Agenda Item 4.2	Special Species Sessions Lagenorhynchus species
Information Document 4.2b	**Estimates of the Relative Abundance of Long-finned Pilot Whales (Globicephala melas) in the Northeast Atlantic from 1987 to 2015 indicate no long-term trends.**
Action Requested	Take note
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NAMMCO Scientific Publications

ESTIMATES OF THE RELATIVE ABUNDANCE OF LONG-FINNED PILOT WHALES (*GLOBICEPHALA MELAS)* IN THE NORTHEAST ATLANTIC FROM 1987 TO 2015 INDICATE NO LONG-TERM TRENDS

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ABSTRACT

North Atlantic Sightings Surveys (NASS) and associated surveys, covering a large but variable portion of the North Atlantic, were conducted in 1987, 1989, 1995, 2001, 2007 and 2015. Previous estimates of long-finned pilot whale (*Globicephala melas*) abundance, derived using conventional distance sampling (CDS), are not directly comparable to one another because of differing survey coverage, field methods and, in the case of the 1989 NASS, different survey timing. CDS was used to develop indices of relative abundance to determine if pilot whale abundance has changed over the 28-year period from 1987 to 2015. The varying spatial coverage of the surveys is accommodated by delineating common regions that were covered by: i) all 6 surveys, and ii) the 3 largest surveys (1989, 1995, and 2007). These "Index Regions" were divided into East and West subregions, and post-stratification was used to obtain abundance estimates for these index areas only. Estimates are provided using the sightings from the combined platforms for surveys that used double platforms or the primary platform only.

Total abundance in the Index Regions, uncorrected for perception or availability biases, ranged from 54,264 (CV=0.48) in 2001 to 253,109 (CV=0.43) in 2015. There was no significant trend in the numbers of individuals or groups in either the 6 or 3 Survey Index Regions, and no consistent trend over the period. Power analyses indicate that negative annual growth rates of -3% to -5% would have been detectible over the entire period. The Index Regions comprise only a portion of the summer range of the species and changes in annual distribution clearly affect the results. Operational changes to the surveys, particularly in defining pilot whale groups, may also have introduced biases. Recommendations for future monitoring of the long-finned pilot whale population are provided.

Keywords: pilot whale, Globicephala melas, North Atlantic, surveys, abundance, trends

INTRODUCTION

North Atlantic Sightings Surveys (NASS) are a series of internationally co-ordinated cetacean surveys that have been conducted in 1987, 1989, 1995, 2001, 2007 and 2015. The initial surveys were organized under the auspices of the Scientific Committee of the International Whaling Commission (IWC), while surveys after 1989 were planned by the Scientific Committee of the North Atlantic Marine Mammal Commission (NAMMCO), with formal oversight by the IWC Scientific Committee. Although sightings of all cetacean species were recorded, the target species of the surveys have been: fin whales (*Balaenoptera physalus*) (Iceland and Spain), common minke whales (*Balaenoptera acutorostrata*) (Iceland, Norway, Greenland, Faroe Islands), sei whales (Balaenoptera borealis) (Iceland 1989) and long-finned pilot whales (*Globicephala melas*) (Faroe Islands). The spatial and temporal extent of the surveys, and to some extent the survey and analytical methods employed, were optimized to the extent feasible for the target species. Ships were used in most areas, however the coastal areas of Iceland and Greenland were covered by aircraft. In 2007 the Cetacean Offshore Distribution and Abundance in the European Atlantic (CODA) survey was conducted in offshore European waters (Hammond et al., 2009). This survey was planned in conjunction with the 2007 Trans-NASS (T-NASS) so that the survey areas were contiguous and the survey methodologies were compatible.

The long-finned pilot whale is an oceanic species that occurs in offshore as well as coastal areas (Buckland et al., 1993). They are very widely distributed in the North Atlantic, from about 35º - 65º N in the west and from about 40º - 75º N in the east (ICES, 1996; NAMMCO, 1998a, 1998b). While there is little evidence of extensive migrations, their distribution does change on a seasonal basis, probably in relation to the abundance of their principle prey, which consists mainly of squid of several species

Pike, D.G., Gunnlaugsson, T., Desportes, G., Mikkelsen, B., Víkingsson. G.A. & Bloch, D. (2019). Estimates of the Relative Abundance of Long-Finned Pilot Whales (Globicephala Melas) in the Northeast Atlantic From 1987 to 2015 Indicate No Long-Term Trends. *NAMMCO Scientific Publications 11*. https://doi.org/10.7557/3.4643

(ICES, 1993, 1996; Payne & Heinemann, 1993; Zachariassen, 1993; Hátun & Gaard, 2010; Sigurjónsson, Víkingsson & Lockyer, 1993).

The long-finned pilot whale has been the object of a drive hunt in several areas of the North Atlantic, including the Faroe, Shetland and Orkney Islands, Iceland, Greenland, the eastern USA and Newfoundland in Canada (Joensen, 1976; Bloch, 1994a; Nelson & Lien, 1996). This has most notably occurred in the Faroe Islands where the hunt has been sustained for several hundred years and continues to this day (Hoydal, 1985; Bloch, 1994b; Faroe Islands, 2017).

The most recent assessment of the long-finned pilot whale in the northeast and central North Atlantic was conducted by NAMMCO in 1997 (NAMMCO, 1998b). At that time, it was concluded that the Faroese drive hunt is likely sustainable at current levels, given the estimated abundance and evidence that the population exploited in the hunt was recruited from a large area, rather than an insular stock. This evidence included high inter-annual variability in distribution and catch around the Faroe Islands, and the variation in pollutant loads and parasite burdens between schools of long-finned pilot whales taken in the Faroese drive fishery (NAMMCO, 1998b). This assessment was based heavily on the abundance estimate from the 1989 NASS, the only survey so far to cover a large proportion of the summer distribution of the species. Given that both the survey and the assessment are now dated, this paper reports a response to NAMMCO Scientific Committee recommendations in 2008 and in 2011 that indexes of relative abundance be developed and applied to the area that is common to all or several surveys, with the aim of determining trends in abundance over the full period of the NASS.

MATERIALS AND METHODS

Survey design and field methodology

The survey design and field methods used in the NASS have been described elsewhere (Sigurjónsson, Gunnlaugsson & Payne, 1989; Sigurjónson, Gunnlaugsson, Ensor, Newcomer & Víkingsson, 1991; Sigurjónson, Víkingsson, Gunnlaugsson & Halldórsson, 1996; Joyce, Desportes & Bloch, 1990; Desportes et al., 1996, 2001; Desportes & Halldórsson, 2008; Gunnlaugsson et al., 2002; Víkingsson, Gunnlaugsson, Halldórsson & Ólafsdottir, 2002; Víkingsson, Ólafsdottir & Westerberg, 2008; Gunnlaugsson, 2008; Mikkelsen, 2008a; Øien 2009; Pike et al., in press-a, in press-b) and will not be repeated in detail here.

Base stratification

Stratification for all surveys is shown in Figure 1 and Table 1. Surveys up to and including 1995 were stratified into smaller blocks than later surveys. For example, the 1987 survey had 17 strata compared to 9 in 2007 for a somewhat greater area. As knowledge of the distribution of the target species was accumulated, there was no justification for retaining some of the finer divisions.

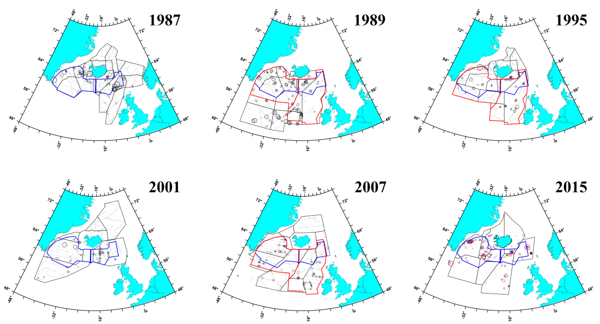

Figure 1. Base stratification, survey effort (BSS<5) and sightings of long-finned pilot whales. Symbol size varies with group size from 1 to 500. Sightings outside of the survey area in 2007 were made by extension vessels. The Index Areas are outlined in blue (6-SIR) and red (3-SIR).

