REPORT OF THE WORKSHOP "CETACEAN ABUNDANCE AND DISTRIBUTION IN THE NORTH ATLANTIC"

28 and 29 October 2017
Halifax, Nova Scotia, Canada

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1. Introduction

Jill Prewitt (NAMMCO) welcomed participants to the workshop, and reiterated the objectives of the meeting, which were:

i. To generate a set of North Atlantic wide design-based abundance estimates for 2015/16 for those cetacean species for which sufficient data are available. Species will include minke, fin, humpback, pilot whales and others that the data support. Estimates will be corrected for biases to the extent possible. The expected outcome is a complete set of estimates, or, more likely, an incomplete set of estimates and an action plan to achieve a complete set in timely fashion.

ii. To discuss modelling the spatial and temporal distribution and habitat use of cetaceans in the North Atlantic using data from 2015/16. Discussion will be focussed on the most important and available variables to inform modelling; the merits or otherwise of modelling the entire northern North Atlantic; the challenges of combining multiple datasets from different projects/platforms/methodologies; and the logistics and timelines of moving forward with modelling. The expected outcome is an action plan for moving forward.

She noted that the workshop included a wide spectrum of expertise, including aerial and shipboard cetacean surveys, oceanography and spatial/habitat modelling and that this should facilitate moving forward.

2. Presentations

Authors provided summaries of their presentations.

2.1 Surveys and existing abundance estimates, focussing on 2015-2016

Daniel Pike: overview of North Atlantic Sightings Surveys

The North Atlantic Sightings Surveys (NASS) are a series of international line transect surveys that have covered a large area of the Northeast and Central North Atlantic six times, in 1987, 1989, 1995, 2001, 2007 and 2015. The main purpose of the surveys has been to provide data necessary to manage anthropogenic takes of several species of cetaceans. Ships have been used to cover large offshore areas while airplanes have covered coastal areas of Iceland, Greenland and (in 2007) Canada. While the spatial extent of the surveys has varied, a large common area centred around Iceland has been covered every time. The most extensive spatial coverages were achieved in 1989 and 2007. The early surveys used mainly single platforms but since 1995 double platform methods have been used, enabling correction for whales missed by observers. Norway began their "mosaic" survey program after 1995; therefore the Eastern part of the survey area has not had single-year coverage since then. The 28 year time span of the surveys has already revealed interesting trends in distribution and abundance, including increases in the numbers of fin and humpback whales in the central area over the period, and a decrease in the numbers of minke whales around Iceland. While most estimates up to 2001 have been published, subsequent estimates (2007 and 2015/16) are available mostly as working papers, but there are plans to publish them in an upcoming volume of *NAMMCO Scientific Publications*.

Nils Øien: Norway; Joint Norwegian/Russian ecosystem surveys

The background for these surveys is a longtime Norway-Russia fisheries cooperation on 0-group and capelin abundance surveys in early fall in the Barents Sea. In 2003 different survey activities were combined into a Joint Norwegian-Russian ecosystem survey to be conducted seasonally in August-September to collect data on marine environment, zooplankton, fish recruitment, pelagic fish abundance, demersal fish, benthos, marine mammals and seabirds. The survey is based on a grid of stations and the transits between them are used as transects for marine mammal detection with a basic line transect arrangement with one platform and two observers. The Barents Sea has experienced a general warming which also through the years have extended the survey area northwards. Over the period 2003-15, about 3500 cetacean sightings have been made on transect, with common minke, fin and humpback whales as well as white-beaked dolphins as the most abundant species. The numbers have, however varied between years. A study of baleen whale distributions and prey associations based on ecosystem data revealed that krill, amphipods, capelin and polar cod fitted very well with distributions of common minke, fin and humpback whales in the north, and more importantly, they did not feed on herring which was available in the southern part of the Barents Sea at this time of the year.

Discussion
Øien noted that while the surveys provided an important medium-term dataset including oceanography and ecosystem data, future surveys may include marine mammal observers only biannually, as space on the vessels was limited.

There are several species of krill in the area but it has not been possible to date to quantitatively associate the species distribution found in net hauls with bioacoustic data: this issue is an area of active research.

Thorvaldur Gunnlaugsson: Iceland/Faroe Survey abundance estimation
The sixth North Atlantic sightings survey in 2015 survey Iceland – Faroese part was conducted in the period June the 10ht to August the 9th. Each of the three participating vessel had two independent platforms (IO), each platform with a minimum of two observers. One of the Icelandic research vessels was simultaneously conducting a redfish survey between Iceland and Greenland and later a mackerel survey around Iceland and over to Greenland. The other Icelandic research vessel was dedicated to cetacean surveying in the area outside the fisheries survey areas, to the South West and North. Both vessels had an upper and lower observation platform as in the recent surveys. The Faroese rented fishing vessel with two independent observation stations on the same platforms side by side was covering the area around the Faroes and to the South West. The dedicated vessels had the option to do delayed closing. Track design was with the Distance program. Using fisheries survey tracks had been criticized, but expert statisticians of the IWC SC RMP sub-committee accepted the tracks of the 2015, as for the earlier surveys, after inspection and adjustments to exclude compromised effort aligned along features likely to influence density of whales. Outside Icelandic and Faroese economic zone waters there was no overlap with EU survey waters and no overlap with the Norwegian multi-year mosaic cyclic survey area. This was the first ship survey with significant overlap with coastal Iceland aerial (Partenavia) survey in coastal Icelandic waters, but the aerial survey had the lowest coverage of these surveys, due to unfavourable weather and realized ship effort in low Beaufort was a small proportion in this area, so comparison between air and ship would be imprecise. The fisheries surveys did not cover the southerly East-Greenland coastal area, while ice drift hindered the coverage of the northern part. This area was covered by the Greenland coastal aerial survey. The independent double platform effort data has been convenient to collect with Dictaphones and although g(0) corrections for perception bias have not been great for the target species fin whales, this should guarantee against unnoticed cruise observation failure. While most platforms/teams are not significantly different, there are exceptions. Earlier surveys without IO, used experienced whalers so a serious perception bias was then not considered an issue.

The effort in 2015 was similar to the 2007 effort in tracking mode (BT), but the Icelandic redfish survey went rather farther to the South West. The 2001 effort (BT) went farther north-east (overlap with Norwegian blocks) but less south east. In 1995 (BT on Faroese vessel, no IO delayed closing on Icelandic vessels) there was less effort south and south-west. The 1989 effort was in closing mode, no IO, one man in barrel, went south to 50°N, an area never covered again, while no effort to the North, one to three weeks later in the season. In 1987 there was little effort to the south-west and more effort overlaps with EU and Norway. The 1987 and 1989 have been combined (labelled 1988) in abundance estimation (with no additional variance).

Blue and sei whale estimates from recent surveys are unreliable because the fisheries survey vessels could not stop or close on sightings abeam, precluding positive identification in many cases. A small relative error in fin whale identification could be a large error for these species. More photographing from the vessels (integrated with binoculars) or a drone may address this. Experienced whalers on earlier surveys were quite accurate on large whale identification.

Double platform analysis needs to choose the identification confidence level to operate at and ignore all sightings with lower confidence, also as duplicates. Different species identification between platforms is an unresolved issue, as well as differences in group size estimates between platforms, but, for example, Rogan et al (2017) apply a group size correction to primary platform based on trackers. Platforms must record their best identification and confidence and group size, and not post correct (validate) the species based on discussion with the other platform, just leave comments if needed. Both platforms may fail to identify or may be found to have wrongly identified after closing, which is also an unresolved issue in analyses.

The convention has been to use the first detection of a sighting for the perpendicular distance which is a proxy for the perpendicular distance abeam, even when the species is first identified at a later point. In the Iceland-Faroese NASS data the last detection before abeam has been used as more precise. This was criticized by some members of the IWC SC in 2010. Both approaches have a potential bias. Therefore, Gunnlaugsson brought a

paper (SC/63/RMP2) to the meeting in 2011 that was presented in the RMP subcommittee and quoting the report in (Annex D 2.6.1):

> "The subcommittee endorsed the use of the last detection distance for analysis of data from the T-NASS surveys."

