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SUMMER ABUNDANCE OF HARBOUR PORPOISES (PHOCOENA PHOCOENA) IN THE COASTAL WATERS OF ICELAND AND THE FAROE ISLANDS

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ABSTRACT

This study presents the first fully corrected abundance estimates for the harbour porpoise (*Phocoena phocoena*) for Iceland and the Faroe Islands. In both regions reliable estimates are needed to assess the impact of by-catch and other threats to harbour porpoises. Aerial surveys with harbour porpoise as a secondary and main target species were conducted in the summers of 2007 and 2010 in Icelandic and in Faroese coastal waters respectively. In Iceland, the cue counting procedure was used (which also produces the data required for line transect analysis), while in the Faroese, standard line transect sampling was applied, following the SCANS-II (Small Cetacean Abundance in the North Sea) survey protocol. In both surveys, identical aircraft surveyed at an altitude of 600 ft and a speed of 90–100 kn. Only data collected during Beaufort Sea States (BSS) lower than 3 and during good or moderate porpoise sighting conditions were used for abundance estimates. Abundance estimates were corrected using stratified estimates of *esw* (incorporating g*(0)*) values derived during the SCANS-II survey in 2005 as principal observers took part in this survey as well. In Iceland, realised effort in good or moderate harbour porpoise sighting conditions totalled 8,289 km in 13 survey strata, where 77 sightings (109 individuals) were made by the experienced harbour porpoise observer only. In Faroese waters, only part of the area inside the 300 m depth curve could be surveyed and 1,564 km were surveyed in good or moderate porpoise sighting conditions, yielding 39 sightings (49 individuals). The total abundance estimates were 43,179 porpoises (CV=0.45; 95% CI: 31,755–161,899) for Icelandic coastal waters and 5,175 porpoises (CV=0.44; 95% CI: 3,457–17,637) for Faroese waters.

Keywords: harbour porpoise, abundance estimate, Iceland, Faroe Islands, aerial survey, distance sampling, cetacean

INTRODUCTION

The Icelandic aerial survey component of the T-NASS project (Trans-North Atlantic Sightings Survey) carried out in summer 2007 was a continuation of a series of surveys using nearly identical design and methodology conducted in 1987, 1995 and 2001 (Pike, Paxton, Gunnlaugsson & Víkingsson, 2009) and later in 2009, 2015 and 2016 (Pike, Gunnlaugsson, Sigurjónsson & Víkingsson, 2020). The main target species of these surveys has been the common minke whale (*Balaenoptera acutorostrata*), however, sightings of all species are registered. Pike et al. (2020) present abundance estimates corrected to the extent feasible for known biases for common minke whale, humpback whale (*Megaptera novaeangliae*) and white-beaked dolphin (*Lagenorhynchus albirostris*) from the 2007 aerial survey around Iceland. However, despite it being the most frequently sighted species in the 2007 survey, no estimate has yet been developed for the harbour porpoise (*Phocoena phocoena*), which is one of the smallest cetacean species and, due to its elusive behaviour at the water surface, very difficult to sight from any survey platform (Teilmann, 2003; Gilles, Scheidat & Siebert, 2009).

The situation is similar for waters around the Faroe Islands, where no historical or current estimates of harbour porpoise abundance are available. The Faroese aerial survey in 2010, which was the first ever and the first dedicated survey undertaken for harbour porpoises in these waters, should be considered a pilot survey.

The stock structure of harbour porpoises in the north-eastern and central North Atlantic is still poorly known. Present delineations are largely operational and based on conservative assumptions. A recent international workshop on harbour porpoise stock structure and status recommended the use of separate assessment units (AU) for Iceland and the Faroe Islands, with both being distinct from the AUs of Greenland, western Scotland and the North Sea (North Atlantic Marine Mammal Commission and Norwegian Institute for Marine Research [NAMMCO & IMR], 2019). It was, however, also acknowledged that this delineation was precautionary since there is a lack of information on stock structure of porpoises around the Faroes and Greenland and the wider NE Atlantic.

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Although there is practically no direct hunting for harbour porpoises in Icelandic waters, there is significant by-catch, particularly in the gillnet fisheries for cod and lumpfish. Preliminary estimates of the by-catch levels in the cod gillnet fishery indicated that annual by-catch numbers may have been around 1,000 in 2003–2004 but decreased with decreasing fishing effort to around 400 in 2007–2009 (Ólafsdóttir, 2010). The most recent estimate of by-catch in the cod gillnet fishery is 811 (95% CI: 575–1065 animals) (Marine Freshwater Research Institute [MFRI], 2020), confirming a large decrease in by-catch in recent years in agreement with reduced fishing effort in the cod gillnet fishery (Ólafsdóttir 2010; Pálsson, Gunnlaugsson & Ólafsdóttir, 2015). Adding estimated by-catch from other fisheries (MFRI, 2019, 2020), the best estimate of total annual by-catch of harbour porpoises in Icelandic waters is around 1,300 animals. Although these numbers are highly uncertain and could be improved, they demonstrate a potential conservation concern and the need for better estimates of harbour porpoise abundance around Iceland, as well as more precise estimates of by-catch levels in the Icelandic fishery.

Current knowledge about direct and by-catch mortality in the Faroese AU is inadequate and no reliable hunting statistics are available (NAMMCO & IMR, 2019). However, there are indications that current mortality is low given low interest in hunting (Larsen, 1995) and because there are no commercial gillnet fisheries inside the 380 m depth contour (Mikkelsen, 2016); the only reported by-catch being a single animal caught on longlines during depredation (Mikkelsen, 2016).

Some information on the distribution and abundance of harbour porpoises in Icelandic and Faroese waters is available from previous North Atlantic Sightings Surveys (NASS). Harbour porpoises have been sighted in all ship and aerial surveys conducted as part of the NASS (see map at NAMMCO, 2018), but these surveys have not used the specialised survey protocols and design required to produce reliable abundance estimates for this species.

