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Updating analyses for relationship between bigeye tuna catch and school type of Japanese purse seine fishery

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Title
Updating analyses for relationship between bigeye tuna catch and school type of Japanese purse seine fishery

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Abstract
As part of approaches to reduce bycatch of bigeye tuna by Japanese purse seine on FAD, relationship between bigeye catch and school type was investigated. The survey is corresponding to CMM2008-01 Paragraphs 25 and 26 (Juvenile Tuna Catch Mitigation Research). This is updating analysis for previous study in SC8 and newly concerned for the effect of oceanographic conditions. The catch information was collected from log book and market slip (fish unloading data). The vessels have targeted both free school and associated school from the beginning, and the proportion of number of set with free school had been about 40% with some annual fluctuation from 2002 to 2009. The proportion of free school suddenly have increased in 2010 and reached to around 80%. At the same time the catch amount of small sized tuna species (bigeye, yellowfin and skipjack) and large sized bigeye tuna were decreased. Generalized additive model analysis (GAM) was applied for investigating the relationship between amount of catch for tuna species (bigeye, yellowfin and skipjack), school type, purse seine mesh size and oceanographic conditions (sea temperature, mixing layer depth, eddy kinetic energy (EKE) and standard deviation of horizontal current velocity). GAM analysis accounted for 48-57% and 22-37% of the variance in catch per set for small and large sized tuna species (bigeye, yellowfin and skipjack), respectively. After considering effect of oceanographic conditions, the effect of school type (ratio of log associated set per cruise) showed strong impact on catch per set especially in small sized tuna species.

Introduction
As part of approaches to reduce bycatch of bigeye tuna by Japanese purse seine on FAD, relationship between bigeye catch and school type are investigated. The survey is corresponding to CMM2008-01 Paragraphs 25 and 26 (Juvenile Tuna Catch Mitigation Research).

Japanese purse seine started to operate sporadically in tropical area (from 20˚N to 20˚S) of the western and central Pacific Ocean in 1970s. The number of Japanese purse seine vessels operated in tropical area gradually increased and reached to 32 in 1983, to 35 in 1996 and has not changed after that (Japan Far Seas Purse Seine Fishing Association 2004). The vessels have targeted both free school and associated school from the beginning, and the proportion of number of set with free school had been about 40% with some annual fluctuation from 2002 to 2009. The proportion of free school suddenly have increased in 2010 and reached to around 80%. At the same time the catch amount of small sized tuna species (bigeye, yellowfin and skipjack) and large sized bigeye tuna were decreased. These remarkable changes are considered as the response to the high sea pocket closure and three month FADs closure introduced since 2010. The aims of the present study were (1) to updating of information about catch by school type of Japanese purse seine in tropical area reported in previous study (Satoh et al 2012) and (2) to discuss the relationship between these species catch and school type in consideration of several oceanographic conditions.

Materials and methods
Data collection
Material and method is almost same in the previous study (Satoh et al 2012) except for collecting data set of oceanographic condition. Data of the species composition in weight by fish size, school type and fishing area for each cruise with information about purse seine mesh size were collected by logbook, market slip (fish unloading data) and historical purse seine mesh information from 2002 to 2012. The catch and effort data in 2012 is nearly final but preliminary.

Logbook data: The number of set by school type and fishing location for each cruise recorded in logbook was used. The fishing location was average location in longitude and latitude for each cruise.

Market slip: The species composition in weight by fish size for each cruise was collected from market slip (amount of landing by market category; **Appendix Table 1**) in major three Japanese ports (Yaizu, Makurazaki and Yamagawa), where these vessels landed more than 95% of their catch from the tropical area of the Pacific Ocean. The data landed catch in other ports were excluded for the analysis. The market categories in the three markets are classified to small fish and large fish. The criteria of the class for skipjack, yellowfin and bigeye are 1.8 kg, 2.5 kg (or 3.0 kg) and 2.5 kg (or 3.0 kg).

Purse seine mesh size: The information of historical purse seine mesh size was collected by interview from fisherman and industrial fishing company in corporation with Japan Far Seas Purse Seine Fishing Association. The main part of purse seine is composed of different mesh size between float line to sinker chain, therefore we collected the vertical composition of net depth for every mesh size by vessel and the temporal changes of the composition since 2002, and then we assembled the maximum mesh size for each cruise of each vessel.

Oceanographic conditions: We used GODAS data (NCEP Global Ocean Data Assimilation System), which is provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/. Four oceanographic conditions were selected in this study, that is, sea temperature (K; ST), mixing layer depth (m; MD), eddy kinetic energy (m^2/s^2; EKE) and circular standard deviation for horizontal current (m/s; CSD, Arai 2011). The original data are provided by month, 1 degree longitude and 20 minutes latitude. In this study, the data set was compiled as 1 degree by 1 degree for each month from January 2007 to December 2012. EKE and CSD was not directly provided in the GODAS dataset, which was calculated from UVX (velocity for north-south direction) and VVY (velocity for east-west direction) as follows. EKE = $0.5*UVX^2+VVY^2$ (Cheng & Qi 2010). CSD was also calculated using the method described in Arai (2011). EKE can be used as a measure of the strength of mesoscale variables, mesoscale eddy, jets, front and so on (Cheng & Qi 2010). All data except for MD were provided for each specific layer, therefore ST were averaged from 5 m depth to 262 m depth in water column, and EKE and CSD were averaged from 5 m depth to 282 m depth in water column. These depths are slightly larger than maximum depth of purse seine reaching in operation. Thus, ST, EKE and CSD in this study are considered to show representativeness for environmental conditions fish encountered during operation.

Data analysis

The generalized additive model analyses (GAM) assessed effects of school type on catch amount of fish by species and body size per set (catch per set) using mgcv-package of R software (ver. 3.0.1, R core Team 2013). We selected for log book and market slip dated from 2007 to 2012 in order to balance number of data between two year groups (2007-2009, 2010-2012). For cruise based, landing year groups, landing month (1-12), ratio of associated school, maximum purse seine mesh size (mm) and four oceanographic conditions mentioned above in detail were used as main explanatory variables, and interaction of latitude and longitude was also considered. To stabilize the variance, natural log-transformations were conducted for independent variables. The full model of GAM analysis is as follows;

Log [catch per set] = Intercept + landing year group + s (landing month) + s (ratio of associated school in a cruise) + s (maximum mesh size of purse seine)+ s (ST) +s (MD) + s (EKE) + s (CSD) + s (interaction of latitude and longitude)

where error ~ normal $(0, \sigma^2)$, s (X) denotes a spline smoother function of the covariate X. Landing year groups effect are treated as a parametric function because there are only two year groups. Smoothing parameter was estimated by generalized cross-validation. Method of all possible combinations were applied for selecting final model, which represent lower AIC (Akaike's Information Criterion), and all determinants in the final mode were significant. Distribution of residuals and qq-plot were used for diagnosis for assumption of error distribution (**Appendix Figs. 1- 3**).

When the catch per cruise is zero, these data were omitted from the analysis. Total number of cruise without unusual low catch less than 100 metric ton landing per cruise was 1443, and the number of cruise with zero catch for small bigeye, large bigeye, small yellowfin, large yellowfin, small skipjack and large skipjack is 969, 34, 61, 4, 25 and 0, respectively. It is needed to pay attention to the high ratio of zero catch (969 cruises / 1447 cruises) for the small bigeye group when the results are interpreted.

