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ESTIMATED ABUNDANCES OF CETACEAN SPECIES IN THE NORTHEAST ATLANTIC FROM NORWEGIAN SHIPBOARD SURVEYS CONDUCTED IN 2014–2018

Deanna M. Leonard[1,2] & Nils I. Øien[1]
[1] *IMR - Institute of Marine Research, Bergen, Norway. Corresponding author: deanna.leonard@hi.no*
[2] *NAMMCO - North Atlantic Marine Mammal Commission, Tromsø, Norway*

ABSTRACT

A ship-based mosaic survey of Northeast Atlantic cetaceans was conducted over a 5-year period between 2014–2018. The area surveyed extends from the North Sea in the south (southern boundary at 53ºN), to the ice edge of the Barents Sea and the Greenland Sea. Survey vessels were equipped with 2 independent observer platforms that detected whales in passing mode and applied tracking procedures for the target species, common minke whales (*Balaenoptera acutorostrata acutorostrata*). Here we present abundance estimates for all non-target species for which there were sufficient sightings. We estimate the abundance of fin whales (*Balaenoptera physalus*) to be 11,387 (CV=0.17, 95% CI: 8,072–16,063), of humpback whales (*Megaptera novaeangliae*) to be 10,708 (CV=0.38, 95% CI: 4,906–23,370), of sperm whales (*Physeter macrocephalus*) to be 5,704 (CV=0.26, 95% CI: 3,374–9,643), of killer whales (Orcinus orca) to be 15,056 (CV=0.29, 95% CI: 8,423–26,914), of harbour porpoises (*Phocoena phocoena*) to be 255,929 (CV=0.20, 95% CI: 172,742–379,175), dolphins of genus *Lagenorhynchus* to be 192,767 (CV=0.25, 95% CI: 114,033–325,863), and finally of northern bottlenose whales (*Hyperoodon ampullatus*) to be 7,800 (CV=0.28, 95% CI: 4,373–13,913). Additionally, our survey effort in the Norwegian Sea in 2015 contributed to the 6th North Atlantic Sightings Survey (NASS) and the survey was extended into the waters north and east of Iceland around Jan Mayen island. This NASS extension, along with our Norwegian Sea survey in 2015, was used to estimate the abundance of fin whales, humpback whales, and sperm whales. All estimates presented used mark-recapture distance sampling techniques and were thus corrected for perception bias. Our estimates do not account for additional variance due to distributional shifts between years or biases due to availability or responsive movement.

Keywords: North Atlantic, cetacean, abundance, line-transect, fin whales, humpback whales, sperm whales, killer whales, harbour porpoises, dolphins, northern bottlenose whales

INTRODUCTION

Norwegian shipboard line-transect surveys of the Northeast Atlantic have been ongoing since 1987 as part of a program to estimate abundance of common minke whales (*Balaenoptera acutorostrata acutorostrata*) as input to the Revised Management Procedure (RMP) of the International Whaling Commission (IWC, 1994). All non-target cetacean species are also documented throughout the surveys. In 1995, a full synoptic survey of the study area (described under Materials and Methods) was completed, prior to which only subsets of the total study area were surveyed. The current multi-year mosaic survey design was introduced in 1996 as a way of providing complete coverage of the study area with smaller-scale effort each year (Øien & Schweder 1996). To date, 4 complete cycles of the multi-year program have been completed (1996–2001, 2002–2007, 2008–2013, 2014–2018). Abundance estimates of non-target species have been published from surveys conducted in 1988, 1989, 1995 (Christensen et al., 1992; Øien 1990, 2009), and the mosaic surveys in 1996–2001, 2002–2007 and 2008–2013 (Øien 2009; Leonard & Øien, 2020). This paper presents new abundance estimates from the 2014–2018 mosaic survey for all cetacean species for which there were a sufficient number of sightings. This includes fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), killer whales (*Orcinus orca*), harbour porpoises (*Phocoena phocoena*), northern bottlenose whales (*Hyperoodon ampullatus*), and dolphins (*Lagenorhynchus* spp). Throughout this paper, the term *Lagenorhynchus* spp. refers collectively to white-sided dolphins (*Lagenorhynchus acutus*) and white-beaked dolphins (*Lagenorhynchus albirostris*), which are estimated to genus, rather than species level.

In addition to providing information for the management of whaling under the RMP, the survey in 2015 also contributed to the synoptically conducted North Atlantic Sightings Survey (NASS). In collaboration with the North Atlantic Marine Mammal Commission (NAMMCO), survey blocks around Jan Mayen were added to the planned 2015 survey to create continuous survey coverage from areas around Iceland extending north to the Jan Mayen region and westward covering the Norwegian Sea. The areas to the south and west of Jan Mayen were surveyed simultaneously by 3 Icelandic and Faroese vessels. Results from the analysis of data from these surveys are presented in Pike et al. (2019).

The design of Norwegian line-transect surveys for minke whales has remained consistent since 1995, with slight changes to improve the precision of the abundance estimates (Schweder, Skaug, Dimakos, Langaas, & Øien, 1997; Skaug, Øien, Schweder, & Bøthun, 2004). For example, beginning in 2008, a plan to survey each Small Management Area (SMA – as defined by the

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RMP) in a single year was implemented to reduce additional variance caused by distributional shifts of minke whales between years (Skaug et al., 2004). A modification was made to the data collection in this 2014–2018 cycle, which involved assigning confidence ranking to each duplicate judgement for all species to allow for a sensitivity analysis. Some of the analysis methods have also changed since the earlier surveys. Standard distance sampling methods were used to estimate the abundances of non-target species from data collected in 1995 and 1996–2001 (Christensen et al., 1992; Øien, 2009, 1990). All later surveys (2002–2007, 2008–2013, including the current survey) have used mark-recapture distance sampling methods applied to combined-platform data to correct for perception bias in the estimates.

MATERIALS AND METHODS

Survey Design

The study area extended from the North Sea in the south, with a southern boundary at 53ºN, to the ice edge of the Barents Sea and the Greenland Sea in the north (Figure 1a) and comprised the Small Management Areas (SMA), as revised by the North Atlantic Minke Whale Implementation in 2003 (IWC, 2004). The five SMAs were CM, ES, EB, EW, and EN. The survey block structure was defined within the SMAs using previous knowledge of minke whale density to minimize within-block variation. Transects within each block were constructed as zig-zag tracks with a random starting point, with survey effort distributed proportional to area (Buckland et al., 2001). Calculated block areas were adjusted for ice-cover.

The 2015 survey area consisted of 6 blocks (Figure 1b) and was conducted over the period of 22 June to 30 August. The NASS extension blocks (CM) were surveyed from 13 July to 2 August.

Data collection

Throughout the survey cycle, one vessel operated alone, starting in mid-June and ending in mid-August in each of the 5 survey years. In 2014, the Svalbard area was surveyed; in 2015 the Norwegian Sea and NASS extension blocks (see below); in 2016 the Jan Mayen area; in 2017 the Barents Sea; and in 2018 the North Sea was surveyed as well as a small block of the Norwegian Sea (EW4).

Each vessel was outfitted with 2 survey platforms that were visually and audibly separated to facilitate observer independence. Each platform operated with 2 observers searching forward 45º from 0º (centre of the bow) on either the starboard or port side. The lower platform, platform 2, was positioned on the wheelhouse roof and the upper platform, referred to as platform 1, was typically placed in the barrel on the mast of the ship. The height of the platforms varied between vessels, with eye-height above sea level averaged 13.8 m for platform 1 and 9.7 m for platform 2 (Figure 2). Four 2-person teams of observers operated in 1- to 2-hour shifts, rotating between platforms.

Observers recorded sightings nearly instantaneously using a microphone connected to GPS-equipped computer system, monitored on the bridge. The species, radial distance, angle from the transect line, and group size were recorded for each sighting. The search method was by naked eye, angles were read from an angle board, and radial distances were estimated without equipment. Observers were trained to estimate distances through exercises conducted during the surveys using buoys as targets.

Specific tracking procedures were followed for minke whale sightings, where each surfacing was recorded until the whale passed the ship's abeam. For all other species, only the first sighting was recorded, with occasional updates to species

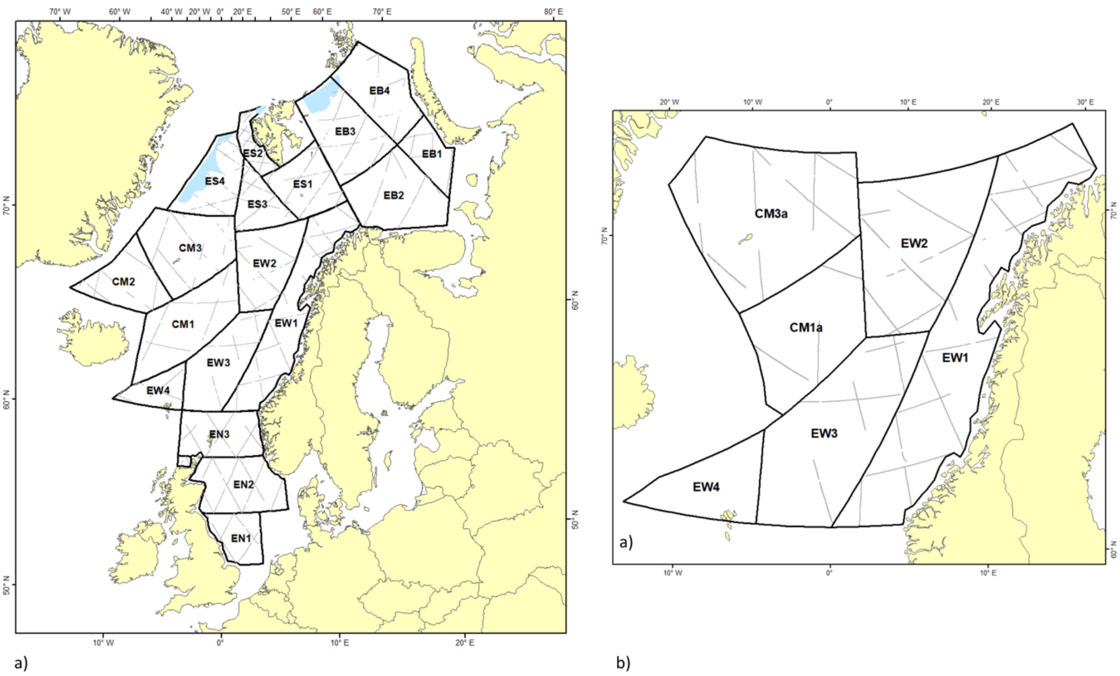

Figure 1. (a) Survey blocks (derived from minke whale SMAs) and realized search effort on predetermined transect lines during the 2014–2018 sighting surveys, with the blue areas representing ice coverage; (b) the 2015 NASS extension survey blocks and transects.

identification and position information to aid in judging duplicates. Dolphin groups were often recorded as *Lagenorhynchus* spp. and not identified to species level. Large whales that were not identified to species level were recorded as 'unidentified large whales'. After each completed recording of a minke whale or other large whale sighting, observers reported the sighting to the team leader by radio. The platforms operated on separate radio channels to maintain independence. The team leader, operating from the bridge, assisted with species identification by using binoculars to confirm uncertain identifications.

