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ABSTRACT

Seasonal spatial distributions of common minke, sei and Bryde's whales in the JARPNII survey area from 2002 to 2013 were estimated by using generalized additive models (GAM). All species shifted their distribution area toward the north of the survey area as season progress but the extents were different among species. Relative abundance of common minke whales was high in coastal area of Japan. Relative abundance of sei whales was high in the offshore area of the survey area where SST was moderate within the area. Relative abundance of Bryde's whales was high in the southern part of the survey area where SST was high. The results suggested that spatial distributions of three baleen whale species were segregated in the JARPNII survey area although some overlaps were occurred. Extent of direct competition (e.g. competitive exclusion of feeding area) could be minimal among the species but indirect competition for prey might be occurs as they share same prey species.

INTRODUCTION

A preliminary result of spatial modelling of sei whales was presented to the JARPNII expert workshop held in 2009 (Murase *et al.*, 2009) and the Panel of the workshop recommended to expand the analysis further as a medium to long term project (IWC, 2010).Spatial distribution of whales has been investigated further by using JARPNII data since then and some of the results were published in scientific literatures. Sasaki *et al.* (2013) investigated that spatial habitat differentiation between sei and Bryde's whales using generalized liner model (GLM) taking presence of these whales as binomial response variable. Murase *et al.* (2014) investigated spatial distribution of sei whales in relation to oceanic fronts by using generalized additive model (GAM) taking relative abundance as response variable. However, seasonal changes in spatial distributions of common minke, sei and Bryde's whales in relation to oceanographic conditions have not been investigated fully in the JARPNII survey area

In this paper, results of estimation of seasonal spatial distributions of common minke, sei, and Bryde's whales in the JARPNII survey area are presented to see whether the distributions is heterogeneous in both spatially and seasonally.

MATERIALS AND METHODS

Sighting survey

A brief summary of sighting survey related to this s provided hear. The details can be found in Matsuoka *et al,* (2016: SC/F16/JR2) and Bando *et al.* (2016: SC/F16/JR4). The cetacean sighting surveys were conducted in the western North Pacific in July from 2002 to 2013 as part of JARPNII (Fig. 1). The boundaries of the survey area were 35°N, the boundary of the economic exclusive zone (EEZ) claimed by countries other than Japan and 170°E and the eastern coast line of Japan. Sighting data obtained outside but adjacent to the area during the period were also used as supplemental data. Several survey vessels were engaged in the cetacean sighting surveys but their specifications were similar. Their gross tonnages were approximately 1000 GT with two main observation platforms: top barrels were set at 20 m above the sea surface and upper bridges were set at 10 m above the sea surface. Data obtained by sighting vessels (SVs) and sighting and sampling vessels (SSVs) were used in the analysis as the relative abundances were estimated using a model based method instead of a design based method. Three observers at each observation platform using 7 × 50 binoculars were engaged in the sighting surveys. Sightings within 3 n.miles from the survey tracklines were counted. The survey vessels steamed around 10.5 knots along the survey tracklines during the survey hours. The survey was conducted during the daytime from 1 hour after sunrise to 1 hour before sunset. Surveying was stopped when the visibility was <3.7 km (≈ 2 nm) and/or sea state >4 on the Beaufort wind force scale.

Activities aboard the ship were basically classified into two categories: on-effort and off-effort. On-effort activities were times when a full search effort was executed within the acceptable conditions. Off-effort activities were all times other than on-efforts. On-effort data used in the analysis. All sightings of sei whales recorded during on-effort activities were classified as primary-sightings. All other sightings were considered secondary sightings and not used in this analysis. On-effort surveys were conducted in the closing and passing mode; the survey vessels approached all sightings during the closing-mode to confirm the species and number of individuals in a school, and all sightings during the passing-mode were not approached although the species and estimated number of individuals in a school were recorded.

Spatial modelling

Generalized additive models (GAM) having a Tweedie error distribution with logarithmic link function were used to estimate spatial distributions of common minke, sei and Bryde's whales. A Tweedie random variable with $1<p<2$ is a sum of N gamma random variables in which N has a Poisson distribution (Wood, 2015). If p equals 1, then it is a generalization of a Poisson distribution and a discrete distribution supported on integer multiples of the scale parameter. If p is larger than 1 and smaller than 2 ($1<p<2$), then the distribution is supported on the positive reals with a point mass at zero. If p equals 2, then it is a gamma distribution. Initially, we experimentally changed the value of p in each GAM and set it as 1.1. The models with the lowest GCV scores were selected. For this analysis, the mgcv package (Wood, 2006) version 1.8-7 of the R software version 3.2.2 (R Development Core Team, 2015) was used. The shapes of the functional forms for the all covariates were also plotted with that package. When the slopes of the functional forms were positive, the covariates were related positively to the response variable, and vice versa.

Sea surface temperature (SST), sea surface height anomaly (SSHa) and sea surface chlorophyll-a concentration (Chl-a) recorded by satellites and a digital seafloor depth data were used as environmental covariates in the models. SST and Chl-a data (4x4 km grid) obtained by Moderate Resolution Imaging Spectroradiometer aboard the Aqua satellite (Aqua MODIS) were used. Monthly mean from July 2002 to September 2013 in Level 3 Standard Mapped Image products downloaded from Ocean Color Web (http://oceancolor.gsfc.nasa.gov/, NASA Goddard Space Flight Center "Last accessed on 10 January 2014") were used. It should be noted that recording of MODIS data was started in July 2002. Missing data in these data were estimated by ordinary kriging with the aid of the geographic information system (GIS), ArcGIS 10.1 (ESRI, California, USA). Daily data of Map of Sea Level Anomalies (MSLA) were also downloaded and used as SSHa. The altimeter products were produced by Ssalto/Duacs and distributed by Aviso, with support from Cnes (http://www.aviso.oceanobs.com/duacs/ "Last Last accessed on 18 September 2014"). ETOPO1 Global Relief Model for bottom topography" (Amante and Eakins, 2009) was used as seafloor depth data. "A Global Self-consistent, Hierarchical, High-resolution Geography Database" (Wessel and Smith, 1996) was used in figures to depict coastline. Year and month were used as categorical covariates in the model. Spatial resolution considered in the models was 1x1 longitude and latitudinal grid cell. Data recoded from May to September in each (2002-2013) were used in the modelling. Mean values in 1x1 longitude and latitudinal grid cell in each month in each year were calculated using these data.

Relative abundances of common minke, sei and Bryde's whales in a grid cell was used as response variables. The following procedures were conducted to estimate relative abundance. Original sighting effort data were divided first into 1 km segments, and then these segments were pooled in each grid cell (d). Because sighting effort was discontinuous in closing mode, especially in high density area of baleen whales, a relatively short segment length (1 km) was chosen for the analysis. The number of schools of sei whales was also pooled in each grid cell (n). Effective strip width (esw) and mean school size (E(s)) were estimated by a program, DISTANCE version 6.2 release 1 (Thomas *et al.*, 2010). All sighting data from 2002 to 2013 recorded by SVs and SSVs were pooled for the estimation. Probability of detection on the trackline (g(0)) was assumed as 1. Abundance in a grid cell was first calculated by unit density, i.e. $(n \times E(s))/(d \times 2 \times esw \times g(0))$, and then multiplied by the area of the grid cell. Some grid cells had unusually high abundance. Abundances of common minke, sei and Bryde's whales falling more than 99, 95 and 97 percentiles, respectively, were treated as outliers and not considered in the GAM to avoid unrealistic over estimation.