Results and Discussions

Fishing ground, number of set by school

The fishing ground of Japanese purse seine vessel in tropical area of western central Pacific Ocean widely distributed in east and west. They concentrated to operate mainly in western area such as economic exclusive zone (eez) of Papua New Guinea, Federated States of Micronesia, Solomon Islands, Republic of Nauru and high seas after 2006 (**Fig. 1**). After 2010 they had not fished in the high seas surrounded by these eez areas by fishery management regulation in WCPFC (CMM2008-01) and other regulation. This is principle reason why there was high density of effort in these eez zones (PNG, FSM, Solomon Islands and Nauru) since 2010. In 2012 some of vessel moved to east and operated in eez of Kiribati, which may relate to limitation of VD (Vessel Day) in other eez. The proportion of number of set with free school had been about 40% with some annual fluctuation from 2007 to 2009, and suddenly has increased in 2010 and 2011, and reached to 84.4 % and 81.2%, respectively. In 2012, the proportion was 74.3%. The total number of set gradually increased 4,000 to 5,000 sets through 2002 to 2009, and then rapidly increased in 2010 and reached to more than 7,000 in 2011, decreased to 6,300 in 2012 (**Fig. 2**). After 2010, the catch of small sized tuna in three species and large bigeye decreased comparing previous three years (2007-2009), on the other hand large skipjack and yellowfin increased (**Fig. 3**). The annual changes of number of set by maximum mesh size showed that purse seine with larger mesh size was gradually introduced since 2004 and the proportion of set using more than 300 mm mesh was nearly 60 % in 2012 (**Fig. 4**). The proportion of set using lager than 360 mm mesh also had increased since 2009.

Influence of various factors on fishery performance

All final models for six size-species categories contained fishing ground effect (longitude and latitude), seasonal effect (month) and school type effect (ratio of associated school in a cruise) as highly significant determinant (P< 0.001). The school type effect for small category of all three species showed highest F-value (**Tables 1-3**), which indicated that school type had strongest impact for amount of catch per set of small fish. Adjust r-square for smaller categories showed higher values (0.48-0.57) than larger category (0.22-0.37). Scale estimates except for large skipjack were nearly 1.0 (1.06-1.53), which indicated that there was no overdispersion. However for large skipjack showed small value (0.36). Distribution of residuals for large yellowfin large and skipjack skewed right (**Appendix Figs 1-3**), partially because of unusual low catch. Further investigations for model specifications were needed for large yellowfin and large skipjack. However the assumption of error distribution was satisfied for small sized fish especially in small bigeye tuna, because of normal error distribution for these categories.

There were clear positive relationship between the ratio of log set and catch for all categories (**Figs. 5-10**), although it showed relatively weak relationship for large yellowfin and large skipjack (**Figs. 8, 10**). For small skipjack and small bigeye, there were inflexion points around 0.4. Rapid increases of catch per set for these size-species were detected before 0.4. The limitation for the ratio under 0.4 may be effective solution for reducing small bigeye tuna.

Sea temperature presented significant effect but species specific effect on catch per set for all categories except for small skipjack. Only for small bigeye it showed positive relationship between sea temperature and catch per set, whereas for remain four categories there were negative relationships. Although EKE showed significant effect and extremely high EKE (> 4 m^2/s^2) always resulted in lower catch except for small skipjack and small yellowfin, typical EKE (<4 m^2/s^2) show smaller impact for catch per set (**Figs 5-10**). Thermocline is considered to affect vertical movement and distribution of fish. Typical MD distributed from 40 to 100 m depth, which is central depth of purse seine net depth. Therefore MD is assumed to have effect on availability of fish. Effect of MD were significant in some cases, it presented slightly U-shape, that is, moderate mixing layer depth reduced availability of fish for bigeye (**Figs 5, 6**). The effect of MD showed positive relationship linearly in large skipjack. For these three categories in deep range the effect of MD increased, however large MD (deeper mixing layer) is assumed to allow fish distributing widely in vertical, which result in reducing availability of fish. There is difference of the effect between these two species in shallower range. Mixing depth layer might not good indicator for representing vertical movement of tuna species. We need for further investigation for the effect of MD. CSD is considered as the variation in horizontal sea water movement in water column. Larger CSD means that there is a number of current with different direction in a water column. The CSD in magnitude is assumed to effect on fishing efficiency. The effect of CSD was species and size specific. Catch per set reasonably decreased with increasing CSD for large yellowfin and small skipjack. However for small bigeye and large skipjack the effect of CSD did not show such changes.

Although the confidence interval was large for larger mesh size (> 360 mm), the purse seine mesh size presented significant negative effect for small sized yellowfin (**Fig. 7**), which is not reported in previous study (Satoh et al 2012). Such negative relationship suggests that using large mesh size is effective for reducing small sized yellowfin catch. Large mesh more than 360 mm had been gradually introduced for Japanese purse seine (**Fig. 4**). It is curious for the effect of purse seine mesh size of large skipjack, although the number of set using larger mesh size (> 360 mm) was scares,. The amount of catch per set for large skipjack, which is main component of Japanese purse seine, was smaller for >= 360 mm mesh than < 360 mm mesh (**Fig. 10**). The increasing of number of Japanese vessel using the large mesh may result from the ingenuity to operate more efficiently for the free school, that is, the net with the large mesh tend to sink faster. Large yellowfin is one of large component of free school set of Japanese purse seine. However the effect of mesh size for this category was not significant. Thus we need to continue to monitor and gather information about these purse seine mesh size.

Highlights

- In 2012, dominated of set for free school have been continued
- In 2012, introducing purse seine with larger mesh have been continued
- Generalized additive model concerning oceanographic conditions was applied
- After considering oceanographic conditions, the effect of school type showed strong impact on catch per set especially in small sized bigeye, yellowfin and skipjack

Acknowledgement: We would like to thank fish market stuffs for collecting data. We are also grateful to Japan Far Seas Purse Seine Fishing Association for their cooperation.

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Table 1. Results of generalized additive model (GAM). Effects of significant explanatory variables on catch amount of (A) small bigeye tuna, (B) large bigeye tuna, (C) small yellowfin tuna, (D) large yellowfin tuna, (E) small skipjack tuna, and (G) large skipjack tuna. edf is array of estimated degrees of freedom for the model terms. Ref. df is estimated residual degrees of freedom.

(A) small bigeye tuna

Parametric coefficients:

Source	Estimate	SE	t-value	p-value
(Intercept)	4.853	0.048	101	<0.001

Approximate significance of smooth terms:

Source	edf	Ref.df	F-value	p-value
long, lat	16.686	29	1.653	<0.001
month	5.734	9	2.824	<0.001
ratio of associated school	5.564	9	33.059	<0.001
ST	0.820	9	0.968	<0.001
MD	2.957	9	1.368	0.002
EKE	7.821	9	3.912	<0.001
CSD	3.028	9	0.778	0.043
adjust R^2	0.566	Deviance explained	60.50%	AIC = 1434.86
GACV score	1.196	Scale estimate	1.0957	n = 475
deviance	472.657			
degree of freedom of residual	431.390			

(B) large bigeye tuna

Parametric coefficients:

Source	Estimate	SE	t-value	p-value
(Intercept)	5.81106	0.03186	182.4	<0.001

Approximate significance of smooth terms:

Source	edf	Ref.df	F-value	p-value
long, lat	16.993	29	3.371	<0.001
month	6.046	9	3.144	<0.001
ratio of associated school	2.915	9	55.469	<0.001
ST	7.675	9	6.438	<0.001
MD	2.713	9	0.809	0.030
EKE	6.750	9	2.379	0.001
adjust R^2	0.374	Deviance explained	39.30%	AIC = 4548.32
GACV score	1.4752	Scale est.	1.0957	n = 1409
deviance	1952.381			
df.residual	1364.908			

Table 1. (Continue)

(C) small yellowfin tuna				
Parametric coefficients:				
Source	Estimate	SE	t-value	p-value
(Intercept)	6.49615	0.11947	54.374	<0.001
year	-0.25271	0.07797	-3.241	0.001
Approximate significance of smooth terms:				
Source	edf	Ref.df	F-value	p-value
long, lat	20.505	29	2.113	<0.001
month	6.198	9	11.45	<0.001
ratio of associated school	4.837	9	80.361	<0.001
maximum mesh size	3.809	6	3.655	<0.001
ST	7.84	9	3.138	<0.001
adjust R^2	0.548	Deviance explained	56.20%	AIC = 4137.19
GACV score	1.167	Scale estimate	1.1299	n = 1382
deviance	1510.492			
degree of freedom of residual	1336.811			