Figure 2. Platform 1 (upper) and platform 2 (lower) aboard the ACC Mosby. Photo credit: Deanna Leonard

All survey effort was conducted at a speed of 10 knots at a Beaufort Sea State (BSS) of 4 or less with visibility greater than 1 km. On an hourly basis and as conditions changed, the weather conditions, BSS, visibility, and glare were recorded. More detail on the survey design, observer protocols, and covariate classification is provided in Øien (1995).

Data treatment

The sightings from each platform were combined to constitute a single dataset. When possible, duplicate sightings were identified in real time by a team leader operating from the bridge, however most were determined post-cruise. Sightings were judged as duplicates based on species identification, group size, and sighting location, considering the time between the sightings and the relative position to the vessel while accounting for the vessel track and speed, allowing for small differences in recorded radial distances. Due to the absence of tracking procedures for non-target species, there was occasionally the need to match duplicates of disparate surfacings of the same whale. The team leader played an important role in identifying these duplicates in the field. When only one platform reported a sighting, the team leader could track the whale so that it could be identified as a duplicate if the other platform detected it closer to the ship. In rare instances where one observer of an obvious duplicate sightings pair identified the species, while the other recorded it as an 'unidentified large whale', the positive ID was used.

The effect of duplicate identification uncertainty was explored by assigning each duplicate judgement a confidence level of 'D' for definite (high confidence), 'P' for probable (medium confidence), and 'R' for remote (low confidence). This allowed for comparison of the resulting abundance estimates to determine the influence of variation in identifying duplicates.

The analytical method used required that the perpendicular distance and group size fields be identical for duplicate sightings (Laake & Borchers, 2004). Thus, information recorded by the platform from which the whale was first sighted was used.

Analysis

Sightings used in the analyses were all initially detected before coming abeam of the ship and recorded from platform 1, 2 or both. Only sightings that were identified to species by at least one platform were used in the estimates (with the exception of dolphins, which were estimated by genus (*Lagenorhynchus* spp.)).

Data analyses were carried out using the DISTANCE 7.2 software package (Thomas et al., 2010). Density and abundance were estimated using mark-recapture distance sampling (MRDS) techniques (Laake & Borchers, 2004). The mark-recapture method uses the double-platform configuration to estimate $p(0)$ to account for sightings that are missed (perception bias), rather than assume that all animals on the transect line are detected ($p(0)=1$), as with standard distance sampling methods (Thomas et al., 2010). The "independent observer configuration" was used because the platforms were fully independent of each other (Laake & Borchers, 2004). Two levels of independence were tested and selected based on a comparison of the AIC values: "full independence" (FI) and "point independence" (PI). The full independence method treats sightings as independent at all perpendicular distances and requires a conditional detection function (Mark Recapture model: MR model) to estimate detection probabilities conditioned on detection by the other platform. The assumption of point independence treats sightings as independent on the trackline only (Laake & Borchers, 2004) and requires a second detection function: one for the probability of detection by one or more observers (Distance Sampling model: DS model) in addition to the conditional detection function (MR model). The conditional detection function is modelled as a Generalized Linear Model (GLM) with a log link function.

Detection functions were fitted using sightings pooled over all blocks for each species. Hazard-rate and half-normal models were explored, and the sightings were truncated by 5-10% of the overall distance if it improved the Q-Q plot and goodness of fit metrics (Kolmogorov-Smirnov or Cramer-von-Mises test statistics). Models were tested with candidate covariates including BSS, vessel identity, weather code, group size, glare, and visibility. Some covariates were simplified by aggregating values or levels, as described in Table 1, to improve model fit. Covariates were added to the detection functions through the scale parameter in the key function, and thus affected the scale but not the shape of the detection curve (Thomas et al., 2010). Model selection was achieved through visual inspection (especially of data around the transect line), goodness of fit test statistics, and by minimizing Akaike's information criterion (AIC). Covariates were retained only if their inclusion resulted in a lower AIC value when compared to base models.

Table 1. Descriptions of covariates included to improve model fit. Some covariates were aggregated into levels for simplification.

Covariate	Description	Symbol	Aggregated Covariates: Levels	Aggregated Covariates: Definition
Beaufort	5 categories	B	BI, BII, BIII	BI: [0–1], BII: [2], BIII: [3-4]
Weather	12 categories	W	good, bad	good: W01–W04, bad: W05–W12
Vessel	3 vessels	Ves	-	-
Visibility	numerical	V	high, low	low < 50% of Max high > 50% of Max
Glare	4 categories	G	glare, no glare	G0: no glare, G1: glare
Group size	numerical	S	-	-
Distance	numerical	D	-	-

Estimates of density, abundance, and group size for each species were estimated by block, and the effective search half width (*eshw*) was estimated globally. Encounter rate variances were estimated by weighting transect lines by length using a design-based empirical estimator (Fewster et al., 2009) from the mark-recapture distance sampling (MRDS) engine in DISTANCE 7.2 (Buckland et al., 2001).

In 2015, the NASS extension blocks (CM3a, CM1a) were added to the regularly planned survey effort (EW blocks) to create a continuous expansion of the NASS survey covering the Jan Mayen region and the Norwegian Sea. The 2015 effort and sightings were used to fit detection functions and produce estimates separate from the regular 2014–2018 survey. Abundances were estimated for 3 large whale species: fin whales, humpback whales, and sperm whales. Data from the 2015 CM blocks were only used in the NASS extension estimates and the regularly planned mosaic CM blocks were resurveyed completely in 2016. The duplicated effort achieved in 2015 (CM blocks) was excluded from the regular 2014–2018 cycle estimates due to differences in stratification.

RESULTS

General

In total, 25,564 km of transects were surveyed during the 2014–2018 survey cycle (Figure 1a), covering a total area of 3,431,179 sq. km (Table 2). The distribution of search effort by Beaufort Sea State was 3% in BSS 0, 12% in BSS 1, 23% in BSS 2, 31% in BSS 3 and 31% in BSS 4.

There were 571 records of large whale sightings (Table 2). Of these, 298 were identified as fin whales, 94 as sperm whales, 98 as humpback whales and 10 as blue whales, 2 as sei whales, 5 as bowhead whales, and 64 were categorized as 'unidentified large whales'. There were 980 sightings of small odontocete groups (Table 2). Of these, 46 were identified as killer whales, 435 as harbour porpoises, 461 as *Lagenorhynchus* spp., 27 as northern bottlenose whales and 11 as pilot whales.

In all cases, the PI models resulted in lower AICs than the FI models, therefore the PI method was accepted as superior. The fitted covariates for each species, for both the Distance Sampling models (DS model) and the Mark Recapture models (MR model), are detailed in Table 3.

A comparison of estimates using 3 levels of confidence in duplicate judgement showed no significant difference (p>0.05) between the estimates of *p*(0) and resulting abundance when using D+P+R duplicates or D+P duplicates, but substantial differences when only D duplicates were used (Table 4). Using only D duplicates resulted in a 5–45% decrease in *p*(0) and proportional increase in the resulting abundance estimates (Table 4). The differences were significant (p<0.05) for fin whales, humpback whales, and *Lagenorhynchus* spp. All abundance estimates reported henceforth use D+P duplicates to estimate *p*(0). The final number of sightings by platform and duplicates (D+P) used to estimate the abundance for each species are shown in Table 5.

Fin whales

Figure 3 depicts the distribution of fin whale sightings from the 2014–2018 survey. Fin whales were most prevalent in the northern Norwegian sea (EW1) as well as in blocks ES1, ES4 (west of Spitsbergen) and in the western Iceland/Jan Mayen survey block CM2 (Table 6). The DS detection function model was fitted with a half-normal function with weather as a covariate to sightings truncated at a distance of 4000 m. The fitted DS detection function and MR conditional detection function are shown in Figure 4a. The probability of detection on the transect line was estimated to be *p*(0)=0.84 (CV=0.03) and the resulting *eshw* was 2004 m. Total corrected abundance of fin whales was estimated to be 11,387 (CV=0.17, 95% CI: 8,072–16,063). Table 6 details the results by survey block.

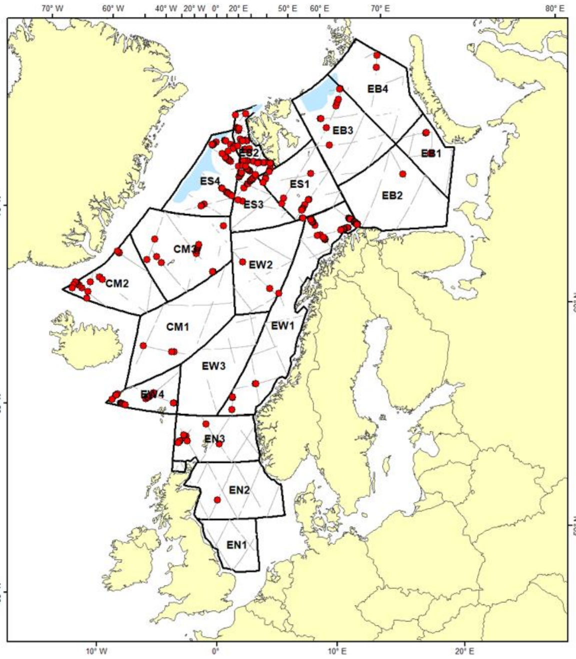

Figure 3. Distribution of sightings recorded as fin whales during the 2014–2018 sighting surveys. The blue areas represent ice coverage.