Rikke Hansen: Greenland: Aerial surveys in West and East Greenland in 2015

An aerial line transect survey of whales in West and East Greenland was conducted in August-September 2015. The survey covered the area between the coast of West Greenland and offshore (up to 100 km) to the shelf break. In East Greenland, the survey lines covered the area from the coast up to 50 km offshore crossing the shelf break. A total of 423 sightings of 12 cetacean species were obtained and abundance estimates were developed for common minke whale (32 sightings), fin whale (129 sightings), humpback whale (84 sightings), harbour porpoise (55 sightings), long-finned pilot whale, (42 sightings) and white-beaked dolphins (50 sightings). The developed at-surface abundance estimates were corrected for both perception bias and availability bias if possible. Data on surface corrections for common minke whales and harbour porpoises were collected from whales instrumented with satellite-linked time-depth-recorders. Several options for estimation methods are presented and the preferred estimates are: Common minke whales: 5,262 (95% CI: 2,475-11,189) in West Greenland and 2,614 (95% CI: 1,256-5,440) in East Greenland, humpback whales: 1,068 (95% CI: 523-2,181) in West Greenland and 4,540 (95% CI: 2,222-9,275) in East Greenland, harbour porpoise: 83,321 (95% CI: 43,377-160,047) in West Greenland and 1,642 (95% CI: 318-8,464) in East Greenland, pilot whales: 9,190 (95% CI: 3,635-23,234) in West Greenland and 258 (95% CI: 50-1,354) in East Greenland, white-beaked dolphins 15,261 (95% CI: 7,048-33,046) in West Greenland and 11,889 (95% CI: 4,710-30,008) in East Greenland. No corrections for submergence could be applied to the fin whales but the estimates corrected for perception bias was 465 (95% CI: 233-929) in West Greenland and 1,932 (95% CI: 1,204-3,100) in East Greenland. The abundance of cetaceans in coastal areas of East Greenland has not been estimated before, but despite the lack of previous information from the area the achieved abundance estimates were remarkably high. When comparing the abundance estimates from 2015 in West Greenland with a similar survey conducted in 2007 there is a clear trend towards lower densities in 2015 for the three baleen whale species and white-beaked dolphins. Harbour porpoises and pilot whales however, did not show a similar decline. The decline in baleen whale and white-beaked dolphin abundance is likely due to emigration to the East Greenland shelf areas where recent climate driven changes in pelagic productivity may have accelerated favourable conditions for these species.

Discussion

Hansen noted that the survey area off West Greenland did not cover the entire summer distribution of several species. Common minke whales are known to occur further north, albeit in low numbers, while some tagged harbour porpoises moved farther offshore. She also informed the group that one tagged humpback whale moved from W to E Greenland waters during the summer, suggesting that there is exchange between these two areas. There has been a much reduced ice cover off East Greenland in recent years.

The observed declines in abundance off West Greenland between 2007 and 2015 were driven by lower encounter rates but also by reduced group sizes for fin and humpback whales.

Jack Lawson and Jean-François Gosselin: The large-scale 2016 Northwest Atlantic International Sightings Survey (NAISS) in eastern Canadian waters

To understand the roles of the diverse cetacean assemblage of cetaceans in the northwest Atlantic ecosystem the Department of Fisheries and Oceans (DFO) conducted a large-scale aerial survey of Atlantic Canadian shelf and shelf break habitats extending from the northern tip of Labrador to the U.S border off southern Nova Scotia in August and September of 2016. Using three fixed-wing aircraft (a Twin Otter and two Skymasters) DFO achieved almost the same coverage, 49,591 km of line transect effort, as in our previous large-scale marine megafauna survey in 2007 (TNASS); much poorer weather and an extended NATO naval exercise meant that DFO completed 89% of their planned lines in 2016, versus 96% in 2007. The 2016 NAISS was the second systematic survey coverage for the entire eastern Canadian seaboard, with transect lines that extended from the shoreline to at least 20 miles beyond the shelf breaks, and crossing bathymetric profiles. Flying at 183 metres ASL and 185-204 km/hr airspeed, observers in the survey aircraft collected data on the identity, group size, position, and behaviour of large and small cetaceans, plus environmental covariates. In the Labrador and Newfoundland areas the team sighted almost twice as many cetaceans as they did in 2007 (1,073 sightings = 10,956 animals), although there were relatively fewer large whales (fin, humpback, common minke); white-beaked dolphins were the most encountered and numerous cetacean. Most of the additional

sightings were collected on Labrador and Newfoundland NE coasts, perhaps a function of intentionally initiating the survey two weeks later than 2007, the later and prolonged presence of spawning capelin, or some other type of environmental change. An even greater number of sightings would have been collected had DFO been able to complete four long transect lines off the Newfoundland south coast that were precluded by poor weather. The two Skymaster teams amassed slightly fewer cetacean sightings in the Gulf of St. Lawrence and on the Scotian Shelf than in 2007 (1,182 sightings = 4,819 animals; fewer common and unknown dolphins, principally). This smaller sighting total may have been function of the poorer weather conditions and the weather-related loss of multiple transects on the centre of the Scotian Shelf. DFO is using Distance sampling approaches to estimate species abundance and derive detectability bias corrections for the common cetaceans. As well, DFO will compare the 2016 results with the distribution patterns and estimates from the 2007 survey using density surface mapping and MaxEnt habitat models.

Discussion

With regard to the increased numbers of harbour porpoises, Lawson noted that by-catch of this species may have been substantially reduced after the cod fishery moratorium in 1992. On the other hand, he also conjectured that there may be a negative association with the increased numbers of white-beaked dolphins in the area, as they tend to be aggressive towards harbour porpoise as well as other small odontocete species.

No large groups of fin or humpback whales were observed in 2016. Groups of tens of animals of both species have occasionally been observed off West Greenland.

There is little data on the summer occurrence of cetaceans in the offshore Labrador Sea between Canada and Greenland. While there were plans to use a large Canadian Air Force aircraft to survey this area in 2007, this has not been possible as yet. This should be a priority for future surveys in the area.

Debi Palka: USA: Surveys off Northeastern USA in 2016

During 27 June – 28 September 2016, the US National Marine Fisheries Service conducted a line transect abundance survey in US Atlantic waters within a study area of about 1,100,000 km^2. This survey is part of the longer-term AMAPPS project (Atlantic Marine Assessment Program for Protected Species). The 2016 summer survey utilized two NOAA Twin Otters and two NOAA research vessels, the *Henry B. Bigelow* and *Gordon Gunter*. All platforms used the two-independent team data collection method to account for perception bias. The planes flew at 600 feet altitude at about 100-110 knots, while the ships traveled at 9-10 knots. The target species were cetaceans, pinnipeds, sea turtles and some large fish. To search for animals, from each shipboard team two observers used 25x150 powered binoculars and one observer recorded the data and searched with naked eye. On the plane each team had two observers searching by naked eye and one recorder. On the ships, in addition to the two visual teams searching for marine mammals, there were teams of scientists that collected strip transect sea bird data, passive acoustic data from a towed hydrophone array, and physical and biological oceanographic data using an EK60, bongo nets, mid water trawls and continuous sea surface water sampling. During these four shipboard and plane surveys observers detected about 2,300 groups of cetaceans (over 25,000 individuals) of 28 positively identified species and about 1,920 groups of sea turtles (over 2,060 individuals) from 4 species. Abundance estimates are currently not available. The plan is to complete design-based abundance estimates by February 2018 at which time, the US and Canadian abundance estimates will be combined, as is appropriate for the stock structure of each species. In addition, these data, along with other AMAPPS data will be used in spatial-habitat models.

Discussion

Palka informed the group that data and reports up to 2013 are available online, and include a user-friendly interface for generating estimates for specific areas. Estimates for most species are corrected for availability bias, although dive profile data for some species is limited and more work and collaboration are required on this topic.

So far there has been no evidence that the active sonar system used on the vessels has caused attraction or avoidance, although it does appear to reduce acoustic detections of beaked whales.

The visual survey monitoring software used on the vessels enables tracking of sightings in real time as well as post survey, which facilitates duplicate matching between platforms.