(D) large yellowfin tuna				
Parametric coefficients:				
Source	Estimate	SE	t-value	p-value
(Intercept)	8.8720	0.1145	77.4870	<0.001
yearf	-0.5330	0.0739	-7.2180	<0.001
Approximate significance of smooth terms:				
Source	edf	Ref.df	F-value	p-value
long, lat	13.463	29	12.045	<0.001
month	6.073	9	6.843	<0.001
ratio of associated school	6.703	9	3.301	<0.001
ST	7.294	9	13.933	<0.001
EKE	6.871	9	1.848	0.0104
CSD	3.05	9	2.186	<0.001
adjust R^2	0.351	Deviance explained	37.10%	AIC = 4270.02
GACV score	1.1367	Scale est.	1.1019	n = 1439
deviance	1535.503			
df.residual	1393.545			

Table 1. (Continue)

(E) small skipjack tuna

Parametric coefficients:

Source	Estimate		SE	t-value	p-value
(Intercept)	8.9033		0.1307	68.1170	<0.001
year	-0.7036		0.0844	-8.3370	<0.001

Approximate significance of smooth terms:

Source	edf		Ref.df	F-value	p-value
long, lat	23.228		29	4.061	<0.001
month	6.648		9	18.869	<0.001
ratio of associated school	4.7		9	38.795	<0.001
CSD	1.839		9	0.745	0.0172

adjust R^2	0.482	Deviance explained	49.50%	AIC = 4663.50
GACV score	1.5675	Scale estimate	1.5262	n = 1418
deviance	2105.516			
degree of freedom of residual	1379.584			

(F) large skipjack tuna

Parametric coefficients:

Source	Estimate		SE	t-value	p-value
(Intercept)	10.156		0.066	154.980	<0.001
yearf	-0.171		0.042	-4.040	<0.001

Approximate significance of smooth terms:

Source	edf		Ref.df	F-value	p-value
long, lat	15.037		29	1.425	<0.001
month	5.296		9	7.318	<0.001
ratio of associated school	5.017		9	3.402	<0.001
maximum mesh size	3.737		6	4.103	<0.001
ST	2.409		9	2.252	<0.001
MD	1.970		9	1.092	0.003
EKE	5.994		9	2.519	<0.001
CSD	3.009		9	0.802	0.039

adjust R^2	0.22	Deviance explained	24.30%	AIC = 2668.8
GACV score	0.372	Scale est.	0.36055	n = 1443
deviance	504.244			
df.residual	1398.530			

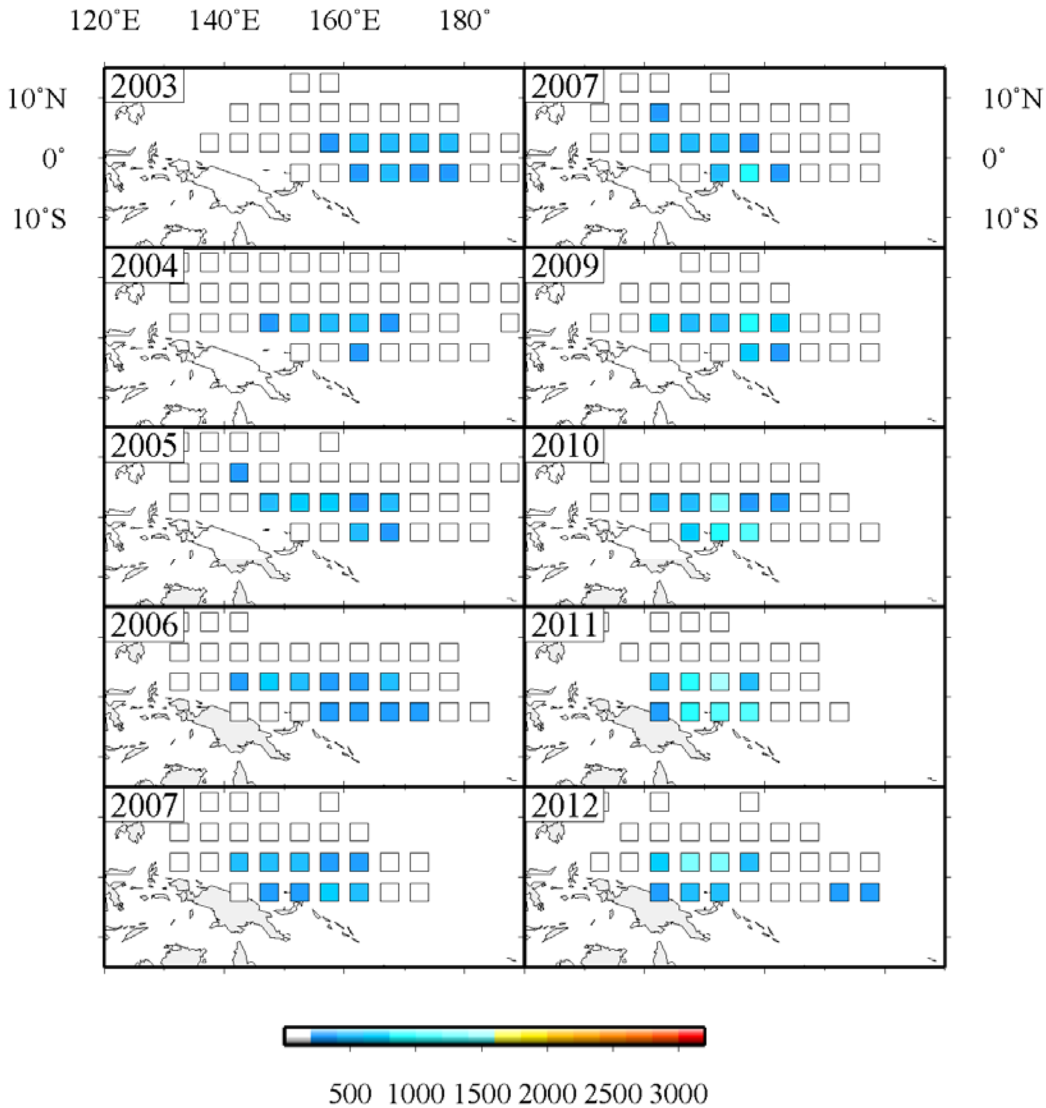


Fig. 1 Historical changes of fishing ground of Japanese purse seine in the tropical area of western and central Pacific Ocean. The legend is number of set.

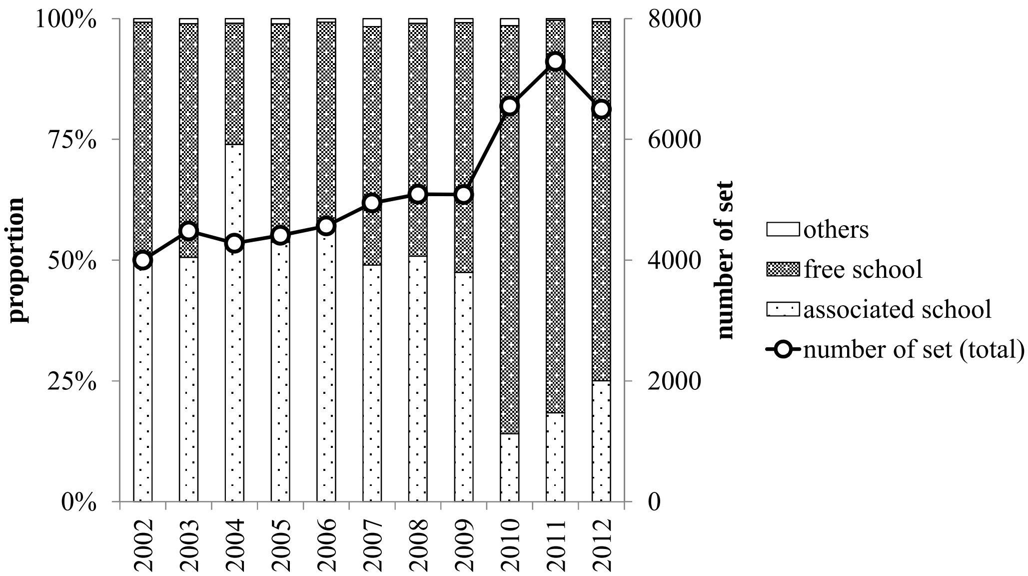


Fig. 2 Annual changes of number of set by school type of Japanese purse seine in the tropical area of western and central Pacific Ocean.