RESULTS AND DISCUSSION

Totals sighting effort in grids in each month from 2002 to 2013 are shown in Fig. 2. Totals of number of sighted schools of common minke, sei and Bryde's whales in grids in each month from 2002 to 2013 are shown in Figs. 3-5. Maps of mean SST, SSHa and Chl-a in each month from 2002 to 2013 are shown in Figs. 6-8.Estimated esw and E(s) are summarized in Table 1. Selected GAMs based on GCV score for relative abundance of three species are summarized in Table 2. Selected environmental covariates were different among species but SST was used for all species. The shapes of the functional forms for selected covariates for three species are shown in Figs. 9-11. The shapes of SST for three species showed pronounced differences. Relative abundance of common minke whales increased as SST was decreased. A peak of relative abundance of sei whales occurred around 15°C. Relative abundance Bryde's whales increased as SST increased. Relative abundance of Common minke whales was high in shallow water depth while that of sei whales was high in deep depth. Depth was not selected for Bryde's whales. Estimated spatial distributions of three species are shown Figs. 12-14. All species shifted their distribution area toward the north of the survey area as season progress but the extents were different among species. Relative abundance of common minke whales was high in coastal area of Japan. Relative abundance of common minke whales was also high around 50°N and 170°E where seafloor depth is relatively shallow because of existence of the Emperor Sea mounts. Relative abundance of sei whales was high in the offshore area of the survey area where SST was moderate within the area. Relative abundance of Bryde's whales was high in the southern part of the survey area where SST was high. The results suggested that spatial distributions of three baleen whale species were segregated in the JARPNII survey area although some overlaps were occurred. Extent of direct competition (e.g. competitive exclusion of feeding area) could be minimal among the species but indirect competition for prey might be occurs as they share same prey species.

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Table 1. Estimated effective search widths (esw) and mean school size E(s) for common minke, sei and Bryde's whales used in this study. Coefficient of variation (CV) fro esw and E(s), and truncation distances are also shown.

Species	Truncation (km)	ESW (km)	CV	E(s)	CV
Minke whale	2.78	0.84	0.05	1.05	0.01
Sei whale	5.56	2.73	0.03	1.30	0.01
Bryde's whale	5.56	3.03	0.03	1.55	0.01

Table. 2. Selected generalized additive models (GAMs) for common minke, sei and Bryde's whales. Approximate significance levels (p-value) and degrees-of-freedom (edf) are shown for each covariate.

Species	Minke whale		Sei whale		Bryde's whale	
Family	Tweedie		Tweedie		Tweedie	
Link function	log		log		log	
Power (p)	1.1		1.1		1.1	
Adjusted R^2	0.14		0.08		0.21	
Deviance explained (%)	31.3		21.1		48.8	
GCV score	41.55		33.60		26.79	
Parametric coefficients	Estimate	p-value	Estimate	p-value	Estimate	p-value
Intercept	-8.05	<0.05	-7.93	<0.05	-10	<0.05
Year						
2003	0.61	0.06	-0.48	0.07	0.95	0.07
2004	0.22	0.51	-0.20	0.42	0.80	0.11
2005	-0.20	0.57	-0.02	0.94	0.78	0.12
2006	0.22	0.50	0.04	0.87	1.09	<0.05
2007	-0.36	0.33	0.21	0.37	1.33	<0.05
2008	-0.41	0.33	-0.30	0.26	1.19	<0.05
2009	-0.57	0.18	-0.13	0.65	0.94	0.09
2010	-1.82	<0.05	-0.01	0.98	0.95	<0.05
2011	-0.76	0.12	-0.32	0.28	1.15	<0.05
2012	-0.02	0.97	-1.11	<0.05	1.06	<0.05
2013	-1.02	0.08	-0.01	0.96	0.71	0.15
Month						
6	0.44	<0.05	0.56	<0.05	-0.37	0.46
7	0.43	0.06	0.59	<0.05	-0.67	0.20
8	0.37	0.14	0.43	<0.05	-0.82	0.13
9	0.82	<0.05	0.53	0.07	-1.819	<0.05
Approximate significance of smooth terms	edf	p-value	edf	p-value	edf	p-value
SST	5.48	<0.05	4.39	<0.05	4.60	<0.05
SSHa	-	-	-	-	5.43	<0.05
log(Chl-a)	-	-	-	-	6.36	<0.05
Depth	8.29	<0.05	6.99	<0.05	-	-

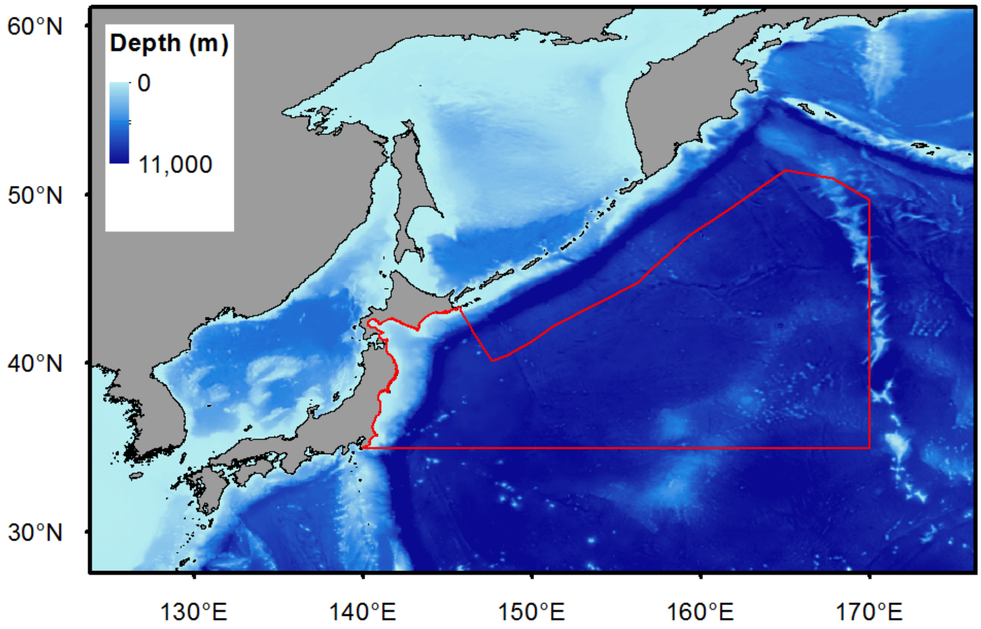

Fig. 1. The survey area of JARPNII (red line). A Seafloor depth is also shown.

