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Relationship between bigeye tuna catch and school type of Japanese purse seine operated in tropical area of the western and central Pacific Ocean

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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 are investigated. The survey is corresponding to CMM2008-01 Paragraphs 25 and 26 (Juvenile Tuna Catch Mitigation Research). The catch information is collected from log book and market slip (fish unloading data). In recent two years, set with free school of Japanese purse seine has been dominated, that is, the ratio of set number with associated school has been reduced. In same time catches of bigeye tuna, small yellowfin and small skipjack decreased. Generalize linear model analysis indicate that the decrease of these catches are significantly influenced by the decrease of the ratio of set number with associated school.

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 2011, and reached to 79.3 % and 69.4%, respectively. At the same time the catch of bigeye, small yellowfin and small skipjack were decreased, and Japanese purse seine vessels have concentrated on the particular fishing grounds. 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 describe recent changes of catch, effort and gear configuration for Japanese purse seine in the tropical area, and (2) to discuss the relationship between these species catch and school type of this fisheries.

Materials and methods

Data collection

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 2011. The catch and effort data in 2011 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, and was classified into four areas (area 1; north hemisphere and west of 155˚E, area 2; north hemisphere and east of 155 ˚E, area 3; south hemisphere and west of 155˚E, area 4; south hemisphere and east of 155 ˚E).

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.

Data analysis

The fishery data only after 2008 is applied for statistical analysis, and two year groups (2008-2009, 2010-2011) were set in order to balance number of data and location of fishing ground between the two year groups. The PNG area is one of the current main fishing ground, however Japanese purse seine vessel had not fished in this area from the late 1980s to 2005 (**Fig. 1**).

The general linear model analyses assessed effects of school type on catch amount of fish by species and size per set (catch per set) using GLM procedure of SAS software (version 9.3, SAS Inst., Inc.). The detail of analysis is as follows;

General linear model with catch per set

Log [catch per set] = Intercept + landing year group + landing month + operating area + ratio of associated school + purse seine mesh size + year*area interaction

where error ~ normal (0, σ2).

The determinants of landing year group (year), landing month (month), operating area (area) and purse seine mesh size (mesh) were treated as categorical variable. The ratio of number of set with associated school for each cruise (ratio of associated school) was treated as continuous variable. Final models were selected after variable selection with backward stepwise F test with a criteria of P-value = 0.05 except for a variable of the "ratio of associated school".

When the catch per set is zero, these data were omitted from the analysis. Total number of cruise is 938, and the number of cruise with zero catch for small bigeye, large bigeye, small yellowfin, large yellowfin, small skipjack and large skipjack is 660, 30, 49, 4, 23 and 1, respectively. It is needed to pay attention to the high ratio of zero catch (660 cruises / 938 cruises) for the small bigeye group when the results are interpreted. The effect size ($\eta^2_{partial}$) for each significant determinant was calculated as SS / (SS+SSE), where SS is sum of square for each determinant, SSE is sum of square of error term.

Results and Discussions

Data set

The Japanese purse seine vessel mainly operated from 160˚E to 180˚E in 2002, and after 2003 the vessel also operated in west area, thus the fishing ground 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). This may be principle reason why there was high density of effort in these eez zones (PNG, FSM, Solomon Islands and Nauru) since 2010. The proportion of number of set with free school had been about 40% with some annual fluctuation from 2002 to 2009, and suddenly has increased in 2010 and 2011, and reached to 79.3 % and 69.4%, respectively. The 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 (**Fig. 2**). Annual catch by all three species before 2009 regardless of their fish size fluctuated without apparent trend. After 2010, the catch of small sized tuna in three species and large bigeye decreased, on the other hand large skipjack and yellowfin increased (**Fig. 3**). The annual changes of number of cruise by maximum mesh size showed that purse seine with larger mesh size was gradually introduced since 2004 and the proportion of cruise using more than 300 mm mesh was 62.5% in 2011 (**Fig. 4**).

Catch per set in nominal data

The relationship between the nominal catch per set and factors (year, month, ratio of associated school, area and mesh) indicated in **Appendix Fig. 1**. For all species and sizes, the catch per set was relatively small in the recent two years. Seasonal changes were founded in some species and size. There were clear relationship between the catch per set and the ratio of associated school in small sized three species and large bigeye. Although it is not clear, the catch per set using small mesh is slightly higher. The overview of these nominal data indicated that all factor might influence the catch per set. Therefore these all factors were included in the statistical model and investigated its effect.

Data analysis

The year, month and area were significant determinants on the catch per set. Least squares mean of the catch per set for each determinant were showed in **Fig. 5**, which resemble those of nominal catch per set in general. However the seasonal changes in the standardized one are clearer than nominal and the year-area interaction was detected in the small and large yellowfin. These results indicate that the standardized catch per set is more informative for interpretation the relationship between catch per set and the ratio of associated school. The effect of purse seine mesh size was not found in all species and sizes, when the mesh was divided by 300 mm. The increasing of number of 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.

Significant positive effects of the ratio of associated school were found in small bigeye, large bigeye, small yellowfin and small skipjack (small bigeye; $F = 141.6$, $P < 0.0001$, effect size = 0.3491, large bigeye; $F = 270.3$, $P < 0.0001$, effect size = 0.2326, small yellowfin; $F = 349.1$, $P < 0.0001$, effect size = 0.28240, small skipjack; $F = 220.1$, $P < 0.0001$, effect size = 0.1969; **Table 1**). The effect sizes of the factor were predominant in analyses for these species and sizes, which indicate that the ratio of associated school is main cause of decreasing catch of these fish in the recent two years. For large yellowfin and large skipjack there were no significant effect of the ratio of associated school in both (large yellowfin; $F = 3.570$, $P = 0.05900$, effect size = 0.00290, large skipjack; $F = 3.020$ $P = 0.08280$, effect size = 0.003300, **Table 1**), which is curious, because these fishes are generally caught from free school operation rather than from associated school. If so the low ratio of associated school (high ratio of free school) explains high catch of these large fish in the recent two years. The low success rate of free school operation might the reason why the ratio of associated school has no clear negative effect on these species catch per set.

Estimated catch per set by species and size when the ratio of associated school is from 0 to 1 were showed in **Fig. 6**. The estimated values are average value for all month and all area in the recent year group. Although it is rough estimation because of the broad confidence interval of the estimated value, if the ratio of associated school in a cruise decrease from 70 % to 40%, the catch per set regardless school type for small bigeye, large bigeye, small yellowfin and small skipjack reduced to 37%, 48% 42% and 46%, respectively. These results suggest that if the ratio of associated school is monitored appropriately, the regulation for the ratio is possible management measures for mitigation measures of juvenile tuna described in CMM 2008-01.

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 arrangements of this study. We are thanks to Taro Kawamoto to useful comments on the draft of this manuscript.

Reference

Japan Far Seas Purse Seine Fishing Association 2004. History of fishery of Japan Far Seas Purse Seine (Kaigai Makiami Gyogyou-shi). pp. 1-358. Tokyo

Table 1. 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. Effect size of each factor is also presented.

