uncertain or the platforms did not agree on the identification or group size. In such cases duplicates were identified in the field. In higher density areas and on the non-dedicated vessels, duplicates were identified after the survey. Fin whale sightings were generally classified as non-duplicates if they differed by 10° in angle to track when seen within a short interval, or the distance between sighting spots was estimated to be over a mile when different dive cycles were observed by the platforms at some minute intervals. Duplicates were classified as D for "certain" or R for "remotely likely". When one platform had a low confidence species identification while the other had high or medium confidence identification, the duplicate was classified as L. When one platform had an undefined species or a different species from the other platform, the duplicate was classified as B. For the purposes of abundance estimation, only D and L duplicates were retained.

Analysis

Combined platform estimates
Density and abundance were estimated using stratified line transect methods (Buckland *et al.* 2001) using the DISTANCE 6.2 (Thomas *et al.* 2010) software package. The perpendicular distance data were truncated such that about 15% of the greatest distances were discarded.

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.* 2010). Covariates were retained only if the resultant AIC value was lower than that for the model without the covariate. The following covariates were considered: vessel identity, BSS, cloud cover (scale 1=0%-24%, 2=25%-69%; 3=70%-89%; 4=>90%), visibility (nm), species identification certainty (0=high confidence; 1=medium confidence; 2=low confidence), vessel platform making the sighting (vessel identity combined with: 1=lower on Icelandic vessels, starboard on Faroese vessel, 2=upper or port, 3=both, *i.e.* duplicate sighting), and the observation team on the platforms (one code for both platforms). The detection function was estimated at the stratum level and could therefore vary in scale by stratum depending on covariate levels. Stratum and total variance was estimated using the method of Innes *et al.* (2002).

Double platform analyses

Only effort that was conducted in full double platform mode was retained for these analyses, which resulted in a small (0.3%) reduction in available survey effort.

Density and abundance were estimated using stratified mark-recapture distance sampling (MRDS) techniques (Laake and Borchers 2005) using the DISTANCE 6.2 (Thomas *et al.* 2010) software package. As the platforms were completely independent from one another and did not communicate about sightings (unlike in 2007, when Buckland-Turnock mode (Buckland and Turnock 1992) was used, (Pike *et al.* 2008), the "independent observer" (IO) analysis mode was specified. In this mode, the platforms are considered to be equivalent and either platform can "mark" a sighting for the other. We initially attempted two types of analyses: using the assumption of "full independence" (FI) wherein sightings from the platforms are considered independent at all perpendicular distances, and under the assumption of "point independence" (PI), wherein sightings from the platforms are considered independent only on the trackline (Laake and Borchers 2005). The AIC values resulting from both approaches were compared before deciding on a final model. The assumption of point independence requires the estimation of two detection functions: one for combined platform (*i.e.* unique) detections, and the other for primary platform detections conditional on detection by the tracker platform (conditional detection function), whereas the assumption of full independence requires only the latter detection function.

The detection function for the combined platforms was modelled as described in the previous section. The conditional detection function was implemented as a logistical model with the most of the same covariates (but not the vessel platform making the sighting, as this includes the response variable) available for the combined platform detection function. Again the final model was chosen by minimization of AIC.

RESULTS

Sightings and distribution

Fin whale sightings by stratum are summarized in Table 1 and Fig. 3. As in most previous surveys fin whales were most commonly sighted to the west of Iceland in blocks IW and IG. Unlike in previous surveys, substantial numbers were sighted in the Faroese strata FC and FW. In contrast very few fin whales were sighted to the east of Iceland in block IE.

Combined platform estimates

A truncation distance of 2,700 m was found to be suitable, however other truncation distances were tried and results were not sensitive to truncation.

Mean school size varied between strata so stratum specific estimates were used. Expected school size (*E(s* was higher (not significantly so) in the Faroese strata (FC and FW) and blocks IG and IW than in other areas (Tables 3-6.)

The half-normal model provided the best fit to the data in all cases. Covariates which improved the model fits are given in Table 2. The factor covariate VESSPLATSIGHT, which is the identity of the vessel platform which made the sighting, improved model fit in all cases and was by far the most influential covariate. Vessel A generally had a wider strip width than the other two vessels (Fig. 4). For all vessels, duplicate sightings had a narrower strip width than non-duplicates. There was little difference between the strip widths for the upper and lower platforms on vessels A and B, but the port platform made more sightings and had a wider strip width on vessel H (Fig. 4). The covariates VISIBILITY, CLOUD and SPECIES_CERTAINTY had less effect but did improve model fit in some runs.

Estimates for the two species ID confidence cases, with and without compromised survey effort are provided in Tables 3 to 6. Restriction to high and medium confidence species identification resulted in a loss of 11% of sightings and a reduction in overall abundance of 10%. Rejection of compromised effort reduced sightings by 6% but resulted in a slight increase in overall abundance (6% for all species ID confidence, 5% for high and medium species ID confidence), mainly because of a slight reduction in *esw* when using the revised effort.

The total estimate for the survey area using all fin whale sightings and rejecting compromised effort (Table 4) was 35.995 (cv 0.15, 95% CI 26,588 to 48,731). Restricting to high and medium confidence sightings using the same effort (Table 5) reduced the total estimate to 32,022 (cv 0.15, 95% CI 23,472 to 43,686). Fin whale density was highest in blocks IG and IW west of Iceland, and lowest in block IE to the east of Iceland.

Double platform estimates

Comparisons of FI and PI models revealed that PI models always had lower AIC's when the same covariates were included in the conditional detection function. Therefore PI was retained as the preferred approach.

Since nearly all effort was conducted in full double platform mode, the best detection function models from the combined platform analyses were retained in the PI models (Table 2). In all cases, the best conditional model (as indicated by minimum AIC) included the interaction term between perpendicular distance (DIST) and VESSOBS, the identity of the vessel combined with the particular team occupying the platforms (Table 2). The average combined platform probability of sighting a whale at perpendicular distance 0 ($p(0)$) was 0.86 (cv 0.03) for all fin whale sightings and 0.89 (cv 0.03) for fin whales identified with high and medium confidence. The total corrected estimate for the survey area using all fin whale sightings and rejecting compromised effort (Table 3) was 40,788 (cv 0.17, 95% CI 28,476 to 58,423). Restricting to high and medium confidence sightings using the same effort (Table 5) reduced the total estimate to 35,605 (cv 0.18, 95% CI 24,615 to 51,505).