Phil Hammond: SCANS-III

A series of large scale surveys for cetaceans in European Atlantic waters was initiated in 1994 in the North Sea and adjacent waters (project SCANS) and extended in 2005 to all shelf waters south of 62°N (SCANS-II) and in 2007 to offshore waters (CODA). Objectives were to obtain robust estimates of abundance to place estimates of bycatch and other removals in a population context and to assess changes in distribution and abundance at an appropriately large spatial scale. In July/August 2016, SCANS-III, the most extensive collaborative line transect survey in European Atlantic waters to date, was conducted using seven aircraft and three ships, covering an area of approximately 1.8 million km^2 from the Strait of Gibraltar to Vestfjorden, Norway. Data were collected using the circle-back method for aerial and two-team tracker method for ship survey to account for animals missed on the transect line. A total of >50,000 and >10,000 km were surveyed by air and ship, respectively, generating more than 4,000 sightings of 19 cetacean species. Design-based abundance estimates show the most abundant species were harbour porpoise (467,000; CV=0.15), common dolphin (468,000; CV=0.26) and striped dolphin (372,000; CV=0.33). Estimates also include 27,700 (CV=0.23) bottlenose dolphins, 36,300 (CV=0.29) white-beaked dolphins, 20,700 (CV=0.40) pilot whales, 13,100 (CV=0.35) minke whales and 18,100 (CV=0.33) fin whales. Simple trend analysis for harbour porpoise, white-beaked dolphin and minke whale, for which there are three or more comparable estimates of abundance in the North Sea, show no evidence of population change. Post-hoc power analysis shows that these data have 80% power to detect annual rates of change of 1.5% for harbour porpoise, 2.5% for white-beaked dolphin and 0.5% for minke whale. These results are being used to inform assessment of Good Environmental Status (GES) for cetaceans in European Atlantic waters under OSPAR coordination for the European Union's Marine Strategy Framework Directive.

Discussion

There was no evidence for responsive movement among any species in the ship surveys. In some previous surveys, attractive movement has been detected for common dolphins, while there has been weak evidence for aversive movement of minke whales and harbour porpoises. It was noted that the estimated number of common and striped dolphins (around one million animals) is much larger than estimated for SCANS-II/CODA (2005/07) but similar to the approximately 700,000 common/striped dolphins estimated in the French European Atlantic in summer 2011 in the SAMM aerial surveys.

Palka noted that they did not typically observe attractive movement by dolphins off the USA coast, so vessel attraction may vary geographically or among stocks. The large increase in common dolphin numbers observed since the mid-2000s might be a result of immigration of animals that did not exhibit attraction to ships. Different ships were used in this survey than in previous ones, so it is also possible that these particular ships were not attractive to dolphins for unknown reasons.

This is the first time that the "circle-back" aerial survey methodology has been applied to species other than harbour porpoises (minke whales and dolphins) to obtain combined estimates of perception and availability bias. The analytical model presently employed assumes that the dive cycles and speed of movement of minke whales and dolphins are equivalent to those for harbour porpoises. Available information indicates that this is a reasonable assumption; in any case, these estimates should be less biased than previous estimates, which were uncorrected for perception bias.

<u>Emer Rogan: Irish ObSERVE</u>

No summary available.

Discussion

Abundance estimates for harbour porpoise, minke whales and most dolphin species (not bottlenose dolphins) were corrected using the SCANS-III estimates of g(0). The aerial survey was conducted using SCANS-III data collection protocols.

<u>Claire Lacey: June 2017 survey of cetaceans in the sub-polar frontal zone of the Northwest Atlantic</u>

Field work for this project was undertaken as part of NERC cruise DY080, which forms part of a UK Natural Environment Research Council-funded project *Seabirds and wind - the consequences of extreme prey taxis in a changing climate*, which aims to quantify the past and future distributions and ecosystem roles of pelagic seabirds in the Charlie-Gibbs Fracture Zone and sub-Polar Front and similar areas.

The survey was conducted from the RRS Discovery. Standard single platform methods (as per SCANS-III Primary platform) were conducted by a team of four observers -two of which were on effort, one scribing and one on break. Approximately 270 hours of visual survey were conducted, of which 54% was carried out in good weather conditions. A total of 250 marine mammal sightings were made whilst on line-transect survey

effort, representing 12 species.The most frequently sighted species was the fin whale, with 39 individual sightings of 70 individuals. Common dolphins and humpback whales were also frequently seen (34 and 37 sightings respectively). There were large numbers of unidentified sightings of both dolphins and large whales.

Discussion
Much of the effort on this survey was done under poor conditions which would limit sightings of smaller and more cryptic species. As on some other surveys an active sonar bioacoustic system was employed, the effects of which on marine megafauna are unknown. Passive acoustic data, suitable for detection of some odontocetes including sperm whales, were also collected but are as yet unanalyzed.

2.2. Modelling distribution and habitat use – previous work

Gísli Víkingsson: Changes in large whale distributions in the central North Atlantic

Víkingsson summarized changes in some large baleen whale distributions and abundance in the central North Atlantic from shipboard and aerial surveys (NASS) conducted by Iceland and the Faroes during 1987-2016. Appreciable changes in the distribution and abundance of several cetacean species have occurred over this period. The abundance of Central North Atlantic fin and humpback whales increased from 15,200 to 41,500 and 1,800 to 14,600 respectively between 1987 and 2015. In constrast, the abundance of common minke whales in the Icelandic continental shelf area decreased from around 44,000 in 2001 to 10,000 in 2009 and 13,500 in 2016. The decreased abundanc of common minke whales in Icelandic coastal waters is likely a consequence of decreased availability of preferred prey, notably sandeel and capelin in these waters. The increase in fin whale numbers was accompanied by expansion of distribution into the deep waters of Irminger Sea. Modeling of habitat selection of fin whales using generalized additive models suggests that abundance is influenced by an interaction between the depth and distance to the 2,000m isobath but also by sea surface temperature (SST) and sea surface height. The distribution of the endangered blue whale in Icelandic waters has shifted northwards in recent years.

In addition to these changes in cetacean distribution, the increased sea temperatures in Icelandic waters during the last decades have also led to appreciable changes (northward shift) in various fish species and poor breeding success of puffin and other seabirds in southern Icelandic waters.

Discussion
Víkingsson considered it likely that the observed decline in common minke whales near Iceland was the result of changes in distribution rather than stock decline, but it remained uncertain where the “missing” common minke whales had gone. The Norwegian survey conducted in 2016 had shown very high densities near Jan Mayen (IWC “CM” Small Area), and areas northwest of there remained unsurveyed. Coincident with increased sea temperatures there has been a general northward shift in the distribution of several fish species (including mackerel, haddock, monkfish and capelin) in Icelandic waters during the last 20 years. These changes, along with the decline in sandeel numbers, likely contribute to the change in common minke whale distribution.

Nadya Ramírez Martínez: Preliminary modelling NILS/NASS surveys pre-2015: Decadal-scale Changes in Cetacean Distribution in the North Atlantic

The talk consisted two parts. The first part consisted in a summary of the overall sighting data from the North Atlantic Sightings Surveys (NASS) and the Norwegian Independent Line Transect Surveys (NILS) surveys from 1987 to 2013. For analysis, data were grouped in Mysticeti (fin, humpback and minke whales), deep divers (sperm, pilot and northern bottlenose whales) and Delphinidae (killer whales, Atlantic white-sided, short-beaked common, white-beaked and bottlenose dolphins). The second part of the talk was the presentation of distance sampling results and preliminary analysis of habitat modelling, specifically for the NILS data from 1995 to 2013. The distance sampling results presented included the species in the groups Mysticeti and deep divers. In the habitat modelling the covariates evaluated in the models were depth and monthly sea surface temperature (SST), while the species evaluated were fin, humpback and minke whales (Mysticeti) and sperm whales. The best models for Mysticeti included depth and SST with lagged relationships but only within the summer months. For sperm whales, the best model included depth and May STT, showing a more lagged relationship than baleen whales. These are preliminary results, further analysis and model validation needs to be made.

Discussion
This is a preliminary analysis, and additional covariates, such as those related to bottom topography will be integrated as analysis progresses. However because of the time span covered by the surveys (1987-2013), only a limited number of remotely sensed variables are available for the entire period. Even for those for which a

complete series is available, such as SST, the spatial and temporal resolution is constrained by that of the early data.

It was noted that habitat modelling for deep divers such as sperm and beaked whales using surface covariates such as temperature and chlorophyll tends to fail, presumable because bottom topography and features deeper in the water column are more important to these species.