Source	DF	SS	MS	FValue	ProbF	effect size (partial ETA^2)
(A) small bigeye tuna						
year	1	9.112	9.112	7.170	0.007900	0.02640
month	11	68.86	6.26	4.920	<.0001	0.1702
ratio of associated	1	180.0	180.0	141.6	<.0001	0.3491
(B) large bigeye tuna						
month	11	68.539	6.231	3.520	<.0001	0.04160
area	3	22.58	7.525	4.250	0.005400	0.01410
ratio of associated	1	479.0	479.0	270.3	<.0001	0.2326
(C) small yellowfin tuna						
year	1	113.1	113.1	85.01	<.0001	0.08910
month	11	103.9	9.445	7.100	<.0001	0.08250
area	3	26.95	8.983	6.750	0.0002000	0.02280
ratio of associated	1	454.7	454.7	341.9	<.0001	0.28240
year*area	3	16.50	5.499	4.130	0.006400	0.01410
(D) large yellowfin tuna						
year	1	16.90	16.90	12.55	0.0004000	0.01030
month	11	164.9	14.99	11.13	<.0001	0.10020
area	3	77.03	25.68	19.06	<.0001	0.04680
ratio of associated	1	4.813	4.813	3.570	0.05900	0.00290
year*area	3	11.92	3.974	2.950	0.03190	0.00720
(E) small skipjack tuna						
year	1	145.0	145.0	84.15	<.0001	0.08570
month	11	279.1	25.37	14.72	<.0001	0.1528
area	3	13.55	4.518	2.620	0.04960	0.008700
ratio of associated	1	379.4	379.4	220.1	<.0001	0.1969
(F) large skipjack tuna						
year	1	3.691	3.691	10.04	0.001600	0.01080
month	11	38.20	3.47	9.440	<.0001	0.1014
area	3	12.42	4.139	11.25	<.0001	0.03540
ratio of associated	1	1.109	1.109	3.020	0.08280	0.003300

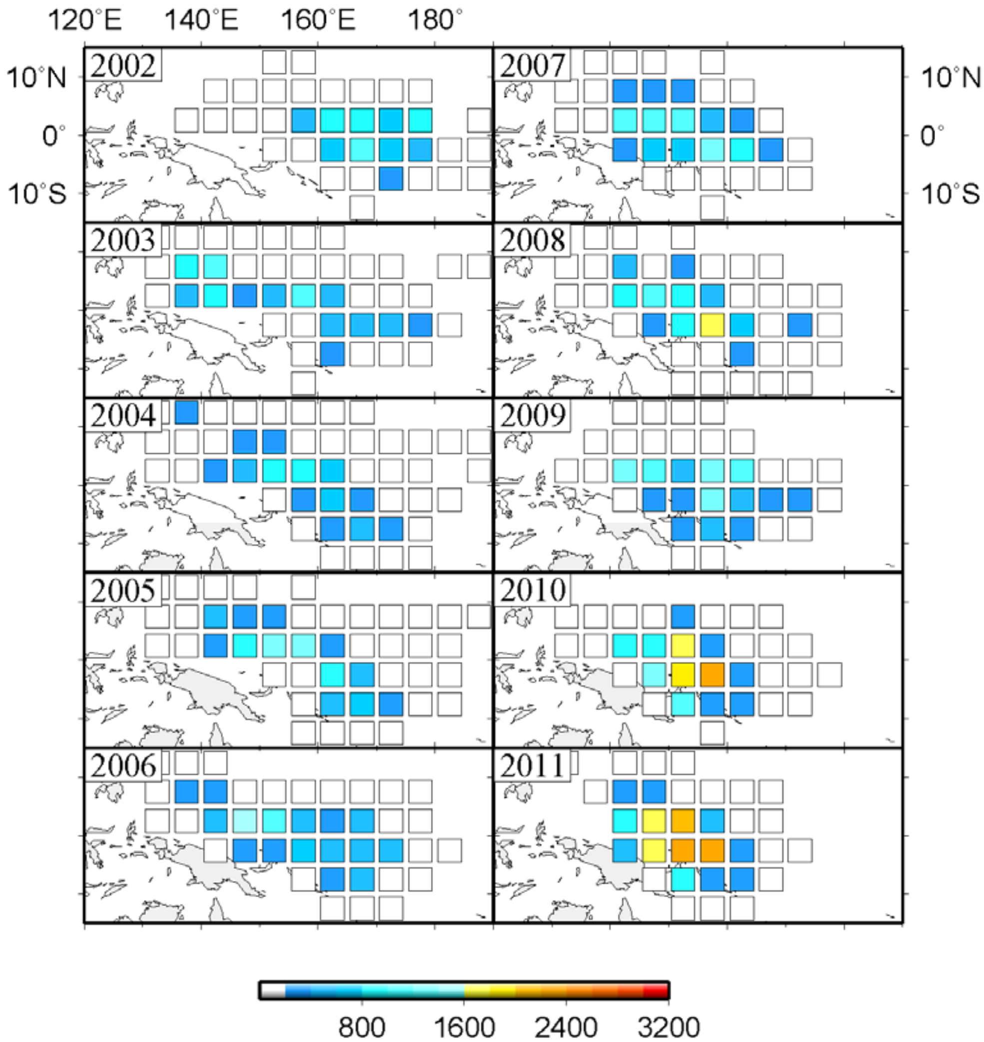


Fig. 1 Historical changes of fishing ground of Japanese purse seine in the tropical area of western and central Pacific Ocean. The legend is number of set.

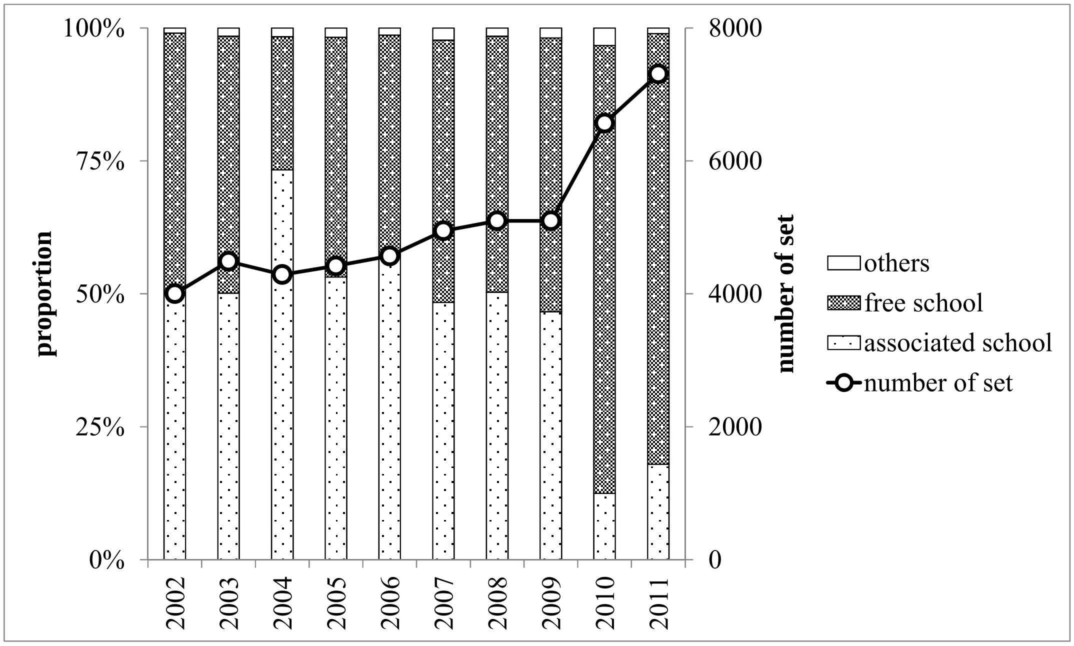


Fig. 2 Annual changes of number of set by school type of Japanese purse seine in the tropical area of western and central Pacific Ocean.