DISCUSSION AND CONCLUSIONS

Potential biases

Coverage

While survey coverage was acceptable in most areas, ice coverage and fog hampered effort in the western and north-western areas near the East Greenland coast, where fin whale densities have been high in some previous surveys (Pike *et al.* 2008, Víkingsson *et al.* 2009, 2015,). A contiguous area NE of Iceland around Jan Mayen Island was covered simultaneously by a Norwegian vessel, but the results from this survey were not yet available.

Rejecting the compromised effort that was aligned with expected density gradients made very little difference to abundance estimates. We infer that sighting rates along these transects were similar to those along the designed transects.

Species identification

The identification of sightings as fin whales has been recorded with various levels of certainty in all previous surveys. The same confidence classification was used in 2007 (only fin and like-fin used in earlier surveys) and the sensitivity of the estimation of abundance to inclusion or exclusion of the Low certainty class was then assessed (Pike *et. al.* 2008). Sensitivity is roughly proportional to the number of sightings included or excluded. Restriction to the high and medium certainty classifications resulted in an 11% reduction in sightings and a 10% reduction in abundance. We noted the same phenomenon for the 2007 survey (Pike *et al.* 2008), when we observed that confidence in species identification was not closely associated with the distance of the sighting from the trackline. The same seems to be true for this survey, in that species identification certainty had a small and inconsistent effect on the scale of the detection function (Table 2). However the number of very uncertain sightings was small relative to the total number (70/630, Table 1). Some of the sightings included in the least certain identification category were likely not fin whales, while other sightings of unidentified baleen whales or identified more likely as other species may have been fin whales. We consider the estimate including all confidence levels of fin whales the least biased and most comparable to earlier NASS estimates reported by Víkingsson *et al.*.(2009, 2015), however the High+Medium confidence identification estimate for 2007 was considered most appropriate for the IWC Implementation trials..

Bias in distance estimation

Bias in distance measurement can be a serious problem in distance sampling surveys as it leads directly to bias in abundance estimation (Buckland *et al.* 2001). Pike *et al.* (2008) noted that the primary platforms in the 2007 survey underestimated distances by eye to targets by about 10% in trials. Comparison of distances to duplicate sightings by the primary and tracker platforms also suggested a negative bias by the primary platform. In 2007 binoculars were not in regular use on the primary platform. Distance measurement experiments were not conducted during this survey as the main emphasis was on using binocular reticles for distance estimation and distance estimation was constantly scrutinized by observers comparing their readings and by comparison to re-sightings and distances measured when closing on sightings. Also, distance estimations from the upper platform were prioritized over the lower ("primary") platforms, other things being equal as mentioned above. Future surveys should incorporate a method of validating a proportion of distance estimations, for example by using an Unmanned Aerial Vehicle to measure some distances.

Perception bias correction
This is the first NASS in which full Independent Observer (IO) mode, with each vessel incorporating two independent, isolated platforms using identical methods, has been used. Previous surveys which have used double platforms (2001, 2007) have used Buckland-Turnock (BT) mode, with a Tracker platform scanning ahead of the field of view of the primary platform using binoculars and tracking sightings until they were sighted by the primary or passed abeam. As the Tracker platform is not independent (*i.e.* it monitors the primary platform), Tracker platform sightings are considered "trials" for the primary platform and the perception bias correction is applied to the primary platform only, unlike IO mode in which bias is estimated for the combined sightings by both platforms. Pike *et al.* (2006) found that $p(0)$ was 0.81 for the primary platform in the 2001 survey, while Pike *et al.* (2008) estimated $p(0)$ as 0.77 for the 2007 survey. Our $p(0)$ values for this survey (0.89 for High+Medium certainty sightings, 0.86 for all sightings) are higher than those estimated for the primary platform in 2001 and 2007, probably because they apply to the combined sightings by both platforms rather than to a single platform. In addition the earlier corrected estimates may have incorporated a larger portion of availability bias, the proportion of whales that would be missed by the primary platform because they are submerged, because the Tracker platform scanned far ahead of the vessel while the primary platform did not use binoculars regularly. The 2015 correction is estimated with better precision, as the calculation makes use of all between-platform duplicates, unlike B-T mode which uses only one-way duplicates. In this sense it appears that IO may be a more "efficient" survey mode, in that it should result in greater precision in bias estimation. However the B-T configuration may produce better information on responsive movement (not considered of significance for fin whales in these surveys) and availability bias. In addition, duplicate identification may be more certain when B-T mode is successfully implemented, as primary sightings are immediately communicated and most duplicates identified in the field.

This latter problem is significant as there is considerable uncertainty in identifying duplicates post-survey. We were conservative in duplicate identification in the sense that the criteria we used are likely to overestimate the number of duplicate sightings (*i.e.* by identifying pairs as duplicates when they are not), which in turn will lead to overestimation of $p(0)$ and a negative bias in the corrected abundance estimate. More accurate and precise measurement of sighting angles, distances and times would improve the certainty of duplicate identification (and likely result in higher corrected estimates).

Comparison to previous estimates
Víkingsson *et al.* (2009) provide regional abundance estimates for fin whales for all NASS up to 2001, and Víkingsson *et al.* (2015) extended this series to 2007. In the area between Iceland and East Greenland ("West" region of Víkingsson *et al.* (2009), Irminger Sea in Víkingsson *et al.* (2015)), fin whale numbers, uncorrected for perception and availability biases, increased from 3,600 (cv 0.18) in 1987 to 14,000 (cv 0.18) in 2001, a rate of increase of 10% (95% CI 6% – 14%). There was no detectable change in abundance in other areas. Abundance in the Irminger Sea areas in 2007 was similar to that seen in 2001, suggesting that the increase in numbers in this area had ceased. The Irminger Sea/West area is roughly equivalent to our W region, which had an abundance of 27,178 (95% CI 19,347 – 38,179) (high+medium identification certainty, revised effort, uncorrected, Table 6), suggesting a substantial increase since 2007 in this area.