Anita Gilles: Modelling harbour porpoise distribution in the North Sea

In this study, a large set of dedicated surveys for the harbour porpoise (*Phocoena phocoena*), collected in the UK (SCANS II, Dogger Bank), Belgium, the Netherlands, Germany and Denmark, was aggregated to develop seasonal habitat-based density models for the North Sea. All these systematic aerial surveys were part of national monitoring programmes conducted throughout most of the year. In all surveys the same field protocol was used and the fraction missed on the transect was also estimated. Visual survey data were collected over 11 yrs. (2005–2015) by means of dedicated line-transect surveys. Generalized additive models of porpoise density were fitted to >173,000 km of on-effort survey data with 16,000 sightings of porpoise groups. Candidate predictors included static variables, such as water depth, slope, distance to shore and distance to sandeel (*Ammodytes* spp.) foraging habitats. The dynamic oceanographic features were remote-sensed sea surface temperature (SST), spatial and temporal variation in SST (as proxies for fronts) and day length (see Gilles et al. 2016 for more details). Porpoise densities were modelled with a temporal resolution of day to capture relatively short timescales of habitat variation. As new feature, modelled ocean products were used, derived from the 3d coupled physical-biological ecosystem model ECOSMO, where both fish and macrobenthos were included in the model formulation as functional groups linked to the lower trophic levels via predator-prey relationships. Predictive power was evaluated on novel data sets. Results demonstrated that the best model could effectively predict daily variations in porpoise densities, providing maximum flexibility to meet a variety of temporal scales for dynamic species management. Seasonally-explicit density predictions were also presented that will inform EU Habitats and Marine Strategy Framework Directives and will be implemented in marine spatial planning where fine-scale predictions of porpoise distribution are required to assess risks of increasing human activities at sea.

Discussion

The habitat models included candidate covariates related to forage fish production, either including the distance to sandeel foraging habitats or fish production predicted from the coupled physical-biological model. Sandeel is a major component of the diet of porpoises in the area and the covariate used was selected in the best-fitting models. However, sandeel density is also closely related to ocean fronts and this dynamic pattern could be better captured in the models fitted with the outputs of the ecosystem model. Sandeel numbers can change greatly over time; however there were no data on this to include in modelling.

Seasonality was captured by surface temperature and day length, and porpoise distribution was dynamic over seasons.

Laura Mannocci, Jason Roberts, Patrick Halpin: Cetacean models in the western North Atlantic

To inform management needs in the United States, our group has developed two sets of habitat-based density models of cetaceans. The first set of models (Roberts *et al*., 2016) concerns the U.S. East coast. The second set of models (Mannocci *et al*., 2017), which concerns the Atlantic Fleet Testing and Training (AFTT) area, is the most relevant to the present workshop. The AFTT area extends from a well-surveyed region within the U.S. Exclusive Economic Zone into a large region of the western North Atlantic sparsely surveyed for cetaceans. We modeled densities of 15 cetacean taxa with available line transect survey data throughout the North Atlantic and habitat covariates and extrapolated predictions to sparsely surveyed regions. We formulated models to reduce the extent of extrapolation beyond covariate ranges, and constrained them to model simple and generalizable relationships. To evaluate confidence in the predictions, we mapped where predictions were made outside sampled covariate ranges, examined alternate models, and compared predicted densities with maps of sightings from sources that could not be integrated into our models. We also conducted a cross validation experiment to assess the sensitivity of model results to the heterogeneous coverage of survey effort. Confidence levels in model results depended on the taxon and geographic area and highlighted the need for additional surveying in environmentally distinct areas. Our model results are being used by the U.S. Navy to quantify potential cetacean interactions with military training exercises in the western North Atlantic, and are freely available at http://seamap.env.duke.edu/models/AFTT-2015/

Discussion

The authors noted that seasonal models were made for those species which exhibited seasonal changes in distribution within the areas surveys. A few species, for example minke whales, remain within the area year round. However seasonal predictions were made when adequate data were available.

One method used for testing the robustness of the models was to drop a portion of the surveyed area or a specific jurisdiction or province from the model to determine if specific geographical areas responded differently to environmental correlates. In most cases models were robust to removals, but a few cases (e.g. sei whales, Eastern and Western Atlantic) were found where responses differed by area, and for these spatially segregated models were developed.

Jessica Redfern: Cetacean-Habitat Relationships: From basic science to conservation and management
Spatially explicit risk assessments require spatial representations of human activities and species distributions. Previous estimates of marine mammal abundance were available at spatial scales that were typically much larger than the scale of human activities. To provide finer-scale estimates of species densities, researchers at NOAA fisheries' Southwest Fisheries Science Center developed habitat models for 15 species or species groups in the eastern tropical Pacific using 10 cetacean and ecosystem assessment surveys conducted between 1986-2006 (Barlow *et al*. 2009, Forney *et al*. 2012), 9 species in the central North Pacific using 11 cetacean and ecosystem assessment surveys conducted between 1997-2012 (Forney *et al*. 2015), and 11 species in the California Current using 7 cetacean and ecosystem assessment surveys conducted between 1991-2009 (Becker *et al*. 2016). Generalize additive models were used to relate species encounter rate and group size to habitat variables. Models were validated using multiple techniques, including evaluating ratios of observed to predicted values in each survey year and in geographic strata, comparison to abundance estimates for the entire study area derived using distance sampling techniques, expert review of predicted density patterns, and assessments of predictions on novel survey data. Details of current methods can be found in Becker *et al*. (2016). During the development of these models, we conducted a review of modelling techniques (Redfern *et al*. 2006), explored the spatial resolution of input variables (Redfern *et al*. 2008), and evaluated the possibilities of using alternative habitat data sources (Becker *et al*. 2010, Becker *et al.* 2016). We also explored the ability of the models to predicted seasonal changes in species distributions (Becker *et al*. 2014, Becker *et al.* 2017), forecast changes in species distributions (Becker *et al*. 2012), and predict species distributions in data-poor ecosystems (Redfern *et al*. 2017b). The models have been used to assess the risk of ships striking whales (Redfern *et al*. 2013) and the overlap between shipping noise and whale habitat (Redfern *et al*. 2017a).

Discussion
Redfern explained that the real spatial resolution of the model was limited by that of the input data. Although predictions at smaller scales can be made, they should not be relied upon.

2.3 Oceanographic features influencing animal distribution

Igor M. Belkin: Fronts and whales
Whales and other cetaceans are known to congregate at oceanic fronts. The cetaceans' affinity to fronts is species-specific and depends on the animal's activity such as breeding, nursing, feeding and migration. A meta-analysis of approximately 200 papers on cetaceans and fronts published in 1991-2017 and indexed by the Web of Science has shown that case studies of spatial and temporal correlations between cetaceans and ocean circulation features such as fronts, current jets, and eddies are exceedingly rare. Meanwhile, remote sensing and in situ data on oceanic features, particularly on fronts, are becoming widely available for use in ecological studies, population modelling, and conservation. Two front detection algorithms have been developed at the University of Rhode Island by Cayula and Cornillon (1992; CCA) and Belkin and O'Reilly (2009; BOA; in collaboration with NOAA). The CCA-generated global climatology of SST fronts, 1981-2017, and the BOA-generated climatology of SST and CHL fronts off the North America Eastern Seaboard, 1997-2017, revealed numerous fronts that have not been reported or documented before. These fronts likely play a significant role in cetacean ecology.

Discussion
The recent availability of model-detected front data for SST and chlorophyll for a large area of the North Atlantic and encompassing the time span of most (but not all, particularly for chlorophyll) should simplify the inclusion of front data in habitat models. Other features such as sea surface height are also available.

It is likely that several features of fronts are important to whales, including location, size, magnitude (*i.e*. gradient) and persistence. Most studies that have included front covariates have done so using some metric of the distance to the nearest front, but other front covariates are certainly possible. While indices could be

developed that combine two or more of these features, they could also be included in models as separate covariates.

Many, but not all fronts are "topographically steered" in that their location is largely determined by ocean bottom and/or shoreline features. While these may show great variation in size and magnitude over seasonal and annual time scales, their locations are largely fixed. Fronts that are not so steered can be far more dynamic in time and space, and some may be ephemeral, non-reoccurring features. It was noted that front "persistence" – the length of time the feature persists, and front predictability in time and space, might be particularly important to migratory cetaceans. However it seems difficult to capture these features in a simple covariate. It will be of interest to determine if cetaceans can take advantage of more ephemeral frontal features.

Climate change will change the location, magnitude and other features of fronts, affecting whale distributions: indeed this may already have occurred in some areas, such as SW of Iceland (see 2.2).