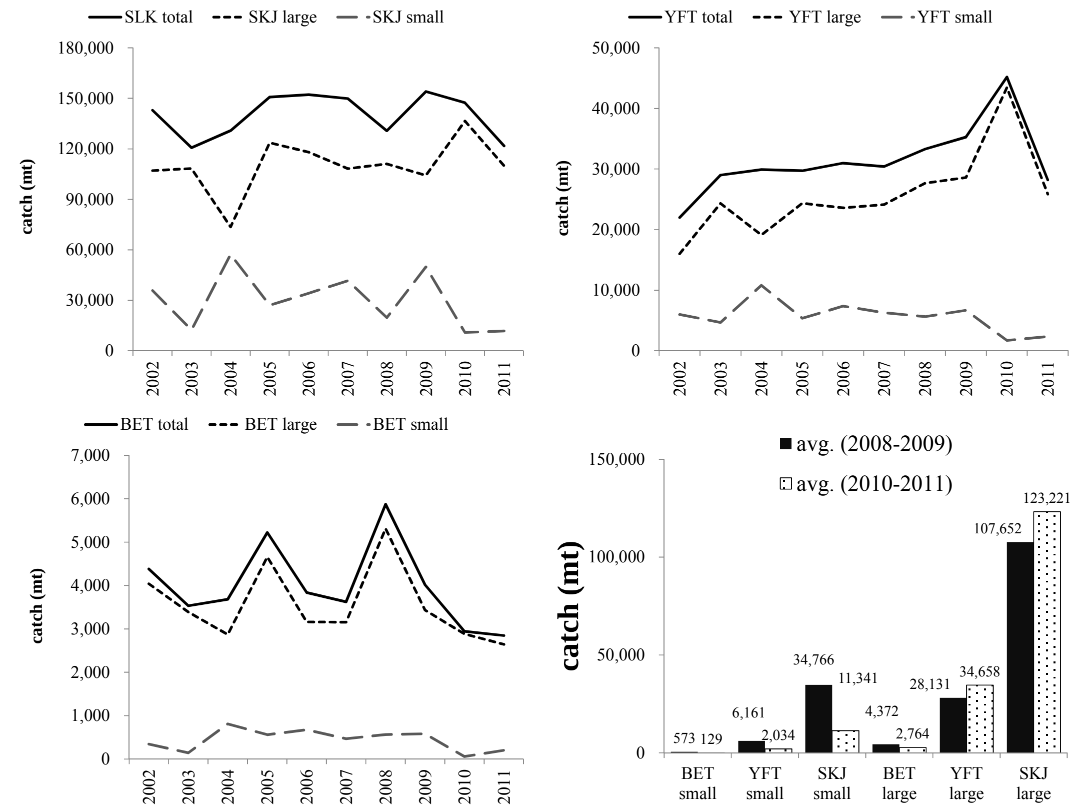


Fig. 3 Annual variation of amount of catch by species and size from 2002 to 2011 of Japanese purse seine in the tropical area of western and central Pacific Ocean. The lower right panel shows comparison of average catch by species and size between previous two years (2008-2009) and recent two years (2010-2011). 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)

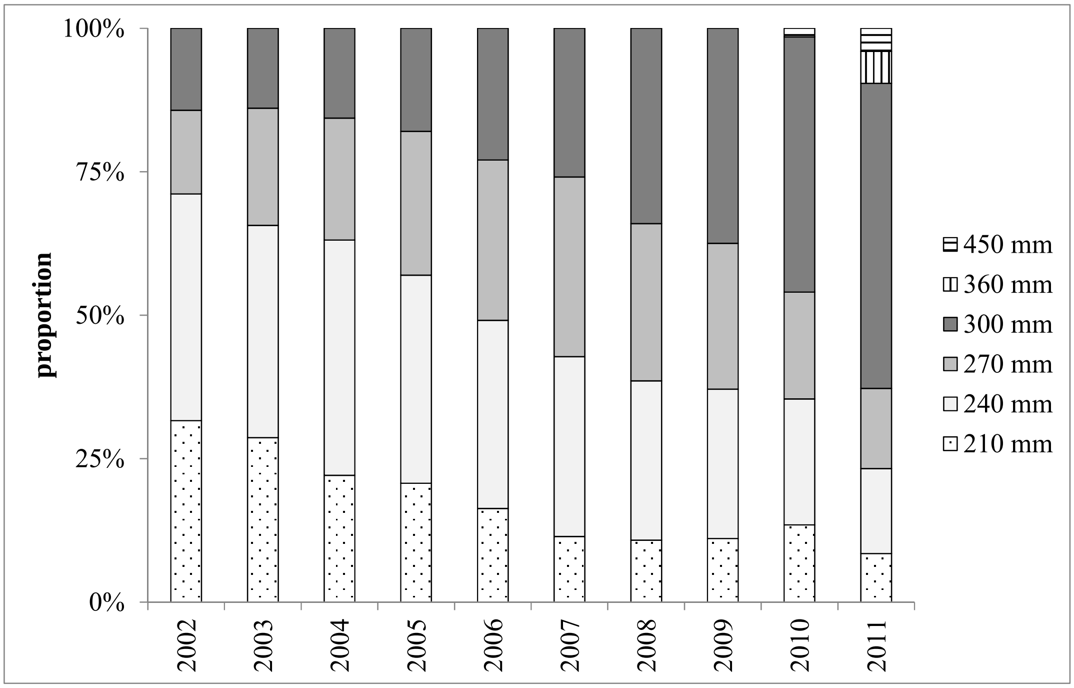


Fig. 4 Annual changes for number of cruise by maximum mesh size of Japanese purse seine in the tropical area of western and central Pacific Ocean.