Robust estimates of harbour porpoise abundance are urgently needed to evaluate the effect of by-catch, as well as potential impacts from other human activities such as whale watching, depletion of prey stocks due to overfishing, disturbance from noise, chemical pollution, as well as their cumulative effects. Here, we present corrected absolute abundance estimates for harbour porpoises from the 2007 aerial survey in Icelandic waters and from the 2010 pilot aerial survey in Faroese waters.

MATERIALS AND METHODS

<u>Survey design</u>

The Icelandic survey design (Figure 1) was identical to that used in 2001 (Pike et al., 2009), except that additional effort was applied to some fjord areas (see below). All areas were surveyed using an equally spaced zig-zag pattern, except for the fjords where randomly placed, diagonally oriented equally spaced parallel lines were designed using the program DISTANCE v. 6.2 (Thomas et al., 2010). A total effort of 11,940 km (6,447 nm) was planned to cover the study area of 294,377 km^2 (85,717 nm^2).

For the study area in Faroese waters, 6 strata were designed: 3 inshore strata (I1–I3) and 3 offshore strata (O1–O3) (Figure 2). The outer bounds of the inshore strata line up the 300 m depth contour. The decision for this line up was to keep a clear definition of inshore and offshore waters. Allocated effort was higher in the inshore strata, due to an expected higher density there. Equally-spaced parallel transects with a randomly chosen starting point, such that all areas within strata had an equal chance of being surveyed, were designed using the program DISTANCE v. 6.2 (Thomas et al., 2010). Transects were oriented roughly parallel to depth gradients to the extent possible. This resulted in a total planned effort of 4,656 km (2,514 nm) in the 116,793 km^2 (34,250 nm^2) study area.

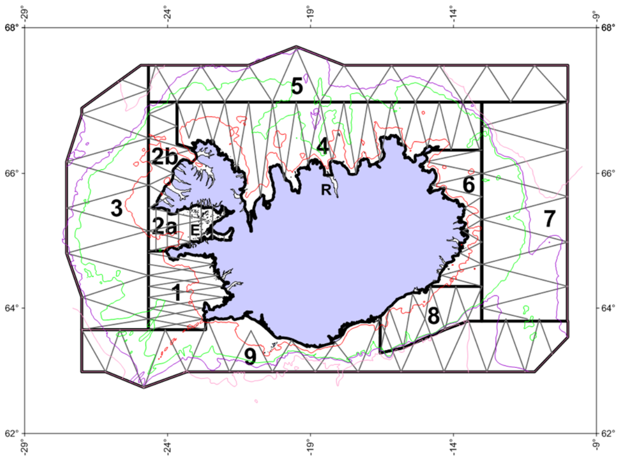

Figure 1. Planned survey design for the 2007 aerial survey around Iceland. The numbers identify the strata, the letters the fjords (see Table 1). Isobaths shown are (in m) 100 (red), 300 (green), 500 (purple) and 1,000 (pink).

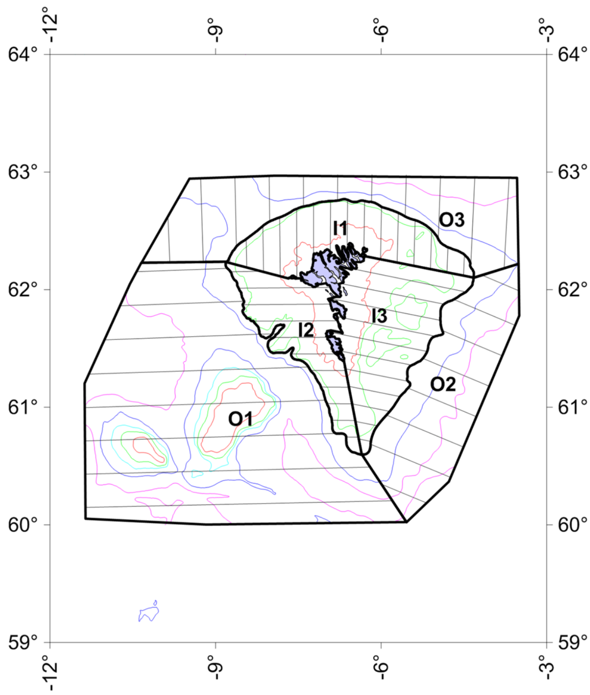

Figure 2. Overview of planned survey strata and transect lines for the 2010 aerial survey around the Faroe Islands. The letters identify the 6 strata. Depth contours shown (in m) are 100 (red), 200 (green), 300 (black), 500 (purple) and 1,000 (pink).

Data collection

In both surveys, the same aircraft was used: a Partenavia P68, twin-engine, high-wing aircraft equipped with 2 bubble windows to allow scanning directly underneath the plane (Figure 3). Surveys were flown at an altitude of 600 ft with a target ground speed of 90–100 kn (167–185 km h^{-1}), however, this varied somewhat with wind direction and speed. One of the principal observers took part in both surveys and 2 of the observers in the Faroese survey took part in SCANS-II. In SCANS-II, and other dedicated harbour porpoise aerial surveys, the circle-back or "racetrack" method of Hiby (1999) was applied to collect data, from which correction could be made for the fraction missed on the transect line (commonly known as g*(0)*). However, in both the Icelandic and Faroese surveys discussed here, the circle-back procedure could not be implemented; in the Icelandic survey due to the choice of cue counting protocol and in the Faroese survey due to logistics and bad weather conditions that would not have allowed for the collection of the large number of "recaptures" needed to estimate capture probability reliably (Scheidat, Gilles, Kock & Siebert, 2008; Gilles et al., 2009; Gilles et al., 2016).

Figure 3. Survey crew and pilot of the 2007 survey in Iceland. The same aircraft, a Partenavia P-68 Observer with 1 set of bubble windows, was also used in the Faroese survey in 2010. (Photo by Daniel Pike).

Icelandic aerial survey

A complete description of the methodology used in the 2007 Icelandic aerial survey is provided by Pike et al. (2020). The cue counting procedure (Hiby & Hammond, 1989) has generally been used only for common minke and fin (*Balaenoptera physalus*) whales while for other species, standard line transect methods are used (Buckland et al., 2001). The cue counting field protocol, as used in the 2007 Icelandic aerial survey (Pike et al., 2020), generates data that can be used in both types of analysis.

