Preliminary analysis of spatial distribution of fin, sei and humpback whales in the offshore eastern subarctic Pacific using 2010-2012 IWC-POWER data

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ABSTRACT

Preliminary analysis of spatial distribution of fin, sei and humpback whales in the offshore eastern subarctic Pacific was conducted using data obtained by the IWC-POWER. Data in summer (July and August) from 2010 to 2012 were used in the analysis. The survey area in this time period was bounded by 40°N in the south, the coast of the Aleutian Islands and Alaska in the north, 170°E in the west and 135°W in the east. In the survey area, fin whale (199 schools/326 animals) was dominant baleen whale species in number followed by sei (162/300), humpback (71/125), blue (15/15), common minke (7/7) and North Pacific right whales (1/1). Spatial distribution of fin, sei and humpback whales was estimated using generalized additive models (GAM). Presence and absence of whales was used as response variable while sea surface temperature (SST), sea surface height anomaly (SSHa) chlorophyll-a concentration (chl) and seafloor depth were used as explanatory variables. Fin whales were mainly distributed in the north eastern part of the survey area. Sei whales were mainly distributed in the southern part of the survey area. Humpback whales were mainly distributed near the coast of the Aleutian Islands and Alaska. Main distribution areas of these three species were segregated although some overlaps were observed. The results fill gaps of information of recent distribution of baleen whales in this region. Additional sighting data obtained in the eastern North Pacific Transition Zone and the eastern subtropical North Pacific by upcoming the POWER cruises will provide comprehensive knowledge of current distribution of baleen whales in the eastern North Pacific.

INTRODUCTION

The IWC-POWER (the International Whaling Commission-Pacific Ocean Whale and Ecosystem Research) has been conducted since 2010 as a joint project between the IWC and Japan (IWC, 2011a; 2011b; 2012b; 2012d; 2013a; 2013b, 2013c; Matsuoka et al., 2011; 2012; 2013). The workshop on planning for an IWC co-ordinated North Pacific research programme was held in Tokyo in 2010 (IWC, 2012b). The workshop identified gaps of information of recent distribution of baleen whales in the offshore eastern Pacific. One of the research objectives of the POWER is to provide baseline information on distribution and abundance for a poorly known area for several large whale species/populations, including those that were known to have been depleted in the past, but whose status is unclear. The offshore eastern subarctic Pacific was covered by the POWER from 2010 to 2012. This paper presents a summary of sightings of baleen whales and results of preliminary analysis of spatial distribution of fin, sei and humpback whales in the region.

MATERIALS AND METHODS

Survey Protocol

The Technical Advisory Group (TAG) was established by the IWC Scientific Committee (IWC/SC) to recommend appropriate technical advice for the cruise plan including short term and mid-long term planning (IWC, 2013b). Plans for the cruises were endorsed by the Committee and the Committee agrees that it was duly conducted following the guidelines of the Committee (IWC, 2011b; 2012d; 2013c). The details of survey protocols were described in the information for researchers (e.g. IWC, 2012a) and Matsuoka *et al.* (2011; 2012; 2012). Brief descriptions related to this analysis are provided below.

The survey area of the POWER from 2010 to 2012 was bounded by 40°N in the south, the coast of the Aleutian Islands and Alaska in the north, 170°E in the west and 135°W in the east. The subarctic boundary is located approximately at 40°N and the survey area is in the subarctic domain. Three longitudinal sectors, 170°E–170°W, 170°W–150°W and 150°W–135°W, were surveyed in 2010, 2011 and 2012, respectively. The survey periods in the survey areas were 7 July–25 August in 2010, 21 July–31 August in 2011 and 24 July–30 August in 2012. A dedicated cetacean sighting survey vessel was provided each year by the Government of Japan. The *Kaiko–Maru* (860 GT, KK1) was used in 2010 while the *Yushin–Maru No.3* (747 GT, YS3) was used in 2011 and 2012. The barrel, independent observer platform (IOP) and front bridge heights of KK1 are 19.5m, 14.5m

and 9m above the water surface, respectively. The barrel and front bridge heights of YS3 are 19.5m and 11.5m, respectively.