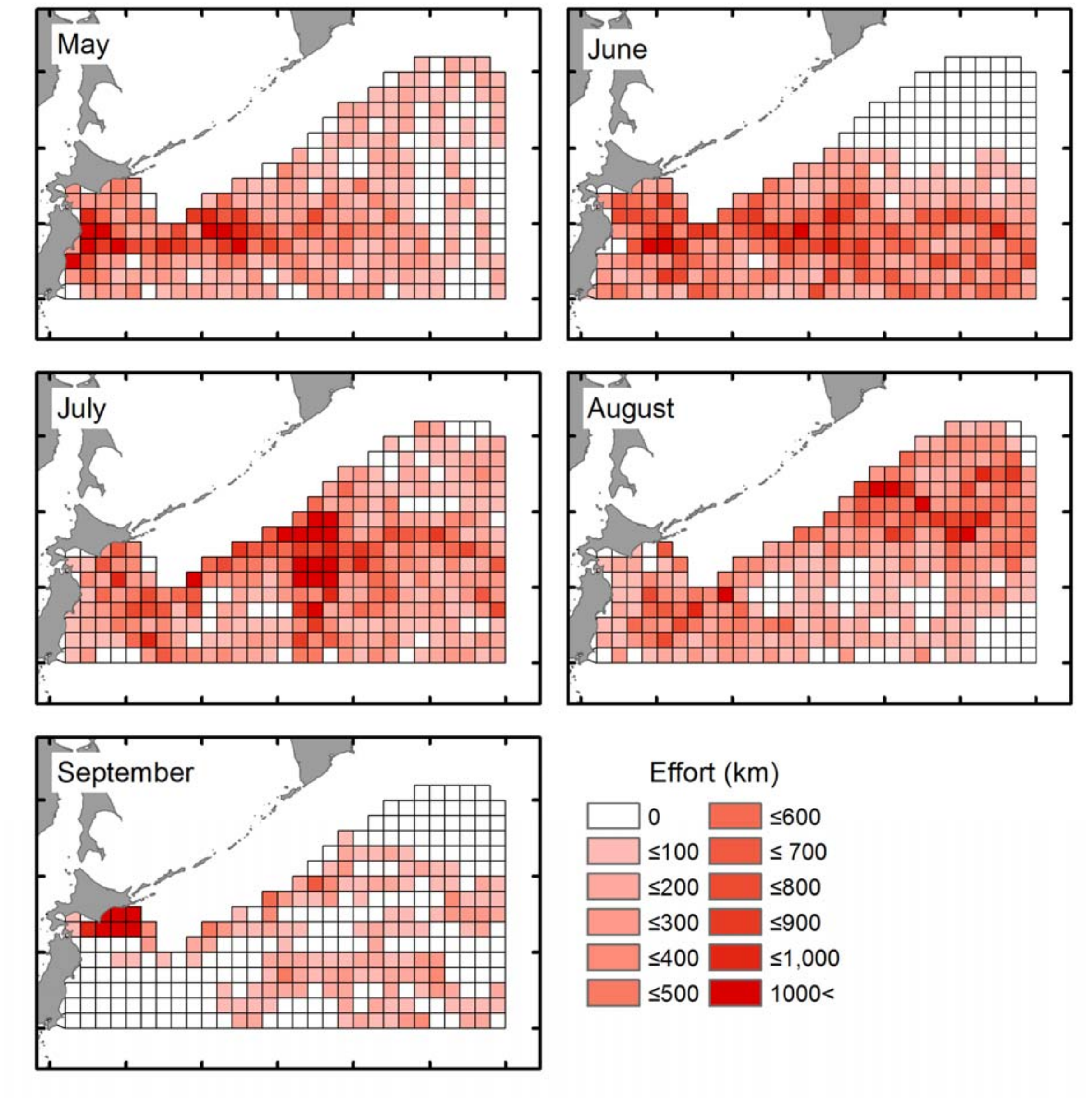

Fig. 2. Sighting effort (km) from May to September. Totals from 2002 to 2013 are shown.

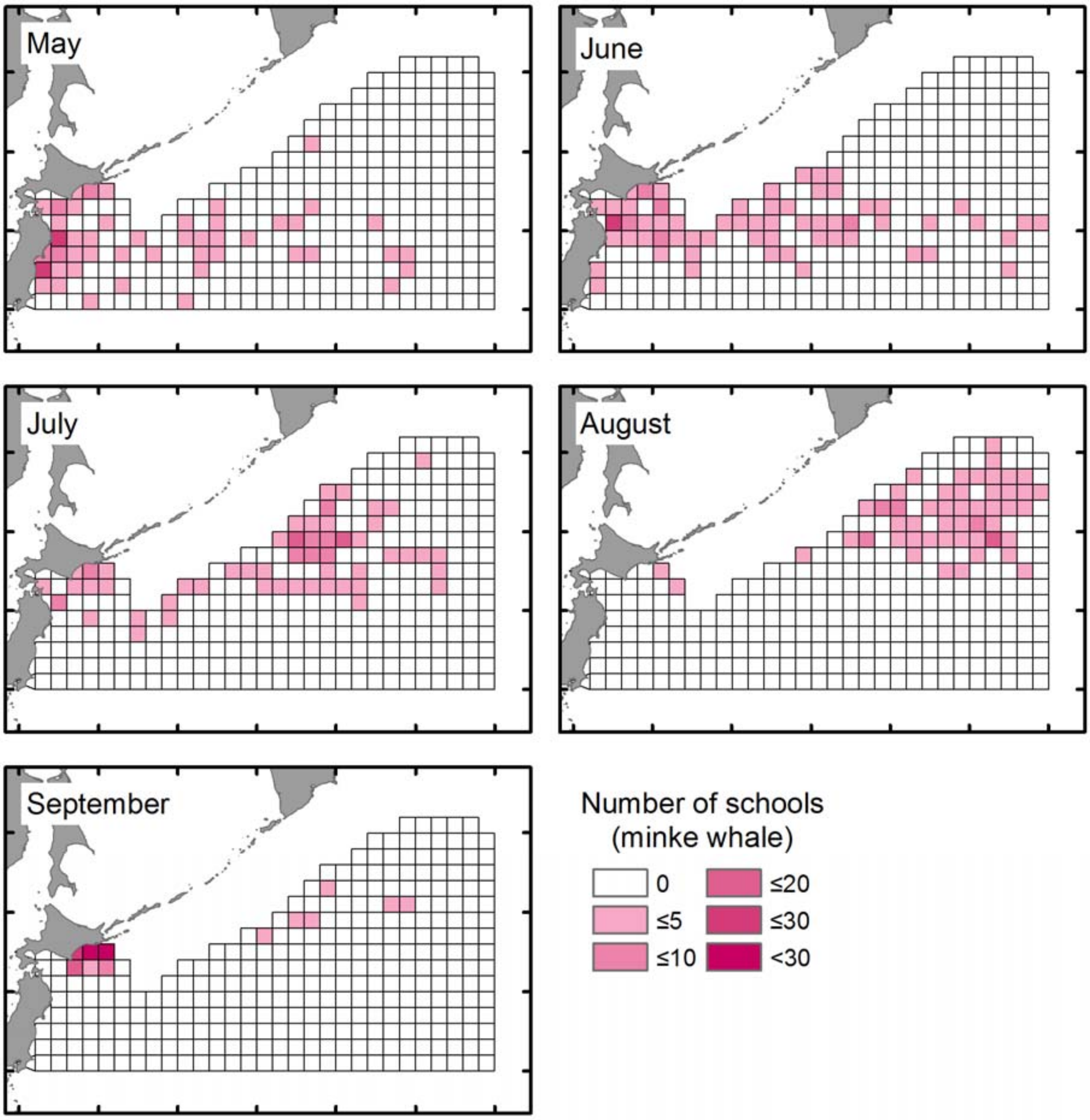

Fig. 3. Number of sighted schools of common minke whales in 1×1 longitude and latitude grids from May to September. Totals from 2002 to 2013 are shown.