In 2007, while the minke whale was still the primary target species as in previous Icelandic surveys, the following three changes were adopted to improve the survey performance for the secondary target species, the harbour porpoise. In previous years, the survey was flown at 750 ft (229 m) while in 2007 the survey altitude was 600 ft (183 m) as this is the preferred altitude used during the SCANS surveys (Hammond et al., 2002) and other dedicated harbour porpoise surveys (e.g. Gilles et al., 2009). 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 and Baltic Sea. Additional effort was allocated to 4 fjords (Ísafjörður, Eyjafjörður, Breiðafjörður and Reyðarfjörður), using diagonally oriented equally spaced parallel lines, to assess whether harbour porpoises were concentrated in these fjords.

Faroese aerial surveys

In the Faroese surveys, standard line transect distance sampling methodology was applied (Buckland et al., 2001). Details on field protocol can be found in Gilles et al. (2009). This was the same protocol as that used during the SCANS-II aerial survey in 2005 (Hammond et al., 2013), for which the target species had been the harbour porpoise. However, data were collected for all species encountered so long as this did not compromise data collection for the target species. The survey team consisted of 2 observers and 1 data recorder (navigator; sitting in the co-pilot's seat). All 3 team members were highly experienced observers in harbour porpoise surveys. Sighting data were acquired simultaneously by the 2 principal observers, each positioned on one side of the aircraft at a bubble window. Observers and data recorder rotated during breaks, i.e. every 2–3 hours. The data recorder entered all reported data directly into a laptop computer running dedicated data collection software and interfaced with a Global Positioning System (GPS). Communication between all team members was ensured via the intercom system.

Data collection was based on the "VOR" software described by Hammond et al. (1995). The aircraft's position was stored every 2 seconds. Additionally, the start and end positions of the transect lines and the exact sighting positions were recorded. Surveys were only conducted during Beaufort Sea States (BSS) lower than 3 and with visibilities greater than 5 km. Environmental conditions were recorded at the beginning of each transect and updated with any change. The following conditions were recorded: (1) BSS, (2) water turbidity (judged visually from 0, clear water with several meters of visibility, to 2, very turbid, no visibility under the surface), (3) percentage of cloud cover, and for each observer side, (4) glare (angle obscured by glare and intensity of glare), and (5) the observer's subjective view of the likelihood that, given all of the conditions, they would see a harbour porpoise should one be present (judged as good, moderate or poor). Sighting data included declination angle (measured using hand-held inclinometers) from the aircraft abeam to the porpoise group, group size, presence of calves, behaviour, swimming direction, cue and any reaction to the survey plane. The perpendicular distances from the transect to the group were later calculated from aircraft altitude and declination angle.

Data analysis

Survey data were filtered to only include transect segments flown in "good" or "moderate" conditions for sighting porpoises.

The following only applies to the Icelandic data: During the Icelandic survey, the information about porpoise sighting conditions was not consistently available during the first 2 survey days. For those days, only data collected at BSS<3 were used. An additional 9 sightings did not have recorded porpoise sighting conditions, and for these we derived the sighting condition post-survey, based on the other recorded environmental factors like BSS and glare. 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 and Baltic Sea. This specialist porpoise observer also recorded the subjective assessment of porpoise sightings conditions and this assessment was used as an analytical covariate as done successfully in SCANS-II. As this observer proved far more effective at sighting porpoises than the other observer, we decided to use only sightings from the experienced porpoise observer when estimating abundance. Therefore, as part of a one-sided survey analysis, effective effort realised in good or moderate conditions was divided by 2 to adjust for one-sided effort.

Estimation of abundance

Since the experienced porpoise observer in the Icelandic survey, and two of the observers in the Faroese survey, also participated in SCANS-II, we used the SCANS-II estimate for total effective strip width (*esw*), taking account of detection probability less than 1 on the transect line (i.e. g*(0)*), to estimate harbour porpoise absolute abundance in the 2 respective aerial surveys in Iceland and the Faroe Islands.

During SCANS-II, as well as in dedicated surveys in German and Dutch waters, the aircraft surveyed using the Hiby "racetrack" design (Hiby, 1999), which involves some circling back to re-survey a defined segment of the transect (see Scheidat et al., 2008 for details). This method, an adaptation of the method developed for tandem aircraft (Hiby & Lovell, 1998), allows estimation of *esw*, taking into account both the availability and the perception bias (Marsh & Sinclair, 1989; Laake, Calambokidis, Osmek & Rugh, 1997); i.e. Hiby's definition of *esw* already incorporates g*(0)*. Synchronous recording of GPS and porpoise subjective sighting conditions allowed the assignment of sighting locations to sections of effort completed under consistent conditions and, therefore, the estimates of *esw* appropriate to those conditions could be specifically applied. The subjective assessment of good and moderate conditions (see above), assessed separately to the left and right of the transect since conditions could differ between observer sides, was chosen to define the sections completed under consistent conditions.

For the SCANS-II aerial surveys, the total effective strip width (i.e. both sides of the transect) was estimated to be 165 m (CV=0.225) under good conditions and 122 m (CV=0.235) under moderate conditions, incorporating g*(0)* values of 0.39 and 0.29, respectively (Hiby, 2006). Given that we aimed to provide an abundance estimate as robust and precise as possible, we decided to apply these *esw* estimates based on data collected by the SCANS-II aerial survey teams 2 and 3. Firstly, the observers for our study had participated in SCANS-II team 2 and, secondly, *esw* estimates had much smaller CVs in comparison to an increase in CVs when including SCANS-II team 1 in the global estimate (Hiby, 2006).

In order to further ground-truth the applicability of using correction from a different porpoise survey, we also fitted detection functions to the sighting data collected in the Icelandic and Faroese surveys.

There was no group size-bias (e.g. due to detecting less small groups at larger distances) detected during SCANS-II (Burt, Borchers & Samarra, 2006a), in the harbour porpoise monitoring surveys conducted in German waters (Scheidat et al., 2008; Gilles et al., 2009), or in this study. Thus, mean group size was estimated using the mean of the observed group sizes separately within each stratum. Mean group size under good conditions was 1.46 (SD=0.61) in the Icelandic and 1.28 (SD=0.70) in the Faroese surveys, under moderate conditions 1.32 (SD=0.78) and 1.20 (SD=0.42) respectively.