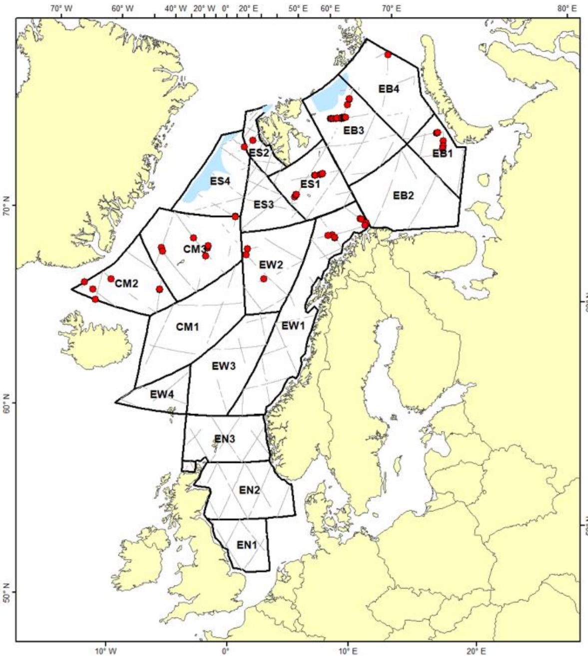

Figure 5. Distribution of sightings recorded as humpback whales during the 2014–2018 sighting surveys. The blue areas represent ice coverage.

Humpback whales

Humpback whales were sighted in 3 key areas: the northern Barents Sea (EB3); around Bear Island (ES1); and north and east of Iceland (CM2, CM3). Figure 5 shows the distribution of humpback whale sightings. The DS detection function was fitted with a hazard-rate key function to data truncated at a distance of 3000 m, which resulted in an estimated *p*(0)=0.76 (CV=0.07) and *eshw* of 1087 m. Figure 4b illustrates the fitted DS detection function and conditional detection function (MR model). Total corrected abundance of humpback whales was estimated to be 10,708 (CV=0.38, 95% CI: 4,906–23,370). Abundance and density estimated by survey block are detailed in Table 7.

Sperm whales

Sperm whale sightings occurred over the deep waters of the Norwegian Sea (EW2), south of Jan Mayen (CM1) (Table 8; Figure 6). The data were truncated at a perpendicular distance of 4000 m and fitted with a half-normal DS detection function, resulting in an estimated *p*(0)=0.69 (CV=0.15) and *eshw* of 1849 m. The fitted DS detection function and MR conditional detection function are shown in Figure 4c. Total corrected abundance of sperm whales was estimated to be 5,704 (CV=0.26, 95% CI: 3,374–9,643) (Table 8).

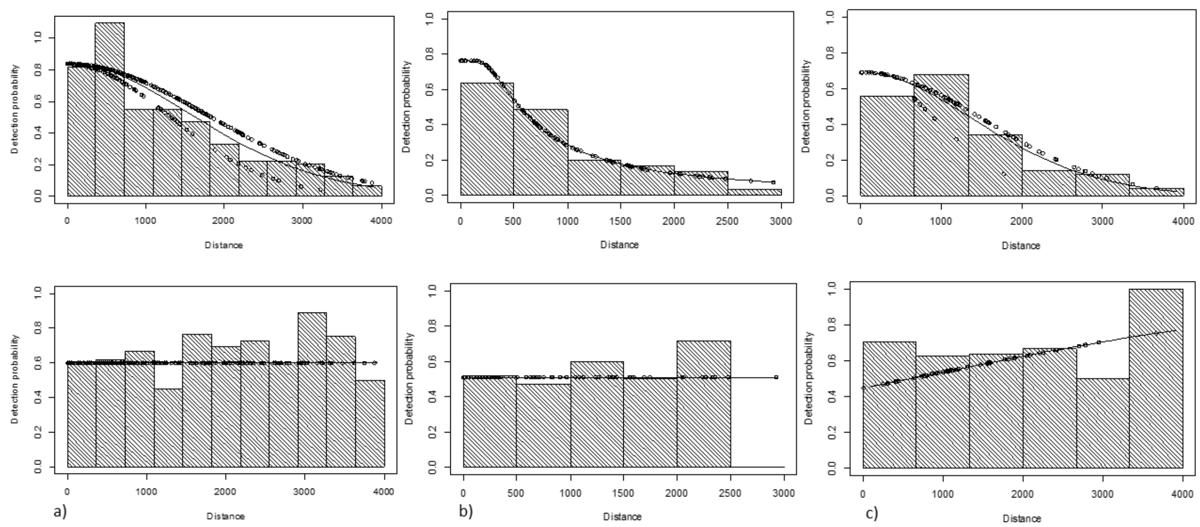

Figure 4. Detection function curves for pooled detections (top) and the conditional detection probabilities of platform 1 (bottom) for (a) fin whales, (b) humpback whales, and (c) sperm whales.

Table 2. Summary of effort and sightings for each species, survey block, and year. The NASS extension survey blocks are shaded grey and excluded from the summed totals.

Year	Block	Area sq. km	Total Transect length	Large whales	Fin whales	Humpback whales	Sperm whales	Blue whales	Sei whales	Killer whales	*Lag. spp.*	Harbour porpoises	Pilot Whales	N. bottlenose whales	Bowhead whales	Total
2014	**ES1**	175,488	1,629	8	24	12	10				116					170
	ES2	53,341	1,594	10	44	1	3	2			76					136
	ES3	118,763	1,359	3	31		10			10	53					107
	ES4	141,180	1,195	2	46	2	1	1	1		2					55
2015	**EW1**	333,180	2,682	8	58	12	8			3	44	12				145
	EW2	218,943	1,339	4	2	3	23			9						41
	EW3	228,406	1,001	1			4			5	2					12
	CM1a	163,337	622		1		13				1					15
	CM3a	295,796	1,772	2	7	2	3	3			8			2		27
2016	**CM1**	297,396	1,611		3		25			11	1		4	4		48
	CM2	177,961	1,220	7	19	7	7	5		1	1			6		53
	CM3	295,929	1,481	4	15	9	1	2		7	1			13		52
2017	**EB1**	107,105	971	1	3	12					17	23				56
	EB2	278,964	1,236	2	1						62	37				102
	EB3	232,370	1,792	4	13	40					36	25				118
	EB4	233,900	938	5	4						3	10			5	27
2018	**EW4**	84,625	861		24				1		2	7	4	4		42
	EN1	95,675	1,027				2				4	92				98
	EN2	197,293	2,124	1	1						23	138				163
	EN3	160,660	1,504	4	10						18	91	3			126
Total		3,431,179	25,564	64	298	98	94	10	2	46	461	435	11	27	5	1551

Table 3. Covariates included in the final models for each species for the distance sampling model (DS model) and the conditional detection function (mark recapture or MR model). Distance (D) is automatically added as a covariate in the DS model. B=Beaufort Sea State, W=weather, Ves=vessel, V=visibility, G=glare, S=group size, D=distance.

	Covariates	
Species	**DS Model**	**MR Model**
Fin whales	W	
Humpback whales		
Sperm whales	W	D
Harbour porpoises	B	B+D+S
Killer whales	S	
Lagenorhynchus spp.	B+S	D
N. bottlenose whales		
NASS Extension (2015)		
Fin whales	B	D
Humpback whales	W	D
Sperm whales		

Table 5. The total number of sightings (n), sightings by platform, and duplicate sighting for each species using definite + probable (D+P) duplicates.

Species	**Sightings (D+P)**			
	n	**Platform 1**	**Platform 2**	**Duplicates**
Fin whales	294	225	197	128
Humpback whales	99	69	64	34
Sperm whales	94	74	56	36
Harbour porpoises	443	261	284	102
Killer whales	47	37	33	23
Lagenorhynchus spp.	426	303	316	193
N. bottlenose whales	36	25	27	16
NASS Extension (2015)				
Fin whales	68	55	39	26
Humpback whales	17	14	10	7
Sperm whales	51	38	32	19

Table 4. Estimated *p*(0) and corresponding abundance estimates using 3 combinations of duplicates: definite (D), definite + probable (D+P), and definite + probable + remote (D+P+R).