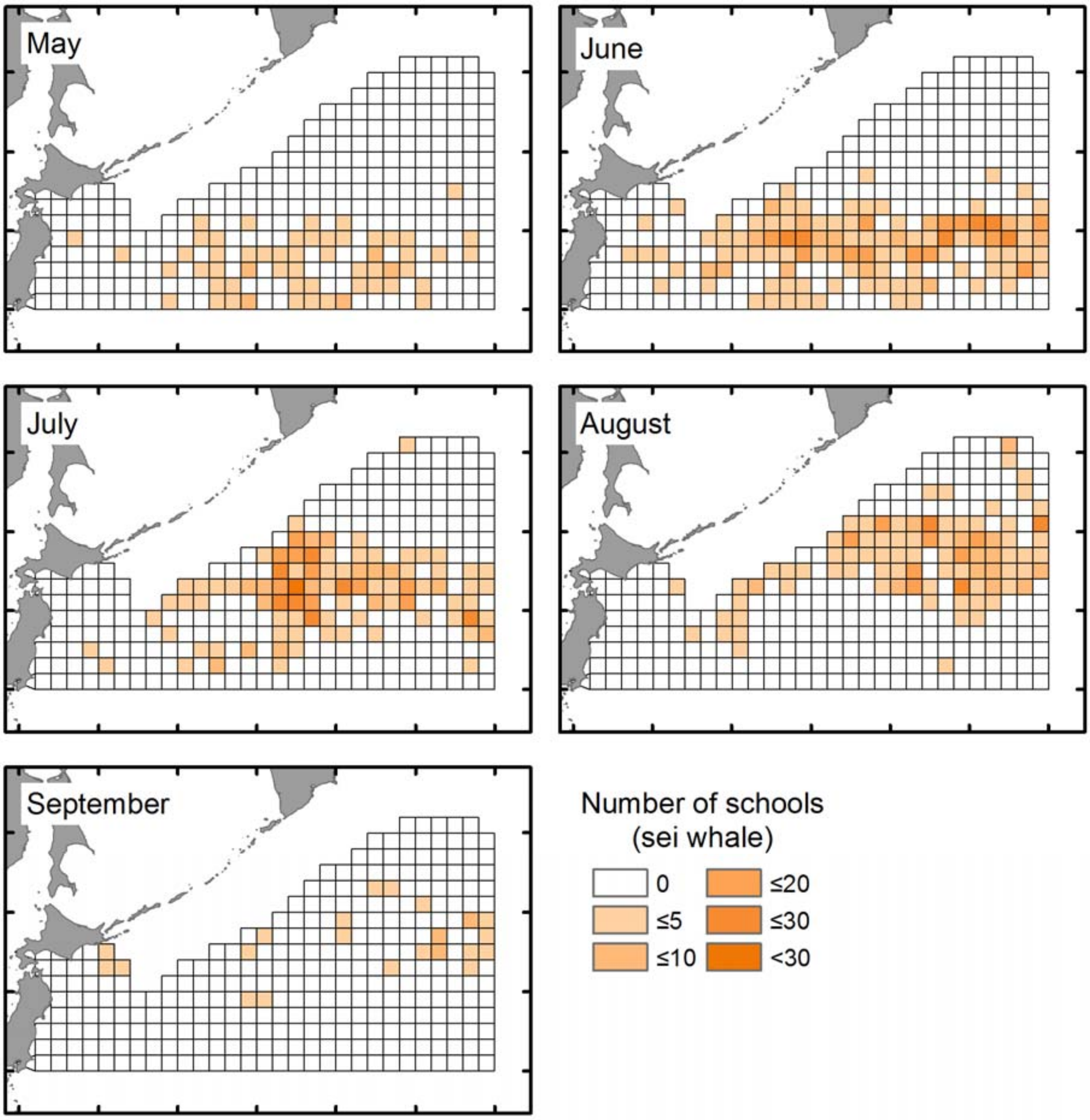

Fig. 4. Number of sighted schools of sei whales in 1×1 longitude and latitude grids from May to September. Totals from 2002 to 2013 are shown.

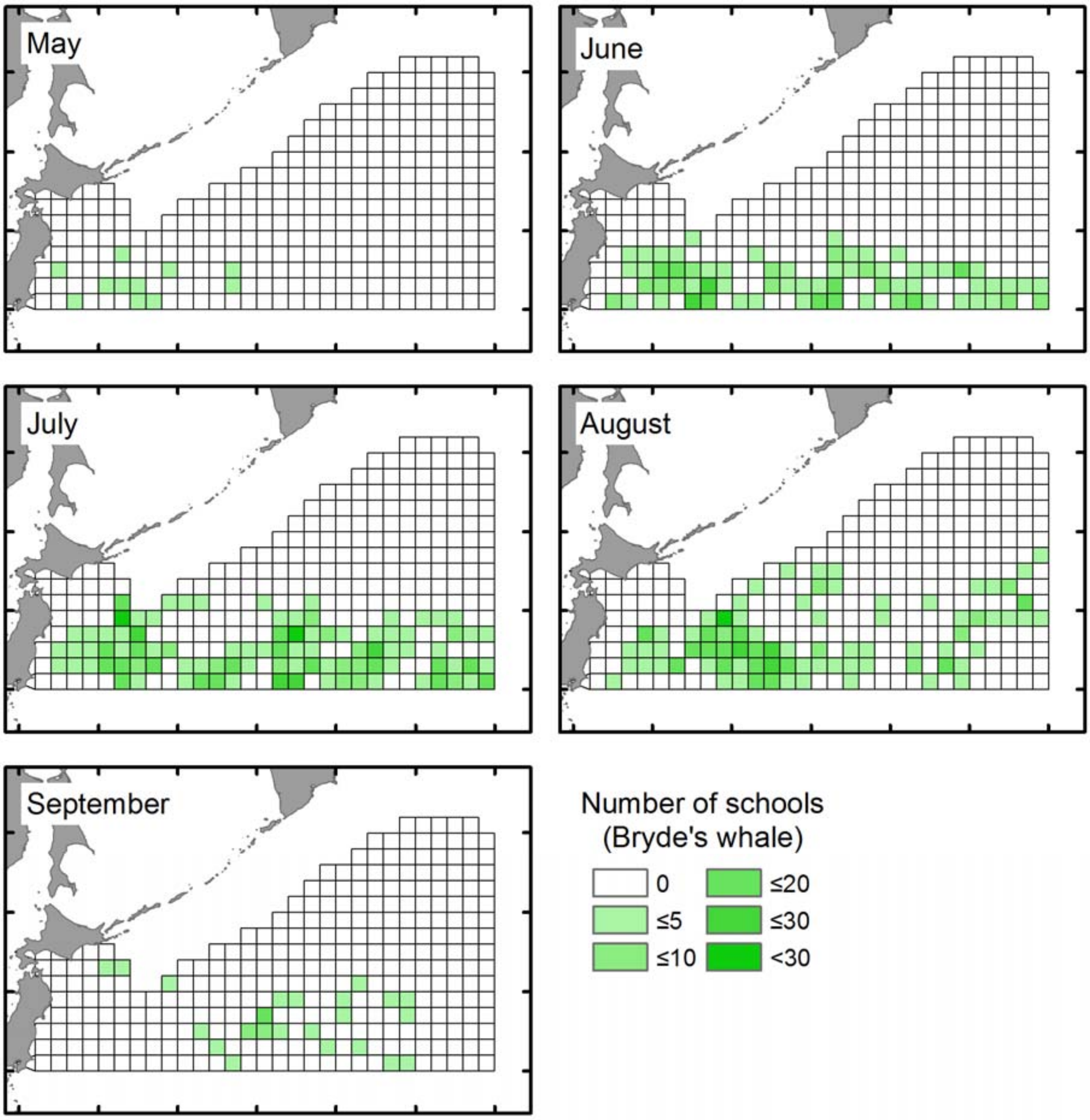

Fig. 5. Number of sighted schools of Bryde’s whales in 1×1 longitude and latitude grids from May to September. Totals from 2002 to 2013 are shown.