Hedin Valdimarsson: Variability in the Northern North Atlantic

A desciption was given on the hydrography of Icelandic waters and its variability. A description of currents, topography and the main water masses was provided. Timeseries from various parts of the waters around Iceland were shown which show the pronounced warming that was taking place in the last two decades. Processes leading to decadal variability were discussed and described. Changes have been observed both in temperature and salinityin these waters and recent changes in salinity were described in detail. Influence on the distribution of fish species was also mentioned, with more numerous species and higher frequency of species from warmer waters appearing in the area in recent years.

Discussion

It was noted that oceanographic data collection by Germany off E Greenland had recently been cut back, however some work by Denmark continued in the area. This is of concern because of the large oceanographic changes, as well as changes in marine ecology, seen in this area in recent decades.

3. North Atlantic wide abundance estimates (Chair: Pike)

3.1 Introduction

Pike reiterated the main objective of this part of the workshop: to generate a set of design-based, North Atlantic wide abundance estimates for 2015/16 for those cetacean species for which sufficient data are available, corrected for biases to the extent possible. This is a desirable goal for two main reasons: to make these estimates available and accessible to a broader range of researchers and the general public; and to provide a resource for those researchers who wish to use these data for other purposes, for example habitat modelling. Presenting estimates should be a relatively straightforward task, perhaps best addressed by a table linked to an associated map, with citation links to the source documents. However all associated information required to use these estimates cannot be presented in a simple table: for this researchers should be directed to the original papers. There may also be spatial, temporal and methodological issues with combining some of these estimates, and these should be explicitly identified. Pike also presented some draft tabular and map formats for discussion.

3.2 Species

The main target species are fin, common minke, humpback, pilot, sperm (but see below), killer and sei whales, harbour porpoise and dolphins. Estimates for all species will not be feasible from all surveys because of an insufficient number of sightings in some areas. Estimates for other species such as beaked whales may also be possible for some areas. It was recognised that most surveys in the Eastern and Central North Atlantic were conducted outside of the peak occupation of sei whales in the area, which tended to be later in the summer, so estimates will be very incomplete for that species.

3.3 Status of estimates from different surveys

Available design-based estimates from North Atlantic surveys conducted in 2015 and 2016 are presented in Table 1, with survey coverage in Fig. 1. Estimates for many, but not all, species from the NASS2015 surveys have been approved by the NAMMCO Abundance Estimates Working Group, and additional estimates are expected in spring 2018. Preliminary estimates for common minke whales from the 2014/15 NASS/NILS surveys are available, and final estimates for common minke and other species are expected in 2018. The US and Canadian estimates are not yet available, and are expected in spring 2018. SCANS-III (2016) estimates are available at https://synergy.st-andrews.ac.uk/scans3/files/2017/05/SCANS-III-design-based-estimates-2017-05-12-final-revised.pdf.

3.4 Issues regarding combining estimates

General issues

The participants agreed that they will focus only on combining summer surveys, while recognizing that "summer" may have a different meaning depending on latitude and other factors.

Although the spatial coverage of all of the surveys is quite large, there is still a lot of area that has not been surveyed. The summed abundance estimates should therefore be considered a best estimate for the North Atlantic, with the caveat that they are likely minimum estimates due to the un-surveyed areas and, in some cases, uncorrected negative biases. These limitations will be discussed in the table description.

Timing – Inter-annual and seasonal differences in surveys

Inter-annual

The two years 2015 and 2016 combined provide the most complete coverage of the North Atlantic ever achieved. However, for some species there may be issues in combining data collected in different years. For example, the NASS series has shown large changes in the distribution of pilot whales (Pike *et al.*2017b), as well as fin, common minke and humpback whales (Víkingsson *et al.* 2015) between surveys. A large change in distribution could introduce a positive (whales counted in both years) or a negative (whales counted in neither year) bias. The NILS mosaic surveys deal with this issue explicitly by including "additional" variance due to distributional changes, but this ideally requires a long time series of estimates from the same area.

In this case, it was considered that the areas surveyed were likely large enough, and in some cases separated geographically, so that bias introduced by inter-annual movement was likely to be minimal. Possible exceptions include: some chance of movement by baleen whales between North America and Greenland/Iceland; and distributional shifts by pilot whales between the SCANS-III and NASS areas. In the latter case the SCANS-III estimate is much smaller than that from NASS so any effect on the total would not be substantial.

Seasonal

All the summer surveys listed in Table 1 were carried out between June and August, except that the Greenlandic survey extended into September. The NAMMCO Working Group on Abundance Estimates discussed combining the East Greenland and Iceland/Faroes surveys, the former of which was conducted about two weeks after the latter, for fin, common minke and humpback whales and concluded that they were likely additive because there was no evidence of any large scale movements by these species between July and September in the area (NAMMCO 2016).

The Irish ObSERVE surveys were conducted in 2015 and 2016 SCANS-III, but commenced a bit earlier than the SCANS-III survey in 2016. There was an overlap in survey timing of 2-3 weeks. This was considered unlikely to be of concern for most species.

The Canadian and US surveys conducted in 2016 were done at roughly the same time, and therefore their combination should not be problematic. However there was some concern that fin whales may have been moving south into the US area during the survey, which could lead to bias. Lawson and Palka will work together to investigate this, possibly by using passive acoustic data collected over several years to determine the timing of fin whale movements along the coast.

Net movement of whales between Canada and Greenland during the summer months was considered unlikely to be of concern. However one tagged humpback whale moved between East and West Greenland during the surveys in 2015, demonstrating exchange between the two areas. However much more data will be required before the ramifications for abundance estimates, if any, can be determined.

For a few species the summer surveys would not capture the peak of abundance in northern areas. Northern bottlenose whales would likely have already begun migrating southwards during the surveys, and sei whales reach their peak numbers in northern areas during August and September. Estimates for these species will therefore be negatively biased by this factor.

Spatial

There was some international cooperation during the planning of these surveys, and therefore overlap or gaps between survey areas were largely avoided.

There was a small overlap between the Norwegian and Faroese survey blocks, but virtually no Norwegian effort in the overlap area. There was a small amount of overlap (3% area) between the western Icelandic and

East Greenland survey blocks, which was taken into account by Pike *et al.* (2016b) in estimating fin whale abundance. If overlap is of concern, it can be dealt with crudely by adjusting the estimates from one or both surveys by the percentage of overlap.

Analysis

The analyses used to derive the estimates listed in Table 1 vary in detail, and any combination of these estimates should consult the original papers. While these differences should not preclude such combinations, in some cases they may have substantial effects on the overall estimate.

Surveys vary in the way uncertainty in species identity is recorded. For rarely sighted species such as the blue whale, which can be difficult to discriminate from fin whales, estimates can be sensitive to the degree of uncertainty allowed. For blue whales particularly, the number of uncertain sightings can outnumber certain ones in some areas. This is generally dealt with by carrying out sensitivity analyses to determine the potential effect on the estimate. To the extent possible, a combination should include the same levels of uncertainty, but this may not be feasible if uncertainty was recorded differently.

In other cases, large numbers of sightings may not be identified to species, classified as "unknown large baleen whale" or "unknown dolphin" for example. While this issue is sometimes dealt with by assigning unknown sightings by proportion, the specific methods used vary.

Most modern surveys use double platform methods to correct for perception bias, and some use other data to correct for availability bias in cases where it is considered significant (see Table 1 for details). SCANS-III used circle-back in aerial surveys to correct both biases simultaneously for harbour porpoise, minke whale and dolphin species. In any combination of abundance estimates the extent to which these biases are corrected should be explicitly stated.

It was noted that there are some abundance estimates available that have used different methods than line-transect surveys, for example mark-recapture estimates from photo-ID. However, methods such as mark-recapture may not be comparable to line-transect surveys because the former samples individuals from an area that is not explicitly known, while the latter estimates density from sampling space within a defined area. It was agreed to include only line-transect surveys in Table 1.

3.5 Future work

Desportes (NAMMCO) indicated that Pike would maintain and enhance the tabular presentation of abundance estimates, updating it as new information becomes available, and also by adding older survey estimates. This will eventually be made available on the NAMMCO web site.

4.0 Towards North Atlantic wide modelling of distribution and habitat use (Chair: Hammond)

Hammond introduced the topic by reiterating the objective of the session: to determine if North Atlantic-wide modelling of distribution and habitat use by cetaceans was viable and worthwhile given the data available, and, if so, to develop a plan for moving forward with such modelling. A major issue to be considered will be the challenges inherent in combining multiple datasets from different projects using various methodologies, but such issues have been dealt with in other modelling efforts. The desired outcome will be a plan and timeline for moving forward.