Species	**D+P+R**				**D+P**				**D**			
	Estimate	**CV**	***p*(0)**	**CV**	***Estimate***	**CV**	***p*(0)**	**CV**	***Estimate***	**CV**	***p*(0)**	**CV**
Fin whales	11,232	0.169	0.846	0.026	11,387	0.173	0.837	0.027	14,636	0.170	0.703	0.047
Humpback whales	10,708	0.385	0.761	0.068	10,708	0.385	0.761	0.068	15,497	0.409	0.591	0.115
Sperm whales	5,704	0.263	0.692	0.148	5,704	0.263	0.692	0.148	5,888	0.275	0.673	0.168
Harbour porpoises	255,929	0.197	0.472	0.131	255,929	0.197	0.472	0.131	314,301	0.223	0.404	0.148
Killer whales	13,909	0.296	0.914	0.067	15,056	0.293	0.860	0.059	17,404	0.286	0.764	0.093
Lagenorhynchus spp.	190,455	0.241	0.858	0.020	192,767	0.248	0.872	0.025	253,874	0.244	0.748	0.052
N. bottlenose whales	7,800	0.280	0.852	0.072	7,800	0.280	0.852	0.072	8,823	0.306	0.800	0.156

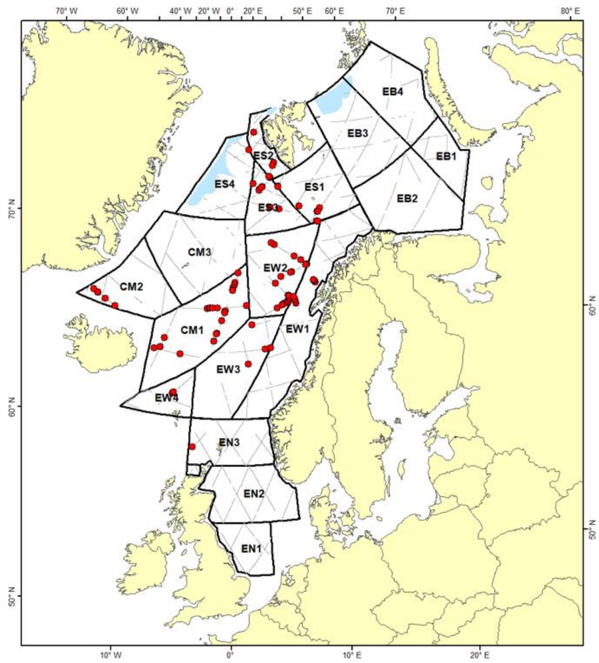

Figure 7. Distribution of sightings recorded as sperm whales during the 2014-2018 sighting surveys. The blue areas represent ice coverage.

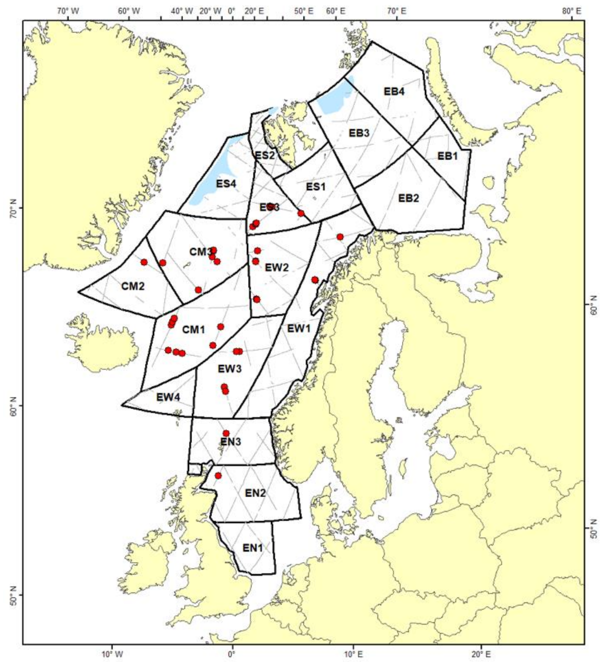

Figure 6. Distribution of sightings recorded as killer whales during the 2014-2018 sighting surveys. The blue areas represent ice coverage.

Killer whales

Killer whale observations were concentrated in the Norwegian Sea (EW2, EW3) south of the Mohn Ridge and in the Icelandic/Jan Mayen survey blocks (CM1, CM3) (Figure 7). A hazard-rate key function with group size as a covariate in the DS model, fitted to data truncated at 2000 m, provided the best fitting detection function (Figure 8a). The probability of detection on the transect line was estimated to be $p(0)$=0.86 (CV=0.06) with resulting *eshw* of 1031 m. Total corrected killer whale abundance was estimated to be 15,056 (CV=0.29, 95% CI: 8,423–26,914). Estimates by block are given in Table 9.

Northern bottlenose whales

Northern bottlenose whales were only detected in the Iceland/Jan Mayen blocks and the neighbouring EW4 block (Figure 9). A half-normal model was fitted without covariates or truncation, producing an estimated $p(0)$=0.85 (CV=0.07) and *eshw* of 1122 m. The fitted DS and MR detection functions are shown in Figure 10. The total corrected abundance of northern bottlenose whales was estimated to be 7,800 (CV=0.28, 95% CI: 4,373–13,913). Detailed results by survey block are given in Table 12.

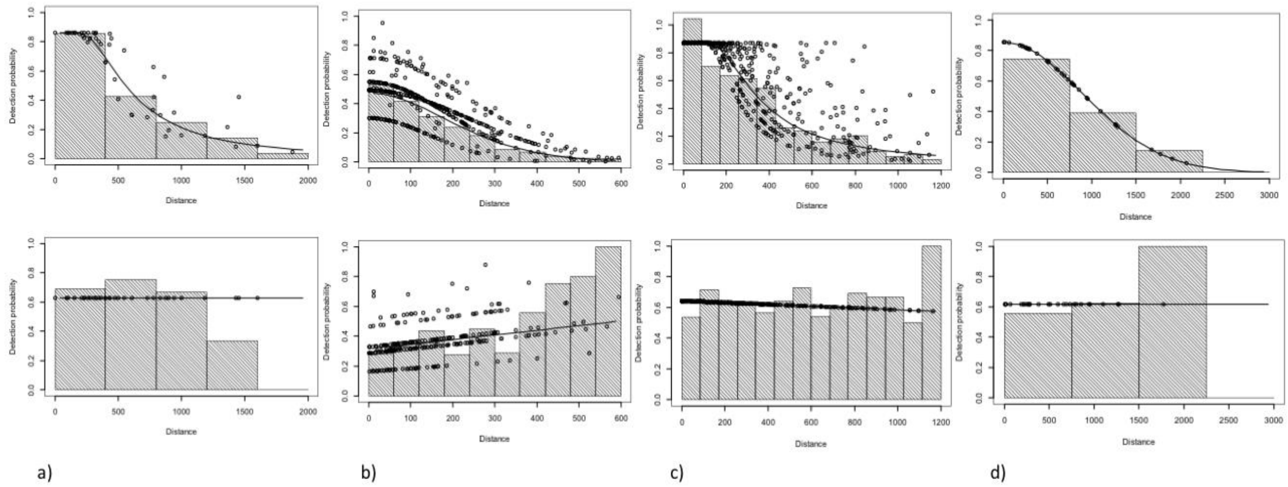

Figure 8. Detection function curves for pooled detections (top) and the conditional detection probabilities of platform 1 (bottom) for (a) killer whales, (b) harbour porpoises, (c) *Lagenorhynchus* spp., and (d) northern bottlenose whales.

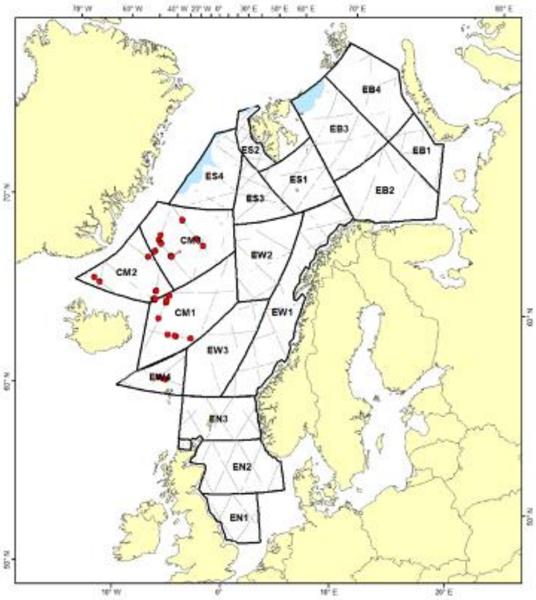

Figure 9. Distribution of northern bottlenose whales sighted during the 2014–2018 sighting surveys. The blue areas represent ice coverage.

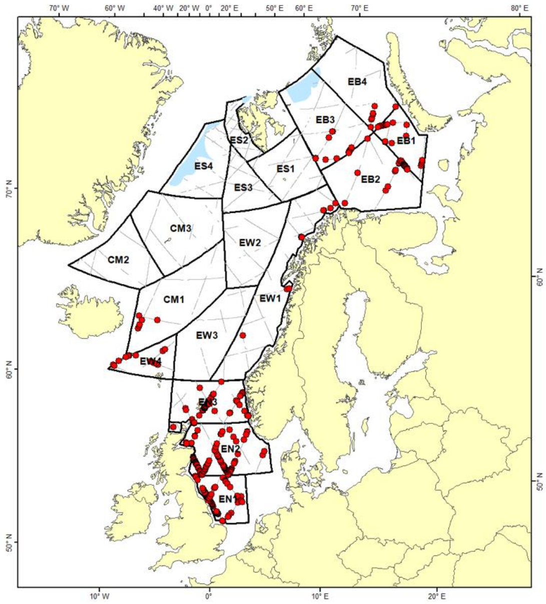

Figure 11. Distribution of sightings recorded as harbour porpoises during the 2014–2018 sighting surveys. The blue areas represent ice coverage.

Figure 10. Northern bottlenose whale. Photo credit: Jane Sproull Thomson.

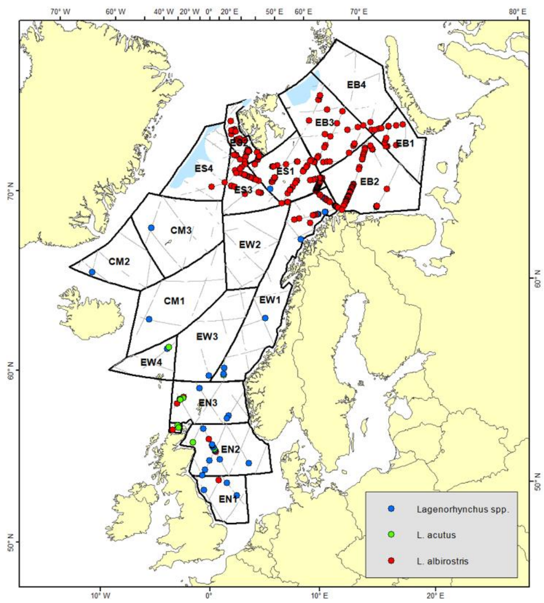

Figure 12. Distribution of sightings recorded as *Lagenorhynchus* spp. during the 2014–2018 sighting surveys. The blue areas represent ice coverage.