The survey was conducted daily from 30 minutes after sunrise and end 30 minutes before sunset, with a maximum of a 12-hour research day. The vessel covered a predetermined trackline at speed around 11.0 konts (20.4 km/h). Activities aboard the ship are classified into two principal groups: On-effort and Off-effort. On-effort observations were only conducted when visibility was greater than 2.0 n.miles (3.7 km), wind speed was lower than 21 knots (38.9 km/h) and sea state was less than Beaufort scale 6. In the sightings survey portion of the research, On-effort activities are times when full search effort is being executed and conditions are within the acceptable parameters to conduct research. Off-effort activities are all activities that are not On-effort. All sightings recorded while the ship is On-effort are classified as Primary sightings. All other sightings are Secondary sightings. During the On-effort, two primary observers on the TOP barrel, another two primary observers (the captain and a helmsman) and three or four researchers were on the upper bridge regardless of the survey mode. For each sighting, the distance from the vessel to the whales was estimated using 7×50 binoculars with reticule and the sighting angle with reference to the course of the vessel was estimated using an angle board installed in each observation booth.

Two survey modes, Normal Closing Mode (NSC) and Independent Observer with passing mode (IO) were used in 2010 cruise as in the case of the SOWER cruises in the Antarctic. However, the use of passing mode in the POWER would result in very high proportions of unidentified cetaceans. For example, priority species such as fin, sei and Bryde's whales are difficult to identify unambiguously unless close to the vessel. Because of the reason, the TAG recommended that Passing with abeam closing mode (NSP) is the most appropriate survey mode, both with respect to confirming species identity and school size (IWC, 2013b). NSP was used in 2011 and 2012. When the sighting passed abeam of the vessel, the ship approached the sighting for confirmation of species and school size. Normally, sightings within 3 n.miles (5.6 km, perpendicular distance from the trackline) were approached. Sighting records were made by the international researchers.

Environmental data

Satellite derived environmental data, sea surface temperature (SST), sea surface height anomaly (SSHa) and chlorophyll-a concentration (chl) were used as covariates of spatial distribution models. SST data, "Level 3 Rolling 32-day composite SST data derived from the Moderate Resolution Imaging Spectro-radiometer (MODIS) aboard the satellite Aqua" were used. The Level 3 Rolling 32-day composite SST data of 20 July–20 August 2010, 28 July–28 August 2011 and 27 July–27 August 2012 were used. Chl data, "Level 3 Aqua MODIS Chlorophyll concentration Seasonal compsite 9km Summer" (21 June to 20 September of each year) were used each year. The Aqua MODIS data were downloaded from Ocean Color Web (http://oceancolor.gsfc.nasa.gov/). SSHa data, "Ssalto/Duacs Monthly mean and Climatology Gridded Sea level anomalies (1/3°x1/3° on a Mercator grid)" were used. Mean of July and August data were used in 2010 while August data were used in 2011 and 2012. The altimeter products were produced by Ssalto/Duacs and distributed by Aviso, with support from Cnes (http://www.aviso.oceanobs.com/duacs/)". In addition, "ETOPO1 Global Relief Model for bottom topography" (Amante and Eakins, 2009) was used as seafloor depth data. Original resolution of ETOPO1 is 1 by 1 arc minute grid cell. SST, SSHa, chl and depth data were converted to 30x30 km grid cell raster data in the Albers projection using ArcGIS 10.0 (ESRI, Redlands, CA, USA) with central meridian at 165°W, standard parallels at 60°N and 40°N and latitude of origin at 50°N. The coastline data, "A Global Self-consistent, Hierarchical, High-resolution Geography Database" for coastline" (Wessel and Smith, 1996) was used in figures.