Stratum areas were re-estimated in the Albers Equal Area Conic projection using MapViewer GIS software (version 8, goldensoftware.com).

Transect design

Up to 1995, an equal-spaced zig-zag transect design was used in all strata except the large Faroese block EA in 1995. In 2001, 2007 and 2015, the large strata west of Iceland and the Icelandic shelf (in 2015) were covered by vessels that were simultaneously carrying out a fish survey. An equal-spaced parallel transect design was used in these areas. There was also some deviation from designed tracklines in all years, but especially in 2001 to the north and east of Iceland, primarily due to adverse weather and time constraints.

Field procedures

Field methodology changed over the course of the surveys as new methods were developed and tested. The main focus of methodological evolution has been to account for the bias associated with visible whales being missed by observers (perception bias) and with whales approaching or fleeing from survey vessels (responsive movement). The early surveys (1987 and 1989) were conducted with a single combined observer

Table 1. Features of NASS 1987 - 2015. K – number of transects, GM – long-finned pilot whales, certain sightings, GM? – long-finned pilot whales, uncertain sightings, GMP – sightings from primary platform only.

SURVEY	AREA	EFFORT	*K*	GM	GM?	GM_P	$GM?_P$	TOT
1987	667,349	14,968	185	86	0	86	0	86
1989	874,659	8,093	99	115	4	115	4	119
1995	709,194	6,182	98	59	7	43	6	66
2001	799,754	8,058	76	71	6	60	3	77
2007	750,410	5,875	47	54	13	34	10	67
2015	812,775	7,490	107	179	12			191

platform incorporating observers on the bridge roof and 1 in the crow's nest, in passing mode with delayed closing on some sightings to confirm species identification and group size estimates. In 1995, the Faroese vessel used a Buckland and Turnock (BT) survey mode (Buckland & Turnock, 1992) which uses asymmetric platforms with one-way independence (i.e. the tracker platform is aware of primary platform sightings but not vice-versa) with the tracker platform surveying farther ahead of the vessel. Duplicate identification was performed in the field by a dedicated observer on the tracker platform, based on coincidence in sighting times, angles, species ID and group size. This method was used to estimate the proportion of visible whale groups missed by the primary observers, and to determine bias due to responsive movement, however, we do not make use of these data in this way since they are not available for all surveys. Other vessels in 1995 used the same methods as used in earlier surveys. In 2001 and 2007, the BT method was used on all survey vessels. A full description of the methodology is provided in Pike et al. (in press-a). In 2015, all vessels again used double platforms, but the platforms were symmetrical and independent from one another and tracking was not carried out. On the Icelandic vessel, the platforms were stacked vertically, while they were side-by-side on the Faroese vessel. A complete description of the methodology used in 2015 is provided in Pike et al. (in press-b).

The switch to double platform methods after 1995 does have implications for the interpretation of these data even if the sight-resight data are not utilized because the later surveys had more observers and thus greater observing power than the earlier ones. Up to and including 1995, the survey vessels operated with 3 or 4 observers operating as a single platform (except on the Faroese vessel in 1995, which had 5 observers divided between 2 platforms). After 1995, all vessels had 5 or 6 observers divided between 2 platforms. We therefore derived index abundance values from the later surveys in 2 ways: 1) using all unique sightings from both platforms, and 2) using sightings from the primary platform only. For the 2015 survey, in which both platforms were equivalent, we averaged the single platform estimates from both platforms to obtain a primary platform estimate.

Group size estimation can be problematic for this species because long-finned pilot whales can form large dispersed aggregations that contain many sub-groups. Therefore, defining a "group" for the purpose of making a sighting and measuring distance to the group centroid can be challenging. In general, there was a greater emphasis on defining sub-groups as sightings in surveys conducted after 1989. As this might influence the estimate of line transect abundance of individuals, we also looked at the abundance of schools (clusters) as an index of relative abundance.

Post-stratification

The general approach was to define the largest possible area that was covered by all surveys (Figure 1), hereafter referred to as the Survey Index Region (SIR). This area in turn was divided into East (E) and West (W) sub-regions. Existing strata that overlapped with these index regions were divided into portions inside the index region and portions outside.

The size of the SIR covered by all 6 surveys (6-SIR) was limited in the west by the extent of the 1987 survey and in the east by the extent of the 2001 survey. Therefore, an additional post-stratification using only the 1989 and 1995 NASS and the combined 2007 T-NASS and CODA surveys was carried out (3-SIR, Figure 1). This required the addition of block 1 from the CODA survey to the NASS effort. As the CODA survey was conducted using a field method slightly different from that used in the concurrent T-NASS 2007, the CODA data were analysed separately from the T-NASS data, using methods identical to those described below.

Data treatment

Species identity

For some sightings there was uncertainty in species identification. Sightings were categorized according to the degree of certainty as High (GM), Medium (coded with one question mark: GM?) and Low (coded with two question marks: GM??). As there were very few sightings (17) of lower certainty than GM?, these were omitted from the analysis.

Duplicate identification

For the 1995 (Faroese), 2001 and 2007 surveys that used BT methodology, duplicate identification was performed in the field by a dedicated observer on the tracker platform, based on coincidence in sighting times, angles, species ID and group size. In high density areas, duplicate identification was performed post-survey based on the recorded data. Duplicate certainty was classified as definite (90% likely), possible (>50% likely) or remote (<50% likely), with only the first 2 categories included as duplicates in the analysis.

For the 2015 survey, which used symmetrical platforms, duplicates were sometimes identified in the field if the vessel closed on the sighting. Otherwise, duplicates were identified later in the day or post-survey. This was done by: 1. Similarity of sighting location taking into account the time interval between the sightings, and; 2. Similarity of species identification and group size. Duplicates were classified as definite (D) or remote as above. When one platform had a low confidence species identification while the other had a high or medium confidence identification, the duplicate was classified as L. When one platform had an undefined species or a different species from the other platform, the duplicate was classified as B. For the purposes of abundance estimation, only D and L duplicates were retained.

Data selection

In some cases, Beaufort Sea State (BSS) was recorded as a range (e.g. 1-2) or as a decimal value (e.g. 2.5). Range values were converted to decimal values at the midpoint of the range. Only effort and sightings of BSS less than or equal to 4 were retained for this analysis, in conformity with most previous abundance estimates for this species (Buckland et al., 1993; Burt & Borchers, 1997; Pike, Gunnlaugsson, Vikingsson, Desportes & Mikkelsen, 2003; Paxton, Gunnlaugsson & Mikkelsen, 2009).

Visibility was recorded variably among surveys but was converted to a common scale as follows: 0=>5 nm, 1=2-5 nm, 2=1-2 nm, and 3=<1 nm. Only effort and associated sightings made at visibility 0-2 were retained for this analysis.

As noted above, for surveys that used double platforms, analyses were performed using combined unique sightings from both platforms (C), and using only primary platform sightings (P). In cases of duplicate sightings between the tracker and primary platforms, distance measurements from the tracker platform were considered more reliable and therefore preferred. For the 2015 survey, what were considered to be the most reliable measurements were used, such as where one platform had higher confidence in species identification or noted more cues.

In 2015, in strata covered by the combined cetacean/fisheries research vessel, some cetacean survey effort was maintained while ferrying between transects, resulting in some transects that paralleled the coast of Iceland or Greenland. As these transects were aligned with suspected gradients in long-finned pilot whale density, their inclusion could result in positively biased estimates (Pike et al., in press-b). Therefore, sightings from these "compromised" transects were not included in the encounter rate. However, sightings from these transects were included in the estimation of the detection functions.

Abundance estimation

Density and abundance were estimated using stratified line transect methods (Buckland et al., 2001) using the DISTANCE 6.2 (Thomas et al., 2010) software package. Abundance was estimated first using the original strata (Figure 1), then using the post-stratified blocks and the same model for the detection function. The perpendicular distance data were truncated such that 10% of the greatest distances were discarded. This was maintained in all analyses for consistency across surveys. Past abundance estimates optimized for individual surveys (e.g. Buckland et al., 1993; Borchers, Burt and Desportes, 1996; Burt and Borchers, 1997; Paxton, et al., 2009; Pike et al., in press-a, in press-b) may have used different truncation distances.