The abundance of fin whales around the Faroe Islands and to the south of Iceland (blocks FC + FS) was also strikingly high compared to earlier surveys. Density surface analyses by Víkingsson *et al.* (2015) identify this as a very low density area in all NASS prior to 2015. Pike *et al.* (2008) estimated 417 fin whales in this area (their blocks FS + FE) in 2007, compared to over 11,000 this year (Table 6). It is interesting to speculate that this might have been due to a northern incursion of fin whales into the area from the Spanish stock area, where earlier surveys found fin whales to be abundant (Sanpera and Jover, 1989, Buckland *et al.* 1992b, CODA 2009).

While overall abundance over the entire survey area is not directly comparable between NASS as coverage has varied between surveys, the numbers seen here are the highest of any NASS in the Central North Atlantic. This suggests either an increase in abundance in northern areas or a distributional shift, or a combination of both of these. A distributional shift is not unlikely as Víkingsson *et al.* (2015) have demonstrated that fin whales have both increased in abundance and changed their distribution patterns within the NASS survey area between 1987 and 2007. This was associated with an increase in sea surface temperature and height, and probably prey availability, particularly in the western part of the area. It appears that this pattern may be continuing, allowing this species to expand its range and numbers in the Central North Atlantic. The results from the Norwegian and Greenlandic parts of NASS-2015 as well as surveys planned in 2016 off Western Europe and Atlantic USA may throw further light on a possible shift in distribution of North Atlantic fin whales.

ACKNOWLEDGEMENTS

The authors would like to thank all participants of the survey both observers, captains and crew. We also thank project- and cruise leaders of the fisheries parts of the combined cetacean/fisheries research vessels for their cooperation and flexibility. We are grateful to the Scientific Committee of NAMMCO and the Scientific Committee of the IWC for their part in the coordination and planning of NASS 2015. Funding was provided by Icelandic and Faroese authorities.

REFERENCES

Buckland, S.T., Cattanach, K.I. and Lens, S. 1992. Fin whale abundance in the eastern North Atlantic, estimated from Spanish NASS-89 data. *Rep. int. Whal. Commn.* 42:457-460.

Buckland, S.T. and Turnock, B.J. 1992. A robust line transect method. *Biometrics* 48:901-909.

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.

CODA, 2009. Cetacean Offshore Distribution and Abundance in the European Atlantic. <http://biology.st-andrews.ac.uk/coda/>.

Gunnlaugsson *et al.* 2016. The 2015 North Atlantic Sightings survey (NASS 2015). Cruise report for the Icelandic and Faroese shipboard surveys.

Innes, S., Heide-Jørgensen, M. P., Laake, J. L., Laidre, K. L., Cleator, H. J., Richard, P. and Stewart, R. E. A. 2002. Surveys of belugas and narwhals in the Canadian High Arctic in 1996. *NAMMCO Scientific Publications* 4: 169-190.

Laake, J.L. and Borchers, D.L. 2004. 2005. Methods for incomplete detection at distance zero. In: Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. (eds) *Advanced Distance Sampling.* Oxford University Press, Oxford, U.K., pp. 108-189.

Pike, D.G and Gunnlaugsson, Th. 2006. Regional estimates of density and abundance of fin whales (*Balaenoptera physalus*) from Icelandic and Faroese North Atlantic Sightings Surveys. SC/14/FW/18

Pike, D.G., Gunnlaugsson, Th. and Víkingsson, G.A. 2006. An estimate of *g(0)* for the NASS-2001 survey for fin whales (*Balaenoptera physalus*) in Icelandic and Faroese waters. SC/14/FW/19 for the NAMMCO Scientific Committee.

Pike, D.G., Gunnlaugsson, Þ., Víkingsson, G.A. and Mikkelsen, B. 2008. Estimates of the abundance of fin whales (*Balaenoptera physalus*) from the T-NASS Icelandic and Faroese ship surveys conducted in 2007. IWC SC/60/PFI13.

Sanpera, C., & Jover, L. (1989). Density estimate of fin whales in the North Atlantic from NASS-87 Spanish cruise data. Rep. int. Whal. Commn, 39, 427-429.

Thomas, L., S.T. Buckland, E.A. Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R.B. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47: 5-14. DOI: 10.1111/j.1365-2664.2009.01737.x

Víkingsson, G.A., Pike, D.G., Desportes, G., Øien, N. and Gunnlaugsson, Th. 2009. Distribution and abundance of fin whales (*Balaenoptera physalus*) in the Northeast and Central Atlantic as inferred from the North Atlantic Sightings Surveys 1987-2001. *NAMMCO Sci. Publ.* 7:49-72.

Víkingsson, G.A., Pike, D.G., Schleimer, A., Valdimarsson, H., Gunnluagsson, Th., Silva, T. Elvarsson, B., Mikkelsen, B. Öien, N. Desportes, G., Bogason, V. and Hammond, P. 2015. Distribution, abundance and feeding ecology of rorqual cetaceans in Icelandic waters: have recent environmental changes had an effect? *Front. Ecol. Evol.* Doi: 10.3389/fevo.2015.00006

BLOCK	AREA (nm^2)	EFFORT (nm)			K		BP		BP?		BP??		BP_{ALL}	
		ALL	R	P	R	P	R	P	R	P	R	P	R	P
FC	77,857	1,150	1,150	979	6	5	12	12	13	12	12	12	**37**	**36**
FW	176,905	1,693	1,645	1,645	9	9	26	26	32	32	11	11	**69**	**69**
FW_E	63,351	718	686	686	8	8	6	6	10	10	4	4	**20**	**20**
FW_W	114,184	959	959	959	7	7	20	20	22	22	7	7	**49**	**49**
IE	108,052	962	937	914	18	17	1	1	7	7	0	0	**8**	**8**
IG	93,953	2,008	1,835	1,697	34	30	190	163	77	74	16	13	**283**	**250**
IP	139,515	1,014	871	871	5	5	15	15	8	8	4	4	**27**	**27**
IQ	75,631	504	504	504	5	5	14	14	8	8	9	9	**31**	**31**
IR	108,550	1,417	1,392	1,317	24	22	24	24	22	20	3	3	**49**	**47**
IW	32,312	909	847	847	13	13	75	75	32	32	15	15	**122**	**122**
SW	0	118	118	118	1	1	3	3	1	1	0	0	**4**	**4**
TOT-F	**254,762**	**2,844**	**2,795**	**2,624**	**15**	**14**	**38**	**38**	**45**	**44**	**23**	**23**	**106**	**105**
TOT-I	**558,013**	**6,931**	**6,503**	**6,267**	**100**	**93**	**322**	**295**	**155**	**150**	**47**	**44**	**524**	**489**
TOT	**812,775**	**9,775**	**9,298**	**8,891**	**115**	**107**	**360**	**333**	**200**	**194**	**70**	**67**	**630**	**594**