Spatial distribution model

Probability of occurrence of baleen whales was modelled using generalized additive models (GAM) having a binomial error distribution with the logistic link function. Sighting effort and sightings were aggregated into 30x30 km grid cells. Primary sightings within 3 n.miles (5.6 km) from tracklines in each side were used in the analysis. Same projection coordinate as environmental data was used for sighting effort and sightings. If at least a school was sighted in a grid cell with sighting effort, the grid was treated as present (1). If no school was sighted in a grid cell with sighting effort, the grid was treated as absent (0). Presence and absence of schools was used as response variable while SST, SSHa, chl and depth were used as explanatory variables. Smoothness parameters were estimated with generalized cross-validation (GCV). Model selection was conducted using GCV scores. The models with the lowest GCV scores were selected. For these analyses, the "mgcv" package (Wood, 2006) version 1.7-16 of R software (version 2.15.0; R Development Core Team, 2012) was used. According to Wood (2001), a covariate with the largest p-value was discarded in each step until the lowest GCV scores were reached. Spatial distribution of baleen whales within surveyed area was then estimated by using selected models.

RESULTS

Sighting survey

A total of 5,749.04 n.miles (10,647.2 km; 1,816.2 (3,363.5 km), 2,397.8 (4,440.7 km) and 1,535.04 (2,842.9 km) n.miles in 2010, 2011 and 2012 respectively) was covered by on effort. Six species of baleen whales, North Pacific right (*Balaena japonica*), blue (*Balaenoptera musculus*), fin (*B. physalus*), sei (*B. borealis*), common minke (*B. acutorostrata*) and humpback (*Megaptera novaeangliae*) were sighted. Number of sightings is summarized in Table 1 while sighting positions with respect to environmental variables are shown in Fig. 1. Fin whale (199 schools/326 animals) was dominant baleen whales in number followed by sei (162/300), humpback (71/125), blue (15/15), common minke (7/7) and North Pacific right whales (1/1).

Spatial distribution model

Because reasonable number of sightings is required for spatial distribution modelling, fin, sei and humpback whales are considered in this analysis. A total of 625 grid cells was used in the models. Among them, 84, 117 and 33 grid cells were treated as presence of fin, sei and humpback whales, respectively. Selected GAMs for fin, sei and humpback whales are summarized in Table 2. The shapes of the functional forms for the selected covariates to model the presence and absence of fin, sei and humpback whales are shown in Figs. 2–4. Natural logarithm of chl and depth are selected for fin and humpback whales while SST and depth are selected for sei whales. Spatial distribution of fin, sei and humpback whales in the surveyed area (8,022 grid cells) estimated by the selected models were shown Figs. 5–7. Fin whales were mainly distributed in the north eastern part of the survey area. Sei whales were mainly distributed in the southern part of the survey area. Humpback whales were mainly distributed near the coast of the Aleutian Islands and Alaska.

DISCUSSION

The results of the spatial distribution modelling reveal that main distribution areas of fin and sei are segregated although some overlaps were observed. Estimated spatial distribution of humpback whales reflects actual sighting positions in some extent but the resultant map indicated highly contrasted distribution (e.g. many 0 (blue) and 1 (red) probability of occurrence grid cells with few intermediate probability grid cells). This is probably due to relatively small number of presence grid cells (33 grid cells) out of 625 grid cells for the modelling.

Regional sighting surveys such as in the coastal region of the California Current system (Barlow and Forney, 2007), near shore waters of the Gulf of Alaska and Aleutian Islands (Zerbini et al., 2006) and coastal British Columbia and adjacent waters (Dalla Rosa *et al.*, 2012; Williams and Thomas, 2007) were conducted recently in the coastal eastern subarctic Pacific. However, no such attempt had been made in the offshore preceding to the POWER. The results fill gaps of information of recent distribution of baleen whales in this region. Additional sighting data obtained in the eastern North Pacific Transition Zone and the eastern subtropical North Pacific by upcoming the POWER cruises will provide comprehensive knowledge of current distribution of baleen whales in the eastern North Pacific.

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Table 1. Number of primary sightings of baleen whales in 2010-2012 POWER. Sightings within 3.miles from tracklines in each side are summarized.