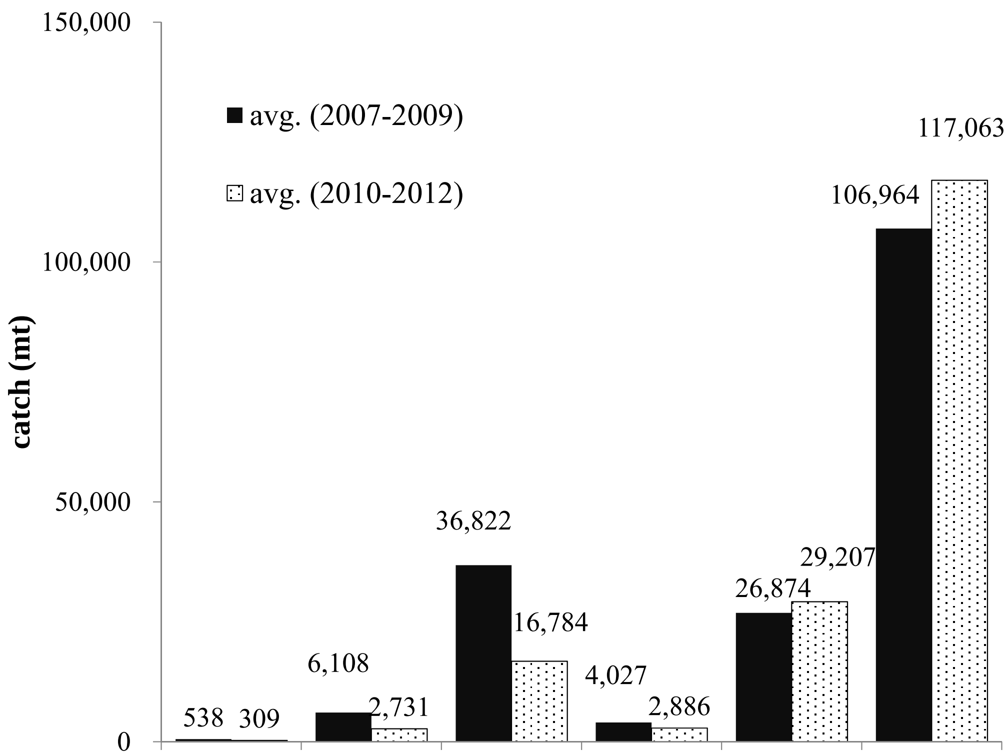


Fig. 3 Comparison of average catch by species and size between previous three years (2007-2009) and recent three years (2010-2012) of Japanese purse seine in the tropical area of western and central Pacific Ocean. The lower right panel shows. The criteria of the class for skipjack, yellowfin and bigeye are 1.8 kg, 2.5 kg (or 3.0 kg) and 2.5 kg (or 3.0 kg)

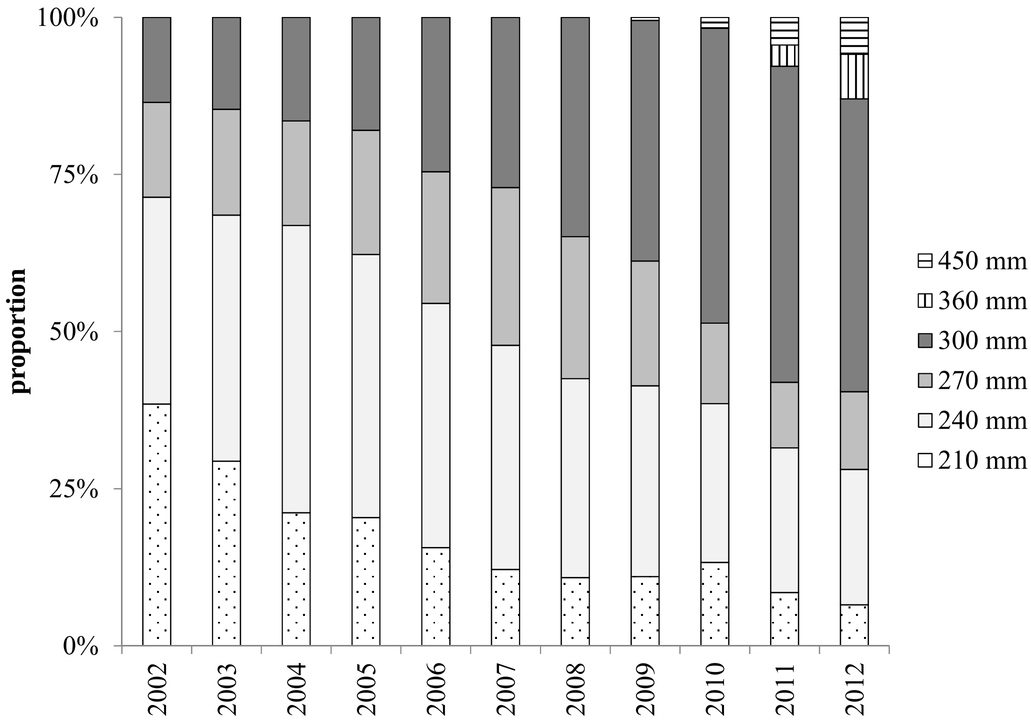


Fig. 4 Annual changes for proportion of number of set by maximum mesh size of Japanese purse seine in the tropical area of western and central Pacific Ocean.