The group considered that a North Atlantic-wide modelling effort could be of value for a number of reasons. It could help in understanding the large-scale distribution of several species, and why those distributions change over time. It could also be useful in predicting future distribution based on predicted changes in the ocean environment. Habitat modelling may identify areas that are likely to have large numbers of animals but which have not been sampled adequately by surveys. Model-based abundance estimates are useful for comparison to design-based estimates and may be more precise and applicable to a smaller scale in some cases. Finally, modelling will identify areas and times that are most susceptible to human impact; in some cases anthropogenic effects, for example noise production, could be included in some models.

While the remit of the workshop was to look at recent (2015-16) survey data, inclusion of older data would be interesting for several reasons. Simply having a larger dataset with better spatial coverage and more sightings is nearly always advantageous. Changes in distribution for several species are apparent in the NASS and to some extent in the SCANS data, and the environmental factors contributing to these changes are of interest

Table 1. Recent abundance estimates for North Atlantic cetaceans. SPECIES: BA-common minke whale, BP-fin, DD-common dolphin, GG-Risso's dolphin , GM-pilot whale, LAC-white sided dolphin, LAL-white beaked dolphin, MN-humpback whale, PM-sperm whale, SC-striped dolphin, TT-bottlenose dolphin. MAP: refer to Fig.1; TYPE: A-aerial, S-ship; MODE: IO-double platform independent observer, BT-double platform tracker configuration, C-aerial circle-back, SP-single platform; BIAS CORR-Bias Correction; PER-perception, AVAIL-availability.

SPECIES	SURVEY NAME	YEAR	Q	DESC.	SURVEY AREA	AREA (nm^2)	TYPE	MODE	DENSITY ($no./nm^2$)	ABUND	CV	95% CI LCL	95% CI UCL	BIAS CORR. PER	BIAS CORR. AVAIL	COMMENT	CITATION
ALL	AMAPPS	2016	3	Atl. USA	9	NA			NA							Available 2018	
ALL	NAISS	2016	3	Atl. Canada	6	NA	A	IO	NA							Available 2018	
ALL	NERC	2016	3	Mid.Atl. Ridge	10	NA	S	SP	NA							Available 2018	
ALL	ObSERVE	2015/16	1-4	Ireland	8	NA	A	R	NA					1	1	Available 2018	
BA	CIC2016	2016	3	Iceland coastal	4	84,332	A	IO	0.1600	13,497	0.50	3,312	5,507	1	1	Poor coverage some areas.	Pike et al. 2017a
BA	NASS	2015	3	Iceland/Faroes	1	735,000	S	IO	0.0492	36,185	0.31	19,942	65,658	1	0	All identification certainties. Includes aerial survey area. Slight overlap with Survey Area 2.	Pike et al. 2016a
BA	NASS	2015	3	E. Greenland	2	33,459	A	IO	0.0781	2,614	0.39	1,256	5,440	1	1	Slight overlap with Survey Area 1.	Hansen et al. 2017
BA	NASS	2015	3	W. Greenland	3	64,421	A	IO	0.0817	5,262	0.40	2,475	11,189	1	1		Hansen et al. 2017
BA	NILS2015	2015	3	Norway	5	359,779	S	IO	0.0994	35,764				1	1	Variance not available. Minor overlap with Survey Area1.	Kato et al. 2016
BA	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	0.0274	14,759	0.33	7,908	27,544	1	1		Hammond et al. 2017
BP	NASS	2015	3	Iceland/Faroes	1	735,000	S	IO	0.0555	40,788	0.17	24,615	58,423	1	0	All identification certainties. Includes aerial survey area, but no fin whales there. Slight overlap with Survey Areas 2 and 5.	Pike et al. 2016b
BP	NASS	2015	3	E. Greenland	2	33,459	A	IO	0.0577	1,932	0.24	1,204	3,100	1	0	Slight overlap with Survey Area 1.	Hansen et al. 2017
BP	NASS	2015	3	W. Greenland	3	64,421	A	IO	0.0072	465	0.35	233	929	1	0		Hansen et al. 2017
BP	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	0.0343	18,142	0.32	9,796	33,599	1	1		Hammond et al. 2017

SPECIES	SURVEY NAME	YEAR	Q	DESC.	SURVEY AREA	AREA (nm^2)	TYPE	MODE	DENSITY ($no./nm^2$)	ABUND	CV	95% CI LCL	95% CI UCL	BIAS CORR. PER	BIAS CORR. AVAIL	COMMENT	CITATION
DD	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	0.8951	467,673	0.26	281,129	777,998	1	1		Hammond et al. 2017
GG	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	0.0274	13,584	0.44	5,943	31,047	1	1		Hammond et al. 2017
GM	NASS	2015	3	Iceland/Faroes	1	735,000	S	IO	0.8023	589,681	0.38	269,116	1,292,140	1	0	Includes aerial survey area, but few pilot whales there. Slight overlap with Survey Areas 2 and 5.	Pike et al. 2017b
GM	NASS	2015	3	E. Greenland	2	33,459	A	IO	0.0077	258	1.02	50	1,354	1	1	Slight overlap with Survey Area 1.	Hansen et al. 2017
GM	NASS	2015	3	W. Greenland	3	64,421	A	IO	0.1427	9,190	0.50	3,635	23,234	1	1		Hansen et al. 2017
GM	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	0.0480	25,577	0.35	13,350	49,772	1	1		Hammond et al. 2017
LAC	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	0.0309	15,510	0.72	4,389	54,807	1	1		Hammond et al. 2017
LAL	CIC2016	2016	3	Iceland coastal	4	84,332	A	IO	0.7111	59,966	0.44	24,907	144,377	1	0	Poor coverage some areas.	Pike et al. 2017a
LAL	NASS	2015	3	E. Greenland	2	33,459	A	IO	0.3553	11,889	0.50	4,710	30,008	1	1	Slight overlap with Survey Area 1.	Hansen et al. 2017
LAL	NASS	2015	3	W. Greenland	3	64,421	A	IO	0.2369	15,261	0.41	7,048	33,046	1	1		Hansen et al. 2017
LAL	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	0.0686	36,287	0.29	18,694	61,869	1	1		Hammond et al. 2017
MN	NASS	2015	3	Iceland/Faroes	1	735,000	S	IO	0.0220	16,206	0.39	7,609	34,518	1	0	All identification certainties. Includes aerial survey area. Slight overlap with Survey Areas 2 and 5.	Pike et al. 2016c
MN	NASS	2015	3	E. Greenland	2	33,459	A	IO	0.1357	4,540	0.38	2,222	9,275	1	1	Slight overlap with Survey Area 1.	Hansen et al. 2017
MN	NASS	2015	3	W. Greenland	3	64,421	A	IO	0.0166	1,068	0.38	523	2,181	1	1		Hansen et al. 2017
PM	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	0.0274	13,518	0.41	6,181	29,563	1	0		Hammond et al. 2017
PP	CIC2016	2016	3	Iceland coastal	4	84,332	A	IO	0.2705	22,808	0.48	9,166	56,746	1	0	Poor coverage some areas.	Pike et al. 2017a
PP	NASS	2015	3	E. Greenland	2	33,459	A	IO	0.0491	1,642	1.00	309	8,464	1	1	Slight overlap with Survey Area 1.	Hansen et al. 2017
PP	NASS	2015	3	W. Greenland	3	64,421	A	IO	1.2934	83,321	0.34	43,377	160,047	1	1		Hansen et al. 2017
PP	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	1.3066	466,569	0.15	345,306	630,417	1	1		Hammond et al. 2017

SPECIES	SURVEY NAME	YEAR	Q	DESC.	SURVEY AREA	AREA (nm^2)	TYPE	MODE	DENSITY ($no./nm^2$)	ABUND	CV	95% CI LCL	95% CI UCL	BIAS CORR. PER	BIAS CORR. AVAIL	COMMENT	CITATION
SC	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	0.7133	372,340	0.33	198,593	698,134	1	1		Hammond et al. 2017
TT	SCANS-III	2016	3	Europe	7	526,163	A/S	C/BT	0.0514	27,697	0.23	17,662	43,432	1	1		Hammond et al. 2017

