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Summer Habitat and Fishing Ground of *Ommastrephes bartramii* Related with the North Pacific Subarctic Frontal Zone Using Long-term Field Research Data

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Abstract
The neon flying squid, *Ommastrephes bartramii*, is an economically important oceanic squid species that has been harvested commercially in the North Pacific by Japan, Korea, China, and Taiwan. The Fisheries Research Agency (FRA) of Japan conducted long-term research for this species from 1980 to 2009 using commercial vessels to clarify the resource ecology and it obtained a total dataset of approximately 9,000 days, where following from this and to better clarify the relationship between habitat preference and oceanographic conditions, a generalized additive model was applied and mapped onto the Simple Ocean Data Assimilation ocean/sea ice reanalysis (SODA) data. The resultant habitat map of the squid showed an area of high abundance at the Subarctic Frontal Zone (SAFZ), with abundance areas increasing the squid abundance from April to August. The SAFZ extends from 40°N to 43°N separating the cold, low-salinity, subarctic water to the north from the waters of the North Pacific Transition Zone to the south. This high abundance area intersects between subarctic area and temperate area. It has characteristic nutrient regimes, productivity cycles, and nektonic faunal compositions. This paper suggests that the SAFZ thus plays an important role in North Pacific ecosystems by providing an optimal balance between environmental temperature and food density for the neon flying squid.

Discipline: Fisheries
Additional key words: habitat model, neon flying squid, SAFZ, squid jigging

Introduction

The neon flying squid, *Ommastrephes bartramii*, which is widespread in subtropical and temperate regions (Roper et al. 2010), is an economically important oceanic squid species that has been harvested commercially by Japan since 1974, and is comprised of two spawning cohorts; an autumn cohort and a winter-spring cohort (Yatsu et al. 1997, 1998), where, found subsequently by Korea, Taiwan and China (Arkhipkin et al. 2015), the North Pacific population is interestingly, despite their apparently contiguous hatching periods, having a marked difference in the mantle length of both cohorts.

The annual catch of neon flying squid is approximately 7,000 tons in Japan (Fisheries Agency 2022). The current shortage of squid products has become a major problem which effect on not only fisheries but also squid processing industry in Japan (Miki & Miki 2021) and has been attributed to poor catches of Japanese flying squid and the withdrawal of squid jigging ships from foreign waters.

Stock levels of the autumn-spawning cohort, which is important in the fishery economy because of its large size, were low when large-scale driftnet fishing was widely practiced (1979-1992). After an international moratorium on all large-scale pelagic drift net fishing at the end of 1992, squid stocks increased rapidly (Yatsu et al. 1998, Ichii et al. 2009).

O. bartramii undertakes an annual round-trip migration between its subtropical spawning grounds and its northern feeding grounds near the subarctic boundary (Murata et al. 1988, Kato et al. 2014, 2015). While the fishing grounds in the summer fishing season (May to July) form beyond the International Date Line (180°)

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near the subarctic boundary (Arkhipkin et al. 2015), the fishing grounds in the winter fishing season (January to March) are located off the coast of the Sanriku region along the coast of Japan.

Several studies have been conducted on the fishing grounds of *O. bartramii* to date (Alabia et al. 2016, Igarashi et al. 2018, Chen et al. 2010, Tian et al. 2009). These studies have typically been undertaken in July at around 160°W, although, whereas there is little information on fishing grounds for the squid jigging fisheries between the western longitudes of 180 and 140 degrees in August, we analyzed the fishing grounds in August by identifying environmental parameters that were similar to those described in previous studies on the squid jigging fishing grounds of this species and subjecting these data to analysis using a high-resolution ocean model.

Methods

1. Catch data for statistical analysis

Data for this habitat analysis used survey data collected by the Fisheries Research and Education Agency and fishing vessels. These surveys were conducted intermittently over an extensive area of the North Pacific Ocean for a total of 9,000 days from 1976 to 2009 (Fig. 1) (JAMRC 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1991, 1992, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009). Every sampling was conducted by automatic jigging machines. The number of jigging machines was 20 to 40.