Table 1. Survey area, effort (BSS<=5) and sightings (BSS<=5) by stratum. Sightings are given for three levels of identification confidence: BP=high; BP?=medium, and BP??=low. Totals are given for the Faroese (F), Icelandic (I) and entire areas. R - using realized effort; P - using revised realized effort; K – number of transects.

ESTIMATE		TABLE	DS MODEL	MR MODEL
Confidence	**Effort**		**Covariates**	**Covariates**
ALL	ORIGINAL	3	*VESSPLATSIGHT* *VISIBILITY* *CLOUD*	*DISTxVESSOBS*
			SPECIES CERT	
ALL	REVISED	4	*VESSPLATSIGHT* *VISIBILITY* *CLOUD*	*DISTxVESSOBS*
			SPECIES CERT	
HIGH+MED	ORIGINAL	5	*VESSPLATSIGHT* *CLOUD*	*DISTxVESSOBS*
			VISIBILITY	
HIGH+MED	REVISED	6	*VESSPLATSIGHT*	*DISTxVESSOBS*
			VISIBILITY	

Table 2. Model specifications for fin whale abundance estimates. Confidence – Species identification confidence; Effort – Original or revised (see text); Table – Refers to table where estimate is given. DS Model – Distance model; MR Model – Mark recapture model. Covariate definitions in text.

Block	**n**	***n/L***	**cv**	***E(S)***	***cv***	***esw***	***f(0)***	**cv**	***D***	***Ns***	**cv**	**LCL**	**UCL**	***p*(0)**	**cv**	***Nc***	**cv**	**LCL**	**UCL**
FC	34	2.96E-02	0.26	1.94	0.29	1058.6	9.45E-04	0.16	5.01E-02	3,906	0.48	1,225	12,460			4,510	0.49	1,415	14,379
FW	64	3.89E-02	0.27	1.34	0.08	1044.5	9.57E-04	0.11	4.61E-02	8,161	0.33	3,934	16,929			9,459	0.33	4,544	19,693
FW_E	20	2.92E-02	0.27	1.14	0.13	1100.3	9.09E-04	0.21	2.79E-02	1,770	0.29	927	3,380			2,058	0.29	1,072	3,951
FW_W	44	4.59E-02	0.33	1.42	0.07	1021.0	9.79E-04	0.13	5.91E-02	6,752	0.40	2,702	16,879			7,820	0.40	3,124	1,957
IE	6	6.41E-03	0.71	1.00	0.00	1835.8	5.45E-04	0.25	3.23E-03	349	0.74	87	1,403			400	0.74	99	1,615
IG	229	1.25E-01	0.15	1.28	0.06	1663.3	6.01E-04	0.05	8.88E-02	8,342	0.15	6,178	11,265	0.86	0.03	9,685	0.16	7,093	13,225
IP	27	3.10E-02	0.58	1.13	0.06	1239.7	8.07E-04	0.15	2.62E-02	3,655	0.54	925	14,436			4,238	0.55	1,050	17,111
IQ	28	5.55E-02	0.64	1.28	0.09	1253.7	7.98E-04	0.16	5.26E-02	3,975	0.63	812	19,453			4,504	0.63	917	22,135
IR	42	3.02E-02	0.23	1.29	0.09	1357.5	7.37E-04	0.14	2.65E-02	2,879	0.34	1,453	5,703			3,233	0.33	1,655	6,315
IW	97	1.15E-01	0.16	1.47	0.10	1881.1	5.32E-04	0.06	8.29E-02	2,679	0.22	1,689	4,247			3,134	0.22	1,964	4,999
SW	3	2.54E-02	0.00	1.00	0.00	1940.8	5.15E-04	0.31	0.00E+00	0	0.00	0	0			0			
TOTAL	**530**					**1462.1**	**6.84E-04**	**0.04**	**4.18E-02**	**33,946**	**0.15**	**25,138**	**45,839**			**39,165**	**0.15**	**28,806**	**53,248**
TOTAL_PS	**530**					**1462.1**	**6.84E-04**	**0.04**	**4.22E-02**	**34,308**	**0.15**	**25,420**	**46,303**			**39,583**	**0.15**	**19,136**	**53,775**
E	**530**					**1462.1**	**6.84E-04**	**0.04**	**2.42E-02**	**6,026**	**0.33**	**2,774**	**13,092**			**6,968**	**0.34**	**3,210**	**15,127**
WI	**530**					**1462.1**	**6.84E-04**	**0.04**	**4.92E-02**	**16,285**	**0.24**	**9,821**	**27,004**			**18,691**	**0.24**	**11,244**	**31,072**
W	**530**					**1462.1**	**6.84E-04**	**0.04**	**5.01E-02**	**28,282**	**0.16**	**20,255**	**39,490**			**32,615**	**0.17**	**23,222**	**45,807**
EG	**530**					**1462.1**	**6.84E-04**	**0.04**	**5.14E-02**	**11,997**	**0.20**	**7,698**	**18,697**			**13,936**	**0.20**	**8,846**	**21,954**

Table 3. Estimated density and abundance of fin whales identified with high, medium and low confidence from the combined platforms using all effort sailed under acceptable conditions. Totals are shown for original and post-stratified (PS) blocks. *n*- number of sightings; *L* – effort (nm); *E(S)*- group size; esw – effective search half width (m); *f(0)* – probability density of the detection function at distance 0; *D*- density of animals (number nm^{-2}; *N*- abundance, N_s uncorrected for perception bias, N_c corrected for perception bias; LCL and UCL – upper and lower confidence limits; *p*(0) – probability of detection at distance

0.