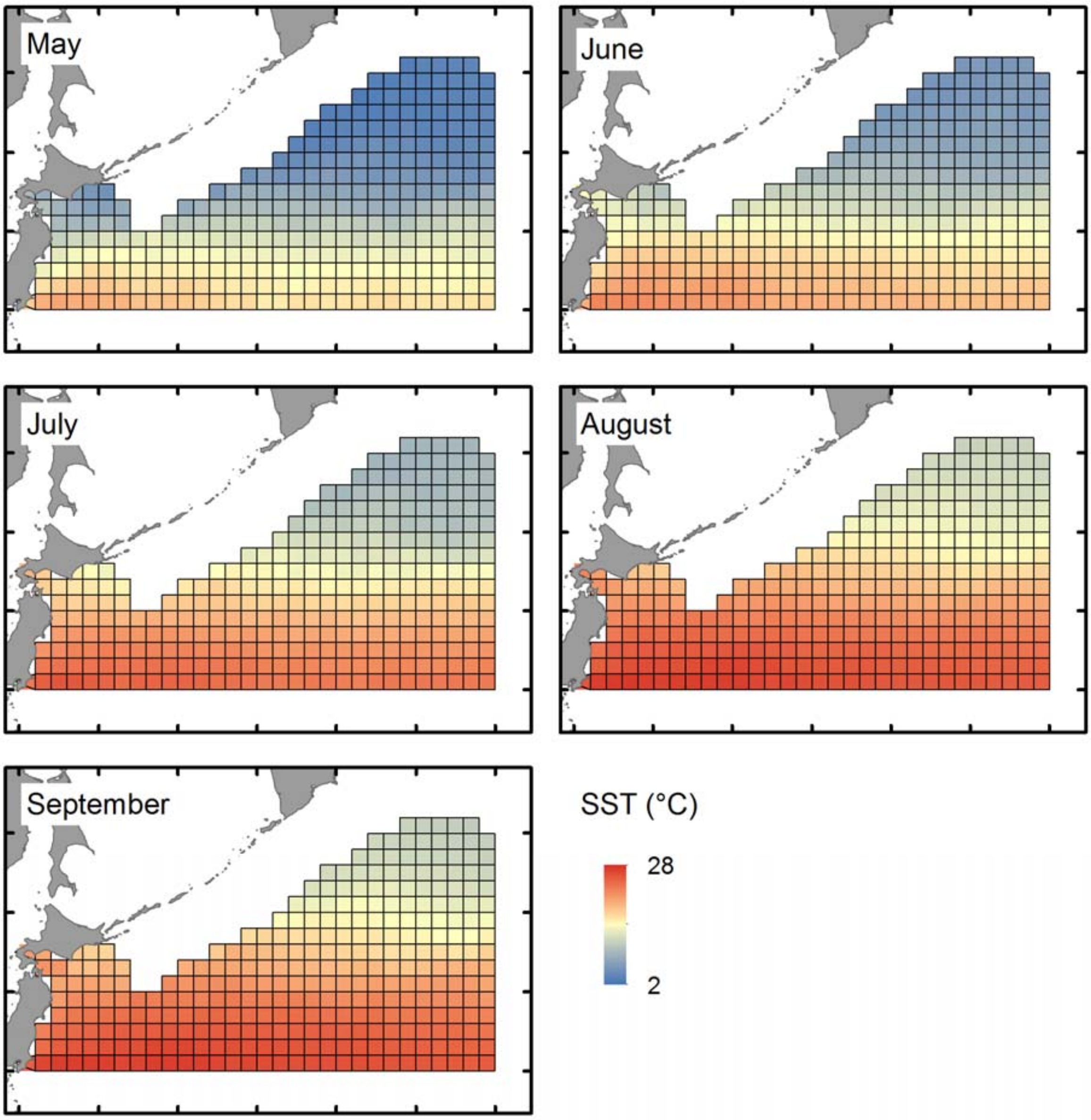

Fig. 6. Sea surface temperate (SST) from May to September. Means of values in 1×1 longitude and latitude grids from 2002 to 2013 are shown.

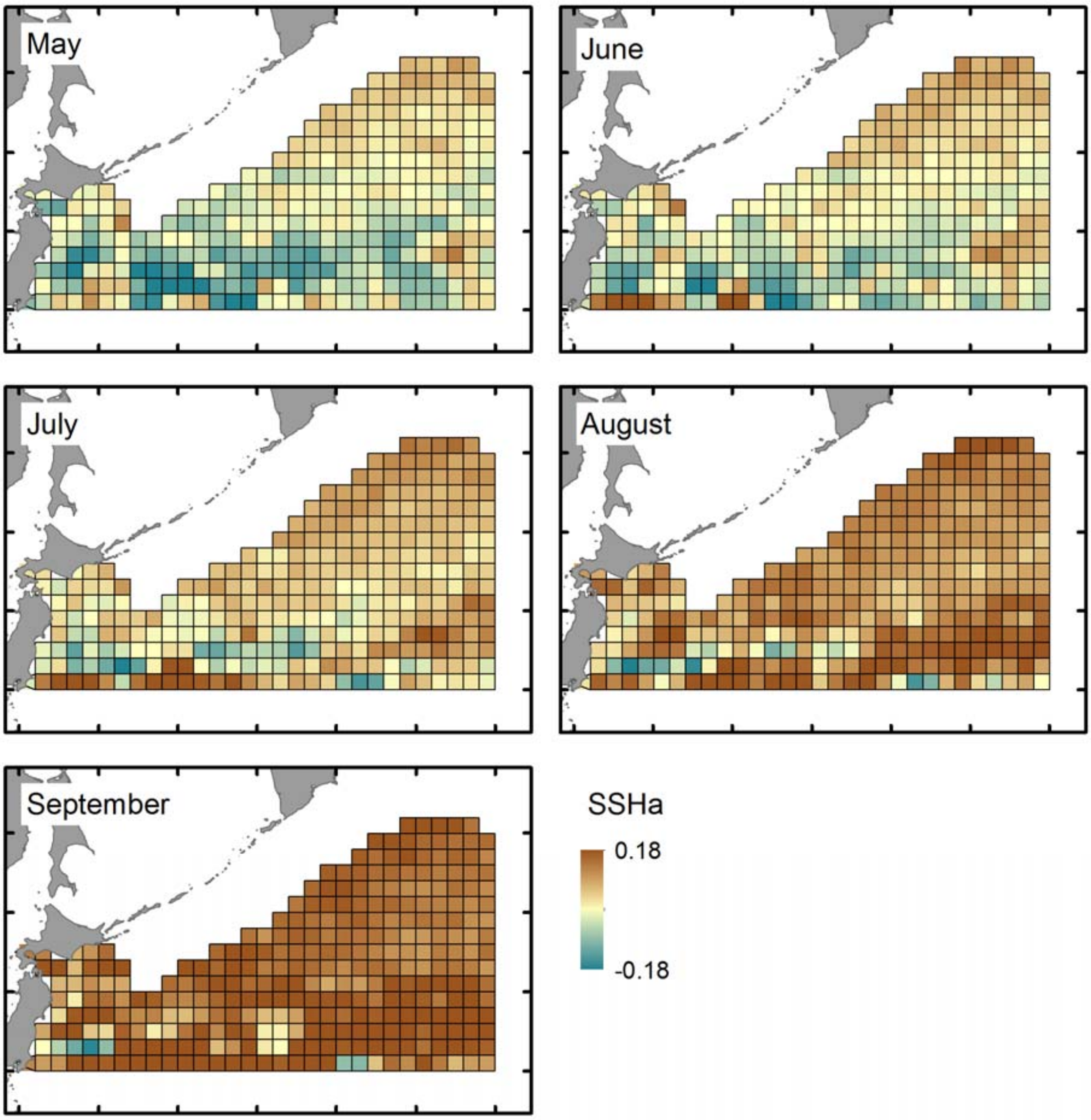

Fig. 7. Sea surface height anomaly (SSHa) from May to September. Means of values in 1×1 longitude and latitude grids from 2002 to 2013 are shown.

