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

Anita Gilles1, Thorvaldur Gunnlaugsson2, Bjarni Mikkelsen3, Daniel G. Pike4 & Gísli A. Vikingsson2

1Institute for Terrestrial and Aquatic Wildlife Research, University of Veterinary Medicine Hannover, Foundation, Büsum, Germany. Corresponding author: anita.gilles@tiho-hannover.de
2 Marine and Freshwater Research Institute, Reykjavík, Iceland
3 Faroe Marine Research Institute, Tórshavn, Faroe Islands
4 Esox Associates, North Bay, Ontario, Canada

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 & Vikingsson, 2009) and later in 2009, 2015 and 2016 (Pike, Gunnlaugsson, Sigurjónsson & Vikingsson, 2020). The main target species of these surveys has been the common minke whale (Balaenoptera acutorostrata), however, sightings of all species are recorded. 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.
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**

**Survey design**

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 km² (85,717 nm²).

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 km² (34,250 nm²) study area.
**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).

**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 counting procedure (Hiby & Hammond, 1989) has generally been used. In the 2007 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. Additional effort was allocated to 4 fjords (Ísafjörður, Eyrarfjörður, 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. 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

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).
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:

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

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, $$n_{esw}$$ is the number of sightings that occurred in good conditions in the stratum, $$n_{gsv}$$ 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 $$\tilde{s}_v$$ is the mean observed group size in the stratum.

Group abundance by stratum was estimated by:

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

Total animal abundances were estimated by:

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

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. $$\mu = (0.165, 0.122)$$ and

$$\Sigma = \begin{pmatrix} 0.0372 & 0.000896 \\ 0.000896 & 0.02892 \end{pmatrix}$$

This constitutes esws 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 SSS 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 survey (Burt et al., 2006a; Hiby, 2006; Hammond et al., 2013).

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

<table>
<thead>
<tr>
<th>Block</th>
<th>Area (km²)</th>
<th>Total line length (km)</th>
<th>One-sided effort (km)</th>
<th>No. sightings</th>
<th>No. individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15,173</td>
<td>1,263</td>
<td>631</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>2A</td>
<td>6,113</td>
<td>441</td>
<td>221</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>2B</td>
<td>7,583</td>
<td>353</td>
<td>177</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>48,307</td>
<td>1,270</td>
<td>635</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>42,558</td>
<td>1,356</td>
<td>678</td>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>37,029</td>
<td>583</td>
<td>292</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>12,370</td>
<td>517</td>
<td>258</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>49,399</td>
<td>553</td>
<td>276</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>12,803</td>
<td>704</td>
<td>352</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>62,456</td>
<td>1,155</td>
<td>578</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>E</td>
<td>457</td>
<td>63</td>
<td>32</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>R</td>
<td>131</td>
<td>30</td>
<td>15</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>All</td>
<td>294,377</td>
<td>8,289</td>
<td>4,144</td>
<td>77</td>
<td>109</td>
</tr>
</tbody>
</table>

Table 2. Animal abundance (N) and density (D; Indiv/km²) 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).

<table>
<thead>
<tr>
<th>Block</th>
<th>N</th>
<th>CV_w</th>
<th>95% CI&lt;sub&gt;94&lt;/sub&gt;</th>
<th>D</th>
<th>95% CI&lt;sub&gt;94&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,225</td>
<td>0.69</td>
<td>536–7,591</td>
<td>0.08</td>
<td>0.04–0.50</td>
</tr>
<tr>
<td>2A</td>
<td>2,791</td>
<td>0.44</td>
<td>930–7,270</td>
<td>0.46</td>
<td>0.15–1.19</td>
</tr>
<tr>
<td>2B</td>
<td>2,342</td>
<td>0.64</td>
<td>0–6,843</td>
<td>0.31</td>
<td>0.00–0.90</td>
</tr>
<tr>
<td>3</td>
<td>9,625</td>
<td>0.59</td>
<td>5,466–46,574</td>
<td>0.20</td>
<td>0.11–0.96</td>
</tr>
<tr>
<td>4</td>
<td>9,733</td>
<td>0.69</td>
<td>4,617–55,236</td>
<td>0.23</td>
<td>0.11–1.30</td>
</tr>
<tr>
<td>5</td>
<td>3,620</td>
<td>0.75</td>
<td>4,00–22,939</td>
<td>0.10</td>
<td>0.01–0.62</td>
</tr>
<tr>
<td>6</td>
<td>3,351</td>
<td>0.81</td>
<td>278–15,022</td>
<td>0.27</td>
<td>0.02–1.21</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0.00</td>
<td>0–0</td>
<td>0.00</td>
<td>0.00–0.00</td>
</tr>
<tr>
<td>8</td>
<td>2,072</td>
<td>0.66</td>
<td>0–8,054</td>
<td>0.16</td>
<td>0.00–0.63</td>
</tr>
<tr>
<td>9</td>
<td>8,367</td>
<td>0.47</td>
<td>4,394–26,736</td>
<td>0.13</td>
<td>0.07–0.43</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>0.00</td>
<td>0–0</td>
<td>0.00</td>
<td>0.00–0.00</td>
</tr>
<tr>
<td>R</td>
<td>52</td>
<td>0.89</td>
<td>0–219</td>
<td>0.40</td>
<td>0.00–1.68</td>
</tr>
<tr>
<td>Total</td>
<td>43,179</td>
<td>0.45</td>
<td>31,755–161,899</td>
<td>0.15</td>
<td>0.11–0.55</td>
</tr>
</tbody>
</table>

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 and only harbour porpoise sightings by the experienced porpoise observer are shown. (Sightings of other species are reported in Pike et al., 2020; this volume).

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

<table>
<thead>
<tr>
<th>Block</th>
<th>Area (km²)</th>
<th>Total line length (km)</th>
<th>No. sightings</th>
<th>No. individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1</td>
<td>9,688</td>
<td>596</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>I2</td>
<td>8,095</td>
<td>207</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>I3</td>
<td>12,460</td>
<td>761</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>O1</td>
<td>51,990</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>O2</td>
<td>16,570</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>O3</td>
<td>17,990</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>All</td>
<td>116,793</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-IS</td>
<td>30,243</td>
<td>1,564</td>
<td>39</td>
<td>49</td>
</tr>
</tbody>
</table>

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 Vikingsson (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 Vikingsson (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, Gislonson & Jonsson, 2007; Vikingsson & Valdimarsson, 2006; Vikingsson 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 (Vikingsson, Olafsdottir & Sigurjonsdottir, 2003). Of particular importance to the harbour porpoise is reduced availability of capelin (Malolotus villosus) and sandeel (Ammod Cronus 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, Halldorsson & Vikingsson, 2019; Vikingsson et al., 2014; Vikingsson 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.

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

ACKNOWLEDGEMENTS

We thank pilot Úlfar Henningsson for safe flights in both surveys, as well as observers Njâll Sigurðsson and Marianne Rasmussen for their hard work during the Icelandic survey. The survey was funded by the Icelandic Ministry of Fisheries. For the Faroe Islands survey, we thank the observers Helena Herr and Linn Lehnerdt for their excellent work. We also thank the late Eyðfinnur Stefansson for his great support during the pilot survey. The Faroese survey was funded by the Faroese Oil Industry Group (FOÍB C35-74-01). Finally, we thank 2 anonymous reviewers for their thorough reviews and are grateful to the support of volume editor, Geneviève Desportes, in the final phase of this paper.

REFERENCES