Block	n	*n/L*	cv	*E(S)*	cv	*esw*	*f(0)*	cv	*D*	*Ns*	cv	LCL	UCL	*p(0)*	cv	*Nc*	cv	LCL	UCL
FC	33	3.37E-02	0.21	1.95	0.29	1036.4	9.65E-04	0.16	5.89E-02	4,582	0.47	1,378	15,228			5,281	0.47	1,591	17,525
FW	64	3.89E-02	0.27	1.34	0.08	1034.0	9.67E-04	0.11	4.67E-02	8,258	0.33	3,993	17,078			9,523	0.33	4,577	19,814
FW_E	20	2.92E-02	0.27	1.13	0.12	1091.8	9.16E-04	0.21	2.81E-02	1,778	0.29	933	3,386			2,064	0.29	1,078	3,953
FW_W	44	4.59E-02	0.33	1.42	0.07	1009.8	9.90E-04	0.13	6.00E-02	6,850	0.40	2,750	17,063			7,917	0.40	3,172	19,759
IE	6	6.57E-03	0.71	1.00	0.00	1882.3	5.31E-04	0.24	3.23E-03	349	0.72	89	1,376			404	0.72	102	1,596
IG	199	1.17E-01	0.16	1.51	0.17	1613.2	6.20E-04	0.05	1.02E-01	9,550	0.22	6,132	14,875	0.87	0.03	8,900	0.16	6,396	12,385
IP	27	3.10E-02	0.58	1.13	0.06	1242.7	8.05E-04	0.16	2.62E-02	3,652	0.53	934	14,274			5,746	0.76	912	36,220
IQ	28	5.55E-02	0.64	1.27	0.06	1256.5	7.96E-04	0.16	5.21E-02	3,938	0.62	818	18,963			4,458	0.63	920	21,591
IR	40	3.04E-02	0.24	1.30	0.07	1321.5	7.57E-04	0.15	2.78E-02	3,011	0.36	1,462	6,201			3,381	0.35	1,669	6,850
IW	97	1.15E-01	0.16	1.46	0.09	1889.9	5.29E-04	0.06	8.22E-02	2,656	0.22	1,679	4,201			3,095	0.22	1,943	4,928
SW	3	2.54E-02	0.00	1.00	0.00	2061.1	4.85E-04	0.29	0.00E+00	0	0.00	0	0			0			
TOTAL	**497**					**1430.9**	**6.99E-04**	**0.04**	**4.43E-02**	**35,995**	**0.15**	**26,588**	**48,731**			**40,788**	**0.17**	**28,476**	**58,423**
TOTAL_PS	**497**					**1430.9**	**6.99E-04**	**0.04**	**4.47E-02**	**36,366**	**0.15**	**26,878**	**19,202**			**41,245**	**0.17**	**28,854**	**58,957**
E	**497**					**1430.9**	**6.99E-04**	**0.04**	**2.69E-02**	**6,708**	**0.34**	**2,921**	**15,408**			**9,993**	**0.33**	**4,995**	**19,989**
WI	**497**					**1430.9**	**6.99E-04**	**0.04**	**4.98E-02**	**16,455**	**0.23**	**9,978**	**27,137**			**18,850**	**0.24**	**11,394**	**31,187**
W	**497**					**1430.9**	**6.99E-04**	**0.04**	**5.26E-02**	**29,657**	**0.16**	**21,210**	**41,469**			**33,497**	**0.20**	**22,233**	**50,466**
EG	**497**					**1430.9**	**6.99E-04**	**0.04**	**5.65E-02**	**13,202**	**0.22**	**8,369**	**20,825**			**14,646**	**0.32**	**6,726**	**31,894**

Table 4. Estimated density and abundance of fin whales identified with high, medium and low confidence from the combined platforms, using revised (see text) effort sailed under acceptable conditions. Totals are shown for original and post-stratified (PS) blocks. *n*- number of sightings; *L* – effort (nm); *E(S)*- group size; esw – effective search width (m); *f(0)* – probability density of the detection function at distance 0; *D*- density of animals (number nm^{-2}; *N*- abundance, N_s uncorrected for perception bias, N_c corrected for perception bias; LCL and UCL – upper and lower confidence limits; *p*(0) – probability of detection at distance 0.

Block	n	*n/L*	cv	*E(S)*	cv	*esw*	*f(0)*	cv	*D*	*Ns*	cv	LCL	UCL	*p*(0)	cv	*Nc*	cv	LCL	UCL
FC	22	1.91E-02	0.33	2.30	0.33	1017.1	9.83E-04	0.20	4.00E-02	3,112	0.56	845	11,462			3,482	0.56	945	12,827
FW	53	3.22E-02	0.27	1.39	0.09	1085.1	9.22E-04	0.13	3.81E-02	6,736	0.33	3,280	13,832			7,560	0.33	3,662	15,610
FW_E	16	2.33E-02	0.23	1.16	0.14	1124.2	8.90E-04	0.24	2.22E-02	1,410	0.29	746	2,663			1,585	0.29	833	3,018
FW_W	37	3.86E-02	0.34	1.48	0.08	1069.1	9.35E-04	0.15	4.94E-02	5,640	0.40	2,258	14,086			6,326	0.40	2,525	15,854
IE	6	6.41E-03	0.71	1.00	0.00	1767.4	5.66E-04	0.25	3.36E-03	363	0.74	91	1,448			402	0.74	100	1,610
IG	217	1.18E-01	0.15	1.29	0.06	1607.3	6.22E-04	0.05	8.76E-02	8,227	0.15	6,087	11,119	0.89	0.03	9,248	0.15	6,778	12,618
IP	23	2.64E-02	0.61	1.14	0.06	1144.7	8.74E-04	0.17	2.44E-02	3,403	0.56	814	14,222			3,804	0.57	891	16,238
IQ	22	4.36E-02	0.67	1.29	0.06	1137.9	8.79E-04	0.18	4.59E-02	3,469	0.70	613	19,633			3,806	0.70	670	21,618
IR	39	2.80E-02	0.26	1.29	0.09	1305.9	7.66E-04	0.14	3.36E-03	2,786	0.35	1,374	5,649			3,027	0.35	1,512	6,062
IW	86	1.02E-01	0.16	1.51	0.10	1812.3	5.52E-04	0.07	7.83E-02	2,529	0.22	1,595	4,012			2,866	0.22	1,796	4,571
SW	3	2.54E-02	0.00	1.00	0.00	1901.8	5.26E-04	0.32	0.00E+00	0	0.00	0	0			0			
TOTAL	**471**					**1439.5**	**6.95E-04**	**0.04**	**3.77E-02**	**30,625**	**0.15**	**22,517**	**41,652**			**34,194**	**0.15**	**25,020**	**46,733**
TOTAL_PS	**471**					**1439.5**	**6.95E-04**	**0.04**	**3.80E-02**	**30,939**	**0.15**	**22,729**	**42,114**			**35,937**	**0.18**	**24,985**	**51,690**
E	**471**					**1439.5**	**6.95E-04**	**0.04**	**2.00E-02**	**4,884**	**0.38**	**2,058**	**11,592**			**5,108**	**0.40**	**2,035**	**12,822**
WI	**471**					**1439.5**	**6.95E-04**	**0.04**	**4.40E-02**	**14,425**	**0.24**	**8,567**	**24,287**			**16,039**	**0.25**	**9,520**	**27,024**
W	**471**					**1439.5**	**6.95E-04**	**0.04**	**4.60E-02**	**26,054**	**0.16**	**18,605**	**34,487**			**30,464**	**0.19**	**20,284**	**45,754**
EG	**471**					**1439.5**	**6.95E-04**	**0.04**	**5.00E-02**	**11,630**	**0.20**	**7,443**	**18,172**			**14,425**	**0.29**	**6,982**	**29,801**