Animal abundance in stratum v was estimated as:

$$\hat{N}_v = \frac{A_v}{L_v}\left(\frac{n_{gsv}}{\hat{\mu}_g} + \frac{n_{msv}}{\hat{\mu}_m}\right)\bar{s}_v$$

Where A_v is the area of the stratum, L_v is the length of transect lines covered on-effort in good or moderate conditions, n_{gsv} is the number of sightings that occurred in good conditions in the stratum, n_{gsm} is the number of sightings that occurred in moderate conditions in the stratum, $\hat{\mu}_g$is the estimated *esw* in good conditions, $\hat{\mu}_m$ is the estimated *esw* in moderate conditions and $\bar{s}_v$ is the mean observed group size in the stratum.

Group abundance by stratum was estimated by:

$$\hat{N}_{v(group)} = \hat{N}_v / \bar{s}_v$$

Total animal abundances were estimated by:

$$\hat{N} = \sum_v \hat{N}_v$$

Total group abundances were estimated by:

$$\hat{N}_{(group)} = \sum_v \hat{N}_{v(group)}$$

Densities were estimated by dividing the abundance estimates by the area of the associated stratum.

Coefficients of variation (CVs) and 95% confidence intervals (CIs) were estimated by non-parametric bootstrapping (999 replicates) within strata, using transects as the sampling units. The variance due to estimation of *esw* was incorporated using a procedure that assumes that the *esw* estimates in good and moderate conditions are log-normally distributed random variables (see also Hiby & Lovell, 1998 and Scheidat et al., 2008). Therefore, for each bootstrap pseudo-sample of transect lines, a bivariate log-normal random variable was generated from a distribution with mean and variance-covariance matrix equal to those estimated, i.e. $\hat{\mu} = (0.165, 0.122)$ and

$$\hat{\Sigma} = \begin{pmatrix} 0.0372^2 & 0.000896 \\ 0.000896 & 0.0289^2 \end{pmatrix}$$

This constitutes *esw*s for the pseudo-sample. 95% CIs were calculated using the percentile method (see Burt et al., 2006a).

RESULTS

Abundance estimates

This study could not produce viable double platform data from either survey and therefore, we decided to apply the SCANS-II correction estimates, as stratified for good and moderate sighting conditions (see above), since our experienced observers took part in SCANS-II aerial surveys and were trained to apply the definition of these subjective sighting conditions in a comparable manner. Also, the shape of (hazard rate) detection function fitted to the sighting data collected in the Icelandic and Faroese surveys (Supplementary File 1) was similar to the one fitted to SCANS-II aerial survey data (see Hiby, 2006; Hammond et al., 2013).

Iceland

The aerial survey around Iceland was conducted between 23 June and 20 July 2007. Total realised effort was 79% of planned effort and 95% of realised effort was flown at BSS 3 or less (Pike et al., 2020). Realised effort in good or moderate harbour porpoise sighting conditions totalled 8,289 km and presented 88% of realised effort (Table 1). A total of 77 sightings with 109 individuals (of these 8 calves) were made by the experienced harbour porpoise observer only (Figure 4, Table 1), resulting in a one-side encounter rate of 0.02 sightings km^{-1}. Highest densities were estimated in block 2A (Breiðafjörður) and 2B as well as in stratum 6, the eastern inshore stratum (Table 2).

Table 1. Surface area of blocks, realised effort for the 2007 Icelandic aerial survey, and overview of harbour porpoise sightings. Only effort in good or moderate porpoise sighting conditions and only harbour porpoise sightings by the experienced porpoise observer are shown. Fjords: 2A = Breiðafjörður, E= Eyjafjörður, R= Reyðarfjörður

Block	Area (km^2)	Total line length (km)	One-sided effort (km)	No. sightings	No. individuals
1	15,173	1,263	631	7	7
2A	6,113	441	221	9	16
2B	7,583	353	177	6	9
3	48,307	1,270	635	11	18
4	42,558	1,356	678	13	22
5	37,029	583	292	4	4
6	12,370	517	258	7	11
7	49,399	553	276	0	-
8	12,803	704	352	8	9
9	62,456	1,155	578	11	12
E	457	63	32	0	-
R	131	30	15	1	1
All	**294,377**	**8,289**	**4,144**	**77**	**109**

Table 2. Animal abundance (N) and density (D; Indiv/km^2) estimates by survey block and for the total area covered during the 2007 Icelandic aerial survey. Estimates of *esw* (incorporating *g(0)*) taken from SCANS-II survey (Burt et al., 2006a; Hiby, 2006; Hammond et al., 2013). $_b$=bootstrap.

Block	N	CV$_b$	95% CI$_b$	D	95% CI$_b$
1	1,225	0.69	536–7,591	0.08	0.04–0.50
2A	2,791	0.44	930–7,270	0.46	0.15–1.19
2B	2,342	0.64	0–6,843	0.31	0.00–0.90
3	9,625	0.59	5,466–46,574	0.20	0.11–0.96
4	9,733	0.69	4,617–55,236	0.23	0.11–1.30
5	3,620	0.75	4,00–22,939	0.10	0.01–0.62
6	3,351	0.81	278–15,022	0.27	0.02–1.21
7	0	0.00	0–0	0.00	0.00–0.00
8	2,072	0.66	0–8,054	0.16	0.00–0.63
9	8,367	0.47	4,394–26,736	0.13	0.07–0.43
E	0	0.00	0–0	0.00	0.00–0.00
R	52	0.89	0–219	0.40	0.00–1.68
Total	**43,179**	**0.45**	**31,755–161,899**	**0.15**	**0.11–0.55**