2. Oceanographic data

The reanalysis data used were developed mainly by the University of Maryland, and model data have been available since 1980. Simple Ocean Data Assimilation ocean / sea ice reanalysis (SODA) was used. SODA uses a simple architecture based on community standard codes with a resolution selected to match available data and scales of motion that are resolvable (Carton et al. 2018a, 2018b, 2019). The native interlaced horizontal velocity and conserved tracer (e.g., temperature and salinity) grids form a tripolar Arakawa-B grid, varying from 0.1° × 0.25° at high latitude to 1/4° × 1/4° in the tropics (quasi-isotropic grid spacing increases from ~11.7 km at 65 latitude to ~28.0 km at the equator, 1,440 × 1,070 grid points).

To know the essential phytoplankton values, we use the visible satellite SeaWiFS data (Ocean color data 2022). We refer to the field salinity data using MOAA GPV salinity data (Hosoda et al. 2008)

3. Field research

To verify compatibility with *O. bartramii* habitat estimated from the statistical model data, while commercial fishing, fishing lamps (300 kW-400 kW) were operated at night and an underwater fishing lamp (5 kW) was operated during the day, as for the large squid fishing boat No. 30 *Kaiyo Maru* (gross tonnage: 349), a field survey was conducted from April to September 2018 using this fishing vessel equipped with 58 automatic fishing machines. The survey was conducted along 20°N, from 160°E to 140°W in the northern Pacific, excluding

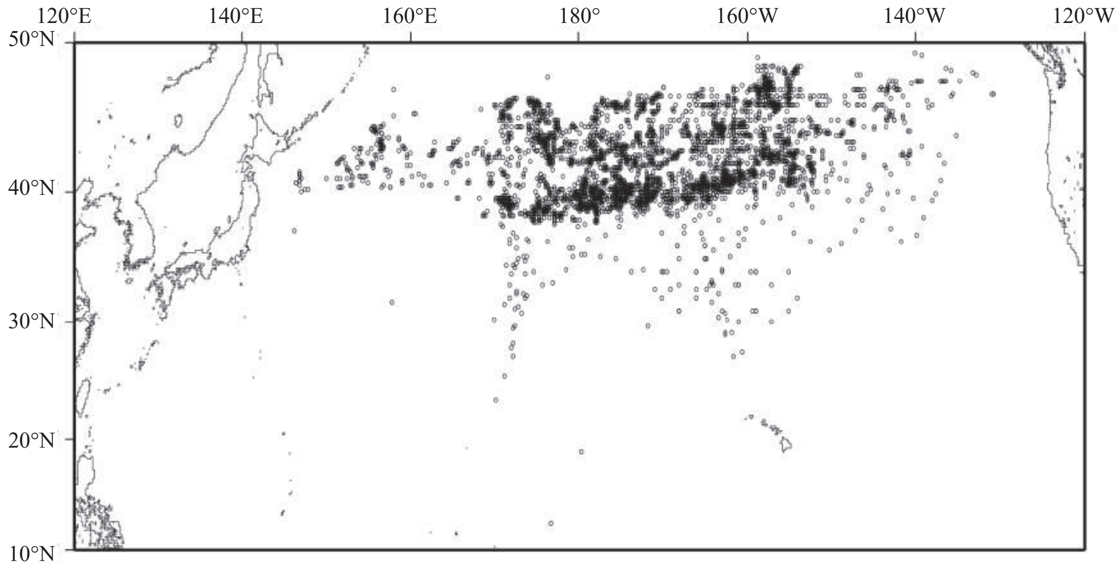

Fig. 1. Distribution of field survey data (1976-2009)
Dots indicate survey points.

foreign exclusive economic zones. The area was divided into six sub-areas (A to F) at intervals of 10° longitude (Fig. 2). A round-trip survey was conducted, and the results were used to verify the model. During this cruise, vertical temperature and salinity profiles at all survey points were measured with CTD (RINKO-profiler, JFE Advantech Co., Ltd.).