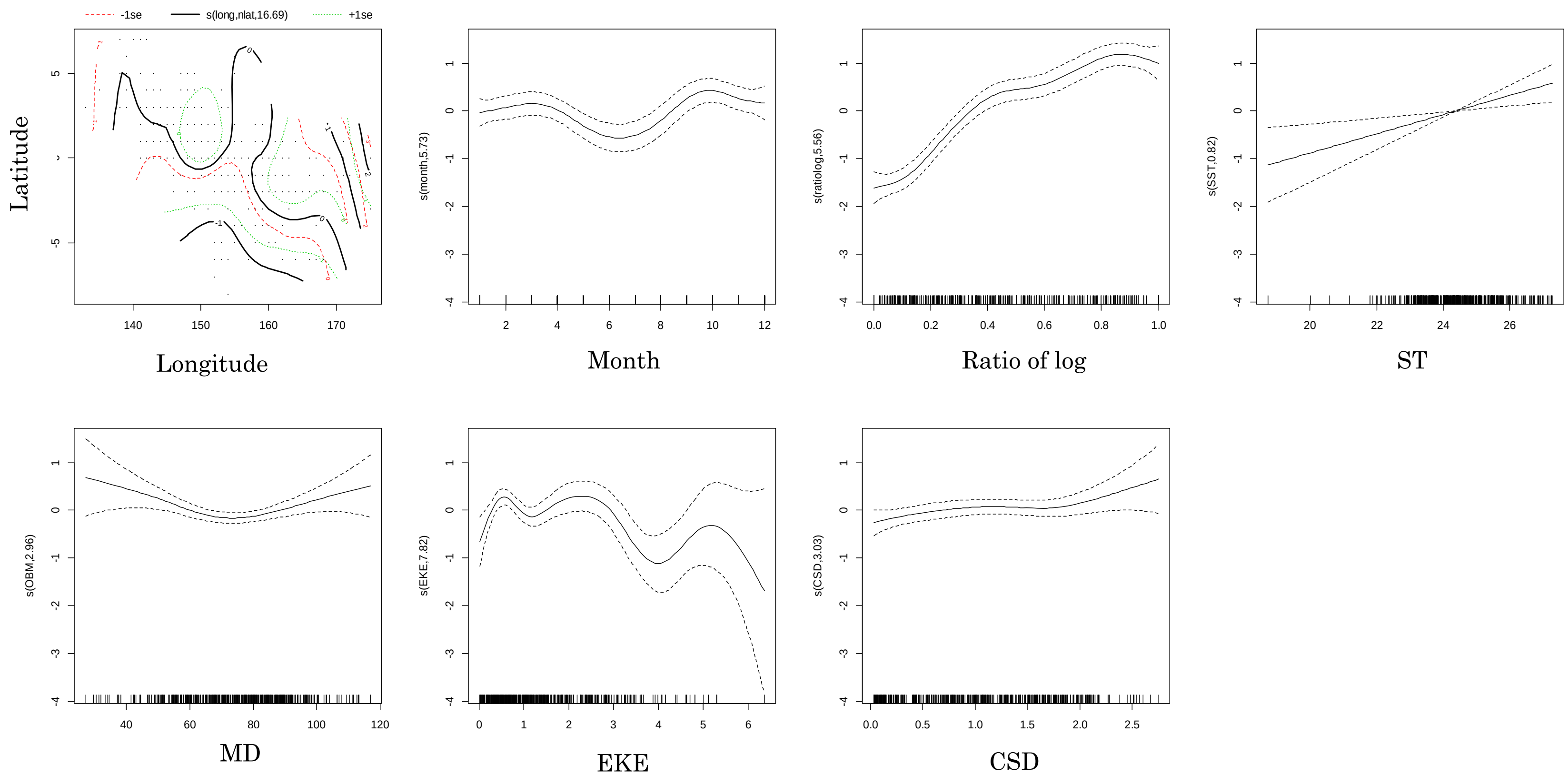


Fig. 5 Generalized additive model (GAM) derived effects of independent variables, latitude and longitude, landing year group, landing month, ratio of associated school in a cruise, oceanographic conditions (sea temperature (℃), mixing layer depth (MD; m), eddy kinetic energy (EKE; m^2/s^2) and standard deviation of EKE (CSD; m/s)) on catch amount of set (Log transformed) for **small sized bigeye tuna**. Dashed lines indicate ±1 se (standard error). The relative density of data points is shown by the vertical line on the x-axis.

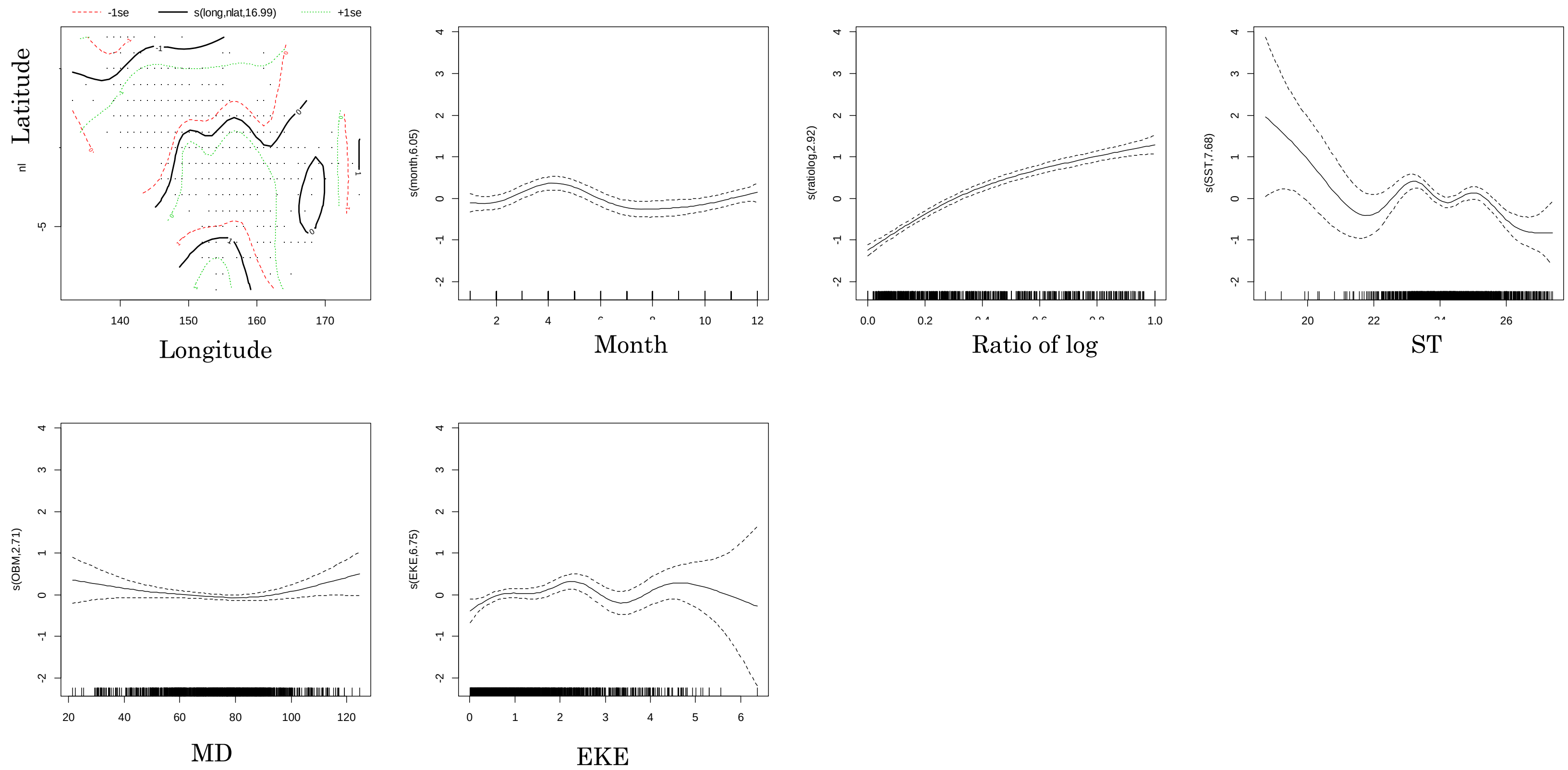


Fig. 6 Generalized additive model (GAM) derived effects of independent variables, latitude and longitude, landing year group, landing month, ratio of associated school in a cruise, oceanographic conditions (sea temperature (℃), mixing layer depth (MD; m), eddy kinetic energy (EKE; m^2/s^2) and standard deviation of EKE (CSD; m/s)) on catch amount of set (Log transformed) for **large sized bigeye tuna**. Dashed lines indicate ±1 se (standard error). The relative density of data points is shown by the vertical line on the x-axis.