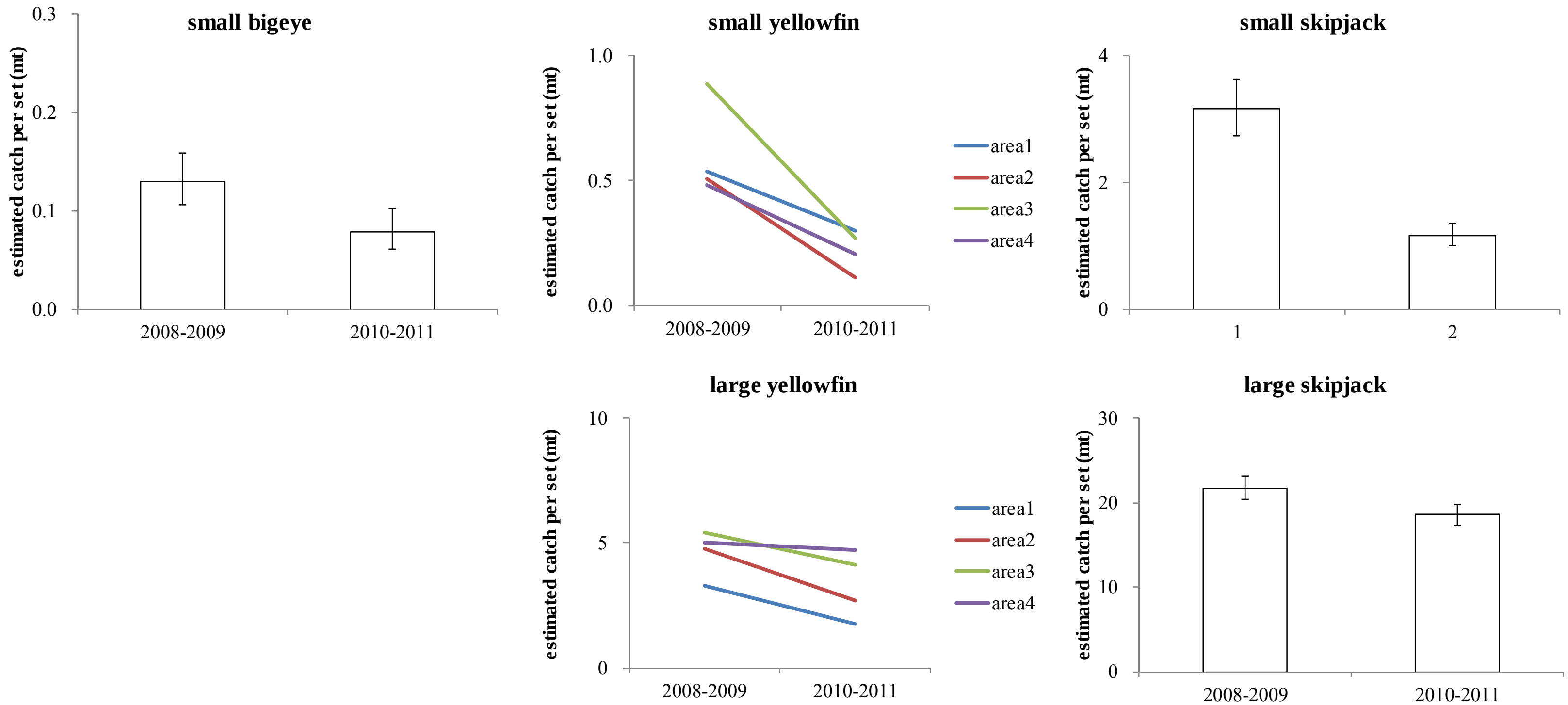


Fig. 5-1 Variation of catch per set (average±2SE) between landing year group (2008-2009 and 2010-2011). The catch per set is Lsmean form GLM analysis of each species and size. The panel for the large bigeye is not showed because the effect of year group is insignificant. The year-area interaction were founded in small and large yellowfin.

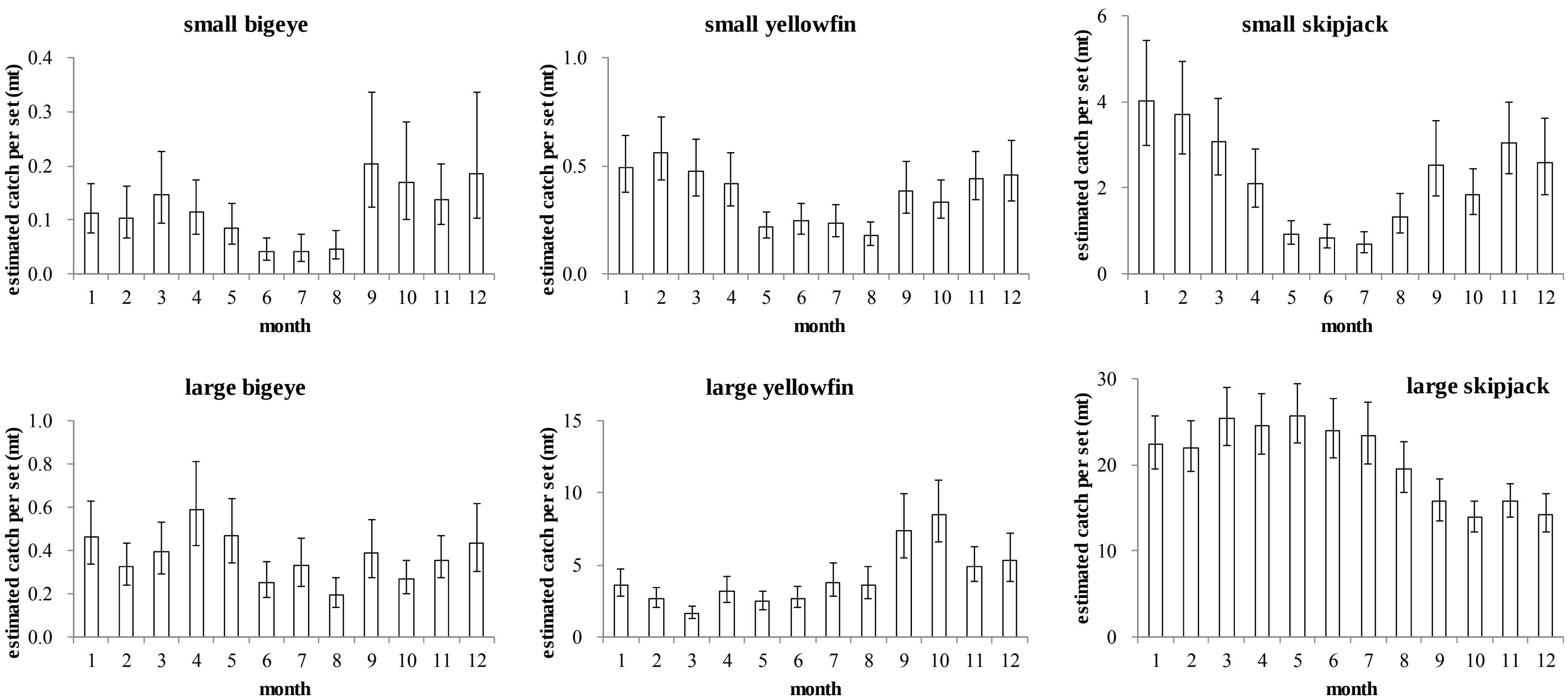


Fig. 5-2 Variation of catch per set (average±2SE) among the landing month. The catch per set is Lsmean form GLM analysis of each species and size.