4. Statistical analysis

A generalized linear model (GLM) analysis was used to clarify habitat differences, year effect, and lunar phase effects in eastern and western regions of the species. Specifically, we used the GLM model to clarify whether differences in habitat were observed on each side of 170°E, which was selected based on an annual summary of the North Pacific Fishing Commission (NPFC 2020). We use log offset GLM, because a response variable prevents a fractional expression (Shouno 2008). The formula used for the model is as follows:

$$Catch_n \sim factor\ (year) + factor\ (month) + factor\ (moon) + factor\ (ew) + SST + T50 + T100,\ offset = log\ (effort),\ poisson\ (link = log) \qquad (1)$$

where the response variable $Catch_n$ indicates the number of fish caught, *year* indicates the year, *month* indicates the month, *moon* indicates the phase category depend on moon age (0 to 5, 5 to 10, 10 to 15, 15 to 20, 20 to 25 and 25 to 30), *ew* indicates east and west divided 170°E, *SST* indicates the sea surface temperature, *T50* indicates water temperature at 50 m depth and *T100* indicates water temperature at 100 m depth. *effort* is calculated by number of machines and operation time. Whereas nominal catch (number of squid) acted as response variable while effort was included in the models as an offset caught following the previous study (Shouno 2008, Setayadji et al. 2018). Variable selection was performed using Akaike's Information Criterion (Akaike 1974).

To the east of 170°E, the formation of fishing grounds from April to September during the main fishing season was examined using a generalized additive model (GAM). with this latitude being the main fishing ground of this species in summer. As the data were compiled every two months and a model was created, when these models are examined monthly, the amount of data is insufficient and accurate estimates are difficult. And parameters were chosen by former GLM model. The formula used for the model is as follows:

$$CPUE \sim factor\ (moon) + s\ (SST) + s\ (T50) + s\ (T100) + s\ (lat) \qquad (2)$$

where *CPUE* indicates catch per unit effort. *CPUE* is calculated by total catch number by fishing time and number of automatic jigging machine. *Lat* indicates latitude. Using equations 2, the relationship between environmental parameters, such as lunar phase and water temperature and the formation of fishing grounds was clarified.

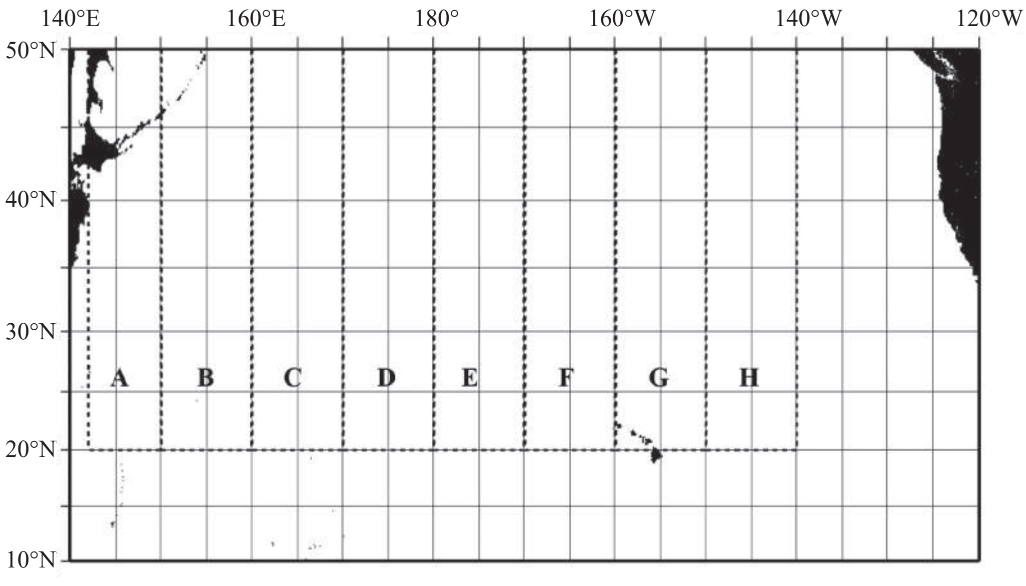

Fig. 2. Field survey area in 2018
Dotted lines delimit separate survey areas.