Common_name	2010			2011			2012			Total		
	School/Animal			School/Animal			School/Animal			School/Animal		
North Pacific right whale	-	/	-	-	/	-	1	/	1	1	/	1
Blue whale	3	/	3	9	/	9	3	/	3	15	/	15
Fin whale	22	/	46	75	/	131	102	/	149	199	/	326
Sei whale	49	/	88	37	/	72	76	/	140	162	/	300
Common minke whale	4	/	4	1	/	1	2	/	2	7	/	7
Humpback whale	3	/	4	61	/	114	7	/	7	71	/	125

Table 2. Results of GAMs based presence/absence models of fin, sei and humpback whales. Approximate significance levels (p-value) and effective degrees of freedom (edf) are shown for each of the covariate (SST: sea surface temperature, SSHa: sea surface height anomalies, log(chl): logarithm of chlorophyll-a concentrations, Depth: seafloor depth).

	Fin whale		Sei whale		Humpback whale	
Family	Binomial		Binomial		Binomial	
Link function	Logit		Logit		Logit	
Adjusted R^2	0.10		0.15		0.26	
Deviance explained (%)	11.5%		19.2%		41.1%	
GCV score	0.90		0.67		0.26	
	edf	p-value	Edf	p-value	edf	p-value
Covariates						
SST	-	-	6.45	<0.01	-	-
SSHa	-	-	-	-	-	-
log(Chl)	6.65	0.03	-	-	5.72	<.001
Depth	7.85	<0.01	7.79	<0.01	7.82	<0.01