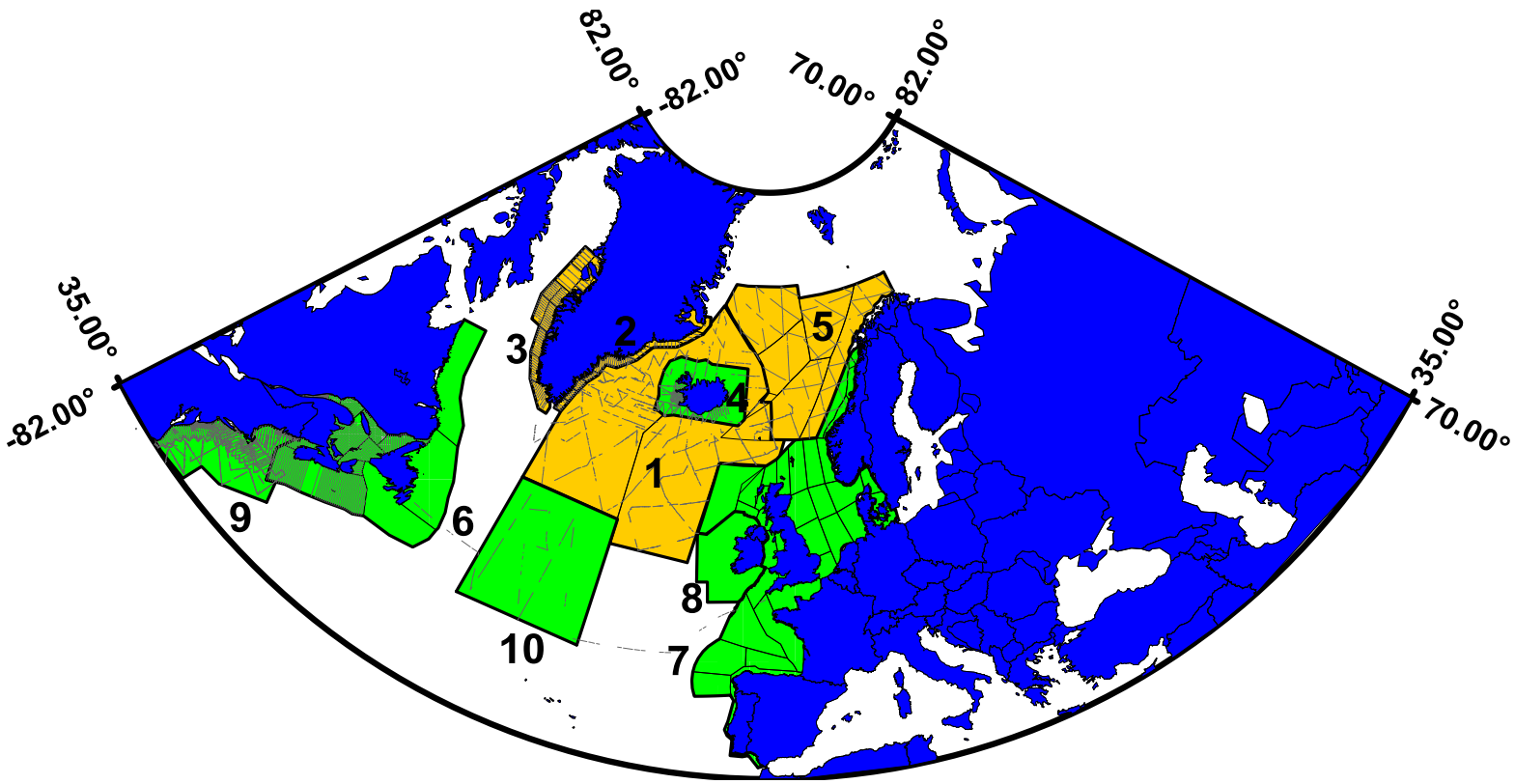

Fig. 1. Survey coverage, 2015 (gold) and 2016 (green). Numbers refer to Survey Areas in Table 1.

and may improve the predictive ability of models. Because understanding why whale distribution changes is a major focus of the work, the inclusion of older data will be helpful. One challenge is that not all environmental covariates of interest are available for or compatible with older surveys: this has been an issue with modelling the NASS series. However, work is underway (Nadya Ramirez PhD thesis, University of St Andrews) to model the NASS and Norwegian data from 1987 to 2013, which is expected to be completed by the end of 2018. This work should provide a useful basis for the inclusion of more recent data. For the purposes of workshop discussions, it was therefore considered most appropriate to focus on the more recent data, and expand to include older surveys as the work is developed.

4.1 Species

The available data largely dictate which species can be adequately modelled. Species for which we have many sightings across a large range of habitat types will obviously be better for modelling. In some cases rare species can also be modelled if several survey years of data are combined, or if species such as deep divers are grouped together as a guild. It is important that the surveys covered most or at least a large portion of the seasonal range of the species in question. For example, sei whales are infrequently encountered in the NASS in the summer, but are known to move into the area in larger numbers later in the year. Modelling based on summer data only might miss the main factors driving their distribution.

Priority species for modelling include the baleen whales: fin, blue, humpback and common minke. Sei whales were considered of lower priority for the reasons mentioned above. Harbour porpoise are abundant in shelf waters throughout the survey area and a species of high interest, not least because of the impact of fisheries by-catch. Several species of dolphin, including the two *Lagenorhychus* species and common and striped dolphins, should also be included. White-beaked and white-sided dolphins are sometimes difficult to distinguish in areas where they occur together but modelling could be useful to discriminate the main environmental factors that separate the two species. While killer whales occur throughout the area, their modelling might prove challenging as they are rarely sighted and apparently occur as separate ecotypes which presumably have differing habitat requirements.

4.2 Explanatory variables

There are broadly two main types of explanatory habitat variables available: those that are sensed remotely and/or measured *in situ*, such as depth, bottom topography, chlorophyll and sea surface temperature (SST), and those that are produced by models, usually using remotely sensed data, such as the location and intensity of ocean fronts, temperature and salinity profiles, primary production and even productivity at higher trophic levels for some models. Such data are measured or predicted with uncertainty but this uncertainty may not explicitly reported and, in any case is generally difficult to propagate into model predictions. However, such model generated environmental features may be very useful in predicting species distribution, even if the uncertainty is not incorporated.

The spatial and temporal resolution of available data varies but generally speaking resolution is coarser for large areas such as the North Atlantic. Finer scale data are sometimes available at a regional level. Also most remotely sensed data are obtained from satellites and the resolution of the data has improved as the technology has progressed. Therefore the inclusion of data from older surveys can be limited by the availability and resolution of data for that time.

At present, model prediction of the location of fronts in temperature, salinity, chlorophyll and other habitat variables is available at a regional but not an ocean basin level; however, larger scale output should be available within a year. Based on observed distributions the group considered that the location of ocean fronts might be a particularly important correlate of distribution for some species. Belkin noted that density gradients in water colder than about 10° C were governed primarily by salinity, while temperature had a larger influence in warmer areas. Therefore, in the high latitude areas covered by most of the surveys, salinity fronts might be of primary importance.

A list of environmental covariates, both measured and model-predicted, that might prove useful in large scale cetacean habitat models of the North Atlantic was developed (Table 2).

4.3 Spatial scale of modelling

Spatial scale encompasses two related concepts: the spatial extent of the area to be modelled, and the spatial/temporal resolution of the model. The latter is usually determined primarily by the resolution of the available covariate data, which may be quite coarse for large areas (see above). The segmentation of transects for modelling is also partially determined by the scale of the covariate data.

Table 2: Covariates used in recent cetacean modelling studies.