Results and discussion

Variable selection using the AIC was performed for the GLM variables. Since all of the variables were significant ($P < 0.05$), they were adopted in the model (Table.1). The results showed that the habitat index of this species differs on either side of 170°E, and that the catch was low for the 6 days immediately preceding the full moon.

Figure 3 shows the results of the GAM model. From these results, it was found that it is difficult to clearly define optimal habitat with the surface water temperature, SST, and the water temperature at 50 m from April to May and June to July, because there are no peaks. On the other hand, GAM result on August to September, showed that the observed peak of SST is about 20°C and peaks of water temperature at 50 m are about 5°C and 10°C.

The GAM model was recalculated using SODA model in the field. As a result, it was observed that the estimated habitat moved northward from April to August and converged with the SAFZ (Fig. 4). The SAFZ is a thermohaline structure across the North

Table 1. Analysis of deviance and summary table of GLM model

	Estimate	Std. Error	z value	Pr (>|z|)	
(Intercept)	−6.36	0.03	−245.17	< 2.00E-16	***
factor(Year)1977	−0.89	0.00	−294.82	< 2.00E-16	***
factor(Year)1978	−0.72	0.00	−363.79	< 2.00E-16	***
factor(Year)1979	−0.26	0.00	−70.437	< 2.00E-16	***
factor(Year)1980	0.72	0.00	204.149	< 2.00E-16	***
factor(Year)1981	−0.85	0.01	−150.98	< 2.00E-16	***
factor(Year)1982	−1.18	0.00	−345.97	< 2.00E-16	***
factor(Year)1983	−4.35	0.03	−164.52	< 2.00E-16	***
factor(Year)1991	−0.96	0.01	−66.703	< 2.00E-16	***
factor(Year)1996	−1.50	0.01	−279.71	< 2.00E-16	***
factor(Year)1997	−1.01	0.00	−242.47	< 2.00E-16	***
factor(Year)1998	−0.38	0.00	−97.473	< 2.00E-16	***
factor(Year)1999	−0.92	0.00	−227.11	< 2.00E-16	***
factor(Year)2000	−0.63	0.00	−162.12	< 2.00E-16	***
factor(Year)2001	−0.95	0.00	−213.28	< 2.00E-16	***
factor(Year)2002	−1.53	0.01	−266.35	< 2.00E-16	***
factor(Year)2003	−1.76	0.01	−283.32	< 2.00E-16	***
factor(Year)2004	−1.29	0.00	−292.13	< 2.00E-16	***
factor(Year)2005	−1.33	0.00	−275.41	< 2.00E-16	***
factor(Year)2006	−1.02	0.00	−254.41	< 2.00E-16	***
factor(Year)2007	−0.81	0.00	−229.54	< 2.00E-16	***
factor(Year)2008	0.29	0.01	53.379	< 2.00E-16	***
factor(Year)2009	0.52	0.01	81.985	< 2.00E-16	***
factor(Month)2	−1.21	0.06	−19.733	< 2.00E-16	***
factor(Month)4	1.30	0.09	14.298	< 2.00E-16	***
factor(Month)5	2.67	0.02	108	< 2.00E-16	***
factor(Month)6	3.01	0.02	121.916	< 2.00E-16	***
factor(Month)7	3.03	0.02	122.586	< 2.00E-16	***
factor(Month)8	3.18	0.02	128.158	< 2.00E-16	***
factor(Month)9	3.02	0.02	121.685	< 2.00E-16	***
factor(Month)10	3.08	0.02	123.586	< 2.00E-16	***
factor(Month)11	3.25	0.03	129.312	< 2.00E-16	***
factor(Month)12	2.57	0.03	101.539	< 2.00E-16	***
factor(EW)2	−0.66	0.00	−220.2	< 2.00E-16	***
factor(Moon_c)2	−0.05	0.00	−31.848	< 2.00E-16	***
factor(Moon_c)3	−0.29	0.00	−153.07	< 2.00E-16	***
factor(Moon_c)4	−0.05	0.00	−28.795	< 2.00E-16	***
factor(Moon_c)5	−0.02	0.00	−13.785	< 2.00E-16	***
factor(Moon_c)6	0.00	0.00	−2.6	< 0.00932	**
SST	0.11	0.00	292.163	< 2.00E-16	***
T_50	−0.04	0.00	−89.218	< 2.00E-16	***
T_100	0.00	0.00	4.194	< 7.40E-04	***