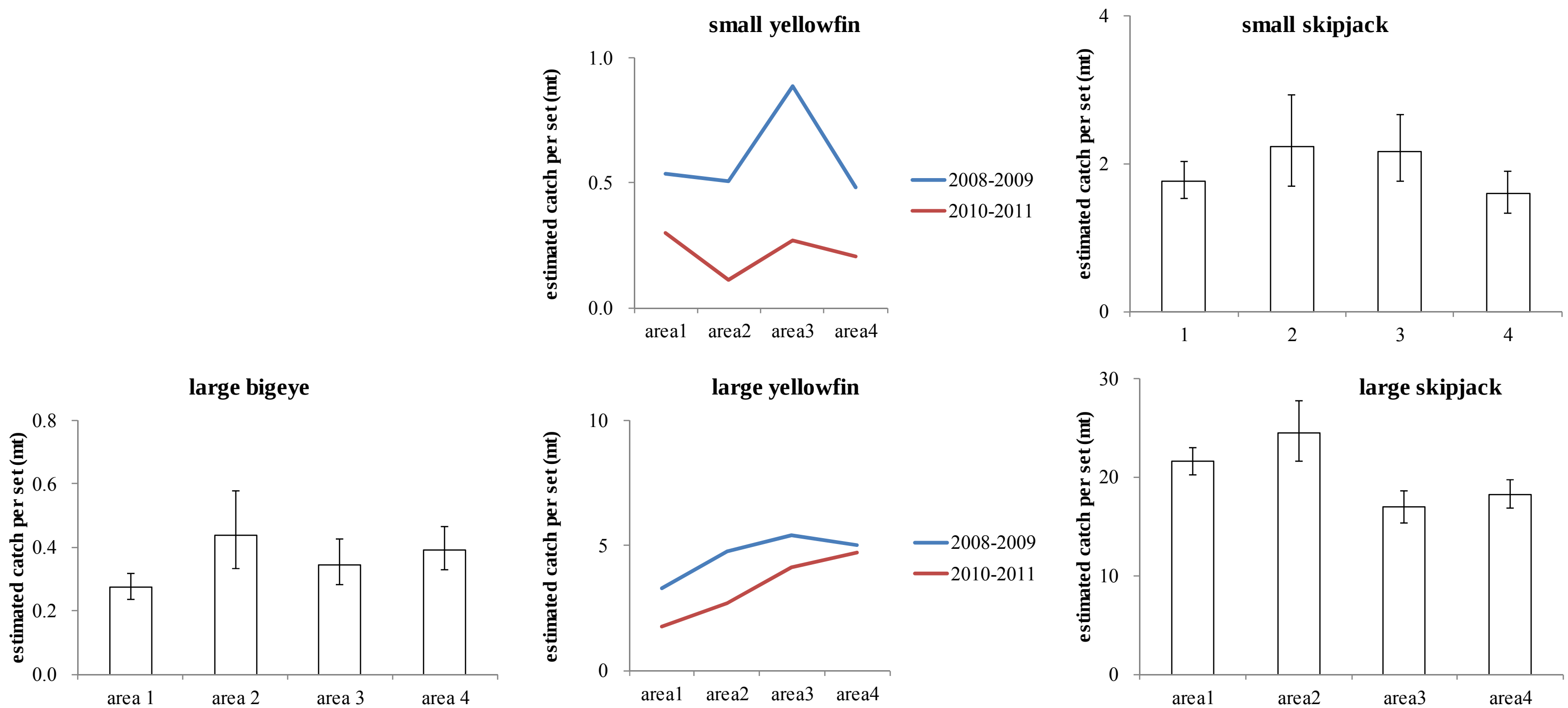


Fig. 5-3 Variation of catch per set (average±2SE) among fishing area (area 1; north hemisphere and west of 155˚E, area 2; north hemisphere and east of 155 ˚E, area 3; south hemisphere and west of 155˚E, area 4; south hemisphere and east of 155 ˚E). The catch per set is Lsmean form GLM analysis of each species and size. The year-area interactions were founded in small and large yellowfin, which are the same results of fig 5-1but different aspect.

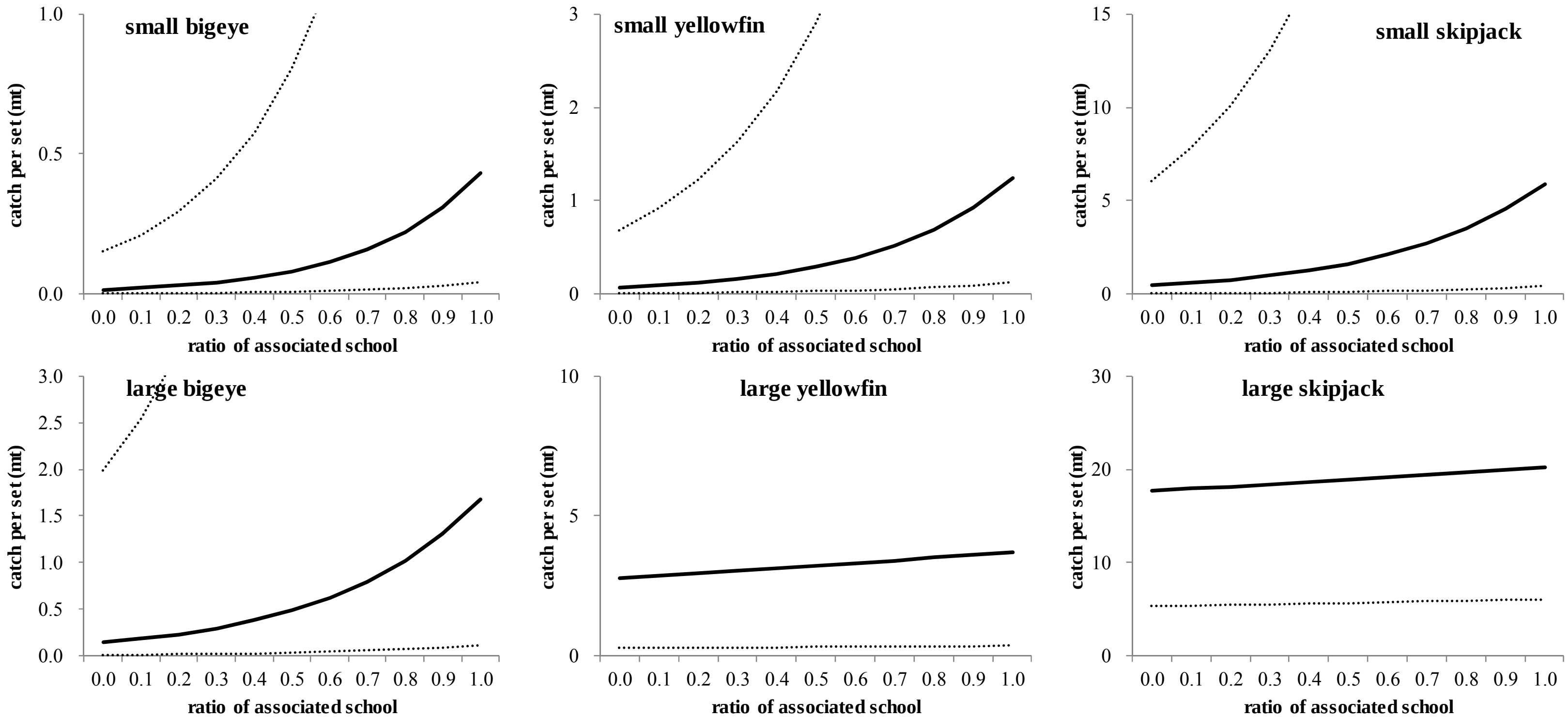
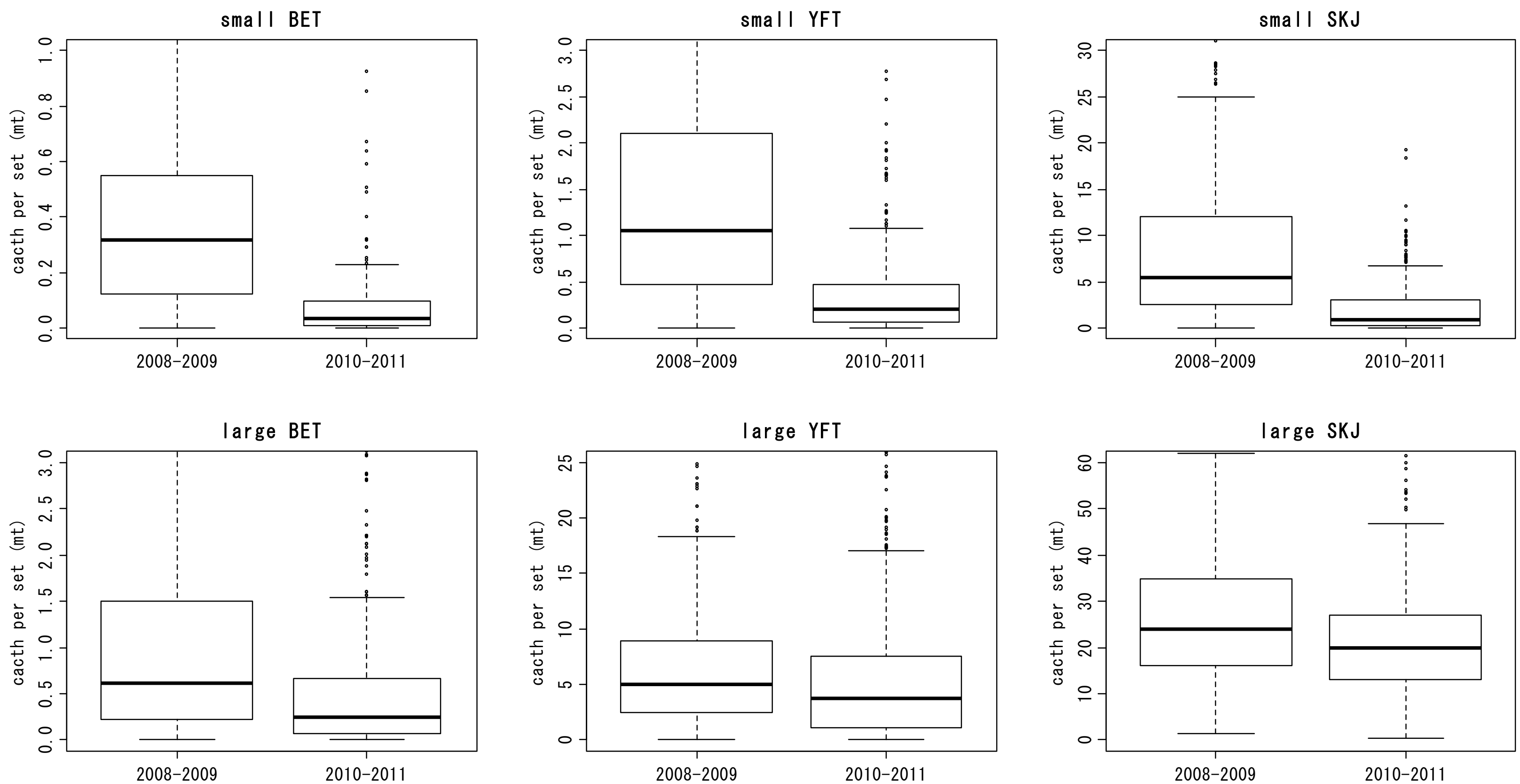