COVNAME	MODELLED MEASURED OR DERIVED	RESOLUTION		TEMP. AVAIL		SOURCE	NOTES
		Temporal (days)	Spatial (km)	Start (mm/yyyy)	End (mm/yyyy)		
Depth	Measured	-	30 arc seconds	-	-	SRTM30-PLUS global bathymetry (http://topex.ucsd.edu/WWW_html/srtm30_plus.html)	Mannocci et al. 2017
Slope	Derived	-	30 arc seconds	-	-	Derived from SRTM30-PLUS	Mannocci et al. 2017
Distance to the nearest submarine canyon or seamount	Derived	-	30 arc seconds	-	-	Derived from the global geomorphology database (Harris et al. 2014)	Mannocci et al. 2017
Sea surface temperature	Measured	daily	0.20°	Jan-91	present	From GHRSST Level 4 CMC 2.0 SST (http://podaac.jpl.nasa.gov/dataset/CMC0.2deg-CMC-L4-GLOB-v2.0)	Mannocci et al. 2017
Distance to the nearest sea surface temperature front	Derived	daily	0.20°	Jan-91	present	Derived from GHRSST Level 4 CMC 2.0 SST and the Canny (1986) edge detection algorithm	Mannocci et al. 2017
Absolute current speed	Measured	daily	0.25°	Jan-93	present	From AVISO DT-MADT geostrophic currents (http://www.aviso.altimetry.fr/duacs/)	Mannocci et al. 2017
Standard deviation of sea level anomaly	Derived	daily	0.25°	Jan-93	present	From AVISO DT-MSLA SSH (http://www.aviso.altimetry.fr/duacs/)	Mannocci et al. 2017
Eddy kinetic energy	Derived	daily	0.25°	Jan-93	present	Derived from AVISO DT-MADT geostrophic currents (http://www.aviso.altimetry.fr/duacs/)	Mannocci et al. 2017

COVNAME	MODELLED MEASURED OR DERIVED	RESOLUTION		TEMP. AVAIL		SOURCE	NOTES
		Temporal (days)	Spatial (km)	Start (mm/yyyy)	End (mm/yyyy)		
Chlorophyll-a concentration	Measured	daily	9km	Jan-98	present	From GSM merged SeaWiFS/Aqua/MERIS/VIIRS chlorophyll-a concentration (http://wiki.icess.ucsb.edu/measures/GSM)	Mannocci et al. 2017
Net primary production	Modelled	8 day	9km	Jan-98	present	From Ocean productivity (http://www.science.oregonstate.edu/ocean.productivity/) , based on the Vertically Generalized primary Production Model (Behrenfeld & Falkowski 1997)	Mannocci et al. 2017
Biomass/Production of epipelagic micronekton	Modelled	7 day	0.25°	Jan-98	present	Model outputs from SEAPODYM (Lehodey et al. 2010, 2014)	Mannocci et al. 2017
Biomass/Production of epipelagic micronekton	Modelled	7 day	0.25°	Jan-98	present	Model outputs from SEAPODYM (Lehodey et al. 2010, 2014)	Mannocci et al. 2017
distance to the shelf edge	Derived	-	10km	-	-	Derived from the global geomorphology database (Harris et al. 2014)	Redfern et al. 2017
wind speed (WSPD) and sea surface temperature (SST), salinity (SSS), and height (SSH)	Modelled	Monthly	0.5°	1871	2010	Simple Ocean Data Assimilation (SODA 2.2.4; Carton & Giese, 2008; http://apdrc.soest.hawaii.edu/dods/public_data/SODA)	Redfern et al. 2017. We extracted SST and SSS values at 5.01 m, which is the shallowest depth available in the SODA data. We derived WSPD from zonal and meridional wind stress.

COVNAME	MODELLED MEASURED OR DERIVED	RESOLUTION		TEMP. AVAIL		SOURCE	NOTES
		Temporal (days)	Spatial (km)	Start (mm/yyyy)	End (mm/yyyy)		
Sea surface temperature	Measured	daily	0.011°(about 1 km)	2002	present	MUR SST (Multi-scale, Ultra-high Resolution), blended high-resolution; equal-angle horizontal resolution from a level 4 (L4; gap-free gridded) SST image; http://coastwatch.pfeg.noaa.gov/erddap/griddap/jplMURSST41.graph	Gilles et al. 2006

While cetaceans of the same species are usually assumed to respond to their environment in the same way, there may be regional and/or population differences that may limit the usefulness of large scale models for some species. For example, Mannocci reported that, for some species, separate models for the Eastern and Western North Atlantic performed better than a combined model, suggesting that cetaceans in the two areas, even of the same species, did not respond in the same way to their environment. A suggested approach would be to begin at the largest scale to discern simple ecological correlates for each species, then focus in at a regional level with more complex and detailed models.

The prediction of temporal changes in distribution and abundance due to oceanographic and ecosystem shifts is of great interest, so the eventual inclusion of older surveys, for example the older NASS, is of high priority. As noted above, work on modelling the earlier NASS and Norwegian data is ongoing. Changes in the distribution and abundance have occurred in some species over the last 30 years, for example fin, common minke, and humpback whales in the Central and Eastern North Atlantic. This could mean that species habitat relationships may have changed over time and accounting for this possibility would need to be incorporated into the modelling. For example, a growing population might expand into less suitable areas due to intraspecific competition, which could change habitat relationships over time.

Belkin noted that ocean fronts occur along a continuum of scales from very large to quite small, defying a simple classification. Smaller fronts may not be apparent in a coarse-scale model. The strength of the front, as measured by the gradient of the frontal agent, may also be very important in defining species-habitat relationships. However there is no single measure that captures both the size and the strength of fronts. The persistence and predictability of these features might also be important to cetaceans. Some features are "topographically steered", meaning that they are heavily influenced by bottom topography, making them predictable and persistent. Other features may be ephemeral or spatially unpredictable over time. One might expect migrating whales to focus on predictable features, but this has not been tested. All three attributes of fronts, i.e. size, strength and persistence, should be considered for inclusion in habitat models.

4.4 Combining multiple datasets from different projects/platforms/methodologies

In many (but not all) models, the response variable is individual density along transect segments. Therefore it is important, when multiple sources of data are included, that equivalent measures of density are used. For example, density should be corrected (or not) for the same biases from all sources. For some surveys, particularly older ones, only single platform estimates of density are available, and correction will not be possible unless factors from extraneous surveys are applied.

Contrast in estimated density could be driven by differences in encounter rate, group size or both. For example, some species may form large groups in some areas or seasons, but not in others. In some studies, group size is modelled separately from encounter rate, however success in finding environmental correlates for group size has been mixed. For the rather coarse spatial and temporal resolution achievable in modelling such a large area as the northern North Atlantic, separate modelling of group size and encounter rate was likely not appropriate for most species; however, the dolphin species in particular may require such separation. In any event, most datasets have the required fields to model these separately if required.

There was some discussion of the transect segment size used in analyses *vs* that available in the original datasets. In most cases such data are already segmented by sightings or changes in observed environmental variables such as Beaufort sea state. Environmental covariates such as SST are available at various spatial resolutions and this tends to drive the transect segment size uses in modelling. Datasets can be easily processed to produce a desired segment size. Some studies use grid cells rather than transect segments, but this was considered less optimal when several sources of survey data are aggregated.

One challenge in this type of modelling has been to propagate the full range of uncertainty, particularly from measured and predicted environmental covariates, through to model predictions. If this is not done the reported uncertainty in model prediction is negatively biased.

A related issue is the uncertainty inherent in extrapolating predictions to un-surveyed areas or seasons. Methods for inflating uncertainty in un-sampled portions are under development but at present it is necessary to explicitly identify such extrapolations.

5. Post workshop action plans

5.1 Abundance estimates

Pike will continue to update tabular presentation under 2. The participants also agreed to create combined maps of observed sightings for all species as a useful and simple first step to represent the data available.

5.2 Modelling distribution and habitat use

Participants agreed that North Atlantic-wide cetacean habitat modelling was worthwhile and should be taken forward. The data holders also agreed in principal to contribute data to such an effort, as detailed in Table 3. Data will be available from most groups within the next year.

It was considered likely that the project would take 2-3 years to complete and will require some funding. To take the project forward a correspondence group was convened under the chairmanship of Hammond to include all interested parties but definitely Hammond, Øien, Palka, Belkin, Víkingsson, Mikkelsen, Rogan, Gilles and Valdimarsson. Hammond noted that it was hoped a Masters student at St Andrews would initiate some preliminary work with some of the 2015 datasets.

Mannocci suggested that a useful preliminary "gap" analysis could be undertaken using only effort data to determine how well the effort covered the space defined by environmental covariates, and to identify areas that might require more sampling. She agreed to forward further information to the correspondence group on this matter.

Table 3. Data sources for a North Atlantic modelling effort. Map numbers refer to Fig.1.

SURVEY	YEAR	DESC.	MAP	AVAIL. Y/N/U
NASS	2015	Iceland/Faroes	1	Y
NASS	2015	E. Greenland	2	Y
NASS	2015	W. Greenland	3	Y
CIC2016	2016	Iceland coastal	4	Y
NILS2015	2015	Norway	5	Y
NAISS	2016	Atl. Canada	6	Y
SCANS-III	2016	Europe	7	Y
ObSERVE	2015/16	Ireland	8	U
AMAPPS	2016	Atl. USA	9	Y
MAR	2016	Mid.Atl.Ridge	10	Y

6. Closing remarks

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