The Hazard Rate and Half Normal functions were considered for modelling the detection function, and the final model was chosen by minimization of Akaike's information criterion (AIC) (Buckland et al., 2001). Covariates affecting only the scale component of the detection function were considered for inclusion in the model to improve precision and reduce bias (Thomas et al., 2010) and AIC was again used to compare models. The following covariates were considered: BSS (as recorded and in 2 (0-2, 3+) and 3 (0-1, 2, 3+) level classifications), vessel identity (actual and with Faroese and Icelandic vessels combined), weather code, visibility, number of observers, and platform ID. For the post-stratified data, index area (in or out) was also tried. Additional covariates for sea swell and cue type were available for the CODA data.

Regression of the natural log of group size (ln(s)) against estimated detection probability was used to determine if there was size bias in group detectability. If this regression was significant at the $P<0.15$ level, the detection of groups was considered to be size biased and the estimate of mean group size was adjusted using this regression; otherwise, the simple mean of group size was used.

Abundance estimates for the index areas were generated operationally by zeroing the surface areas of strata lying outside of the index areas.

Trend analysis

Rates of change in school and animal abundance in the 3-SIR and 6-SIR were calculated using log-linear regression, and confidence intervals for the rates of change were estimated using a parametric bootstrapping procedure, assuming a log-normal distribution for the abundance estimates. This procedure was also used as a power analysis by simulating a series of survey estimates with a known growth rate and the observed variance for each survey to determine the least negative growth rate that could be detected.

RESULTS

Sightings and distribution

Long-finned pilot whale sightings by stratum are summarized in Table 1. The total number of sightings ranged from 191 in 2015 to 66 in 1995. The distribution of long-finned pilot whales varied considerably between surveys, but they were widespread in offshore areas throughout the survey area south of 66º N (Figure 1). The 1989 survey, which was conducted relatively later in the season and extended further south than the others, revealed an area of high density directly south of Iceland, south of 56º N. This area was not well covered in any other survey.

Long-finned pilot whales were most commonly sighted in the southern portion of CODA block 1 (Rogan et al., 2017), south of 55º N. This area borders on the southernmost Faroese block surveyed the same year, however, this block was very poorly covered.

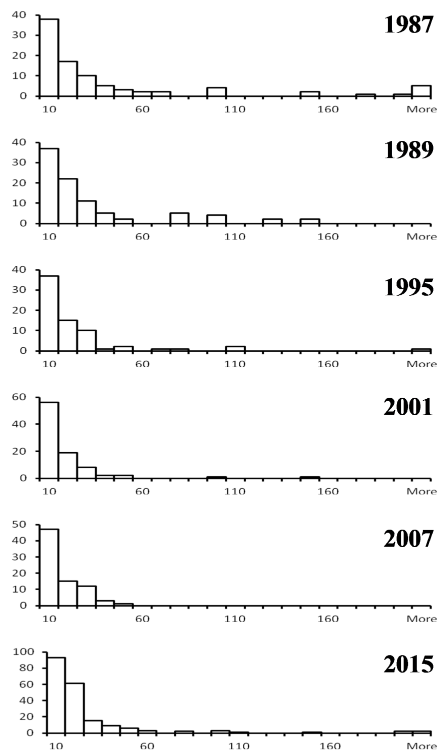

Figure 2. Frequency distribution of long-finned pilot whale school size by survey.

The early surveys, particularly those carried out in 1987 and 1989, tended to record larger groups more frequently than did the later ones (Figure 2). Mean group size generally ranged from 1 to 50 in most strata except in 1987 when it was higher in some areas. In 1987 the Faroese vessel recorded a very high average group size of 118 (Figure 3), significantly (t-test, $P<.05$) greater than that observed in any other year or vessel classification. Group size was not significantly correlated with detection probability so mean group size was used in analyses. There was significant variation in mean group size among strata in every survey, so group size was not pooled over strata.

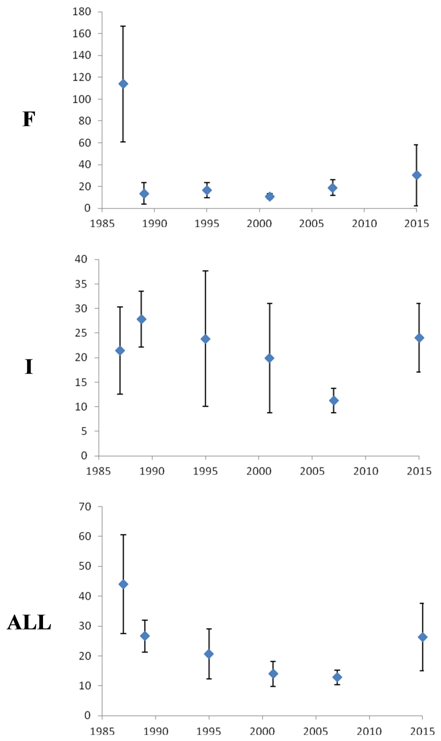

Figure 3. Mean group size for Faroese (F), Icelandic (I), and all (ALL) survey vessels.

Abundance estimates

Estimation of effective strip half-width

Truncation of the greatest 10% of distances resulted in an absolute strip width (*W*) ranging between 1,200 and 2,073 m, except for 2001, which was higher at 2,744 m (Table 2). Restricting the dataset to primary platform sightings only reduced *W* substantially in some years.

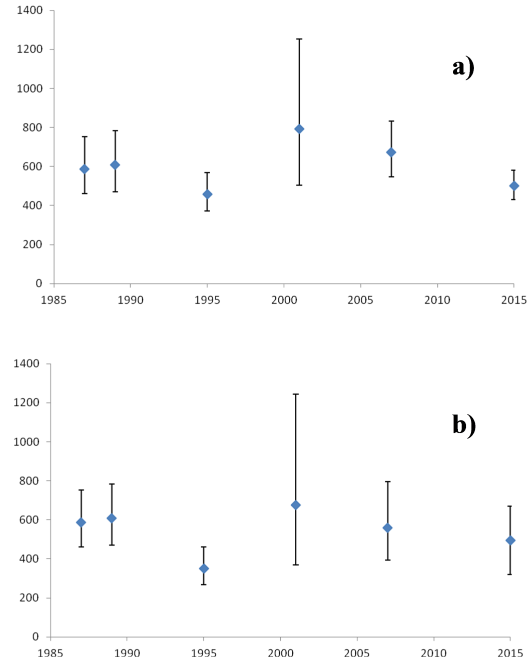

Figure 4. Effective strip half-width (m) for a) all sightings and b) primary platform sightings only from the 1995, 2001, 2007, and 2015 surveys.

Specifications of the models used to fit the detection functions are given in Table 2. Of the covariates tested, only BSS (as recorded and in a 2-level classification), vessel identity (by ship or classified as Faroese or Icelandic) and visibility improved the fit of some models. For the NASS and T-NASS, effective strip half-width (*esw*) for the combined platform models ranged from a low of 459 m in 1995 to a high of 794 m in 2001 and did not show any trend with survey year (Figure 4). Restricting the data to primary platform sightings only resulted in a reduction of *esw*. Effective strip half-width for the CODA survey was lower than that for any NASS or T-NASS, and restriction to primary platform sightings only reduced *esw* still further.

Table 2. Features of detection function models. PLAT – Platform, C – Combined, P – primary only; *W* – right truncation distance; *esw* – effective strip half-width; HZ – hazard rate; HN – half-normal; COS – cosine; BSS – Beaufort sea state; BSS2 – Beaufort sea state, 2 levels (0-2, 3+) ; VESS – vessel identity; VESS2 – vessel, Faroese or Icelandic; VIS – visibility.