Signif. Codes: 0***, 0.001**, 0.01*

Pacific, separating colder, fresher water to the north from warmer, saltier water to the south (Yuan & Talley 1996). While it is indicated that the chlorophyll concentrations are increasing to the boarder SAFZ, Figure 5 shows the chlorophyll concentrations measured at different latitudes based on SeaWiFS data. And SAFZ is a known habitat of numerous fish species, such as swordfish *Xiphias gladius* and Pacific pomfret *Brama japonica* (Seki et al. 2002). Oenologically SAFZ is characterized by having a surface salinity in the range of 33.0 to 33.8 psu (Roden 1991).

According to the 2018 survey data and MOAA GPV salinity data, the latitude of the SAFZ differs to the east and west of 170°W in April, and the southern edge of the subarctic front is located at 40°N (Fig. 6). A frontal structure extending southward was observed in this eastern region. This east-west difference in position of SAFZ was observed in all months during the survey period, but the magnitude of this difference decreased over time. From April to June, the survey was conducted on the southern side of the front, and from July, the survey was conducted on the inside, or northern side of the front. Suggesting that the fishing ground formed to the north of the front, in August, the catch was higher on the northern side of the front compared to that on the southern side. Taken together, the findings indicate that the distribution of the SAFZ, where there has been almost no record of fishing by commercial vessels, can be used as an indicator of neon flying squid fishing grounds in August. Further, it is expected that female neon flying squid will grow and mature in this area and that they will balance their feeding needs and environmental water temperature requirements in this region of high primary production until the spawning season when they will migrate southward.