Harbour porpoises

Harbour porpoise sightings were concentrated in the North Sea (EN1, EN2, EN3), the Barents Sea (EB1, EB2, EB3) (Figure 11). BSS was included as a covariate in both the DS model and MR models giving estimates of $p(0)$=0.47 (CV=0.13) and *eshw* of 260 m. The fitted DS detection function and MR conditional detection function are shown in Figure 8b. Total corrected harbour porpoise abundance was estimated to be 255,929 (CV=0.20, 95% CI: 172,742–379,175) (Table 10).

***Lagenorhynchus* spp.**

Lagenorhynchus spp. were encountered in most of the blocks within the study area, with the highest encounter rate in the Svalbard blocks (ES) and the Barents Sea (EB2) (Table 11; Figure 12). A hazard-rate model provided the best fit to the DS detection function with BSS and group size as covariates and data truncated at 1200 m, resulting in an estimated $p(0)$=0.87 (CV=0.03) and *eshw* of 487 m. The fitted DS and MR detection functions are shown in Figure 7c. The total corrected abundance of *Lagenorhynchus* spp. was estimated to be 192,767 (CV=0.25, 95% CI: 114,033–325,863). Detailed results by survey block are given in Table 11.

Other species

Other species recorded, for which abundance has not been estimated include blue whales, sei whales, bowhead whales, and pilot whales. There were insufficient sightings for these species; typically, a minimum of 20–30 observations are required to model a detection function using our methods (Buckland et al., 2001). Blue whale sightings occurred in the blocks between Iceland and Svalbard, pilot whales were observed around the Faroe Islands, sei whales were spotted west of Svalbard and south of Iceland, and bowhead whales were observed along the ice edge in the northern Barents Sea (Figure 13).

To better understand the effect of unidentified large whale sightings in the dataset, a detection function for these sightings was fit to the data, from which *eshw* was estimated to be 2,583 m (CV=0.10).

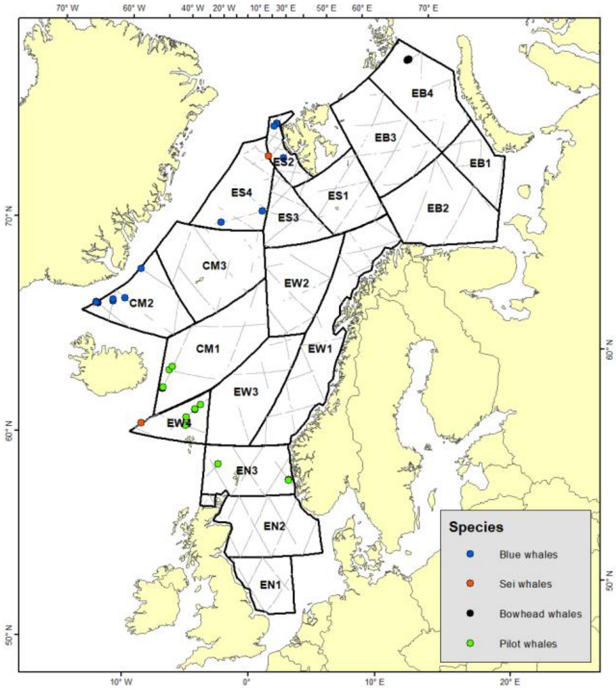

Figure 13 Distribution of blue whales, sei whales, bowhead whales and pilot whales sighted during the 2014–2018 sighting surveys. The blue areas represent ice coverage.

2015 and NASS extension estimates

A total effort of 7,857 km of transects was achieved in 2015, covering a total area of 1,458,127 sq. km. The distribution of effort by Beaufort Sea State was 0.2% in BSS 0, 8% in BSS 1, 22% in BSS 2, 28% in BSS 3 and 44% in BSS 4. The survey achieved good coverage of both the Small Management Area EW and the NASS extension CM Jan Mayen blocks. Survey block EW4 was not surveyed due to time constraints.

In 2015, there were 240 sightings of all whale species (Table 2). These included fin whales (68), sperm whales (51), humpback whales (17), blue whales (3), killer whales (17), *Lagenorhynchus* spp. (55), harbour porpoises (12) and northern bottlenose whales (2). Two sightings were recorded as 'unidentified large whales'. There were too few sightings of blue whales to estimate abundance using our methods and the small odontocetes were not estimated separately for the NASS extension.

Estimates for small odontocetes observed in the EW blocks in 2015 are reported as part of the regularly planned mosaic survey (Tables 9–12). The sightings from the modified CM blocks and EW blocks (Figure 1b) surveyed in 2015 were pooled to fit the detection function models.

The fin whale was the most abundant large whale species in 2015, with 80% of the sightings occurring in the northern most part of EW1, off the Finnmark coast of Norway (Figure 14a). A hazard-rate model provided the best fit to the DS detection function, with data truncated at 3500 m, resulting in an estimated $p(0)$=0.86 (CV=0.07) and *eshw* of 1508 m. The DS and MR detection functions are shown in Figure 15a. Total fin whale abundance in 2015 was estimated to be 3,729 (CV=0.44, 95% CI: 1,531–9,081). Estimates by block are detailed in Table 13.

As with fin whales, about 80% of humpback whale sightings occurred in the northern part of block EW1 (Figure 14b). Even with pooling across survey blocks, humpback whale sightings were insufficient to fit a detection function; thus, it was necessary to pool the data available from other years within the mosaic survey. Sightings recorded in 2014–2017 were used to fit a half-normal DS detection function. The sighting distance was truncated at 3000 m. The resulting model gave an estimate of $p(0)$=0.77 (CV=0.08) and *eshw* of 1260 m (Figure 15b). Total corrected humpback whale abundance in 2015 was estimated to be 1,711 (CV=0.41, 95% CI: 604–3,631). Detailed results by block are provided in Table 13.

Figure 14c depicts the distribution of sperm whales observed in 2015. The highest encounter rate occurred in the Norwegian Sea, in EW3 and CM1a (Table 13). A half-normal DS model fitted to data truncated at 3500 m gave an estimate of $p(0)$=0.70 (CV=0.09) and *eshw* of 1685 m. The fitted detection functions are shown in Figure 15c. Total sperm whale abundance in 2015 was estimated to be 3,828 (CV=0.33, 95% CI: 1,994–7,595). Table 13 details the estimates by survey block.

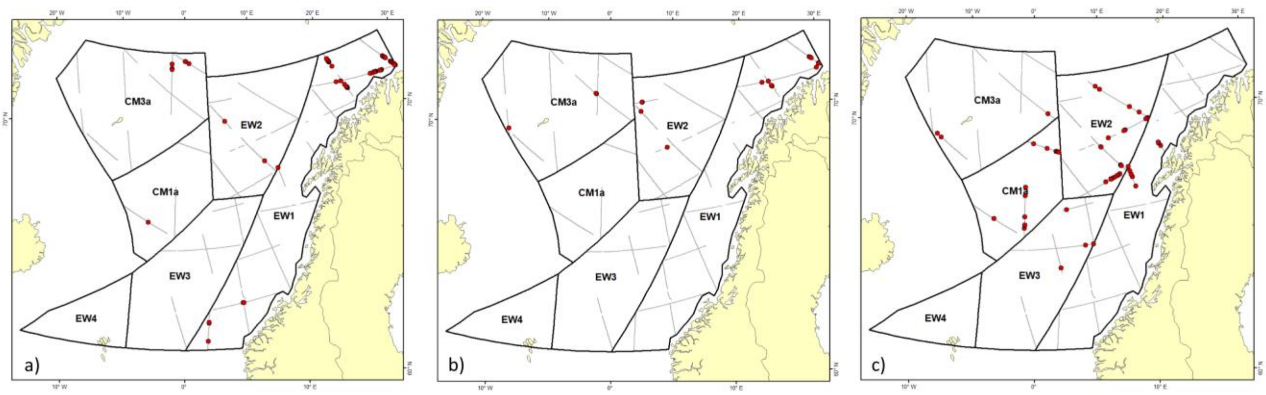

Figure 14. 2015 NASS extension survey sightings: (a) fin whale sightings, (b) humpback whale sightings, and (c) sperm whale sightings.

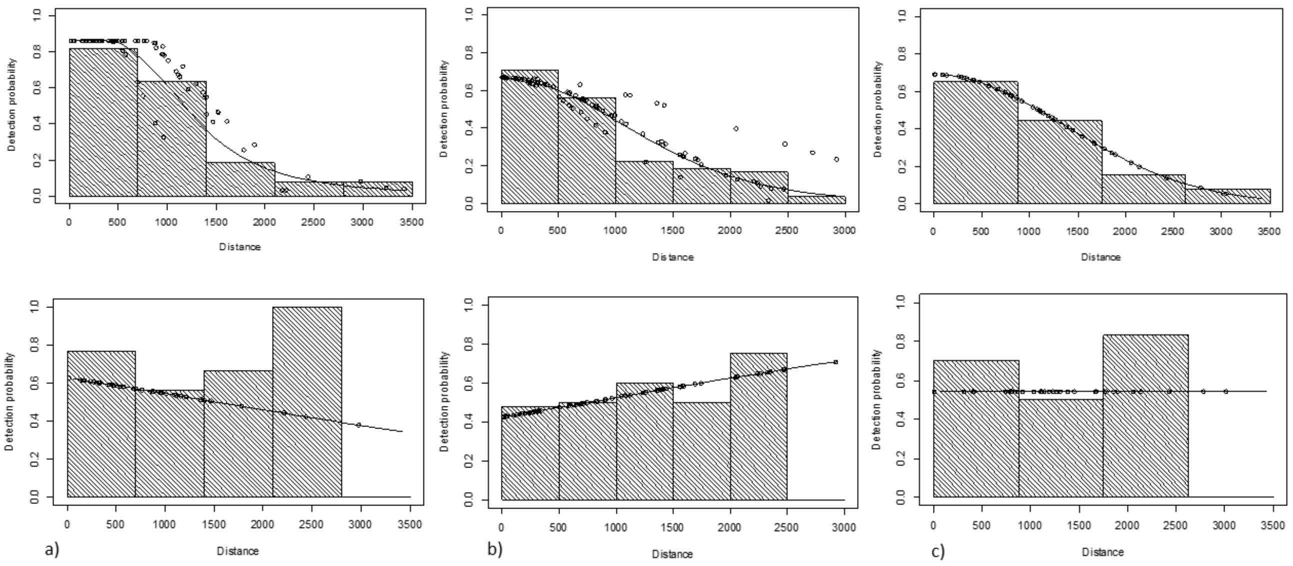

Figure 15. Detection function curves for pooled detections (top) and the conditional detection probabilities of platform 1 (bottom) for the NASS extension survey in 2015 for (a) fin whales, (b) humpback whales, and (c) sperm whales.