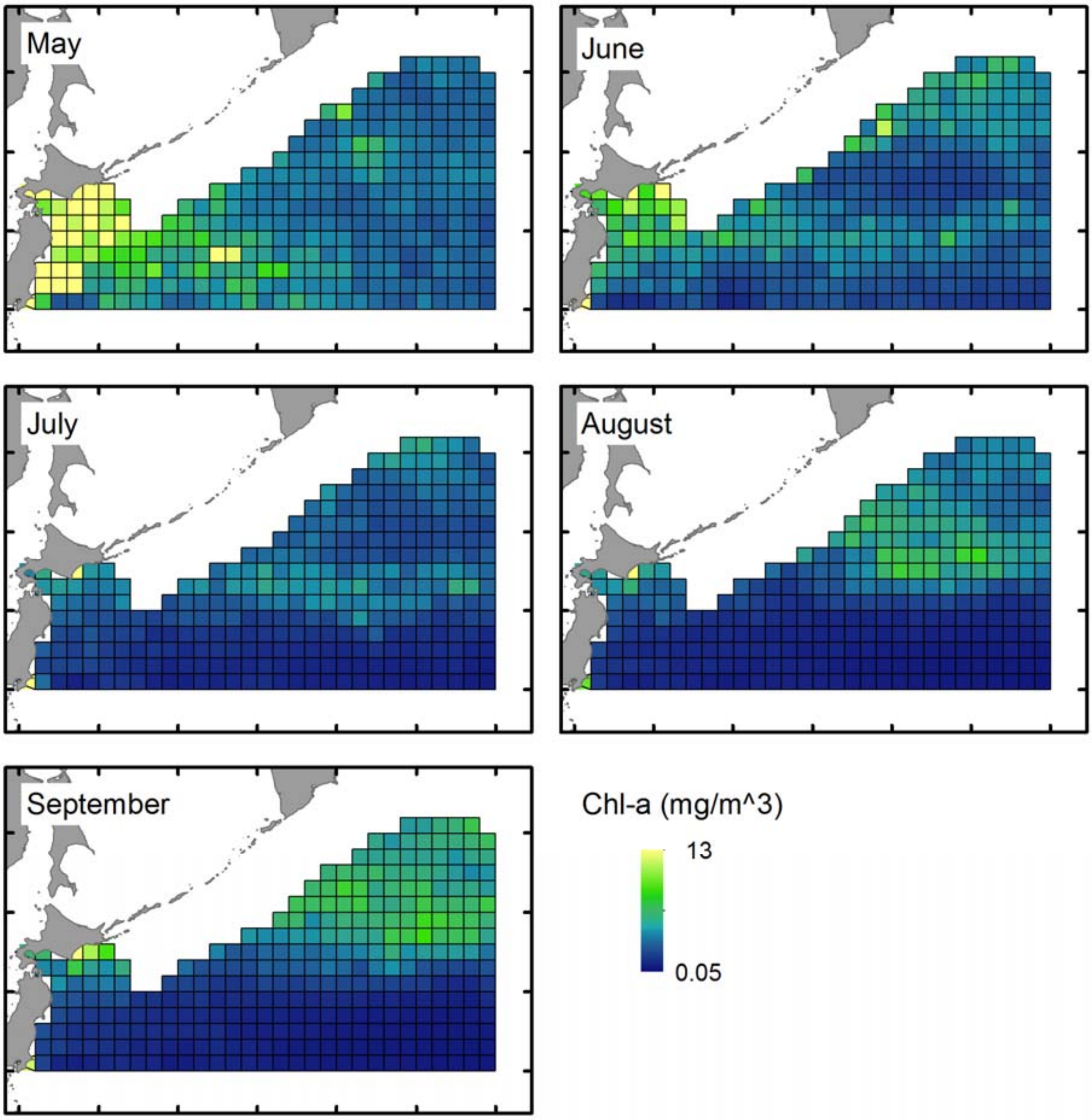

Fig. 8. Chlorophyll-a concentrations (Chl-a) from May to September. Means of values in 1×1 longitude and latitude grids from 2002 to 2013 are shown.

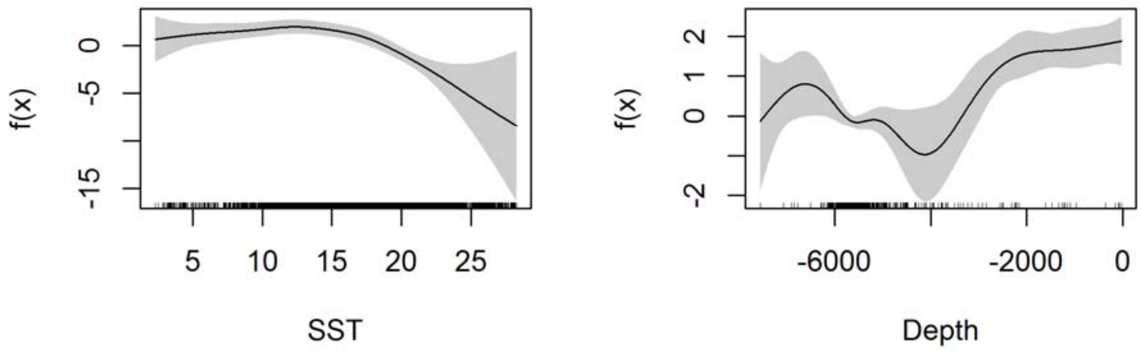

Fig. 9. Smoothed fits of selected covariate modelling number of common minke whale individuals. Ticks on the x-axis are observed data points. The y-axis represents the spline function. Shaded areas indicate 95% confidence intervals

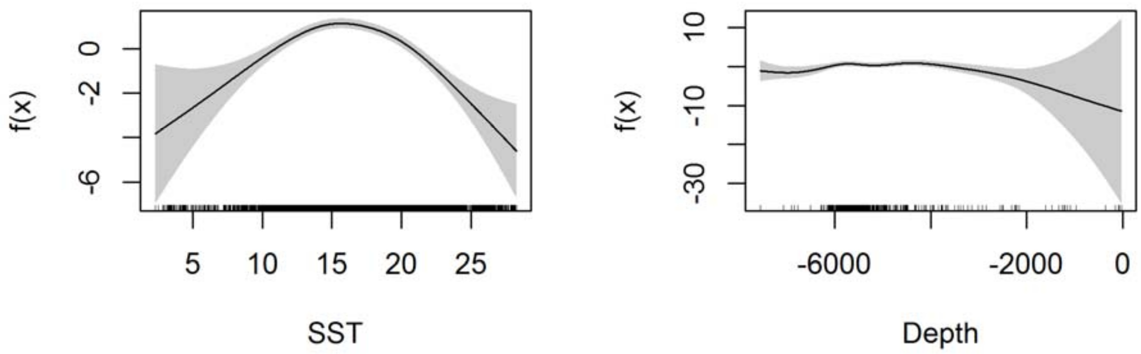

Fig. 10. Smoothed fits of selected covariate modelling number of sei whale individuals. Ticks on the x-axis are observed data points. The y-axis represents the spline function. Shaded areas indicate 95% confidence intervals