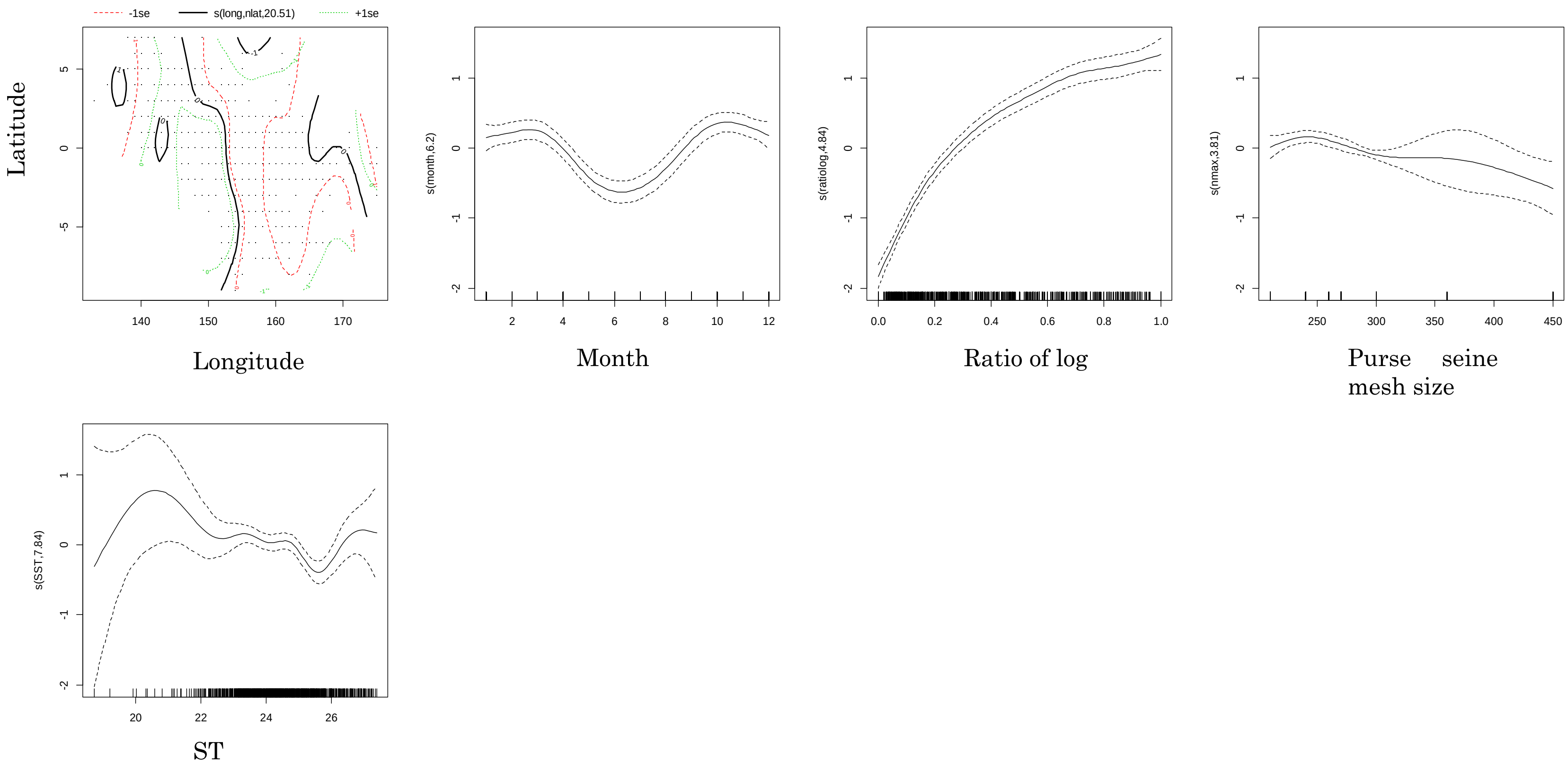


Fig. 7 Generalized additive model (GAM) derived effects of independent variables, latitude and longitude, landing year group, landing month, ratio of associated school in a cruise, oceanographic conditions (sea temperature (℃), mixing layer depth (MD; m), eddy kinetic energy (EKE; m^2/s^2) and standard deviation of EKE (CSD; m/s)) on catch amount of set (Log transformed) for **small sized yellowfin tuna**. Dashed lines indicate ±1 se (standard error). The relative density of data points is shown by the vertical line on the x-axis.

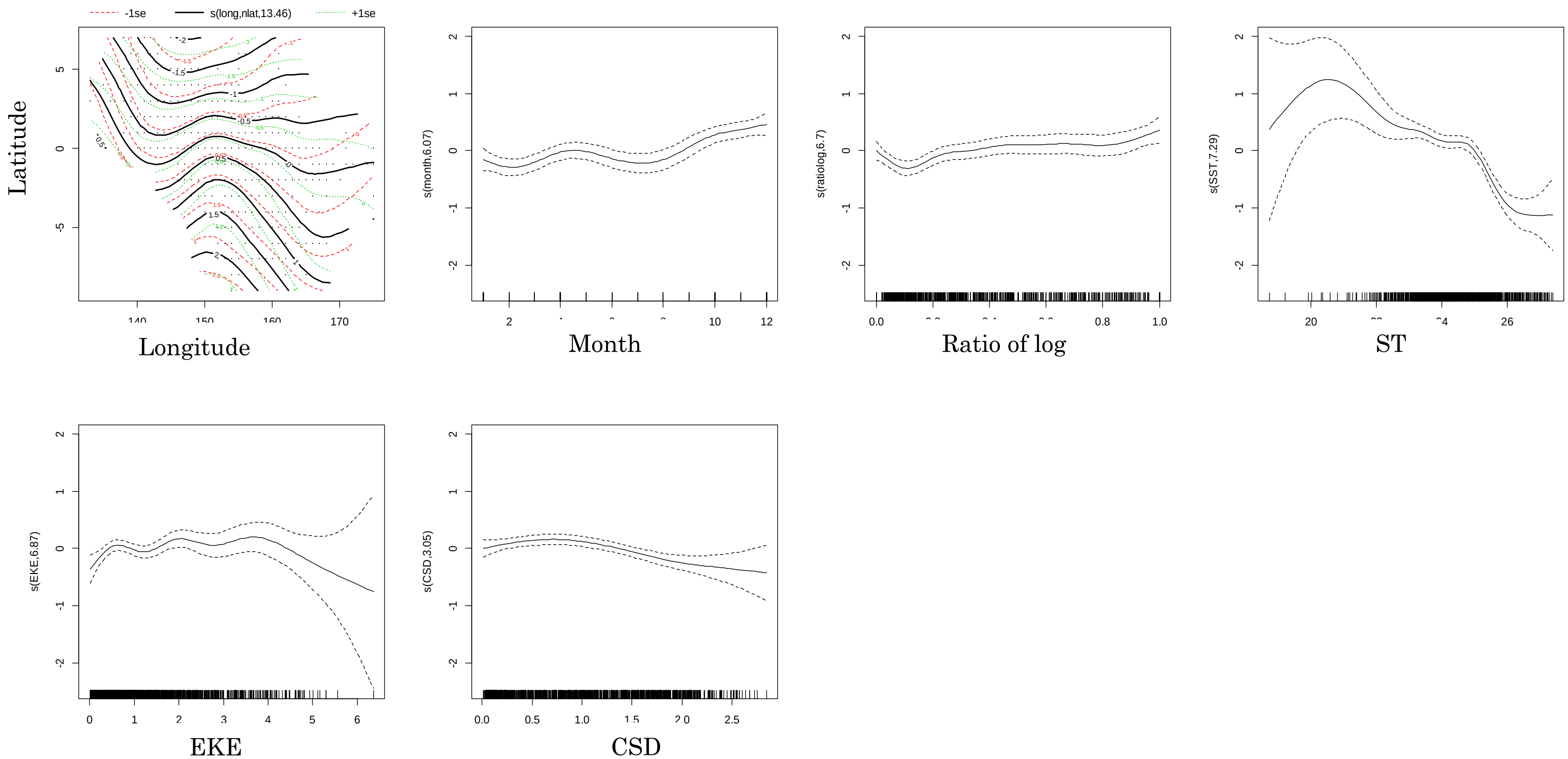


Fig. 8 Generalized additive model (GAM) derived effects of independent variables, latitude and longitude, landing year group, landing month, ratio of associated school in a cruise, oceanographic conditions (sea temperature (℃), mixing layer depth (MD; m), eddy kinetic energy (EKE; m^2/s^2) and standard deviation of EKE (CSD; m/s)) on catch amount of set (Log transformed) for **large sized yellowfin tuna**. Dashed lines indicate ±1 se (standard error). The relative density of data points is shown by the vertical line on the x-axis.