SURVEY	PLAT	*W*	*esw*	MODEL	ADJUSTMENTS		COVARIATES
		(m)	(m)		TYPE	NO.	
1987	C	1,535	588	HZ			BSS2, VESS2
1989	C	1,852	608	HN	COS	3	
1995	C	1,208	459	HN	COS	1	VESS2
2001	C	2,744	794	HN	COS	1	VIS
2007	C	1,832	674	HN	COS	1	BSS
2007CODA	C	2,228	403	HZ			BSS
2015	C	2,073	501	HZ			BSS
1995	P	655	352	HN			VESS2
2001	P	2,778	677	HN	COS	1	BSS, VESS
2007	P	1,047	559	HZ			
2007CODA	P	701	276	HZ			
2015	P	2,010	495	HZ			

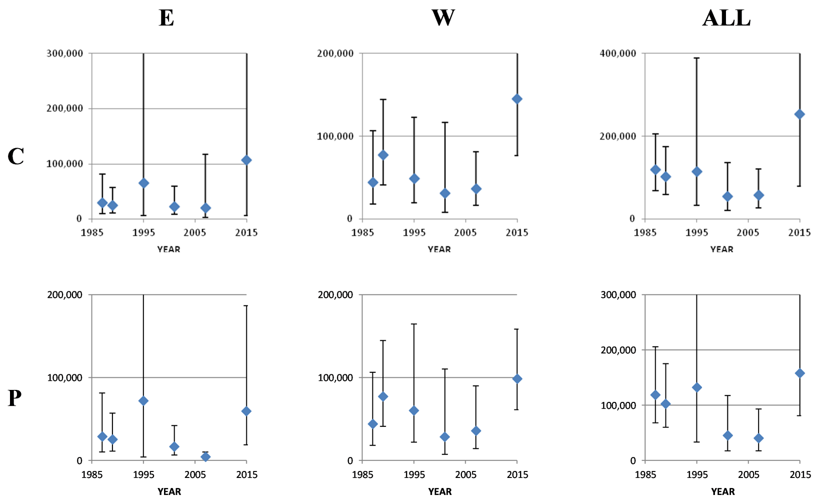

Figure 5. Long-finned pilot whale abundance by 6 Survey Index Region (E, W, ALL). C – Combined platforms used on 1995-2007 surveys. P – Primary platforms only used on 1995-2007 surveys.

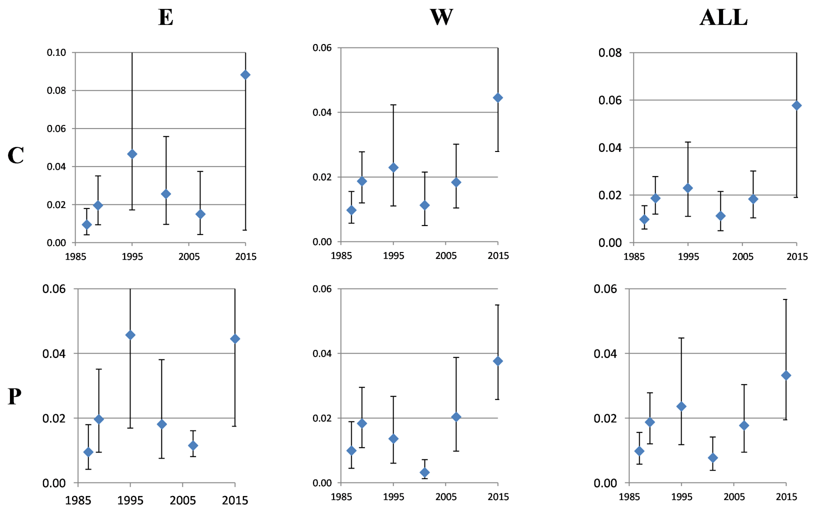

Figure 6. Long-finned pilot whale school density (no. nm-2) by 6 Survey Index Region (E, W, ALL). C – Combined platforms used on 1995-2007 surveys. P – Primary platforms only used on 1995-2007 surveys.

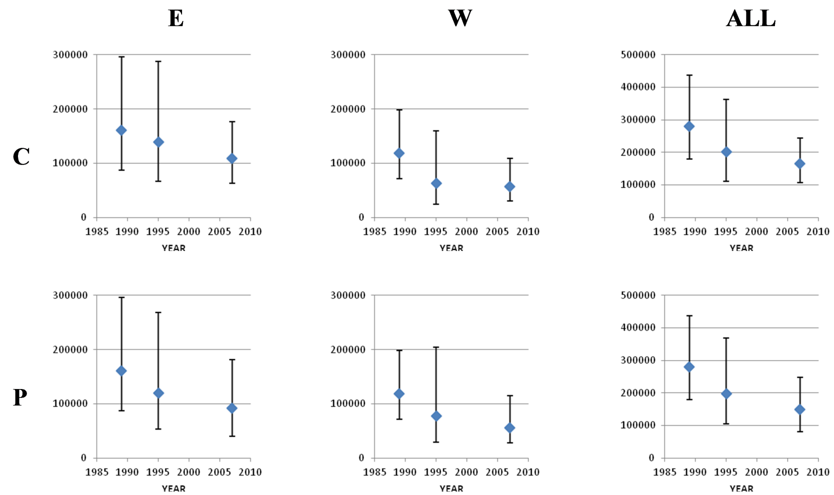

Figure 7. Long-finned pilot whale abundance by 3 Survey Index Region (E, W, ALL). C – Combined platforms used on 1995-2007 surveys. P – Primary platforms only used on 1995-2007 surveys.

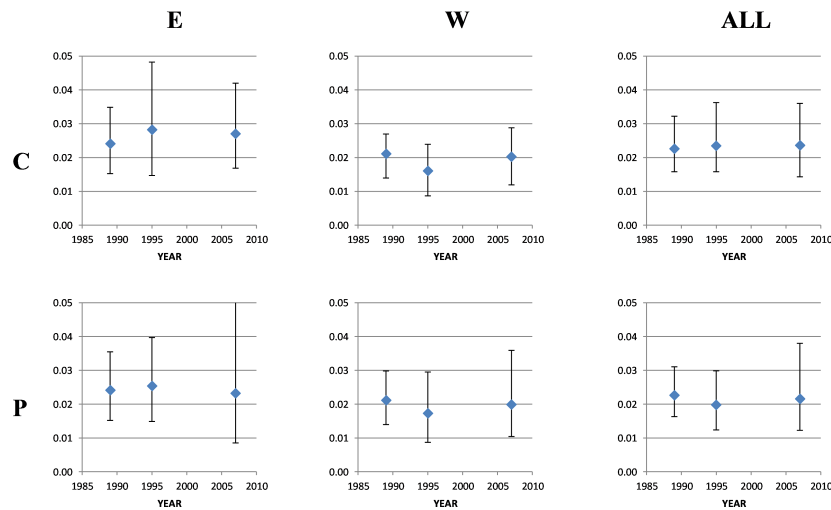

Figure 8. Long-finned pilot whale school density (no. nm-2) by 3 Survey Index Region (E, W, ALL). C – Combined platforms used on 1995 and 2007 surveys. P – Primary platforms only used on 1995-and 2007 surveys.

Table 3. Abundance estimates for the 6 Survey Index Regions. PLAT – platform, C (combined) or P (primary); *n* – number of sightings; *esw* – effective strip half-width; *DS*– density of schools; *DI* – density of individuals; *N* – number of individuals; LCL and UCL – upper and lower 95% confidence limits.