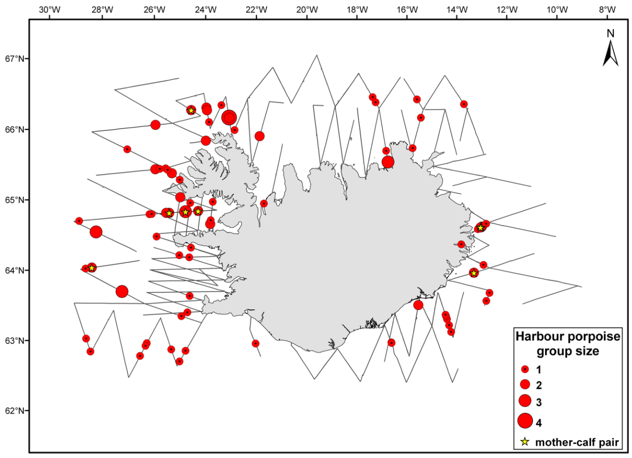

Figure 4. Realised effort (grey line) and harbour porpoise sightings during the 2007 Icelandic survey. Only sightings made by the more experienced porpoise observer are shown. (Sightings of other species are reported in Pike et al., 2020, this volume).

Faroe Islands

The aerial survey around the Faroe Islands took place between 20 June and 02 July 2010. Because of persistent foggy conditions (Figure 5) at the airport preventing VFR (visual flight rule) flights, and otherwise poor weather conditions, total realised effort was only 35% of planned effort. It was possible to cover 1,656 km (894 nm) of transect lines; of which 1,564 km (845 nm) were surveyed in good or moderate porpoise sighting conditions (Table 3). However, it was not possible to survey any transect in the offshore strata. Of the 3 inshore strata, I1 and I3 were covered successfully, whereas I2 could only be partly covered (Figure 6). A total of 39 harbour porpoise sightings with 49 individuals (of these 4 calves) were recorded in good or moderate sighting conditions (Figure 4, Table 3), resulting in an overall encounter rate of 0.03 sightings km^{-1}. Highest density was estimated for the eastern inshore strata I3 (Table 4). The low coverage and number of sightings in I2 made the estimate very imprecise (CV=0.94; Table 4).

Figure 5. Foggy conditions during the aerial survey in the Faroe Islands (Photo by Helena Herr).

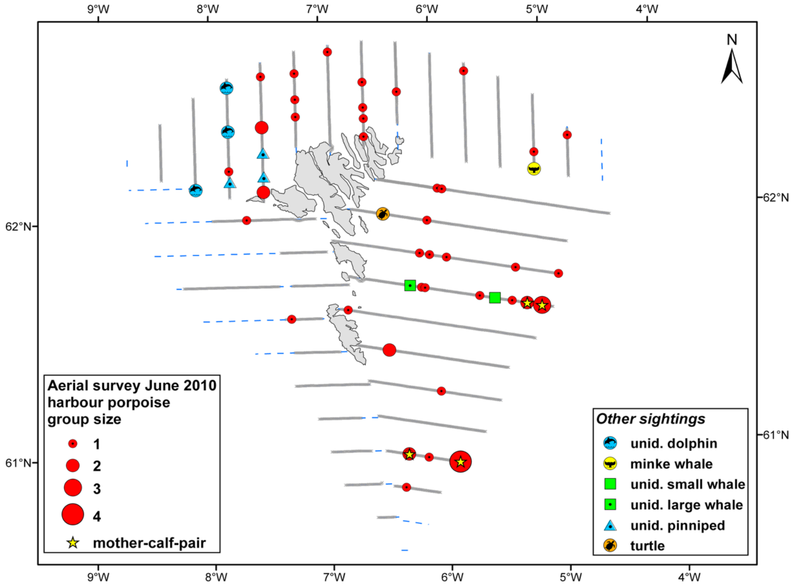

Figure 6. Realised effort (grey line) and harbour porpoise sightings during the 2010 Faroese survey. Other species sightings are indicated as well. Uncovered transects and segments in the inshore strata are indicated as dashed blue line.

Table 3. Surface area of blocks, realised effort, and overview of harbour porpoise sightings during the 2010 Faroese aerial survey. Only effort in good or moderate porpoise sighting conditions is shown. All-IS refers to inshore strata.

Block	Area (km^2)	Total line length (km)	No. sightings	No. individuals
I1	9,688	596	16	18
I2	8,095	207	1	1
I3	12,460	761	22	30
O1	51,990	0	-	-
O2	16,570	0	-	-
O3	17,990	0	-	-
All	**116,793**			
All-IS	**30,243**	**1,564**	**39**	**49**

Table 4. Animal abundance (N) and density (D; Indiv/km^2) estimates by survey block and for the total area covered during the 2010 Faroese aerial survey. "Total (excl. I2)" excludes block I2 due to low coverage and only a single sighting. Estimates of *esw* (incorporating g*(0)*) taken from SCANS-II survey (Burt et al., 2006a; Hiby 2006; Hammond et al., 2013). $_b$=bootstrap

Block	N	CV_b	95% CI_b	D	95% CI_b
I1	2,006	0.56	983–9,169	0.21	0.10–0.95
I2	237	0.94	0–788	0.03	0.00–0.10
I3	3,169	0.45	1,671–9,708	0.25	0.13–0.78
Total	**5,413**	**0.42**	**3,632–18,096**	**0.17**	**0.12–0.60**
Total (excl. I2)	**5,175**	**0.44**	**3,457–17,637**	**0.23**	**0.16–0.80**

DISCUSSION AND CONCLUSIONS

The abundance estimates presented here are the best available for Iceland and the very first for the Faroe Islands based on surveys where the harbour porpoise was a target species. These estimates are a large improvement relative to previous NASS surveys for this species and area. This improvement could be achieved due to experienced harbour porpoise observers, adapted survey technique, as well as optimised survey altitude and applying correction for bias. Although this bias correction came from another survey (SCANS-II) we argue that this approach is justified since the observers and survey platform were the same, the detection functions were similarly shaped and resulting *esw* similar. Also, group sizes were similar among strata and between surveys, and therefore should not introduce any bias in the application of the Hiby (1999) methods. Given that no "circle-backs" were carried out and no viable double platform data were available from either survey, this was the best alternative to obtain corrected estimates and still present robust estimates.