Table 5. Estimated density and abundance of fin whales identified with high and medium confidence from the combined platforms using all effort sailed under acceptable conditions. Totals are shown for original and post-stratified (PS) blocks. *n*- number of sightings; *L* – effort (nm); *E(S)*- group size; esw – effective search width (m); *f(0)* – probability density of the detection function at distance 0; *D*- density of animals (number nm^{-2}; *N*- abundance, N_s uncorrected for perception bias, N_c corrected for perception bias; LCL and UCL – upper and lower confidence limits; *p*(0) – probability of detection at distance 0

Block	n	*n/L*	cv	*E(S)*	cv	*esw*	*f(0)*	cv	*D*	*Ns*	cv	LCL	UCL	*p*(0)	cv	*Nc*	cv	LCL	UCL
FC	21	2.14E-02	0.31	2.27	0.33	1016.0	9.84E-04	0.21	4.45E-02	3,462	0.54	913	13,133			4,076	0.55	1,031	16,122
FW	53	3.22E-02	0.27	1.41	0.09	1119.7	8.93E-04	0.12	3.76E-02	6,644	0.33	3,252	13,573			7,622	0.33	3,703	15,688
FW_E	16	2.33E-02	0.23	1.15	0.13	1164.0	8.59E-04	0.23	2.14E-02	1,354	0.27	739	2,480			1,582	0.55	1,028	16,088
FW_W	37	3.86E-02	0.34	1.51	0.09	1101.6	9.08E-04	0.15	4.91E-02	5,611	0.40	2,250	13,994			6,408	0.40	2,572	15,965
IE	6	6.57E-03	0.71	1.00	0.00	1885.0	5.31E-04	0.24	3.22E-03	348	0.71	90	1,350			410	0.72	105	1,600
IG	190	1.12E-01	0.16	1.52	0.17	1560.3	6.41E-04	0.05	1.01E-01	9,509	0.22	6,066	14,905	0.89	0.03	8,587	0.16	6,171	11,948
IP	23	2.64E-02	0.61	1.14	0.07	1218.0	8.21E-04	0.16	2.30E-02	3,207	0.56	771	13,329			5,155	0.77	794	33,467
IQ	22	4.36E-02	0.67	1.30	0.07	1170.4	8.54E-04	0.17	4.50E-02	3,400	0.71	590	19,601			3,760	0.70	668	21,173
IR	37	2.81E-02	0.27	1.31	0.09	1243.8	8.04E-04	0.15	2.74E-02	2,979	0.37	1,428	6,218			3,133	0.36	1,522	6,447
IW	86	1.02E-01	0.16	1.48	0.10	1825.0	5.48E-04	0.07	7.65E-02	2,473	0.21	1,597	3,829			2,863	0.22	1,796	4,563
SW	3	2.54E-02	0.00	1.00	0.00	2158.2	4.63E-04	0.27	0.00E+00	0	0.00	0	0			0			
TOTAL	**441**					**1427.6**	**7.00E-04**	**0.04**	**3.74E-02**	**32,022**	**0**	**23,472**	**43,686**			**35,605**	**0.18**	**24,615**	**51,502**
TOTAL_PS	**441**					**1427.6**	**7.00E-04**	**0.04**	**3.80E-02**	**32,342**	**0.15**	**23,685**	**44,164**			**35,914**	**0.18**	**24,854**	**51,895**
E	**441**					**1427.6**	**7.00E-04**	**0.04**	**2.10E-02**	**5,164**	**0.37**	**2,071**	**12,880**			**6,071**	**0.39**	**2,359**	**15,625**
WI	**441**					**1427.6**	**7.00E-04**	**0.04**	**4.40E-02**	**14,463**	**0.24**	**8,619**	**24,269**			**16,177**	**0.24**	**9,659**	**27,094**
W	**441**					**1427.6**	**7.00E-04**	**0.04**	**4.80E-02**	**27,178**	**0.17**	**19,347**	**38,179**			**29,919**	**0.20**	**19,790**	**45,232**
EG	**441**					**1427.6**	**7.00E-04**	**0.04**	**5.40E-02**	**12,715**	**0.22**	**8,070**	**20,034**			**13,742**	**0.31**	**6,432**	**29,356**

Table 6. Estimated density and abundance of fin whales identified with high and medium confidence from the combined platforms using revised (see text) effort sailed under acceptable conditions. Totals are shown for original and post-stratified (PS) blocks. *n*- number of sightings; *L* – effort (nm); *E(S)*- group size; esw – effective search width (m); *f(0)* – probability density of the detection function at distance 0; *D*- density of animals (number nm^{-2}; *N*- abundance, N_s uncorrected for perception bias, N_c corrected for perception bias; LCL and UCL – upper and lower confidence limits; *p*(0) – probability of detection at distance 0