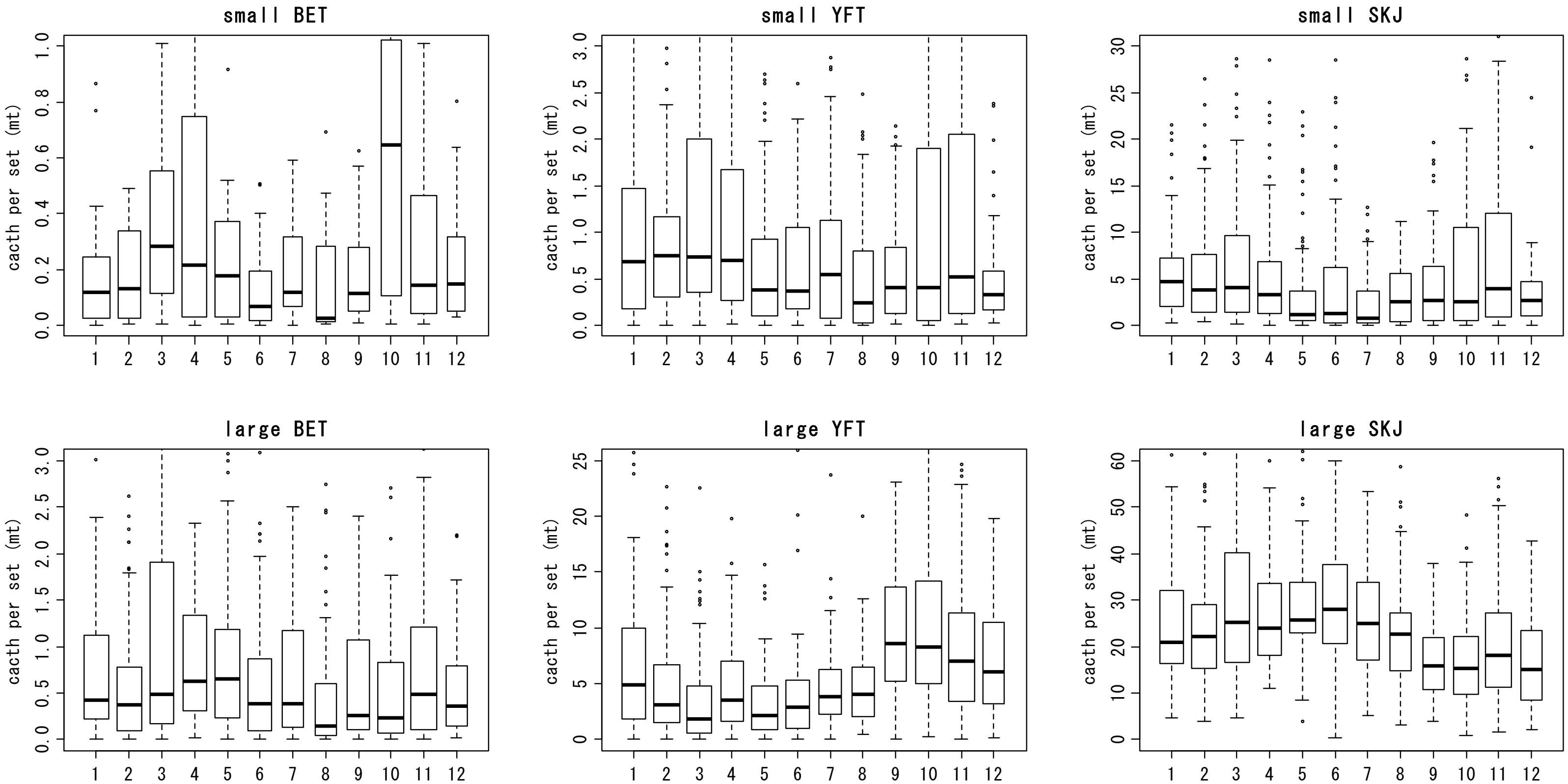
Fig. 6 Estimated catch per set (solid line) for each species and size when the ratio of associated school is from 0 to 1. The values are average value for all month and all area in the year group 2010 to 2011. The dotted line is 95% confidence interval, and the upper dotted lines are out of range in almost cases.