The aerial survey in the Faroe Islands was a pilot study with limited funding available and conducted over a short period of time (2 weeks). For the first time, however, it was possible to estimate density for a significant portion of the shallow regions (<300 m) of the Faroe Plateau (i.e., 2 out of 3 inshore strata). The survey effort was reduced due to a limited number of days without fog; a weather condition needed for visual landing of the survey aircraft. With only 1 airport available in the islands, and the nearest alternative airports located in east Iceland and the Orkneys, the planning and logistics of carrying out an aerial survey in the Faroe Islands is challenging. A longer survey period and a larger aircraft are suggested improvements to increase the chances of surveying also the offshore strata (representing roughly 75% of total allocated effort).

Earlier estimates for harbour porpoises were produced using what would now be considered non-standard techniques and were not optimised for this species. For example, Sigurjónsson and Víkingsson (1997) estimated the abundance of harbour porpoises in Icelandic waters at around 27,000 (no estimate of variance) from the Icelandic shipboard part of NASS-87. The shipboard survey area was mostly offshore, thus, covering an area overlapping that of our aerial survey to only a small extent. Also, this rough estimate most likely represents an underestimation of abundance as g*(0)* for ship surveys of porpoises can be quite low; e.g. in the SCANS-II shipboard survey a g*(0)* of 0.22 (CV=0.16) for the primary platform was estimated (Burt, Borchers & Samarra, 2006b; Hammond et al., 2013) whereas Sigurjónsson and Víkingsson (1997) applied a g*(0)* of 0.7.

Pike et al. (2009) found a significant negative trend in relative abundance of harbour porpoises in Icelandic coastal waters from aerial surveys during 1986–2001. Most of this trend was attributable to a low sighting rate in the 2001 survey. While recognising that this apparent negative trend might have methodological explanations, Pike et al. (2009) concluded that this was a cause for concern and should be investigated further. Estimates from 1986 and 1995 surveys (Table 5) are 8-10 times lower than the one presented here, suggesting that these uncorrected estimates are gross underestimates.

In 2009, the 2007 aerial survey in Iceland was repeated surveying the same stratification but at 750 ft altitude, and the harbour porpoise was not a main target species (Pike et al., 2020). In addition, the principal observers were not the same as those in earlier surveys. A total of 42 sightings of harbour porpoises were made, which is in the range of the pre-2001 survey. However, given the low number of sightings and the paucity of duplicate sightings, Pike et al. (2020) did not consider it feasible to estimate harbour porpoise abundance from this survey.

For an aerial survey in 2016 (Pike et al., 2020), total estimated abundance, uncorrected for perception or availability biases, was 10,506 (CV=0.26, 95% CI: 6,120–18,036), which is higher but not significantly so than the estimates provided by Pike et al. (2009) for 1986 and 1995. Correction for perception bias roughly doubled this estimate (Table 5). Pike et al. (2020) concluded that correction for availability would make this estimate similar to that from 2007 as reported here. This suggests that harbour porpoise numbers may be relatively stable in the area. However, Pike et al. (2020) cautioned that, with only one fully corrected estimate available, no firm conclusions about trends in harbour porpoise abundance around Iceland could be reached.

The corrected harbour porpoise abundance estimates presented in this paper constitute an important contribution for assessing the impact of by-catch as well as other threats and pressures on porpoises. A recent international workshop on harbour porpoise stock structure and status applied a population dynamic model for the Iceland AU, including estimated by-catch levels as a single pressure component, and concluded that the porpoise population in the Icelandic area seems to be recovering (NAMMCO & IMR, 2019). However, some limitations needed to be addressed and should be improved for future assessments. For example, the 3 abundance estimates used in the model included the absolute abundance originating from this study and 2 relative abundance estimates based on the genetic close-kin analysis. An additional estimate of relative abundance is now available (Pike et al., 2020), but clearly dedicated surveys for harbour porpoises are needed to improve abundance estimates. Furthermore, the by-catch estimates for gillnet fisheries included an extrapolation back to 1950 based on data on fishing effort, whereas the available data (without extrapolation) only goes back to 1980 (NAMMCO & IMR, 2019). Using Management Strategy Evaluation (MSE), Punt et al. (2020) concluded that the harbour porpoise population around Iceland is close to or above its maximum net productivity level (MNPL) and, according to the model, will continue to increase even if current levels of human-caused mortality are unchanged.

During the past decade, appreciable changes have been demonstrated in the marine ecosystem of the Icelandic continental shelf (Astthorsson, Gislason & Jonsson, 2007; Víkingsson & Valdimarsson, 2006; Víkingsson et al., 2015). These include changes in distribution and abundance of fish species that have been shown to be important in the diet of harbour porpoises in Icelandic waters (Víkingsson, Ólafsdóttir & Sigurjónsson, 2003). Of particular importance to the harbour porpoise is reduced availability of capelin (*Mallotus villosus*) and sandeel (*Ammodytidae* sp) in the Icelandic continental shelf area in recent years. These changes appear to have affected the ecology of several cetacean species in Icelandic waters (Pike, Gunnlaugsson, Mikkelsen, Halldórsson & Víkingsson, 2019; Víkingsson et al., 2014; Víkingsson et al., 2015) and the significance to top predators should be further investigated.

Table 5. Summary of further abundance estimates for harbour porpoises in Iceland (I-C=Icelandic coastal) from aerial surveys (altitude 750 ft). Corrections, P=perception bias.

Year	Area	Estimate	CV	LCL	UCL	Corrections	Ref.
1986	I-C	4,239	0.35	2,724	6,599	NONE	Pike et al. (2009)
1995	I-C	5,156	0.42	3,027	8,783	NONE	Pike et al. (2009)
2016	I-C	10,506	0.26	6,120	18,036	NONE	Pike et al. (2020)
2016	I-C	22,806	0.48	9,166	56,746	P	Pike et al. (2020)

Dedicated harbour porpoise surveys are needed to arrive at a series of robust absolute abundance estimates for Icelandic and Faroese waters. These estimates are necessary to reliably set significant levels of by-catch into context. In order to increase accuracy of the estimates, future porpoise surveys should preferably incorporate an assessment of availability and perception bias based on the team performance in the actual survey, rather than relying on external data as we have here. However, this would require a larger amount of survey effort to increase the number of sightings (for the Faroe Islands) and possibly to incorporate the racetrack method to estimate precise values for these parameters. An alternative approach would be to use mark-recapture distance sampling methods to estimate perception bias and data from tagged animals to estimate availability bias as a separate component (e.g. Hansen et al., 2019).