Table 6. Estimated density and abundance of fin whales. The *eshw* (effective search half width (m)) was estimated for the entire study area. Encounter rate, group size, density, abundance, and upper and lower confidence limits were estimated by block and corrected for perception bias, with the estimated *p*(0).

Survey Block	*eshw*		Encounter Rate		Group Size		Density		Corrected Abundance		95% Confidence Interval	
	Estimate	CV			Estimate	CV	Estimate	CV	Estimate	CV	Lower	Upper
CM1			0.002	1.078	1.00	0.000	0.001	1.080	151	1.080	9	2,440
CM2			0.020	0.328	1.33	0.121	0.006	0.328	1,029	0.328	461	2,298
CM3			0.010	0.565	1.00	0.000	0.003	0.555	836	0.555	223	3,132
EN1												
EN2			0.000	0.932	1	0.000	0.000	0.934	25	0.934	4	147
EN3			0.009	0.506	1.30	0.220	0.002	0.511	378	0.511	117	1,214
ES1			0.021	0.469	1.46	0.141	0.006	0.474	1,025	0.474	357	2,944
ES2			0.031	0.418	1.09	0.018	0.011	0.453	563	0.453	223	1,425
ES3	2004.4	0.042	0.025	0.553	1.10	0.058	0.008	0.560	891	0.560	250	3,173
ES4			0.044	0.353	1.16	0.091	0.013	0.339	1,820	0.339	858	3,863
EW1			0.024	0.520	1.14	0.029	0.007	0.528	2,353	0.528	802	6,904
EW2			0.001	0.900	1.00	0.000	0.000	0.902	89	0.902	12	642
EW3			0.000	0.000	0.00	0.000	0.000	0.000	0	0.000	0	0
EW4			0.044	0.479	1.58	0.130	0.013	0.523	1,099	0.523	285	4,245
EB1			0.002	0.649	1.00	0.000	0.001	0.653	60	0.653	12	309
EB2			0.001	1.123	1.00	0.000	0.000	1.125	61	1.125	3	1,077
EB3			0.009	0.540	1.27	0.117	0.003	0.528	668	0.528	200	2,231
EB4			0.005	0.898	1.25	0.000	0.001	0.900	339	0.900	52	2,220
Total							**0.003**	**0.173**	**11,387**	**0.173**	**8,072**	**16,063**

Table 7. Estimated density and abundance of humpback whales. The *eshw* (effective search half width (m)) was estimated for the entire study area. Encounter rate, group size, density, abundance, and upper and lower confidence limits were estimated by block and corrected for perception bias, with the estimated *p*(0).

Survey Block	***eshw***		**Encounter Rate**		**Group Size**		**Density**		**Corrected Abundance**		**95% Confidence Interval**	
	Estimate	**CV**			**Estimate**	**CV**	**Estimate**	**CV**	**Estimate**	**CV**	**Lower**	**Upper**
CM1												
CM2			0.010	0.313	1.71	0.163	0.006	0.380	1,058	0.363	478	2,344
CM3			0.007	0.486	1.22	0.068	0.005	0.532	1,328	0.520	411	4,292
EN1												
EN2												
EN3												
ES1			0.016	0.800	2.17	0.204	0.011	0.829	1,693	0.821	320	8,944
ES2			0.001	1.032	1.00	0.000	0.000	1.054	20	1.048	3	128
ES3	1086.9	0.173										
ES4			0.002	1.042	1.00	0.000	0.001	1.064	143	1.058	20	1,033
EW1			0.006	0.533	1.33	0.184	0.004	0.575	1,201	0.564	392	3,679
EW2			0.002	0.500	1.00	0.000	0.001	0.545	296	0.533	89	987
EW3												
EW4												
EB1			0.018	0.781	1.42	0.155	0.012	0.811	1,134	0.803	173	7,442
EB2												
EB3			0.026	0.836	1.175	0.037	0.017	0.864	3,684	0.856	624	21,747
EB4			0.001	0.898	1.00	0.000	0.001	0.923	151	0.916	23	982
Total							**0.003**	**0.401**	**10,708**	**0.385**	**4,906**	**23,370**

Table 8. Estimated density and abundance of sperm whales. The *eshw* (effective search half width (m)) was estimated for the entire study area. Encounter rate, group size, density, abundance, and upper and lower confidence limits were estimated by block and corrected for perception bias, with the estimated *p*(0).

Survey Block	***eshw***		**Encounter Rate**		**Group Size**		**Density**		**Corrected Abundance**		**95% Confidence Interval**	
	Estimate	**CV**			**Estimate**	**CV**	**Estimate**	**CV**	**Estimate**	**CV**	**Lower**	**Upper**
CM1			0.017	0.356	1.08	0.076	0.007	0.393	1,944	0.395	709	5,329
CM2			0.005	0.965	1.00	0.000	0.002	0.980	329	0.980	41	2,612
CM3												
EN1												
EN2												
EN3			0.001	1.073	1.00	0.000	0.000	1.086	40	1.087	5	340
ES1			0.006	0.631	1.00	0.000	0.002	0.653	405	0.654	103	1,600
ES2			0.002	0.739	1.00	0.000	0.001	0.758	38	0.758	9	160
ES3	1849	0.076	0.007	0.380	1.00	0.000	0.003	0.416	329	0.417	132	817
ES4			0.001	1.042	1.00	0.000	0.000	1.056	44	1.056	6	321
EW1			0.003	0.760	1.00	0.000	0.001	0.778	374	0.779	85	1,649
EW2			0.017	0.362	1.00	0.000	0.007	0.399	1,678	0.473	593	4,755
EW3			0.004	0.297	1.00	0.000	0.002	0.342	449	0.374	207	973
EW4			0.002	0.856	1.00	0.000	0.001	0.872	74	0.872	10	562
EB1												
EB2												
EB3												
EB4												
Total							**0.002**	**0.253**	**5,704**	**0.263**	**3,374**	**9,643**

Table 9. Estimated density and abundance of killer whales. The *eshw* (effective search half width (m)) was estimated for the entire study area. Encounter rate, group size, density, abundance, and upper and lower confidence limits were estimated by block and corrected for perception bias, with the estimated *p*(0).

Survey Block	*eshw*		Encounter Rate		Group Size		Density		Corrected Abundance		95% Confidence Interval	
	Estimate	CV			Estimate	CV	Estimate	CV	Estimate	CV	Lower	Upper
CM1			0.030	0.409	3.76	0.215	0.016	0.485	4,861	0.485	1,519	15,555
CM2			0.004	0.969	5.00	0.000	0.002	1.004	404	1.004	51	3,181
CM3			0.014	0.533	3.10	0.169	0.009	0.616	2,595	0.616	655	10,278
EN1												
EN2			0.001	1.045	3	0.000	0.001	1.063	198	1.063	29	1,354
EN3			0.002	0.909	3.00	0.000	0.001	0.930	228	0.930	34	1,514
ES1												
ES2												
ES3	1031.2	0.106	0.019	0.491	2.43	0.071	0.015	0.542	1,768	0.542	547	5,712
ES4												
EW1			0.002	0.702	1.72	0.480	0.002	0.711	543	0.711	138	2,139
EW2			0.010	0.603	1.45	0.134	0.009	0.659	1,878	0.659	443	7,966
EW3			0.017	0.504	3.31	0.065	0.011	0.534	2,582	0.534	730	9,129
EW4												
EB1												
EB2												
EB3												
EB4												
Total							**0.004**	**0.293**	**15,056**	**0.293**	**8,423**	**26,914**

Table 10. Estimated density and abundance of harbour porpoises. The *eshw* (effective search half width (m)) was estimated for the entire study area. Encounter rate, group size, density, abundance, and upper and lower confidence limits were estimated by block and corrected for perception bias, with the estimated *p*(0).

Survey Block	*eshw*		Encounter Rate		Group Size		Density		Corrected Abundance		95% Confidence Interval	
	Estimate	CV			Estimate	CV	Estimate	CV	Estimate	CV	Lower	Upper
CM1			0.004	0.636	1.28	0.197	0.015	0.674	4,529	0.674	703	29,169
CM2												
CM3												
EN1			0.108	0.516	1.13	0.038	0.461	0.380	44,124	0.380	15,710	123,929
EN2			0.079	0.370	1.14	0.049	0.336	0.292	66,194	0.292	35,970	121,813
EN3			0.074	0.513	1.18	0.028	0.276	0.402	44,408	0.402	17,929	109,991
ES1												
ES2												
ES3	259.86	0.042										
ES4												
EW1			0.006	0.372	1.23	0.067	0.038	0.456	12,748	0.456	5,148	31,565
EW2												
EW3												
EW4			0.024	0.331	1.28	0.037	0.129	0.325	10,943	0.325	5,237	22,866
EB1			0.035	0.594	1.30	0.096	0.112	0.457	11,947	0.457	3,719	38,376
EB2			0.035	0.784	1.15	0.038	0.130	0.638	36,369	0.638	6,083	217,446
EB3			0.018	0.679	1.33	0.070	0.067	0.560	15,592	0.560	4,478	54,288
EB4			0.015	0.687	1.35	0.141	0.039	0.633	9,075	0.633	2,234	36,863
Total							**0.075**	**0.197**	**255,929**	**0.197**	**172 742**	**379,175**

Table 11. Estimated density and abundance of *Lagenorhynchus* spp. The *eshw* (effective search half width (m)) was estimated for the entire study area. Encounter rate, group size, density, abundance, and upper and lower confidence limits were estimated by block and corrected for perception bias, with the estimated *p*(0).