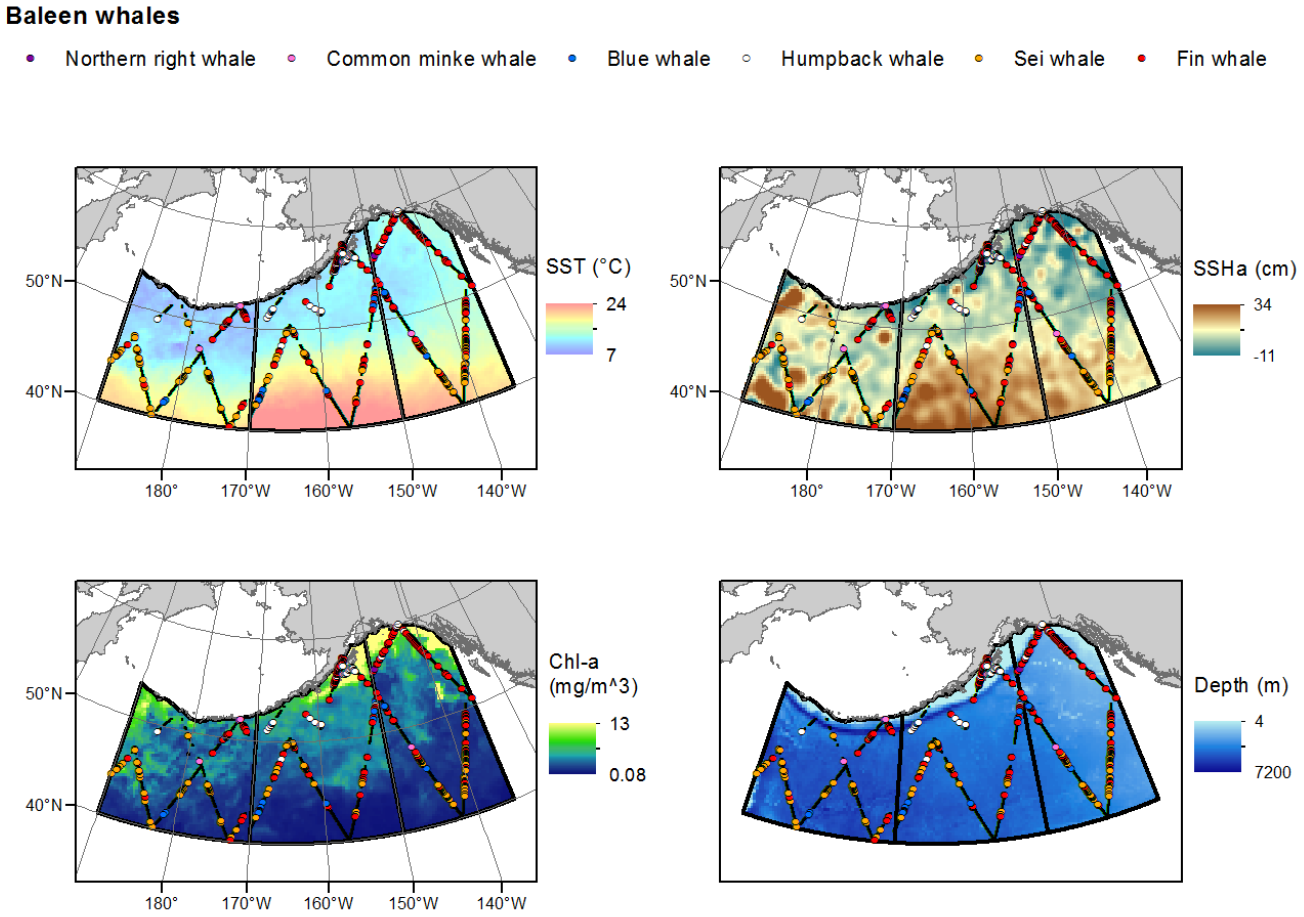

Fig. 1. Survey effort (black lines) and sighting positions of baleen whales in 2010-2012 POWER.

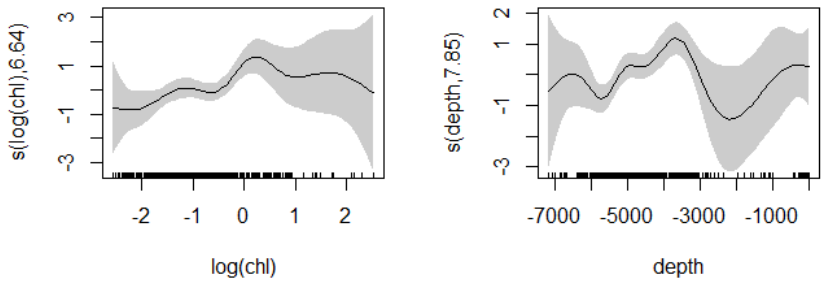

Fig. 2. Smoothed fits of selected covariates modelling the presence-absence of fin whales. Tick marks on the x-axis are observed data points. The y-axis represents the spline function. Shaded areas indicate the 95% confidence bounds.

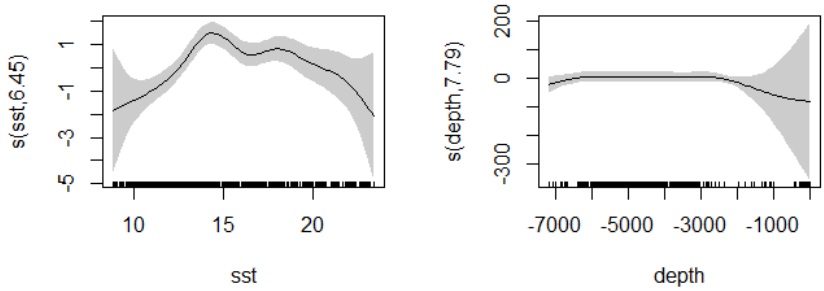

Fig. 3. Smoothed fits of selected covariates modelling the presence-absence of sei whales. Tick marks on the x-axis are observed data points. The y-axis represents the spline function. Shaded areas indicate the 95% confidence bounds.