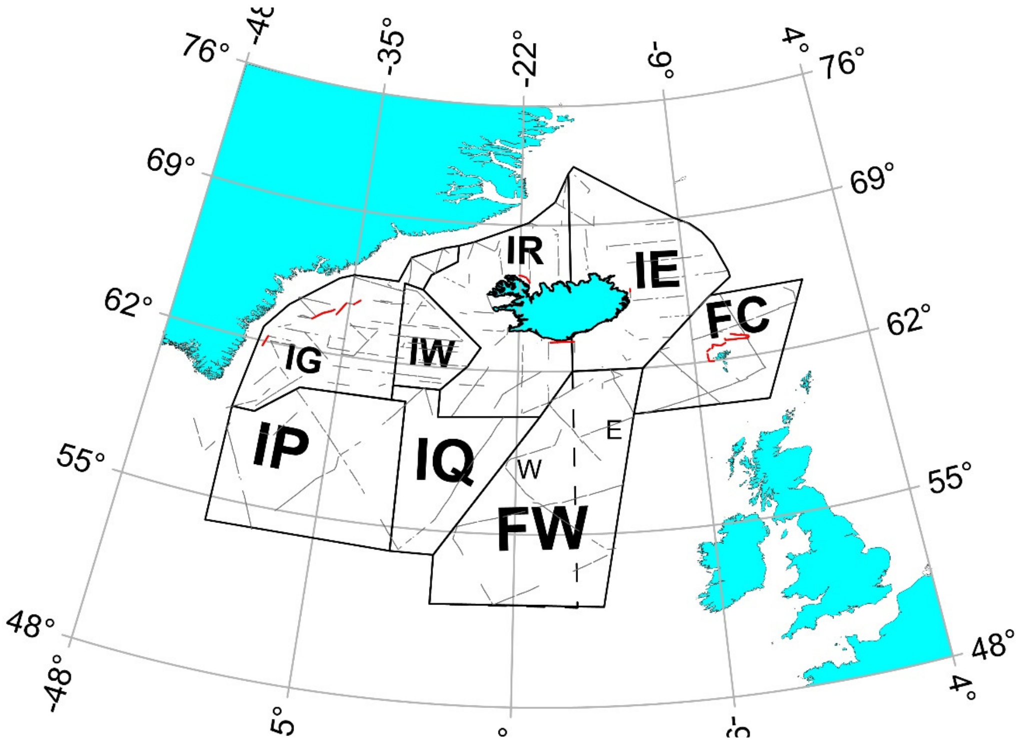

Fig. 1. Stratification and realized survey effort (BSS<=5) of NASS-2015. Dashed line shows post-stratification of FW into FW_W and FW_E. Effort shown in red was removed for "revised" abundance estimates

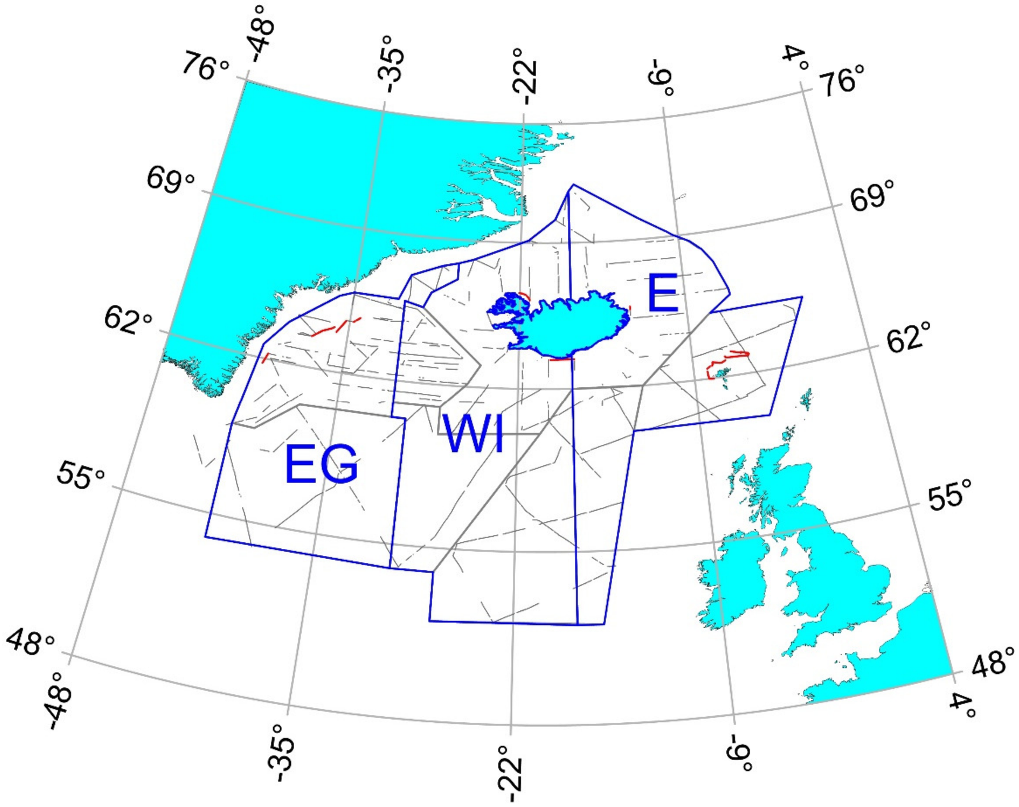

Fig. 2. Regional estimates provided. Region W (not shown) is the combination EG + WI.