SURVEY	REGION	PLAT	*n*	*esw* (m)	CV	*DS*	CV	LCL	UCL	*DI*	*N*	CV	LCL	UCL
1987	E	C	16	588	0.12	0.0095	0.39	0.0044	0.0208	0.3643	29,005	0.54	10,331	81,435
1987	W	C	31	588	0.12	0.0099	0.38	0.0047	0.0211	0.2425	44,081	0.46	18,263	106,398
1987	**REG**	**C**	**47**	**588**	**0.12**	**0.0066**	**0.25**	**0.0040**	**0.0108**	**0.1760**	**73,086**	**0.29**	**68,189**	**205,791**
1989	E	C	18	608	0.13	0.0197	0.34	0.0098	0.0395	0.3264	25,421	0.41	11,313	57,124
1989	W	C	32	608	0.13	0.0183	0.26	0.0108	0.0311	0.4248	77,220	0.32	41,200	144,730
1989	**REG**	**C**	**50**	**608**	**0.13**	**0.0187**	**0.23**	**0.0120**	**0.0293**	**0.3953**	**102,640**	**0.27**	**60,132**	**175,200**
1995	E	C	9	459	0.11	0.0467	0.48	0.0134	0.1628	0.8245	65,408	0.72	6,607	647,538
1995	W	C	13	459	0.11	0.0145	0.37	0.0069	0.0304	0.3286	49,111	0.46	19,570	123,248
1995	**REG**	**C**	**22**	**459**	**0.11**	**0.0256**	**0.34**	**0.0116**	**0.0568**	**0.5005**	**114,520**	**0.46**	**33,730**	**388,810**
1995	E	P	6	352	0.13	0.0457	0.49	0.0090	0.2312	0.9087	72,086	0.82	4,263	1,218,982
1995	W	P	11	352	0.13	0.0160	0.39	0.0074	0.0348	0.4038	60,354	0.50	22,122	164,659
1995	**REG**	**P**	**17**	**352**	**0.13**	**0.0263**	**0.34**	**0.0110**	**0.0628**	**0.5789**	**132,440**	**0.51**	**33,369**	**525,640**
2001	E	C	40	794	0.23	0.0278	0.46	0.0109	0.0711	0.3099	22,724	0.48	8,673	59,539
2001	W	C	10	794	0.23	0.0051	0.47	0.0020	0.0126	0.1727	31,540	0.70	8,534	116,565
2001	**REG**	**C**	**50**	**794**	**0.23**	**0.0116**	**0.38**	**0.0054**	**0.0246**	**0.2120**	**54,264**	**0.48**	**21,506**	**136,920**
2001	E	P	33	928	0.12	0.0196	0.43	0.0080	0.0483	0.2283	16,739	0.45	6,645	42,167
2001	W	P	7	928	0.12	0.0032	0.47	0.0013	0.0082	0.1567	28,619	0.71	7,422	110,357
2001	**REG**	**P**	**40**	**928**	**0.12**	**0.0079**	**0.34**	**0.0039**	**0.0159**	**0.1772**	**45,357**	**0.49**	**17,498**	**117,580**
2007	E	C	7	674	0.11	0.0150	0.59	0.0011	0.2105	0.2612	20,442	0.71	3,546	117,845
2007	W	C	28	674	0.11	0.0198	0.30	0.0103	0.0382	0.2007	36,739	0.38	16,604	81,289
2007	**REG**	**C**	**35**	**674**	**0.11**	**0.0184**	**0.28**	**0.0102**	**0.0334**	**0.2188**	**57,180**	**0.56**	**26,875**	**121,660**
2007	E	P	2	674	0.11	0.0115	0.18	0.0081	0.0164	0.0575	4,504	0.27	1,983	10,230
2007	W	P	23	674	0.11	0.0204	0.36	0.0095	0.0435	0.1964	35,955	0.45	14,355	90,060
2007	**REG**	**P**	**25**	**674**	**0.11**	**0.0177**	**0.31**	**0.0093**	**0.0336**	**0.1548**	**40,459**	**0.41**	**17,559**	**93,225**
2015	E	C	27	497	0.07	0.0915	0.56	0.0113	0.7380	1.3657	107,499	0.88	6,147	1,880,120
2015	W	C	66	497	0.07	0.0544	0.22	0.0348	0.0849	0.7995	145,610	0.31	76,831	275,954
2015	**REG**	**C**	**93**	**497**	**0.07**	**0.0656**	**0.27**	**0.0307**	**0.1399**	**0.9704**	**253,109**	**0.42**	**78,975**	**811,180**
2015	E	P	13	495	0.16	0.0446	0.48	0.0175	0.1137	0.7556	59,479	0.61	18,943	186,755
2015	W	P	36	495	0.16	0.0376	0.19	0.0258	0.0550	0.6611	98,570	0.24	61,299	158,503
2015	**REG**	**P**	**49**	**495**	**0.16**	**0.0..2**	**0.27**	**0.0195**	**0.0567**	**0.6059**	**158,049**	**0.34**	**81,088**	**308,053**

Table 4. Abundance estimates for the 3-SIR. [1]*esw* for CODA is 403 m (CV 0.12). [2]*esw* for CODA is 277 m (CV 0.34). PLAT – platform, C (combined) or P (primary); n – number of sightings; *esw* – effective strip half-width; DS – density of schools; *DI* – density of individuals; *N* – number of individuals; LCL and UCL – upper and lower 95% confidence limits.

SURVEY	REGION	PLAT	*n*	*esw* (m)	CV	*DS*	CV	*DI*	*N*	CV	LCL	UCL
1989	E	P	42	608	0.13	0.0241	0.22	0.5731	160,966	0.31	87,554	295,932
1989	W	P	34	608	0.13	0.0211	0.19	0.4427	119,239	0.26	71,456	198,973
1989	**TOTAL**	**P**	**76**	**608**	**0.13**	**0.0227**	**0.17**	**0.5093**	**280,200**	**0.23**	**179,580**	**437,220**
1995	E	C	29	459	0.11	0.0283	0.3	0.4917	138,881	0.36	66,880	288,397
1995	W	C	18	459	0.11	0.0161	0.32	0.2362	62,710	0.47	24,638	159,616
1995	**TOTAL**	**C**	**47**	**459**	**0.11**	**0.0235**	**0.24**	**0.3679**	**201,590**	**0.3**	**111,900**	**363,170**
1995	E	P	17	352	0.13	0.0254	0.26	0.4239	119,733	0.38	53,495	267,986
1995	W	P	15	352	0.13	0.0173	0.32	0.2929	77,786	0.49	29,646	204,098
1995	**TOTAL**	**P**	**32**	**352**	**0.13**	**0.0198**	**0.22**	**0.3604**	**197,520**	**0.31**	**105,680**	**369,170**
2007	E	C	14	674[1]	0.11	0.0271	0.24	0.2256	109,066	0.27	62,453	176,987
2007	W	C	36	674	0.11	0.0203	0.27	0.2138	57,405	0.32	30,350	108,579
2007	**TOTAL**	**C**	**50**	**674[1]**	**0.11**	**0.0237**	**0.24**	**0.2184**	**166,471**	**0.21**	**107,671**	**244,190**
2007	E	P	31	686[2]	0.21	0.0232	0.48	0.0848	92,476	0.4	40,311	181,633
2007	W	P	36	686	0.21	0.0199	0.33	0.2101	56,399	0.36	27,620	115,163
2007	**TOTAL**	**P**	**67**	**686[2]**	**0.21**	**0.0216**	**0.29**	**0.1542**	**148,875**	**0.28**	**81,156**	**248,226**

Regional estimates and trends

Estimates of long-finned pilot whale abundance for the 6-SIR are provided in Table 3 and Figure 5, while those for the 3-SIR are provided in Table 4. For the 6-SIR, abundance was greater in the western (W) subregion than in the eastern (E) in all survey years except 1995. Abundance in the E subregion was lowest in 2007 and highest in 1995 or 2015 (using combined platforms) but there was no significant difference between survey years. Abundance in the W subregion was highest in 2015 and lowest in 2001 but again there was no significant difference between survey years. Total regional abundance was lowest in 2001 and highest in 2015, almost 5 times higher than in 2001 but nevertheless not significantly so (P>0.05).

Restriction of the data to only primary platform sightings had a variable effect on the estimates. For 2015, the estimate for the primary platform was 38% lower than that for the combined platforms, while it was 16% higher in 1995.

Point estimates of population growth rates for the E, W, and Total regions of the 6-SIR were variable but not significantly different from 0 over the period for any area (Table 5). Power analysis indicated that decrease rates from -0.02 to -0.04 would have been detectable in all areas over the period.

Estimates of long-finned pilot whale school density are provided in Table 3 and Figure 6. While school density was generally higher in 2015 than any other year in most cases, there was no monotonic trend over the period. The rate of growth in school density ranged from 2.2% to 4.5% and was significantly different from 0 in most cases (Table 5). Power analysis indicated that school density decrease rates from -0.03 to -0.04 would have been detectable over the period.

For the 3-SIR (Table 4 and Figure 7), abundance was higher in the E subregion than in the W in all years. Abundance generally declined over the period in the E, W, and Total regions at a rate ranging from -0.02 to -0.04 (Table 5) for both the combined and primary platform estimates. However, in no case was the rate of decline significantly different from null (P>0.05). Power analysis indicated that a rate of decline ranging from -0.03 to -0.05 would have been detectable by these surveys over the period.