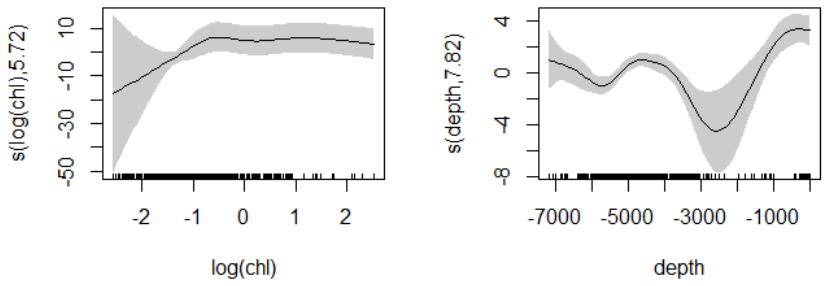

Fig. 4. Smoothed fits of selected covariates modelling the presence-absence of humpback whales. Tick marks on the x-axis are observed data points. The y-axis represents the spline function. Shaded areas indicate the 95% confidence bounds.

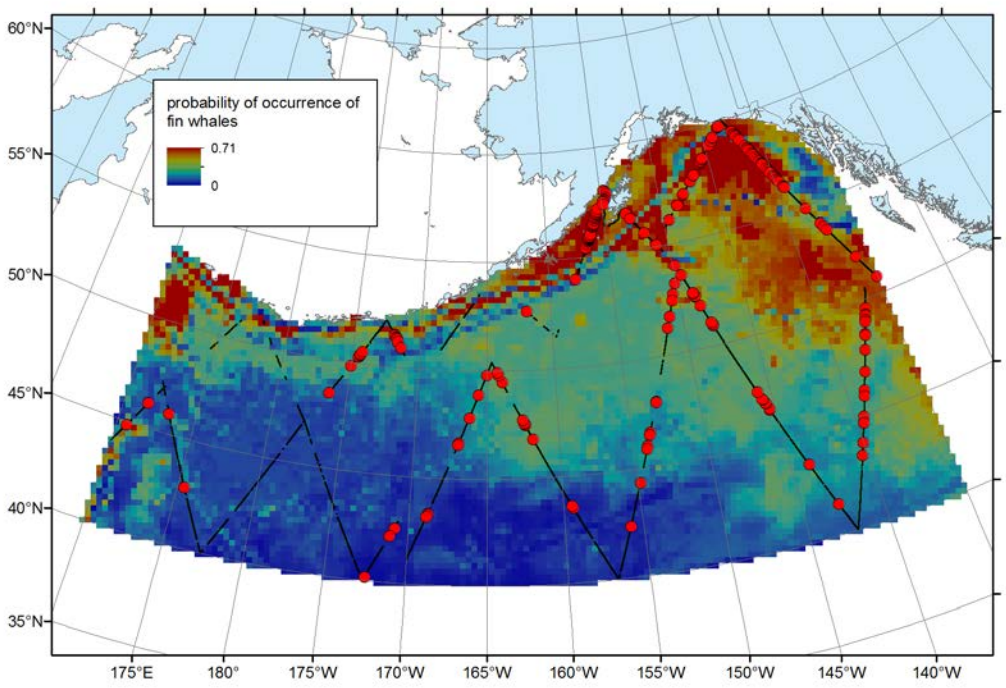

Fig. 5. Predicted spatial distribution (probability of occurrence) of fin whales in 2010-2012 POWER.