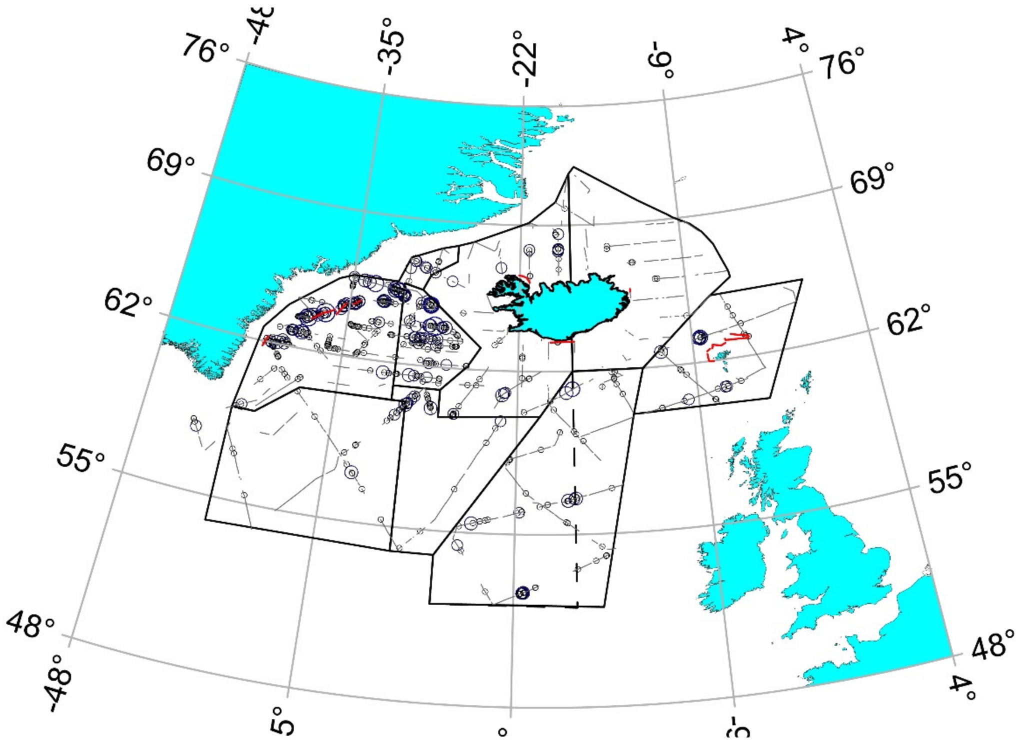

Fig.3. Sightings of fin whales (BSS<=5). Symbol size is proportional to group size in the range of 1 to 7.

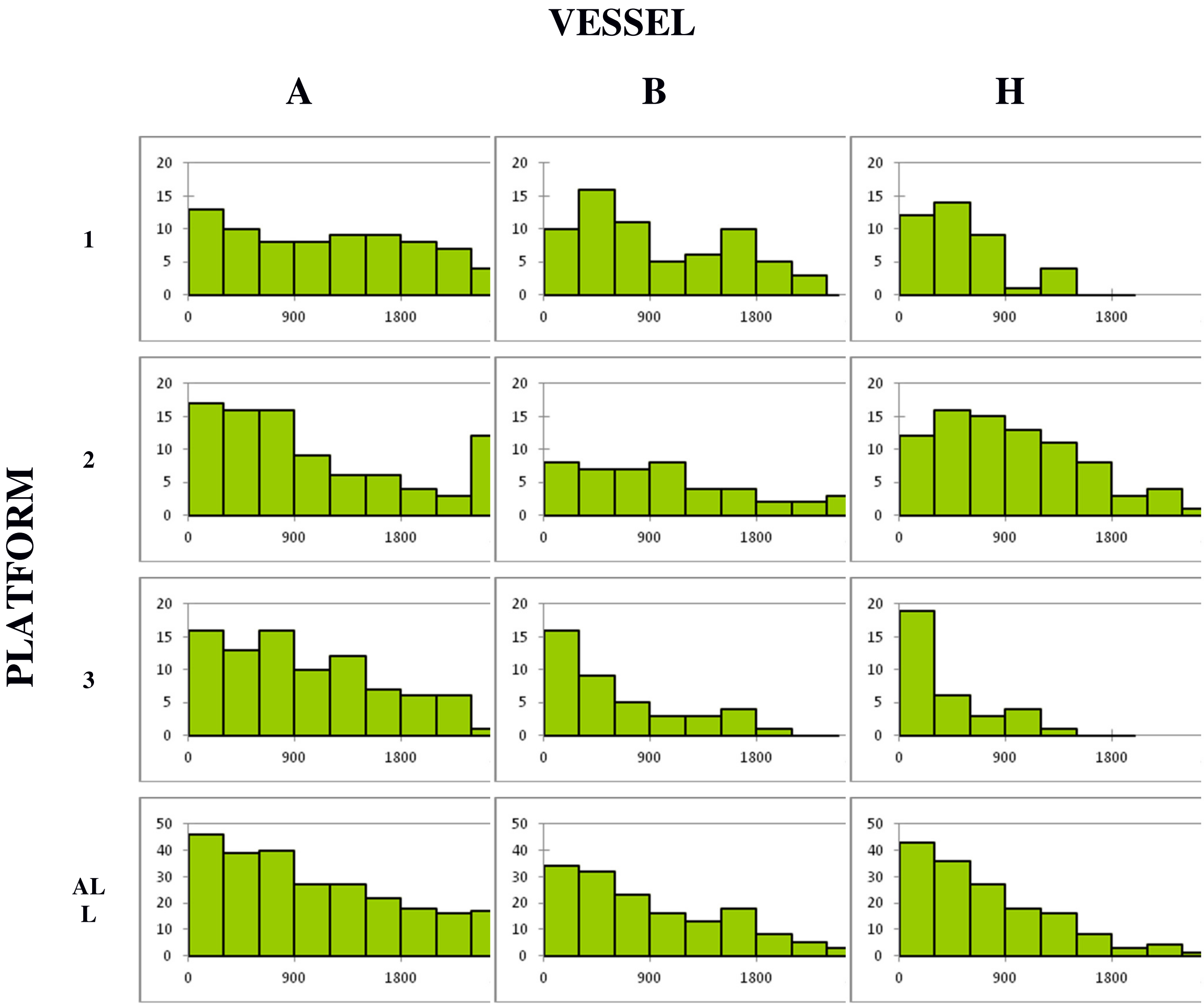

Fig. 4. Effect of vessel and vessel platform on the detection function. "Platform" is the observation platform that detected the sighting: 1 is lower on vessels A and B, starboard on vessel H; 3 is both platforms (duplicate sighting).