School density (Table 4, Figure 8) showed even less change over the period and in no case was the growth rate significantly different from null (P>0.05) (Table 5). Power analysis indicated that a rate of decline ranging from -0.04 to -0.05 would have been detectable at the P<0.05 level over the period.

Table 5. Annual growth rate (G) of abundance estimates for the 3 and 6 survey index regions. SURVEYS – 6 or 3 survey post-stratification; OBJECT – *I* – individual whales, S – whale schools; PLAT – platform, C (combined) or P (primary); LGR – Least negative growth rate detectable.

SURVEY INDEX	REGION	OBJECT	PLAT	*G*	LCL	UCL	LGR
6	E	I	C	0.021	-0.030	0.078	-0.04
6	W	I	C	0.020	-0.009	0.049	-0.03
6	TOTAL	I	C	0.008	-0.022	0.042	-0.03
6	E	I	P	-0.011	-0.053	0.029	-0.04
6	W	I	P	0.007	-0.022	0.036	-0.03
6	TOTAL	I	P	-0.009	-0.035	0.015	-0.03
6	E	S	C	0.045	0.002	0.090	-0.04
6	W	S	C	0.038	0.014	0.064	-0.03
6	TOTAL	S	C	0.041	0.016	0.066	-0.03
6	E	S	P	0.024	-0.008	0.055	-0.04
6	W	S	P	0.031	0.006	0.056	-0.03
6	TOTAL	S	P	0.023	0.002	0.047	-0.03
3	E	I	C	-0.020	-0.061	0.022	-0.05
3	W	I	C	-0.035	-0.075	0.008	-0.05
3	REG	I	C	-0.027	-0.057	0.004	-0.04
3	E	I	P	-0.030	-0.084	0.024	-0.05
3	W	I	P	-0.040	-0.084	0.007	-0.05
3	TOTAL	I	P	-0.033	-0.071	0.003	-0.04
3	E	S	C	0.014	-0.040	0.068	-0.04
3	W	S	C	-0.002	-0.041	0.037	-0.04
3	TOTAL	S	C	0.022	-0.009	0.055	-0.04
3	E	S	P	0.000	-0.034	0.036	-0.05
3	W	S	P	-0.009	-0.050	0.035	-0.04
3	TOTAL	S	P	0.013	-0.022	0.048	-0.04

DISCUSSION AND CONCLUSIONS

The main focus of this paper is to develop and use an index of relative abundance to determine if long-finned pilot whale abundance in the eastern and central North Atlantic may have changed over the 28-year period from 1987 to 2015, a period over which 6 large-scale surveys have been conducted. Over this period, field methods have changed considerably to accommodate the data demands of new analytical techniques that eliminate some of the biases associated with earlier methods. We use Conventional Distance Sampling to provide a "lowest common denominator" estimate of relative abundance, as the data available from all the surveys supports this approach. Mark-Recapture Distance Sampling would be possible using data from surveys carried out after 1995, but surveys prior to and including 1995 did not use independent double platforms, precluding this approach. Bias-corrected estimates from the 2007 and 2015 surveys are provided by Pike et al. (in press-a, in press-b).

In addition to the analytical issues, the spatial extent of the survey coverage varied greatly from survey to survey. This necessitated the delineation of a common index region that was covered by all the surveys, here referred to as the 6 Survey Index Region or 6-SIR. A second and larger 3 Survey Index Region (3-SIR) was covered by 3 of the surveys spanning the period 1989-2007.

Potential biases

All of our estimates are negatively biased because we did not account for visible whales that were missed by observers (perception bias) or whales that were submerged and invisible to observers (availability bias). A central assumption of our trend analysis is that these biases remain constant or at least do not have a temporal trend. However, changes in survey methodology and experience gained over 28 years and 6 surveys may have changed the efficiency of the surveys, and it is worth exploring what effects this may have had on the apparent trends in relative abundance.

Number of observers and perception bias

It is reasonable to assume that increasing the number of observers will increase the proportion of visible whales that are sighted (i.e. reduce perception bias). The early NASS (1987 and 1989) used 3 or 4 observers, with 1 in a high barrel and 2 or 3 on the primary platform. Both of these stations were combined into 1 platform for the purposes of analysis. In 1995 the Icelandic vessels used 4 observers while the Faroese vessel used 5, 3 on a tracker platform and 2 on the primary platform). In 2001 and 2007, all dedicated vessels used 5 or 6 observers, 3 or 4 on the tracker platform and 2 on the primary platform. Although 1 or 2 of the observers on the tracker platform were not dedicated observers but acted as data recorders and duplicate identifiers, they likely improved observer performance by minimizing distractions for the dedicated observers on the tracker platform. In 2015, each platform used the same protocol and had at least 2 observers on effort at all times. Therefore, while the total number of observers has increased over the course of the NASS from 3 or 4 in the early surveys to as many as 6 in the later surveys and the CODA survey, the number of observers on the primary platform has actually decreased from at least 3 in the early surveys to 2 in the 2001, 2007, and 2015 surveys. All other factors excluded, we might therefore expect an increase in survey efficiency over time for the combined platforms and perhaps a decrease for the primary platforms only. The single platform estimates were lower for all surveys except 1995, suggesting that including additional observers does reduce perception bias. Trends in regional abundance followed roughly the same pattern using either combined or single platform estimates (Figure 5).

Pike et al. (in press-b) estimated perception bias for the combined platforms in the 2015 survey as 0.74 (CV=0.09). Including platform identity in the conditional detection function (which was not supported in the final model as determined by AIC) resulted in single platform bias estimates of 0.43 to 0.52. Similarly, Pike et al. (in press-a) estimated perception bias as 0.52 (CV=0.44) for the primary platforms of the 2007 survey, and Rogan et al. (2017) estimated a primary platform bias of 0.52 for the CODA survey in the same year. These results suggest that perception bias is relatively high for this species, with half or more visible sightings missed by a single platform. It also suggests that using sightings from the combined platforms will result in estimates 20-30% higher than using a single platform estimate. Unfortunately, using these data, we can reach no conclusion as to whether the sighting efficiency of the primary platforms has increased or decreased over the course of the surveys, as bias is impossible to estimate for surveys up to and including 1995.

Group size estimation

If it is correct that a) the estimation of group size had been consistent for all surveys, and b) actual average long-finned pilot whale group size had not changed over the period, we would expect the temporal patterns of long-finned pilot whale group density and individual density to be the same. That they are not (see Figures 6 and 7) suggests that one or both of these assumptions is false.

Figure 9. Long-finned pilot whales often occur in large tightly-packed schools, making the estimation of group size challenging. Photo credit: Faroese Museum of Natural History.

Group size estimation is problematic for this species as they form large dispersed groups (Figure 9), often with many apparent "sub-groups", depending on the operational definition employed. The first whales from such an aggregation that are detected by observers will naturally tend to be close to the vessel and hence the centre of the aggregation might be measured as being closer to the vessel than it actually is. Mean school size may tend to be overestimated because larger schools are seen more easily than smaller ones. The usual method of correcting this bias, by adjustment using the regression of school size and detection probability is not effective because the distances to the group centres are not accurate, and this leads to a lack of correlation between group size and sighting distance (Buckland et al., 1993). In this study there was in no case a significant (P<0.15) correlation between group size and detection probability. Both of these factors (underestimation of distances to actual group centres and overestimation of mean group size because of greater visibility of large groups) could lead to positive bias in the abundance estimate.

Another related issue arises because of the difficulty in counting the number of individual long-finned pilot whales in a group. Long-finned pilot whales exhibit non-synchronous diving behaviour at sea and therefore the number visible to an observer at any one time will be less than the real group size. Group size can be accurately estimated only by viewing the group at close range for an extended period of time.

Various strategies have been employed to overcome these difficulties. After 1987, more effort was put into recording accurate distances to long-finned pilot whale sub-groups, which were designated as "sightings" in the datasets. While sub-groups' affinities to larger aggregations were also noted, features of these larger aggregations were not used in abundance estimation. In addition, greater emphasis was put on recording distances to all sub-groups that were relatively close (i.e., within about 1,000 m) to the vessel.