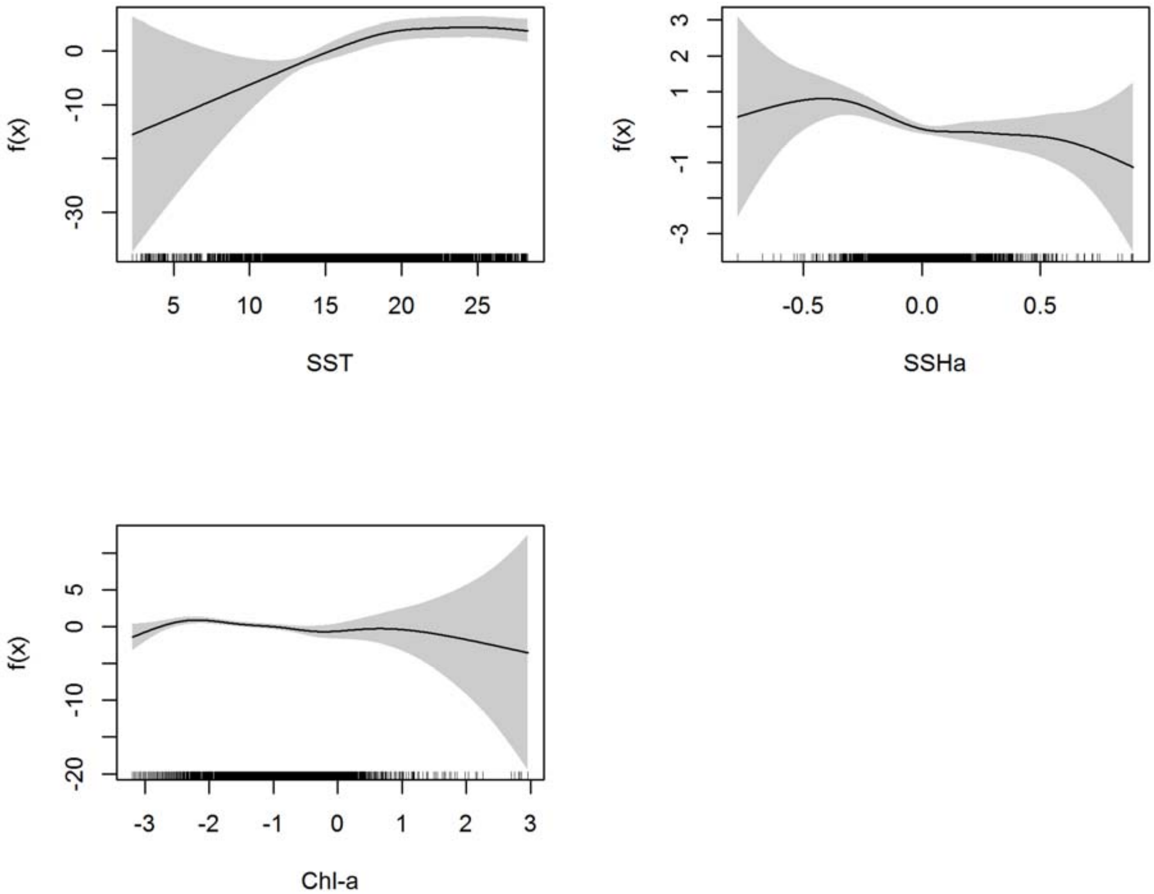

Fig. 11. Smoothed fits of selected covariate modelling number of Bryde's whale individuals. Ticks on the x-axis are observed data points. The y-axis represents the spline function. Shaded areas indicate 95% confidence intervals

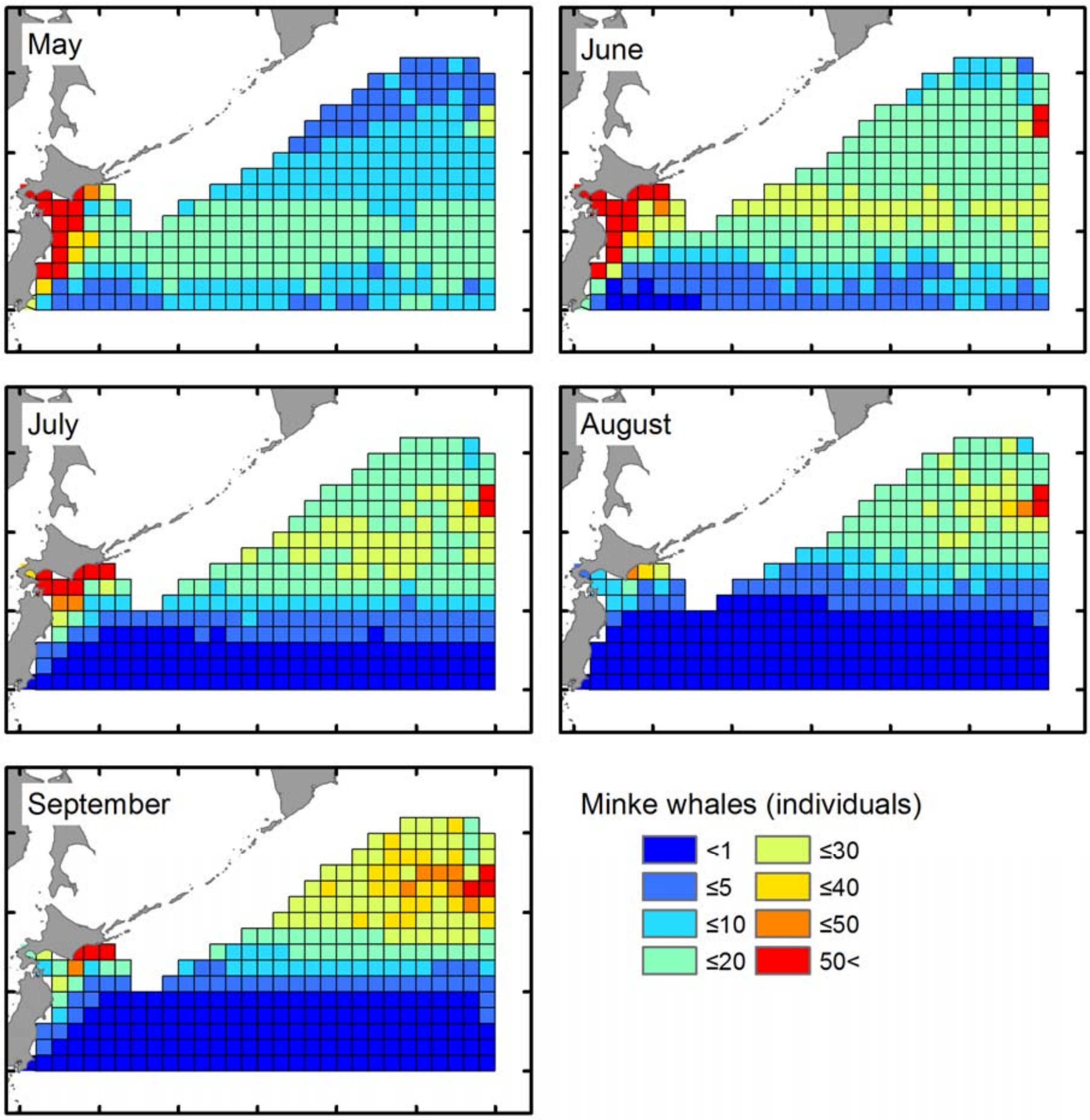

Fig. 12. Estimated spatial distribution of common minke whales from May to September. Means of estimated number of individuals in 1×1 longitude and latitude grids from 2002 to 2013 are shown.