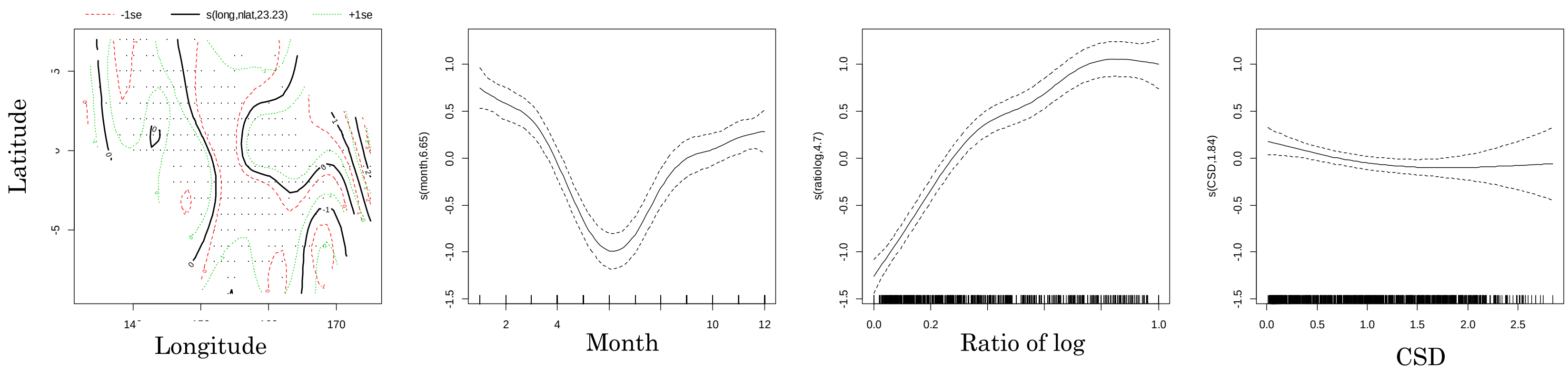


Fig. 9 Generalized additive model (GAM) derived effects of independent variables, latitude and longitude, landing year group, landing month, ratio of associated school in a cruise, oceanographic conditions (sea temperature (℃), mixing layer depth (MD; m), eddy kinetic energy (EKE; m^2/s^2) and standard deviation of EKE (CSD; m/s)) on catch amount of set (Log transformed) for **small sized skipjack tuna**. Dashed lines indicate ±1 se (standard error). The relative density of data points is shown by the vertical line on the x-axis.

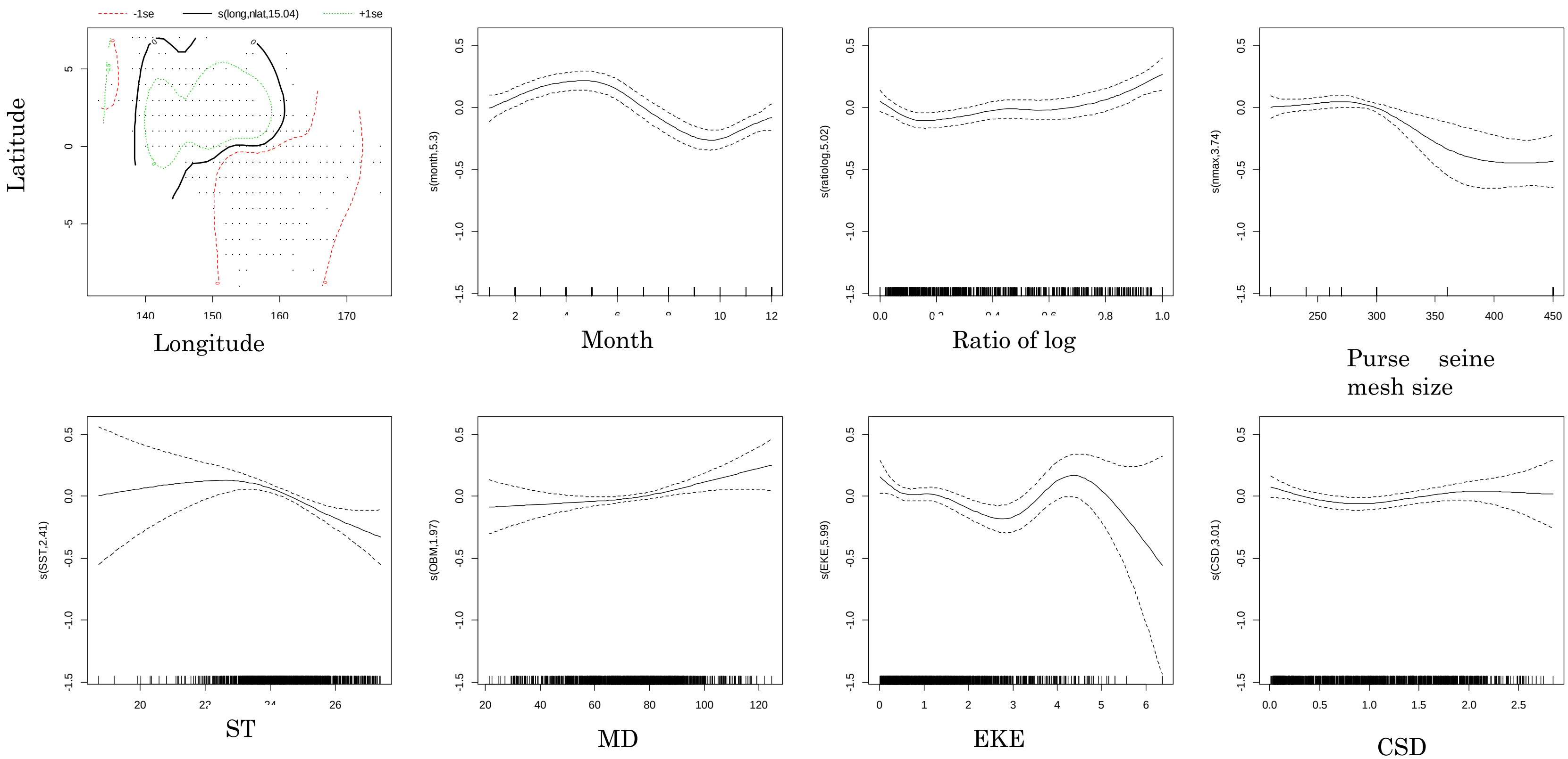
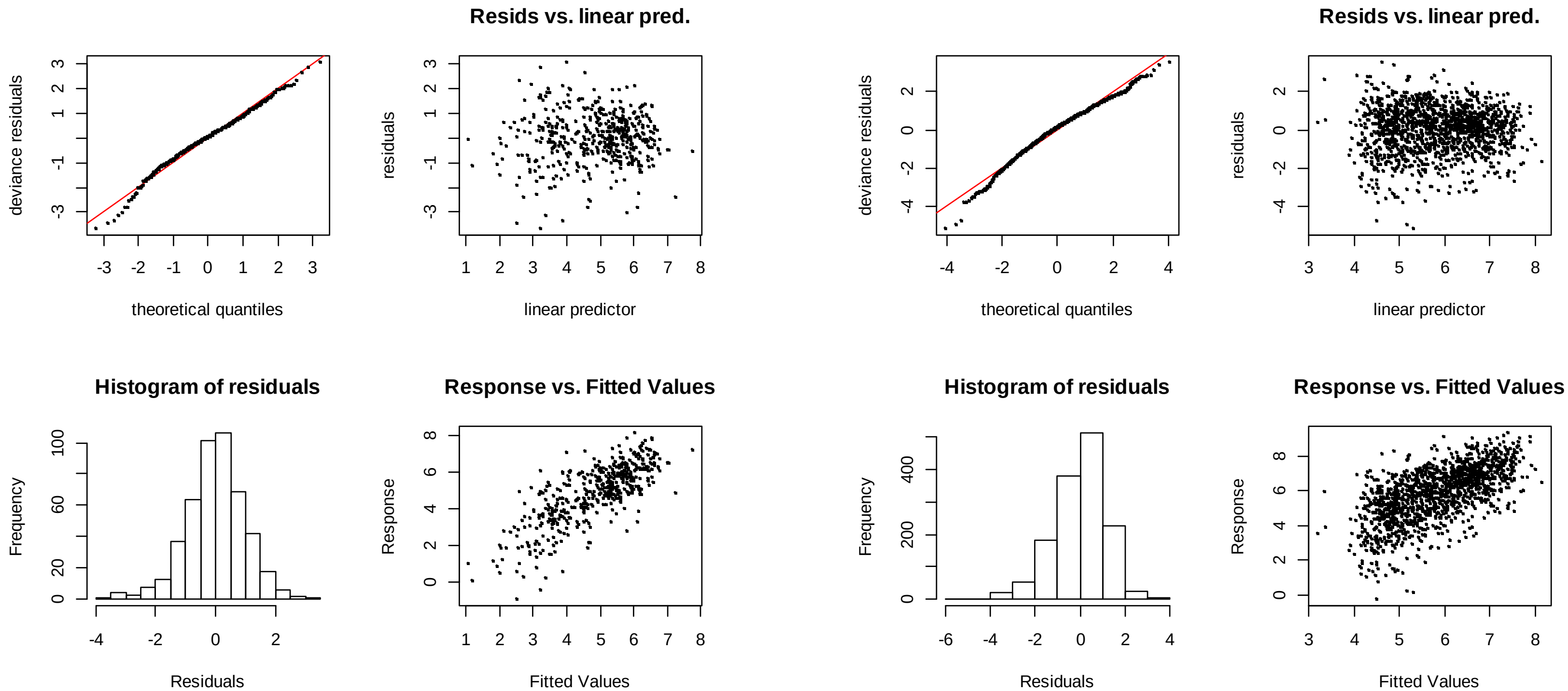