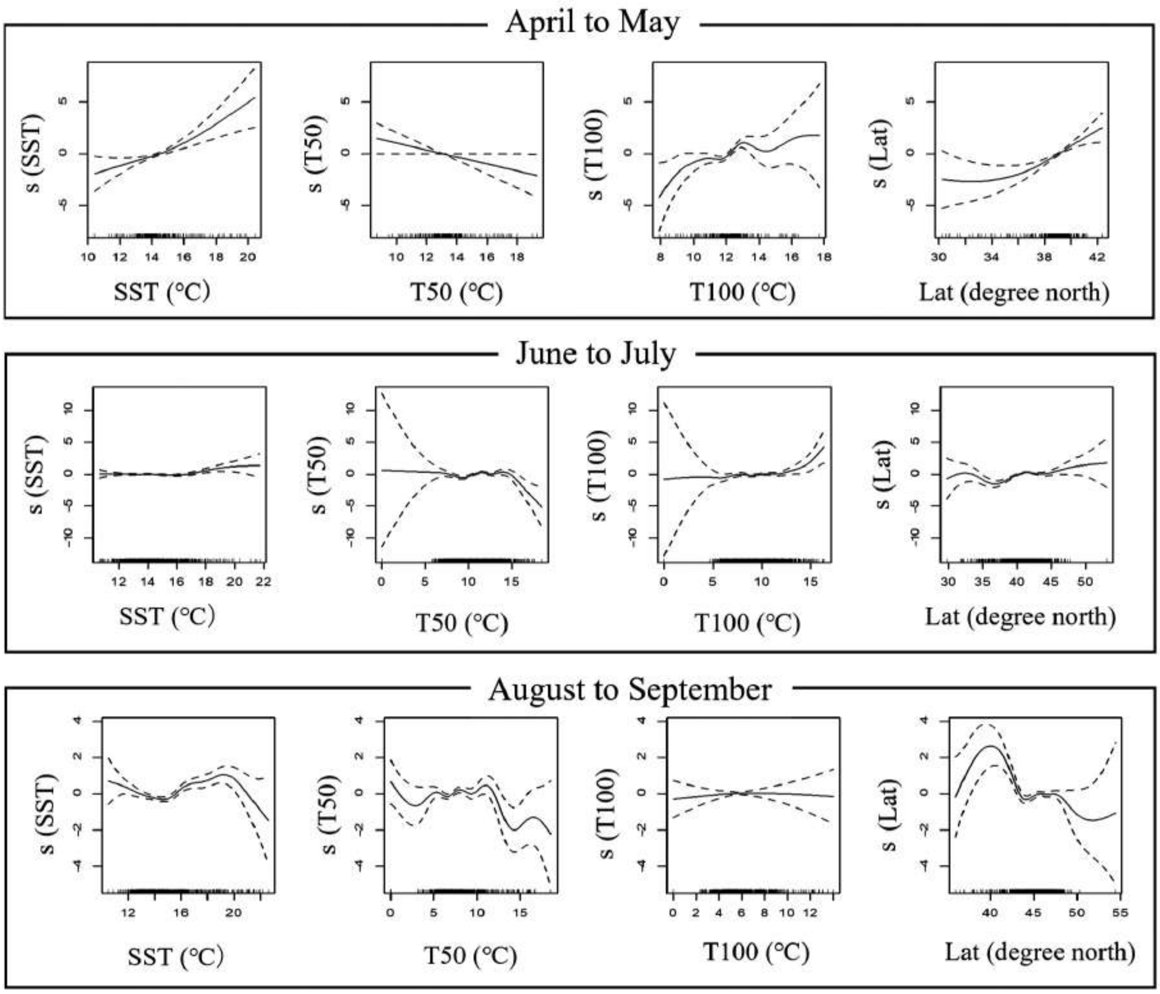

Fig. 3. Model fits
Smoothed curve showing the additive effect of the estimated habitat of *O. bartramii* for the individual environmental parameters in the GAM. Dotted lines represent 95% confidence intervals, small vertical bars along the lower axis represent single observations.