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

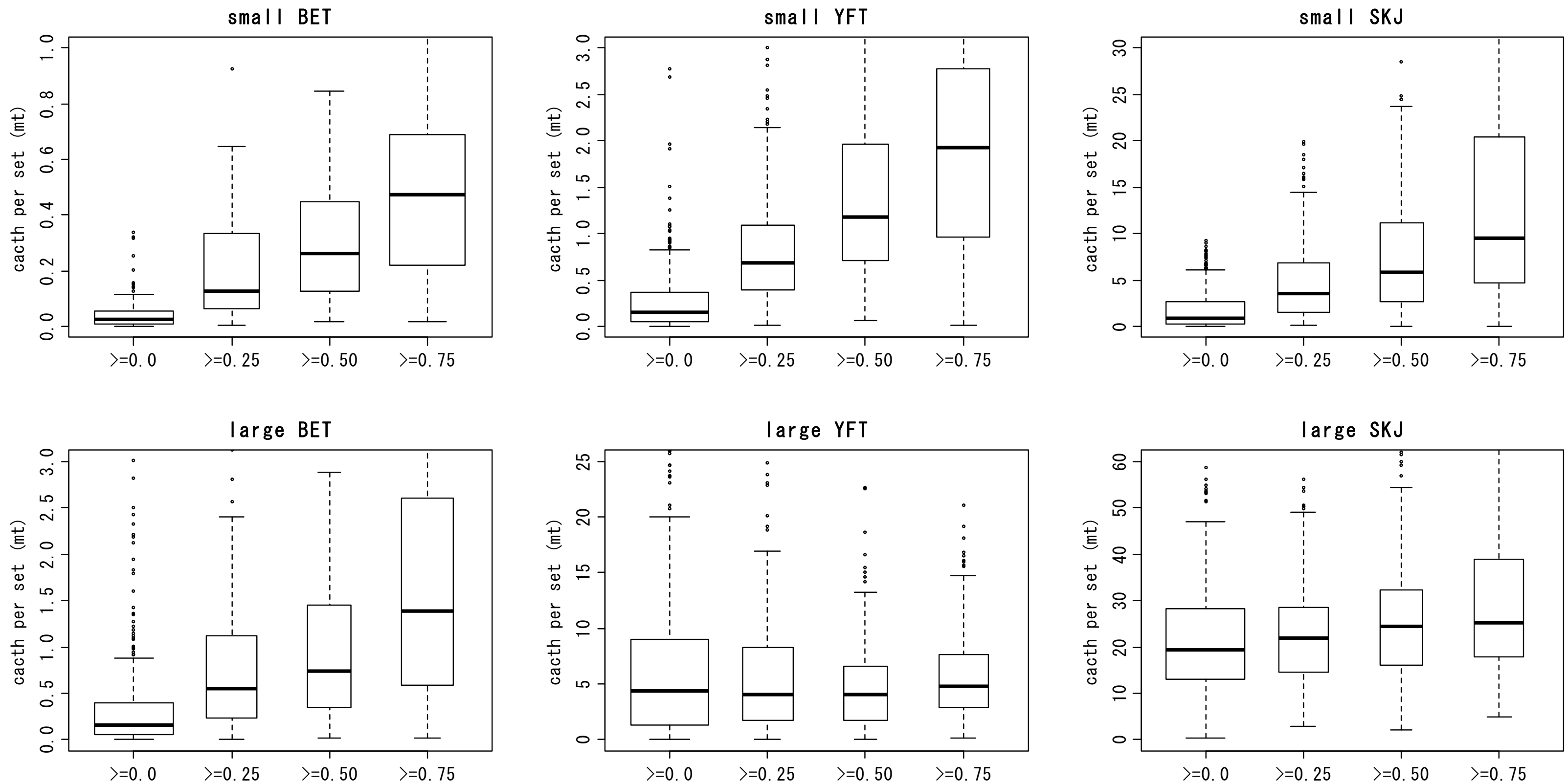
species	marcket category	small size	marcket category	small size	marcket category	small size
	Yaizu		Makurazaki		Yamagawa	
skipjack	1.8down	Yes	0.5down	Yes	1.0down	Yes
	1.8up		1.8down	Yes	1.8down	Yes
	2.5up		1.8up		2.5down	
	4.5up		2.5up		2.5up	
	7.0up		4.5up		4.5up	
	wounded		6.0up		6.0up	
			8.0up		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	



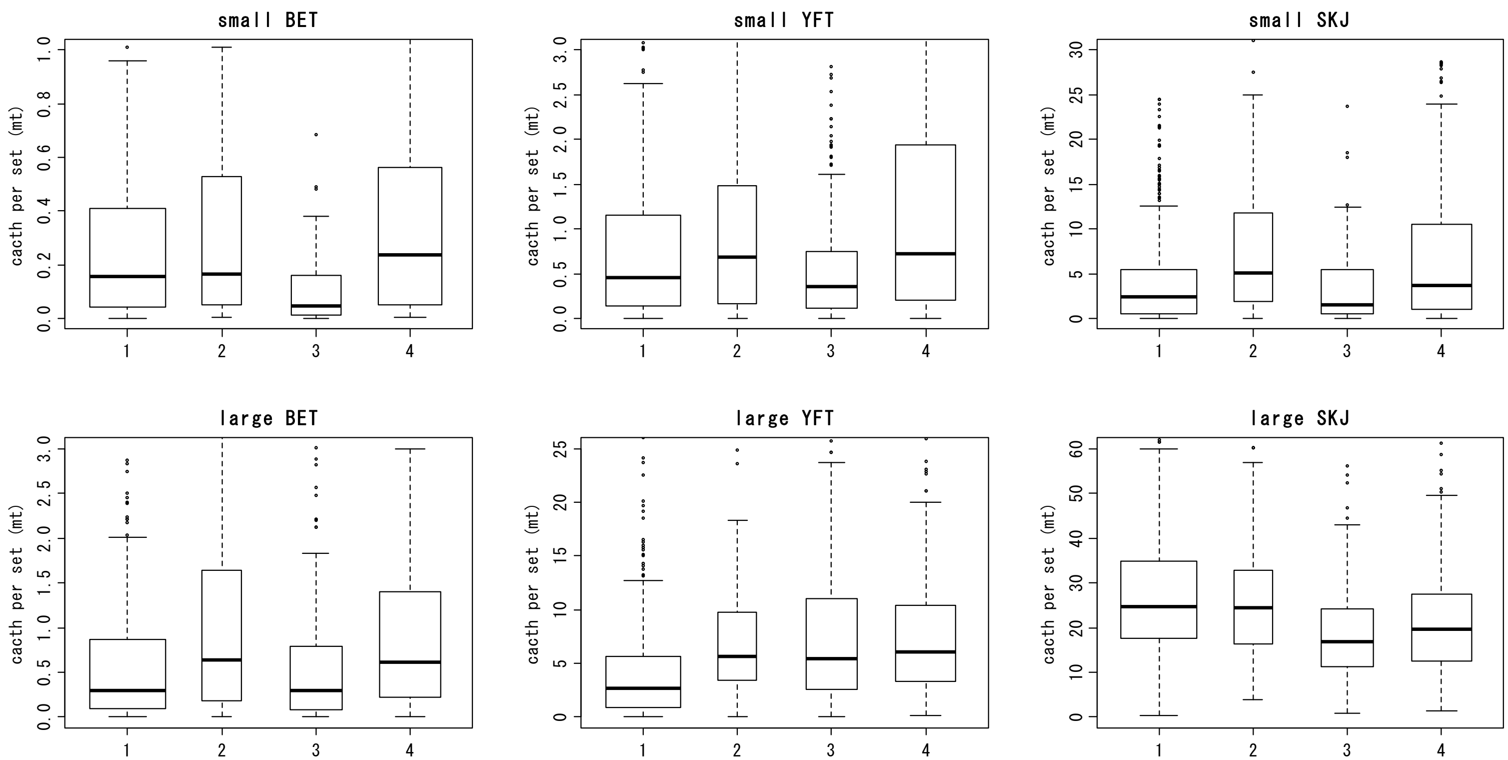
Appendix Fig. 1 Catch per set by the landing year group (2008-2009, 2010-2011) for each species and size (raw data). box: 25th and 75th percentile, horizontal line in the box: median, bars: maximum and minimum observation between 1.5 IQR (interquartile range) above 75th percentile and 1.5 IQR below 25th percentile, dots: outliers.