Fig. 10 Generalized additive model (GAM) derived effects of independent variables, latitude and longitude, landing year group, landing month, ratio of associated school in a cruise, oceanographic conditions (sea temperature (℃), mixing layer depth (MD; m), eddy kinetic energy (EKE; m^2/s^2) and standard deviation of EKE (CSD; m/s)) on catch amount of set (Log transformed) for **large sized skipjack tuna**. Dashed lines indicate ±1 se (standard error). The relative density of data points is shown by the vertical line on the x-axis.

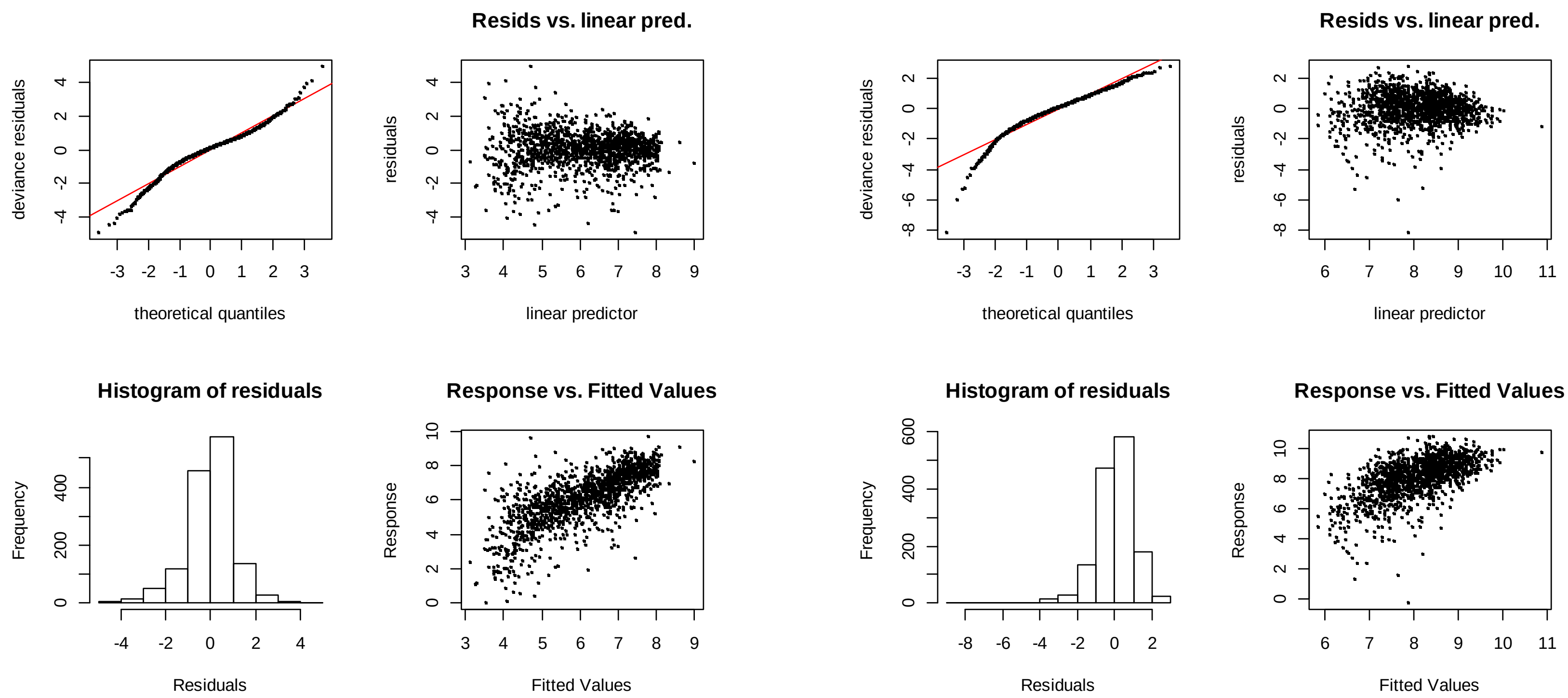
Appendix Table 1. Marcket category for tuna species in three major Japanese marckets (Yaizu, Makurazaki and Yamagawa)

species	marcket category	small size	marcket category	small size	marcket category	small size
	Yaizu		Makurazaki		Yamagawa	
skipjack	1.8down	Yes	0.5down	Yes	1.0down	Yes
	1.8up		1.8down	Yes	1.8down	Yes
	2.5up		1.8up		2.5down	
	4.5up		2.5up		2.5up	
	7.0up		4.5up		4.5up	
	wounded		6.0up		6.0up	
			8.0up		wounded	
			wounded			
yellowfin	1.5down	Yes	1.5down	Yes	1.5down	Yes
	1.5up	Yes	1.5up	Yes	3.0down	
	2.5up		3.0up		3.0up	
	10.0up		5.0up		5.0up	
	wounded		10.0up		10.0up	
			wounded		wounded	
bigeye	2.5down	Yes	1.5up	Yes	2.5down	Yes
	2.5up		3.0up		2.5up	
	10up		10.0up		10.0up	

Appendix Fig. 1 Diagnosis for the model fit for **small sized bigeye tuna** (left panels) and **large sized bigeye tuna** (right panels)



Appendix Fig. 2 Diagnosis for the model fit for **small sized yellowfin tuna** (left panels) and **large sized yellowfin tuna** (right panels)



Appendix Fig. 3 Diagnosis for the model fit for **small sized skipjack tuna** (left panels) and **large sized skipjack tuna** (right panels)