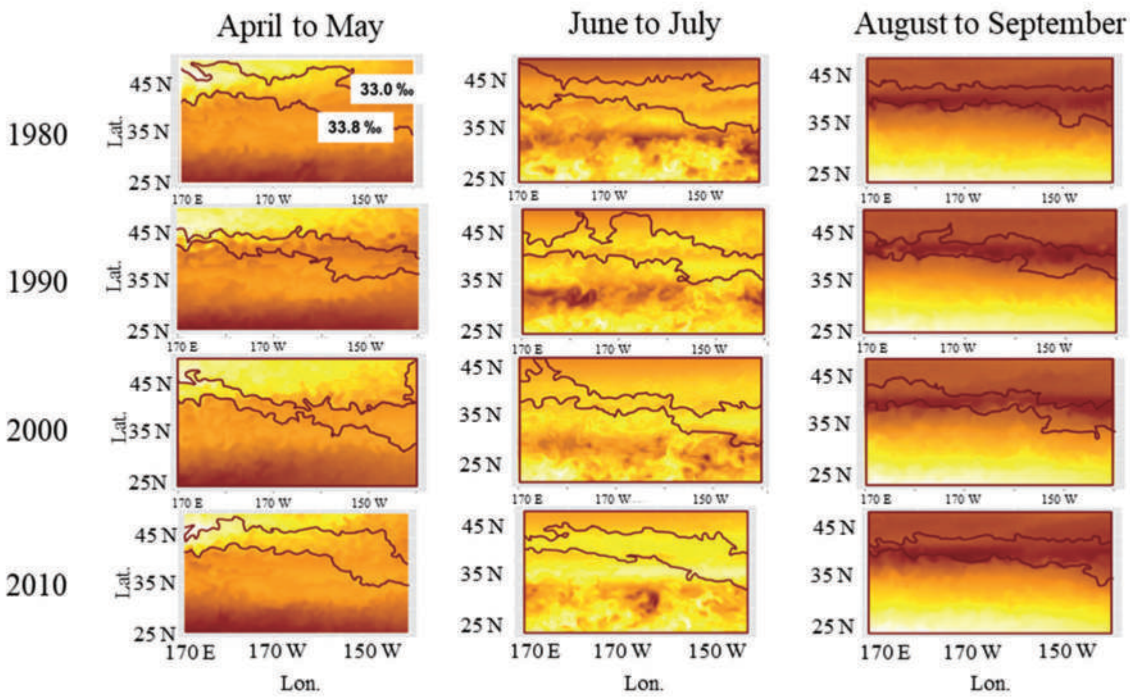

Fig. 4. Habitat model

Where light yellow showed low potential, dark yellow showed higher potential areas. Upper layers showed models in 1980, second layers showed models in 1990, third layers showed models in 2000, 4th layers showed models in 2010. Bold lines indicated SAFZ boundary based on salinity 33.0 psu and 33.8 psu.

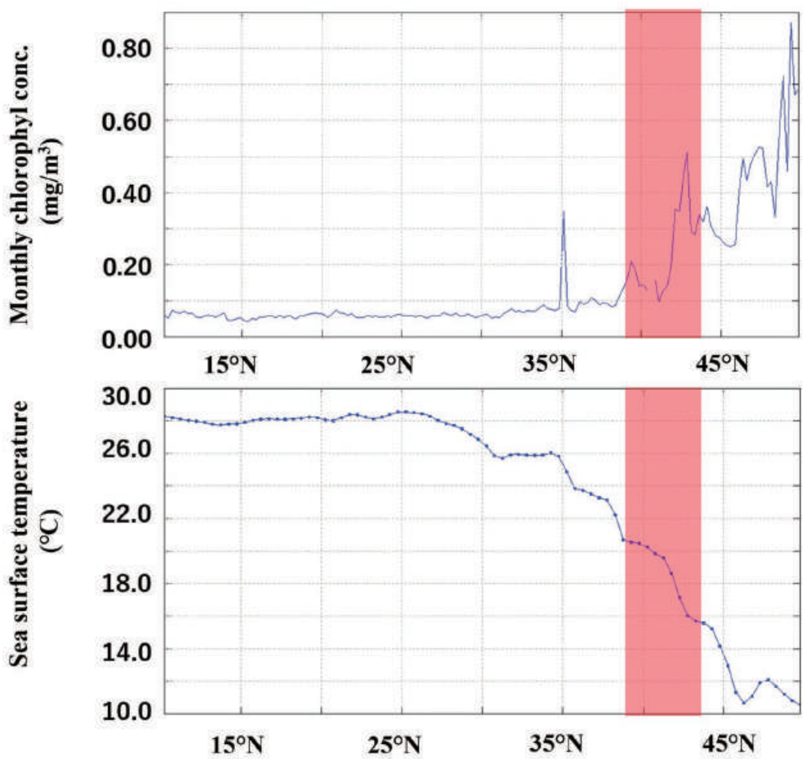

Fig. 5. Latitudinal profiles of (a) Monthly chlorophyll concentration gradient in August and (b) sea surface temperature gradient in August

The red box indicates approximate position of SAFZ.