Survey Block	*eshw*		Encounter Rate		Group Size		Density		Corrected Abundance		95% Confidence Interval	
	Estimate	CV			Estimate	CV	Estimate	CV	Estimate	CV	Lower	Upper
CM1			0.001	1.078	2.00	0.000	0.001	1.102	350	1.102	23	5,174
CM2			0.003	1.027	4.00	0.000	0.003	1.047	451	1.046	55	4,152
CM3			0.001	0.949	2.00	0.000	0.001	0.976	379	0.976	49	2,864
EN1			0.014	0.513	3.57	0.138	0.015	0.539	1,510	0.582	293	7,069
EN2			0.031	0.565	2.68	0.143	0.032	0.569	6,371	0.569	1,944	20,511
EN3			0.037	0.635	2.63	0.164	0.038	0.588	6,403	0.588	1,626	23,236
ES1			0.367	0.618	4.26	0.044	0.311	0.575	55,932	0.575	15,719	194,939
ES2			0.173	0.424	3.44	0.107	0.165	0.436	8,884	0.436	3,634	21,947
ES3	487.4	0.037	0.155	0.606	4.01	0.077	0.144	0.583	16,725	0.583	4,662	64,979
ES4												
EW1			0.050	0.662	3.16	0.109	0.051	0.648	17,713	0.647	4,761	62,522
EW2												
EW3			0.007	1.026	3.02	0.033	0.007	1.028	1,694	1.027	158	17,428
EW4			0.008	0.856	7.00	0.000	0.007	0.859	589	0.859	80	4,851
EB1			0.093	0.562	4.42	0.166	0.073	0.557	7,059	0.545	1,719	28,117
EB2			0.171	0.535	3.02	0.071	0.177	0.538	52,629	0.540	10,250	246,260
EB3			0.054	0.255	2.53	0.090	0.055	0.273	13,400	0.286	6,817	24,585
EB4			0.016	0.709	4.74	0.122	0.013	0.743	2,684	0.743	601	14,714
Total							**0.055**	**0.242**	**192,768**	**0.248**	**114,033**	**325,863**

Table 12. Estimated density and abundance of northern bottlenose whales. The *eshw* (effective search half width (m)) was estimated for the entire study area. Encounter rate, group size, density, abundance, and upper and lower confidence limits were estimated by block and corrected for perception bias, with the estimated *p*(0).

Survey Block	*eshw*		Encounter Rate		Group Size		Density		Corrected Abundance		95% Confidence Interval	
	Estimate	CV			Estimate	CV	Estimate	CV	Estimate	CV	Lower	Upper
CM1			0.013	0.636	2.62	0.116	0.007	0.652	2,027	0.652	336	12,246
CM2			0.017	0.595	2.63	0.243	0.009	0.433	1,601	0.433	587	4,365
CM3			0.023	0.314	2.13	0.184	0.012	0.342	3,553	0.342	1,628	7,751
EN1												
EN2												
EN3												
ES1												
ES2												
ES3	1121.95	0.088										
ES4												
EW1												
EW2												
EW3												
EW4			0.014	1.080	3.00	0.263	0.007	0.741	617	0.741	104	3,678
EB1												
EB2												
EB3												
EB4												
Total							**0.002**	**0.280**	**7,800**	**0.280**	**4,373**	**13,913**

Table 13. Estimated density and abundance of large whale species from the NASS extension survey conducted in 2015. The *eshw* (effective search half width (m)) and *p*(0) were estimated for the entire study area. Encounter rate, group size, density, abundance and upper and lower confidence limits were estimated by block and corrected for perception bias, with the estimated *p*(0)).

Sp.	Survey Block	*eshw*		*p*(0)		Encounter Rate		Group Size		Density		Corrected Abundance		95% Confidence Interval	
		Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Lower	Upper
	CM1a					0.002	0.933	1.00	0.000	0.001	0.940	101	0.940	4	2,830
	CM3a					0.005	0.718	1.29	0.025	0.002	0.727	579	0.727	111	3,016
Fin	EW1	1507.9	7.47	0.861	0.085	0.019	0.508	1.14	0.030	0.009	0.534	2,935	0.534	1,005	8,573
	EW2					0.001	0.914	1.00	0.000	0.001	0.921	114	0.921	15	839
	EW3														
	Total									**0.002**	**0.442**	**3,729**	**0.442**	**1,531**	**9,081**
	CM1a														
	CM3a					0.004	0.418	1.18	0.065	0.002	0.445	555	0.445	223	1,380
Humpback	EW1	1260.1	11.26	0.771	0.104	0.006	0.534	1.33	0.184	0.003	0.555	933	0.555	307	2,835
	EW2					0.002	0.481	1.00	0.000	0.001	0.505	224	0.505	70	715
	EW3														
	Total									**0.000**	**0.410**	**1,712**	**0.410**	**604**	**3,631**
	CM1a					0.021	0.470	1.00	0.000	0.009	0.523	1,465	0.523	313	6,870
	CM3a					0.002	0.729	1.00	0.000	0.001	0.764	215	0.764	41	1,127
Sperm	EW1	1684.7	10.84	0.692	0.203	0.003	0.761	1.00	0.000	0.001	0.795	396	0.795	90	1,755
	EW2					0.016	0.328	1.00	0.000	0.007	0.401	1,460	0.401	624	3,416
	EW3					0.004	0.302	1.00	0.000	0.002	0.380	355	0.380	156	808
	Total									**0.002**	**0.328**	**3,891**	**0.328**	**1,994**	**7,595**

DISCUSSION AND CONCLUSIONS

Bias and estimation issues

Survey coverage

While survey coverage was acceptable in most areas, ice coverage hampered efforts in the northernmost regions of the study area, reducing the survey area coverage by 2.6%. This is similar to past surveys (Øien, 2009; Leonard & Øien, 2020) and should not have a large effect on overall abundance, as these species are not expected to aggregate in ice covered areas.

Duplicate identification uncertainty

In this analysis, duplicate judgements were given a subjective confidence rating, which had not been done for previous surveys. By comparing 3 estimates of *p*(0), first using only definite duplicates (D), then including probable duplicates (D+P), then remote duplicates (D+P+R), the effect of duplicate uncertainty on the abundance estimates could be investigated. Generally, we expect that duplicate uncertainty is higher in our surveys than some other surveys, for example SCANS surveys (Hammond et al., 2002; 2013), because only initial sightings are recorded for non-target species. We found no significant difference ($p>0.05$) between the estimates of *p*(0) for D+P+R duplicates and for the D+P duplicates used in this analysis, however we did find a significant difference ($p<0.05$) when using only D duplicates for fin whales, humpback whales, and *Lagenorhynchus* spp. (see Table 4). Observations of large whales, such as fin whales and humpback whales, are particularly susceptible to uncertainty in duplicate identification due to the large range over which these species are first sighted by observers. Although *Lagenorhynchus* spp. are typically sighted at shorter distances, they too show higher uncertainty in duplicate judgement, likely due to their group behaviour. Being gregarious species, dolphins join, split, and re-join groups continuously, which makes it difficult to match duplicates of multiple small groups over a short range. We also expect there to be higher risk of error in observer measurements of group size, distance, and angles when observing groups of animals (Buckland et al., 2001). The exclusion of less certain duplicate identifications may lead to an underestimation of *p*(0) and positively biased estimates. For this reason, we accepted the D+P duplicates to estimate abundance.

Species identification

Failure to identify some sightings to species likely resulted from the focus on minke whales and the fact that whales were observed in passing mode. Identification of non-target species was likely further compromised when tracking procedures for minke whales were underway (Skaug et al., 2004). Comparing the *eshw* for 'unidentified large whale' sightings (2583 m) to the *eshw* for fin, humpback and sperm whales (2004 m, 1087 m and 1849 m, respectively), we find that the sightings of 'unidentified large whales' were made at greater distances than identified large whales. Given that detections that occur far from the transect line have a reduced effect on the scale of the detection function, we expect their effect on estimates of density to be fairly small.

As described in our methods, under rare circumstances, when both platforms observed a whale that was a clear duplicate (distance, angle, and timing of the sightings match), but only one observer provided a positive species ID, we accepted the positive ID for the duplicate pair. This has the potential to lead to an overestimation of the number of duplicates and therefore result in an underestimation of the abundance; however, given the challenges our methods pose for duplicate judgement (discussed above under section Duplicate identification uncertainty) we expect that an underestimation of *p*(0) and positively biased estimates are more likely. In future surveys, providing a confidence rating for each identification, as was done for duplicate judgements, would allow for a sensitivity analysis of the effect of the uncertainty in species identification. Additionally, it is also possible to apportion the unidentified large whales to species based on their relative abundance (Rogan et al., 2017). This was not done here, however, as it could introduce further bias if identification uncertainty differs between species or regions.

Distance estimation

Bias in distance estimation is perhaps one of the greatest sources of error in line transect surveys, particularly when distance measurements rely on naked-eye measurements (Leaper, Burt, Gillespie, & Macleod, 2010). Error in distance measurements can affect both the successful identification of duplicates and the overall shape of the detection function (Buckland et al., 2001). This is complicated by the fact that the bias may be non-linear, where large distances are underestimated and short distances, overestimated (Leaper et al., 2010). Our survey, which has been using consistent methods since 1995 (Øien, 1995), attempts to mitigate this type of error by maintaining experienced observers and providing regular training. In future surveys, the effect of this type of error could be evaluated by validating some proportion of the measurements through the use of precise distance-measuring devices such as cameras, reticle binoculars, or drones.

Distributional shifts

Shifts in a species' distribution between survey years and between survey blocks increases the variance in the estimates for a mosaic survey conducted over several years to an unknown degree. Additional variance has been accounted for in minke whale estimates (Bøthun et al., 2009; Solvang et al., 2015); however, this has not been possible for other species due to the lack of necessary information regarding population growth, movement, residency, etc.