Some effort was made to better quantify sub-group size by closing on a random sub-sample of groups. This practice was carried out in 1989 (Joyce, Desportes & Bloch, 1990) and in 1995 (Desportes et al., 1996). In many cases, closing resulted in revision of the number of groups sighted, usually increasing from one to two or more groups. Usually the "confirmed" group sizes were larger than those estimated in passing mode. For example, in 1995, in those 5 cases where only 1 group was sighted both before and after closing, the mean ratio of confirmed group size to initial group size was 1.86 (CV=0.77). However, it is less than clear whether or not these data were used to correct group sizes estimated in passing mode. There is no indication that Buckland et al. (1993) used data from closings to correct group size estimates in their work on the 1987 and 1989 surveys. While Borchers et al. (1996) used group size estimates from closings in their abundance estimate for the Faroese blocks from 1995, Burt & Borchers (1997) apparently did not. We did not use these data as they are not available consistently from all surveys, or even for all vessels within surveys. In 2015, an attempt was made to use a drone aircraft equipped with a video camera to record some long-finned pilot whale groups, for comparison of group size estimation methods, however, results from this experiment have not been reported.

Group sizes in the 1987 survey were strikingly larger than in any other year, and this difference is primarily attributable to the very high group sizes recorded by the Faroese survey vessel in that year (Figures 2 and 3). Group size estimates by the Icelandic vessels show a slight declining trend up to 2007 with an increase in 2015, and overall group sizes declined up to 1995 and exhibited no trend thereafter. The main contributing factor to this decline is the decreasing frequency of recording very large groups (Figure 2). Assuming that the lower group sizes recorded by the Faroese participants after 1987 did not reflect an actual decrease in long-finned pilot whale group sizes in the area, at least 2 factors may have contributed to the difference. Firstly, the Faroese observers likely defined groups differently in 1987 than in other years, as larger aggregations rather than smaller sub-groups. Evidence for this is that the density of groups was lower in the Eastern (primarily Faroese) index region in 1987 than in any other year (Figure 6) whereas the density of animals was not. This means that the observers in this area recorded fewer larger groups than in other years, which probably indicates that they defined groups differently at that time.

Secondly, it appears that the Faroese observers may have used a traditional heuristic derived from the drive fishery, which assumes that the number of whales on the surface - multiplied by ten - approximates the number of whales in the school (Desportes et al., 1996). While this "rule of thumb" may hold at least proximately for compact groups of agitated whales being driven into shore, it appears not to work for the much more dispersed aggregations seen at sea. In this respect it is interesting to note that the mean group size observed by the Faroese vessel in 1987 is roughly ten times that observed in other years. Some of the observers used in 1987 were experienced whalers, but none had much experience in whale surveys because few had been conducted in the area prior to that time. After 1987, a much greater emphasis was placed on getting more accurate group size estimates and group size estimates presumably improved as the observers gained experience. This may account for the overall decline in group size estimates seen over the course of the NASS surveys, as observers became more adept at and committed to discriminating smaller long-finned pilot whale sub-groups within overall aggregations.

Taken together, the difficulties in estimating group size inherent with this species probably did not have much influence on the trend analysis of individual long-finned pilot whale abundance estimates presented here. Group size estimates are reasonably consistent except in 1987 as noted. Field methods used since that time have not changed greatly, so the inherent biases should be relatively constant. Assuming that the differences observed are mainly the result of different levels of splitting of subgroups among observers, vessels and surveys, they should be compensated by concomitant changes in the size of the groups in the estimates of abundance.

Nevertheless, the problems observed may mask real trends in long-finned pilot whale group structure and size. It is obvious that further work needs to be done to obtain accurate group size estimates for long-finned pilot whales. Some recommendations are as follows:

1. Future surveys should rigorously define the meaning of "group" in the field protocol. For the 2007 survey, a group was defined as "... the smallest unit that can be tracked. A convenient rule is to define a group as containing individuals not more than 2-3 animal lengths from each other. The group may be exhibiting the same swimming pattern and/or general behaviour such as travelling, milling or resting, although not necessarily with a synchronised surfacing pattern" (Anonymous, 2007). Unfortunately, this definition does not appear to have been documented before 2007 so we are uncertain how groups were defined prior to that.
2. The importance of discriminating and counting all groups, especially those close to the vessel, should be reiterated and emphasized to observers. Groups far from the vessel

should be ignored if they interfere with the accurate recording of closer groups.

3. All vessels should close on a random subsample of sightings to obtain accurate counts of group sizes, and the correction factors so obtained, with associated variance, should be used in abundance estimates. Alternatively, a subsample of "true" group sizes could be obtained using a drone or a simultaneous aerial survey in the same area.

Spatial extent

As long-finned pilot whale density is likely to vary over large spatial scales and distribution does evidently vary from year to year (Figure 1), increasing the size of the Index Region should provide a more accurate reflection of trends in abundance over the species' range. We therefore attempted to maximize the extent of the Index Region by limiting the analysis to 3 surveys only. This provided a substantial southern extension of the E subregion, and a more modest extension in the W (Figure 1). The overall effect of this was to decrease the magnitude of the trend in observed abundance in the 6-SIR (up to 2007), showing a negative but non-significant trend over the period (Figures 7 and 8).

Ideally, if detecting trends in abundance is a major objective of the NASS survey series, all surveys should cover a common core area and that area should be as large as possible to capture the summer range of the target species. However, we recognize that effort is limited by available funding and that extending the covered area without a proportional increase in effort would result in a decrease in precision for abundance estimates.

Survey timing

All NASS (except that of 1989) have been conducted within the period from late June until the first week of August. This was considered optimal for the target species of common minke and fin whales based primarily on whaling records and other observations (e.g., Rorvik, Jónsson, Mathiesen & Jonsgard, 1976; Sigurjónsson, 1982; Sigurjónsson & Víkingsson, 1997). In 1989 the participants decided to extend the coverage area farther south and conduct the survey later in the season, primarily in the hope of obtaining a better estimate for sei whales, which tend to arrive later in the season in northern areas (Sigurjónsson et al., 1991). That survey began on 10 July and concluded on 13 August, about 1-3 weeks later than the other NASS.

It is difficult to say what effect, if any, the later timing of the 1989 survey had on the relative abundance of long-finned pilot whales in the Index Regions. Much of the index region is at the northern limit of the range of long-finned pilot whales in this area, so one might expect more whales in the area later in the summer. This expectation is supported by the seasonal distribution of long-finned pilot whale catch events in the Faroes (referred to as grind in Faroese), which peaks in August (Zachariassen, 1993; Bloch, 1994b). However, the estimate for 1989 for the 6-SIR (Figure 5) is not exceptionally large and is very similar to that for 1987. The estimate for the 3-SIR for 1989 (Figure 7) is greater than those for other years, but this is attributable mainly to larger numbers seen in the southern part of the index area. Overall the evidence for a seasonal effect on abundance is equivocal.

The spatial extension of the 1989 survey farther south of Iceland did have a large effect on the estimate of abundance, as the far southern blocks contributed heavily to the abundance estimate for that year (Buckland et al., 1993). However, this did not affect the estimates for the Index Regions. The estimate for 2015 is nearly as large and that survey did not extend far to the south (Pike et al., in press-b). This confirms that the seasonal distribution of long-finned pilot whales varies substantially from year to year.

Availability bias

Whales that are submerged and not visible to observers are not counted. This "availability bias" was thought to be small for long-finned pilot whales because they occur in groups that usually do not dive synchronously (Buckland et al., 1993). However, more recent data from satellite tagging experiments (Figure 10) indicates that long-finned pilot whales stay submerged below 7 m depth for a substantial proportion of their time around the Faroes. Heide-Jorgensen et al. (2002) found that long-finned pilot whales were submerged below this depth an average of 40% of the time in July, while Mikkelsen (2008b) observed that the whales spent 75% of their time below 16 m in fall and early winter. While a group may be detected if diving is asynchronous and some members are visible at the surface, group size will be underestimated as some members will not be visible. If diving is synchronous, entire groups will be missed. Either scenario leads to a negative bias in estimated abundance, the magnitude of which will depend on the diving cycle of the whales and the time they are potentially in the viewing field of observers on a passing ship. However, it is unlikely that the magnitude of this bias would change over time, making uncorrected estimates useful for detecting trends in abundance.