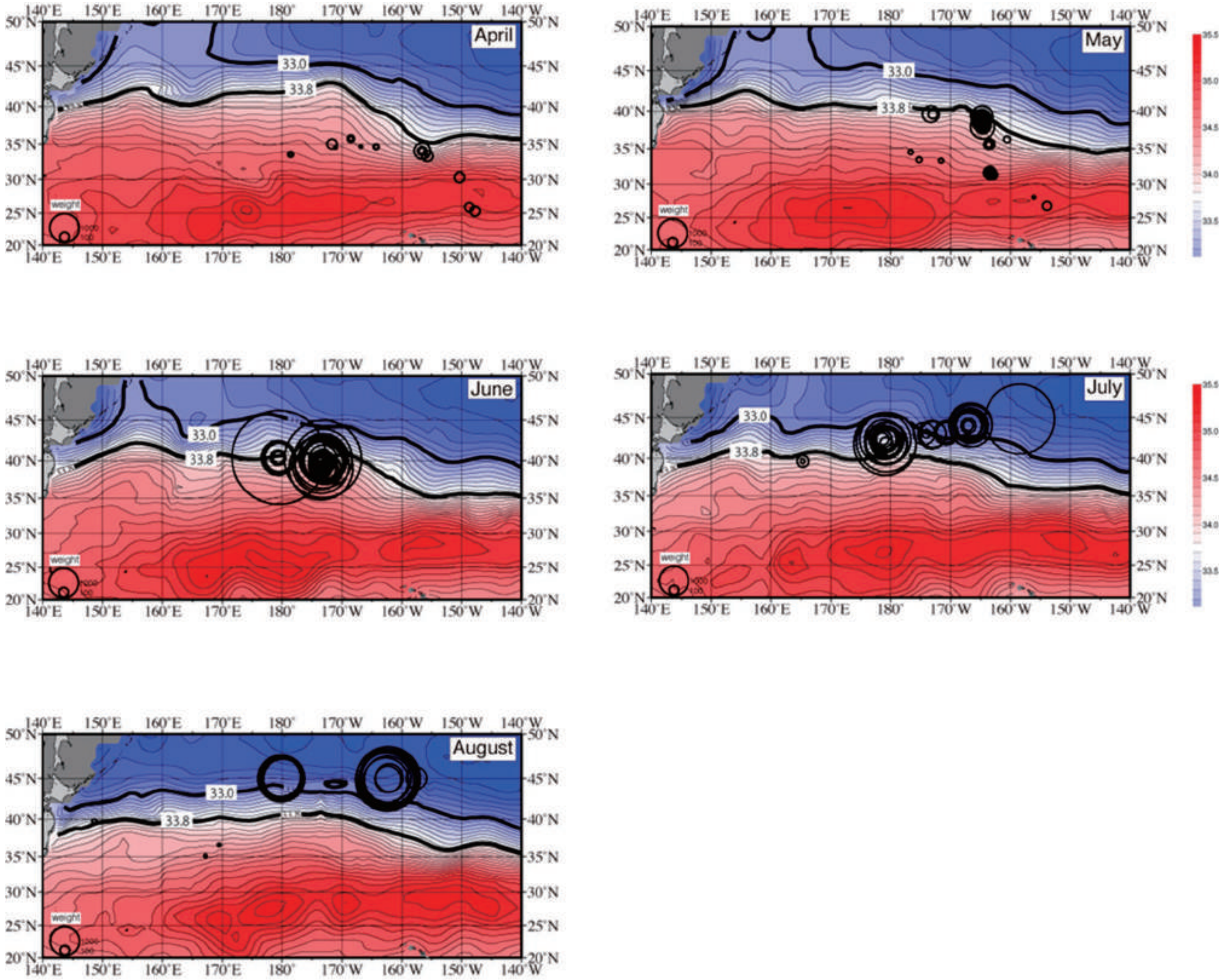

Fig. 6. Geographical distribution and catch size of *O. bartramii* in 2018 recorded during survey
Background indicated salinity from MOAA GPV. Bold lines indicated salinity 33.0 psu and 33.8 psu.

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