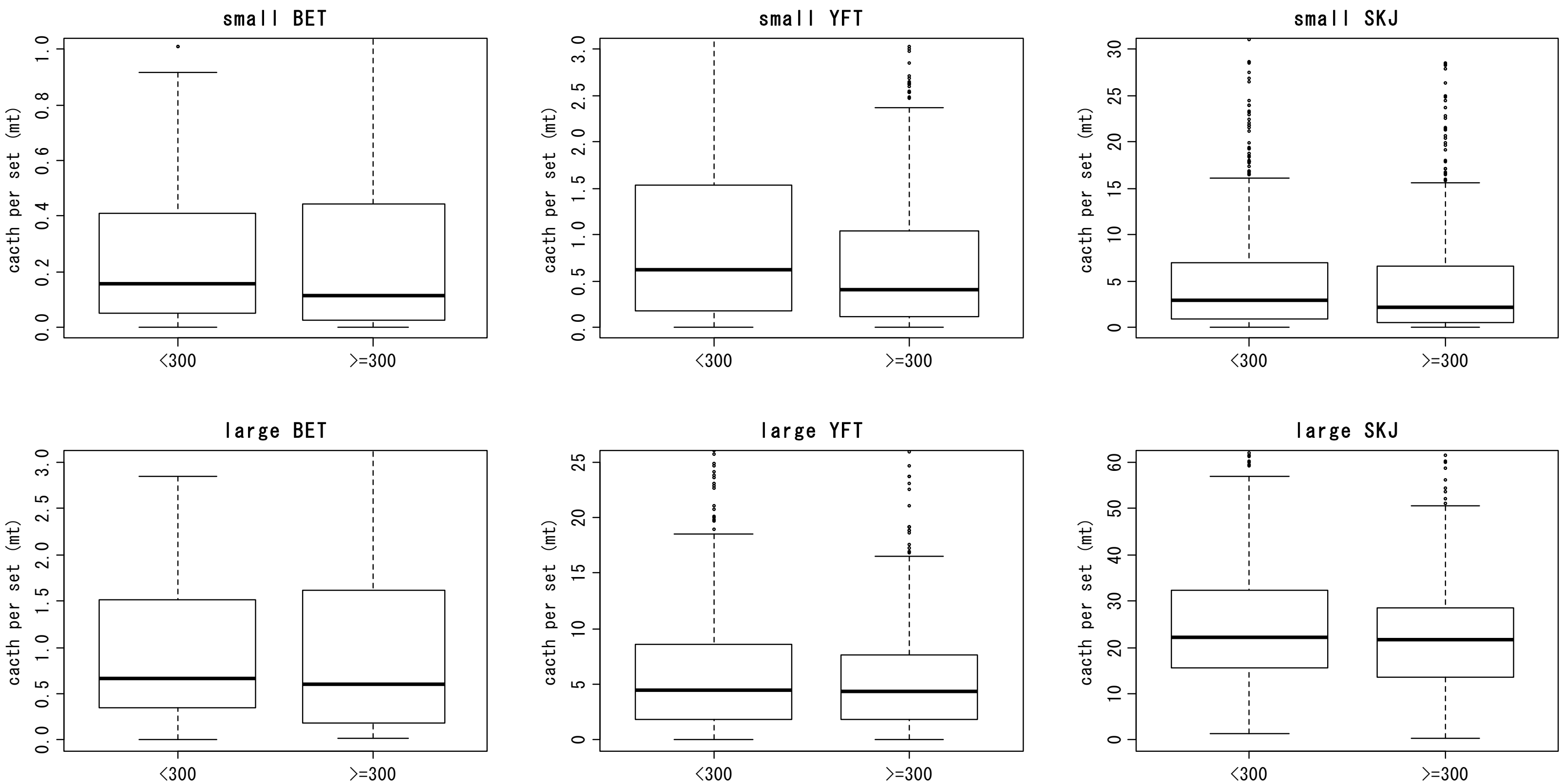
Appendix Fig. 1 Catch per set by the landing month for each species and size (raw data). box: 25th and 75th percentile, horizontal line in the box: median, bars: maximum and minimum observation between 1.5 IQR (interquartile range) above 75th percentile and 1.5 IQR below 25th percentile, dots: outliers.



Appendix Fig. 1 Catch per set by the ratio of number of set with associated school in a cruise each species and size (raw data). box: 25th and 75th percentile, horizontal line in the box: median, bars: maximum and minimum observation between 1.5 IQR (interquartile range) above 75th percentile and 1.5 IQR below 25th percentile, dots: outliers.



Appendix Fig. 1 Catch per set by area (raw data; area 1; north hemisphere and west of 155˚E, area 2; north hemisphere and east of 155 ˚E, area 3; south hemisphere and west of 155˚E, area 4; south hemisphere and east of 155 ˚E). box: 25th and 75th percentile, horizontal line in the box: median, bars: maximum and minimum observation between 1.5 IQR (interquartile range) above 75th percentile and 1.5 IQR below 25th percentile, dots: outliers.



Appendix Fig. 1 Catch per set by purse seine mesh size (raw data). box: 25th and 75th percentile, horizontal line in the box: median, bars: maximum and minimum observation between 1.5 IQR (interquartile range) above 75th percentile and 1.5 IQR below 25th percentile, dots: outlier