Figure 10. Tagging long-finned pilot whales in the Faroe Islands. Satellite tags provide valuable information on spatial and temporal distribution, as well as diving behaviour. The latter can be used to correct surveys for bias caused by animals that are diving while the survey vessel passes (availability bias). Photo credit: Faroese Museum of Natural History.

Species identification

For some species, such as blue whales, uncertainty in species identification is a serious issue that must be accounted for in analyses (Pike et al., in press-a, in press-b). However, only 8% of long-finned pilot whale sightings were recorded as uncertain, suggesting that they are relatively easy to distinguish from other species at sea. Nevertheless, this proportion has increased from 0% in 1987 to 24% in 2007, probably because a greater emphasis has been put on recording uncertainty in later surveys. This probably has little or no effect on estimates of abundance, as almost all sightings identified as long-finned pilot whales are included in the estimates.

Trends in relative abundance

Relative abundance in the E, W and combined 6-SIR's appeared to decline over the 18-year period from 1989 to 2007 (Figure 5, Table 3), thereafter recovering to the highest levels yet seen in 2015. The observed pattern was similar whether combined or primary platform estimates were used. As a result, there was no significant population growth rate, positive or negative, in the region (Table 5). Similarly, no monotonic trend in group density (Figure 6, Table 5) was seen over the period, but again density in 2015 was higher than in other years.

For the larger 3-SIR used in 1989, 1995, and 2007, a slight and non-significant decline in animal abundance was observed over the period (Figure 7, Table 5). No such trend was observable in group density (Figure 8, Table 5). The 2015 estimates from the western 6-SIR are close to the estimate for the larger western 3-SIR in 1989, eliminating any possibility of a negative trend in that part of the survey area if the larger area had been surveyed in 2015.

The analysis of relative abundance in the index areas therefore provides no evidence of any change in the numbers of long-finned pilot whales over the period 1987-2015. Power analyses suggest that an abundance decrease rate of -3% to -5% per year would have been detectable (Table 5). This is, however, optimistic as it requires a monotonic change over the entire period. The survey series is therefore not very powerful in detecting trends in abundance for this species. By way of illustration, a 3% annual rate of decrease in the index area over the period would have resulted in a population size in 2015 nearly 60% lower than that seen in 1987.

The index areas encompass only a relatively small proportion of the summer range of long-finned pilot whales as revealed by the NASS series (Figure 1), and most of the NASS do not cover their full range in the northeast and central North Atlantic. The 1989 NASS showed that long-finned pilot whales occur in large numbers farther south than surveyed in other years, and even in 1989 pilot whales occurred on the southern edge of the survey area, suggesting that their range might extend still further south, as has also been demonstrated by the movements of tagged animals (Mikkelsen, 2008b). Moreover, it is obvious that the spatial distribution of long-finned pilot whales does change from year to year. For example, long-finned pilot whales were concentrated farther north in the western part of the survey area in 1987 than in other years. Such annual variation is also seen in the Faroese catch series, assuming it reflects the availability of long-finned pilot whales in the local area (table 6). This in turn is probably influenced by changes and variability in the marine climate (Hátun & Gaard, 2010). The flying squid (*Todarodes sagittatus*), a major prey species for long-finned pilot whales off the Faroes and Iceland (Desportes & Mouritsen, 1993; Sigurjónsson, Víkingsson & Lockyer, 1993), occurs in large aggregations around Iceland, the Faroe Islands, and off the north-western coasts of Norway in so-called "squid years". For example, squid were abundant in the area from the late 1970s to the mid-1980s but have been virtually absent after the mid-1980s (Hátun & Gaard, 2010). Therefore, the proportion of long-finned pilot whales occupying the index area may vary greatly from year to year, making the detection of trends in abundance less powerful. Only surveys that consistently encompass all or most of the summer distribution range could overcome this problem.

While many factors could affect long-finned pilot whale numbers in the area, 1 on which we have good information is the annual drive hunt conducted in the Faroe Islands. Catch records from the Faroes go as far back as 1584, and are unbroken since 1709 (Bloch, 1994a). Catch, corrected for hunting effort, shows a cyclic pattern with a period of 100-120 years, with peaks in catch occurring in 1720-1730, 1840-1850, and 1935-1985 (Hoydal & Lastein, 1993). There is no long-term indication of declining or increasing catch over the period (Hoydal & Lastein, 1993; Zachariassen, 1993; Bloch & Lastein, 1995). Catch since 1987 has varied from 0 in 2008 to 1,738 in 1988, with an average take of 808 (CV=0.55) over the period (table 6). Given the minimum size of the population, as indicated by the 1989 survey of over 600,000 animals (Buckland et al., 1993), it seems very unlikely that an annual harvest of around 1,000 whales could have caused the population to decline. However, the stock delineation of long-finned pilot whales is uncertain. In 1997, the Scientific Committee of NAMMCO concluded that it was likely that there was more than 1 stock of long-finned pilot whales in the North Atlantic, and more than 1 stock subject to harvesting in the Faroe Islands (NAMMCO, 1998b). Therefore, the stock unit or units that is/are subject to harvesting in the Faroes could be smaller than that indicated by the maximum total survey abundance. The Eastern sub-Index Regions may be most relevant to the Faroese harvest and there is no evidence of decline in either the 3-SIR or 6-SIR (table 5). The fact that the population has been subject to approximately the same level of harvest for at least 300 years, with apparently little change in availability (Hátún & Gaard, 2010), suggests that the Faroese harvest is probably not causing the stock to decline. The NAMMCO Scientific Committee concluded in 2012 that a minimum stock size of 50,000 animals would be required to sustain recent Faroese harvest levels (NAMMCO, 2012).

Table 6. Annual takes of long-finned pilot whales in the Faroese drive hunt. Source: NAMMCO (https://nammco.no/topics/catch-database/).

YEAR	HARVEST	YEAR	HARVEST
1987	1,450	2002	626
1988	1,738	2003	503
1989	1,260	2004	1,012
1990	917	2005	302
1991	722	2006	856
1992	1,572	2007	633
1993	808	2008	0
1994	1,201	2009	310
1995	228	2010	1,107
1996	1,524	2011	726
1997	1,162	2012	713
1998	815	2013	1,104
1999	608	2014	48
2000	588	2015	501
2001	918	2016	295

Utility of the NASS series for indexing long-finned pilot whale abundance

While long-finned pilot whales have been a specific target of the Faroese component of the NASS, they have not been for Iceland or other participants. As a consequence, the surveys have never covered the full geographic range of the species in the northeast and central North Atlantic. The 1989 survey covered a larger part of this range, and as a result produced a higher estimate than any of the other surveys. However, this estimate is now 30 years old and its use as the basis of a conservation management program is questionable. The more recent 2015 survey covered a smaller area of potential long-finned pilot whale habitat, however the resultant abundance estimate is the highest observed since 1989 (Pike et al., in press-b).

The spatial extent and stratification of the NASS have been highly variable. As a result, the area that has been covered by all surveys equates to the smallest area covered by any of the surveys. While there may have been valid reasons for these changes, they are clearly detrimental to monitoring and interpreting trends in distribution and abundance in the area. In contrast, the Norwegian minke whale survey has used a common design since 1995 (Skaug, Schweder & Bothun, 2004), and the Icelandic aerial survey has used the same design since 1987 (Pike et al., in press-c). If the NASS series is to be continued, maintaining a standard design should be seriously considered.

A synoptic survey covering the entire range of the long-finned pilot whale in this area would have to extend even farther to the south than the 1989 survey. Given the resources available to the participating countries, this is probably not feasible in the near future. “Mosaic” surveys, in which the total survey area is covered over several years, are used by Norway for common minke whales (Skaug et al., 2004) and could be successful for this species. However, the NASS experience suggests that there may be extreme temporal variation in the distribution of long-finned pilot whales which would limit this approach.

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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