ADHERENCE TO ANIMAL WELFARE PROTOCOLS

The research presented in this article has been done in accordance with the institutional and national animal welfare laws and protocols applicable in the jurisdictions in which the work was conducted.

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REFERENCES

Astthorsson, O. S., Gislason, A. and Jonsson, S. (2007). Climate variability and the Icelandic marine ecosystem. *Deep-Sea Research Part II: Topical Studies in Oceanography, 54*(23–26), 2456–2477. https://doi.org/10.1016/j.dsr2.2007.07.030

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. and Thomas, L. (2001). Introduction to distance sampling. Estimating abundance of biological populations (S. T. Buckland Ed.). New York: Oxford University Press.

Burt, M. L., Borchers, D. L. and Samarra, F. (2006a). Aerial survey abundance estimates for harbour porpoise. Unpublished manuscript (In SCANSII (2008), *Small Cetaceans in the European Atlantic and North Sea*. Final report to the European Commission under project LIFE04NAT/GB/000245. Appendix D3.2).

Burt, M. L., Borchers, D. L. and Samarra, F. (2006b). Design-based abundance estimates from SCANS-II. Unpublished manuscript (In SCANSII (2008), *Small Cetaceans in the European Atlantic and North Sea*. Final report to the European Commission under project LIFE04NAT/GB/000245. Appendix D3.4).

Gunnlaugsson, T. and Sigurjónsson, J. (1990). Estimation of whale abundance based on observation made onboard Icelandic and Faroese survey vessels. *Reports of the International Whaling Commission, 40*, 571–580.

Gilles, A., Scheidat, M. and Siebert, U. (2009). Seasonal distribution of harbour porpoises and possible interference of offshore wind farms in the German North Sea. *Marine Ecology Progress Series, 383*, 295–307. https://doi.org/10.3354/meps08020

Gilles, A., Viquerat, S., Becker, E.A., Forney, K.A., Geelhoed, S.C. V, Haelters, J., … Aarts, G. (2016). Seasonal habitat-based density models for a marine top predator, the harbor porpoise, in a dynamic environment. *Ecosphere, 7*, e01367. https://doi.org/10.1002/ecs2.1367

Hammond, P. S., Benke, H., Berggren, P., Borchers, D. L., Buckland, S. T., Collet, A., … Øien, N. (1995). Distribution and abundance of harbour porpoises and other small cetaceans in the North Sea and adjacent waters. European Community LIFE Programme, Life, LIFE 92-2/IL/027, 240 pp. Retrieved from https://core.ac.uk/download/pdf/30844818.pdf

Hammond, P. S., Macleod, K., Berggren, P., Borchers, D. L., Burt, L., Cañadas, A., … Vázquez, J. A. (2013). Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. *Biological Conservation, 164*, 107–122. https://doi.org/10.1016/j.biocon.2013.04.010

Hansen, R. G., Boye, T. K., Larsen, R. S., Nielsen, N. H., Tervo, O., Nielsen, R. D., … Heide-Jorgensen, M. P. (2019). Abundance of whales in West and East Greenland in summer 2015. *NAMMCO Scientific Publications, 11*. https://doi.org/10.7557/3.4689

Hiby, A.R. and Hammond, P.S. (1989). Survey techniques for estimating current abundance and monitoring trends in abundance of cetaceans. *Reports of the International Whaling Commission*, (special issue 11), 47–80.

Hiby, L. (1999). The objective identification of duplicate sightings in aerial survey for porpoise. In G. W. Garner, S. C. Amstrup, J. L. Laake, B. F. J. Manly, L. L. McDonald and D. G. Robertson (eds.), *Marine Mammal Survey and Assessment Methods*, 179–189. Rotterdam: Balkema.

Hiby, L. (2006). Effective strip width estimates from aerial survey data. Unpublished manuscript. In: SCANSII (2008). *Small Cetaceans in the European Atlantic and North Sea*. Final report to the European Commission under project LIFE04NAT/GB/000245. Appendix D3.1.

Hiby, L. and Lovell, P. (1998). Using aircraft in tandem formation to estimate abundance of harbour porpoise. *Biometrics, 54*(4), 1280–1289. https://doi.org/10.2307/2533658

Laake, J. L., Calambokidis, J., Osmek, S. D. and Rugh, D. J. (1997). Probability of detecting harbor porpoises from aerial surveys: estimating g*(0)*. *Journal of Wildlife Management, 61*(1), 63–75. https://doi.org/10.2307/3802415

Larsen, B. H. (1995). A note on catches and exploitation of Harbour Porpoises (*Phocoena phocoena* L. 1758) around the Faroe Islands. *Reports of the International Whaling Commission*, (special Issue 16), 155–158.

Marine and Freshwater Research Institute (MFRI). (2019). Meðafli fugla og sjávarspendýra í grásleppuveiðum 2014-2018 [*Bycatch of seabirds and marine mammals in lumpsucker gillnets 2014-2018*]. Retrieved from https://www.hafogvatn.is/static/extras/images/medafli-fugla-og-spendyra-i-grasleppuveidum1158397.pdf

Marine and Freshwater Research Institute (MFRI). (2020, in press). Bycatch of marine mammals and seabirds in Icelandic waters 2016-2019. Unpublished manuscript (MFRI Tech Report).

Marsh, H. and Sinclair, D. F. (1989). Correcting for visibility bias in strip transect surveys of aquatic fauna. *Journal of Wildlife Management, 53*, 1017–1024. https://doi.org/10.2307/3809604

Mikkelsen, B. (2016). Fisheries in Faroese waters and the potential for by-catch of marine mammals. Unpublished manuscript (document NAMMCO/SC/23/BYC/05 for the North Atlantic Marine Mammal Commission).