Since the mosaic survey program began, steps have been taken to reduce the potential for additional variance by surveying each SMA within a single year (Skaug et al., 2004). This was successfully achieved in this survey cycle with the exception of block EW4, which was surveyed in 2018 rather than 2015 due to time constrains. These measures are intended to reduce the variance for minke whales for which the SMAs are defined. However, given that the SMAs are large geographic regions with unique physical and biological distinctions, surveying them completely within a single year may also reduce the variance for regional species such as dolphins and other small odontocetes.

Encounter rate variance

Variance in estimated encounter rate was typically high for all non-target species (Tables 6–13). For design-based estimates, encounter rate variance can be minimised by creating survey blocks, within which the density of a species is homogeneously distributed, and the transects are placed perpendicular to any density gradients (Buckland et al., 2001). This is generally not possible for multiple species within a survey; thus, our minke-whale-tailored design likely contributes to the encounter-rate variance we observe. For example, in block EW1 the density of humpback whales is concentrated in the northern part of the block, suggesting our stratification is not ideal for the species (Figure 5).

A potential alternative to design-based estimates is to use a model-based approach, which would allow for fitting models as a function of spatially referenced environmental variables. This would account for some of the spatial variation in the distribution of non-target species.

Harbour porpoise estimates and Beaufort Sea State

Survey effort used to estimate harbour porpoise abundance is typically restricted to BSS of 2 or less because of their reduced detectability at higher sea states (Barlow, 1988; Hammond et al., 2002; 2013). We opted to use all data up to BSS of 4 because encounter rates were reasonably high at higher sea states in our survey, and because including all survey effort resulted in lower variance in estimated abundance than when restricting BSS to 2 or less. The inclusion of BSS and other covariates appears to have been effective for modelling the lower detectability at higher sea states in our data. This conclusion was reviewed and supported by the NAMMCO Abundance Estimates Working Group (NAMMCO, 2019). Thus, we conclude that the model constructed utilizing all harbour porpoise sightings (BSS 0–4) is appropriate for estimating harbour porpoise abundance for this survey.

Comparison to past surveys

Fin whales

The distribution of fin whales in our surveys was similar to what was found in past surveys where fin whales were most abundant in the Icelandic blocks and Svalbard blocks, ranging from the Finnmark coast to Bear Island, and northwards to the westernmost point of Spitsbergen (ES1, ES2). Our survey estimated 11,387 (CV=0.17, 95% CI: 8,072–16,063) fin whales overall, which is consistent with the past two surveys, which found corrected estimates of ~10,000 fin whales (Leonard & Øien, 2020).

Humpback whales

Our humpback whale abundance estimate of 10,708 (CV=0.39, 95% CI: 4,906–23,370) falls within the range of the previous two surveys of 12,411 (CV=0.30, 95% CI: 6,847–22,497) in 2008–2013 and 9,749 (CV=0.34, 95% CI: 4,947–19,210) in 2002–2007 (Leonard & Øien, 2020). This suggests that the rather dramatic increase in humpback whale occurrence in Norwegian waters since our earlier surveys in 1995 and 1996–2001 (Øien, 2009) has now subsided and the population has stabilised over the last 3 survey periods.

The increase in abundance we have observed, beginning in 2002–2007, appears to have occurred largely in the Bear Island shelf area and the northern Barents Sea (Øien, 2009). We estimated 1,693 (CV=0.82, 95% CI: 320–8,944) for the Bear Island area (block ES1), while the past two surveys estimated 4,040 (CV=0.52 95% CI: 1,304–12,515 in block BJ) in 2002–2007 and 3,963 (CV=0.45, 95% CI: 1,197–13,117) in 2008–2013 (Leonard & Øien, 2020). Older surveys estimated an uncorrected abundance of 144 (CV=0.61, 95% CI: 34–601) in 1996–2001 and 656 (CV=0.31, 95% CI: 344–1,253) in 1995. The summed estimates for the Barents Sea (EB blocks) in the 2014–2018 survey period was 4,968. Estimates for the same area in

2002–2007 and 2008–2013 were 1,832 and 4,292, respectively (Leonard & Øien, 2020), while the older, uncorrected estimates in comparable blocks (BAE, KO, GA) found 118 humpback whales in 1995 and 54 humpback whales in 1996–2001 (Øien, 2009). Given that the humpback whales we observe in Norwegian waters are part of a much larger population (Smith, 2010; Smith et al., 1999), we cannot distinguish between what might be population growth versus immigration, without an effort to identify and track humpback whales between our study area and other feeding grounds. Nevertheless, the Barents Sea ecosystem appears to have become an attractive area for North Atlantic humpback whales in recent decades and this is likely due to the dramatic shifts in Atlantic herring and capelin abundances that coincide with our surveys (Gjøsæter, Bogstad, & Tjelmeland, 2009).

Sperm whales

Sperm whale distribution has been consistent among survey periods and is generally associated with the deep water of the Norwegian Sea basin. The 2014–2018 survey estimated 5,704 (CV=0.26, 95% CI: 3,374–9,643) sperm whales, within the range of the two prior survey estimates: 8,134 (CV=0.18, 95% CI: 5,695–11,617) in 2002–2007 and 3,962 (CV=0.29, 95% CI: 2,218–7,079) in 2008–2013. It is comparable to older survey estimates (6,375 (CV=0.22; 95% CI: 4,163–9,762) in 1996–2001 and 4,319 (CV=0.20 95% CI: 2,903–6,424) in 1995), although these were not corrected for perception bias (Øien, 2009). Our estimates do not account for availability bias, which could be an issue for sperm whales as they spend long periods of time underwater on deep dives (Drouot, Gannier, & Goold, 2004; Watkins, Moore, Tyack, 1985). This likely results in an underestimate for this species.

Killer whales

The current estimate for killer whales (15,056; CV=0.29 95% CI: 8,423–26,914) falls between the previous two survey estimates of 9,563 (CV=0.36, 95% CI: 4,713–19,403) in 2008–2013 and 18,821 (CV=0.24, 95% CI: 11,525–30,735) in 2002–2007. Variation among repeated survey estimates has been noted for surveys of neighbouring regions (Foote et al., 2007), suggesting that killer whales may have a highly variable summer distribution. Our estimates of killer whale abundance may also be susceptible to additional variance due to distributional shifts from one year to the next, given that they are local species thought to be strongly associated with dynamic distributions in prey (Nøttestad, 2015). The population size of the killer whales in the entire North Atlantic is not known, however, a report on the status of killer whales in the North Atlantic was published recently and summarizes all of the estimates available (Jourdain et al., 2019). Our survey estimates can contribute to filling some of the gaps in the population status of North Atlantic killer whales.

Harbour porpoises

Our 2014–2018 estimate of harbour porpoise abundance (255,929 CV=0.20, 95% CI: 172,742–379,175) was similar to the 2002–2007 estimate of 189,604 (CV=0.19, 95% CI: 129,437–277,738) (Leonard & Øien, 2020). Our estimate is also comparable to SCANS surveys for the North Sea, which estimated 355,408 (CV=0.22) in 2005 and 245,373 (CV=0.18) in 2016 (Hammond et al., 2013, 2017).

A much lower estimate of harbour porpoises was found for the North Sea in our 2008–2013 survey (38,351 CV=0.58, 95% CI: 13,158–111,777), but this was considered to be an anomaly (Leonard & Øien, 2020).

***Lagenorhynchus* spp.**

Our total abundance estimate of 192,767 (CV=0.25, 95% CI: 114,033–325,863) *Lagenorhynchus* dolphins of is comparable to past survey periods. The 2008–2013 survey estimated an abundance of 163,688 (CV=0.18, 95% CI: 112,673–237,800) and the 2002–2007 survey estimated 213,070 (uncorrected, CV=0.18 95% CI: 144,720–313,690) from a single platform (Leonard & Øien, 2020).

White-beaked dolphins have made up 90% of sightings for *Lagenorhynchus* spp. in our study area (Øien, 1996), and this is consistent with what we found, where 94% of *Lagenorhynchus* spp. identified to species level were white-beaked dolphins. Our data also suggest that the observations in the northern part of the study region are almost exclusively white-beaked dolphins while white-sided dolphins tend to be observed in the south (Figure 12). Observer effort to identify dolphin species has improved from earlier surveys. However, due to the focus on minke whales and that fact that the northern regions tend to be 'busier' with sightings, this improvement may not be even across the study region, with a greater potential to identify dolphins to species in the 'quieter' southern survey regions. For this reason, we estimate *Lagenorhynchus* spp. to genus only.

Northern bottlenose whales

The abundance of northern bottlenose whales was not estimated in our earlier surveys due to there being too few observations. In the past two surveys (Leonard & Øien, 2020), there were 12 sightings (2002–2007), and 10 sightings (2008–2013) with distributions consistent with what we have observed in the current survey (Figure 9). The region between Svalbard and Jan Mayen, where most of our sightings occurred, was an area of intense whaling of northern bottlenose whales up to 1973 (Reeves, Mitchell, & Whitehead, 1993) and the population likely remains depleted (Benjaminsen & Christensen, 1979). While there are no directly comparable recent estimates for this region, one of the Faroese blocks (block FC) from the 2015 Icelandic and Faroese NASS survey covered an area of partial overlap with the CM1 and EW4 blocks in our 2016 survey and generated an estimate of 11,384 (CV=0.94, 95% CI: 1,492–86,861) northern bottlenose whales (Pike et al., 2019, supplementary file 8). Combining the total Icelandic-Faroese estimate of 19,975 (CV=0.06, 95% CI: 5,562–71,737) (Pike et al., 2019) with the part of our estimate of 7,800 (CV=0.28, 95% CI: 4,373–13,913) that does not overlap with the FC block, provides a recent estimate for the whole Northeast Atlantic. Similar to sperm whales, northern bottlenose whales are deep divers that spend long periods underwater (Hooker & Baird, 1999), which likely results in a negative bias in our estimates.

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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