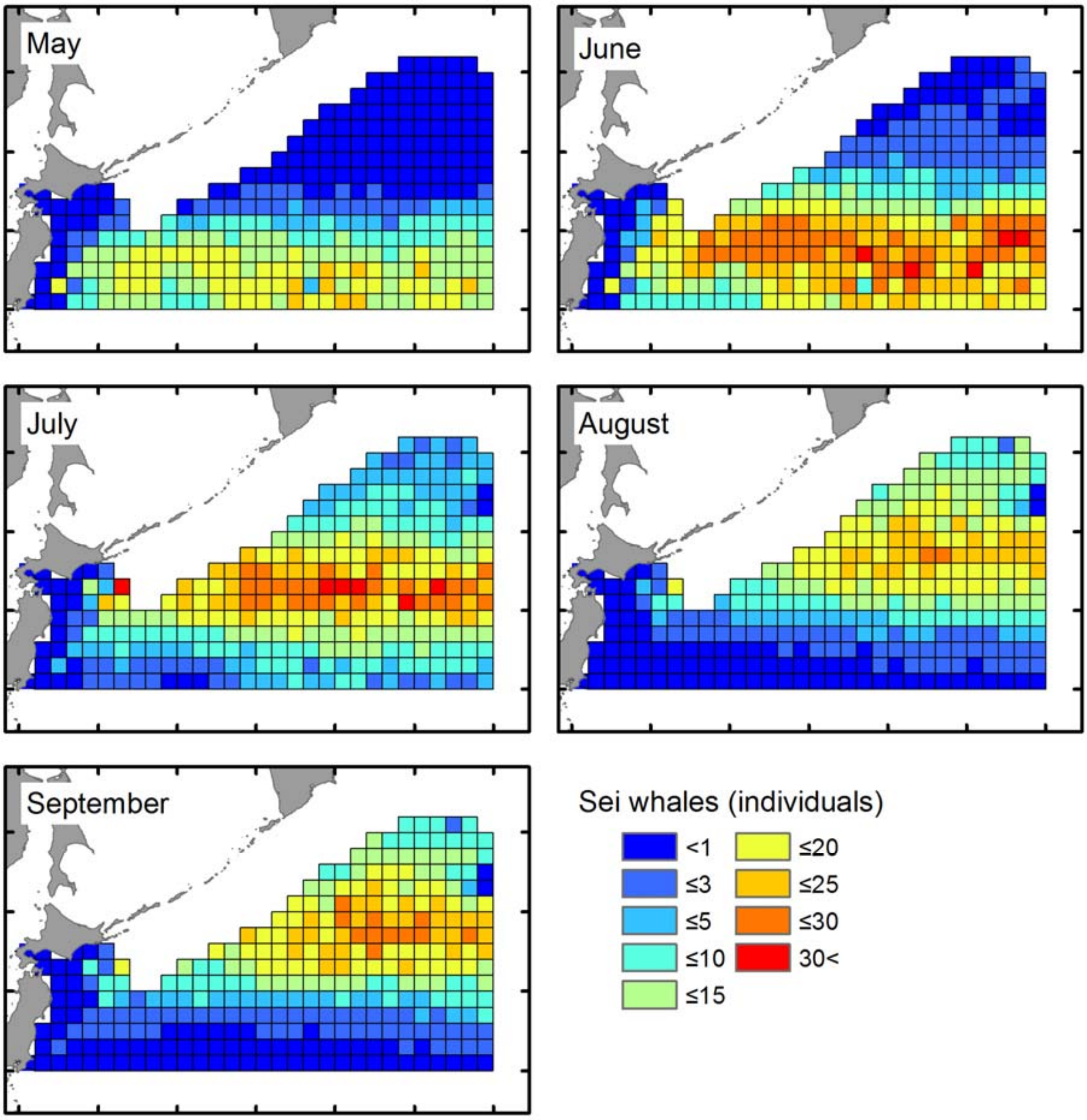

Fig. 13. Estimated spatial distribution of sei whales from May to September. Means of estimated number of individuals in 1×1 longitude and latitude grids from 2002 to 2013 are shown.

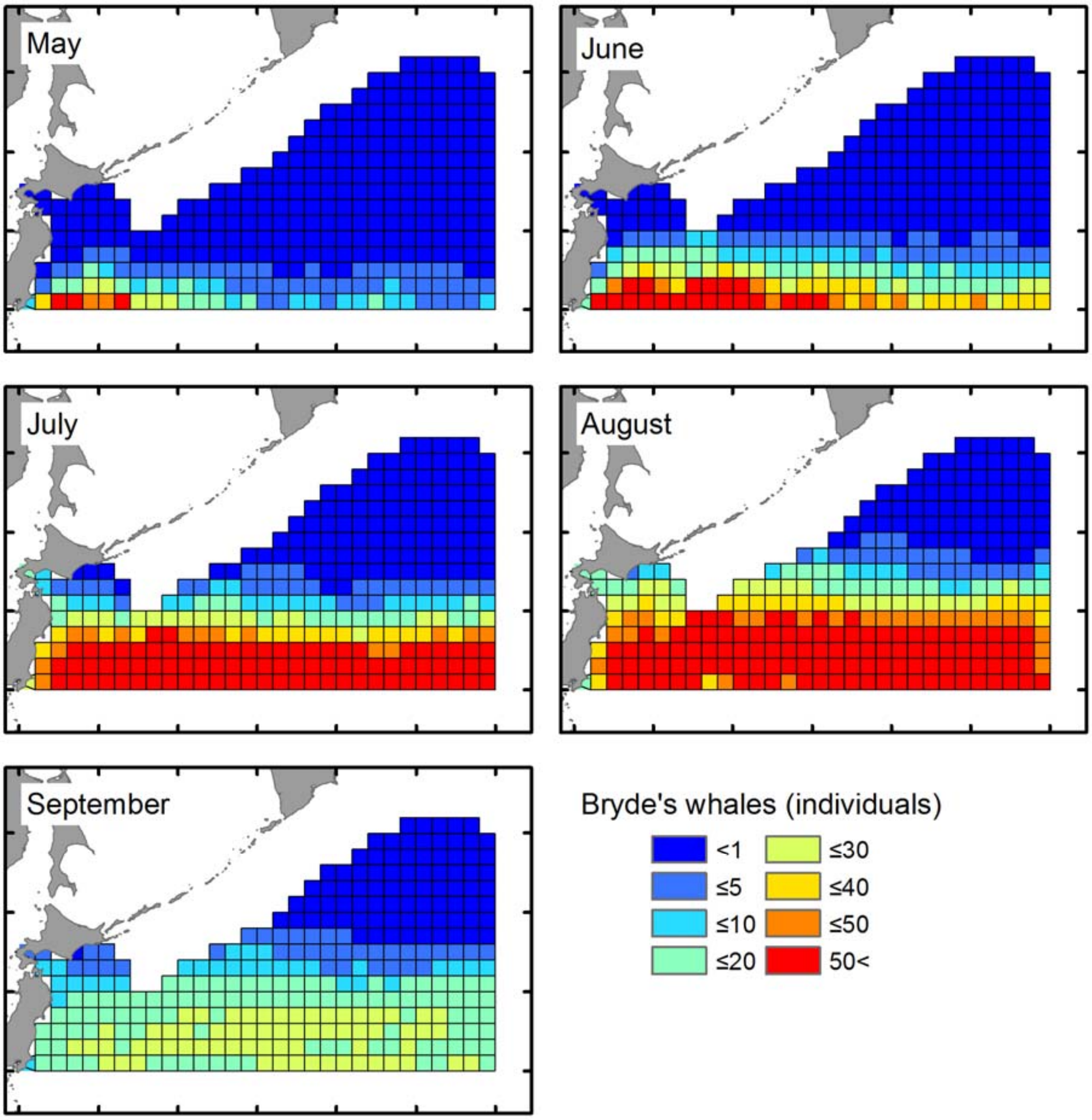

Fig. 14. Estimated spatial distribution of Bryde’s whales from May to September. Means of estimated number of individuals in 1×1 longitude and latitude grids from 2002 to 2013 are shown.