North Atlantic Marine Mammal Commission (NAMMCO). (2018). Harbour porpoise. Retrieved from https://nammco.no/topics/harbour-porpoise/

North Atlantic Marine Mammal Commission and the Norwegian Institute of Marine Research (NAMMCO and IMR). (2019). Report of Joint IMR/NAMMCO International Workshop on the Status of Harbour Porpoises in the North Atlantic. Tromsø, Norway. Retrieved from https://nammco.no/wp-content/uploads/2020/03/final-report_hpws_2018_rev2020.pdf

Ólafsdóttir, D. (2010). Report on monitoring of marine mammal bycatch in Icelandic fisheries, Statistics for 2009 and review of previous information. Unpublished manuscript (document NAMMCO/SC17/16 for the North Atlantic Marine Mammal Commission).

Pálsson, Ó. K., Gunnlaugsson, T. and Ólafsdóttir, D. (2015). By-catch of seabirds and marine mammals in Icelandic Fisheries. Marine Research No. 178. Retrieved from https://www.hafogvatn.is/static/research/files/fjolrit-178.pdf

Pike, D. G., Paxton, C. G. M., Gunnlaugsson, T. and Víkingsson, G. A. (2009). Trends in the distribution and abundance of cetaceans from aerial surveys in Icelandic coastal waters, 1986-2001. *NAMMCO Scientific Publications, 7,* 117–142. https://doi.org/10.7557/3.2710

Pike, D. G., Gunnlaugsson, T. and Víkingsson, G. A. (2010). Distribution and abundance of humpback whales in Icelandic coastal waters in summer 2007. Unpublished manuscript (document SC/62/O14 for the IWC Scientific Committee).

Pike, D. G., Gunnlaugsson, T., Mikkelsen, B., Halldórsson, S. D. and Víkingsson, G. (2019). Estimates of the abundance of cetaceans in the central North Atlantic based on the NASS Icelandic and Faroese shipboard surveys conducted in 2015. *NAMMCO Scientific Publications, 11*. https://doi.org/10.7557/3.4941

Pike, D. G., Gunnlaugsson, T., Sigurjónsson J. and Víkingsson, G. A. (2020). Distribution and abundance of cetaceans in Icelandic waters over 30 years of aerial surveys. *NAMMCO Scientific Publications, 11*. https://doi.org/10.7557/3.4805

Punt, A. E., Siple, M., Sigurðsson, G. M., Víkingsson, G., Francis, T. B., Granquist, S. M., … Moore, J. E. (2020). Evaluating management strategies for marine mammal populations: an example for multiple species and multiple fishing sectors in Iceland. *Canadian Journal of Fisheries and Aquatic Sciences, 77*(8), 1316–1331. https://doi.org/10.1139/cjfas-2019-0386

Sigurjónsson, J. and Víkingsson, G. A. (1997). Seasonal abundance of the estimated food consumption by cetaceans in Icelandic and adjacent waters. *Journal of Northwest Atlantic Fishery Science, 22*, 271–287. https://doi.org/10.2960/J.v22.a20

Sigurjónsson, J., Gunnlaugsson, T. and Payne, M. (1989). NASS-87: Shipboard sightings surveys in Icelandic and adjacent waters June-July 1987. *Report of the International Whaling Commission, 39*, 395–409.

Scheidat, M., Gilles, A., Kock, K. and Siebert, U. (2008). Harbour porpoise *Phocoena phocoena* abundance in the southwestern Baltic Sea. *Endangered Species Research, 5,* 215–223. https://doi.org/10.3354/esr00161

Teilmann, J. (2003). Influence of sea state on density estimates of harbour porpoises (*Phocoena phocoena*). *Journal of Cetacean Research and Management,* 5, 85–92.

Thomas, L., Buckland, S. T., Rexstad, E. A., Laake, J. L., Strindberg, S., Hedley, S. L., … Burnham, K. P. (2010). Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology, 47*(1), 5–14. https://doi.org/10.1111/j.1365-2664.2009.01737.x

Víkingsson, G. A., Ólafsdóttir, D. and Sigurjónsson, J. (2003). Geographical and seasonal variation in the diet of harbour porpoises (Phocoena phocoena) in Icelandic coastal waters. *NAMMCO Scientific Publications, 5*, 243–270 https://doi.org/10.7557/3.2829

Víkingsson, G. A., Ólafsdóttir, D. and Hauksson, E. (2004). Iceland – Progress report on marine mammal research in 2002. In NAMMCO Annual Report 2003, NAMMCO, Tromsø, 323–327. Retrieved from https://nammco.no/topics/annual-reports/

Víkingsson, G. A. andValdimarsson, H. (2006). Hvalir og umhverfisþættir [Whales and the environment]. Þættir úr vistfræði sjávar 2005 [Environmental conditions in Icelandic waters 2005]. *Hafrannsóknastofnunin Fjölrit, 125*, 30–33 [In Icelandic].

Víkingsson G. A., Elvarsson, B. Þ., Ólafsdóttir, D., Sigurjónsson, J., Chosson, V. and Galan, A. (2014). Recent changes in the diet composition of common minke whales (*Balaenoptera acutorostrata*) in Icelandic waters. A consequence of climate change? *Marine Biology Research, 10*, 138–152. https://doi.org/10.1080/17451000.2013.793812

Víkingsson, G. A., Pike, D. G., Valdimarsson, H., Schleimer, A., Gunnlaugsson, T., Silva, T., … Hammond, P. S. (2015). Distribution, abundance and feeding ecology of baleen whales in Icelandic waters: have recent environmental changes had an effect? *Frontiers in Ecology and Evolution, 3*, 1–18. https://doi.org/10.3389/fevo.2015.00006

Zerbini, A. N., Ward, E. J., Kinas, P. G., Engel, M. H. and Andriolo, A. (2011). A Bayesian Assessment of the conservation status of humpback whales (*Megaptera novaeangliae*) in the western Atlantic Ocean (Breeding Stock A). *Journal of Cetacean Research and Management, 3*, 131–144.