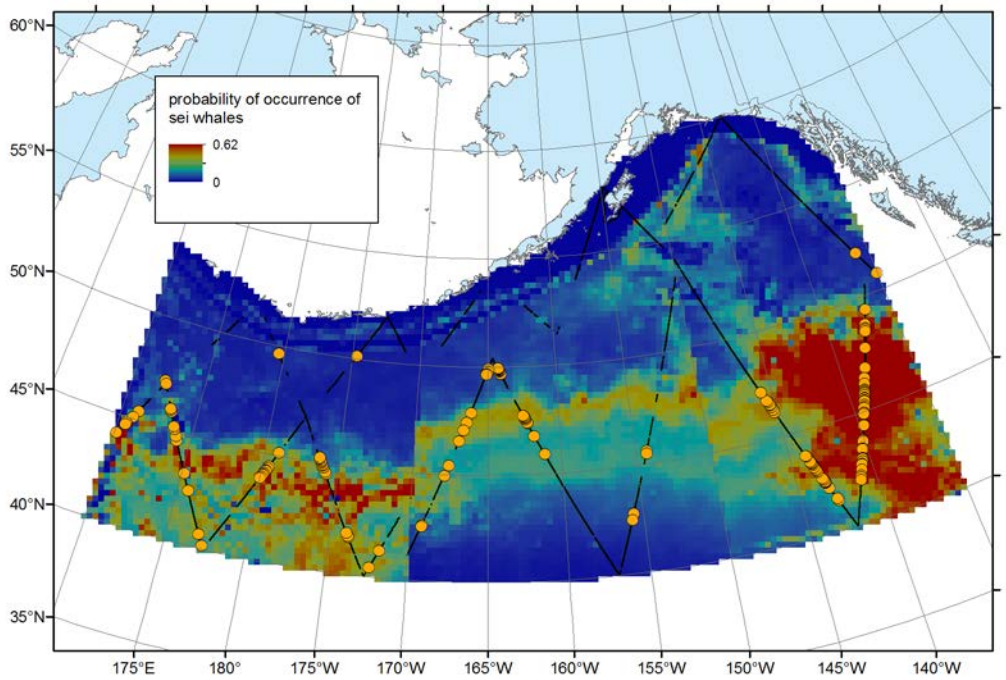

Fig. 6. Predicted spatial distribution (probability of occurrence) of sei whales in 2010-2012 POWER.

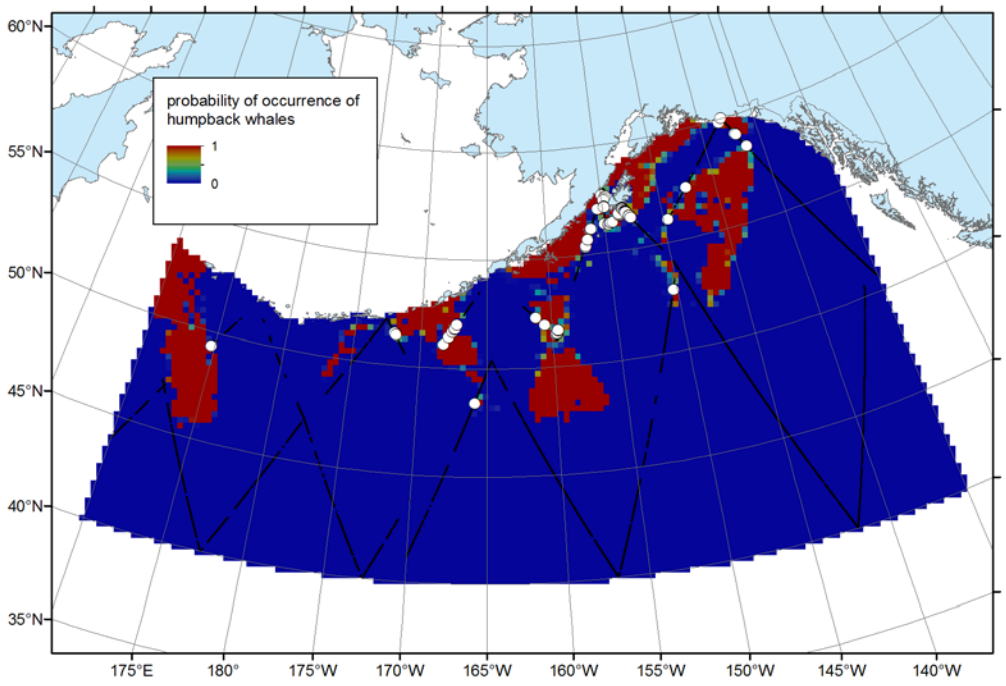

Fig. 7. Predicted spatial distribution (probability of occurrence) of humpback whales in 2010-2012 POWER.